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Advancing Inclusive Resilience in Durban: A Framework for Upscaling Community-Based Flood Early Warning Systems

Advancing Inclusive Resilience in Durban: A Framework for Upscaling Community-Based Flood Early Warning Systems

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Authors: Jason Matthew, Catherine Sutherland, Jo Douwes and Geoff Toole,
University of KwaZulu-Natal, ICLEI Africa, Tooley Solutions

CLARE Climate Adaptation & Resilience
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University of KwaZulu-Natal Inyuvesi Yakwazulu-Natali
eThekwini Municipality
Universidade Eduardo Mondlane

1. Executive summary

1.1 The need for CBFEWS

Durban's informal and peri-urban settlements, identified in Durban's Resilience Strategy as the city's most vulnerable spaces (eThekwini Municipality, 2017), face intensifying flood risk, yet the municipal systems designed to protect them are not adequate. Conventional municipal-scale early warning systems lack the granularity to account for settlement-specific terrain, social vulnerabilities and the local dynamics that determine whether a warning is received, understood and acted upon. The April 2022 KwaZulu-Natal floods, which led to the loss of more than 450 lives and displaced 40,000 people in the eThekwini Municipal Area, exposed the human cost of this gap most starkly. For the vast majority of informal settlement residents, relocation is not a viable option. The risk must therefore be addressed through people-driven, place-based early warning and in-situ adaptation.

The Community-Based Flood Early Warning System (CBFEWS) Upscaling Framework, presented in this report, is a direct response to this challenge. Built on a decade of operational experience in Quarry Road West and pilot implementation across three additional settlements, Pholani, uMzinyathi and Tshelimnyama, the framework provides a replicable, scalable roadmap for implementing CBFEWS across the eThekwini Municipal Area and potentially other municipalities. It moves beyond purely top-down, technical early warning models toward an integrated, co-produced approach that places community knowledge and lived experience at its centre, while remaining formally anchored within municipal governance structures.

1.2 How the framework works

The framework operates through three interlocking pillars. The Knowledge Pillar identifies six knowledge domains – scientific, local, indigenous, state (including municipal and traditional authorities), legal and specialist intermediaries – that must be integrated for the system to function effectively. The Procedural Core Pillar provides a six-step implementation pathway, from initial community engagement and risk profiling through to co-design, communication mapping, preparedness planning and formal institutionalisation. A cross-cutting institutional layer ensures each step is aligned with existing municipal standard operating procedures (SOPs), forecasting systems and legal mandates. Further research on integration with traditional authority practices will be undertaken in the future, as this framework focuses on municipal systems. The Guiding Principles Pillar navigates the central challenge of upscaling – how to expand a place-based methodology across diverse contexts – by standardising the implementation process while keeping local thresholds, knowledge and governance arrangements site-specific.

1.3 How government and stakeholders can apply it

Organisations and municipal disaster risk managers can use the six-step procedural core as an implementation guide when establishing CBFEWS in new settlements. Key entry points include leveraging existing municipal projects, such as infrastructure repairs, informal settlement upgrading or sanitation upgrades, to initiate community engagement. The cross-cutting institutional layer provides explicit guidance on embedding community-based flood risk management within official standard operating procedures and the city's Joint Operations Centre. Critically, the framework identifies what must be resourced, including sustained community engagement, trained local mediators, maintained gauge infrastructure and cloud-based data systems.

1.4 Strategic recommendations and the way forward

Ten strategic recommendations provide a clear agenda for transitioning the CBFEWS from a successful research pilot into a formalised, city-wide disaster risk management programme. Most fundamentally, they call for a holistic, multi-knowledge approach to flood risk, with locally generated thresholds formally validated through co-production before integration into official standard operating procedures; legislative formalisation of the CBFEWS as a local impact advisory system to unlock dedicated funding and institutional mandates; and use of the framework's six-step procedural core as a replicable implementation roadmap that standardises process while keeping local content site-specific.

They further call for long-term institutional custodianship to be defined and distributed across relevant municipal departments, rather than relying on individual champions or short-term funding; for community engagement and relationship infrastructure to be formally budgeted as a core implementation requirement; and for Traditional Authorities to be integrated as key custodians within governance arrangements in peri-urban areas. Communication networks should be tailored to each settlement's connectivity and trust context, and socio-economic vulnerability, including gender, disability and age, must be explicitly addressed in early warning design. The framework should be used to downscale climate science into hyperlocal, actionable thresholds, with citizen science formally recognised as a valid municipal data stream. Finally, the CBFEWS must be treated as a living system, with post-event reviews and Learning Labs institutionalised within standard disaster risk management planning to ensure continuous refinement. Together, these recommendations make clear that effective flood early warning in informal and peri-urban settlements is as much a governance and social challenge as a technical one, and this framework provides a practical, tested pathway to address both.

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2. Introduction and context

The April 2022 KwaZulu-Natal (KZN) floods were a large-scale disaster which impacted and devastated municipal infrastructure and settlements across the province. They exposed how standard municipal early warning systems (EWS) are increasingly insufficient to address and respond to the complex landscape of Durban's – and the Province's – settlements, most particularly informal and peri-urban settlements. The eThekwini Municipal Area (EMA), more commonly known as Durban, experienced 359mm of rainfall in 24 hours induced by a cut-off low pressure system (Sutherland, 2024). Simulations suggest climate change likely increased the amount of rainfall by 40% (Engelbrecht et al., 2025). This extreme hazard interacted with high levels of urban vulnerability, producing widespread flooding, localised landslides and significant loss of life, property and infrastructure (see Table 1) (Sutherland 2024).

Table 1: The impacts of the April 2022 floods in the EMA (Engelbrecht et al., 2025).

Impact category	Reported data
Mortalities	>450
Social displacement	>40,000
People directly impacted	140,000
Economic losses	>US$3.6 billion

The April 2022 KZN floods, which are listed as South Africa's most significant flood disaster (Engelbrecht et al., 2025), acted as a major catalyst for action, exposing critical gaps in South Africa's and EMA's disaster risk management. However, it is important to recognise that flooding has become a recurrent and increasingly significant component of the broader risk profile within the EMA, and the need for localised, proactive and adaptive flood risk management extends well beyond a single disaster event. The 2022 floods are therefore best understood not as an anomaly, but as an acute expression of a longer-term climate resilience challenge that the EMA must systematically address.

While the South African Weather Service (SAWS) provides critical broad-spectrum alerts and the EMA release alerts through their Forecast Early Warning System (FEWS), these warnings lack the granularity required to trigger effective local action in informal settlements and peri-urban settlements characterised by contextual social, economic and environmental vulnerability to floods (O'Donoghue et al., 2025).

2.1 The need for local flood early warning systems

Standard EWS often fail because they lack the necessary and effective downscaling of scientific information into usable end-user action, resulting in a gap between what producers provide and what decision-makers and residents at the local scale actually require (Kruk et al., 2017; Andersson et al., 2020). Broad SAWS and municipal alerts cannot account for settlement-specific terrain, including erodible soils or localised drainage failures, let alone predict how the flood hazard will interact with local vulnerabilities. When alerts do not translate into experienced impacts, communities develop warning fatigue, diminishing trust in early warnings (O'Donoghue et al., 2025).

Closing the usability gap requires a shift toward co-production, where users of climate information services are actively involved in knowledge creation and dissemination (White et al., 2017). Effective EWS must move beyond purely technical outputs to build messages that are locally understood, trusted and actionable, which requires the integration of local knowledge to ensure warnings are downscaled and refined for the local context rather than remaining abstract (Aitsi-Selmi et al., 2016; O'Donoghue et al., 2025). A robust EWS must systematically embed community engagement across all four standard pillars – risk knowledge, monitoring and warning, dissemination and communication, and response capability – as failure to do so tends to result in ineffective community responses during disasters (Sufri et al., 2020).

The Community-Based Flood Early Warning System (CBFEWS) emerged from a critical usability gap between high-level scientific forecasting and the hyperlocal realities of some of Durban's most flood-vulnerable settlements. In addition to this, many of the informal settlements are located on high-risk land, such as floodplains and steep slopes. This context, combined with the fact that relocation is rarely viable due to land scarcity and socio-economic necessity, means that the flood risk must be mitigated through hyperlocal early warning and in-situ adaptation.

2.2 The Durban CBFEWS

> **A note on the evidence base**
>
> This report is a synthesis of collective research, implementation and learning accumulated over a decade of work on community-based flood early warning in Durban. It draws on the University of KwaZulu-Natal's longitudinal research in the Palmiet Catchment; eThekwini Municipality's technical and disaster management contributions, including work on the Forecast Early Warning System and catchment management; ICLEI Africa's coordination, learning processes and joint empirical research undertaken through the INACCT Resilience Project in partnership with the University of KwaZulu-Natal and eThekwini Municipality; and the empirical work conducted with communities across Quarry Road West, Pholani, uMzinyathi and Tshelimnyama by ICLEI Africa and UKZN teams.

Durban has developed a well-established policy discourse around ecological infrastructure and community ecosystem-based adaptation (Sutherland, 2024). This approach is reflected in the Transformative Riverine Management Programme (TRMP), launched in 2021, which promotes nature-based solutions to protect the city from flooding and build state-citizen relationships across Durban's 18 major river systems (Sutherland, 2024). However, these commitments are being tested by rapid urbanisation, weak governance, infrastructure failure and deepening inequality, compounded by climate change, all of which can disrupt and reverse the city's development trajectory in ways that take years to fully emerge – such as the 2022 floods which heavily impacted Durban's development trajectory (Sutherland, 2024).

The CBFEWS evolved organically through the Palmiet Catchment Rehabilitation Project (PCRP), established in 2014, which brought together University of KwaZulu-Natal (UKZN) researchers, municipal officials and residents, and proved a successful proof of concept that contributed to the establishment of the TRMP (O'Donoghue et al., 2025; Sutherland, 2025). Durban's resilience trajectory, and the PCRP in particular, has been characterised by a deliberately bottom-up approach in which the meaning and focus of resilience emerged through broad stakeholder deliberation rather than global frameworks, producing a version of resilience embedded in the power struggles and realities of a southern African city (Sutherland et al., 2019).

While the April 2022 floods damaged areas across income levels, the urban poor suffered disproportionately, facing unrestored services, lost homes and livelihoods, and largely bearing the costs alone in the face of limited state and private sector capacity to respond (Sutherland, 2024). Because informality is a socio-political construct, with those in power having real influence over the degree of access informality has to rights and services, urban resilience planning must address the power asymmetries between formal and informal spaces to improve social equity (Eakin et al., 2025). Boundary organisations can bridge this divide and address power asymmetries by enhancing procedural and distributive justice while building collective capacity (Eakin et al., 2025).

UKZN researchers initiated this bridging process in Quarry Road West – hereon referred to as 'Quarry', the residents' preferred name – an informal settlement located on the banks of the Palmiet River in central Durban. Quarry's proximity to jobs, education and the urban core has made relocation economically and socially untenable for the majority of residents despite recurrent and intensifying flood risk and attempts by the city to relocate residents (Sutherland, 2024). It is within this context of contested urban space that Quarry became the founding site of the CBFEWS, and through the PCRP, the centre of a collaborative coalition committed to improving climate resilience and environmental governance in the Palmiet Catchment (Sutherland, 2025). The 2019 and 2022 floods, which destroyed 60 and 250 houses respectively, demonstrated both the severity of the risk and the importance of the early warning system that had been built in the settlement (Sutherland, 2024).

Since 2015, the CBFEWS developed iteratively: residents began sharing rain gauge data and real-time river observations with researchers by WhatsApp and phone respectively; the spread of affordable smartphones from 2017 onwards enabled bi-directional WhatsApp channels through which community photos of river levels helped refine technical monitoring and modelling and the development of flood thresholds; and in 2018, the municipality's FEWS, which utilises hydraulic models (PCSWMM[1]) and SAWS data to predict riverine water level increases across 250 city-wide risk zones, was formally linked to this community network (O'Donoghue et al., 2025; Sutherland, 2025).

The result is a socio-technical bridge. Mediated through researchers and organisations, the CBFEWS integrates municipal-scale scientific forecasting with indigenous and local knowledge systems and citizen science to produce context-specific alerts that residents understand and trust (see Figure 1). In Quarry, the most advanced CBFEWS site, a co-produced correlation between a 1.6m upstream stream gauge threshold and a documented 40-minute lag time provides residents with a reliable evacuation window. During the April 2022 floods, the system is estimated to have saved between 250 and 400 lives in the settlement alone, demonstrating that effective early warning is ensuring they are received, understood and acted upon (O'Donoghue et al., 2025).

[1] PCSWMM (Personal Computer Storm Water Management Model) is an advanced modelling software for stormwater, wastewater, watershed and water distribution systems.

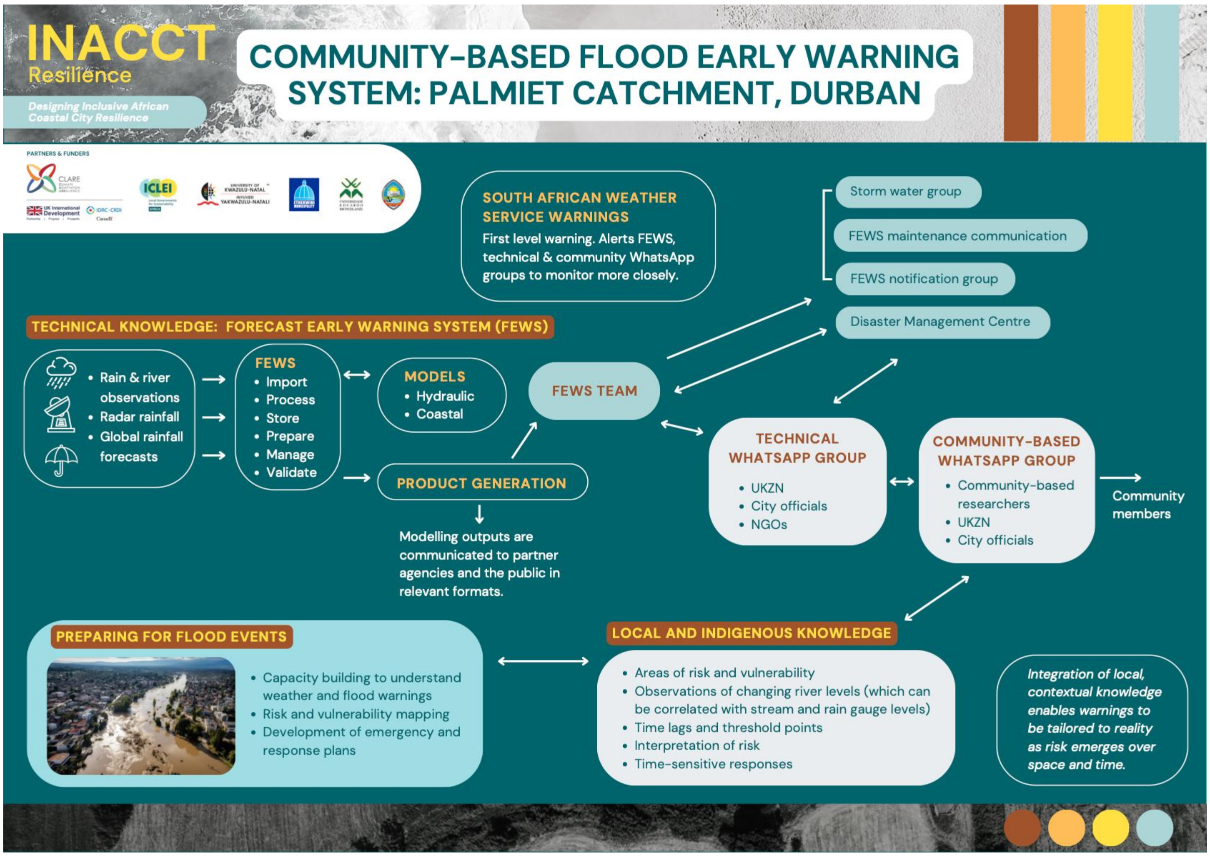

Figure 1: A simplified version of the CBFEWS, showing the communication channels that exist to alert municipal officials and Quarry residents (Source: O'Donoghue et al., 2025).

The CBFEWS has now developed into a series of interconnected phases, each building on the last. Table 2 below summarises this progression, from the foundational work in Quarry through to the upscaling framework presented in this report (column three) and the settlement prototypes to follow. Together, these phases represent a deliberate and iterative journey from a deeply contextual, single-settlement system toward a transferable methodology capable of guiding CBFEWS implementation across EMA's diverse informal and peri-urban settlement landscape.

Table 2: Situating the CBFEWS Upscaling Framework in relation to the other three interconnected projects.

	Original CBFEWS	**CLARE INACCT and the Research for Impact (R4I) opportunities fund**	**CBFEWS upscaling framework**	**Settlement prototypes**
Focus & Purpose	Establish a community-led flood EWS rooted in the specific context of the Palmiet Catchment (including Quarry)	Expand CBFEWS learnings from Quarry to three new, diverse settlement contexts across Durban	Generalise methodologies from all four pilot settlements into a replicable, scalable implementation roadmap	Develop settlement-type specific templates that can be directly applied to settlements with similar characteristics
Geographic & Hazard Scope	Quarry only: lower Palmiet River floodplain; fast-rising fluvial and pluvial risk	Expanded to Pholani (steep slopes, flooding from surface water flow), uMzinyathi (peri-urban wetland, tributary and pluvial flooding) and Tshelimnyama	Cross-cutting synthesis across all four sites; transferable regardless of specific geographic context	Grouped by settlement type and hazard profile (e.g. floodplain, steep-slope, peri-urban)

	Original CBFEWS	CLARE INACCT and the Research for Impact (R4I) opportunities fund	CBFEWS upscaling framework	Settlement prototypes
		(urban fringe, fluvial and pluvial flood risk)		
Governance & Knowledge Context	Single governance authority (eThekwini Municipality); deep longitudinal knowledge built over a decade of co-production with UKZN	Introduced governance diversity: EMA settlements alongside uMzinyathi (under dual Traditional Authority and municipal governance); new knowledge contexts across each site	Formalises six knowledge domains as a structured foundation; accounts for governance variation as a key variable in implementation pace	Prototypes pre-populated by governance typology and relevant knowledge domains, reducing groundwork in new sites
Methodology & Scalability	Bottom-up evolution over ten+ years; deeply embedded in	Structured inclusive research tools introduced across sites	Codifies methods into a six-step procedural core, explicitly	Bridges the general framework and on-the-ground

	Original CBFEWS	CLARE INACCT and the Research for Impact (R4I) opportunities fund	CBFEWS upscaling framework	Settlement prototypes
	Quarry's specific relationships and history; co-production and trans-disciplinarily; requires adaptation for upscaling and replication	(multiple focus groups, language-sensitive surveys, photovoice, playdough modelling, learning labs), but each site still required substantial contextual engagement	separating universal processes from contextual content to enable structured upscaling	application with ready-to-use, typology-specific templates
Stage of Development	Operational and ongoing; continuously refined through post-event reviews, university community engagements	Active implementation across four pilot sites	Complete: presented in this report	In development: next phase of the programme

	Original CBFEWS	CLARE INACCT and the Research for Impact (R4I) opportunities fund	CBFEWS upscaling framework	Settlement prototypes
	and citizen science			

2.3 Rationale for upscaling

The CBFEWS has demonstrated, over more than a decade of operation in Quarry, that community-based flood early warning is both feasible and life-saving, filling a critical gap between smaller geographical scale municipal alerts, which cover larger areas, and the hyperlocal realities of informal settlement flood risk. The CBFEWS success lies in its contextual depth, the product of sustained co-production between researchers, municipal officials and residents, refined iteratively through lived experience. Yet this same depth presented a challenge: The Quarry model was deeply embedded in a single settlement's specific relationships, history and geography, and was not readily transferable to other contexts. This matters because Quarry is not unique in its flood risk. Hundreds of informal and peri-urban settlements across the EMA face recurrent, climate-intensified flood impacts with comparable levels of exposure and social vulnerability, and many could benefit from the social and technical learnings developed at Quarry. The case for expanding the CBFEWS is therefore both urgent and well-founded.

Boundary organisations and intermediaries have proven pivotal to the CBFEWS, translating information across scales and governance levels and coordinating action between stakeholders who may lack the mandates or internal capacity to collaborate effectively (Andersson et al., 2020; Eakin et al., 2025; Mulligan et al., 2019). To facilitate the horizontal expansion of the CBFEWS, Urban Reform Coalitions

(Sutherland, 2025), also referred to as Urban Living Labs in the literature, which are collaborative platforms and spaces dedicated to co-production across stakeholders with varying degrees of authority, offer a complementary tool, reconfiguring actor networks through trust-based peer exchanges between residents, researchers and municipal officials, and enabling the kind of non-linear, contextually grounded transformation that more top-down approaches cannot achieve (Barcena et al., 2026).

Led by ICLEI Africa in partnership UKZN, Eduardo Mondlane University and eThekwini Municipality, the Designing Inclusive African Coastal City Resilience (INACCT Resilience) project works to strengthen inclusive, gender-responsive urban flood planning in Durban's informal settlements. INACCT, which is funded through the IDRC-FCDO Climate Adaptation and Resilience Initiative (CLARE), is a multi-stakeholder initiative operating across Durban, South Africa, and Beira, Mozambique. The project's primary objectives are to understand inclusive hazard response and to strengthen scalable, climate-resilient coastal municipal planning (Marais et al., 2026). Key to these objectives has been to document the existing CBFEWS, understand the foundational knowledge components required for its success, and pilot its upscaling to other flood-prone settlements (column two in Table 2).

It is within this context the CLARE R4I Opportunities Fund pilot programme (2025–2026) tested whether the key processes and methods developed in Quarry could be applied across three new settlements – Pholani, uMzinyathi and Tshelimnyama. While many core processes transferred well, each settlement presented a distinct combination of hydrological characteristics, governance arrangements, settlement typology, communication infrastructure and local vulnerability that required careful contextual adaptation through co-production methods to achieve appropriately tailored risk reduction responses. This experience across four diverse sites generated a substantial body of outputs and learning, summarised in Table 3 below, that collectively provided the evidence base to synthesise a generalisable framework – one that identifies the key processes and methods transferable to new contexts, while providing structured guidance for incorporating the site-specific content and contextual input that each settlement requires.

Table 3: Six key outputs and outcomes from the pilot upscaling of Durban's CBFEWS (ICLEI Africa, UKZN & R4I, 2026).

	Output	Description
1	Mutual knowledge sharing and capacity development	Risk mapping and settlement walk-throughs conducted with communities as co-researchers to understand the nature of flood risks and identify preventative actions.
2	Defined flood thresholds for FEWS 'critical points'	Co-produced warning thresholds for the pilot settlements have been integrated into the municipal FEWS "critical points". uMzinyathi and Tshelimnyama established tiered watch, alert, and warning elevations using Lidar, while Pholani identified a provisional rainfall threshold (70mm in 10 hours) to flag heightened risks of localised landslides.
3	Collected community-level flood data for model calibration	Community members recorded historical flood levels reached in homes to facilitate the calibration of technical hydraulic models.
4	Correlation/forecasting app-based tool	Development of an open-access tool that enables residents to monitor forecast river levels following official SAWS warnings and set localised warning levels based on lived experience.
5	Historical rainfall analysis tool	A technical tool that analyses historical rainfall records to identify significant storm events and rainfall depths for engineering use.

6	Initial response planning and emergency kits	Collaborative planning for actions before, during, and after flood events, supported by the provision of practical tools like emergency kits.

3. The CBFEWS upscaling framework

3.1 Aim

To develop a transferable implementation framework for community-based flood early warning systems across eThekwini's informal and peri-urban settlements, by synthesising and generalising the processes and methodologies developed across four pilot sites while preserving the contextual integrity essential to each system's effectiveness.

3.2 Objectives

1. Synthesise the implementation processes, methodologies and knowledge domains drawn from four pilot settlements (Quarry, Pholani, Umzinyathi and Tshelimnyama) into a structured, generalisable implementation pathway.
2. Resolve the scale paradox by explicitly separating universal processes from context-specific content, ensuring the framework is transferable without being prescriptive.
3. Embed guiding principles that account for variation in risk profiles, social vulnerability, relationship infrastructure and contextual project implementation pacing.

3.3. Logic of construction

The CBFEWS Upscaling Framework was constructed through a synthesis of multiple evidence streams accumulated across several years of collaborative work, drawing on four pilot settlements – Quarry, Pholani, uMzinyathi and Tshelimnyama – each capturing a distinct combination of topography, settlement density, social dynamics and governance structures (see Figure 2 and Table 4). These evidence streams include: longitudinal research and co-production processes conducted by UKZN in Quarry; joint empirical research by ICLEI Africa and UKZN across the four settlements as part of the INACCT Resilience and R4I projects; technical flood modelling, forecasting and catchment management contributions from eThekwini Municipality; and learning generated through community engagement processes, Learning Labs and post-event reviews conducted with residents, community researchers and eThekwini Municipality across all four settlements. Drawing on this diverse evidence base, the framework distils the universal implementation processes that can be standardised across contexts while ensuring local content remains site-specific, providing the necessary foundation for upscaling the CBFEWS across the EMA.

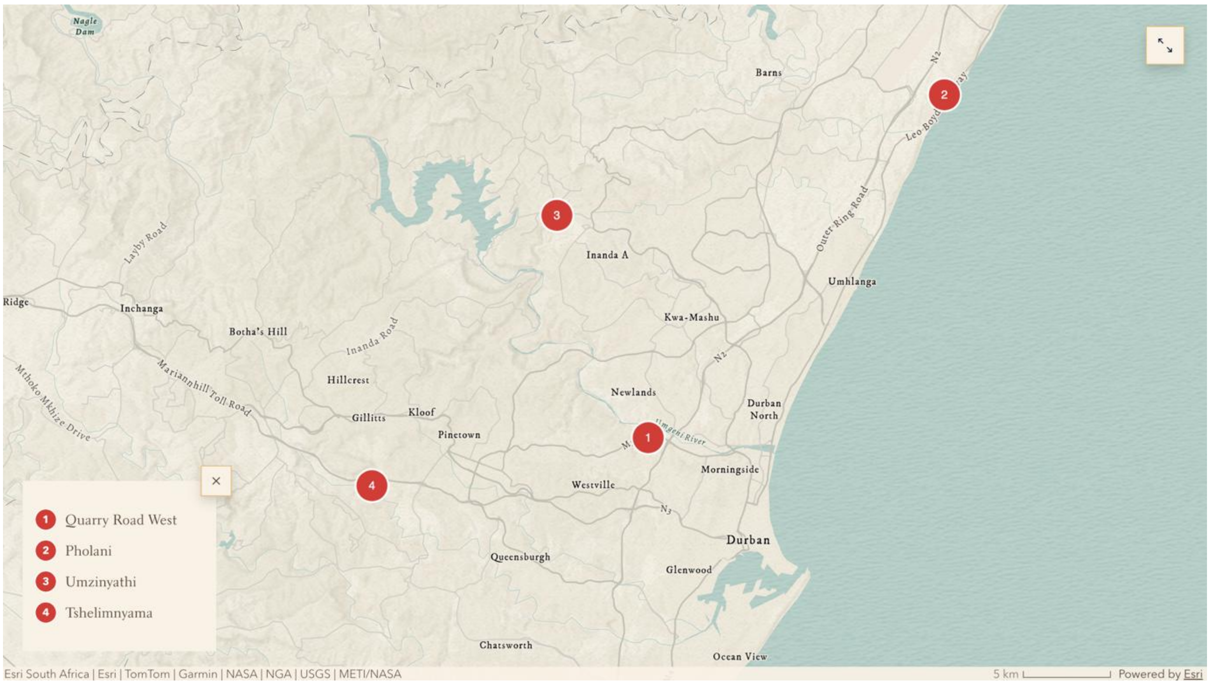

Figure 2: Map showing the locations of the four settlements where the CBFEWS is being tested and implemented.

Table 4: The characteristics associated with the sample of settlements where the CBFEWS is being implemented.

Settlement	Type	Characteristics	Key flood risks
Quarry Road West	Informal	Central Durban; foundational CBFEWS case-study with ~1,100 households and ~4,500 residents; high-density housing on the low-lying Palmiet River floodplain.	Acute fluvial risk (bank collapse/scouring); runoff from the M19 freeway; rapid river rise.

Pholani	Informal	Northern Durban; relatively small (~600 households and ~2,000 residents) medium density; steep slopes featuring highly erodible Berea Red soil.	Simultaneous fluvial and pluvial flooding; saturated soils following periods of heavy rain create conditions for localised landslides that can undercut houses.
Umzinyathi	Peri-urban	North-West of Durban; under dual governance (Traditional Authority and Ward Councillor); characterised by large plots and significant development in wetlands. CBFEWS focused on a sub-catchment of 600 households (~5,000 people). Rapidly densifying due to investment in peri-urban settlements.	Fluvial flooding from the main uMzinyathi River and a minor tributary; surface runoff in "bowl" catchments; persistent groundwater dampness in houses; localised landslides on deeply incised, clay-rich slopes over weathered granite and gneiss, exacerbated by unregulated cut-and-fill house platforms.
Tshelimnyama	Mixed	West Durban urban fringe; complex mix of formal, informal, and township housing; located near industrial developments and bridge crossings. CBFEWS focused on a sub-catchment of	Flooding from the uMhlathuzana River; high-velocity runoff from elevated areas; potential exacerbation by stormwater from neighbouring industrial

	1000 households (~3,000 people).	parks; localised landslides on steep slopes.

Translating this evidence base into a generalisable framework required careful consideration of several interconnected challenges. The various knowledge systems and knowledge holders that underpin the CBFEWS needed clear demarcation to ensure each was meaningfully represented and not collapsed into a single technocratic logic. The processes and methods used to implement the CBFEWS across four distinct settlement contexts required analysis and synthesis to identify what was truly transferable and what remained inherently site-specific. And the tension between contextual integrity and universal process, the scale paradox, required a set of guiding principles to navigate explicitly, rather than leaving practitioners to resolve it ad hoc in each new setting. Together, these considerations necessitated a hybrid process-implementation framework that distils the key steps for establishing comprehensive community-based early warning systems in new contexts into a repeatable and scalable roadmap, while building in structured mechanisms for contextual input at every stage. Figure 3 displays the key pillars and general structure of the CBFEWS upscaling framework, while the following sections provide a detailed discussion of each pillar and the processes and methodologies that inform it.

Figure 3: Mind map outlining the general structure of the CBFEWS Upscaling Framework, created using Google's NotebookLM.

A note on 'upscaling'

Firstly, ‘local’ as used in this report refers to a specific geographic area, which may be defined as a neighbourhood, community, sub-catchment or city, characterised by a distinct set of physical, social and governance conditions (O’Donoghue et al., 2025).

Secondly, within this framework, 'upscaling' refers to horizontal expansion – scaling the CBFEWS from a few pilot sites to multiple settlements across the EMA – rather than vertical scaling into a centralised city- or province-wide system. While the framework can be institutionalised through city-level policy, its intended operational purpose remains firmly at the settlement scale.

3.3.1 Pillar 1: Knowledge foundation layer

Pillar 1 of the CBFEWS upscaling framework establishes six knowledge domains (see Table 5) required for effective, socially embedded and politically conscious system implementation, addressing a common failure in traditional early warning systems to engage meaningfully at the local level (Sufri et al., 2020). By deliberately integrating diverse domains, the framework adopts a political posture that challenges the historical dominance of positivist paradigms, which privilege ‘objective’, technical scientific knowledge over experiential and contextual ways of knowing (Eriksen et al., 2015; Israel et al., 1998). It treats scientific, local and indigenous knowledges as equally valid, essential inputs, recognising that flood risk in informal settlements cannot be adequately managed through technical data alone. Ultimately, by embracing ontological pluralism, the framework allows marginalised voices to contest existing power dynamics in urban governance, creating opportunities for transformational adaptation (Eriksen et al., 2015).

Table 5: Pillar 1: A summary of the six foundational knowledge domains that the CBFEWS is built upon.

Knowledge domain	Components	Strategic purpose
Scientific (physical science & engineering)	Hydraulic and climate models, rain and stream gauges.	Provides numerical data and technical thresholds for forecasting.
Scientific (social science)	Social, political and historical context; vulnerability analysis.	Analyses socio-economic context, uneven risk distribution and social constructions of risk.
Local	Lived experience, situational understandings.	Supports interpretation of site-specific risks and responses. Informs community-based definitions of flood thresholds.
Indigenous	Cultural and spiritual relations to land and hazards.	Determines relational responses and temporal understanding of risk.
Municipal	DRM protocols, SOPs, boundaries.	Defines the governance context and formal response authority.
Legal and Procedural	Mandates, responsibilities, state and customary law.	Outlines legal consequences and formal orders of procedures.
Intermediary and Bridging Knowledge	Mediators and integrators of different knowledges; interdisciplinary and transdisciplinary research.	Synthesises technical and social insights for knowledge integration.

1. Scientific knowledge

Physical science and engineering knowledge provide the numerical and technical backbone of the CBFEWS, encompassing the analysis of flood hazard causes, distinguishing between fluvial and pluvial events to tailor monitoring strategies, hydraulic forecast models, telemetry from rainfall and stream gauges, and the downscaling of climate science to settlement level. Models such as PCSWMM and other hydraulic models convert forecasted rainfall data into specific flow depths, providing the technical outputs from which locally relevant warning thresholds and evacuation windows can be established (ICLEI Africa & UKZN, 2025).

Social science knowledge is equally essential, providing the analytical tools to understand the socio-economic, political and historical contexts, power hierarchies and structural inequalities that determine how flood risk is produced and experienced in informal settlements. By analysing systemic governance gaps and the conditions that concentrate risk among the urban poor, this knowledge domain identifies who is exposed, how, why, and under what structural conditions – insights that technical data alone cannot provide (Nightingale et al., 2020). Ultimately, both physical and social sciences are necessary for a comprehensive understanding of flood risk. A disaster is not merely a physical event but a social construct emerging from the dynamic interaction between the hazard, the exposure of people and assets and the underlying environmental and social vulnerabilities of the settlement, as well as people's capacity to respond and adapt (Wisner et al., 2004). Synthesising these variables within the CBFEWS allows for the development of early warning systems that are not only technically robust but socially legitimate and trusted by those they are designed to protect.

2. Indigenous and local knowledge

Local knowledge grounds abstract predictive scientific data in the everyday lived realities of the settlement. Place-based understandings of ecological, social and political dimensions are crucial in understanding site-specific vulnerabilities and exposures to floods. Importantly, local knowledge supports the interpretation of site-specific flood risk levels and contributes to the co-production of formal flood thresholds. In uMzinyathi, for example, the community established these thresholds by selecting a specific goat kraal, based on their experience of flooding, as a reference point to define tiered watch, alert and warning levels (ICLEI Africa & UKZN, 2026). These community-defined levels were then directly linked back into the science of the municipal FEWS by using Lidar to convert the physical reference point into technical elevations (ICLEI Africa & UKZN, 2026). This alignment allows residents to better understand technical system outputs in relation to their own experienced risk levels. Similarly, in Pholani, settlement walks with residents identify water pathways to determine where risk levels are highest, informing the strategic placement of sandbags and trenches to mitigate runoff (ICLEI Africa & UKZN, 2025).

Indigenous knowledge is a critical determinant of relational responses a community has towards hazards, influencing temporal and cultural understandings of risk (Agrawal, 2002; Nightingale et al., 2020). In many Durban settlements, the concept of the Inkanyamba – a river snake associated with causing hazards – can be integrated into technical training to build trust and local relevance (O'Donoghue et al., 2025). In Pholani, the practice of beating drums or banging pots to spiritually chase away storms serves as a highly effective audible early warning mechanism when modern communication infrastructure fails (O'Donoghue et al., 2025).

Including Indigenous and Local Knowledge Systems (ILKS) in CBFEWS upscaling is complex due to their deeply context-specific nature, rooted in local environments, cultures and lived experience. Unlike scientific knowledge, ILKS cannot be easily transferred between settings, meaning upscaling must focus on replicating the participatory processes – such as engagement, trust-building, knowledge co-production and collective risk interpretation – through which this knowledge is meaningfully applied (Andersson et al., 2020; Barcena et al., 2026).

A further complexity lies in how ILKS is defined and applied, as "indigenous" and "local" knowledge are often conflated despite key differences. Indigenous knowledge tends to be rooted in long-term cultural and ancestral ties, while local knowledge is more place-based (IPCC, 2019). In practice, the CBFEWS draws on a spectrum of knowledge forms, including experiential knowledge and citizen science, and the challenge for upscaling is to meaningfully bridge these with scientific systems without reducing them to purely technical inputs.

A note on epistemology and knowledge

The framework recognises two broad epistemological traditions most prominently at play. Western scientific epistemology tends toward a singular ontology – striving for the “supremely abstract” through theories and experiments that transcend individual cases to remain generalisable and grounded in cause-effect logic (Agrawal, 1995; Lévi-Strauss, 1966). In contrast, Indigenous and Local Knowledge Systems (ILKS) are broadly characterised by ontological pluralism, acknowledging multiple simultaneous realities that are deeply situated within ecological, cultural and temporal contexts (Nightingale et al., 2020). These knowledges are place-based, emphasising meaning-making and relational values, such as collaborative reciprocity and interdependence, while remaining rooted in livelihoods and lived experience (Agrawal, 1995; Nightingale et al., 2020).

In practice, however, these positions are rarely neatly distinguishable, as the boundaries between ILKS and scientific knowledge are often blurred. Hybridisation is common: ILKS becomes enmeshed in urban contexts, modernity reshapes cultural frameworks, and individuals simultaneously hold multiple, layered forms of knowledge (Agrawal, 1995; Nakashima et al., 2018). The framework does not attempt to resolve these complexities but acknowledges them as the terrain within which the CBFEWS must operate.

It is worth distinguishing this from how the framework actually operationalises knowledge. Rather than identifying the epistemological traditions that stakeholders subscribe to, it takes a more pragmatic approach, recognising that different actors hold different, equally important bodies of knowledge that must be synthesised for a comprehensive CBFEWS. Legal, municipal, scientific and local knowledge are treated as essential inputs for a system that is both technically robust and contextually grounded.

3. Municipal knowledge

Municipal knowledge defines the formal governance context within which the CBFEWS must operate – administrative boundaries, disaster risk management protocols, standard operating procedures (SOPs) and city-wide risk profiles. It ensures settlement-scale systems are nested within official structures, with the CBFEWS now being a standing agenda item in the city's Joint Operations Centre (JOC) during disaster activations (O'Donoghue et al., 2025).

Drawing this knowledge domain into the CBFEWS will also help navigate contestations found in traditional authority areas. Approximately 43% of eThekwini's land area falls under Ingonyama Trust Land, governed by traditional authorities who are responsible for land allocation, while the municipality holds a mandate for service delivery and spatial planning in these areas of dual governance (Sutherland, 2024).

In practice, many households in these peri-urban areas build without meeting municipal planning requirements or building regulations, resulting in poor stormwater management and inadequate foundations that significantly increase disaster risk (Sutherland, 2024). For example, uMzinyathi falls under dual governance, sitting within the Qadi Traditional Authority area where land is communally held under the Ingonyama Trust Board and allocated by the local *Izinduna*. Although eThekwini Municipality holds theoretical administrative jurisdiction over spatial planning, in practice, there has been limited enforcement, resulting in poorly controlled land allocation and evident development challenges in the sub-catchment (ICLEI Africa & UKZN, 2025; Sim et al., 2018).

4. **Legal and procedural knowledge**

Legal and procedural knowledge outlines the mandates and responsibilities that govern the system's operation, ensuring the CBFEWS complies with national laws and formal orders of procedure. Critically, only the SAWS hold the legal authority to issue official weather warnings. eThekwini Municipality issues warnings following the SAWS warnings, and the CBFEWS helps to translate these into the local context (O'Donoghue et al., 2025). Legal knowledge also helps navigate state and customary law contestations in conjunction with municipal knowledge brokers.

5. **Intermediary and bridging knowledge**

Intermediaries and facilitators with strong knowledge-bridging capabilities synthesise technical, social and environmental insights through interdisciplinary and transdisciplinary research, supporting continuous system innovation and providing the evidence base that justifies investment in the CBFEWS. Researchers from universities, some municipal officials and research practitioners from boundary organisations act as essential mediators and integrators of perspectives, data and knowledge, effectively serving as passage points through which risk information is circulated and translated (Barcena et al., 2026; Sutherland, 2025). In Quarry, for instance, they translate complex stream gauge data into simple, actionable WhatsApp alerts for residents (O'Donoghue et al., 2025). The integration of scientific, technical and local knowledge has not only strengthened the CBFEWS and reduced loss of life, but has also deepened relationships between informal settlement residents, researchers and local government officials, opening doors to broader opportunities such as river rehabilitation projects and learning exchanges with other settlements (Sutherland, 2025; O'Donoghue et al., 2025).

3.3.2 Pillar 2: Procedural core layer

The Procedural Core (see Table 6) of the CBFEWS upscaling framework provides a repeatable, six-step implementation roadmap designed to guide CBFEWS in informal and peri-urban settlements across the EMA. Six processes have been designed to be site agnostic, providing a consistent structure while allowing site-specific context, such as local flood thresholds and social vulnerabilities, to be included. The Procedural Core embodies co-production methodologies throughout its phases, facilitating a constant flow of feedback between knowledges and decision-makers. Iteration and a cyclical design process that encompasses design, representation and knowledge exchanges helps the framework and CBFEWS to be dynamic and a living methodology that can morph depending on the contextuality of social realities (Israel et al., 1998; Kruk et al., 2017).

Running alongside the six-step procedural core is a cross-cutting layer of institutional integration. It is a parallel phase which details how each step is connected to larger governance systems. The CBFEWS does not operate in isolation. Therefore, for the CBFEWS to be effective and have longevity, each procedural step should be aligned with existing municipal structures, technical forecasting systems and legal mandates.

Table 6: Pillar 2: A summary of the 6-step procedural core describing the methodologies and processes taken to effectively implement the CBFEWS, alongside the cross-cutting layer that details how each procedural step should be integrated into existing institutional systems.

Step	**Process**	**Description**	**Integration into existing systems**
1	Context Engagement & Foundation	Accessing settlements through existing collaborations (e.g., sanitation or philanthropic projects) or through identification of issues in high-risk areas, to build rapport	Integrate context with municipal understandings.

Step	Process	Description	Integration into existing systems
		and map power dynamics.	
2	Risk Profile	Identifying fluvial vs. pluvial flooding, and mapping existing exposures and vulnerabilities using scientific (e.g., hydraulic models) and arts-based methodologies (e.g., playdough modelling and photovoice).	Integrate risk/hazard/vulnerability profile with existing risk assessments.
3	Co-design & Knowledge Integration	Calibrating models via citizen science, using community-led observations of river levels and community-defined warning thresholds to validate and update hydraulic models.	Integrate findings with existing hydrological, meteorological and broader forecasting entities, and with vulnerability assessments.
4	Communication Channels	Mapping connectivity blind spots and identifying viable methods (e.g., cell towers vs. WhatsApp) to ensure multi-directional information flow.	Integrate settlement-scale early advisory with municipal warning.

Step	Process	Description	Integration into existing systems
5	Preparedness & Response	Co-producing a preparedness and response plan across three phases: pre-hazard (equipment procurement, preventative measures); during-hazard (activating the response and evacuation plan); and post-hazard (immediate recovery and structured review to improve the system).	Integrate settlement-scale preparedness and response with existing municipal disaster response. Adhere to official SOPs and legal mandates.
6	Operationalisation & Institutionalisation	Formally nesting the CBFEWS within municipal structures to ensure long-term maintenance and funding.	Key binding element between the procedural core and the cross-cutting layer for institutionalising the CBFEWS within broader governance systems, ensuring longitudinal effectiveness.

1. Context engagement and foundation

This process involves using equitable and ethical protocols to build legitimacy and rapport in the settlement. By focussing on actor mapping and building social connection between community members, researchers and disaster officials, it prioritises learning through the community's perceptions of risks and their needs, understanding existing power dynamics and working with the community to gain comprehensive insights into the settlement's socio-political, economic and historical context. Exploring and establishing these initial methodologies produces a deeper understanding of the relationship infrastructure that exists within communities and between the community, organisations, researchers and the municipality. The contextual understanding developed in this procedural process of the CBFEWS should be integrated with municipal knowledge of the settlement, such as ward boundaries, existing service delivery arrangements and governance relationships.

Having a rich understanding of the power dynamics and trust between entities and stakeholders provides a crucial foreshadow of the implementation pace of the CBFEWS. Social environments that have deeper, pre-existing trust networks will allow for a more rapid deployment of the CBFEWS. For instance, in Pholani, implementation of the CBFEWS progressed rapidly by leveraging pre-existing relationships established through municipal sanitation projects and community gardening projects funded by the Gates Foundation and Wellcome Trust, whereas, CBFEWS implementation pace has been slower in Tshelimnyama, where existing relationship infrastructure between CBFEWS researchers and the community had to be built from the ground, building on initial relationships developed through the SHEFS-SA project (ICLEI Africa & UKZN, 2025). Thus, a strong social foundation should precede technical components of the CBFEWS.

2. Co-production of the risk profile

The risk profile should aim to integrate as many knowledges necessary, such as residents with lived experience, officials with disaster and procedural experience and researchers with theoretical and scientific experience, to provide a holistic, mutual understanding of flood risk, and any interconnected or cascading hazards that may influence any variables that interact with flood risk, such as vulnerability. Researchers, officials and residents should synthesise technical data (rainfall/stream gauges) with lived experience through settlement walks, participatory mapping on aerial photos and arts-based tools like playdough modelling.

Combining localised flooding models with co-produced exposure and vulnerability assessments creates the settlement-scale flood risk map that is essential to responding to a key issue that faces conventional municipal early warning systems: that they lack the granularity required to trigger settlement-scale effective action. The risk profile produced in this process should be integrated, where possible, with the municipality's existing hazard and vulnerability assessments.

3. Integrate local and technical knowledge through co-design

Process 3 represents the critical technical-social bridge of the framework, where scientific models and local knowledge are integrated through co-design to transform abstract data into accurate, trusted and actionable early warning mechanisms. Based on the experience in the pilot sites to date, this socio-technical interface happens in at least three ways. Firstly, community-led observations of river levels are used to develop and refine correlations between upstream gauge readings and downstream impacts, improving the predictive accuracy of technical forecasting tools at the settlement scale (O'Donoghue et al., 2025). Secondly, residents identify familiar landscape reference points, such as a particular house or kraal, to define 'watch', 'alert' and 'warning' levels based on lived experience, which are then converted into precise technical elevations using Lidar analysis and formally integrated into the municipal FEWS at critical points (ICLEI Africa & UKZN, 2026). Thirdly, community members record historical flood levels reached in their homes, providing citizen science data that municipal engineers can use to calibrate PCSWMM hydraulic models against documented real-world conditions (ICLEI Africa & UKZN, 2026). By feeding locally derived findings back into official hydrological forecasting systems, this process ensures that broad scientific forecasting is ground-truthed in each settlement's specific context, reducing warning fatigue and building the local trust necessary for residents to take decisive action when warnings are issued.

As an example, in Quarry, this process of the CBFEWS has resulted in an accurate threshold: when the upstream river gauge reaches 1.6 metres, there is a documented 40-minute lag time where the river will then overflow its banks downstream at Quarry, which provides a critical evacuation window (O'Donoghue et al., 2025). Building on these physical observations, the Obscape-developed Correlation Tool forecasting app empowers residents to monitor real-time rainfall and streamflow trends, as well as forecast rainfall and streamflow, on personal mobile devices, allowing them to set localised warning thresholds based on their own lived experience (ICLEI Africa & UKZN, 2026). This digital interface uses catchment-specific rainfall-streamflow correlations to model and reflect site-specific river level predictions, providing an additional advisory tool that enhances individual monitoring and response capacity (ICLEI Africa & UKZN, 2026) along with SAWS warnings and municipal advisories.

4. Communication channels

This process aims to operationalise a strategic flow of knowledge. Ideally bi-directional communication flows are implemented, where residents receive broad-scale SAWS warnings, municipal alerts and warnings and advisories developed by the CBFEWS, as well as residents being able to report actual experience and flood levels to researchers and disaster officials. Once communication channels are established, they should be connected to, and help refine, official municipal warning systems, ensuring that CBFEWS advisories complement the city-wide warnings.

Mapping connectivity blindspots within settlements is essential, as this will determine the extent of multi-directional communication flows that are possible to implement. For example, on the one hand, Quarry has a dual WhatsApp group design: one for communication between researchers and disaster officials and another for researchers and community members (O'Donoghue et al., 2025). This way researchers can facilitate the mediating of knowledge and communication that the city and residents require respectively. On the other hand, because cell signal is very limited in Pholani, audible redundancy is relied upon, such as loudhailers and the beating of pots (ICLEI Africa & UKZN, 2025).

5. Preparedness and response

Process 5 synthesises the outputs of all preceding steps into a co-produced preparedness and response plan, developed collaboratively with community members, researchers and municipal officials where possible. Early warnings and response plans save lives when they are received, understood and acted upon, which requires established protocols. This involves establishing roles and responsibilities, procuring emergency toolkits and capacitating community members with the necessary knowledge and skills to increase their risk ownership. Learning labs and interactive focus groups are a key method for increasing this capacity, where community members and other practitioners such as researchers and disaster officials learn how to adapt to and control flood risk, and when facilitated across settlements, they also serve as an important way to share flood risk knowledge between communities facing similar challenges (O'Donoghue et al., 2025).

This process is delineated in three core phases: pre-hazard, during hazard, and post-hazard, though each phase contains critical sub-steps. The pre-hazard phase encompasses “long before” work, focusing on implementing preventative and adaptive measures like debris clearing, opening of local drainage trenches and ecological rehabilitation and procuring necessary equipment, such as high-visibility vests, torches and colour-coded flags for visual alerts (O'Donoghue et al., 2025; ICLEI Africa & UKZN, 2026). In Pholani, for example, this includes re-grading the entrance road and stabilising steep pathways with tyres and carpets to slow water velocity and erosion (ICLEI Africa & UKZN, 2025). Within this phase, a “just before” step is activated when heavy rainfall is imminent; here, the community monitors rain and stream gauges against site-specific thresholds (such as 70mm in 10 hours in Pholani) and prepares emergency bags containing identification and essential medicines (ICLEI Africa & UKZN, 2025).

The during hazard phase involves the active construction and implementation of the response plan, activating it alongside municipal disaster management authorities using sirens, whistles and loudhailers to coordinate evacuations to safe spaces. This phase requires enough flexibility to accommodate unfolding conditions, such as debris-blocked culverts or power outages.

The post-hazard phase is divided into two distinct parts: “immediately after with immediate recovery,” where residents alert authorities and NGOs to needs and report infrastructure challenges, and “learning and future improvements”. This final component utilises Learning Labs and structured post-event reviews to capture lessons learned and update the living documents underpinning the system, ensuring that these insights are integrated back into the "long before" work to enhance the functioning of the CBFEWS for the next hazard event (ICLEI Africa & UKZN, 2025). These co-designed preparedness and response plans must adhere to official disaster management SOPs and legal mandates, ensuring community-led responses are coordinated with municipal structures whenever possible.

6. Operationalise and institutionalise

Process 6 shifts focus from implementation to long-term sustainability, ensuring the CBFEWS outlasts any individual project, champion or funding cycle. It also serves as the key binding element between the procedural core and the cross-cutting layer, formalising the point at which the CBFEWS transitions from a project-based initiative into a standing component of the municipality's disaster risk management architecture.

The first step involves clarifying roles and responsibilities, funding, maintenance protocols, and system redundancy to formally nest the CBFEWS within municipal structures and prevent single points of failure. A common challenge for community-based initiatives is a lack of SOPs and weak linkages to formal government EWS (Sufri et al., 2020). By formalising this nesting, the framework addresses these systemic barriers. In practice, this means the CBFEWS becomes a standing agenda item in the city's JOC during disaster activations (O'Donoghue et al., 2025). To ensure technical resilience, the system must transition technical data and hydraulic modelling systems to cloud-based platforms, ensuring that critical risk information remains accessible even if local physical servers are compromised by power outages or load shedding (O'Donoghue et al., 2025). Furthermore, institutional memory is protected by training multiple CBFEWS champions at both the community and municipal levels, ensuring the system remains functional during staff transitions or turnover (O'Donoghue et al., 2025).

The second step establishes a pipeline for continuous refinement through a structured feedback loop, iterating the advisory flow from data through thresholds to action and back to feedback. This involves structured post-event reviews and Learning Labs that compare real-time data and co-produced thresholds against actual flood impacts to iteratively update living documents such as response plans and advisory levels, ensuring the system improves with every hazard event.

The third step looks further ahead, exploring opportunities to enhance the system through automation, improved modelling and digital tools such as artificial intelligence, ensuring the CBFEWS remains technically current as new capabilities become available (O'Donoghue et al., 2025).

3.3.3 Pillar 3: Guiding principles layer

A key challenge of upscaling the CBFEWS is what might be called the scale paradox – the tension that lies between upscaling and standardising methodologies while preserving each settlement's unique context. While the procedural core provides generalised structure and the knowledge domains identify key inputs, neither fully resolves how implementation should be navigated when contexts differ as significantly as a dense riverside informal settlement and a sprawling peri-urban area under traditional governance. The guiding principles are designed to address this tension, embedding within the framework a deliberate focus on local-scale knowledge, relationships and context-specific vulnerabilities, ensuring that resilience is built from the ground up rather than imposed through global frameworks that tend to omit the social, economic, political and environmental relations that have produced the very inequalities making resilience necessary in the first place (Sutherland, 2025). The five principles outlined below do not prescribe what to do, but guide how decisions should be made throughout implementation, accounting for variation in relationship infrastructure, governance arrangements, social vulnerability and geographical scale (see Table 7). They function as a strategic filter that keeps the framework both transferable and contextually grounded across diverse settlement environments.

Table 7: Pillar 3: The five principles to guide the CBFEWS implementation.

Principle	Description
Scale Processes, preserve context	Scale methodologies (Processes 1-6) to provide structure. Keep content (local knowledge/local thresholds) context-based to ensure local relevance and legitimacy.
Balance Abstraction & Co-production	Engage with scientific and technical data through community participation to prevent top-down failures. Bridge knowledge domains iteratively to produce trusted, meaningful advisories.
Adaptive Pacing	Prioritise relationship infrastructure (trust between entities) and social embeddedness alongside technical systems. Allow progress at a rate relevant to the context; deeper relationships enable faster implementation.
Gender and Social Inclusion	Balance gender inputs in co-production and locate socially vulnerable groups. Protect those most exposed to avoid reinforcing structural inequalities.
Geographical Scale	Scale the framework relative to the settlement's size and geography. Assess how the specific scale compares to past cases to refine replication.

1. Scale processes, preserve context

The six-step procedural core provides a universal structure that can be standardised across settlements. What must not be standardised is the content – local flood exposure, vulnerability, knowledge and governance arrangements must remain specific to each settlement (O'Donoghue et al., 2025). Generalising the methodology does not mean homogenising the CBFEWS across sites. Effective CBFEWS that address the granularity missing in conventional flood EWS ought to depend on continuous contextual input, supported by innovative, evidence-based methodologies outlined in the procedural core pillar. Thus, effective utilisation of the CBFEWS upscaling framework should scale the universalised processes of the procedural core pillar, while preserving the context existing in each locale.

2. Balance abstraction with co-production

This principle aims to bridge the gap between more abstract and modelled scientific data and the local lived realities. Broad scientific models must be iteratively filtered through local knowledge to produce warnings that residents trust and act upon. Where this balance is not maintained, top-down failures will surface, resulting in warnings that are technically accurate but locally meaningless (O'Donoghue et al., 2025). Bridging knowledge domains is therefore not a one-off step but an ongoing process throughout implementation. Essentially, balancing top-down climate science and governance systems with bottom-up realities and knowledge must move beyond a purely tokenised phrase to a constant, iterative practice embedded across the CBFEWS, especially amongst the knowledge integrators and facilitators.

3. Adaptive pacing

The speed of implementation will largely be determined by the strength of relationships between residents, researchers and officials – the state of the settlement's relationship infrastructure – not by top-down technical readiness. Settlements with deeper existing trust and established networks will move faster in the uptake of the CBFEWS, whereas those where relationships are still emerging require more time before technical components of the CBFEWS can be meaningfully deployed (ICLEI Africa & UKZN, 2025). Attempting to accelerate beyond what the relational context allows risks undermining the legitimacy and community up-take of the CBFEWS.

4. Gender and social inclusion

Effective early warning must reach everyone, and this requires deliberate effort. Inclusive design is a primary principle, as global findings indicate that the full range of vulnerable groups is rarely routinely engaged in EWS, leading to systems that fail those most at risk (Sufri et al., 2020). Gender inputs should be balanced throughout co-production. In Pholani, for instance, focus groups aimed at developing co-produced flood risk maps were often conducted in a gendered format to incorporate the risk perceptions of women and men, without certain perceptions being overshadowed by others (ICLEI Africa & UKZN, 2025). Gender-responsive risk reduction should critically engage with the various ways flood risk intersects with gendered social norms. This includes mitigating risks faced by women due to care burdens or gender-blind response strategies, while also addressing the specific post-hazard vulnerabilities of young men driven by restrictive norms around masculinity that discourage help-seeking (Marais et al., 2026; Blanchard, 2024).

Social groups that are particularly vulnerable to flooding, including those with disabilities, children and the elderly, must be actively located and included in flood risk profiles and co-production processes. Without this, the system risks reinforcing existing structural inequalities by incorporating only the perspectives of those already best positioned to receive and act on warnings (Sufri et al., 2020).

5. Geographical scale

The framework must be adjusted relative to the size, density and topography of each settlement. A system designed for a compact riverside settlement will not translate directly to a large peri-urban area with dispersed housing and multiple drainage catchments. While comparing the characteristics of a new site against past cases helps practitioners, the CBFEWS upscaling framework aims to generalise all processes and be utilised in such a way that the practitioner calibrates it for the scale of the settlement. The upscaling framework is built using data from the four pilot settlements that span a range of local scales and flood typologies – from dense riverside and steep-slope informal settlements to sprawling peri-urban settlements – collectively capturing a diversity of contexts. However, there will invariably be settlement scales and contexts that require more significant adaptation of the CBFEWS upscaling framework in order for it to be transferrable to the new settlement profile. For example, the CBFEWS is being implemented to the entire settlement of Pholani because it is a relatively dense settlement of 630 households. Whereas, in Umzinyathi, a sub-catchment had to be identified for implementation of the CBFEWS due to the vast scale of the peri-urban settlement (ICLEI Africa & UKZN, 2025).

3.3.4 The pillars interlocked

The three pillars of the CBFEWS upscaling framework – Knowledge Domains, Procedural Core and Guiding Principles – should not be viewed as independent components but as a mutually reinforcing system. Pillars 1 and 3 continuously drive and guide Pillar 2, with the Knowledge Domains establishing who, with what knowledge, must be consulted before and during implementation, the Procedural Core determines how that understanding is built and translated into action, and the Guiding Principles filter the decisions made at every step along the way (see Figure 4). Together, they resolve the key challenge of upscaling the CBFEWS, in terms of providing enough structure for the system to be transferable, while preserving enough flexibility for it to remain contextually grounded. Figure 4 presents the CBFEWS Upscaling Framework as a synthesised process typology that brings these three pillars together.

The Knowledge Domains do not only inform the first step and then recede. Scientific knowledge is continuously updated as citizen science refines and ground truths gauge correlations and hydraulic models. Local and indigenous knowledge provide profound contextual input, and local realities will change as the CBFEWS develops, ideally resulting in positive flood risk ownership. Municipal and legal knowledge helps determine what is institutionally possible at each procedural phase. This means that as implementation progresses through the six procedural steps, the knowledge base is simultaneously being tested and refined, not simply applied in advance in a top-down manner. Running across all of this is the role of intermediary and bridging knowledge – mediators, boundary organisations and transdisciplinary researchers who synthesise technical and social insights, translate across knowledge domains and ensure that the various forms of knowledge informing the system are meaningfully integrated rather than siloed.

The Guiding Principles operate in a similar way, functioning less as a checklist and more as a set of ongoing decision-making filters. Adaptive pacing, for instance, does not only apply in Process 1 when relationships are being established, it remains relevant in Process 6 when determining the pace of municipal integration. Gender and social inclusion should not be a box-ticking practice during risk profiling and initial community engagement but rather a consideration that must be actively practiced throughout decision-making processes.

The versatility of the CBFEWS framework is demonstrated by its application across diverse environments and its ability to be flexible and adaptable to new contexts. Lemos et al. (2012) outline three variables that guide the narrowing of the climate information usability gap: i) *fit*, the relevance to local needs; ii) *interplay*, how information relates to existing local knowledge; and iii) *interaction*, the quality of collaboration between producers and users. The three pillars synthesise the CBFEWS to its key processes and methodologies that effectively ensure climate science and local flood early warning systems have the *fit, interplay* and *interaction* required at the local level to enact critical flood risk response. The three pillars therefore form an integrated framework, shown below in Figure 4, where knowledges, procedures and guiding principles work together to turn place-based flood risk management and early warning into transferable methodologies.

Pillar 1: Knowledge Foundation Layer

Knowledge Domain	Components	Purpose
Scientific Knowledge - Physical Science & Engineering	Flood hazard causes (e.g., fluvial, pluvial), forecast models and rain/stream gauges	Provides scientific, quantitative data and technical thresholds for flood forecasting
Scientific Knowledge - Social Sciences	Socio-economic, political and historical context; power hierarchies; structural vulnerability and exposure analysis.	Analyses uneven risk distribution; identifies who is most exposed and under what structural conditions to ensure a socially grounded, relevant system.
Local Knowledge	Place-based knowledge on ecological/social/ cultural/political dimensions and land tenure/land use situational understandings	Grounds the system in everyday lived realities, supports the interpretation of site-specific risks, impacts and responses, and contributes to locally relevant flood thresholds
Indigenous Knowledge	Cultural, ancestral and spiritual relations to environment and hazards	Determinant of relational responses and temporal understanding of risk
Municipal Knowledge	Administrative boundaries, DRM and hazard forecasting protocols and SOPs, and city-wide and settlement risk profiles	Defines governance context and legislative and policy frameworks and practices of local authority
Legal & Procedural Knowledge	Mandates, legal responsibilities and state vs. customary law	Outlines legal consequences and the formal order of procedures
Intermediary and Bridging Knowledge	Mediators and knowledge integrators across technical, social and community domains; Interdisciplinarity & transdisciplinarity.	Synthesises technical, social and environmental insights to support knowledge integration.

Pillar 2: Procedural Core Layer

Process	Components	Purpose
Process 1: Context engagement & foundation	Equitable and ethical protocols adapted to each context to access communities; leverage existing collaborations (e.g., sanitation or philanthropic projects)	Build relationships from the outset that support the co-production of knowledge and build legitimacy, trust and rapport to understand the community's priorities and needs
	Actor map relationship architecture (infrastructure) between community, local leadership structures, authorities, organisations and researchers (co-produced)	Understand governance arrangements, power relations and roles/responsibilities to determine implementation and integration approach and pace
	Co-produce contextual histories; situational analysis (political economy & political ecology)	Build a shared understanding of power, livelihoods and services and build trust
Process 2: Risk profile	Access context-specific technical data (e.g., rainfall and stream data), instrumentation and flood models	Scientific and technical overview of risk and data for forecasting
	Co-produce risk profile using multiple methodologies: settlement walks, risk mapping on aerial photos, surveys and arts-based (playdough, photovoice)	Identify hazard causes (fluvial/pluvial), exacerbating factors (e.g., location in floodplains, surface hardening), water flow patterns and impacts to inform threshold markers and identify scientific or local knowledge that is needed to refine these
	Gain comprehensive understanding of the vulnerabilities and possible mitigation options	Ensures a deep understanding of the experienced vulnerabilities and possible mitigating options feeding into future preparedness and response
Process 3: Integrate local and technical knowledge through co-design	Calibrate models via citizen science (ground-truthing, river level observations, thresholds, impact time lags) and determine locally-relevant flood thresholds	Integrate knowledges into context-relevant flood warnings
	Use long-term citizen science to validate and update systems	Ensures ongoing accuracy of models and correlations
Process 4: Communication channels	Define strategic knowledge flow (who receives what, when, how)	Operationalise communication across all actor levels
	Map connectivity blindspots and viable methods such as one-way (cell towers) and two-way (Whatsapp)	Co-produced understanding of settlement's communication landscape, identifying effective communication relative to the context
	Integrate SAWS warnings, technical thresholds and internal advisories and establish communication channels	Translate technical data and co-produce contextually sensitive, rapid, multi-directional (where possible) communication flow into actionable warnings
Process 5: Preparedness and response	Co-design preparedness and response plan: synthesise previous processes, develop toolkits, outline roles and responsibilities, establish evacuation protocols and conduct learning labs	Comprehensive, co-produced, context-based preparedness and response plan that draws on previous processes and continuous co-learning to lower the hazard's impact
	Pre-hazard: Procure necessary equipment (e.g., flags, vests, loudhailers) and implement relevant preventative and mitigating measures (e.g., road grading, clearing, rehabilitation) based on co-designed plan	physical equipment and mitigation measures to adequately prepare for the hazard
	During hazard: Implement response plan, support disaster management authorities	Ensures co-designed plan is followed during the hazard, while being flexible to unfolding events and complementing developing disaster response authorities
	Post-hazard: Review events and update living documents	Capture learnings to refine the holistic FEWS
Process 6: Operationalise and institutionalise	Step 1: Clarify overarching processes, roles and responsibilities, financial health, maintenance protocols and system redundancy (roles and data)	Ensures institutionalisation and the effectiveness and sustainability of the system, nesting it within municipal response and preventing single points of failure
	Step 2: Iteration and refinement of system and advisory flow (Data → Thresholds → Action → Feedback)	Facilitate a pipeline for continuous refinement
	Step 3: Explore options to improve (AI, automation, modelling)	Refine modelling and utilise digital systems to improve system

Cross-cutting layer
Integration into existing systems

- Integrate context with municipal understandings
- Integrate risk/hazard/vulnerability profile with existing risk assessments
- Integrate findings into existing hydrological, meteorological and broader forecasting entities, and with vulnerability assessments
- Integrate settlement-scale early warning with South African Weather Service warning
- Integrate settlement-scale preparedness and response with existing municipal disaster response
- Adhere to official SOPs and legal mandates
- Key binding element between the procedural core and the cross-cutting layer for institutionalising the CBFEWS within broader governance systems, ensuring longitudinal effectiveness

Pillar 3: Guiding Principles Layer

Principle	Upscaling Guidance
Principle 1: Scale universal processes, preserve contextual content	Scale methodologies (Processes 1-6) to provide structure. Keep content (local knowledge/local thresholds) context-based to ensure local relevance and legitimacy.
Principle 2: Balance abstraction with co-production	Engage with technical data through community participation to prevent top-down failures. Bridge knowledge domains iteratively to produce trusted, meaningful advisories.
Principle 3: Adaptive pacing	Prioritise relationship infrastructure (trust between entities) and social embeddedness alongside technical systems. Allow progress at a rate relevant to the context; deeper relationships enable faster implementation.
Principle 4: Gender equality & social inclusion	Balance gender inputs in co-production and locate socially vulnerable groups. Protect those most exposed to avoid reinforcing structural inequalities.
Principle 5: Adjust for geographical scale	Scale the framework relative to the settlement's size and geography. Assess how the specific scale compares to past cases to refine replication.

Figure 4: The CBFEWS Upscaling Framework

4. Conceptualising the CBFEWS beyond early warning

While the CBFEWS was initially designed as a socio-technical tool to translate different forms of flood risk alerts into localised awareness and action, its implementation has revealed a far more complex risk landscape. Over a decade of longitudinal engagement, it became evident that addressing flood risk in EMA's informal settlements needed to move beyond only focussing on the flood hazard but also the broader interconnected determinants of risk, including systemic governance gaps, social vulnerability, inequality, power and institutional challenges. In actuality, a purely technical warning is insufficient if a community lacks the relationship infrastructure to trust the data or the practical means to respond to it. Consequently, the CBFEWS has evolved iteratively, moving beyond the narrow scope of early warning to encompass a proactive and holistic flood adaptation and resilience system.

Beyond digital alerts, the success of CBFEWS relies on inclusive, co-production methods that capture local knowledge often missed by standard data approaches. These include participatory tools like photovoice and playdough modelling, and learning exchanges between settlements that foster a 'community of practice' across the city (ICLEI Africa & UKZN, 2025). These methodologies inform outputs such as co-produced risk maps, training manuals and community-led evacuation systems. These are supported by practical, proactive measures that build physical resilience, such as emergency toolkits (containing loudhailers, sirens and safety gear), bank stabilisation and the safeguarding of important documents (ICLEI Africa & UKZN, 2025).

Once risk is understood more comprehensively, through the interaction between contextual exposures, vulnerabilities and the hazard itself, the CBFEWS is concretised as a thorough flood adaptation and response system. It has evolved iteratively through Learning Labs and post-hazard reviews, ensuring it remains responsive to both changing flood conditions and the lived realities of residents. Therefore, rather than creating a sudden rupture, the CBFEWS is incremental in its approach and method, where new relations are sedimented over time through horizontal learning exchanges, such as the Learning Labs (Barcena et al., 2026)

This ongoing process of reflection and refinement demonstrates that effective early warning is both a social and technical one. It is through this lens that the CBFEWS has grown into a comprehensive flood adaptation and risk reduction initiative, deeply embedded in the settlements it serves and capable of bridging the gap between municipal protocols and community-led action.

What is most significant about this EWS framing is that it moves beyond the conventional early warning model, conceptualising instead a system that responds to a multitude of interconnected risk components. It is comprehensive, adaptable and flexible, built specifically for the informal and peri-urban settlement scale within the unique urban context of EMA. What began as a relatively standard EWS, focused on finding correlations between upstream river levels and downstream inundation, has gradually evolved into a far richer practice. It now encompasses multi-hazard EWS, emergency planning and response, climate change adaptation and the vital work of building trust and shared learning. Unpacking the interacting determinants of vulnerability, exposure and hazard has allowed the CBFEWS to deepen its scope from the purely physical flow of water to the social and political dynamics that define who is protected from flood risk and who is not. This transformation is the direct outcome of deep, sustained engagement between academia, organisations, the municipality and the residents themselves, reflecting a broader recognition that climate change adaptation processes have the potential to contest established authority and knowledge hierarchies, opening up space for transformational adaptation (Eriksen et al., 2015).

In this sense, the CBFEWS should be – and is by those involved – conceptualised as a disaster risk reduction intervention distinct from a conventional EWS. While it retains all the expected components – risk knowledge, technical monitoring, dissemination tools and response capability (Sufri et al., 2020) – it departs from the standard model in several important ways: i) levelling the knowledge hierarchy; ii) applying hyperlocal thresholds; iii) treating residents as active producers rather than passive recipients of the system; iv) explicitly addressing social vulnerability; and v) embedding co-production across the system. The result is not a static EWS infrastructure but an iterating, living methodology that extends early warning into a more comprehensive approach to flood adaptation and risk reduction.

5. Limitations

While the CBFEWS upscaling framework represents an advancement in settlement-scale disaster risk reduction, several limitations must be addressed to transition from a successful pilot to a sustained municipal program.

1. Single-hazard focus and compound risks

The framework is currently single-hazard focused, concentrating on pluvial and fluvial flood risk. While this provides depth, it does not yet overtly account for compounding or cascading risk scenarios, such as flooding triggering disease outbreaks or lightning strikes during evacuation scenarios. Expanding toward a multi-hazard EWS, that this framework and the existing CBFEWS is well positioned to do, is a critical next step that will necessitate a shift from siloed departmental responses toward a multi-departmental governance structure that integrates health, energy and social services into a unified, interoperable early warning protocol.

2. Technical vulnerabilities and maintenance responsibilities

At the technical level, load-shedding and connectivity blind spots remain persistent threats to gauge telemetry and digital communication. Physical gauge infrastructure is also maintenance-sensitive, and damage to a single gauge can compromise localised modelling. Mitigation requires the municipality to move beyond pilot-phase dependency on research funding and formally assign lifecycle responsibility to the Engineering Unit. Furthermore, transitioning data to cloud-based platforms and establishing analogue communication backups would bring in resilient redundancy into the system (O'Donoghue et al., 2025).

3. Dependence on relationship infrastructure and institutional memory

The framework's reliance on relationship infrastructure can be heavily dependent on specific individuals and champions, such as researchers, community leaders and municipal officials (O'Donoghue et al., 2025). Staff turnover and stakeholder transitions can paralyse systems built on personal rapport rather than formalised institutional SOPs. Addressing this requires deliberate role redundancy and training multiple mediators at each level of the CBFEWS to ensure the system survives political and administrative cycles.

4. **Political, social and institutional barriers to access.**

Political and social barriers to upscaling remain significant: community gatekeepers may restrict information flow to vulnerable sub-groups, and deep-seated mistrust of local government means technical deployment must always be preceded by sustained relationship building. Resource poverty also constrains WhatsApp-dependent systems where airtime and data access are inconsistent (ICLEI Africa & UKZN, 2026). The eThekwini Municipality should explore partnerships with telecommunications providers to create zero-rated data zones during flood hazard events.

Beyond these social factors, the system faces complex institutional barriers, including fragmentation between municipal departments that often work in isolation. Implementation is further constrained by unclear custodianship and mandates, particularly in peri-urban areas where the interface between state administrative jurisdiction and Traditional Authority makes long-term governance ownership and funding responsibilities difficult to establish.

5. **Funding and long-term municipal adoption**

Long-term municipal adoption depends on dedicated budgets within the Disaster Management and Climate Adaptation branches (O'Donoghue et al., 2025). Expanding the CBFEWS will remain limited unless it is integrated into broader city-level by-laws and investment pipelines, establishing it as a core municipal service (O'Donoghue et al., 2025). Achieving this requires legislative formalisation of the CBFEWS as a local impact advisory system to unlock permanent institutional mandates.

6. Strategic Recommendations

The following strategic recommendations provide a robust operational and institutional roadmap for government officials and disaster risk managers to transition the CBFEWS from a successful research pilot into a formalised, city-wide disaster risk management program. These recommendations explicitly address critical gaps in legislation, governance and long-term custodianship.

1. Adopt a holistic, multi-knowledge framework for flood risk

Effective early warning cannot rest on technical data alone. Integrating scientific, local, indigenous, municipal, legal and specialist intermediary knowledge produces more accurate and actionable flood warnings than any single knowledge domain can achieve independently. Locally generated flood early warning indicators, such as river height thresholds should be formally validated through a co-production process between community members and officials or researchers before integration into official SOPs, ensuring local warnings and advisories carry institutional weight.

2. Seek legislative formalisation to unlock funding and mandates

While SAWS holds the legal authority to issue official severe weather warnings, the municipality should pursue legislative avenues to formally recognise the CBFEWS as a local impact advisory system. Formalising this within municipal by-laws or district-level protocols can unlock dedicated funding streams and transform the CBFEWS from a research project into a core municipal service. This legislative standing would unlock dedicated funding streams for infrastructure maintenance and permanent community liaison roles, ensuring the system outlasts individual research cycles.

3. Use this framework as a replicable, step-by-step implementation roadmap

The six-process procedural core provides clear, sequenced guidance for establishing settlement-scale flood early warning and risk reduction, from first settlement engagement to full institutionalisation. Practitioners should standardise the implementation process while ensuring that site-specific content, like local thresholds, cultural meanings and contextual vulnerabilities, remains grounded in the reality of each settlement.

4. **Define long-term institutional custodianship and maintenance**

If the CBFEWS is reliant on a single champion or short-term project funding, it will not be viable in the long-term. The Coastal Stormwater and Catchment Management Department should assume formal responsibility for the lifecycle and maintenance of the physical telemetry network, while Disaster Management should hold custodianship of response protocols and ensure CBFEWS advisories are a standing agenda item in the city's JOC. Any further necessary branches of government, such as the Climate Change Adaptation Branch, should be consulted by the primary government departments that have custodianship over the CBFEWS.

5. **Invest in relationship infrastructure alongside technical systems**

The efficacy of the CBFEWS is determined by the level and quality of interaction between residents, researchers, and officials. The municipality should formally budget for sustained community engagement and the role of intermediaries who maintain the essential communication links between technical teams and residents. This relationship infrastructure is a core implementation requirement that ensures technical data is trusted and acted upon. Therefore, it must be treated as a technical necessity rather than an optional add-on.

6. **Integrate traditional authorities into the CBFEWS governance loop**

In peri-urban areas under dual governance, Traditional Authorities must be integrated as primary custodians alongside municipal authorities. In these contexts, land is often held under communal tenure and allocated through social norms governed by *nkosi* and *izinduna*, making their leadership essential for negotiating local flood risks and facilitating community-led responses through established customary protocols. Furthermore, integrating this governance lens helps navigate historical contestations over land and service delivery where municipal enforcement may be limited.

7. **Build communication networks tailored to the settlement context**

Generic city-wide alerts are insufficient for informal settlements with connectivity gaps and low institutional trust. Mapping multi-directional, hyperlocal communication channels collaboratively with residents ensures warnings are received, understood and acted upon. This process must account for connectivity blind spots. For instance, in settlements where cell signal is poor, the system must rely on audible redundancy such as loudhailers or whistles.

8. **Address socio-economic vulnerability explicitly in early warning design**

Warning systems that do not account for gender, disability, age and socio-economic status will fail the most exposed residents. The Municipality should implement gender-sensitive response protocols, convene separate focus groups where necessary to capture women and men's knowledge, and those of other gendered identities, of flood exposure and vulnerability, and develop specialised evacuation plans for elderly and disabled residents concentrated in high-risk zones.

9. **Use the framework to downscale climate science to hyperlocal risk**

Larger-scale climate models and meteorological forecasts become actionable for informal and peri-urban settlements when translated into settlement-specific thresholds and impact timelines. Citizen science, including time-stamped river photos, household floor-level measurements and local observations, should be formally recognised as a valid data stream for municipal modelling, connecting national and provincial climate data to the lived realities of individual settlements.

10. **Treat the CBFEWS as a living system requiring ongoing refinement**

Post-event reviews, Learning Labs and continuous citizen science keep the CBFEWS accurate and trusted over time. Municipalities should institutionalise these refinement cycles as part of standard disaster risk management planning, ensuring the system learns from every flood hazard event rather than simply responding to it.

7. Looking Ahead

The construction of this framework marks the beginning of a broader programme of work to expand the CBFEWS across the eThekwini Municipal Area. This report, and INACCT's work, represents the first phase in a deliberate sequence of steps toward full CBFEWS institutionalisation and wide-scale expansion. Table 8 outlines the phases that follow.

Table 8: Roadmap for the next phases of CBFEWS upscaling and institutionalisation.

Phase	Description	Status
1. Upscaling Framework	The foundational scaffold presented in this report; a generalisable roadmap that standardises process while preserving contextual integrity	Current
2. Settlement Prototypes	Development of settlement-specific analogues grouped by shared hazard profile, topography, governance and socio-economic context; bridging the gap between the general framework and more specific settlement characteristics	Next phase
3.1 Institutionalisation: Co-development with city officials	Validating and aligning the framework with existing municipal SOPs, governance structures and policy mandates	Future
3.2 Institutionalisation: Capacity building and training	Equipping municipal officials, community researchers and partner organisations to independently implement and sustain the CBFEWS in new settlements	Future

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