

Building risk knowledge for multi-hazard early warning and early action in humanitarian crises: Insights from the Dadaab Refugee Complex

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Abstract

Multi-hazards and their associated impacts are increasingly affecting lives and livelihoods across regions of the world. Refugee camp settings are disproportionately affected. While highly exposed to multiple hazards, such as heatwaves, droughts, and floods, refugee camps face a unique interplay between risk drivers and root causes of vulnerability, characteristic of protracted humanitarian crises. Early warning and early action (EWEA) constitute an essential instrument for reducing disaster risks and preventing harm. Effective EWEA requires not only knowledge of which hazards to warn about, but also a deep understanding of who is at risk, what triggers action, and when and how to act. However, risk knowledge for EWEA remains scarce in refugee camp settings, hampering anticipatory responses. This study co-produces disaster risk knowledge for EWEA tailored to humanitarian refugee camp settings. Empirical evidence was derived through participatory engagement with refugees, humanitarian actors, and host community actors, combining qualitative methods and a literature review in the Dadaab Refugee Complex, one of the world's largest protracted humanitarian settings. Results provide a new understanding of complex disaster risks within the Dadaab Refugee Complex, encompassing multiple hazards such as droughts, heatwaves, and extreme precipitation, and compounding shocks such as fire, disease outbreaks, and armed conflict, revealing how their interconnected and cascading impacts and underlying root causes shape EWEA. The analysis offers concrete barriers and enablers across the early warning early action chain, including youth-led response groups, inter-agency preparedness, cross-sectoral dissemination strategies, impact-based forecasts, and risk-informed camp coordination across scales. The study provides implications for building disaster risk knowledge in Dadaab and offers entry points for strengthening forecasting, communication, and preparedness in refugee camp settings.

Highlights

- Co-produces disaster risk knowledge for early warning and early action in Dadaab Refugee Complex
- Utilizes impact webs to understand disaster risks, their drivers, and root causes in Dadaab
- Identifies barriers and enablers of risk-informed early warning and early action in refugee camp settings with multi-actors.

1. Introduction

Refugees living in camp settings are among the most vulnerable to disaster risks. Protracted displacement, loss of livelihoods, constrained living conditions, and dependency on host communities and international aid fundamentally undermine their capacity to cope with and recover from disaster risks (Ashour et al., 2023; Bernhofen et al., 2023; Dampha et al., 2025; Fransen et al., 2024; Zaman et al., 2020). Approximately 32 million refugees were registered as refugees by the United Nations High Commissioner for Refugees globally, of whom about 22% reside in refugee camps (Gnowa et al., 2026). Many of the largest camps sit in climate and extreme weather hotspots, in remote, marginal areas of

poor-quality land with limited livelihood opportunities, prone to floods, heat stress, cyclones, and droughts, and their associated risks (Bernhofen et al., 2023; Owen et al., 2023; Pollock et al., 2019; Xie & Chen, 2024; Zaman et al., 2020). Climate change drives enhanced current and future risks under global warming and can lead to extremes (Clarke et al., 2026; S. Dash et al., 2025), which hit climate-vulnerable areas hardest.

One of the promising approaches to reduce disaster risk is Early Warning Early Action (EWEA), comprising risk knowledge, monitoring and analysis, warning dissemination, and response preparedness (Glantz & Pierce, 2023; Kelman & Fearnley, 2025; WMO & UNDRR, 2023). Of these, risk knowledge is foundational, as effective EWEA requires not only knowing which hazards to warn about, but also who is at risk and why, what triggers action, and who must act, when, and how (Kelman & Fearnley, 2025). Kelman & Fearnley find that a vulnerability perspective is necessary to account for varying experiences of the same hazard and differential vulnerabilities across hazards to achieve people-centered Early Warnings for All (EW4All), which targets global coverage of EWEA by 2027 (WMO & UNDRR, 2023).

Despite empirical research on disaster risks in refugee camps, evidence on EWEA is scarce. The literature is fragmented, providing evidence on single hazards, such as localized landslide early warning for Rohingya refugees (Ahmed et al., 2020) and landslide susceptibility mapping in refugee camps (Emberson et al., 2021). Another cluster of scholarly work centers on disease surveillance in camp settings, such as the EWARS Mobile tool piloted among Sudanese refugee children in Eastern Chad (Tewo et al., 2025). Despite existing work addressing individual sectors, such as gender-based violence, WASH, or infrastructure challenges related to disaster, intersectoral perspectives are missing. For example, a study on how Cyclone Idai disrupted women's WASH activities at Tongogara Refugee Camp in Zimbabwe provides sector-specific insights (Bellizzi et al., 2023; Haggag et al., 2023; Sibanda et al., 2022). While literature finds multi-actor stakeholder contribution in cascading and multi-hazard context significant (Leahy & Ermagun, 2026), however, the substantial body of literature exists on quantitative assessments, such as GIS-based methods, applied to everything from crisis control in migration settings (Lemenkova, 2025) to climate and disaster risk mapping in refugee-hosting districts in Rwanda (Dampha et al., 2025). Participatory and qualitative approaches are limited in the context of risks in camp settings. Despite various studies on the largest refugee camps globally, such as Cox's Bazar, Bangladesh; Um Rakuba in Sudan; and Za'atari in Jordan, Kenya, which are among the countries hosting multiple of the largest refugee complexes and have seen increasing influxes of refugees in recent decades, these camps remain understudied. While studies investigate the advancements of Impact-based Forecast and Warning (IbFW) services for hydro-meteorological hazards, such as in India (B. Dash, 2024), as well as their role in delivering high-resolution, impact-based forecasts for better-informed decisions and tailored emergency actions (Najafi et al., 2024), they are limited in downscaled services for refugee camp contexts.

Sitting in a hotspot area for harsh climate and weather conditions, Dadaab in Kenya offers a particular case: as the world's largest refugee camp complex, it combines high population density with recurring risks, such as droughts and floods, drivers of vulnerability in a protracted crisis, and other shocks and

threats such as disease outbreaks, and conflict (ASAL Humanitarian Network, 2022; Fransen et al., 2024; Golicha et al., 2018; IGAD ICPAC, 2022; Pfeiffer, 2025; UN-HABITAT, 2021; UNHCR, 2024; United Nations, 2022). A recent study assessing the multi-hazard environmental and climatic exposure across refugee camps found that Dadaab Camps (Ifo and Hagadera) belong to the second-highest quartile of climate exposure (Owen et al., 2023), while others found that Dadaab is 0–85% above the national average of sudden-onset events such as extreme rainfall, and 27.73 to 20.19 above the national average in temperature. In combination with low average rainfall, settlement locations in Kenya experience increased heat, drought, and limited water supply (Fransen et al., 2024). Populations in areas with socio-economic development challenges are significantly more likely to experience frequent multi-hazards and associated impacts now and, in the future (Kelman & Fearnley, 2025; Tiggeloven et al., 2026).

Three main knowledge gaps are addressed in this study (Geisemann et al., 2025; Glantz & Pierce, 2023). First, existing work lacks a multi-risk, vulnerability perspective, considering the complexity of managing and understanding disaster risk in refugee camp settings, which shapes the effectiveness of EWEA. Second, technical rather than people-centered insights are available, hampering participation by refugees, host communities, or humanitarian actors in advancing forecasting, preparedness, and communication. Third, despite evidence from other settings, disaster risk knowledge for EWEA has rarely been examined in the specific context of refugee camps; it is particularly scarce in Kenya, despite the region's prominence as a hotspot for climate- and weather-related disaster risks (Fransen et al. 2024).

To address these gaps, this study co-produces disaster risk knowledge for EWEA in humanitarian camp settings. It examines how warning chains enable or constrain early action in camp settings, how vulnerability shapes EWEA, and how disaster risk knowledge interacts with decision-making, with Dadaab Refugee Complex as a case study. Drawing on a participatory engagement process with refugees, humanitarian actors, and host communities in Dadaab, the study contributes empirical evidence toward the Sendai Framework (Target G) and EW4All in vulnerable humanitarian settings, and toward people-centered EWEA.

2. Methods

2.1 Data collection

This research took a qualitative approach to co-producing disaster risk knowledge for EWEA in the Dadaab Refugee Complex. Dadaab is located in the semi-arid lowlands of Garissa County, Kenya (Fig. 1). As of January 2025, the complex hosted approximately 419,155 refugees across five camps: Dagahaley, Ifo, Ifo 2, Hagadera, and Kambioos (UNHCR, 2025). The study used a qualitative, multi-method design combining focus group discussions (FGDs), key informant interviews (KIIs), storytelling, participatory mapping, and transect walks. This combination was selected to capture multi-actor perspectives on risk knowledge and decision-making, surface challenges and opportunities associated with EWEA, and document lived experience (Cumiskey et al., 2025; Krishna et al., 2021). A total of 151 participants took part, spanning three stakeholder groups: refugees, humanitarian actors, and host-community

representatives, as well as additional national and international expert informants (See Table 1). Engagements took place in two rounds, in January and September 2025. During the first engagement, empirical data were collected; in the second, those results were reviewed with stakeholders and validated. This included a Training of Trainers with 21 refugee representatives to share back the results and strengthen capacities. Additionally, the second engagement included further empirical data collection through additional focus groups, workshops, and interviews. For security reasons, access to camps outside Ifo and Ifo 2 was restricted, and all sessions were held either in community spaces there or at the humanitarian compound in Dadaab. Interviews were audio-recorded, and group discussions were facilitated in local dialects by humanitarian field staff. Field notes captured contextual observations and non-verbal cues during and after each session. All participants gave informed consent.

2.2 Sampling

Participants were selected using purposive sampling, seeded through disaster risk reduction focal points operating in Dadaab. From these seed contacts, snowball sampling was used to identify additional participants, including cluster leads and sector focal points. Additionally, two multi-actor UN-led workshops focused on early warning and early action in camp settings were held in parallel with the field engagement, yielding additional contacts with refugees, humanitarian organizations, and host-community actors. Within each group, the selection sought to capture variation in role, sector, gender, and age to reflect a range of perspectives on disaster risk knowledge. Additionally, expert interviews were conducted to provide context with national disaster management authorities, UN agencies, and humanitarian actors, using snowball sampling starting from the authors' network.

Access constraints such as restricted movement outside Ifo and Ifo 2 for security reasons limited engagement to agency-approved locations and participants reachable through existing networks. This was a limitation, introducing potential selection bias toward stakeholders already engaged with institutional structures. Additionally, building on the two workshops introduced biases towards selecting interviewees who were already participating in the workshop. As a non-probability sampling approach, the sample was not designed to be statistically representative; therefore, the findings are not generalizable to the Refugee Complex or the broader Dadaab population. Table 1 reports the participants in the study by method, participant number, and stakeholder group.

Table 1
Participants in the study by method, participant number, and stakeholder group

Method	Participants	Stakeholder group
Focused Group Discussions	7	Women refugee group
	16	Youth refugee group
	13	Refugee representative group
	10	Humanitarian stakeholders
Round table Discussions	48	Humanitarian actors, refugee representatives, host community
	22	Youth refugees
Key Informant interviews & Storytelling	28	Refugees, humanitarian actors, host community
Expert interviews	6	National and international experts
Transect Walks	2	Humanitarian Actors

2.3 Data analysis

Data were analyzed using qualitative content analysis (Mayring & Fenzl, 2019). The codebook used for analysis can be found in Supplementary Material A, Fig. 4. Two categories of codes were pre-defined, and then additional codes were added deductively. First, to structure empirical evidence on disaster risk knowledge in the Dadaab Refugee Complex, the impact web approach (Sparkes et al., 2025) was used as an analytical tool. Impact webs, building on the Climate Impact Chains framework (Menk et al., 2022), provide a systems-focused, non-linear method for mapping interconnections among hazards, risk drivers, root causes, responses, and their direct and cascading impacts. This approach to analysis was used to co-produce knowledge of the complexity of disaster risk, with different elements of risk interacting across scales in Dadaab. As a first step in coding, data were aggregated into impact web sub-codes (e.g., hazard, risk drivers, cascading impacts). The second code category was added to cluster data related to EWEA, such as forecasting, dissemination and communication, and response preparedness. Third, a code category was added for cross-cutting findings.

Triangulation of field-based insights occurred alongside data analysis to contextualize with existing literature and reports, which were collected non-systematically. Additionally, to triangulate empirical results and provide a historical climatological context for the study area, we constructed a multi-hazard timeline for the Dadaab refugee camp (00°03'N, 40°18'E) (Fig. 2) covering the period 1992–2025 based on existing data. All climate data processing was performed using the xclim and xarray Python libraries (Bourgault et al., 2023). First, we derived climate indices at 0.1° spatial resolution from ERA5-Land reanalysis data (Muñoz-Sabater et al., 2021). For this, we used the full available record (1951–2025), which allows us to establish a robust baseline for calculating climate statistics before subsetting to the study period. Given that Dadaab experiences two distinct rainy seasons, the long rains (April–June,

locally known as Gu) and the short rains (October–December, locally known as Deyr), we aggregate precipitation-related indices per rainy season, which allows us to reflect the agricultural and livelihood calendar relevant to camp residents. Seasonal rainfall anomalies were expressed as z-scores relative to the long-term seasonal mean and standard deviation computed over the full 1951–2025 baseline. Consequently, negative values indicate anomalously dry seasons. Heatwave days were defined as consecutive periods of 5 or more days that exceeded both the local 95th percentile of daily mean temperature and an absolute threshold of 25°C, and were summed annually. Extreme precipitation events were defined as daily rainfall exceeding the 95th percentile of the full baseline distribution and were counted per rainy season, expressed as z-scores to enable comparison across seasons.

2.4 Limitations

The Dadaab Refugee Complex is a highly vulnerable research setting shaped by ongoing hardship, security constraints, and protracted crisis. These conditions informed every stage of the study design and implementation. Research activities followed the regulations of humanitarian actors operating on-site and were embedded within existing stakeholder engagements on disaster risk reduction, coordinated with official authorities present in the Complex. Stakeholder engagement was conducted in close collaboration with on-site field staff to avoid imposing further burden on an already stretched operational context.

Collected data were reviewed for sensitivity to protect participants; accordingly, not all data collected are disclosed in the data availability statement. Written and verbal informed consent was obtained from all participants in the Focus Group Discussions and workshops; verbal consent was obtained for Key Informant Interviews and storytelling, a context-specific consideration to avoid burdening participants with additional documentation that captures sensitive information and documents which could be associated with administrative processes. Given the sensitivities of this setting, all stakeholders were pseudonymized. A limitation of this approach is that power asymmetries between different stakeholder groups could not be fully captured or analyzed. Data collection began only after participants had given consent, and the researchers reminded participants of their role throughout the research process.

We acknowledge that security protocols and restricted access constrained sampling diversity, and that the temporal gap between hazard events and data collection introduced potential recall bias, partially mitigated through methodological triangulation. Findings are context-specific and not statistically generalizable.

4. Results

4.1 Disaster Risk Knowledge in Dadaab Refugee Complex

The literature indicates that since its establishment, Dadaab has experienced multi-hazard risks (see Fig. 2). Multi-year droughts have occurred three times in the past 30 years, with a generally drying trend across both rainy seasons. Furthermore, Fig. 2 shows punctuated extreme precipitation, and severe

flood events were recorded in multiple years, hitting the Dadaab Refugee Complex. Heat stress at temperatures above 40°C has been recorded.

Empirical results from stakeholder engagement with refugees, humanitarian actors, and municipality representatives in this study identified 4 climate and weather-related hazards — drought, heat, heavy rainfall, and seasonal flooding — and, additionally, 5 compounding hazards and shocks, including fire, garbage, disease outbreaks, armed conflict, and terrorism, as the main threats in the camp. Furthermore, 3 FGDs and 15 KIIs reported several interconnections and cascading effects. For instance, heat dries vegetation and soil, heightening both fire risk and, after prolonged drought, the likelihood that sudden heavy rainfall produces flash flooding through rapid surface run-off rather than absorption. 9 KIIs and 2 FGDs discuss that disaster risks in the camps do not occur in spatial isolation and highlight transboundary issues. Drought is a regional risk, from cross-border conditions in Somalia and Kenya into Garissa County and Dadaab, amplifying the influx of new refugees. Flooding, in turn, compounds pre-existing WASH and health vulnerabilities and disrupts the very infrastructure (roads, schools) that would otherwise support response and recovery from other hazards, not only in Dadaab but also in the host community, as multiple KIIs reported. Figure 3 shows the interconnections among multi-hazards and risks in the Dadaab Refugee Complex, as identified through participatory engagements.

Heat-related risks

Recent years have seen exceptional heatwaves, with 2016, 2017, 2019, 2020, and 2024 recording particularly high numbers of heatwave days. As shown in Fig. 3, the empirical evidence of this study complements local perspectives on the experience of heat-related risks. 2 KIIs identified extreme heat as a major hazard in the camp, while literature finds that the long dry seasons temperatures regularly reach 35–37°C and can peak at 40–42°C (Amou et al., 2020), with approximately 50–80 days per year exceeding 35°C producing prolonged heat stress and water scarcity in Garissa County. Although the majority of FGDs identified deforestation for fuel and shelter, compounded by high temperatures, as a key human driver that exacerbates heat-related risks by reducing shade cover, informants nonetheless described extreme heat as a permanent environmental condition in Dadaab. As shown in Fig. 3, heat is linked to cascading effects, including the drying of vegetation and flammable materials, increased fire risk to huts, tents, and marketplaces, and mental health concerns among refugee informants.

Drought-related risks

As a semi-arid area, Dadaab is disproportionately exposed to droughts, as 18 KIIs in this study reported. Triangulation of this insight with literature shows that droughts recorded in 2010/2011, 2018, 2019, and 2020–2023 have grown more frequent, as shown in Fig. 2, doubling from roughly once every six years to once every three years, making it four major drought periods between 1980–2004 compared with eight between 2005–2024 (Masih et al., 2014; Nicholson, 2017; UNDRR, 2024). For example, major humanitarian crises have coincided with drought periods, as evidenced by the 2020–2023 La Niña-driven drought, which led to multiple consecutive failed rainfall seasons across the Horn of Africa (UNDRR, 2024). Subsequently, this period has also seen 46% of new arrivals at Dadaab in 2022 cite drought as the

primary reason for flight, which is consistent with empirical insights in this study, where 3 FGDs reported Drought as a transboundary driver of displacement in Somalia, increasing the influx of refugees to the Dadaab Refugee Complex. One FGD explains that drought affects livestock, people, and children going to school, and causes famine, leading people to walk long distances to find water and lose time during the day. The participants also connect it to the arrival of new refugees and pressure on already scarce resources in the camps. 14 KIIs reported that drying boreholes have triggered acute water scarcity, forcing longer water-fetching distances that fall disproportionately on children, many of whom drop out of school to assist their families.

Heavy rainfall-related risks and flooding

Despite the prevailing drying trend illustrated in Fig. 2, several anomalously wet seasons have produced extreme precipitation events with severe humanitarian consequences. For example, the 2024 long rains season triggered severe flooding across Kenya, displacing over 20,000 people in the Dadaab complex alone, according to a key informant. Participatory engagements in this study confirmed that drought interacts with extreme precipitation, as soil drying has amplified runoff. In particular, the IFO II camp was reported by 21 KIIs to be a low-lying area that was primarily exposed to flash floods in the past. Informants described how flooding submerges roads and disrupts aid delivery, compounding already limited WASH and health conditions.

"The rain is heavy often, and Ifo camp is a flood zone; last time they had to use food dropped from the air as the camp was not accessible. In comparison, Hagadera camp is higher" (KII, Dadaab).

A total of three informants reported that the severity of these impacts is amplified by inadequate spatial planning, settlement in flood-prone areas, and insufficient drainage and sewage infrastructure, factors that also link flooding to downstream health risks and disease outbreaks, and that restrict access to schools and other essential services.

Drivers of risks and root causes

Gender inequality, poverty, infrastructure and development deficits were reported across the majority of participants as underlying drivers of risk, compounded by a lack of livelihood opportunities, the continuous influx of new refugees, and security threats that constrain preparedness capacity. Droughts dry up pastures and water sources, weakening livestock, stunting crop growth, and slashing milk production for both host communities and refugees, an informant explained. The informant added that pre-existing poverty and livelihood insecurity constrain their capacity to respond to drought-related risks. One informant explained that the majority of refugees are not allowed to engage in longer-term livelihood or skill-development activities in Kenya; however, they earn cash from short-term income-generating options, e.g., tailoring, day-labor-based cash-for-work activities, volunteering, kitchen gardens, micro-businesses, teaching, and other activities. 12 KIIs reported, as pictured in Fig. 3, that drought slashes livelihood opportunities, disrupting the thin net of livelihood options and leading to cascading impacts:

incomes erode, small business opportunities shrink, and food insecurity deepens, with local markets for meat, milk, and petty trade contracting sharply.

“We are all vulnerable, and helping others is sometimes hard because when you all are at the same level of that vulnerability, to help others is a problem, but still, we try to contribute things for the ones which we think are most urgent during droughts” (KII, Dadaab).

Participatory mapping further illustrated that disaster risks associated with heavy rainfall, floods, fire, and drought are not experienced equally. FGDs with women, youth leaders, and community representative refugees highlighted that the main vulnerable groups to disaster risks reported were children below 5 years, women, pregnant women, older persons, persons with disabilities, unaccompanied minors, and new arrivals, facing heightened vulnerability. For example, these groups were mentioned as more often struggling with capacity to respond, access to information, and pre-existing vulnerabilities. In particular, 14 KIIs reported gender-based violence as a major issue associated with disaster risks, such as floods.

Figure 3 synthesizes the co-produced disaster risk knowledge based on the empirical insights derived using an impact web approach. It illustrates the interactions among hazards, threats, and shocks; the negative impacts; the drivers of risk; and the root causes of vulnerability identified in the engagements. The Figure design and approach for impact webs to characterize risks are based on (Sparkes et al. 2025).

4.2 Barriers and enablers of Early Warning, Early Action.

Participatory stakeholder engagement reveals insights into barriers and enablers for strengthening EWEA. Insights are presented across the four main components of EWEA: Disaster Risk Knowledge; forecasting, monitoring, and analysis; warning communication and dissemination; and response preparedness, illustrating how complex Disaster Risks interact with EWEA in the case context.

Disaster Risk Knowledge

Results show that Disaster Risk Knowledge exists across all three stakeholder groups; the majority of participants agree that it is not the lack of Risk Knowledge but its translation into short- and long-term actions that constrains EWEA. 3 barriers and 2 enablers that were dominant in the engagements related to disaster risk knowledge, including fragmented risk knowledge across humanitarian sector clusters (WASH, Food, Protection) and a lack of interagency coordination for disaster risk-related aspects. 2 enablers were identified, including the opportunities emerging from established structures in self-organized refugee groups, and field staff for conducting regular community-based disaster risk assessments (participatory spatial mapping, storytelling), and further, to conduct post-disaster risk assessments, mapping areas and collecting data specifically for purpose of disaster risks, such as facilitating storytelling and participatory sessions for documenting lived experiences. Youth groups were especially identified as key actors for building community-based risk knowledge.

"The camps have also been mapped; we know the highlands and the flood-prone zones; we know where people are vulnerable. That's why I said, it's not about knowing, it's about doing something with that knowledge. Moving from knowledge to action is the missing link. That's the real gap: knowing is not the problem; the problem is acting on it." (KII, Dadaab)

Forecasting, monitoring and analysis

Engagements were primarily centered on 2 barriers and 1 enabler related to forecasting, monitoring, and analysis. Data gaps were the key concern shared across 12 KIIs and 2 FGDs. This included incomplete historical records, gaps in vulnerability and exposure data, and siloed data use across sectors such as WASH, food, and protection, without cross-sectoral data sharing to inform forecasting, monitoring, and analysis. For example, despite good data availability in the health sector, information is not frequently shared for disaster risk management, limiting the consideration of complex risks, such as disease outbreaks following flood events. Another barrier was identified as cross-border observation and monitoring, contextualized with exposure and vulnerability datasets, to warn of potential consequences for Dadaab (e.g., an influx of new refugees due to drought). This remains limited despite the existence of advisories and regional climate and weather observations. An enabler discussed with humanitarian actors in FGDs is forecast-based financing and impact-based forecasting to strengthen the monitoring and analysis of forecasts in humanitarian operations.

Data mainly comes from the sectors specifically but is not streamlined in one place for the purpose of warning. Also, we do that usually more for the sector purposes and more limited for identifying vulnerability data for anticipating flood impacts.

Communication and Dissemination

Engagements found 3 main barriers and 2 enablers related to communication and dissemination in the complex. A barrier across FGDs with humanitarian actors was inter-agency communication, which, despite existing working groups, encounters difficulties in a dynamic, highly time-constrained, and resource-scarce environment when seeking information on complex disaster risks. Despite that, participants report that there are accessibility barriers for newly arrived refugees and women-headed households, as they are less likely to be closely tied to the local social information network across camps and blocks. A shared barrier across FGDs with women's groups, community representatives, and youth committees was refugees' dependence on information from humanitarian actors due to limited engagement with external information channels. Findings show that, among refugees, communication is generally perceived as well established, and the majority of participants noted that information spreads quickly, including warnings during past flood events.

Everybody here is connected, information generally spreads like fire, everybody knows who is there, what is happening, and any circumstances quickly

Local communication channels, such as youth networks and self-organizing groups, reportedly provide a tight network of communication and information flows across different neighbourhood blocks and with humanitarian field staff. 5 KIIs flagged the importance of multilingual, multi-source communication ranging from mobile devices, mouth-to-mouth, speakers, and dedicated representatives for each block who are tasked with spreading information. Furthermore, information flowing through established structures within humanitarian organizations was considered to enable effective communication, such as through WhatsApp, SMS, phone calls, and direct focal points in the different blocks, which are utilized for warning communication. At the same time, other participants reported challenges for people who do not have access to mobile devices, and that internet access is limited.

"Most of the population here is young, many recently out of school. In recent years, they've begun forming refugee-led organizations. We now have quite a number of them, with different thematic focuses who can support warning dissemination and emergency response" (KII, Dadaab).

Response capabilities and preparedness

The component of response and preparedness was considered the most concerning across all actor groups. Fragmented response capacities due to siloed organization of humanitarian clusters (e.g., food, WASH, health), limiting the resources for targeted preparedness for complex risks. Gaps in the operationalization of SOPs and EAPs were identified, particularly due to resource constraints.

"While we receive warnings through our own channels, the relief items are often delayed and not enough; with heavy rain we have limited capacities to respond" (KII, Dadaab).

Addressing the high flood exposure of some camps in the Complex would substantially increase preparedness. An informant described the weaknesses in responding to past disasters less as an issue with technical forecasting systems and more as an amplification of people's location in flood-prone zones within the camp and a lack of infrastructure to prepare people in advance. As an enabler, capacity building was the most frequently mentioned aspect, with a particular focus on training of trainers for multiple actors, including field staff, cluster leads, camp coordinators, refugee representatives, and the younger generation in the refugee camps.

Dadaab is extremely young; we have the majority of children and youth. We should integrate it into the school curricula. Like hygiene, safe tracks for kids to evacuate

Furthermore, enablers for response capacities were an anticipatory action financing mechanism, such as establishing forecast-based finance triggers linked to humanitarian needs (food, relief items), to pre-position resources. Examples suggested during FGDs included establishing an inter-agency working group for disaster preparedness, a refugee-led DRM committee, and regular cross-sectoral assessment cycles for complex risks.

A lack of funding, especially for preparedness and anticipatory action, emerged as an acute issue. For example, informants reported that risk knowledge is available, and that EWEA could be technically

improved with the identified enablers; however, resources are already scarce in the context of a continuous, protracted crisis. One informant reported that response capacities are reduced throughout the year, so when a flood hits, it becomes an additional issue that amplifies the lack of resources to respond.

"People assume others don't know what they're doing, but often (..) it's a lack of resources. We have the warning systems, plans, and commitments; we all know what must be done. The question is: how do we mobilize resources?" (KII, Dadaab).

This financial constraint was described as compounding the protracted nature of the crisis, weakening response capacities even when forecasts reach relevant actors, and further slashing already scarce resources. Multiple informants identified a strengthened investment in comprehensive risk management as a priority enabler. The full list of barriers and enablers identified in stakeholder engagements can be found in the supplementary material B.

5. Discussion

5.1 Contributions to EWEA in Dadaab Refugee Complex

Early warning in protracted displacement settings is not only a data, forecasting, and technology gap; this study's co-produced risk knowledge shows that the binding constraint is instead the disconnect between what is known and who can act on it, when and how, embedded in the unique context of a protracted crisis. Five key contributions can be discussed following the analysis of the results.

First, a multi-hazard and all-vulnerability lens is critical for EWEA in the Dadaab Refugee Complex. This study shows that the Dadaab refugee complex is a disaster-risk setting. Multi-hazards and associated impacts are interacting with entrenched vulnerabilities of a protracted crisis context. For example, heavy rainfall, drought, and extreme heat were found not to act as isolated hazards but to interact and amplify deeply entrenched vulnerabilities (dependency on humanitarian aid, lack of infrastructure, lack of livelihoods) that are unique to a refugee camp context. This finding reinforces the need for the suggested all-vulnerability approach to multi-hazard early warning by Kelman & Fearnley (2025). Furthermore, vulnerability was found to be differentiated across the camp population. Drivers of risk included access to warning information and capacity resources, which differed by gender, disability, age, health status, and length of time in the camp. In contrast, informants also noted that all refugees in the camp are at the "same level of vulnerability" (Quote: KII). It suggests that camp-level EWEA needs to consider differential vulnerabilities and their capacities to act. This finding is consistent with literature on differentiated access to warning information, which finds that warning effectiveness depends as much on differentiated capacity to receive, interpret, and act on information as on dissemination reach (Seager, 2014). However, findings also highlight the agency and driving role of refugees in responding to disaster risks, such as youth-led representative groups, which underscores their role in EWEA not only as being at the forefront of response but also in challenging the idea of uniform warning recipients or end-users.

Conversely, refugees play a leading role in interacting with different aspects of EWEA in Dadaab for multi-hazard preparedness and complex risks.

Second, the results show that disaster risk knowledge is particularly relevant to all four elements of EWEA in the Dadaab Refugee Complex. For example, the interaction and feedback loop of forecasting and response preparedness falls short. For example, in addition to improving single-hazard forecasting, key informants consistently identified impact-based early warning (IbEW), such as translating forecasts into numbers of people affected, infrastructure disrupted, or livelihoods potentially lost, as a critical enabler of risk-informed planning in a dynamic humanitarian setting. While this finding echoes persistent gaps identified in hazard-based early warning elsewhere, humanitarian crisis settings amplify the need for impact-based approaches, for example, to pre-position relief and to strengthen interagency coordination.

Third, multi-actor engagement is a key element of EWEA, especially for translating warnings into response actions and decision-making. This is consistent with studies such as Geisemann et al., who argue that responding to these challenges requires moving beyond technical fixes in early action toward a systemic perspective that understands anticipatory action as a dynamic and complex governance and decision-making challenge involving multiple actors (Geisemann et al. 2025).

Fourth, the effectiveness of EWEA in Dadaab is constrained less by a lack of disaster risk knowledge than by structural barriers to operationalizing it. Informants repeatedly cited various barriers, such as limited resources, constrained institutional capacity, and competing humanitarian priorities that urge them to prioritize immediate relief over preparedness investment. The case of IFO and IFO II, low-lying and flood-prone with inadequate WASH infrastructure, healthcare, and shelter, illustrates that functioning EWEA alone cannot compensate for these deficits. This suggests that the effectiveness of EWEA further depends on its embedding within broader resilience-building and comprehensive risk management efforts.

5.2 Wider implications for EWEA in multi-hazard humanitarian contexts

Beyond Dadaab, implications reach to EWEA in comparable humanitarian and multi-hazard settings. Effective EWEA requires attention to transboundary and temporal dimensions of disaster risk. Dadaab's exposure to drought-induced refugee influxes and upstream rainfall events indicates that hazards are frequently shaped by spatially distant drivers, reinforcing calls to link community-based warning with national, regional, and transboundary forecasting systems, particularly to protect mobile refugee populations (He et al., 2023; Krishna Prabhakar, 2022). This suggests strengthening a vulnerability lens for EWEA tailored to camp contexts, in line with Kelman & Fearnley's vulnerability lens for multi-hazard early warning (2025).

Multi-actor fragmentation is a second, recurring issue. EWEA effectiveness in Dadaab is undermined by limited engagement in managing complex disaster risks in camps among humanitarian agencies,

government bodies, and national meteorological services, despite strong internal coordination reported among these actors on other related matters (WASH, Food clusters). Particularly, data-availability gaps, also documented in other resource-constrained refugee settings (Embersson et al., 2021), and challenges of managing risks in protracted refugee camps, where disaster risks are only amplifying an already existing crisis. Actors in this study suggested strengthening inter-agency platforms with defined roles, shared data protocols, and joint action triggers to address it, supporting the study's argument that a multi-actor approach is essential.

Community-based EWEA and refugee-led capacities remain underleveraged. Assessments in camp settings tend to be top-down and quantitative, overlooking refugee agency and the role of participatory engagement (Gonzalez Benson et al., 2022; Nungsari & Chuah, 2022). While cultural, historical, and socio-economic factors such as clan structures, transnational ties to Somalia, and protracted refugee status were not the central focus of this study, findings indicate that they plausibly shape adaptive capacity (Bernhofen et al., 2023; Montclos & Kagwanja, 2000) and warrant dedicated research. For example, refugee-led organizations and school-based DRR education were suggested as entry points for embedding local preparedness.

Finally, structural funding constraints bind all of the above. Humanitarian budget shortfalls in Dadaab continue to force trade-offs between immediate needs and investment in anticipatory capacity, which is a tension replicated across major refugee complexes globally as humanitarian funding contracts (Yüksel, 2026). Sustained resources for comprehensive risk management are critical for effective EWEA.

5.3 Future research

The study co-produced disaster risk knowledge through participatory engagement but did not assess how the proposed early actions could be subsequently implemented or their effectiveness. Existing evaluation approaches for early warning systems are largely designed for single-hazard, non-displacement contexts and may not capture the compounding institutional and resource constraints distinct to camp settings. Longitudinal research is needed to test whether co-produced knowledge of this kind translates into improved anticipatory response over time and to develop evaluation metrics for EWEA effectiveness adapted to humanitarian camp contexts.

The conceptual risk model, impact web, developed was used as an analytical and stakeholder-validation tool, offering a visual means of co-producing risk knowledge and linking it to EWEA. Its operational value for decision-making, for example, for advancing early action protocols and standard operating procedures, remains untested, as does its capacity to simplify complexity while retaining comprehensiveness. Future work should assess this actionability, extending the comparative basis established with other displacement settings to strengthen cross-context learning on EWEA in protracted humanitarian crises.

Although this study focused on disaster risk knowledge for EWEA, it did not aim to investigate the operational governance of EWEA, including relevant actors from national and regional institutions,

particularly regarding existing EAPs and SOPs. We recommend future studies to do so.

6. Conclusion

This study provided empirical evidence on co-produced disaster risk knowledge to strengthen multi-hazard early warning and early action in the Dadaab Refugee Complex. It illustrated multi-hazards, shocks, and threats in the camp through participatory engagement with refugees, humanitarian actors, and host-community representatives; documented the drivers and root causes of these risks; and its impacts. Furthermore, it illustrated how disaster risk knowledge interacts with early warning and early action, such as forecasts, warning communication, preparedness, and response capacities, as well as the barriers and enablers that shape its effectiveness in humanitarian settings. Results indicate that the Dadaab Refugee Complex represents a distinct disaster risk setting, where multi-hazard exposure and entrenched vulnerabilities combine to amplify impacts across the camp, host community, and surrounding region. Addressing such risks requires an EWEA that responds to the complex condition of protracted humanitarian crises. This spans scales, from household- and camp-level dynamics to host-community and regional interdependencies, and involves sustained engagement among multiple actors, including humanitarian agencies, meteorological services, camp coordination structures, and refugee and host communities. It emphasises the need for people-centred approaches and considering the societal dimensions of multi-hazards in humanitarian context for reducing risks and preventing harm with forecasts and warning. Finally, EWEA in protracted humanitarian contexts requires future work on embedding early action within comprehensive risk management efforts.

Declarations

Competing interest

The authors declare no competing interests.

Author Contribution

Samira Pfeiffer: Conceptualization, Methodology, Investigation, Visualization, Formal Analysis, Writing-Original Draft; Timothy Tiggloven: formal analysis; prepared figure 2, Writing - Review & Editing; Taiwo Ogunwumi: Formal Analysis, prepared figure 1, Writing - Review & Editing; Sylvester Chapotera: Investigation, Writing - Review & Editing; Mohamed Omar: Writing - Review & Editing; Maria del Pozo Garcia: Supervision; Saskia Werners: Conceptualization, Supervision, Writing - Review & Editing; Michael Hagenlocher: Conceptualization, Methodology, Investigation, Visualization, Supervision, Project administration, Funding acquisition, Writing - Review & Editing. All authors reviewed the manuscript.

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Data Availability

The data that support the findings of this study are available in the manuscript and supplementary material. Additional data can be requested from the authors for transparency.

References

1. Ahmed, B., Rahman, Md. S., Sammonds, P., Islam, R., & Uddin, K. (2020). Application of geospatial technologies in developing a dynamic landslide early warning system in a humanitarian context: The Rohingya refugee crisis in Cox's Bazar, Bangladesh. *Geomatics, Natural Hazards and Risk*, 11(1), 446–468. <https://doi.org/10.1080/19475705.2020.1730988>
2. Amou, M., Gylbag, A., Demelash, T., & Xu, Y. (2020). Heatwaves in Kenya 1987–2016: Facts from CHIRTS High Resolution Satellite Remotely Sensed and Station Blended Temperature Dataset. *Atmosphere*, 12(1), 37. <https://doi.org/10.3390/atmos12010037>
3. ASAL Humanitarian Network. (2022). *Drought situation in Kenya's ASAL areas reaches crisis level*. <https://asalnetwork.org/2022/10/05/drought-situation-in-kenyas-asal-areas-reaches-crisis-level/>
4. Ashour, L., Khattab, R., Yaghi, A., & Qatamin, H. (2023). The Climate Change Impact on Refugee Camps, Al Za'atari Case Study. In E. L. Krüger, H. P. Karunathilake, & T. Alam (Eds.), *Resilient and Responsible Smart Cities* (pp. 135–141). Springer International Publishing. https://doi.org/10.1007/978-3-031-20182-0_11
5. Bellizzi, S., Molek, K., & Nivoli, A. (2023). The link between drought and violence against women and girls in the Horn of Africa. *International Journal of Gynecology & Obstetrics*, 160(2), 451–452. <https://doi.org/10.1002/ijgo.14499>
6. Bernhofen, M. V., Blenkin, F., & Trigg, M. A. (2023a). Unknown risk: Assessing refugee camp flood risk in Ethiopia. *Environmental Research Letters*, 18(6), 064041. <https://doi.org/10.1088/1748-9326/acd8d0>
7. Bernhofen, M. V., Blenkin, F., & Trigg, M. A. (2023b). Unknown risk: Assessing refugee camp flood risk in Ethiopia. *Environmental Research Letters*, 18(6), 064041. <https://doi.org/10.1088/1748-9326/acd8d0>
8. Bourgault, P., Huard, D., Smith, T. J., Logan, T., Aoun, A., Lavoie, J., Dupuis, É., Rondeau-Genesse, G., Alegre, R., Barnes, C., Laperrière, A. B., Biner, S., Caron, D., Ehbrecht, C., Fyke, J., Keel, T., Labonté, M.-P., Lierhammer, L., Low, J.-F., ... Whelan, C. (2023). xclim: Xarray-based climate data analytics. *Journal of Open Source Software*, 8(85), 5415. <https://doi.org/10.21105/joss.05415>

9. Clarke, B., Barnes, C., Rodrigues, R., Zachariah, M., Alves, L. M., Haarsma, R., Pinto, I., Yang, W., Vahlberg, M., Vecchi, G., Izquierdo, K., Kimutai, J., Philip, S., Kew, S., Biehl, J., Mugge, M., & Otto, F. E. L. (2026). Climate change and El Niño behind extreme precipitation leading to major floods in southern Brazil in 2024. *Npj Natural Hazards*, 3(1), 4. <https://doi.org/10.1038/s44304-025-00162-8>
10. Dampha, N. K., Salemi, C., Polasky, S., Egziabher, A. G., & Rappeport, W. (2025). Refugees and host communities' vulnerability to climate and disaster risks in Rwanda. *Frontiers in Climate*, 7, 1465223. <https://doi.org/10.3389/fclim.2025.1465223>
11. Dash, B. (2024). Gap between impact-based and impact forecast and warning: Implications for people-centric early warning system (EWS) in India. *Natural Hazards Research*, 4(1), 110–117. <https://doi.org/10.1016/j.nhres.2023.09.005>
12. Dash, S., Maity, R., Maity, S. S., & Kunstmann, H. (2025). Population exposure to compound climate extremes: Global analysis to identify continent wise age group disparities in a warming world. *Npj Natural Hazards*, 2(1), 88. <https://doi.org/10.1038/s44304-025-00145-9>
13. Emberson, R. A., Kirschbaum, D. B., & Stanley, T. (2021). Landslide Hazard and Exposure Modelling in Data-Poor Regions: The Example of the Rohingya Refugee Camps in Bangladesh. *Earth's Future*, 9(2), e2020EF001666. <https://doi.org/10.1029/2020EF001666>
14. Fransen, S., Werntges, A., Hunns, A., Sirenko, M., & Comes, T. (2024). Refugee settlements are highly exposed to extreme weather conditions. *Proceedings of the National Academy of Sciences*, 121(3), e2206189120. <https://doi.org/10.1073/pnas.2206189120>
15. Geisemann, P., Seidemann, I., Olawuyi, D., & Geiger, D. (2025). Early Warnings, No Actions: A Practice Perspective on Barriers to Anticipatory Action Approaches. *Journal of Contingencies and Crisis Management*, 33(4), e70083. <https://doi.org/10.1111/1468-5973.70083>
16. Glantz, M. H., & Pierce, G. (2023). For the Record: Second Thoughts on Early Warning, Early Action (EWEA), EW4All, or EWEA4All? *Atmosphere*, 14(11), 1631. <https://doi.org/10.3390/atmos14111631>
17. Gnowa, J. G., Verschuur, J., & Comes, T. (2026). Resilient infrastructure planning in refugee and internally displaced person settlements: A systematic review of scholarly and grey literature. *Progress in Disaster Science*, 30, 100575. <https://doi.org/10.1016/j.pdisas.2026.100575>
18. Golicha, Q., Shetty, S., Nasiblov, O., Hussein, A., Wainaina, E., Obonyo, M., Macharia, D., Musyoka, R. N., Abdille, H., Ope, M., Joseph, R., Kabugi, W., Kiogora, J., Said, M., Boru, W., Galgalo, T., Lowther, S. A., Juma, B., Mugoh, R., ... Burton, J. W. (2018). Cholera Outbreak in Dadaab Refugee Camp, Kenya—November 2015–June 2016. *MMWR. Morbidity and Mortality Weekly Report*, 67(34), 958–961. <https://doi.org/10.15585/mmwr.mm6734a4>
19. Gonzalez Benson, O., Routte, I., Pimentel Walker, A. P., Yoshihama, M., & Kelly, A. (2022). Refugee-Led Organizations' Crisis Response during the COVID-19 Pandemic. *Refuge: Canada's Journal on Refugees*, 38(1), 62–77. <https://doi.org/10.25071/1920-7336.40879>
20. Haggag, A. G., Zaki, S. H., & Selim, A. M. (2023). Emergency camps design using analytical hierarchy process to promote the response plan for the natural disasters. *Architectural Engineering and Design Management*, 19(3), 305–322. <https://doi.org/10.1080/17452007.2022.2125359>

21. He, F., Lai, Q., Ma, J., Wei, G., & Li, W. (2023). Design and Application of an Early Warning and Emergency Response System in the Transboundary Area of the Taihu Lake Basin. *International Journal of Environmental Research and Public Health*, 20(2), 1340.
<https://doi.org/10.3390/ijerph20021340>
22. IGAD ICPAC. (2022). *State of Climate, Peace and Security in the Horn of Africa*.
https://www.un.org/climatesecuritymechanism/sites/default/files/2025-06/State_of_Climate_Peace_and_Security_in_the_Horn_of_Africa_2022_gttu3PO.pdf
23. Kelman, I., & Fearnley, C. J. (2025). From multi-hazard early warning systems (MHEWS) to all-vulnerability warning systems (AVWS). *iScience*, 28(7), 112977.
<https://doi.org/10.1016/j.isci.2025.112977>
24. Krishna Prabhakar, S. V. R. (2022). Implications of Regional Droughts and Transboundary Drought Risks on Drought Monitoring and Early Warning: A Review. *Climate*, 10(9), 124.
<https://doi.org/10.3390/cli10090124>
25. Leahy, C., & Ermagun, A. (2026). Stakeholder perspectives inform cascading hazard resilience. *Npj Natural Hazards*, 3(1), 60. <https://doi.org/10.1038/s44304-026-00243-2>
26. Lemenkova, P. (2025). Geo-Information for Humanitarian Mapping and Monitoring Crisis-Affected Regions: A Scoping Review. *Journal of Migration and Political Studies*, 3(2), 196–220.
<https://doi.org/10.69510/mipos.1684741>
27. Masih, I., Maskey, S., Mussá, F. E. F., & Trambauer, P. (2014). A review of droughts on the African continent: A geospatial and long-term perspective. *Hydrology and Earth System Sciences*, 18(9), 3635–3649. <https://doi.org/10.5194/hess-18-3635-2014>
28. Mayring, P., & Fenzl, T. (2019). Qualitative Inhaltsanalyse. In N. Baur & J. Blasius (Eds.), *Handbuch Methoden der empirischen Sozialforschung* (pp. 633–648). Springer Fachmedien Wiesbaden.
https://doi.org/10.1007/978-3-658-21308-4_42
29. Menk, L., Terzi, S., Zebisch, M., Rome, E., Lückerrath, D., Milde, K., & Kienberger, S. (2022). Climate Change Impact Chains: A Review of Applications, Challenges, and Opportunities for Climate Risk and Vulnerability Assessments. *Weather, Climate, and Society*, 14(2), 619–636.
<https://doi.org/10.1175/WCAS-D-21-0014.1>
30. Montclos, M.-A. P. D., & Kagwanja, P. M. (2000). Refugee Camps or Cities? The Socio-economic Dynamics of the Dadaab and Kakuma Camps in Northern Kenya. *Journal of Refugee Studies*, 13(2), 205–222. <https://doi.org/10.1093/jrs/13.2.205>
31. Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Boussetta, S., Choulga, M., Harrigan, S., Hersbach, H., Martens, B., Miralles, D. G., Piles, M., Rodríguez-Fernández, N. J., Zsoter, E., Buontempo, C., & Thépaut, J.-N. (2021). ERA5-Land: A state-of-the-art global reanalysis dataset for land applications. *Earth System Science Data*, 13(9), 4349–4383.
<https://doi.org/10.5194/essd-13-4349-2021>
32. Najafi, H., Shrestha, P. K., Rakovec, O., Apel, H., Vorogushyn, S., Kumar, R., Thober, S., Merz, B., & Samaniego, L. (2024). High-resolution impact-based early warning system for riverine flooding.

- Nature Communications*, 15(1), 3726. <https://doi.org/10.1038/s41467-024-48065-y>
33. Nicholson, S. E. (2017). Climate and climatic variability of rainfall over eastern Africa. *Reviews of Geophysics*, 55(3), 590–635. <https://doi.org/10.1002/2016RG000544>
 34. Nungsari, M., & Chuah, H. Y. (2022). Refugee Community-Based Organizations: Resources, Power, and Dependency. *Journal of Refugee Studies*, 35(2), 780–804. <https://doi.org/10.1093/jrs/feac005>
 35. Owen, M., Kruczkiewicz, A., & Van Den Hoek, J. (2023). Indexing climatic and environmental exposure of refugee camps with a case study in East Africa. *Scientific Reports*, 13(1), 7533. <https://doi.org/10.1038/s41598-023-31140-7>
 36. Pfeiffer, S. (2025). *Risk and Resilience in Dadaab Refugee Complex: Managing complex risks in fragile settings*. https://collections.unu.edu/eserv/UNU:10314/Risk_and_resilience_Dadaab_web.pdf
 37. Pollock, W., Wartman, J., Abou-Jaoude, G., & Grant, A. (2019). Risk at the margins: A natural hazards perspective on the Syrian refugee crisis in Lebanon. *International Journal of Disaster Risk Reduction*, 36, 101037. <https://doi.org/10.1016/j.ijdrr.2018.11.026>
 38. Seager, J. (2014). Disasters Are Gendered: What's New? In A. Singh & Z. Zommers (Eds.), *Reducing Disaster: Early Warning Systems For Climate Change* (pp. 265–281). Springer Netherlands. https://doi.org/10.1007/978-94-017-8598-3_14
 39. Sibanda, W., Mukwada, G., & Hansen, M. M. (2022). Disaster (Un)preparedness under cyclone Idai: Revisiting women activities in water and sanitation at tongogara refugee camp, Zimbabwe. *Cogent Social Sciences*, 8(1), 2137964. <https://doi.org/10.1080/23311886.2022.2137964>
 40. Sparkes, E., Cotti, D., Valdiviezo Ajila, A., Werners, S. E., & Hagenlocher, M. (2025). Impact Webs: A novel conceptual modelling approach for characterising and assessing complex risks. *Hydrology and Earth System Sciences*, 29(14), 3297–3313. <https://doi.org/10.5194/hess-29-3297-2025>
 41. Tewo, S., Thierno, B., Banza, F. M., Mahamat, I. M., Eric-Didier, N. K., Raoul, D. N., Otshudiema, J. O., Jorge, C. E., Brahimi, M., Maina, D., Egmond, E., Woung, M., Shimizu, K., Pavlin, B. I., Tamuzi, J. L., Katoto, P. D. M. C., Wiysonge, C. S., & Anya, B.-P. M. (2025). Evaluation of the implementation of the EWARS Mobile epidemiological surveillance tool in Sudanese refugee camps in Eastern Chad: A retrospective and population-based surveillance study. *Frontiers in Epidemiology*, 5, 1604446. <https://doi.org/10.3389/fepid.2025.1604446>
 42. Tiggeloven, T., Stolte, T., Claassen, J. N., Chang, C.-W., Paszkowski, A., Schneiderbauer, S., Yotsui, S., & Van Maanen, N. (2026). Multi-hazard exposure disproportionately affects vulnerable populations globally. *Communications Earth & Environment*, 7(1), 544. <https://doi.org/10.1038/s43247-026-03652-3>
 43. UNDRR. (2024). *Horn of Africa floods and drought, 2020–2023—Forensic analysis*. <https://www.undrr.org/resource/horn-africa-floods-and-drought-2020-2023-forensic-analysis>
 44. UN-HABITAT. (2021). *Dadaab Spatial Profile*. <https://unhabitat.org/dadaab-spatial-profile>
 45. UNHCR. (2021). *Refugee Camps Explained*. <https://www.unrefugees.org/news/refugee-camps-explained/#Howmanyrefugeesliveinrefugeecamps?>

46. UNHCR. (2024). *Dadaab Refugee Complex*. <https://www.unhcr.org/ke/about-us/where-we-work/dadaab-refugee-complex>
47. UNHCR. (2025). *Refugee Data Finder* [Dataset]. <https://www.unhcr.org/refugee-statistics>
48. United Nations. (2022a). *Drought and conflict force 80,000 Somalis to shelter in Kenya's Dadaab refugee camps*. <https://un.dk/drought-conflict-force-80000-somalis-to-shelter-in-kenyas-dadaab-refugee-camps/>
49. WMO & UNDRR. (2023). *Early Warning for All Executive Action Plan 2023–2027*. <https://library.wmo.int/>
50. Xie, M., & Chen, L. (2024). Turning every disaster into an opportunity: An exploratory study on refugees' perceived emergency management capacity and community resilience. *International Journal of Disaster Risk Reduction*, 111, 104727. <https://doi.org/10.1016/j.ijdr.2024.104727>
51. Yüksel, Y. U. C. (2026). *Humanitarian funding cuts: Power, prioritisation, and systemic injustice in global humanitarian aid*. <https://cadmus.eui.eu/entities/publication/e14656cc-b3fc-43df-af70-0ad7d5b53ee6>
52. Zaman, S., Sammonds, P., Ahmed, B., & Rahman, T. (2020). Disaster risk reduction in conflict contexts: Lessons learned from the lived experiences of Rohingya refugees in Cox's Bazar, Bangladesh. *International Journal of Disaster Risk Reduction*, 50, 101694. <https://doi.org/10.1016/j.ijdr.2020.101694>

Figures

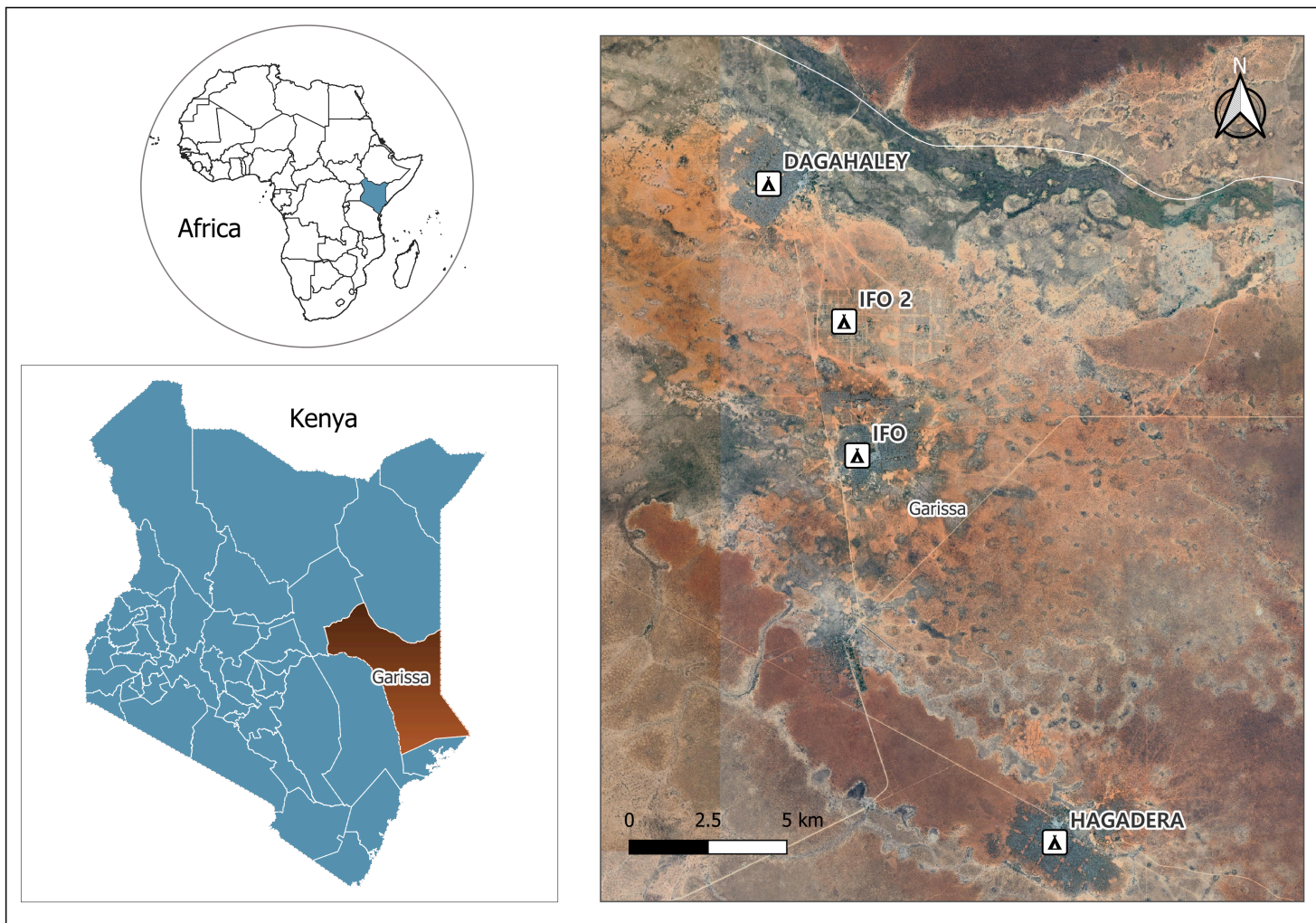


Figure 1

Map showing the location of the Dadaab Refugee Complex in Kenya

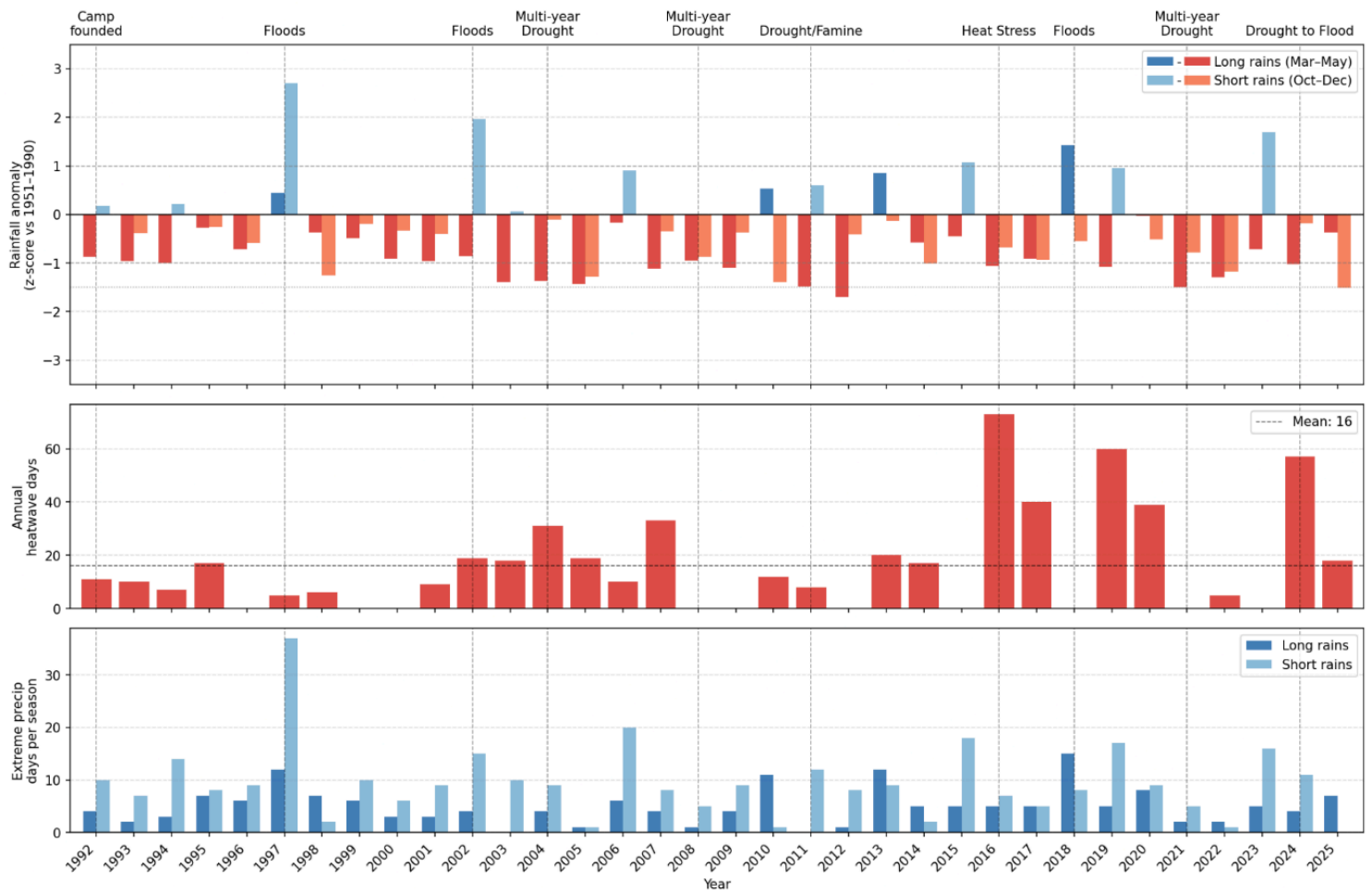


Figure 2

Multi-hazard context of the Dadaab Refugee Complex, 1992 to 2025

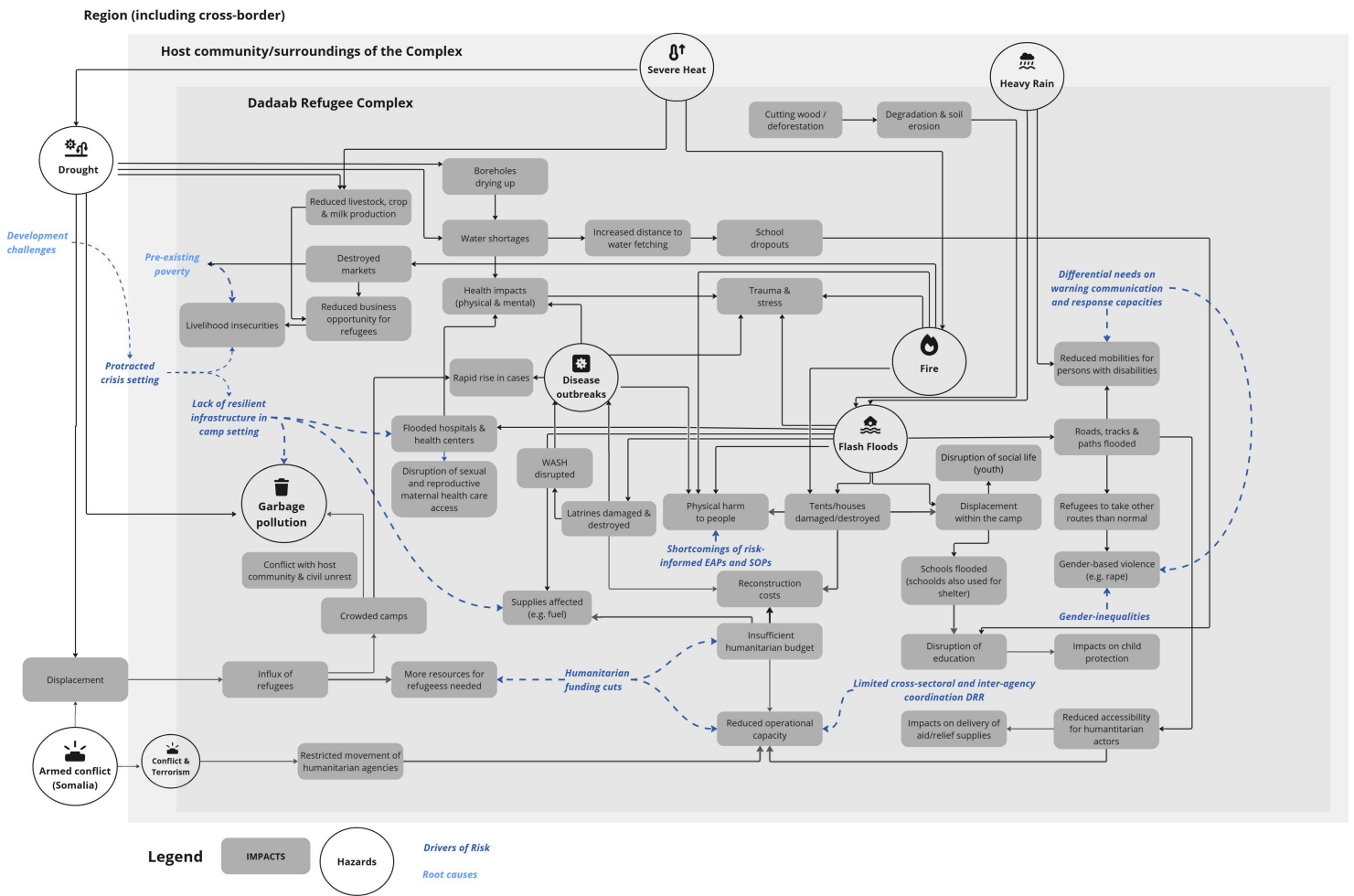


Figure 3

Impact web illustrating co-produced Disaster Risk Knowledge in Dadaab Refugee Complex

Supplementary Files

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