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Co-production of knowledge for effective flood risk management

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Abstract. Flood risks (FR) represent one of the most pressing global challenges, exacerbated by factors such as climate change, urbanization, and land use changes. Effective flood risk management (FRM) faces significant challenges, including the need for robust decision-making, the need to address existing risks, and the need to implement strategies across the disaster risk reduction (DRR) cycle. Transdisciplinary research (TD) research is expected to address complex problems by enabling processes of mutual learning in which knowledge is co-produced between science and society, integrating various knowledge claims to solve societal or real-world problems. This study makes use of TD concepts and methods and specifies them for flood risk research. It connects three conceptual perspectives: First, we identify flood-risk-specific characteristics and their implications for the design of TD research, tools, and methods. Second, we adapt the framework for impact generation in TD research (Schneider et al., 2019) by focussing on a set of generic mechanisms (i.e., knowledge production, social learning, and competence building). And third, we consider these mechanisms for generating impact as embedded in mediating processes along the flood risk research (i.e., developing joint research questions and design, building trust and creating ownership, and the institutional anchoring of results). These conceptual perspectives are used for analysing and reflecting empirical experiences from the PARADeS project in Ghana, a project that aimed for participatory flood risk reduction.

The study produces in-depth insights in a transdisciplinary flood risk research project and offers conceptually and empirically grounded applications of flood-risk specific transdisciplinary methods and tools. In doing so, the study demonstrates that flood risk research requires collaborative, adaptive, and context-sensitive approaches, employing purposefully a range of methods and tools capable of integrating multiple forms of knowledge and supporting interaction across disciplines, institutions, and various stakeholder groups.

The findings underline that effective flood risk management cannot rely solely on technical expertise or isolated scientific outputs. Rather, it requires reflexive and participatory processes that explicitly engage with questions of power, governance, vulnerability, and epistemic diversity. Further, the study shows that particularly in North–South collaborations, equitable partnerships and sensitivity to local contexts are crucial for generating socially robust and actionable knowledge. Finally, the study concludes that the transformative potential of flood risk research lies not only in producing better knowledge about floods, but in fostering inclusive processes of co-learning, shared ownership, and long-term institutional engagement.

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1 Introduction

Flood risks are among the most serious of all risks, and severe flooding events are increasing worldwide due to many interlinked factors, among them climate change-induced changes in precipitation patterns, changes in land use and vegetation cover, soil degradation, and an increase in urbanisation processes (Tabari, 2020; IPCC, 2023). At the same time, flood risk management (FRM) faces three significant challenges: first, the need for a sound knowledge base on which to build robust decisions for disaster risk reduction (DRR) along the DRR cycle (i.e., mitigation, prevention, emergency response, and recovery) (Alexander, 2020); second, the development of strategies and measures as well as robust decisions that address both existing risks and consider inherent uncertainties of knowledge (Mens et al., 2011); and third, the implementation of DRR and flood management strategies and action plans within the different phases of the DRR cycle (Rötzer et al., 2023).

Accordingly, research on FRM and DRR needs to consider these challenges, as in other fields of socio-environmental problems and sustainability transformation, where research is expected to produce a sound knowledge base and support the development of robust decisions and implementation of strategies and action plans. Transdisciplinary (TD) research, specifically the co-production of knowledge, is often considered to help overcome, or at least tackle, these challenges (Lane et al., 2011; Krueger et al., 2016).

Transdisciplinarity is regarded a research approach that involves inter-scientific cooperation between various disciplines and cooperation between science and society, including practitioners and non-scientific actors in the research project (Jahn et al., 2012). In doing so, TD research is expected to address complex societal problems by enabling processes of mutual learning in which knowledge is co-produced between science and society, integrating various knowledge claims to solve societal or real-world problems (Jahn et al., 2012; Lang et al., 2012; Norström et al., 2020; Schroeder, 2022). As co-production of knowledge, we understand the "iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future" as Parviainen et al. (2024, p. 183) suggested. As Klein (2008) notes, the transformative capacity of transdisciplinarity depends on embracing uncertainty, values, and lived experience. Without authentic co-production, solutions may be scientifically robust yet socially disconnected or culturally inadequate. Therefore, the assessment, measurement, modelling, and governance of risks necessitates transdisciplinarity, stakeholder engagement, and knowledge co-production, combining information across sectors, disciplines, and scales toward improved understanding of their interrelatedness and the dynamics between, inter alia, socio-economic and environmental processes, and the uncertainties associated with these (Parviainen et al., 2025).

A review by Carvalho Silva et al. (2026) reveals that, although transdisciplinary research is now widely recognized in scientific and policy agendas of water management, it does not automatically lead to adaptive strategies and implementation or generates impacts. In the broader field of sustainability transformation, researchers have identified key mechanisms in TD research that are aimed at generating impact (Schneider et al., 2019). Schneider et al. (2019) suggest – based on a meta-study of 31 case studies from TD projects – three generic mechanisms they deduced for impact generation are (a) promoting systems, target, and transformation knowledge for more informed and equitable decision-making, (b) fostering social learning for collective action, and (c) enhancing competencies for reflective leadership. In our study, we adapt this framework for reflecting on impact generation in transdisciplinary flood risk research (FRR).

In the following chapter, we first develop a set of characteristics for FRR and related transdisciplinary methods in order to delineate how TD FRR can be designed in a way that correspond to those characteristics. Second, we introduce and adapt the proposed mechanism for generating impact through TD research by introducing a set of mediators that enable or facilitate these mechanisms to general impact. Together, these three components – characteristics of FRR, mechanisms and mediators for impact generation – create our conceptual perspective that we illustrate and reflect based on our experience in a North–South collaborative project on flood risk management in Ghana.

2 Conceptual considerations for designing transdisciplinary flood risk research

2.1 Linking characteristics of flood risk research and transdisciplinary methods

Flood risk research needs to respond to a set of inherent characteristics. Every flood event relates to specific factors at different spatio-temporal scales that influence the generation of floods, the exposure of the site to hazard, and the vulnerability of the society – together resulting in the actual flood risk. One of several challenges of TD research is the integration of methods (Brandt et al., 2013). Frölich et al. (2026) highlight the need in sustainability research in general for a context-related design for successful TD research. They developed a concept where spatial and temporal dimensions and the different TD phases are shaping the methods being applied. Another approach is to structure the research design along specific challenges of the research field as the TD Handbook is structuring the methods either along phases or along challenges (Swiss Academy of Natural Sciences, 2026). In the following, we argue that in FRR suitable methods and tools for TD knowledge co-production can be identified based on specific inherent FR characteristics.

We start with a description of these characteristics and their implications for TD research design and methods. Details are also summarised in Table 1.

2.1.1 Complexity and interdependencies

Flood risk is not caused by a single factor but a product of interacting physical and societal elements. We define a hazard as the potential for a specific event to occur. Risk implies that a hazardous event could have negative effects such as damage or fatalities (Cardona et al., 2012). To be effective, risk management needs to be based on a sound understanding of the controlling risk drivers (Kreibich et al., 2022). Parviainen et al. (2024) state that understanding the complex and systemic nature of multi-scalar climate and disaster risks is crucial to risk reduction.

We see FR as a system whose components interact and depend on multiple drivers, leading to non-linearity and randomness. It emerges through complex relationships involving climate change, urbanisation, population growth, land use, vulnerability, infrastructure, and human behaviour which requires a holistic systems approach that recognises the interconnections between environmental processes, social vulnerability, economic conditions, institutions, and human decision-making (Awah et al., 2024). The complexity of flood risk problems calls for broad and cross-cutting interdisciplinary expertise. Thus, flood risk assessments require collaboration among different disciplines to understand and model the underlying components of hazard, exposure, and vulnerability (Sieg et al., 2023; Fuchs et al., 2024).

Di Baldassarre et al. (2018) highlight that a focus on just one aspect of flood risk can cause a systematic bias in the selection or prioritization of alternative strategies for flood risk reduction, and that we can draw from new approaches that have been developed for the study of socio-nature interactions in various interdisciplinary fields. Hence, a diversity of disciplines needs to be involved in TD FRR (e.g., hydrology, engineering, land use planning, policy studies, sociology, anthropology, economy, law, and others). However, this interdisciplinary research alone is not sufficient, since the expertise of the respective local and regional stakeholders through the inclusion of local knowledge is needed to address the full range of complexities. Academic and non-academic knowledge, including local and experiential insights are important to co-develop solutions (Lattanzio et al., 2021). A shift from linear problem-solving to reflective and collaborative practise is essential (Cavalho Silva et al., 2026).

Maskrey et al. (2021) state that participatory modelling can bridge the gap between scientific expertise and local knowledge, helping to produce decisions that are technically credible, locally relevant and more inclusive. Participatory or collaborative modelling with stakeholders could address this complexity and enable the development of scenarios and understanding of possible developments ("futures") before developing and implementing adaptation strategies and measures (Jonoski and Evers, 2013). Evers et al. (2016) and Almoradie et al. (2023) found, based on case studies in London, Hamburg, and Togo/Benin, that collaborative modelling is supportive in social learning processes. Modelling different flood risk-related situations and scenarios is often used as a tool, yet it is so complex that scientific experts from other disciplines, as well as practitioners, decision-makers, and citizens often view it as a black box (Almoradie et al., 2023; Evers et al., 2016). Therefore, it is central before starting with the collaborative or participatory modelling process to develop a shared understanding of the system or problem under investigation. Models are inherently simplifications of complex systems and are shaped by underlying assumptions and methodological choices. Maskrey et al. (2021) call this stage before the actual modelling process "problem scoping". Participatory system conceptualisation, for example through the development of causal loop diagrams as a preliminary step to system dynamic modelling, can help make these assumptions explicit, integrate diverse perspectives on system components and their interrelationships, and establish a more robust conceptual foundation for subsequent modelling approaches.

Maskrey et al. (2021) suggest criteria such as accessible, transparent, adaptable, evaluative and holistic for participatory modelling to overcome the "black box problem". They evaluated Bayesian Networks, System Dynamics and Fuzzy Cognitive Mapping against these qualities showing that each technique has potential but also limitations and that participatory modelling technique should be determined by the specific local context and decision-making objectives.

2.1.2 Multi-scalar spatiality

The genesis of a flood event depends on various spatial factors on different scales, such as the shape of the catchment, precipitation pattern, and structure of land use and land cover (Bronstert et al., 2003; Kundzewicz et al., 2014). Furthermore, interactions among adjacent sub-catchments, as well as upstream and downstream dynamics, determine whether the incident becomes a disaster. Moreover, cascading effects across scales must be considered (Parviainen et al., 2024).

In contrast to the natural spatial boundary conditions in the formation of floods, the management of flood risk is mostly organised at the administrative level (Evers and Nyberg, 2013). The way in which the different administrative levels interact depends on the administrative and governance structure of the respective national or transboundary governance system. Accordingly, the different spatial scales relevant to flood risk research require a multi-layered and interlinked system of spatial levels and boundaries. This implies that a TD approach needs to be spatially sensitive, particularly regarding the representation of involved actors. Interactive identification of flood-exposed areas or hotspots by participatory mapping is a valid tool for integrating local knowledge and expertise about hazards such as areas where floods

Table 1. Flood-risk-specific characteristics, implications for transdisciplinary knowledge co-production and examples for methods.

Characteristic	Characteristic specifically in flood risk research	Implications for TD knowledge co-production	Examples for methods in TD FRR
Complexity and interdependencies	Flood risk emerges from interactions between hazard, exposure and vulnerability, including hydrological processes, land use, infrastructure, settlement patterns, institutional responsibilities and individual/collective responses. Interventions can generate feedbacks and unintended consequences across these domains.	Requires integration of hydrological, technical, social, institutional and experiential knowledge and the joint development of a shared understanding of system relationships.	Stakeholder analysis, Surveys, Questionnaires, institutional/network analysis, system mapping, causal-loop diagrams, participatory modelling, bayesian networks, system dynamics and fuzzy cognitive mapping, network analysis
Multi-scalar spatiality	Flood processes and their consequences cross hydrological and administrative boundaries. For example, upstream land use and retention can affect downstream communities, while responsibilities for land-use planning, emergency management and water management are distributed across administrative levels.	Requires representation of actors and knowledge from relevant hydrological, territorial and administrative scales and explicit negotiation of cross-scale relationships and responsibilities.	Participatory GIS, multi-level stakeholder mapping, scenario development, participatory mapping
Multi-temporal dynamics	Flood risk develops through interactions between short-term events (e.g. warning and emergency response), medium-term processes (e.g. recovery and adaptation) and long-term changes in climate, land use, exposure and vulnerability. Decisions must therefore be made under uncertainty and may create path dependencies.	Requires methods that allow actors to jointly explore alternative futures, feedbacks, uncertainty, adaptation pathways and consequences over different time horizons.	Participatory scenario development, visioning/back casting, adaptation pathways, exploratory modelling, (quantitative) system dynamics modelling
Situatedness and contextual vulnerability	Flood impacts and vulnerability differ according to local physical conditions, settlement structures, socio-economic characteristics, institutional arrangements, historical experiences, risk perceptions and capacities to act. The same hazard may therefore generate different risks and adaptation options in different places.	Requires contextual and experiential knowledge and joint definition of relevant risk, vulnerability and adaptation criteria. Methods should enable local actors to articulate values, experiences and priorities.	Participatory appraisal, interviews/focus groups, participatory mapping, local knowledge elicitation, workshops, participatory vulnerability assessment, MCDA
Uncertainty and incomplete knowledge	Flood risk assessments involve uncertainty in hazard projections, exposure and vulnerability data, model assumptions and future socio-economic developments. Local knowledge may complement but not necessarily reduce all uncertainties.	Requires transparent discussion of uncertainty, assumptions and knowledge gaps and opportunities for different knowledge holders to challenge and refine model assumptions.	Participatory/collaborative modelling, scenario analysis, uncertainty elicitation, model co-development, sensitivity analysis, expert/stakeholder validation, co-evaluation, participatory monitoring, serious games, agent-based modelling, citizen science, bayesian networks, system dynamics and fuzzy cognitive mapping
Socio-technical character	Flood risk reduction depends on interactions between technical measures (e.g. dikes, retention, warning systems), spatial planning, institutional arrangements, behavioural responses and governance. Technical interventions can redistribute risk spatially or temporally.	Requires integration of technical and social knowledge and joint assessment of management options, including trade-offs, distributional effects and feasibility.	Participatory/collaborative modelling, options appraisal, multi-criteria assessment, serious games, scenario workshops, co-design of interventions, ranking of alternatives, citizen science, future visioning, story telling

often occur, severe damages were experienced or areas with hight vulnerability. It is also helpful for setting up the flood model by enhancing the data base and validating its outcomes comparing model results and stakeholders' experiences (Almoradie et al., 2023). This can be done either in an analogue or web-based format – depending on the context and aim of this activity as well as internet connectivity.

2.1.3 Multi-temporal dynamics

Different temporal scales and dynamics play an important role in reliable flood risk research. Specifically, for DRR, these relate to the phases before, during, and after the event. Di Baldassarre et al. (2018) explain that particular attention needs to be paid to assessments, which support long-term decisions. Scenario techniques, projections of possible future dynamics of flood-generation processes, including their uncertainties, are helpful in FRM (Kundzewicz et al., 2018).

Rapid development and the uncertainty with respect to future development require that future studies employ methods which address uncertainties of knowledge and values, e.g., participatory scenario development, back-casting, collaborative development of strategies (Höllermann et al., 2026; Kok and van Vliet, 2011; Quist and Vergragt, 2006; Heijden, 2005). Thus, it is essential to consider various and diverging temporal patterns, paces, and processes, which can be shaped as appropriately as possible in the composition of the TD research project group expertise.

In scenario development in FRR, there is a general need for advanced technical methods and tools for data collection (remote, on-site, real-time, historical timelines, etc.) and processing of data for hydrological and hydro-dynamic modelling, which include aspects of Land Use Land Cover Change (LULCC) or climate change effects. Furthermore, socio-economic data, qualitative ethnographic data, or data derived from empirical social science methods need to be integrated into socio-hydrological frameworks, models, and scenarios. We think that in this context quantitative scenarios using System Dynamics models (SDM) to simulate the temporal evolution of complex, feedback-driven systems are useful. Unlike static "what-if" analyses, quantitative scenarios in SDMs examine the interaction of stock variables, flow variables and feedback loops over time.

However, we suggest applying a TD and co-production approach to generate results from the latter methods and sources, as this goes a step further by connecting to co-design and social learning processes. This is supported by Jafarzadegan et al. (2023), who suggest enhancing our understanding of flood-generating mechanisms and recommend, inter alia, a coupling of hydroclimatic and hydrological perspectives. We think that, in addition to this, human influence should also be integrated into the coupling approach since the human factors have a reciprocal influence on the flood risk system (Evers et al., 2017). Höllermann et al. (2026) found that collaborative exploratory scenario development can encourage transformative thinking and enhance an adaptive approach to flood risk management beyond incremental adjustment. In order to analyse and visualise root causes and interconnections within the flood risk system, participatory qualitative system dynamic modelling with identifying causal loop diagrams is extremely beneficial to identify central elements and dependencies which can create a better understanding of the complexity by all stakeholders before quantitative modelling. Furthermore, the process itself can also be very useful for social learning (Höllermann et al., 2026). Accordingly, risk assessments require a clear understanding of the temporal dynamics or pathways to be explored. Risk assessment of flood events includes a consideration of hydrology, climate, weather, mid- and long-term climate change aspects, history and development of legal frameworks, societal and economic settings, and situations, the evolution and persistence of cultural and historical aspects should be considered.

2.1.4 Situatedness and contextual vulnerability

Flood risk and vulnerability are highly context-specific and situated in the specific historical, cultural, economic, and social setting of the respective situation and location. Thus, the situatedness of the respective flood risk research needs to be taken into account for co-creation of knowledge. Ziga-Abortta and Kruse (2023b) identified a broad set of factors explaining the institutional context of FRM in Ghana, including socio-cultural, socio-political, legislative-regulatory, and fiscal-economic drivers that can be used to characterise the specific situation of vulnerability to flood. In a case study in Brazil, de Brito et al. (2018) found that perceptions and assessment of vulnerability vary greatly depending on the stakeholders' perspectives, experiences, and professional backgrounds. For example, the evaluation of criteria such as gender, income, or technical flood protection varied depending on the stakeholder's perspective, thus influencing vulnerability and risk assessment. They applied a participatory multi criteria decision analysis (MCDA) approach to model and visualise the different perspectives. As a consequence, vulnerability criteria have to be adjusted and specified, resulting in a different flood risk characterisation related to the situatedness of the observed case (de Brito et al., 2018). The consequence for TD FRR projects is the need for a thorough stakeholder analysis, which entails identifying expertise, perspectives, roles, and power relationships to ensure the inclusion of diverse stakeholder views, knowledge, and co-production processes. Joint identification and prioritisation of criteria that address, e.g., social vulnerability, adaptive capacity, or institutional settings are important since these are situated in a specific socio-cultural, historical, political, and spatial context (Juhola and Kruse, 2015; de Brito et al., 2018).

2.1.5 Uncertainty and incomplete knowledge

FRM is characterized by a high degree of uncertainty. This uncertainty arises from hazard projections, exposure and vulnerability data, model assumptions, and future socio-economic developments. Idowu and Alfahid (2026) identify eight open problems in uncertainty quantification for flood modelling, including: long-term prediction errors, poor calibration of predictive intervals, incomplete representation of uncertainties, inadequate handling of spatial and temporal variability, non-linearity, data scarcity and integration issues, high computational costs, and failure to capture uncertainties in extreme events. Local knowledge can complement scientific assessments, but it cannot necessarily reduce all uncertainties. Therefore, transparent communication of uncertainties, assumptions, and knowledge gaps is essential. Involving different knowledge holders can also help to challenge and refine model assumptions. Approaches such as participatory or collaborative modelling, scenario analysis, uncertainty elicitation, sensitivity analysis, model co-development, expert and stakeholder validation, co-evaluation, and participatory monitoring can support this process.

The ever-present challenge of data availability, or data scarcity, can be addressed through citizen science, which can help to reduce data gaps where necessary. This approach is not limited to technical aspects; it also engages citizens in the project by enabling them to collect data themselves and thereby contribute to the project and process.

2.1.6 Socio-technical character

FR reduction depends on the interaction between technical measures, such as dikes, retention areas, and warning systems, and social and institutional factors, including spatial planning, governance, institutional arrangements, and behavioural responses. It requires the integration of technical and social knowledge and the joint assessment of different management options. This includes considering trade-offs, distributional effects, and the feasibility of potential measures.

The complexity of floods, including spatio-temporal scale challenges and the importance of situatedness, calls for socio-technical tools and methods for visualisation and communication of flooding with stakeholders, to, e.g., address the assessment of flood risk or adaptation capacity (Jonoski and Evers, 2013). Parviainen et al. (2024) identified tools with an iterative co-production process as a cornerstone of implementation of co-designed fit-for-purpose solutions, methods and approaches contributing toward strengthened risk governance alongside stakeholders. Joint identification and ranking of alternatives and criteria or indicators, especially for vulnerability criteria in order to include different views and values, can be materialised through multi-criteria decision analysis and tools such as Analytic Hierarchy Process (AHP) or Analytic Network Analysis (ANP) (de Brito et al., 2018). Participatory approaches such as collaborative modelling, options appraisal, multi-criteria assessment, serious games, scenario workshops, co-design of interventions, and the ranking of alternatives can support this process and help develop more balanced and context-sensitive risk reduction strategies.

Geo data, measured/in situ hydrological data, remote sensing, socio-economic data, and land use data play an important role, but also increase the complexity and potential uncertainty of the research results. Thus, trust in data, methodologies, and processing is core to TD methods in flood risk research, validation, and ground-truthing of data and models, as well as improving the database. This requires a transparent presentation and explanation of the data, the processes, and the models used, as well as the capabilities and limitations of the models and socio-technical tools (Maskrey et al., 2020). Otherwise, the usage of the socio-technical tool will not be accepted and thus not be helpful for the process (Jonoski and Evers, 2013; Evers, 2008). Pereira et al (2020), cited in Cavalho Silva et al. (2026) emphasized the importance of building empathy in the TD process and suggested tools such as participatory mapping or future visioning, or storytelling as tools.

Table 1 summarizes the derived implications for designing transdisciplinary co-production of knowledge to effectively address the characteristics of flood risk research. The selection should therefore be understood as a fit-for-purpose methods portfolio rather than a fixed list of methods for flood risk research. Method choice depends on the specific research question, actors involved, phase of the TD process, available knowledge and data, and institutional and spatial context. The PARADeS project (Sect. 3.2) serves as an empirical illustration of how such methods can be combined in practice, rather than as the primary basis for selecting the methods.

2.2 Mechanisms and mediators for impact generation by transdisciplinary research

The specific characteristics of FRR, as indicated, have implications for the design, implementation, and effects of TD tools and methods for co-creation of knowledge and thus for the generation of real-world impacts. As already shortly sketched, Schneider et al. (2019) studied 31 TD projects from Asia, Africa, Latin America, and from the global scale to uncover the mechanisms through which TD co-production of knowledge can foster sustainability transformations. They further propose these mechanisms to evaluate the effectiveness of different impact strategies. These identified generic mechanisms for impact generation form are another foundational component of the analytical perspective on transdisciplinary FRR. The generic mechanisms include (a) promoting systems, target, and transformation knowledge for more informed and equitable decision-making, (b) fostering social learning for collective action, and (c) enhancing competencies for reflective leadership. The authors combined the

three generic mechanisms with seven activating, recurrent strategies, such as access to information, advice, and training. The three mechanisms for impact generation can be seen as fundamental elements in which, through the involvement of different actor groups, new knowledge, shared understanding, and new competencies are co-produced and materialised in concrete activities or outcomes. Schneider et al. (2019) pointed out that their research provides evidence that the most promising pathways to impact are long-term, adaptive processes that combine elements of the three mechanisms of impact generation in parallel or over time. They conclude that the question is not which mechanisms or strategies are better than others, but in which situations and combinations they might be most effective.

We agree with the synthesis of Schneider et al. (2019) on impact generation mechanism, however, we think, that these mechanisms need enabling conditions and processes.

For our research, we add a third component to our analytical perspective: the mediators. Mediators are processes that enable the mechanisms to unfold and to create impact generation alongside the research process. The mediator creates the necessary conditions, structures, and environments in which impact creation is embedded. The first mediating process involves the joint formulation of research questions and research design. The nature of TD research includes joint framing of problems and goals for constitutive transformative change where multiple and diverse actors engage in the very first phases of a research process of co-formulating questions (Lang et al., 2012; Carvalho Silva et al., 2026). The second mediator includes the process of building trust and creating ownership not only through co-formulating questions but along the whole research process. These mediating processes of building trust and creating ownership have been described in transdisciplinary water research. Carvalho Silva et al. (2026) for example point to the need to build empathy to create a safe environment that fosters trust and openness. Walter et al. (2007) also identified increased trust and network building as important mediators and at the same time outcome of TD research more generally. Yet, we consider trust-building and creation of ownership as recursive processes, where on the one hand trust and ownership emerge through the co-formulating of questions, the co-designing and conducting of the research itself and on the other hand enables and facilitates social learning and production of knowledge in the first place. Accordingly, as a consequence, we argue that it is important to deliberately initiate grounds for those mediators. Rather than assuming trust must already exist, the TD processes generate trust, which in turn, mediates transformation.

The third cross-cutting mediator, which enables and facilitates the unfolding of the mechanisms of impact generation, focuses on the process of embedding the results. Anchoring of results can be achieved through technical means, but also social relational, institutional embeddedness. The anchoring of results starts already early in the TD research process and is highly influential to the generation of impacts within and beyond the timeline of the research project.

2.3 Analytical perspective on transdisciplinary co-production of knowledge in Flood Risk Research

Subsuming, our analytical perspective entails three components. First, we identify – based on a literature review – characteristics of flood risk research and their implications for the design of transdisciplinary co-production of knowledge (cf. Table 1). Further, we describe the different research phases and reflect the generic mechanism for creating impact through TD research (Schneider et al., 2019) with our empirical approach in the PARADeS project. Third we develop an analytical concept where we identify three mediating processes accomplishing the mechanisms (Fig. 1). This analytical concept – this is our claim – is supportive for designing, implementing and reflecting TD projects – specifically when being tailored towards the characteristics of FRR.

In the following, we present and reflect on our approach and experiences we gained within the TD Flood Risk Research project in Ghana, the PARADeS project. After describing the four collaborative phases of our TD approach (Sect. 3.2), we analyse which phase contributed to which impact generating mechanism (Sect. 3.3.1–3.3.3). Finally, we reflect how our collaborative phases were designed to particularly address the mediating processes. From our perspective, the three mediators were crucial to our TD approach (as we will explain in Sect. 3.3.4), as they helped ensure that the key mechanisms of co-production/TD research are functioning.

3 Transdisciplinary co-production of knowledge in Flood Risk Research – implementation and experiences from the PARADeS project in Ghana

3.1 Introduction to the case study area: Current flood risk situation and challenges of FRM in Ghana

Ghana is one of the countries in West Africa most prone to floods (Amoateng et al., 2018; World Bank, 2009) with devastating effects, especially for the urban poor (Okyere et al., 2013). In recent years, many parts of Ghana have experienced extreme floods that have affected about 1million people (Adegoke et al., 2019; IFRC, 2017). The Floodlist database lists 33 extreme flood events in Ghana during the last 20 years. In addition to the annual occurrence of major floods, Ghana experiences cascading disasters triggered by floods, which disrupt critical infrastructure.

Studies on the future of floods in Africa show a likely increase in extreme flood risk in Western Africa (Hounkpè et al., 2022). Flood magnitudes in Western Africa are projected to increase at 96 % of stations for the 20-year event in the near-term future and at 93 % of stations for the 20-year event in the long-term future (Diop et al., 2025). It has been esti-

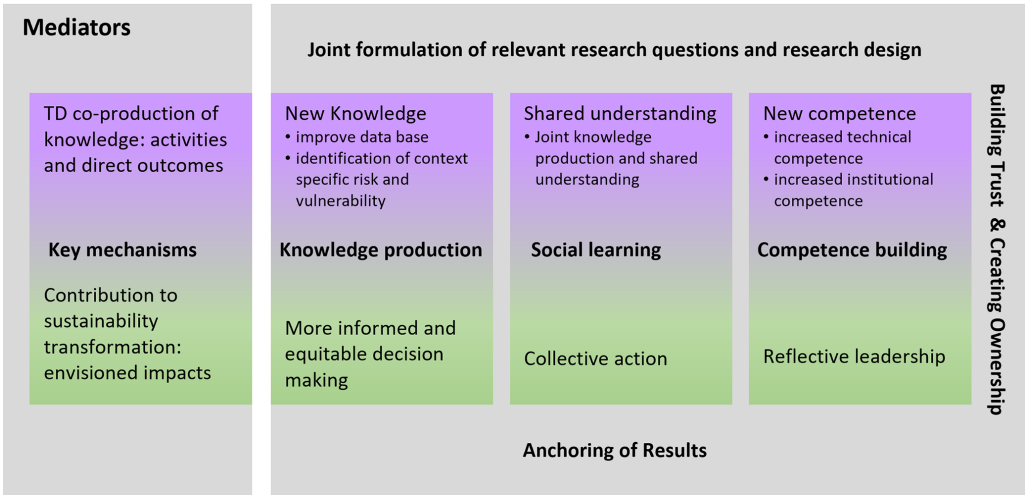


Figure 1. Overview of the generic key mechanisms of impact generation through TD research (knowledge production, social learning, and competence building) embedded in a set of mediators as prerequisites as central cross-cutting. Mediators are processes that enable of facilitate impact generation, starting with joint research questions at the beginning of TD activities (joint research questions), supplemented by building trust & creating ownership along the course of the project, and accomplished by the anchoring of results.

mated that about 12 % of the African population face food insecurity after 2020, with various cascading effects such as increasing levels of poverty, loss of lives, and conflicts (IPCC, 2021; Gil, 2022). FRM and DRR regimes and sustainable adaptation approaches are thus urgently needed.

To tackle this, the Ghanaian government has established several policies to reduce flood impacts, such as the National Water Policy (Ministry of Sanitation and Water Resources, Ghana, 2024) or the Blue Agenda (Addo and Danso, 2017), which address flooding and related threats by focusing on public education and the enforcement of building regulations. However, there remains a knowledge gap with respect to detailed hazard and flood dynamics and means of sustainable implementation of measures to reduce flood risk (Almoradie et al., 2020).

3.2 The PARADeS project: a multi-method approach along the TD research process

The PARADeS project (https://www.geographie.uni-bonn.de/parades/de, last access: 28 October 2026) aimed to enhance Ghana's national flood disaster risk reduction and management strategy by investigating key drivers and pressures, and by analysing existing flood risk and disaster management, governance and policy strategies. This involved addressing human–water interaction, developing scenarios, action plans, and feasible and sustainable flood risk prevention measures. To achieve this, we jointly developed and tested a TD multi-method approach involving multiple stakeholders to enable co-production of knowledge on flood risk disaster dynamics. This provides a core basis for identifying and implementing proactive protection and behavioural measures, thereby increasing competence in sustainable FRM.

Our TD multi-method approach was structured around four collaborative phases: (1) joint problem framing and context setting, (2) empirical grounding and knowledge co-production, (3) co-designing pathways and measures, (4) institutionalisation and anchoring. In the following we outline actors, methods and outputs of each phase to show how the impact-generating mechanisms (Sect. 3.3) were activated.

3.2.1 Phase 1: Joint problem framing and context setting

The initial phase is dedicated to engaging stakeholders in joint problem framing and context setting, hereby ensuring and establishing a shared problem definition among all actors. It allows to move from general FR challenges to a situated and context-specific focus. Actors during that phase included representatives of our Ghanaian project partners from the Water Resources Commission (WRC), the National Disaster Management Organization (NADMO), and the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) as well as initial community representatives. The German consortium consisted of scientists from the University of Bonn, University of Freiburg, University of Applied Sciences Magdeburg, and practitioners from the German Flood Competence Centre (HKC). During the project, there was intensive cooperation and continuous exchange among all partners. Core methods employed during this phase were the distribution of a nation-wide web-based questionnaire to include broad citizen perspective on flood risk. During workshops with flood experts from WRC, NADMO and Ghana's Hydrometeorological Organisation we jointly collected underlying causes of flooding as well as cross-sectoral impacts by using the problem tree approach

(Höllermann and Riemann, 2023; Almoradie et al., 2020) and identified hot spots of flooding during a mapping exercise. This phase was conducted within a six-month preliminary study and gained tangible outputs on an agreed-upon set of relevant research questions, an overview of FRM gaps and consensus on distinct case study areas (Odaw catchment, Accra; Aboabo catchment, Kumasi; Upper White Volta, Bolgatanga) which provided a targeted basis for final project conceptualisation.

3.2.2 Phase 2: Empirical grounding and knowledge co-production

This phase focused on knowledge co-production via a participatory mixed-method approach to combine quantitative flood risk models with situated local knowledge. Actors included modelling experts from both countries and regional Ghanaian experts providing critical ground truthing. The applied methods comprised collecting in-situ cross-sectional data, piloting a citizen science project to collect water level discharge data with the help of community gauges (Meyer et al., 2024), hydrological and hydrodynamic modelling, and participatory web-based mapping as a basis for consequence (damage to buildings and affected people) modelling and failure of critical infrastructure. Stakeholder engagement during these activities was critical to validate model outputs. In addition, focus group discussions with locally affected citizens in all three case study areas in Ghana provided bottom-up perspective on FR and gaps in FRM. On a meta-level a social network analysis based on qualitative interviews and validated in the stakeholder workshops was employed (Ziga-Abortta, 2025). As an output of this phase a Flood Information System (FIS) is established that is aligned with local needs and based on an improved database.

3.2.3 Phase 3: Co-designing pathways and measures

Based on empirically grounded and locally validated evidence of the FR and its impacts (Phase 2), this phase shifted the focus to what can be done. The objective was to facilitate social learning by developing potential interventions and measures to address FR. Actors involved in this phase were drivers and comprised national and regional decisions-makers, community representatives, technical experts (including health sector) and emergency responders. These stakeholders were brought together in series of workshops. The first was conducted in a hybrid format (Ghana in presence, Germany online) due to COVID-19 restrictions. The second workshop series took place in Ghana in person. Roughly a third of participants attended both workshops allowing for continuity and simultaneously opening for new perspectives. The core methods included qualitative system modelling and participatory explorative scenario development using a backcasting approach (Höllermann et al., 2026). Stakeholders participated actively in these exercises via e.g., voting tools, group discussions, world café rounds, and allowed to imagine different futures and debate policy options (Kruse et al., 2023). The direct output of this phase was a comprehensive "Policy Toolbox" and a set of mutually agreed context-specific adaptation measures.

3.2.4 Phase 4: Institutionalisation and anchoring

The final phase ensured that the generated knowledge extends beyond the project funding and aimed at making the research output actionable, and at designing and implementing knowledge translation mechanisms. Actors included the two implementation agencies, NADMO and WRC, with their technical staff, and University of Cape Coast. The core approach was co-creation of application tools. This involved iterative needs-elicitation workshops with end-users to define suitable tool architecture and in case of the Flood Label (a tool to identify flood risk and appropriate risk reduction measures on household level) adaptation to the Ghanaian context. While the FIS addresses experts and decision-makers, the Ghana Flood Label particularly addresses residents who are enabled to better assess their flood risk. These tools are combined with formalisation of stakeholder engagement via Memorandums of understanding and training of multipliers on different institutional levels. Furthermore, specialised training protocols were developed for students, employers of the implementation agencies and participants which were distributed via OER materials. Overall, these activities were process and relationship-focused to ensure that the co-produced knowledge in phases 1–3 is also owned by the co-producers and general stakeholders. The output of this phase are locally embedded, tangible instruments like the FIS which is hosted by WRC competence centre and the Ghana Flood Label which is now under responsibility of NADMO. Furthermore, a first batch of trained multipliers at universities and agencies on modelling, network analysis, and risk assessment and awareness and Open Education Resources (OER) material to proceed with trainings independently.

3.3 From co-production to impact: Analysing the PARADeS TD approach through the lens of impact generation mechanisms and mediators

In the following, we analyse the TD activities described in Sect. 3.2 by interpreting their results through the framework of Schneider et al. (2019) and reflect on its contribution to initiating impact generation. We show that three key mechanisms: knowledge production, social learning, and competence building were activated through the interplay of our employed tools. We also highlight how the three identified mediators: joint research question and design, building trust and ownership, and anchoring results proved to be key in enabling the co-production of knowledge throughout the different phases of our TD approach and throughout our project activities and direct outcomes (cf. Fig. 1).

3.3.1 Knowledge production

Knowledge is differentiated into systems, target, and transformation knowledge (Schneider et al., 2019), and thus the co-production process needs to engage with all three knowledge types. In phase 2 (Empirical grounding and knowledge co-production), the combination of field data and quantitative models with participatory mapping was instrumental in creating reliable *systems knowledge* by generating validated flood hazards and flood risk maps for the case study areas. These maps were now supported by an *improved database* covering input data such as rainfall, discharge, river cross-sections, bridges and culverts, digital elevation models, building surface area, and land use information. The collaborative effort enabled synthesis of new data alongside existing institutional databases significantly enriching the initial database.

Additionally, the citizen-science community gauge pilot has shown high potential not only for data availability but also for awareness raising in the respective communities. However, we also learnt that certain aspects, such as timing or coordination of different sub-activities, are crucial and should be taken into account to make citizen science projects a success. Overall, expert interviews and targeted workshops with experts proved to significantly improve the models.

This improved system knowledge was further refined by local flood perceptions and experiences via focus group discussions and experts' elicitation during workshops who provided bottom-up perspectives, hereby constituting *target knowledge* regarding *context-specific risk and vulnerability*. We found that preferred adaptation measures were highly dependent on individual perceptions of flood, experience, and the degree of being affected. This convergence of different perspectives generated joint knowledge on perceptions of vulnerability and risk by shifting and broadening perspectives. While it also complemented the information on flood hazard and risk derived from the hydrological and hydrodynamic models, this convergence shifted the understanding from a technical hazard into socio-economic vulnerability. In the workshops, we engaged with and exchanged ideas among different groups of stakeholders, experts, and decision-makers such as residents, local government representatives, national and regional disaster managers, and hydro-meteorological experts. The problem tree method allowed for jointly identification of the underlying causes of flooding problems in the three case study areas and to show how they relate also beyond the water sector to land use, urban and rural development, behavioural issues, and waste management problems. Furthermore, social network analysis revealed the interplay of differing, supplementary and sometimes conflicting perspectives, interests, capacities, and resources regarding FRM and made this interplay transparent and visible to all. Phase 3 (co-designing pathways and measures) drove *transformative knowledge* by moving stakeholders from a single risk assessment to a collaborative development of viable pathways, thereby ensuring that the adaptation measures and suggested policy strategies were jointly designed for implementation (Höllermann et al., 2026).

3.3.2 Social learning

Social learning is defined as the development of a common framework of understanding and for joint action, where diverse perspectives and experiences are synthesised into a situated, shared understanding through social interactions between actors within social networks (Reed et al., 2010; Schusler et al., 2003). In the PARADeS project, social learning was activated in multiple ways. Initially, the commitment to joint problem framing during phase 1, where researchers and stakeholders aligned expectations at an early stage. This served as the foundation for social learning, successfully elevating co-framing from a procedural step to a driver of impact mechanism. Joint field visits and reciprocal visits between the participating research and non-academic partners in Ghana and Germany strengthened mutual understanding by sharing pilot case examples and reflecting on the cultural, socio-political, and institutional settings of FRM in the respective countries. However, *social learning*, extends beyond the participating project partners and includes further stakeholders and community representatives. Joint system analysis and participatory scenario development were the key driver behind this *shared understanding and knowledge production*. Particularly, the facilitation of workshops across different affected locations proved to be important, as this spatial differentiation between urban and rural settings revealed distinct adaptation priorities and needs, confirming that sensitivity to situatedness is also important in the organisation of the co-production process (cf. Sect. 2.1 on situatedness).

The workshops in phase 2 generated a common understanding of problems, desirable futures, policy options, and adaptation measures in FRM and revealed a prevailing focus on short-term measures. However, the subsequent phase 3 with scenario analysis successfully catalysed a shift to more transformative and long-term measures and a move beyond the water sector to address interlinked issues, such as housing policy (Höllermann et al., 2026). The co-designing of robust pathways towards improved FRM instead of only addressing reactive measures became a direct result of this evolving process. Additionally, the creation of a policy toolbox was a tangible outcome of this new shared understanding, equipping the stakeholders to produce policies across different policy levels from local to national and supranational, and considering different policy instruments from regulatory and financial to informational, educational, and collaborative instruments (Kruse et al., 2023; Evers et al., 2023). Overall, the visible, evolving consensus on adaptation measures and policy options from the first to the last workshop confirms that continuous exchange itself facilitated the learning.

3.3.3 Competence building

Competence building was addressed on two complementary levels. *Increasing technical competence* and institutional capacities.

To increase technical competence, the design and development of the Flood Information System (FIS) was fundamentally guided by a user-centric approach. The FIS was built to meet the wishes and requirements of the end-users, which was confirmed through iterative needs-elicitation workshops in phase 2. The build-in scenarios of the FIS are based on user-agreed-upon adaptation measures (e.g., adapted land use planning, wetland protection, and the creation of retention ponds and dams) and ensured that the FIS gained acceptance. Various training sessions on this web-based FIS during phase 4 increased technical competence. Furthermore, the transfer of the FIS to the planned Flood Early Warning Centre in Accra was supported by a PARADeS project member at the partner institution for several days. To ensure durability, the tool was supplemented by further accessible Open Education Resource (OER) training materials, enabling self-learning. Additionally, online courses explicitly for students-as-teachers were developed to transfer expertise, knowledge, and skills, and to leverage this group as potential multipliers. The technical output was reinforced by a joint publication of a handbook to ensure that project results are available for decision-makers, practitioners and experts in the field.

Increasing institutional capacities required cultivating reflective leadership for effective FRM. This was achieved by employing a training aiming at strengthening collaborative governance among FRM stakeholders. In a workshop format during phase 4, participants depicted and analysed both existing individual as well as collective network activities to learn about their own collaboration strengths and options for improving collaboration within their network. This activity was complemented with an OER course dedicated to train networking techniques independently within and across the different organisations (Ziga-Abortta and Kruse, 2023b). The development of policy briefs served as critical instruments of institutional competence. By integrating the experience of both Ghanaian and German experts, the policy briefs translated the specific results into differentiated, actionable recommendations, proving the utility of TD teams in identifying the appropriate language and communication channels for the specific target groups.

A summary of these mechanisms (Sect. 3.3.1–3.3.3), alongside the corresponding methods used to conduct each step and the envisioned outcomes and impacts of the PARADeS approach, is juxtaposed in Table 2.

3.3.4 Importance of mediators for impact generation

Mediators play a crucial role for the generic key mechanism of impact generation to unfold. They act as conditions that enable knowledge co-production process, social learning, and competence building to translate into lasting transformative impact. In the PARADeS approach, we highlight three key mediators (cf. Fig. 1): (a) the joint formulation of research questions and research design at the beginning of the TD activities, (b) building trust and creating ownership throughout the project, and (c) anchoring of project outcomes throughout the project as a prerequisite for generating impact.

The commitment to *joint formulation of relevant research questions and a research design* from the start was the most critical mediator in the first project phase. During this phase, the research questions and the case study areas were developed not only with our collaboration partners but together with key stakeholders during joint workshops and informed by a nation-wide distributed questionnaire (Almoradie et al., 2020), ensuring that the problem framing (regular flooding with high damage and different flood types: fluvial, pluvial, and coastal flooding) and case study selection (Accra, Kumasi, and Volta region/Bolgatanga) were highly sensitised to local needs. This mediator also initiated, in a co-evolving and recursive manner, trust-building processes. Most importantly, the actual initiative for the research proposal was started by the Ghanaian practitioner partners.

Our experience shows that the joint formulation of research questions and research design supports creating a crucial basis for TD research, increasing the likelihood of successful co-production processes and implementation. Furthermore, this interaction created a sense of ownership among all participating partners even before the project commenced, since the project owned their questions.

While joint problem framing initiated trust, it can be regarded as a relational outcome of a TD approach, additional efforts to *building trust* need to be initiated and managed throughout the project. Our experience taught us that sustained cooperation depends on continuous relational attentiveness to situational, cultural and social necessities or "standard procedure". In the course of the project, we found the following activities as most effective in building trust and ownership. Intensive reciprocal exchange between high- and mid-level experts and administrative staff from disaster management organisations in Germany and Ghana, and between academics from all career stages fostered (a) understanding of the specific perspectives, expertise, and situational setting of FRM in Germany and Ghana and (b) reflection on cultural, institutional and methodological differences. By consequently evaluating project activities, intermediate outputs, and institutionalising debriefing activities throughout phases 2–4. More generally, by having a reliable presence and responsiveness at all levels, including higher hierarchical levels through regular group meetings and ad-hoc bilateral visits and meetings proved to successfully bridge and navigate the identified differences. A central element in *creating ownership* was the FIS. Based on a FIS demonstrator, it was tailored to the Ghanaian users' needs and technical requirements and only build after mutual agreement on its

Table 2. Mechanisms and sub-elements for the co-production of knowledge in Flood Risk research identified by Schneider et al. (2019) and applied/modified in the PARADeS project.

Mechanisms for co-production adapted from Schneider et al. (2019)	Mechanisms and sub-elements according to flood risk research applied in the PARADeS project	Envisioned outcome and impact for PARADeS project	Transdisciplinary methods in PARADeS project (exemplified)
Knowledge promotion	Knowledge co-production		
New knowledge*	Improve database	Validation & groundtruthing of data and models which increases the quality and increases trust in data and models, contributing to more and useful information	– Surveys – Community gauges (citizen science) – Participatory mapping of flood hot spots – Focus group discussions with local and regional experts – Field work/mapping by project partners – Synthesis of different databases
	Identification of context-specific risk and vulnerability	– Validation & groundtruthing of data and models which increases the quality and increases trust in data and models – The co-production leads to more equitable and informed decision-making	– Hazard modelling – Hydrological and hydrodynamic and risk cascade models – Participatory mapping of flood hot spots – Focus group discussions with flood affected communities – Household survey – Network analysis of flood risk reduction decision-makers – Validation workshop for institutional vulnerability
Social learning	Social learning		
Shared understanding	Joint knowledge production and shared understanding	– Understanding complexity of Human–flood interaction and root causes – Identifying interventions for collective action – Creating mutual understanding through an outside perspective and a shift in perspectives, respectively supporting collective action	– Participatory explorative scenario analysis – Exercise with Flood Information System (FIS) on scenarios and effects of interventions – Visit and return-visit of stakeholders and researchers in the respective Organizations in Ghana/Germany – Field visit by researchers
Competence building	Competence building		
New competence	Increase technical competence	– Tailored FIS to the needs of users – Competence building on the usage of the FIS – Capacity development on technical knowledge to increase the potential for usage	– Elicitation of requirements for the FIS in a workshop – Training on web-based FIS, which includes a flood early warning system – Production of training material and training of specialists, decision and policy makers and students
	Increase institutional capacities	– Delineate a variety of policy choices to decision makers – Enable networking outside established collaborations, increasing reflexive leadership – Target-group oriented communication supports uptake in decision-making processes – Policy briefs	– Policy toolbox – Training for collaborative governance – Training on collaborative governance and network building – Raise awareness regarding potential institutional challenges

* While Schneider et al. (2019) use the term "knowledge promotion", we prefer "knowledge production" as we find that the creation of new knowledge is central to the co-production process.

technical and functional architecture. Moreover, the commitment to shared ownership on the basis of mutual trust was demonstrated when the practice partners actively requested to also produce non-academic outcomes, thereby leading to joint formulation of policy briefs, a documentation of lessons learnt, a detailed handbook, and OER materials. By adding these valuable and tangible outcomes, ownership was created simultaneously. To further strengthen ownership, events involving the heads of the respective partner organisations allowed to publicly affirm their commitment to the aim of the project.

To ensure that the generated project outcomes last beyond the project, PARADeS deliberately introduced mechanisms from the beginning of the project, to prepare for the transferability and continuation of the results at different levels. This involved securing formal embedding and *anchoring of project results*. The completion of the FIS, for example, was formalised by signing a Memorandum of Understanding (MoU) between the University of Bonn and the partner institution, the Water Resources Commission (WRC). This guarantees that the FIS is implemented and be integrated into the Flood Early Warning System Centre (FEWSC) hosted by WRC. Parallel to this, another anchor was established by developing the Ghana Flood Label in close co-operation with NADMO, the official authority in Ghana for civil protection. This anchor was strengthened by providing a training unit on the Ghana Flood Label with NADMO employees, and by institutionalising this training for multipliers and future application at the University of Cape Coast.

Overall, these trust building, ownership creating and anchoring strategies ensured that generated knowledge and developed tools were not only reported, but trusted and institutionally owned and embedded, thus providing grounds for lasting project results beyond the project. Thus, we see these mediators not only as enablers of collaboration but also enablers of impact generation and implementation of results.

4 Discussion and conclusion

4.1 Characteristics of flood risk, their implications and potential tools for TD flood research

The implementation of transdisciplinary research often remains rhetorical or fragmented (Cavalho Silva et al., 2026). With our study, we aimed to identify empirically and conceptually grounded transdisciplinary tools and methods that address the specific characteristics of FRR and to contribute to the broader field of transdisciplinary water and risk research. The identified characteristics of flood risk research – complexity and interdependencies, multi-scalar and -temporal dynamics, situatedness and contextual vulnerability, uncertainty and incomplete knowledge, and socio-technical character – have direct implications for TD research design. Against this background, the study identified and compiled several TD methods and tools that are particularly suitable for TD knowledge co-production in FRR. Methods such as participatory mapping, collaborative modelling, focus group discussions, participatory scenario development, citizen science, social network analysis, system dynamics modelling, and web-based flood information systems proved valuable for integrating different perspectives and enabling social learning. Importantly, the findings suggest that these methods are most effective when applied not as isolated tools but as part of iterative and adaptive co-production processes. This aligns with recent debates in TD research emphasizing that the application of methods alone does not guarantee transformative outcomes; rather, transformation depends on how methods are embedded in collaborative processes, institutional structures, and power relations (French et al., 2024). The experiences from the PARADeS project further illustrate that socio-technical tools, such as flood models and flood information systems, can effectively support decision-making only if they are transparent, understandable, and trusted by users. Collaborative validation and co-design processes therefore played an essential role in improving not only the technical quality of the outputs but also their legitimacy and acceptance. This finding is particularly relevant in FRR, where technical models are often perceived as inaccessible "black boxes" by non-specialists. Through participatory modelling and iterative stakeholder engagement, the project was able to transform modelling processes into opportunities for social learning and ownership creation. It has to be clearly stated that the application of a wide range of methods and tools was made possible only by the interdisciplinary and intercultural composition of the project consortium. Equally important was the coordination with all regional African partners to assess the project's feasibility and appropriateness on the ground and make adjustments as needed.

4.2 Key mechanisms and mediators: the conceptual design for transdisciplinary co-production of knowledge

The adaptation of the Schneider et al. (2019) framework proved highly useful for analysing how impacts emerge in TD flood risk research. The three generic mechanisms identified by Schneider et al. (2019), knowledge production, social learning, and competence building, could clearly applied within the Ghanaian case study. For example, we supplemented the co-production of knowledge with specific activities and direct results that are particularly relevant to flood research. This includes the improved database and identification of context-specific risk and vulnerability indicators, as well as the concretisation of what needs to be specified in joint knowledge production. In terms of new competences, we differentiate between increased technical competence and increased institutional capability. Both are needed to ensure the uptake and implementation of new knowledge. Accord-

ingly, we have illustrated the methods we used to achieve this in Table 2.

Our application in the case of the PARADeS project provided detailed examples of the methods and tools used to achieve the envisioned outcomes. We believe that the general research design and utilisation of the various methods can be used as an example in other research projects and work as a blueprint. In particular, the involvement of stakeholders from the local (affected) community has provided a platform to capture diverse perspectives, interests, and local knowledge. It helped determine the heterogeneity of needs between rural and urban areas, as well as within urban areas. This approach helps to initiate participation of local communities in supporting regionally adapted FRM.

However, our findings also suggest that these mechanisms alone are not sufficient to explain how transformative impacts emerge in practice. The empirical experiences from PARADeS indicate that impact generation depends strongly on enabling conditions and relational dynamics that accompany the co-production process. For this reason, this study extends the Schneider et al. (2019) framework by introducing three mediators to the analytical concept that proved essential in the context of TD FRR: (1) the joint formulation of research questions and research design, (2) building trust and ownership, and (3) the anchoring of project results.

These mediators function as cross-cutting conditions that enable and stabilize the mechanisms of impact generation throughout the project's lifecycle. The joint formulation of research questions and project design proved particularly important, as it shifted stakeholders' roles from passive recipients of scientific outputs to active co-designers of the research process. This created ownership from the beginning and ensured that the project addressed contextually relevant problems and priorities. The findings therefore reinforce calls within TD scholarship to move beyond participation as consultation towards genuine co-framing and co-definition of research agendas (Polk, 2015). Trust-building and ownership creation were equally central. In the PARADeS project, trust did not emerge automatically through participation but required continuous investment in regular communication, reciprocal visits, iterative workshops, transparency in decision-making, and sensitivity to institutional and cultural differences. Understanding the co-evolution of mechanisms and mediators across scales, sectors, researchers, and stakeholder groups can maximise stakeholder engagement and strengthen outcomes and accordingly contribute to sustainable transformation – which we think is fundamental for long-term collaboration and implementation. In the Ghanaian context, trust-building was especially important due to the diversity of actors involved and the asymmetries often present in North–South collaborations (French et al., 2024).

The third mediator, anchoring project outcomes, highlights that TD impacts are unlikely to persist unless results are embedded institutionally and socially beyond the project duration (Pärli, 2023; Pärli et al., 2022b). The PARADeS project attempted to address this through memoranda of understanding, integration of tools into partner institutions, development of training materials and open educational resources, and the co-production of policy briefs and handbooks. Such anchoring activities demonstrate that impact generation in TD research is not a final project stage but an ongoing process that needs to be considered from the outset.

The addition of these mediators contributes conceptually to the field of transdisciplinary water research by demonstrating that transformative impacts in FRR depend not only on co-produced knowledge itself, but also on the relational and institutional environments within which knowledge is generated and implemented. The findings therefore suggest that future TD frameworks should pay greater attention to processual and relational dimensions of collaboration. The combination of key mechanisms and mediators can provide valuable lessons for future TD projects.

4.3 Learning opportunities for North–North flood risk research

Pärli et al. (2022a) depict – based on a systematic literature review – a distinct difference between transdisciplinary research in North-North and North–South projects. They synthesize that North-North projects showed to be more product oriented, e.g. through producing academic publications and outreach materials while North–South projects were more focused on inclusion, societal effects and uptake of knowledge. Our insights do not reflect this difference as we experienced both, a strong product orientation from the side of the Ghanian stakeholders as well as a strong commitment towards inclusion and practical knowledge uptake on in the case study regions. This seems specifically relevant for collaborative FRM that is not only developed and implemented through government agencies, but also actively includes stakeholders from non-governmental and civil society organisations, private companies, and the local population.

Although the study is an example of North–South collaboration, the findings also offer valuable lessons for North–North flood risk research. In many Global North contexts, flood governance remains dominated by technical and engineering-oriented approaches that sometimes insufficiently account for social vulnerability, community perspectives, and relational dimensions of resilience (Pärli, 2023). Accordingly, transdisciplinary research following the conceptual framework proposed would also enable North-North FRR to focus more on societal effects and knowledge uptake the inclusion of diverse stakeholders in a collaborative process. North–North flood risk research may therefore benefit from integrating more reflexive and participatory elements into existing governance structures. The emphasis on social learning, co-design, and collaborative governance identified in PARADeS could support more inclusive adaptation planning in highly institutionalized contexts. Furthermore, the experiences from Ghana highlight the value of mutual learn-

ing processes in which knowledge exchange is not unidirectional but reciprocal.

At the same time, transferability of methods across contexts should not be assumed automatically. Governance structures, institutional capacities, cultural contexts, and funding environments differ significantly between settings (Felt, 2022; Klein et al., 2022; Schegg et al., 2025; Ziga-Abortta and Kruse, 2023a). The findings therefore suggest that the value of TD FRR lies not in transferring standardized methods but in adapting collaborative principles and methodological approaches to local contexts.

4.4 Conclusion

This paper contributes to the empirical work of TD projects in the field of transdisciplinary water and risk research by identifying flood-risk-specific characteristics and discussing their implications for the design of TD research, tools, and methods. Building on conceptual reflections and empirical experiences from the PARADeS project in Ghana, the study demonstrates that flood risk research requires collaborative, adaptive, and context-sensitive approaches, employing a range of methods and tools capable of integrating multiple forms of knowledge and supporting interaction across disciplines, institutions, and various stakeholder groups.

By adapting the framework of Schneider et al. (2019), the study further shows that transformative impacts in TD flood risk research emerge not only through knowledge production, social learning, and competence building, but also through enabling mediators such as joint research design, trust-building and ownership creation, and the institutional anchoring of results. These mediators proved essential for translating co-produced knowledge into practical relevance, long-term collaboration, and implementation potential.

The findings underline that effective flood risk management cannot rely solely on technical expertise or isolated scientific outputs. Rather, addressing increasingly complex and uncertain flood risks requires reflexive and participatory processes that explicitly engage with questions of power, governance, vulnerability, and epistemic diversity. Particularly in North–South collaborations, equitable partnerships and sensitivity to local contexts are crucial for generating socially robust and actionable knowledge.

At the same time, the lessons derived from the Ghanaian case extend beyond the Global South. The study demonstrates that many of the relational and participatory dimensions emphasized in North–South collaborations also provide valuable insights for North–North flood risk research, especially in the context of climate change adaptation and resilience planning.

Ultimately, this study argues that the transformative potential of flood risk research lies not only in producing better knowledge about floods, but in fostering inclusive processes of co-learning, shared ownership, and long-term institutional engagement. Strengthening these dimensions will be essential for developing flood risk governance approaches that are both scientifically robust and socially legitimate in an era of increasing environmental uncertainty.

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