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ORIGINAL ARTICLE

Resilience-building interventions and their linkages to livelihood capitals and capacities: insights from community-based implementation across 19 flood-prone countries

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Abstract
Despite the growing literature on climate change adaptation across diverse academic fields, a significant research gap persists in the documented synthesis of concrete adaptation actions implemented on the ground. The current lack of synthesized documentation hinders effective learning across diverse contexts and limits the development of robust adaptation strategies, especially due to existing monitoring and evaluation frameworks that often rely on high-level, broad categorizations that obscure the true mechanisms of change. This paper directly addresses this under-explored area by analyzing community-level flood resilience interventions undertaken by the Zurich Flood Resilience Alliance (ZFRA) in 19 countries between 2019 and 2024. Employing a mixed-methods approach, we identify seven emergent intervention categories, encompassing infrastructure and physical improvements, community engagement and knowledge building, community flood resilience planning, community action groups, nature-based solutions, asset protection and diversification, and early warning systems. We examine these intervention categories in relation to the Sustainable Livelihoods Framework's five capitals and the crucial resilience capacities of absorptive, adaptive, and transformative abilities. Our analysis demonstrates that interventions within the same broad category can have vastly different functionalities, impacting diverse capitals and contributing to varying resilience stocks (capital) and process (capacities) – suggesting a shift away from monitoring and evaluating interventions through broad, aggregated categorizations. This study underscores the importance of considering the interplay between different intervention types and the various dimensions of community resilience, offering valuable insights for practitioners and policymakers seeking to enhance the effectiveness of adaptation efforts and bridge the persistent gap between adaptation planning and tangible action on the ground.

Keywords Flood resilience · Community interventions · Resilience capacities · Adaptive solutions · Monitoring and evaluation

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1 Introduction

Climate action has gained significant momentum across diverse sectors, from national governments to grassroots initiatives, demonstrating a global commitment to addressing climate change. Under the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement and the 2030 Agenda for Sustainable Development (SDG), overarching goals for climate action are 'increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience' (UNFCCC 2016, Article 2) with a dedicated 'global goal on adaptation' (Lesnikowski et al. 2017; Persson 2019). International conventions have also identified climate change adaptation and risk reduction as important global priorities for sustainable development, specifically the Sendai Framework for Disaster Risk Reduction (SFDRR) (Tozier de la Poterie and Baudoin 2015; UNISDR 2015) and vice versa where SDG and DRR indicators already tailored to the global level can be applied to reveal insights into progress on adaptation (UNFCCC 2021). However, central to achieving these goals is the empowerment of communities to adapt and thrive in the face of known and unknown threats including climate risks (Adger et al. 2005; Shammin et al. 2022). Resilience has thus become widely used for addressing across global challenges as a more broadly defined concept that considers various systems (Folke 2006; Mock et al. 2015) as well as context-specific enabling conditions assessment frameworks (Jones et al. 2017) and assessments after events (Tierney and Bruneau 2007; Cutter et al. 2010).

Despite the proliferation of ambitious goals and agendas designed to address the interconnected challenges of climate change, disaster risk, and sustainable development with building resilience, there persists a lack of comprehensive understanding and coordination amongst the disciplines and practice (World Bank 2024) as well as a gap between aspirations and necessary scale of action (IPCC 2022; Petzold et al. 2023). To promote and support further action, there has been efforts to systematically track adaptation policies, actions and solutions for enhanced accountability, improved coordination, and effective knowledge sharing, as demonstrated by the global stocktake of climate adaptation (Berrang-Ford et al. 2021; Araos et al. 2021). However, as effective adaptation requires a deep understanding of local contexts, which necessitates bottom-up approaches that prioritizes local knowledge and participation (Soanes et al. 2021; Sakic Trogrlic et al. 2022), collecting and consolidating implementation projects at global scale is highly limited (Lesnikowski et al. 2019; Laurien et al. 2020). Furthermore, adaptation options and measures, even when targeting the same vulnerabilities, exhibit significant variations in labeling and description (Leitner et al. 2020; Berrang-Ford et al. 2021).

This paper addresses this critical gap by examining a unique dataset of community-level resilience-building interventions implemented by the Zurich Flood Resilience Alliance (ZFRA) in over 300 communities across 19 countries over a five-year project timeframe. ZFRA is a multi-sectoral partnership consisting of six humanitarian and development NGOs, two research, and one private sector partners focused on enhancing resilience to climate hazards in both rural and urban communities (Fig. 2, map of ZFRA communities that have implemented interventions). We build upon the conceptual richness of resilience, including how it can be assessed against disasters (Cutter 2016; Keating et al. 2017), climate change (Shammin et al. 2022) and community well-being (Folke et al. 2006; Bene et al. 2015) as well as how its dynamics can be characterized in community procedures and processes (Norris et al. 2008; Aldrich and Mayer 2015) and as dynamic outcomes (Hochrainer-

Stigler et al. 2021; Guimaraes et al. 2025). These conceptual frameworks of resilience have yet to be empirically explored with large-scale empirical data of resilience-building actions, particularly at the community level, which explains our limited understanding of what the effects of resilience building are across diverse contexts (Berrang-Ford et al. 2021; Roezer et al. 2023).

We aim to advance the understandings of community-level resilience interventions by first identifying emergent categories of community-level resilience building interventions, then examining how different indicators of resilience explain the heterogeneity of their intended effects among the intervention categories. To achieve these aims, this study employs a mixed-methods meta-analysis approach to analyze community-level flood resilience interventions and synthesize the diverse information available to move beyond individual case studies and identify broader trends and patterns. The analysis proceeds in two stages, where we first conduct a deductive analysis of the intervention data to identify emergent categories or types of interventions, then inductively analyze these categories, examining their alignment with established conceptual frameworks of resilience building, specifically the 'five capitals' and the three resilience capacities (DFID 1999; Bene et al. 2015). Critically, our analysis demonstrates that interventions within the same broad category can have vastly different functionalities, impacting diverse capitals and contributing to varying resilience capacities. This finding challenges the common practice of monitoring and evaluating interventions that are aggregated and based on broad categorizations and emphasizes the need to specify the analytical unit to accurately capture the diverse progress of resilience building.

The following sections detail our approach and findings. Section 2 describes the data and methods. Section 3 presents the results, starting with the empirically deduced intervention categories and then exploring their connection to established resilience frameworks. Section 4 discusses the significance of these findings, highlighting their contributions to both theory and practice, and concludes with a look ahead at future research directions.

2 Methodology

2.1 Data source and sample

This study utilizes data on community-level DRR interventions collected through a structured online survey completed by country teams, of the six implementation partner organizations (international NGOs) involved in ZFRA, implementing interventions in communities. The online survey, conducted annually between 2022 and 2024, covers interventions implemented between 2018 and 2024. Within each NGO, local program managers responsible for the local implementation of interventions provided details about these interventions to country program leaders. As the questionnaire focused on intervention details and did not directly involve community members or collect individual-level data, no additional ethics approval was obtained. The survey instrument (more information in Appendix B1) was designed to capture detailed information about each intervention, including: the communities where it was implemented, a description of the intervention (what and how), the resources and processes required for design and implementation, intended and initial outcomes, and latest status. The questionnaire was explicitly not designed as an M&E or

financial reporting tool used for performance assessment or funding disbursement. Its primary aims focus on learning, not compliance, and to collect detailed information required to develop a replicable solution or a credible lesson learned. The core criteria for a 'solution' were replicability and sustainable increase in resilience, which requires an honest description of the mechanism, not just a positive outcome. The survey data is internally open for the alliance to draw insights on trends and patterns, mainly by research partners, as well as to facilitate internal peer-to-peer learning and exchange ideas between country teams.

For the purposes of this survey as well as this study's analysis, an intervention is defined as "an activity or group of activities that builds community flood resilience." This included a wide range of activities, from tangible assets (e.g. a platform for poultry refuge, a multipurpose shelter, or a bio-dyke) and technological tools (e.g. digital risk mapping, an online app, or an early warning system) to community-based approaches (e.g. developing community disaster management committees) and specific livelihood strategies. However, individual workshops, meetings, or training sessions were not considered interventions unless they were part of a long-term strategy (e.g. first aid training or specific livelihood training) and targeted a specific source or sources of resilience. This definition ensured consistency in reporting across the implementing partners.

A total of 225 discrete flood resilience interventions were selected for analysis based on the exclusion of incomplete entries and the requirement that all key analytical fields, specifically the description, targeted resilience capitals, resources required, expected and achieved results, were fully and logically completed. Each intervention is "discrete" in that we refer to an intervention as one that can be implemented in one or multiple communities in a country by the same implementing NGO.

2.2 Conceptual framework and analytical approach

Prior to interventions programming, as part of ZFRA's induction phase, a standardized resilience assessment is conducted using the Flood Resilience Measurement for Communities (FRMC) framework and tool (Keating et al. 2017; Campbell et al. 2019; Chapagain et al. 2024) in all communities to self-assess their resilience by grading 44 sources of resilience indicators using household surveys, key-informant interviews, and focus groups. The resilience grades can be grouped to be understood according to four different lens – the disaster risk management cycle, 4Rs of resilience, themes and five capitals, namely, human, social, natural, financial and physical capital (DFID, 1999). This baseline assessment serves not only as a metric for identifying gaps and prioritize needs, which influences the selection of interventions but also as an enabler for consensus-building and empowerment of community-led and locally designed interventions due to the participatory nature of the FRMC data collection process (Hochrainer-Stigler et al. 2020).

The FRMC promotes a systems-thinking approach, encouraging analysis of interconnections between different resilience factors and avoiding an isolated view of individual indicators and their relative strengths and weaknesses. Similarly, most ZFRA interventions are related to more than one of the 44 sources of resilience, and maybe even touch upon more than one theme or capital. It should be noted that the FRMC does not generate specific interventions nor do interventions intend to target specific sources of resilience. The process of the FRMC data collection, grading to interpretation, using the measurement framework of resilience sources and related capitals are shown in Appendix A1. To ensure that our analy-

sis remains grounded to the emergent patterns as well as existing resilience frameworks, we implemented an exploratory methodology elaborated in the following sections.

2.2.1 Deductive categorization of interventions

A full screening of the survey data was conducted to gain meta-understanding and familiarization of the qualitative survey data content of the interventions (see Sect. 3.1 and Table 1 for a descriptive overview and list of interventions). We used a thematic analysis approach (Braun and Clarke 2006) to inductively identify key themes and patterns within the intervention descriptions. This involved multiple readings of the data, followed by the development of a preliminary coding scheme. Two researchers independently coded a subset of the interventions to assess inter-coder reliability and discrepancies were resolved through discussion. The coding scheme was iteratively refined until a high level of agreement was reached. Specifically, the qualitative data responses provided from open-ended survey questions directly addressed the intervention's objectives, implementation process, activities, and intended outcomes (see full survey in Appendix B1). Key questions included: 'What resilience problem/gap is the intervention trying to address?', 'Describe the intervention. How does it work?', and 'What short term and long-term outcomes is the intervention expected to provide to the community? Which vulnerable groups will benefit?' These questions provided the core data for understanding the nature and scope of each intervention, allowing for the identification of common thematic elements.

Within this process a rough assessment of the consistency, reliability, potential biases and overall evaluation on substantiation of the responses was conducted. In addition, emergent thematic categories to classify the interventions for further analysis were identified. These categories and their appropriateness to be used for analysis were reviewed with a team of representatives from all implementing NGOs in the Alliance, including members who were responsible in responding to the survey. No specific data analysis software was used throughout this categorization process and was manually conducted.

2.2.2 Inductive analysis of interventions using resilience frameworks

Building upon the intervention categorization established through deductive analysis, the second phase of the data exploration adopted an inductive approach, identifying applicable resilience frameworks for application. Given the conceptual diversity of resilience stemming from various fields, defining the objectives and finding consensus on "good (characteristics of)" resilience (Haider et al. 2021) is a key challenge, especially for monitoring and evaluating resilience-building interventions (Biagini et al. 2014; Sparkes and Werners 2023). Aligned with the focus of ZFRA on community resilience, we identified frameworks that effectively represent the processes and intended outcomes of community-based interventions enhancing resilience against floods. We selected the Sustainable Livelihoods Framework (SLF) (DFID, 1999) and Bene et al.'s (2015, 2018) conceptualization of resilience as a combination of capacities, as they capture both the asset-based and process-oriented dimensions of resilience. The SLF provides a holistic approach to understanding poverty reduction by addressing how a combination of capitals (the 5Cs – natural, physical, human, financial, and social capital) and vulnerability factors influence people's livelihoods and their ability to achieve sustainable outcomes, particularly in the face of shocks.

Table 1 Types of Interventions implemented and recorded

Type code	Full type name	Sub-types	Description	Count	Main sources of resilience targeted	Other sources of resilience targeted	Countries	Main decision-making factor
infra	Infrastructure and physical improvements	-general -flood response	Tangible, on-the-ground actions such as elevating roads and homes, installing sanitation facilities, improving drainage, and developing evacuation centers. These interventions are not just about building infrastructure; they are about creating safer and more resilient living environments that enhance community well-being and reduce vulnerability to floods	34	P06 - Large scale flood protection P03 - Flood emergency infrastructure P05 - Household flood protection	P07 - Transportation interruption P08 - Communication interruption P09 - Flood emergency food supply	13 countries including -Nepal, Bangladesh, Senegal, Malawi	Community priority
edu	Community engagement and knowledge building	-campaign -training	Aim to improve community members' confidence and skills in resilience practice through training, education, awareness-raising, and direct involvement in on-ground activities. They recognize that knowledge is not just about technical expertise but also about empowering individuals and communities to make informed decisions and take ownership of their resilience-building processes. These interventions not only transfer knowledge but also co-create knowledge with communities, valuing local knowledge, and foster a culture of learning.	58	H01 - Evacuation and safety knowledge H02 - First aid knowledge S07 - social inclusiveness	H06 - Future flood risk awareness H04 - Flood exposure awareness H03 - Education commitment during floods	All 19 countries	Resources (technical)
plan	Community flood resilience planning	-assessment -plan and act	Focus on building community preparedness and response capacity through the development of community-led action plans	43	S04 - Community disaster risk management planning S09 - Inter-community flood coordination S10 - Integrated flood management planning	H09 - Governance awareness F06 - Disaster response budget S05 - Community structures for mutual assistance	13 countries including -El Salvador, Malawi, Kenya, Vietnam	Resources (technical and financial) and community priority
cb	Community action groups/ organizing	-response group (brigades) -standing committee	Organize groups of people dedicated to building resilience and strengthening local capacities in the face of flooding, as well as other emergencies and disasters. Not merely tools for disaster response; they are platforms for community empowerment, fostering a sense of ownership and agency in the face of flood risks	23	S01 - Community participation in flood related activities S05 - Community structures for mutual assistance S08 - Local Leadership	P01 - Flood healthcare access S03 - Community safety S04 - Community disaster risk management planning	12 countries including -Philippines, Mozambique, Bangladesh, Malawi	Community priority and technical support

Table 1 (continued)

Type code	Full type name	Sub-types	Description	Count	Main sources of resilience targeted	Other sources of resilience targeted	Countries	Main decision-making factor
nbs	Nature based Solutions	-install -local knowledge	Utilize natural systems to reduce flood risk and enhance resilience, such as restoring wetlands, planting mangroves, and creating bio-dykes. These interventions recognize the interconnectedness of social and ecological systems and the importance of working with nature rather than against it. They provide multiple benefits, not only reducing flood risk but also enhancing biodiversity, improving water quality, and providing livelihood opportunities. These approaches receive a high level of support by communities that recognize their value and are strongly engaged in their implementation.	20	N04 - Natural resource conservation H08 - Environmental management awareness P06 - Large scale flood protection	F05 - Risk reduction investments P11 - Flood waste contamination	11 countries including -El Salvador, Bolivia, Malawi, and Bangladesh	Mixed – community priority, resources and longer-term impact
asset	Asset protection and diversification	-loan association -climate smart agriculture -finance	Strengthen livelihood resilience through trainings and institution-building around good (climate-smart) agriculture, livestock rearing, village-saving loan associations, etc. The sustainability of these new practices and organizations were dependent on how well integrated the operating and coordinating mechanisms were within the community and across higher levels of governance.	26	F04 - Household income continuity strategy F06 - Disaster response budget F01 - Household asset recovery	F03 - Business continuity S02 - External flood response and recovery services S09 - Inter-community flood coordination	13 countries including - Bangladesh, Kenya, South Sudan, Zimbabwe, and Vietnam	Community priority
ews	Early Warning Systems	-establish -new tools -participatory	Improve the timeliness, accuracy, and accessibility of flood warnings to communities. They recognize that early warning is not just about technology but also about effective communication, community engagement, and trust-building. By involving communities in the design and implementation of EWS, the ZFRA ensures that these systems are relevant, reliable, and responsive to local needs.	21	P02 - Early Warning System S01 - Community participation in flood related H05 - Asset protection knowledge	S04 - Community disaster risk management planning S11 - National forecasting policy & plan S09 - Inter-community flood coordination	14 countries including -Nepal, Bangladesh, Vietnam, Peru	Mixed – community priority, resources and feasibility

Complementing the SLF, Bene et al. define resilience as the ability of individuals, groups, or systems to effectively cope with and recover from stressors, which involves: (1) absorbing impacts, (2) adapting to change, and (3) transforming conditions to create a more stable and enabling environment (more detail in Fig. 1).

Using the definitions from the two frameworks, we systematically analyzed each intervention to determine its alignment with the 5Cs and the three resilience building capacities. This process involved developing a detailed coding system that categorized interventions based on the specific capitals they targeted and the resilience capacities they aimed to enhance. Coding was conducted through a meticulous review of the intervention descriptions similar to the deductive categorization method but using the conceptual definitions of the capitals and capacities. To address interventions that appeared to fit within multiple categories of capitals and capacities, we assigned it to the category that represented its primary or most significant impact. In cases of ambiguity, we prioritized the capital or capacity that was most explicitly emphasized in the intervention's description. Additionally, we documented all instances of multiple alignments, allowing for a nuanced understanding of the interventions' multifaceted contributions to resilience building.

2.2.3 Analysis of exploratory findings using Sankey diagrams

To visually represent and analyze the complex relationships between intervention categories, resilience capitals, and resilience capacities, we employed Sankey diagrams. Sankey diagrams are a type of flow diagram that illustrate the magnitude of flows between

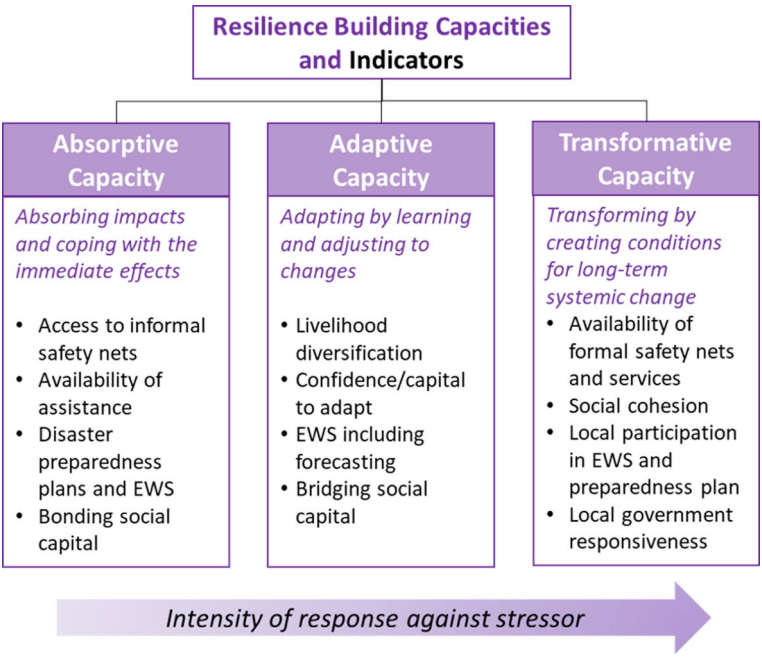

Fig. 1 Components of resilience capacity. (Adapted from Frankenberger et al. 2013; Bene, 2018.)

different sets of variables, with the width of the arrows proportional to the flow's magnitude. Sankey diagrams provide a visual overview of the distribution of interventions across different categories, which identifies what intervention types are most strongly associated with specific capitals or capacities. Second, the diagrams facilitated the exploration of the interconnectedness of the resilience building process, where targeting specific capitals contribute to different resilience capacities. For example, a Sankey diagram could reveal how interventions categorized as "infrastructure improvements" might primarily target physical capital but also contribute to social capital by fostering community participation in construction and maintenance. Analysis using the Sankey diagrams allows us to draw conclusions about which intervention categories are most correlated to strengthening specific resilience capacities and how the different forms of capitals contribute to these capacities.

While the original purpose of the intervention questionnaire was to identify and document "solutions" (knowledge products) based on their replicability and systemic impact, this study utilizes the data to test a more fundamental methodological hypothesis. We argue that broad activity categories (e.g., "training" or "infrastructure") are insufficient units for evaluating resilience, as they fail to capture the diversity of actual outcomes. Consequently, our methodology uses the questionnaire data to generate evidence for a more appropriate aggregated unit of evaluation, one that is defined not by the activity itself, but by the functional linkage between resource stocks (capitals) and resilience processes (capacities). Because resilience outcomes are non-prescribed and context-dependent, this linkage-based unit allows us to map the diverse pathways through which a single intervention can build multiple forms of resilience. The Sankey diagrams, therefore, act as the primary analytical tool for identifying these emergent patterns and validating the linkage as the core unit for capturing systemic resilience outcomes.

2.3 Methodological scope and limitations

It is important to acknowledge the limitations inherent in this dataset. As the data relies on self-reported information from program managers, potential reporting biases may exist. While a standardized survey instrument was employed to mitigate these biases, variations in interpretation and reporting practices across different NGOs should be noted. Furthermore, the data primarily reflects program managers' perspectives and may not fully capture the complex dynamics of community-level resilience building. Notably, this dataset does not constitute a formal Monitoring and Evaluation (M&E) framework or a longitudinal impact assessment. The survey was designed as a cross-sectional inventory to identify best practices and lessons-learned by collecting information on their strategic characteristics rather than to measure long-term resilience outcomes over time. Consequently, the analysis focuses on the alignment and strategic intent and design of the interventions rather than substantiating their lasting efficacy in the field.

It should be mentioned that the nature of our data, primarily qualitative and categorical, precluded the use of advanced statistical methods (e.g. cluster analysis). Instead, our approach allowed us to explore the nuances of each intervention and its impact on community resilience. In the next section, we first present and describe our categorization of intervention, which serves as our basis for further integrated analysis and visualizations.

3 Results

3.1 Overview of implemented interventions

The interventions implemented within the ZFRA show significant diversity in geographical distribution (Fig. 2), decision-making criteria, costs and resources required for implementation based on the survey responses (Appendix B1). For the purposes of this study, we focus mainly on descriptive evidence of what was implemented (survey questions 1 and 9) and what aspects of resilience were targeted (survey questions 6 and 8).

As shown in Fig. 3, these interventions were implemented across multiple levels of social organization from individual households, women's associations, school districts to community and higher-level/local government institutions. Notably, most of the documented interventions (95% of those specifying implementation level) were executed at the household and sub-community level. The implementation durations varied considerably across these levels. Specifically, household-level interventions were typically completed within a maximum of 10 months, with a substantial proportion concluding within 6 months. Conversely, community-level interventions displayed a wider range of durations: 40% were completed within 6 months, 25% within 6 to 12 months, and 35% required more than a year, extending up to three years. Blank cells indicates that there are no interventions with the implementation time and for the level, while the "Null" row shows the number of interventions with inadequate information regarding their implementation time.

Further analysis of the main decision-making factors (Table 1) shows that intervention selection was not uniform but operated under a principle of co-agency. Nearly half of all interventions (49.5%) were driven by community priority, while a substantial portion (43%) were guided by external resources and support (NGO technical expertise or programmatic requirements). The categories primarily focused on longer-term assets (Infrastructure and Asset diversification) were driven by community priority. Conversely, the categories

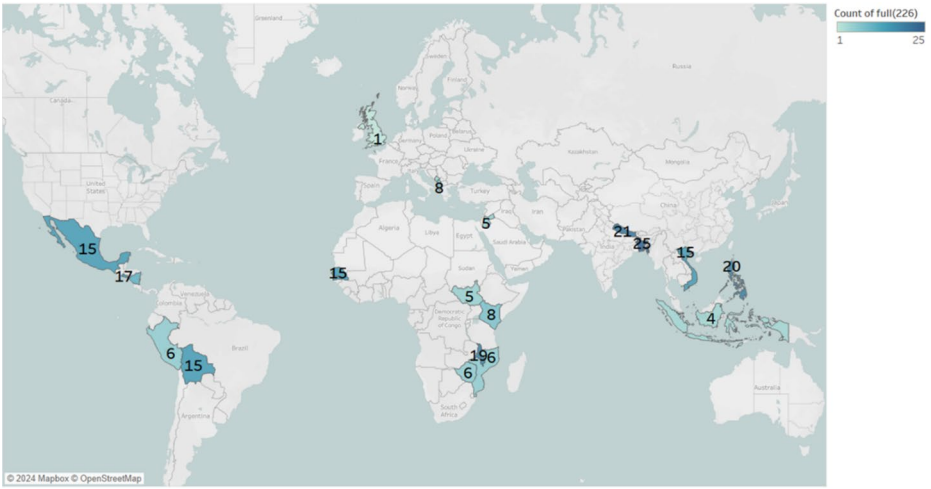

Fig. 2 Count of unique interventions recorded across countries

Fig. 3 Count of interventions across social organization levels and implementation time

Time (months)	Household	Community	Multi-, Higher-
1	6	29	1
2	2	11	
3	3	17	1
4	2	10	
5		1	
6	2	27	3
7		2	
8		2	
9		2	
10	2	3	
11		2	
12		37	2
18		8	
24		4	
36		3	
Null	9	32	3

focused on soft capacity (Education, Community organizing, Planning) were typically driven by external support. This finding explains the selection process, where communities prioritized tangible needs (infrastructure, finance, safety systems), while implementing partners enabled systematic capacity building (training, planning, knowledge transfer) and more complex interventions (EWS and NBS) considered multiple factors.

3.2 Emergent categories of disaster resilience-building interventions

The intervention data revealed seven distinct emergent categories, each representing a unique approach to enhancing community flood resilience. Firstly, "Infrastructure and Physical Improvements" encompass tangible, on-the-ground actions aimed at creating safer and more resilient living environments. These interventions, ranging from elevating infrastructure to installing sanitation facilities, focus on reducing physical vulnerability. Secondly, "Community Engagement and Knowledge Building" interventions emphasize empowering communities through training, education, and direct involvement in resilience-building activities, fostering a culture of learning and informed decision-making. "Community Flood Resilience Planning" interventions focus on developing community-led action plans to enhance preparedness and response capacities. Fourthly, "Community Organizing" facilitates dedicated groups to strengthen local capacities for flood response and community empowerment. "Nature-Based Solutions" utilize natural systems to reduce flood risk and enhance ecological resilience, promoting biodiversity and community engagement. "Asset Protection and Diversification" interventions strengthen livelihood resilience through training and institution-building around climate-smart practices and financial mechanisms. Finally, "Early Warning Systems" focus on improving the timeliness, accuracy, and accessibility of flood warnings through technology, communication, and community engagement.

These emergent categories reflect a diverse range of strategies, each contributing to a multifaceted approach to community flood resilience (see Table 1, columns "sources of resilience targeted") and discussed in more detail in Appendix C1. We find that interventions simultaneously address multiple dimensions across resilience capitals and capacities. For example, "Infrastructure and Physical Improvements" interventions, while primarily targeting physical capital by enhancing community infrastructure, also contribute to social

capital by improving access to essential services and fostering community involvement in construction and maintenance. “Community Engagement and Knowledge Building” interventions, while focused on human capital development through training and campaigns, also strengthen social capital by fostering community ownership and collaboration. “Community Flood Resilience Planning” interventions, encompassing assessments and action plans, enhance both human and social capital by building preparedness and response capacity through community-led processes. “Community organizing”, through local groups for disaster management and advocacy strengthen social capital with collective action and empowerment. “Nature-Based Solutions”, while primarily impacting natural capital by leveraging ecological resources, also contribute to human and social capital through community engagement and the preservation of traditional knowledge. “Asset Protection and Diversification” interventions, focusing on financial capital, also build human capital through training in climate-smart agriculture and financial management. Finally, “Early Warning Systems”, while directly addressing vulnerability to hazards, also strengthen human and social capital by improving access to information and fostering community participation in monitoring and response.

To assess the robustness of the emergent intervention categories, we examined their correlation with the implementing organizations responsible for each intervention. A clear alignment between organizational expertise and intervention selection was evident, as illustrated in the spider chart (Fig. 4). The chart reveals distinct distributions and foci of intervention categories across different implementing organizations, represented by varying colors. The solid lines in the chart indicate the number of interventions within each category implemented by each organization, while the dotted lines serve as axes indicating the total number of interventions. The distribution of the solid lines demonstrates that most implementing organizations (NGO 1–5) concentrated their efforts on specific intervention

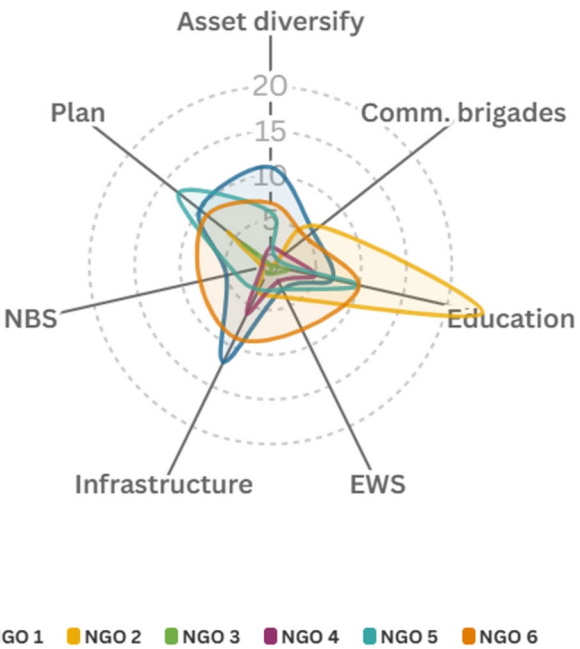

Fig. 4 Type of interventions implemented by implementing partner organization (NGO)

types, suggesting that the emergent categories effectively reflect the established practices and operational focus of these organizations.

For example, NGO 1 targets the most-vulnerable and supports direct assistance with immediate outcomes through physical and economic asset development (climate smart agriculture, infrastructure-based flood risk reduction measures). NGO 2 enables existing networks and community structures to act so their programming has a natural focus on education and community organizing and facilitating disaster response groups. NGO 5 focuses on the development and inclusion of children and women and thus has programming that center around education, planning and inclusive/accessible financing. NGO 6 spearheads innovative solutions to tackle poverty and climate change, which is reflected in their ration of nature-based solutions and early warning tool development. The differentiated likelihood of certain types of interventions implemented by different NGO's and their focus is intuitive and indicates the importance and evidence of feasibility.

Further insight into the specific intervention sub-categories implemented by each NGO is provided in Fig. 5. This figure reveals how implementing organizations leverage their specialized expertise and focus within and across broader intervention categories. For instance, while both NGO 1 and NGO 5 implemented asset diversification interventions, NGO 1 concentrated on climate-smart agriculture, whereas NGO 5 focused exclusively on

Fig. 5 Detailed sub-types of interventions implemented by implementing partner organization (NGO)

finance-related initiatives. Similarly, nuanced differences emerged in the implementation of early warning systems (EWS) and community organizing. Most NGOs emphasized the participatory aspects of EWS, while NGO 6 prioritized the development of technical tools. In the case of community organizing, the distribution of general committees and response groups varied; while most NGOs maintained a relatively balanced approach, NGO 1 leaned towards committees and NGO 2 towards response groups. Notably, education and planning interventions exhibited a consistent sub-category breakdown across organizations, potentially reflecting the ZFRA's emphasis on promoting active knowledge, such as training and planning, over passive information dissemination through campaigns and assessments. It is crucial to acknowledge that these observations, derived from correlational patterns, require further substantiation with direct evidence. The analysis does not establish causality or quantify measured differences.

As supplementary insights to the intervention patterns observed in Figs. 4 and 5, we summarize several critical factors affecting the feasibility and effectiveness of resilience-building interventions that have been highlighted from published 'solutions' knowledge products, especially from a few selected cases (see Appendix D1). Firstly, financial constraints posed a significant barrier to the implementation of complex physical interventions, emphasizing the need for increased funding. Secondly, enhanced community engagement was deemed essential for identifying locally appropriate interventions. Thirdly, limitations in small-scale infrastructure protection necessitated improved collaboration and coordination with government agencies to address institutional gaps and prioritize proactive resilience building. These insights underscore that while interventions are executed at the household and community level, their feasibility is inherently multi-scalar, contingent upon an enabling national environment that must bridge the gap between local initiative and institutional resource allocation.

The 'solutions' review team, comprised of representatives from each ZFRA implementing organization, acknowledged the challenge of limited data and evidence to support the effectiveness of certain interventions, highlighting the need for robust monitoring and evaluation frameworks. Additionally, there was a consensus on the importance of addressing the underlying drivers of vulnerability rather than solely focusing on immediate needs, advocating for long-term, systemic approaches to resilience. Consequently, the lack of an evaluative method capable of capturing the non-linear progress of resilience building remains a significant operational gap. The following exploratory analysis addresses this gap by redefining the analytical unit of interventions, moving beyond simple activity counts to a system of aggregation based on strategic outcomes. By linking intervention types to their respective resource stocks (capitals) and resilience processes (capacities), this framework provides a mechanism to map local household-level actions to the broader, multi-scalar indicators used to measure long-term resilience progress.

3.3 Exploring and visualizing interventions and resilience dimensions linkages

In the previous section we identified different intervention categories based on deductive analysis of community-based resilience building intervention implemented by the ZFRA communities. Using Sankey diagrams, a visualization method that assists explore the connections and relationship between variables of interest, we relate our intervention categories to the five capitals from the Sustainable Livelihood Framework (DFID, 1999) and to the

resilience-building capacities – adaptive, absorptive and transformative capacities (Bene and Doyen 2018). Amongst the 225 discrete interventions, roughly 25% are education related interventions, followed by planning related interventions (approximately 20%) and infrastructure related interventions (15%). The remaining 40% of the interventions are composed of asset diversity, community organizing, early warning systems, and nature-based solutions (all make up for roughly 10% of total interventions). The proportion of which capitals and capacities the interventions target is less evenly spread out – about a third of all interventions target human capital, while financial, physical and social capital are targeted by roughly 20% of interventions. Meanwhile, more than half of the interventions are classified as adaptive capacity building interventions, more than 40% are absorptive capacity building and less the 5% have transformative capacity building characteristics.

Figure 6 illustrates the complex interplay of interventions and their targeted type of capital (e.g. financial, human, social) and type of resilience capacity across and within the intervention categories and vice versa. The varying widths of the flows represent the relative influence or correlation to sub-types of each variable of interest. The diagram reveals that financial capital is significantly correlated to adaptive capacity (approximately 90% of financial capital related interventions) suggesting that financial resources are not merely a safety net for coping (absorptive capacity), but as a primary engine for long-term flexibility and mobilization. In contrast, human capital acts as a foundational "bridging" capacity, split between immediate survival skills (absorptive capacity) and the cognitive flexibility required for future adjustment (adaptive capacity). Meanwhile physical capital plays a dominant role in fostering adaptive capacity (approximately 80%) followed by social capital, which is correlated to other capacities equally. While Natural capital shows a unique path

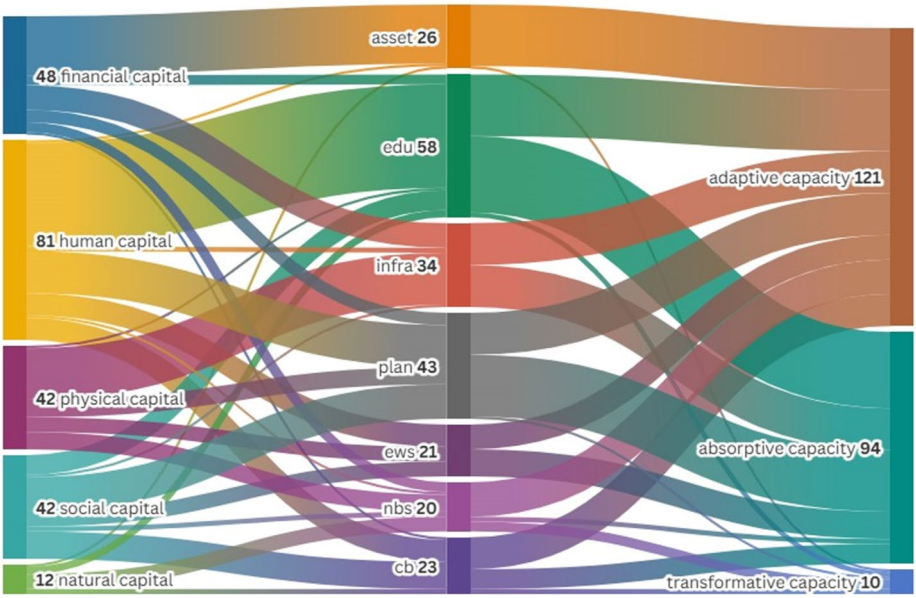

Fig. 6 Sankey diagram showing the proportion of different types of interventions building different capitals and capacities

toward Transformation, its small sample size (10 interventions) suggests that systemic, ecosystem-based shifts remain underutilized, and it is difficult to draw significant conclusions relative to the other sub-types of capital and capacities.

Figure 7 shows the breakdown of interventions designed to enhance resilience by strengthening different capitals. Overall, one type of intervention is found to be mainly associated to building a capital in the following ways. The heavy reliance on education, training, and health-related interventions for human capital (52%) highlights a sector-wide belief that knowledge transfer is an effective entry point for resilience building. The more even distribution within social capital – strengthening community organization building (26%) and planning (33%) interventions, indicates that building collective agency requires a hybrid approach of both formal structure and participatory processes. Physical capital

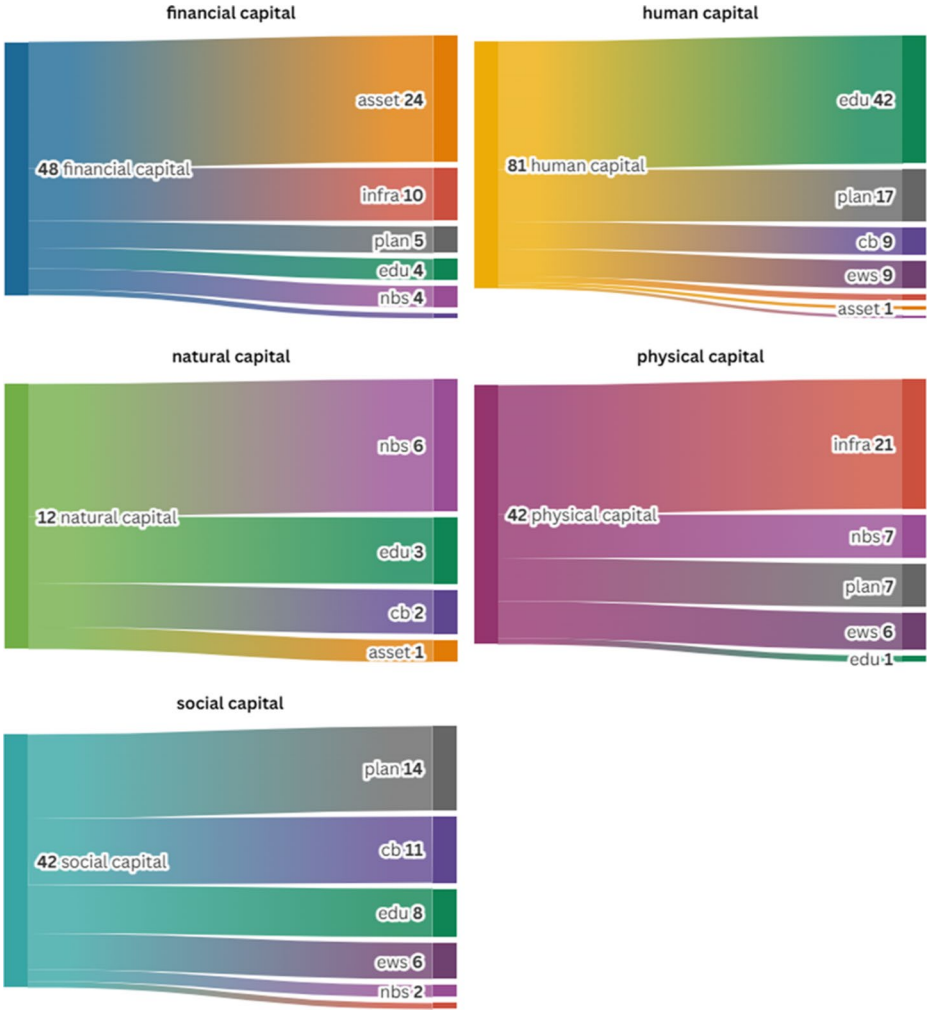

Fig. 7 Number of interventions categorized by types of capital they aim to strengthen for increased resilience

is targeted with infrastructure improvements and construction of shelters (50%), reflecting a priority on immediate protective capacity. However, the inclusion of nature-based solutions (16.7%) suggests an emerging shift toward hybrid infrastructure that combines physical protection with ecological sustainability. Similarly, the focus on financial capital was through livelihood diversification training, access to financial services, and support for income generation, which indicates a strategic intent to move beyond short-term relief toward long-term economic agency, enabling households to self-finance their recovery. Natural capital was least targeted (12 interventions) with the majority using nature-based solutions (50%), ecosystem restoration and sustainable resource management education and community organization. Notably, the fact that Early Warning Systems (EWS) target all five capitals simultaneously marks them as a "multi-dividend" intervention (Hochrainer-Stigler et al. 2025). This suggests that EWS is no longer viewed as a simple technical tool for safety, but as a sophisticated platform that protects physical assets, reinforces social trust, and preserves financial stability.

Figure 8 demonstrates that the distinction between capacities is not necessarily about the type of intervention, but the temporal and strategic depth of its application. While the 94 interventions that target absorptive capacity aim to help communities cope with immediate flood impacts and protect their basic needs, the 121 interventions targeting adaptive capacity represent a shift toward future-proofing – fostering learning, flexibility, and the ability to adjust to changing flood risks. The critical interpretive insight here is that the same activity (e.g., infrastructure) can target different capacities, it is "absorptive" when it protects a home today, but "adaptive" when it is designed to be adjustable to the uncertainties of shifting

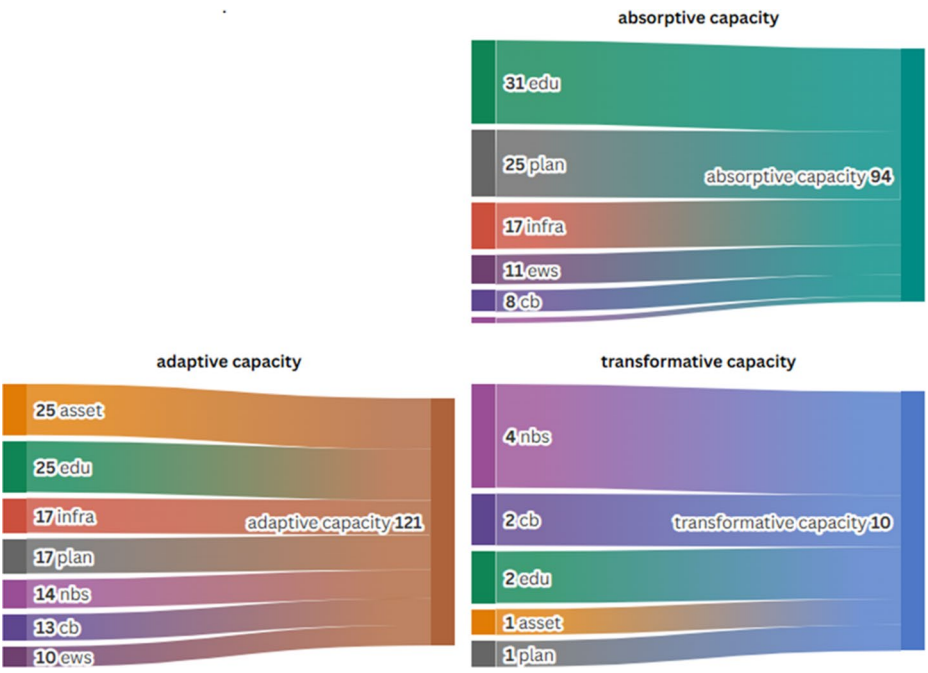

Fig. 8 Types of interventions contributing to different types of resilience capacities

climate patterns tomorrow. This proves that the resilience value of an intervention is not inherent in the activity itself, but in the capacity-linkage intended in the implementation.

Transformative capacity is the most challenging to achieve as it requires fundamental shifts in behaviors, governance, social structures along with longer-term visions. From the 10 ZFRA interventions, we find examples of transformative capacity building interventions to be, advocacy and stakeholder engagement - working with authorities and institutions to influence policies and create an enabling environment for long-term resilience; community knowledge building - empowering communities to advocate for their needs and participate in decision-making processes that affect their resilience; nature-based solutions can contribute to transforming the relationship between communities and their environment, leading to more sustainable practices. To illustrate how nature-based solutions enable transformation capacity building we quote a reflection from the interventions review team, a practitioner from an implementing organization, "the work we are doing with nature-based solutions people are excited and saying that they can protect their communities based on the restorative functions of nature and management from the community based on local knowledge." Iterative bottom-up, community-led initiatives and changes drive the paradigm shifts and investment towards transformative capacity building.

4 Discussion and conclusion

The core insight of this study is that resilience building cannot be understood through isolated activity types, but through the functional linkages between intervention categories, the resource stocks (capitals) they build, and the specific capacities (absorptive, adaptive, or transformative) they activate. This categorization, based on a dataset of unprescribed, community-based, implemented interventions around the world, reflects on-the-ground realities of resilience building. By relating these categories to existing conceptual frameworks and indicators of resilience, the analysis reveals the complexity and multi-faceted nature of interventions and implicates the challenges to systematically tracking, monitoring, and evaluating community-based interventions. The seven emergent intervention categories (*Infrastructure and physical improvements*, *Community engagement and knowledge building*, *Community flood resilience planning*, *Community organizing (brigades and committees)*, *Nature based Solutions*, *Asset protection and diversification*, *and Early Warning Systems*) identified in this study are characterized by a strong emphasis on participatory and co-owned approaches, reflecting the necessity of responding directly to community needs within resource-constrained, rural settings.

Unlike the often top-down, service-oriented strategies prevalent in urban and developed-country contexts (Biagini et al. 2014; Jenkins et al. 2022), these interventions prioritize bottom-up engagement, empowering communities to take ownership of resilience-building efforts (Grady et al. 2016; Rözer et al. 2023). This is evident across all the categories of ZFRA interventions, which ensure that interventions are tailored to local knowledge and build long-term capacity. Notably, resilience-oriented interventions often promote this locally led approach, contrasting with adaptation and risk management strategies that frequently adopt a technical assessment followed by a prescribed action model (Fisher et al. 2015; Šakić Trogrlić et al. 2017). Our analysis also reveals that this local ownership does not exist in isolation; its success is predicated on functional interdependencies with higher-

level governance. For example, while EWS and evacuation planning are executed locally, their efficacy is contingent upon integration into provincial disaster management or national hydrometeorological data frameworks (refer to the case studies summarized in Appendix D1). While the co-ownership model fosters a sense of responsibility and enhances the sustainability of resilience initiatives, it is crucial to acknowledge the inherent limitations of locally led interventions when confronted with the escalating intensity and frequency of climate change-induced events (Nalau and Verrall 2021). Risks that surpass the capacity of community-level action highlight the need for complementary national and sub-national strategies. This raises critical questions about the limits of adaptation within a framework primarily focused on local ownership, prompting a broader discussion on the necessary balance between community-driven resilience and higher-level interventions to address the increasing challenges posed by climate change (Scolobig et al. 2015).

This nuanced understanding of interventions beyond their labeled characteristics can enhance the design and implementation of interventions, ensuring they effectively target specific capitals and contribute to the desired resilience capacities. Specifically, the Sustainable Livelihoods Framework and resilience capacities (absorptive, adaptive and transformative) was applied to compare our seven emergent categories of interventions to find that not one category could be generalized to indicate that a type of intervention (i.e. infrastructure or hygiene education campaign) will align or target a certain indicator of resilience (i.e. capitals and capacities). This finding strengthens the argument for localized, context-specific strategies driven by community-led decision-making (Šakić Trogrlić et al. 2022). Such an approach is essential for ensuring appropriate intervention design, fostering community ownership and agency in operations, and facilitating effective monitoring, evaluation, and learning. It highlights the limitations of a 'one-size-fits-all' approach including universally prescribed interventions (Oliver-Smith 2016; Nightingale et al. 2019).

Furthermore, we address the practical limitations and complexities to development assistance for locally led actions, noting the potential bias and reliance on the NGOs expertise, as evidenced from the concentration of certain intervention categories in Fig. 4. This concentration has duality, in that it allows NGOs to apply their expertise to communities and countries with specific needs, but also risks introducing biases in intervention selection (Brass et al. 2018; Ghafran and Yasmin 2025). By examining these differences across NGOs' selected intervention categories and interests in certain resilience indicators, we can uncover biases and potentially refocus interventions to community needs (identified by baseline resilience assessments, such as the FRMC) and strategies (target resilience capital and capacities). Additionally, our assessment of interventions and their co-benefits across different capitals and capacities, allows implementing organizations and local stakeholders to be critical with the design, selection and upkeep of resilience-building initiatives. In other words, the same category of interventions leads to vastly different resilience capital and capacity building.

Our findings highlight the cross-cutting role of various capitals and capacities in building different dimensions of resilience. Financial and human capital emerges as a significant contributor to adaptive capacity, suggesting that interventions enhancing financial and human capital are often accompanied by increases in adaptive capabilities. While we cannot infer direct causality, the strong association underscores the importance of human and financial capital development. Conversely, physical capital proves vital for absorptive capacity, aligning with the idea that tangible and protective measures are crucial for absorbing shocks. However, transformative capacity is contingent upon specific, context-dependent

enabling environments, as it needs systemic changes through investments in governance, infrastructure, and robust social protection mechanisms (Eriksen et al. 2015). Financial capital exhibits a strong correlation with adaptive capacity, with a substantial portion of financial capital-related interventions also fostering adaptation. Social and human capital further demonstrates its versatility, playing a significant role in both adaptive and absorptive capacities. Finally, natural capital, intrinsically linked to nature-based solutions, shows a potential connection to transformative capacity. However, the limited sample size of interventions targeting natural capital prevents us from drawing definitive conclusions compared to other forms of capital. Further research with larger datasets is needed to fully understand the intricate relationship between capital dimensions of resilience and transformative capacity.

This study, focused on a specific set of interventions within the ZFRA, underscores that the generalizability of resilience interventions is limited by the heterogeneity of these governance contexts. Furthermore, our analysis primarily examined the implementation phase, offering less insight into the crucial design and selection processes that precede it. While we underscored the importance of robust community engagement and context-specific interventions, a more in-depth exploration of the methodologies and challenges involved in achieving these goals is warranted. Exploring the scalability and replicability of successful interventions across varying contexts is also essential for informing future climate adaptation strategies. Our analysis of the implementation phase suggests that the next frontier for resilience evaluation is not merely monitoring activity counts but tracking the maturity of the interdependencies between local agency and sub-national support structures. Only by substantiating these long-term, multi-scalar linkages can we determine if an intervention has truly contributed to sustained transformative change or simply provided a temporary buffer against immediate shocks.

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Declarations

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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