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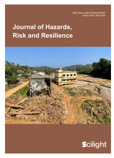

Article

Operational Performance of Community-Based Early Warning Systems for Climate-Related Hazards: Evidence from Lake Kariba, Zimbabwe

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Abstract: Community-based early warning systems (CBEWS) are increasingly promoted as an effective means of reducing disaster risk in climate-vulnerable settings, yet rigorous empirical assessments of their operational performance remain limited, particularly in sub-Saharan Africa. This qualitative single-case study applies the United Nations Office for Disaster Risk Reduction (UNDRR) four-pillar framework and draws on key informant interviews (*n* = 18), household interviews (*n* = 28), and four focus group discussions (*n* = 42) to examine the capacity and functioning of CBEWS among small-scale fishing communities along the southern shoreline of Lake Kariba, Zimbabwe. The findings indicate that while communities possess substantial local risk knowledge and well-established informal communication networks, system performance is constrained by inadequate monitoring infrastructure, poorly maintained equipment, limited accessibility and relevance of official forecasts, and insufficient response resources. Although formal structures and basic preparedness measures are in place, interconnected operational weaknesses undermine system reliability during hazardous events. Climate change is further reducing the predictability of traditional environmental indicators and weakening confidence in formal meteorological information, complicating risk anticipation and response. The study argues for a shift toward the continuous co-production of hybrid knowledge systems through sustained collaboration among holders of indigenous, scientific, practical, and technology-mediated knowledge. It proposes actionable recommendations to strengthen CBEWS in lacustrine and small-scale fishery contexts across Africa, including the establishment of co-production platforms, investment in resilient last-mile infrastructure, the integration of informal and formal risk-financing mechanisms, and the institutionalisation of community-based early warning roles. These findings contribute to efforts to operationalise the Sendai Framework and the Early Warnings for All initiative in resource-constrained rural environments.

Keywords: community early warning; disaster risk reduction; climate adaptation; hybrid knowledge; small-scale fisheries; Zimbabwe

1. Introduction

Climate-related disasters are increasing in frequency and intensity, posing a major threat to lives, livelihoods, economies, and sustainable development worldwide [1]. Floods, droughts, storms, heatwaves, and wildfires now account for the majority of disaster-related deaths, displacements, and economic losses, with the financial burden rising sharply over recent decades [2]. These impacts are projected to worsen as climate change accelerates, compounded by population growth and the concentration of assets in hazard-prone areas [3]. The burden falls disproportionately on low-income regions of the Global South, where residents contribute least to emissions but face the greatest health, income, and poverty losses due to limited adaptive capacity [4,5].

Although some impacts of natural hazards are inevitable, many can be substantially reduced through accurate forecasting, timely warnings, and prepared response plans [6]. Early warning systems (EWSs) that are people-centered and community-based (CBEWS) are increasingly recognized as cost-effective, life-saving tools that deliver at least a tenfold return on investment [7]. Unlike traditional top-down systems led by national agencies, CBEWS actively involve local communities in the design, monitoring, management, and dissemination of warnings, ensuring that warnings are accessible, culturally appropriate, and actionable [8–10]. This participatory approach aligns with Target G of the Sendai Framework for Disaster Risk Reduction 2015–2030 [11] and the UN's Early Warnings for All Initiative, launched in 2022, which aims to ensure that by the end of 2027, every person on earth is protected from hazardous weather, water, and climate events through effective, life-saving early warning systems [12].

Community-based early warning systems (CBEWS) have been pilot-tested in various regions of the Global South, such as Myanmar, Kenya, Sri Lanka, Vietnam, and Uganda [13–16]. These initiatives demonstrate an increasing global recognition of CBEWS as effective tools for disaster risk management. Nevertheless, there is a notable lack of rigorous empirical evaluations, particularly in sub-Saharan Africa. Existing research in the region points to ongoing challenges with community engagement, capacity building, and ensuring the long-term sustainability of these systems [16–18]. Very few studies have specifically explored how CBEWS function within African inland fisheries, where communities rely heavily on daily lake activities and are exposed to hazards like sudden windstorms, changing water levels, and wildlife encounters. Additionally, the blending of scientific and indigenous knowledge—known as hybrid knowledge systems—remains an underexplored aspect in these environments.

Similar challenges have been reported in other climate- and disaster-prone developing countries, including Malawi, Mozambique, Bangladesh, Vietnam, and Indonesia. In these contexts, CBEWS often face obstacles such as limited institutional support, inadequate capacity for system maintenance, fragmented communication networks, and weak community ownership [13,16,17,19]. Research in coastal and riverine areas also shows that pilot projects led by external organizations frequently struggle to remain operational once project funding ends [20]. However, there is still limited empirical evidence from African inland fisheries and large-lake settings, which makes it difficult to apply findings from other contexts to these specific livelihood systems.

This study seeks to fill these gaps by investigating CBEWS among small-scale fishing communities located along the shores of Lake Kariba in Zimbabwe's Mashonaland West province. Lake Kariba is one of the world's largest artificial reservoirs and serves as a vital source of livelihood for thousands of fishers who face increasing climate-related risks, such as sudden windstorms, variable water levels, and wildlife threats [21]. To our knowledge, this is the first empirical analysis to systematically examine the operational performance of CBEWS in the context of African inland fisheries, using the UNDRR four-pillar framework.

The study makes three key contributions. Theoretically, it advances understanding of how hybrid scientific and indigenous knowledge systems function under conditions of climatic uncertainty and institutional fragility. Methodologically, it provides a detailed, practice-oriented framework for evaluating CBEWS performance in remote, resource-constrained settings. Practically, it generates actionable evidence to inform disaster risk management, livelihood protection, and early warning governance in large-lake environments. By examining whether rural communities in Kariba district possess the capacity to establish, operate, and sustain CBEWS under current and future climate conditions, the study identifies strategies to strengthen the design, implementation, and long-term functionality of people-centred early warning systems in similar high-risk settings.

2. Conceptual Framework

This study adopts the widely accepted United Nations Office for Disaster Risk Reduction (UNDRR) four-pillar framework for people-centred early warning systems [8,22,23]. This framework moves beyond purely technical or linear models and treats early warning as an integrated socio-technical process in which all four components must function effectively and interact positively for the system to succeed [24,25]. Failure in any single pillar compromises the entire system [26]

The four pillars—(1) Risk Knowledge, (2) Monitoring and Warning Service, (3) Dissemination and Communication, and (4) Response Capability—provide a clear, operational framework for assessing both existing and potential community-based early warning systems (CBEWS). Because the framework explicitly calls for local participation and the integration of scientific and indigenous knowledge across all pillars, it is particularly well suited to the small-scale fishing communities of Lake Kariba, where formal meteorological coverage is limited and daily hazard exposure is high.

Table 1 presents the UNDRR four-pillar model as applied and adapted in this study. The operational questions presented in Table 1 were developed by the author by adapting the UNDRR four-pillar framework and were informed by prior empirical evaluations of community-based early warning systems [13,16,17]. The questions were further refined through preliminary field observations and consultations with local stakeholders to ensure contextual relevance to small-scale fishing communities along Lake Kariba.

Table 1. UNDRR four-pillar framework and operational questions applied to Kariba CBEWS assessment.

Pillar	Core Objective (UNDRR)	Operational/Research Questions Used in Kariba Study
1. Risk Knowledge	Systematically collect data and undertake risk assessments (hazards, vulnerabilities, exposure, capacities)	• What are the main climate-related and other hazards affecting lakeshore communities? • How well do fishers and residents understand these hazards and their impacts? • How is risk information currently organised, documented, updated, and shared?
2. Monitoring and Warning Service	Provide technical detection, monitoring, forecasting, and warning services that are timely and accurate	• Which hazard parameters are (or could be) monitored? • Is monitoring based on scientific forecasting tools, local indicators, or both, or neither? • Are warnings timely and accurate when issued?
3. Dissemination and Communication	Communicate risk information and warnings effectively to all at-risk populations using multiple channels	• What channels are used to send warnings (sirens, SMS, radio, word-of-mouth, etc.)? • Do warnings reach everyone at risk in time? • Are messages clear, understandable, and actionable?
4. Response Capability	Build national and community response capabilities through plans, training, drills and local ownership	• Do formal or informal preparedness and evacuation plans exist? • Are plans regularly updated and tested? • Do communities have the knowledge, resources, and willingness to act when warnings are received?

By structuring the empirical analysis around these four pillars and their associated questions, the study ensures systematic coverage of both the technical and social dimensions of CBEWS while remaining directly comparable with international evaluations [16,17]. The next sections present the study context and the methodology.

3. Study Context and Methodology

3.1. Study Context

The study was conducted in Nyaminyami Rural District Council (Kariba Rural), Mashonaland West Province, northern Zimbabwe, along the southern shores of Lake Kariba—Africa's largest artificial reservoir. The district falls within agro-ecological regions IV and V, characterised by low and erratic rainfall (400–800 mm annually), frequent droughts, and high climate variability [27]. Lakeshore communities, predominantly Tonga and Shangwe, rely heavily on small-scale capture fisheries for livelihoods and are highly exposed to climate-related hazards including sudden windstorms, flooding, fluctuating lake levels, and wildlife attacks [21,28]. Figure 1 is the map showing the location of Kariba district.

Disaster risk management in Zimbabwe is coordinated by the Department of Civil Protection (DCP) under the Ministry of Local Government and Public Works through a multi-tiered structure (national → provincial → district → ward). Early warning functions remain largely centralised, with the Meteorological Services Department providing forecasts that feed into DCP-led preparedness activities. Figure 2 shows the structure of the DRM system in Zimbabwe.

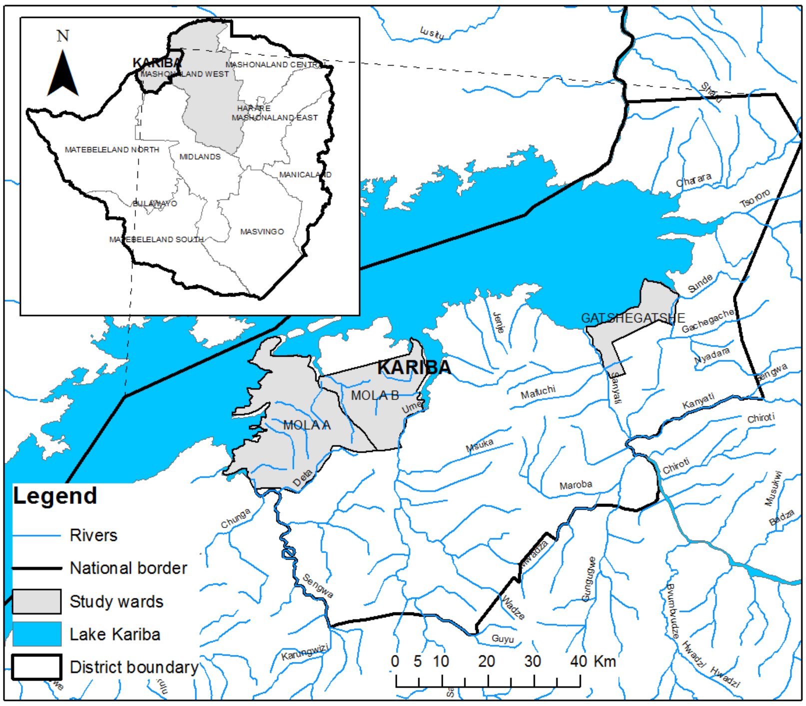

Figure 1. Location of the study area in Zimbabwe (source: Nkoka 2019 [29]).

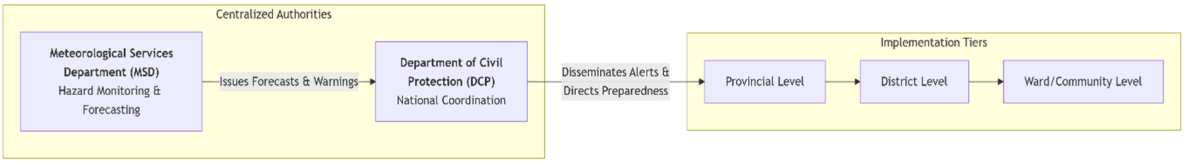

Figure 2. Structure of the DRM system in Zimbabwe.

Community-based early warning systems (CBEWS) are still underdeveloped and fragmented, with most initiatives remaining small-scale NGO pilots introduced after Cyclone Idai in 2019 [30,31]. Fieldwork was carried out in Msampa fishing camp, Ward 3, Mola area—the largest and longest-established inland fishing community on the Zimbabwean side of Lake Kariba. Msampa was purposively selected because of its high exposure to multiple hazards, socioeconomic diversity (resident and migrant fishers), and variation in existing early warning practices.

3.2. Research Design and Methods

This study adopted a qualitative single-case study design to enable in-depth exploration of CBEWS capacity and implementation challenges in a high-risk lakeshore fishery context. Data were collected using multiple complementary methods.

3.2.1. Data Collection Methods

Secondary data were obtained from peer-reviewed literature, government reports, and NGO documentation on disaster risk management and early warning in Zimbabwe.

Primary data were collected through:

- Key informant interviews (n = 18) with national, provincial, and district-level actors (DCP, Meteorological Services Department, ZINWA, National Parks, NGOs, Red Cross, and members of civil protection committees).
- Semi-structured household interviews (n = 28) with fishers and residents of Msampa camp, randomly selected from a complete household list provided by the ward councillor.
- Four mixed-gender focus group discussions (8–12 participants each; total n = 42) that included community members, ward civil protection volunteers, traditional leaders, and local government representatives.

The number of household interviews (28) was determined by theoretical saturation: beyond the 24th yielded no new themes related to the four UNDRR pillars. All interviews and FGDs were guided by the operational questions derived from the four-pillar framework presented in Table 1 (Section 2).

To demonstrate the study's empirical basis, interviews and focus group discussions generated detailed accounts of local hazard experiences, warning practices, and response behaviours. For example, fishers described sudden windstorms as "becoming more frequent and less predictable," while district officials emphasised "limited resources and maintenance challenges" affecting monitoring equipment. Community leaders also highlighted reliance on informal communication networks, noting that "most urgent warnings are shared through word-of-mouth at landing sites". These qualitative accounts provided the primary evidence base for the thematic analysis presented in Section 4.

3.2.2. Data Analysis

Interviews and focus groups were audio-recorded (with consent), transcribed verbatim, and analysed in NVivo 14 using a combined deductive-inductive thematic approach. An initial coding framework was created from the four UNDRR pillars and their operational questions. Open coding was then applied to identify emergent sub-themes (e.g., role of indigenous forecasting signs, influence of migrant fishers, gender dimensions). Two rounds of independent coding by the lead researcher and a second coder were followed by discussion to resolve discrepancies and finalise the codebook. Representative quotations were selected to illustrate key findings.

3.2.3. Ethical Considerations

The study received ethical clearance from the Zimbabwe Department of Civil Protection and Nyaminyami Rural District Council. Informed oral consent was obtained from all participants after explaining the study objectives, voluntary nature of participation, and their right to withdraw at any time without consequence. Because of variable literacy levels, written consent was replaced by recorded oral consent, a procedure approved by the relevant authorities.

Participant confidentiality was protected by assigning pseudonyms and removing identifying details during transcription. Audio files and transcripts are stored on an encrypted drive accessible only to the research team and will be deleted five years after publication. Given power imbalances between the researcher (outsider, educated) and participants (often low-literacy fishers), several steps were taken: interviews were conducted in chiTonga or chiShona with assistance from a local field assistant; sensitive topics (e.g., conflicts with authorities) were approached indirectly; and community gatekeepers were consulted throughout to ensure cultural appropriateness and minimise risk of reprisal.

4. Results

Results are presented according to the four UNDRR pillars used as the analytical framework (see Table 1, Section 2).

4.1. Risk Knowledge

Communities demonstrated detailed knowledge of hazards affecting daily lake-based activities. Participatory mapping and interviews identified the following primary hazards: sudden windstorms and high waves ("dutu" or "mhepo huru"), flash floods, crocodile and hippopotamus attacks, and declining fish stocks forcing fishing into deeper waters. Table 2 summarises community-identified hazards, vulnerable groups/activities, and observed changes. These are further illustrated in the images presented in Figure 3.

Table 2. Community-identified hazards and vulnerability in Msampa fishing camp.

Hazard	Vulnerable Groups & Activities	Observed Changes (Community Perception)	Community Voices (Quote)
Sudden windstorms & waves	Fishers on the lake, especially at midday or night	More frequent, less predictable than in the past	"The lake can be calm at sunrise but by midday winds from the escarpment create waves that capsize boats".
Crocodile/ hippo attacks	Women washing clothes, children playing, shore fishers	Increasing due to declining fish stocks pushing wildlife closer to shore	"Women and children are always at the waterfront".
Flash floods	Fish drying racks, homesteads near seasonal rivers	Higher intensity after upstream rains	"In 2017 flash floods swept along the shoreline and destroyed several camps".
Declining fish stocks	All households dependent on fishing	Forces fishing further offshore into riskier areas	–

Table 2 illustrates that sudden windstorms and wildlife attacks represent the most immediate and life-threatening hazards for lakeshore communities, while declining fish stocks indirectly increase exposure by forcing fishers into deeper and riskier waters. These findings highlight the close interconnection between environmental change, livelihood pressures, and disaster vulnerability.

Figure 3. Daily livelihood and recreational activities along Lake Kariba expose community members to multiple hazards, including sudden weather changes and wildlife encounters (**left**: fishing activities; **right**: children at play).

The research found that updated disaster risk maps, hazard data, and climate scenarios were mostly unavailable or not widely shared at Msampa fishing camp. Participants reported limited awareness of formal risk documentation, and no interviewee or focus group participant could reference a current hazard map or climate projection specific to the camp.

District Disaster Risk Management (DRM) committee members—including officers from the Meteorological Services Department, Department of Civil Protection, Lake Navigation Control, and the Rural District Council—reported providing technical support and conducting awareness activities aimed at improving community understanding of local risks. Despite these efforts, participants consistently described gaps in how information on hazard extent, frequency, intensity, and magnitude was communicated at community level.

Across interviews and focus group discussions, participants indicated that their understanding of local hazards was informed primarily by personal experience and orally transmitted knowledge drawn from previous events.

4.2. Monitoring and Warning Service

Monitoring and Warning Service

The formal monitoring system for the Kariba district relies on two primary sources: the meteorological station at Kariba Airport and regional forecast models from the national office, which incorporate satellite imagery from international agencies. This system generates daily weather forecasts covering the entire district. Interviews with key organizational informants identified a consistent theme of challenges in maintaining localized monitoring equipment. A district civil protection member cited limited financial support and frequent vandalism as key constraints. An automated weather station installed at Bumi Hills near Msampa in 2016 became nonfunctional, with informants attributing this to damage caused by wild animals and past flood events.

Community participants across all focus groups reported receiving official forecasts primarily via radio. These forecasts use general terminology (e.g., “light,” “moderate,” or “strong winds”) and cover 24-h periods for the entire Kariba district. Table 3 presents recurring concerns raised about these official forecasts.

Table 3. Community-Reported Characteristics of Official Forecasts.

Reported Feature	Illustrative Quote
Geographic Coverage	“The radio talks about Kariba district as a whole, but our fishing area near the islands experiences different weather”.
Warning Specificity	“It warns of strong winds but doesn’t specify when or where—whether it’s eastern or western shores...”.
Impact on Planning	“We often stay home unnecessarily or are caught off guard when warnings are absent”.

Table 3 shows that official forecasts are perceived as insufficiently localised and specific to support day-to-day decision-making among fishers. Limited spatial resolution and timing uncertainty reduce their practical value for short-term livelihood planning.

Participant feedback on warning accuracy varied by event type. While some participants acknowledged timely and accurate messages for large-scale events (e.g., cyclones), particularly when the local automated station was operational, the predominant view expressed across focus groups was that routine wind and storm warnings were perceived as inaccurate or lacking local relevance.

A consistent finding across all community discussions was the use of indigenous knowledge for weather monitoring, including observations of animal behavior, cloud formations, and wind patterns. Central to this indigenous system is a named classification of windstorms based on direction of origin, seasonal timing, and associated hazards (Table 4).

Table 4. Community IKS-informed classification of windstorms on Lake Kariba.

Wind Name	Direction	Typical Season/Timing	Reported Characteristics
Matusadonha	East	May (dry season) or January (wet season)	Dry storm in May or wind with heavy rain in January
Zambia	South	Rainy season	Signals approaching rainfall
Binga	West	July–August	Strong, prolonged waves
Sanyati	Southeast	Variable	Combined wind and rainfall
Kariba	North/East	Morning, every 1–3 days	Rapidly developing, short-duration windstorm

Table 4 demonstrates the sophistication of the community's indigenous wind classification system, which links wind direction, seasonality, and associated risks. This system functions as an informal but highly operational monitoring tool that complements formal meteorological information.

Veteran fisherman Shepherd described the application of this system: "When I feel cold air and see clouds over Matusadonha hills, I know the Matusadonha wind is coming. In May, it's a dry storm—wind with no rain—so the main danger is capsizing, while in January, it's wind and heavy rain. The name shows the direction; season, the impact". Participants also widely reported using biological indicators for seasonal forecasting, including the behavior of swallows (mhembera) and the calls of hornbills (dendera) to anticipate the onset of the rainy season.

4.3. Dissemination and Communication

Weather forecasts and early warnings from the Zimbabwe Meteorological Services Department (MSD) are disseminated nationally through television, radio, social media (WhatsApp, Facebook, Instagram), and print media. The Department of Civil Protection (DCP) collaborates with regional units to relay these messages to district and ward levels.

In Msampa fishing camp, a sub-committee of the Ward Disaster Risk Management Committee serves as the primary local node for receiving and disseminating warnings. Reported methods include oral communication, whistles, coloured flags, and traditional drums. An HF radio was installed at the camp for communication with district civil protection.

Community participants reported low television access due to the absence of national grid electricity in Msampa. Radio—particularly Nyaminyami FM—was identified as the dominant modern channel. Survey and focus group data indicated that 65% of households own a radio, but only 30% reported consistent daytime listening while on land. Reception was described as virtually nonexistent while on the lake.

Mobile phone ownership was widespread, but effectiveness for warnings was limited by inconsistent shoreline-only coverage, high data/airtime costs, and frequent water damage to devices. The camp's HF radio was reported as non-operational.

Participants described a rapid, informal word-of-mouth system locally known as the "Lake Herald" as the most frequently used and trusted method for urgent warnings (e.g., approaching storms, crocodile sightings, or dam releases). This system operates through landing sites, markets, and homesteads. Eighty-five percent of respondents stated they would first alert immediate neighbours and kin upon observing a threat. A camp leader explained:

> "*When we see the Matusadonha clouds forming, I send my son to the landing sites to tell everyone to call their people on the lake. We shout, we wave arms. It is not perfect, but it is what we have*".

Owners of larger boats reported using VHF marine radios to share weather observations ad hoc across parts of the lake, though usage was limited by battery failures and low ownership.

The table below summarises the primary hazards identified by participants, the main community coping strategies, and the associated communication channels used.

Table 5 indicates that immediate behavioural responses, supported primarily by informal communication networks, form the backbone of community risk management. Formal warning channels play a secondary role during rapidly developing hazard events.

Table 5. Primary Hazards, Coping Strategies, and Communication Channels.

Hazard	Primary Community Coping Strategy	Key Communication Channel(s) Used
Sudden storms/winds	Immediate return to shore/seek shelter	'Lake Herald' (word-of-mouth), VHF radio (boats), arm signals
Flooding/rising water	Move equipment/assets to higher ground	Radio (if on land), ward committee alerts
Crocodile/hippo sightings	Avoid area, communal alert	'Lake Herald', direct shouting between boats

Participants also compared local/indigenous and official weather information systems with respect to sources, timing, specificity, and perceived strengths, as shown below.

Table 6 highlights the complementary strengths and limitations of local and official information systems, underscoring the need for integrated communication strategies that combine trust, timeliness, and scientific credibility.

Table 6. Local vs. Official Weather Information Systems.

Aspect	Local/Indigenous System	Official Forecast System
Source & Language	Observation, experience, oral tradition; local languages	Meteorological models; primarily English
Delivery & Timing	Immediate, continuous, on-site	Scheduled bulletins (e.g., morning/afternoon news)
Spatial Specificity	Hyper-local (specific stretches of lake/shoreline)	General (district-wide)
Perceived Strength	Timely, trusted, culturally embedded	Authoritative, provides a broader outlook

Table 7 reveals that although multiple communication channels exist, each is constrained by technical, financial, or infrastructural limitations. These overlapping weaknesses reduce system redundancy and reliability.

Table 7. Communication Channels: Usage and Reported Limitations.

Channel	Reported Access/Usage	Reported Limitations
Radio (Nyaminyami FM/ZBC)	65% household ownership; primary mass media source	No signal on lake; limited daytime listening on land; broadcasts in English
Mobile phones/SMS/WhatsApp	Widespread ownership	Inconsistent coverage (shoreline only); high data/airtime costs; frequent water damage
'Lake Herald' (word-of-mouth)	Most cited and trusted for urgent threats	Speed degrades with distance; no formal structure
Ward committee (flags/drums/oral)	Used for community-wide alerts	Limited range; requires committee member to initiate
HF radio (camp to district)	Installed for official communication	Currently non-operational
VHF marine radio (boats)	Used by some larger boat owners	Limited ownership; battery/power failures

4.4. Response Capabilities

Disaster Risk Management (DRM) plans are formally established at Msampa fishing camp. These plans were developed from 2015 onward with technical assistance from the Zimbabwe Red Cross, using participatory methodologies such as community vulnerability assessments and action planning. The plans reference contingency planning arrangements, enforcement of safety standards for fishing activities, use of seasonal calendars, and provision of basic first aid.

Empirical data reveal substantial gaps between the reported ownership of safety resources and their operational readiness.

Table 8 shows a substantial gap between nominal ownership of safety equipment and actual operational readiness, indicating that maintenance and usage practices represent major barriers to effective preparedness. This is further illustrated by the images shown in Figure 4.

DRM committee members, who also engage in full-time fishing activities, reported limited capacity to conduct sustained disaster preparedness activities. Focus group discussions indicated that only 15% of participants had participated in a mock drill or simulation exercise in the preceding 24 months.

In the absence of formal insurance or social protection mechanisms, the community relies on informal risk-financing arrangements. A community emergency fund is maintained through contributions from fish buyers (USD 3 per visit) and tourists participating in village tours (USD 5 per visit). Additional financial support during crises is drawn from church reserves, burial society funds, and emergency door-to-door household contributions, typically amounting to USD 1 per household.

Table 8. Ownership vs. Operational Status of Key Safety Resources.

Resource	Reported Household Ownership	Reported Operational & Accessible	Primary Constraint
Life jackets	85%	35%	Degradation; not carried during fishing
Community rescue boat	Present (1 unit)	Non-operational	Lack of maintenance funds and fuel
First aid kits	Present (community-owned)	Non-operational/expired	No replenishment funds
Communication (loudspeakers)	Identified as needed	Largely absent	Cost

Figure 4. Non-motorised canoes used for fishing and emergency response (**left**) and personal protective equipment including life jackets in various conditions (**right**) illustrate the resource constraints and maintenance challenges facing the fishing community's disaster preparedness capabilities.

A gap was reported between the existence of formal DRM plans and community awareness of their contents. Most focus group participants indicated that they had never seen the DRM plans or were unaware of their provisions. Camp leadership interviews confirmed that DRM-related information was not routinely integrated into community meetings.

Coordination arrangements among the ward DRM committee, Camp Disaster Response Team (CDRT), fishing camp leadership, lake captains, traditional leaders, and district authorities were described as overlapping and unclear. Participants reported that these ambiguities created potential for duplication of response actions or gaps in emergency coverage.

The remoteness of Msampa fishing camp significantly affects access to health services. Reported response times vary widely depending on the availability of transport, as shown in Table 9.

Table 9. Emergency Healthcare Access from Msampa Fishing Camp.

Destination	Mode of Transport	Estimated Travel Time
Mola Health Clinic	Vehicle	1 h
	Walk	2 h 30 min
Padenga Health Clinic	Speedboat	7 min
	Vehicle	30 min
	Fisher-boat	55 min (30 min boat + 25 min walk)
	Walk (road)	2 h
Siakobvu Hospital	Various	Minimum 2 h 30 min
Karoi Hospital	Various	5 h 30 min

Chinhoyi Hospital	Various	6 h 30 min
Kariba Town Hospital	Speedboat	1 h 30 min

Note: "Various" indicates that no single reliable or commonly owned mode of transport is available to most community members.

Table 9 illustrates the severe transport and distance barriers affecting access to emergency healthcare, particularly during adverse weather conditions, which significantly increase disaster-related health risks.

DRM committee members and district-level stakeholders reported resource and training limitations. One committee member stated: "The intensity and frequency of hazards are beyond our preparation and response capabilities".

Table 10 summarises how existing institutional structures and community mechanisms coexist with critical gaps in resources, coordination, and financing, reinforcing the systemic nature of response limitations.

Table 10. Summary of Response Capabilities—Assets and Critical Gaps.

Domain	Existing Assets/Mechanisms	Identified Critical Gaps
Planning & Structure	Formal DRM plan; trained DRM committee; 15 early warning champions	Low community awareness; infrequent drills (15% participation in 24 months); plans not systematically updated
Resources & Equipment	High life jacket ownership (85%); community rescue boat and first aid kits; informal community fund	Low operational readiness (35% functional); non-operational community assets; limited communication equipment
Financing	Community fund; church and burial society reserves; emergency household contributions	Absence of formal insurance or safety nets; reliance on ad-hoc contributions
Coordination	Multiple stakeholders involved in response	Overlapping roles; unclear coordination; weak integration of DRM into community forums
Emergency Access	Clinics reachable within one hour under optimal transport conditions	Limited access to vehicles and speedboats; long walking times; delays to advanced care

5. Discussion

The Lake Kariba fishing community case study reveals a community-based early warning system (CBEWS) that, while structured within formal frameworks, is operationally fragile and critically dependent on informal community improvisation. This disparity underscores a persistent and widespread gap between the "end-to-end" and "people-centered" systems advocated in global policy—such as the Sendai Framework and the Early Warnings for All initiative [12,23] and the fragmented, underfunded realities of implementation in resource-constrained settings.

This finding aligns with broader critiques that CBEWS concepts remain poorly defined and that community engagement is often superficial across all system components [17,18]. Kariba case thus reflects a common pattern across the Global South, where limited government funding and bureaucratic barriers routinely hinder effective disaster risk reduction, as evidenced in similar African contexts [19,32].

A key insight from this case is that standard assessments, which often audit the presence of system components, can dangerously mask systemic fragility. In Kariba, positive indicators, including a disaster risk management (DRM) plan, trained community champions, high ownership of life jackets, and informal mutual-aid mechanisms, coexist with critical operational deficits: low functional readiness of equipment, non-operational community assets, infrequent drills, and limited awareness of plan details. These interconnected shortcomings render the system vulnerable to single-point failures; for instance, lapses in monitoring erode warning credibility, while equipment breakdowns eliminate practical response options. Consequently, the system may function under routine conditions but risks rapid breakdown when a hazard escalates. This underscores the need to shift evaluation paradigms from component checklists toward assessments of integration, sustainability, and real-time operational readiness.

To understand the roots of this fragility, the Kariba case illuminates four critical, interconnected implementation gaps.

First, communities face a disruption in predictive capacity, not merely an information deficit. While local fishers possess deep, experience-based knowledge of their environment, climate change is undermining the reliability of traditional indicators [13]. Concurrently, access to updated, location-specific scientific hazard data and forecasts remains limited [33,34]. This creates a predictive void, complicating the often-straightforward distinction between "local" and "scientific" knowledge in the literature [35,36]. Moving forward, effective CBEWS must move beyond simplistic models of knowledge integration, which often overlook issues of sustainability and power [37,38] and instead foster ongoing co-production processes that strengthen and build upon existing community capacities [39].

Second, community empowerment within the monitoring and warning functions remains severely constrained. The service architecture is predominantly top-down, with information flowing from national meteorological stations to district offices with minimal community input or feedback loops. This hierarchical structure stifles local adaptation and ownership, a documented challenge in other centralized administrative contexts [40]. The inoperative automated weather station at Bumi Hills exemplifies the chronic sustainability challenges facing externally imposed technical solutions, where vandalism and a lack of maintenance protocols render investments obsolete [30]. In stark contrast, the community's sophisticated indigenous wind classification system—with specific names, directions, and associated risks—functions as a robust, actionable monitoring tool. This suggests formal EWS could significantly improve by recognizing, valuing, and formally integrating such locally grounded knowledge systems and terminologies.

Third, communication pathways are fragmented, creating uneven access to warnings. Although multiple channels exist (radio, traditional instruments, interpersonal networks), critical barriers persist. These include non-contextual broadcast timing, language and technical complexity issues, poor radio reception on the lake, and limited mobile network coverage and affordability. Such constraints can exclude the most at-risk individuals, particularly fishers on extended expeditions. While the informal "Lake Herald" network demonstrates vital community agency and aligns with people-centered design principles [23]—a finding supported by studies on social networks in fishing communities [41,42]—reliance on such intermittent, informal pathways is not a resilient strategy. There is a clear need for designed, multi-modal communication systems that formally incorporate and strengthen reliable community channels.

Fourth, response capacity is under-resourced and lacks sustainable maintenance mechanisms. While a DRM plan exists and some training has occurred, readiness is undermined by financial constraints, low participation in drills, and outdated plans. The poor condition of life jackets (only 35% usable) and the non-operational rescue boat reflect a deeper issue of absent ownership and a lack of sustainable maintenance culture, not mere resource scarcity [43]. The community's innovative informal risk-financing through collective funds represents a critical coping capacity but also highlights acute systemic vulnerability and adaptation inequality, serving as a poor substitute for formal safety nets [5]. Combined with severe geographical and transport constraints that delay emergency access, these factors align with broader research on the acute vulnerability of remote fishing communities to compounding disaster risks [44,45]. In synthesis, the Kariba case demonstrates that a functional, people-centered CBEWS requires more than assembling discrete components. It demands a holistic approach that prioritizes the quality of integration across the knowledge, monitoring, communication, and response pillars; invests in sustainable ownership and maintenance; and ensures equitable access and operational readiness during crises. Evaluations must therefore advance beyond auditing checklist items to assess these dynamic, systemic qualities. These findings point toward actionable pathways for strengthening CBEWS in similar remote, resource-constrained fishing communities, including investments in hybrid knowledge co-production, community-led monitoring infrastructure, resilient multi-modal communication networks, and sustainable maintenance frameworks supported by formal safety nets.

Several methodological limitations of this study warrant acknowledgement. The focus on a single community limits the generalisability of findings, though the alignment with broader literature suggests relevant insights for similar remote, resource-constrained settings. The data collection timeframe may not capture seasonal variations in risk perception and behaviour. Furthermore, the study relied primarily on self-reported perceptions and did not quantitatively evaluate the comparative effectiveness of different warning mechanisms, leaving this as an avenue for future research.

6. Conclusions and Recommendations

This study of small-scale fishing communities along Lake Kariba makes three core contributions to the understanding and practice of community-based early warning systems (CBEWS).

Theoretical. The study demonstrates that apparent preparedness in CBEWS can conceal underlying operational fragility, and that under accelerating climate change, simple "integration" of local and scientific knowledge is insufficient. Instead, effective systems depend on the continuous co-production of hybrid knowledge involving indigenous, scientific, practical, and youth/technology-based sources. Such co-production is essential for maintaining relevance, trust, and functionality as environmental conditions and risk patterns evolve.

Policy. The findings indicate that the UN's Early Warnings for All goal will remain difficult to achieve in remote African inland fisheries unless investment priorities shift from short-term technology pilots toward long-term, community-owned governance, maintenance, and financing models. National disaster management policies should therefore prioritise sustained funding for community-level monitoring infrastructure, regular simulation exercises, and locally embedded early warning personnel, rather than episodic equipment installations.

In terms of migration and mobility planning, the study highlights how declining fish stocks, increasing storm frequency, and unreliable warning systems are jointly increasing livelihood insecurity and encouraging risky mobility patterns, including extended fishing trips and temporary migration to distant landing sites. Early warning and DRM policies should therefore be integrated with rural development and migration management strategies, including the provision of safer seasonal livelihood alternatives, improved access to social protection, and targeted support for highly mobile fishing households.

With respect to livelihood adaptation, the results demonstrate that informal risk-financing mechanisms and indigenous forecasting systems already play a central role in household resilience. Policy frameworks should formally recognise and strengthen these existing capacities by linking community emergency funds to national disaster risk financing schemes, supporting co-production platforms between fishers and meteorological services, and embedding climate risk information into fisheries management and extension services.

Overall, the study underscores the need for integrated policy approaches that connect disaster risk reduction, migration governance, and livelihood adaptation within large-lake fishery systems, ensuring that early warning interventions contribute not only to immediate risk reduction but also to long-term socioeconomic resilience.

Practice. Empirically, the study shows that informal community networks and indigenous environmental taxonomies (e.g., locally named windstorms) are often more reliable and actionable than distant official forecasts. These locally grounded systems should form the foundational layer of CBEWS, with external technologies and scientific data designed to complement and strengthen—rather than replace—existing community capacities.

On the basis of these insights, the following four priority actions are recommended for Zimbabwe and similar large-lake fishery contexts in Africa:

1. Establish permanent, funded co-production platforms that bring together elders, fishers, youth, meteorological services, water authorities, and district civil protection officers to jointly interpret forecasts, translate warnings into local languages and terminologies, and regularly update risk maps.
2. Invest in resilient, low-maintenance last-mile infrastructure suited to lake environments, including solar-powered VHF base stations, floating weather buoys, and community-managed monitoring systems, supported by clear maintenance plans, training, and dedicated budgets.
3. Link community emergency funds to formal disaster risk financing mechanisms, such as micro-insurance or contingency funds, and mandate participatory simulation drills with allocated resources to test and strengthen system performance.
4. Institutionalise community "early warning champions" within ward- or district-level disaster risk management structures to ensure sustained local ownership, coordination, and rapid activation during hazard events.

Future research should move beyond single-case qualitative designs toward comparative studies across African inland lakes and incorporate quantitative evaluations of warning lead times, response effectiveness, and reductions in loss and mortality. Longitudinal research examining how co-produced knowledge systems adapt as climate change continues to alter environmental indicators would further strengthen the evidence base.

Ultimately, if Early Warnings for All is to become a practical reality for the millions who depend on Africa's inland waters for their livelihoods, early warning systems must be co-produced with—not merely delivered to—the communities whose lives depend on them.

Institutional Review Board Statement

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the Zimbabwe Department of Civil Protection and the Nyaminyami Rural District Council (approval granted prior to fieldwork in 2023). No formal protocol code was issued for this approval.

Informed Consent Statement

Informed oral consent was obtained from all participants involved in the study prior to data collection. Written consent was waived due to variable literacy levels and field conditions, as approved by the relevant authorities. No individually identifiable information is included in this publication.

Data Availability Statement

The qualitative data supporting the findings of this study are not publicly available due to ethical and confidentiality considerations. Interview transcripts and recordings contain information that could compromise participant anonymity. Data are stored securely by the author and may be made available to qualified researchers upon reasonable request, subject to ethical approval and data protection requirements.

Conflicts of Interest

The author declares no conflict of interest.

Use of AI and AI-Assisted Technologies

AI-assisted tools were used solely for language editing and improving clarity. The author reviewed and approved the final manuscript and takes full responsibility for its content.

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