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Strengthening resilience in reconstruction after extreme events – Insights from flood affected communities in Germany

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ABSTRACT

Disaster resilience and building back better (BBB) are key concepts in the disaster risk and resilience discourse; however, these concepts often remain vague for many stakeholders involved in recovery. Based on the reconstruction process in Germany after the extreme floods of 2021 that caused more than 180 deaths, we explore challenges and opportunities to strengthen resilient recovery in one of the world's wealthiest and most technologically advanced countries. We examine factors that contributed to severe losses and damages and assess different phases of the reconstruction process. In addition, we identify and discuss measures to support resilience building, focusing particularly on issues of land management, planning and infrastructure. Our findings provide new insights into how funding schemes and planning approaches contribute to or block resilience building and BBB. The results are also highly relevant for other world regions hit by extreme events and for the international discourse on disaster resilience, loss and damage and BBB, for example, how funding arrangements and quality criteria need to be designed to support disaster resilient reconstruction.

1. Introduction: reconstruction after extreme events

The international discourse on disaster risk reduction and the discussion on a new global funding scheme for "loss and damage" (see, e.g. Refs. [1,2]) with regard to extreme weather events not only underscores the need to further define (technical) funding arrangements but also to provide scientific information on effective solutions on how to reduce future losses and risks of extreme

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events during post-disaster reconstruction. To enhance this discourse, we explore recovery processes in wealthier countries – particularly in Germany – after the extreme floods of 2021. Post-disaster recovery processes after extreme events are an important window of opportunity to address risks and loss and damage both through the compensation of experienced losses as well as strategic interventions and innovations to build resilience [3,4].

A core concept developed within the disaster risk reduction (DRR) community is the approach of building back better (BBB) [1]. The approach underscores that reconstruction processes should go beyond the re-establishment of the old structures that have proven to be highly vulnerable to flooding. However, at present, most reconstruction funding is dedicated to compensation for actual losses and damage in both developed (e.g., in Germany) and most developing countries. For example, in Pakistan, cash compensation was provided based on the extent of damage to crops and houses after the massive floods of 2010 and 2012 [5]. These brief examples underscore that the question of whether and how reconstruction can strengthen disaster resilience and BBB remains unresolved globally as indicated by Slavíková et al. [6]. This issue also gains additional relevance in the discussion about global funding schemes for addressing loss and damage [7] and respective quality standards for climate resilient recovery [8].

1.1. State of the art

Earlier research has been conducted on developing post-disaster reconstruction frameworks [9–11] and assessing the effects of post-disaster recovery and reconstruction initiatives on social vulnerabilities (e.g. Refs. [12,13]). In addition, past research has focused on evaluating the role of nature-based solutions in recovery and reconstruction (e.g. Ref. [14]); examining sustainable livelihood strategies as a resilience layer in post-disaster reconstruction (e.g. Ref. [15]); and assessing the recovery of the housing sector after disasters and extreme events (see e.g. Refs. [11,16–21]). In Germany, research has focused on recovery and reconstruction in terms of the replacement and repair of buildings and personal belongings [22,23] and on changes that mitigate future flood risks [24]. The role of funding schemes and land management in building resilience was partially considered in these studies. While these streams of research are important, insufficient attention has been given to the overall process of reconstruction and recovery, particularly when looking at different phases of recovery and their potential to support disaster resilient development. In this regard, Slavíková et al. (2021) recommended that future research should address how post-disaster financial schemes can increase resilience in the recovery phases of relief and reconstruction [6].

1.2. Extreme precipitation and unprepared communities in Germany

In the summer of 2021, heavy precipitation events in Germany and central Europe triggered floods that caused 134 deaths along a 40 km long stretch in the Ahr Valley in the state of Rhineland-Palatinate (RLP) – even to this day, two people are still missing. Moreover, the event caused 49 fatalities in smaller river basins in the state of North Rhine-Westphalia (NRW). These extreme rainfall events affected approximately 42,000 people and destroyed and damaged more than 9000 houses in the Ahr Valley alone [25–28].

The federal government of Germany and the state governments of Rhineland-Palatinate and North Rhine-Westphalia provided 30 billion euros for loss and damage compensation and reconstruction, which is a significant amount of funding considering that the affected areas are primarily rural settings, particularly the most affected area of the Ahr Valley [29]. The reconstruction funding in response to the 2021 floods (30 billion euros) far exceeds the loss and damage funds provided after the severe floods in 2002 and 2013 (e.g. € 8 billion in 2013) [30,31]. Thus, funding for loss and damage compensation is available; however, important discussions emerged on the need for rapid and non-bureaucratic access to these funding sources and the question of whether and how recovery funds should also allow for buiding resilience.

This paper explores options and barriers within the reconstruction process to promote disaster resilient development. While some aspects might be specific to this case study, several challenges identified in this research can also be found in other world regions and thus have global relevance, such as the role and design of funding schemes or the challenge of rapid recovery versus resilience building in the medium and long-term. Specific examples illustrate the challenges and opportunities that exist within the reconstruction processes to BBB – including a case from Australia highlighting some limitations of BBB. The paper fills an important gap by enhancing the debate from a rather conceptual discussion about post-disaster resilience and BBB towards the concrete question of how reconstruction processes after extreme events offer opportunities to do so.

Overall, we take a new approach to identify options for building resilience during reconstruction processes after extreme events in highly developed countries that are normally perceived as capable of BBB since funding and knowledge are available. We examine factors that contributed significantly to the severity of damage and losses experienced and analyse strategies and actions within the reconstruction process that influence exposure, vulnerability and risk. Finally, we assess barriers and obstacles that constrain options to strengthen resilience within reconstruction processes. The findings can inform future reconstruction and adaptation policies in the context of extreme events.

2. Disaster resilience and building back better (BBB)

Many papers discuss the concepts of disaster resilience and BBB through a conceptual lens [1,32]. However, little knowledge exists on how such concepts can provide practical and actionable information and guide reconstruction processes within post-disaster contexts in specific regions. In the following, we outline the core characteristics and principles of resilience, disaster resilience and BBB.

2.1. Disaster resilience

Resilience focuses on the capacities of communities, societies, and social-ecological systems (SES) to deal with the impacts of a hazardous event or stressor [33–36]. Even though the term and concept of resilience in SES research and DRR has made a significant etymological journey, as Alexander (2013) shows, the concept of resilience in SES research is an established field [37]. It underscores the relevance of crises for triggering learning processes within SES [33,34]. Core elements of SES resilience thinking, such as the "adaptive cycle", "panarchy" and "cross-scale interactions" (see Refs. [34,38]), have also informed disaster risk research. Resilience signifies that disasters and crises provide a window of opportunity for change and innovation [3,33]. Today, building disaster resilience is considered an important strategy for communities and societies to learn, reorganize and transform in response to changing environmental conditions, e.g., extreme events [39,40].

2.2. Building back better (BBB)

The Sendai Framework for Disaster Risk Reduction 2015–2030 [1] defines, among the four priority actions, the need to prioritize the enhancement of disaster preparedness for effective response and to "Build Back Better" (BBB) in recovery, rehabilitation and reconstruction (see Ref. [1]). It underscores that post-disaster contexts offer an opportunity for building back better in terms of ensuring that recovery, rehabilitation and reconstruction reduce the overall risk - particularly through addressing exposure and vulnerability. The important role of land-use planning is emphasised as an opportunity to develop capacities to reduce disaster risk (see, e.g., Ref. [41]). While there is high agreement on the overall concept, the more precise questions remain unsolved, including what governance and funding structures, goals and new standards for land-use planning and infrastructure development and housing reconstruction need to look like to promote BBB and disaster resilient development. The application of both concepts in post-disaster and reconstruction processes has been limited.

Against this background, we examine different phases within the reconstruction process after the extreme flooding and assess strategies, funding schemes, regulations (e.g., flood related regulations) and specific action areas where these principles are applied or could be applied. Prior to this, we analyse factors that determined the severity of losses and damage and that need to be addressed and reduced during reconstruction.

3. Extreme floods in Ahr Valley: factors that significantly contributed to the severity of losses and damages

Post-disaster assessments are not mandatory by law in Germany; however, within a larger research project - involving 13 scientific institutions from Germany - we assessed core factors that significantly influenced the magnitude and severity of the disaster (see KAHR project[1]). Fig. 1 provides an overview of the Ahr Valley and a zoom into one of the most impacted areas - the city of Bad Neuenahr-Ahrweiler (see Fig. 1). While more than 134 people were killed in the entire Ahr Valley, the city of Bad Neuenahr-Ahrweiler alone accounted for 69 fatalities. The total economic damage in Germany was approximately 33 billion euros (in Rhineland-Palatinate and North Rhine-Westphalia), with many non-economic losses as well (e.g., traumatization, out-migration, etc.). Core factors that contributed to the high number of fatalities and losses were as follows:

1. High flood magnitude with estimated return periods of >1000 years [42].
2. High levels of exposure of settlements and infrastructure close to the river [43].
3. Massive and widespread cascading effects due to the disruption of critical infrastructure services such as power supply, telecommunication, water supply, transportation etc.
4. Low level of community awareness about flood exposure [44].
5. High human vulnerability due to the older demographics in the Ahr Valley [25].
6. Ineffective early warning systems, short response times due to rapid flood occurrence combined with a lack of knowledge about how to react [25,45].
7. Bridges that trapped debris and partially blocked the flood water increased the height of the flood wave significantly (by approx. 2 m) in many communities [46].
8. Steep hillslopes contributed to high amounts of sediment transport and resulted in the accumulation of much woody debris, causing higher damage to buildings and infrastructures [47].
9. Oil tanks for heating systems increased the likelihood of water contamination and thus contributed to high economic damage due to the contamination of buildings

While not all of these factors that contributed to a high number of fatalities and losses can be addressed by a single actor or institution, we find that the reconstruction process can directly or indirectly influence the various factors outlined above. To systematically identify opportunities for increasing resilience, we differentiate various phases of the reconstruction process based on our analysis and assess changes triggered and catalysed by the reconstruction process (see Section 4). We outline selected strategies and measures to build resilience in the different reconstruction phases in more detail and thereby show, for example, how funding regulations, land-use policies and building regulations need to change in order to support resilience building.

[1] KAHR is a research project that aims to support the reconstruction process with scientific expertise. It is funded by the Federal Ministry of Education and Research and encompasses 13 scientific institutions and practice partners that should support the reconstruction process with scientific concepts and evidence (see website: https://www.hochwasser-kahr.de/index.php/en/about-kahr).

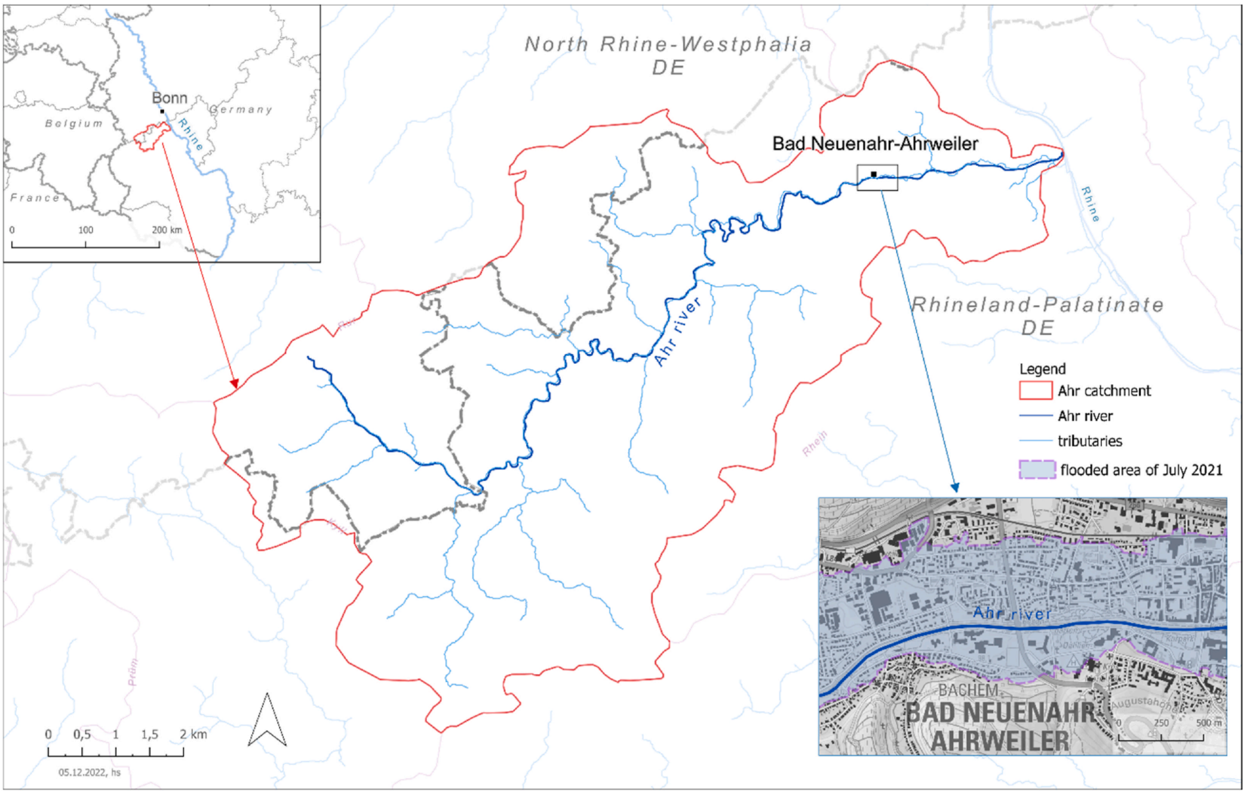

Fig. 1. Map of the Ahr Valley and a zoom into the city of Bad Neuenahr-Ahrweiler. Source: own illustration; basedata: administrative boundaries:© GeoBasis-DE / BKG 2022; drainage basin, rivers: ©Bundesanstalt für Gewässerkunde 2022; floodline July 2021: © Landesamt für Umwelt Rheinland Pfalz 2022; Topographic Map (DTK250: ©GeoBasis-DE / LVermGeoRP, 2022

4. Methods and material

4.1. Data sources and methods applied

The paper is based on a mixed method approach, including expert workshops and discussions (see Table A1 in the Annex), a household survey, document analyses, and the authors' assessments of damage patterns and reconstruction progress. The quantitative and qualitative data examined allow us to summarise important insights about opportunities and limitations to strengthen disaster resilient development within different phases of the reconstruction processes, based on the examples of Germany and in part Australia (see Box). To date, very few studies exist that examine lessons learned and synergies between reconstruction and resilience building. Hence, the paper provides a new perspective and builds on various data sources examined in the post-disaster and reconstruction processes, including a household survey by the authors involving more than 500 affected households located in the Ahr Valley (see Section 6 and [44]).

4.2. Document analysis

The document analysis encompasses the assessment of legal and planning documents, e.g., funding regulations for reconstruction that guide the reconstruction process (see Ref. [28]), reconstruction reports from the state ministry (see, e.g., Refs. [28,48]) as well as newspaper reports (e.g., Refs. [49–51]), that inform about the reconstruction process and its challenges. In addition, document analysis encompasses the examination and comparison of flood hazard maps before and after the disaster (see Refs. [52,53]) and the analysis of media reports regarding obstacles within the reconstruction process. A review of the literature about past floods [22,30,54] also informed the research.

4.3. Expert discussions

Expert discussions with ministry officials and other authorities, planners of affected communities, counties and regions, scientists, engineers as well as policy-makers were conducted in different settings, for example, within a larger science-policy conference (see Ref. [55]), but also in expert working groups focusing on specific thematic aspects within the region, for example, the reconstruction of bridges or the reconstruction of critical infrastructures and sport fields (see, e.g., Refs. [56–58]). Moreover, workshops with the institutions responsible for flood risk management, such as the Ministry for the Environment in RLP, are an important source of information for the findings of this paper. Expert workshops with authorities and experts in the field of spatial planning, zoning and urban planning at local, state and federal levels critically revisited existing norms and planning tools [59]. These discussions resulted, for example, in the formulation of 10 recommendations on how to BBB and build resilience through reconstruction (see the recommendations in Ref. [60]). A list of the various workshops and discussions that informed this paper can be found in Table A1 - Annex.

4.4. Field observations and household survey

The assessment within this paper is also based on a quantitative household survey that was conducted in the county of Ahrweiler between June and August in 2022 (see details in Ref. [44]). Since the focus of the survey was on the July 2021 flood event, we contacted and interviewed only affected individuals. To identify this group, we used the list (provided by the county of Ahrweiler, one of the project partners in the KAHR project) of almost 16,000 people who were personally affected and thus applied for state emergency aid after the flood. Since we already expected a response rate of 10–20% and wanted to interview approximately 500–1000 people, every third person on the list was contacted according to the principle of systematic sampling. Thus, 5250 people were contacted by the county by postal mail and asked to participate in the survey, of which 516 people in total participated. The survey was conducted mostly online using the survey software EvaSys. However, 21 people filled out a paper questionnaire, which also allowed people without internet access to participate in the study. The questionnaire took about 30 min to complete, covering topics from the 2021 event to mental stress and the recovery and reconstruction process to preparedness, settlement retreat, as well as information and governance. It included Likert scale and dichotomous questions as well as single- and multiple-choice questions. There were also a few open-ended questions. All participants were at least 20 years old (see Table 1). Slightly more men than women participated, and the majority lived in their own homes or those of close relatives (see Table 1). Overall, due to the selection methodology, only affected persons participated in the survey, so the group of affected persons is well represented. One problem, however, is the fact that hardly any unemployed people or low-income earners took part – presumably, because they often did not know that they could apply for emergency aid. Since we provided the questionnaire only in German, people with poor to no knowledge of German probably will not have participated. In addition, people in nursing or retirement homes, for example, were also excluded, since they did not apply for emergency aid. Therefore, some marginalized groups were not part of our survey, which is why we could not focus on them.

SPSS software was used for the analysis, whereby mainly frequency analyses, cross-tabulations and Spearman's correlation were performed. The survey allows us to better assess the impacts of the flood event on different households, opportunities and challenges within the reconstruction process, and specific measures – using quantitative methods.

5. Different phases of reconstruction

International research on reconstruction and recovery focuses primarily on housing reconstruction or displacement and relocation (see, e.g., Refs. [16–21,61,62]). Within these streams of research, various reconstruction phases have been identified; however, these phases differ between research communities and studies (see, e.g., Refs. [63–66]). While there is agreement that emergency relief immediately after the event is different from medium and long-term reconstruction, there is little consensus on the number, duration and characteristics of reconstruction phases.

The classification of post-disaster phases typically consists of four or five phases, e.g. search and rescue, emergency relief, early recovery, medium and long-term recovery and community development (see, e.g., Ref. [65]). Based on our research and field observations, we view “search and rescue” as part of emergency management and add an additional phase that encompasses the recovery of landscapes. According to our assessment and the analysis of reconstruction reports [48], we differentiate the following five phases.

- 1st Phase: disaster assistance within the first weeks after the event and cleaning of damaged buildings and blocked roads (volunteers and disaster emergency response institutions)
- 2nd Phase: recovery and relief support (e.g., in terms of tents and the installation of temporary infrastructure; drying of wet buildings)
- 3rd Phase: cleaning and recovery of landscapes and open spaces (ongoing)
- 4th Phase: reconstruction of houses and public infrastructure, mainly on-site but partly also off-site (relocation) (ongoing)
- 5th Phase: community development and full recovery of livelihoods (ongoing)

While the first two phases were characterised by immediate assistance within hours, days and weeks after the disaster with limited options to support disaster resilience, we found that particularly the reconstruction phase (phase 4) of private houses and lifelines as well as public infrastructure and phase 5 (community development) offer various entry points to strengthen resilience, even though some of these opportunities were missed in the aftermath of the 2021 event. The cleaning and recovery of landscapes and open spaces (phase 3) also encompass options to build resilience, for example in terms of land-use policies that promote flood retention and water capture within the reconstruction of landscapes (e.g. agriculture, forestry). Phase 5 includes the full recovery of livelihoods and communities that are relevant for resilience building, since in this phase the further development of a community and respective livelihoods can include resilience measures.

Table 1
General information about the sample of the household survey.

Socioeconomic variables	Statistics
Age (0–19/20-39/40–64/65 + years) [%]	0.0/10.7/56.3/33.0
Gender (male/female/diverse) [%]	52.4/47.6/-
Income per month (median)	2600–3599€ per household (median)
Homeowners (including owned by close relatives) [%]	67.6

Fig. 2 provides an overview of the five phases differentiated for the Ahr Valley case study. It must be noted that different phases overlap and that communities in the same valley might be in different phases of reconstruction (see Fig. 2). This means that reconstruction is quite fragmented within a region (see Table A1, Point 7 in the Annex).

Moreover, the graphic of recovery phases (Fig. 2) gives the impression that most people and communities do recover; however, we observe that some people and businesses do not recover and migrate out of the region [44]. Furthermore, reconstruction includes the relocation of exposed private houses, public infrastructures and lifelines (such as electricity networks) to safer places. For example, 34 houses were relocated due to state regulations, but more people relocated voluntarily, for example, very old people and especially tenants [44]. In addition, some households still live in temporary houses (see Table A1, Point 7 in the Annex).

The structure, processes and organisation in one phase also influence the next phase. For example, strategies for temporary houses or early business recovery in phase 2 influence conditions in phases 4 and 5, and funding regulations for loss and damage compensation established in phase 2 influence phases 4 and 5.

Overall, the figure underscores that options for resilience building do exist in the short, but also in the long-term processes that encompass recovery (see Fig. 2). Furthermore, post-disaster contexts encompass complexity, chaos and governance dynamics that cannot fully be predicted. Therefore, an adaptive and flexible planning approach is needed. Scientific studies suggest that signs of critical transitions can be identified [67]; thus, shifts from one phase of recovery to another are detectable. In the following, we examine changes and opportunities to strengthen resilience along selected strategies and measures while considering the different phases of the reconstruction process.

6. Changes identified and first entry points to strengthen resilience

Changes and opportunities to strengthen resilience are mainly based on research in the Ahr Valley; however, we also juxtapose these results with data and information from flood exposed areas in Australia (see Box). Both examples underscore that various changes and opportunities exist in reconstruction processes to build resilience.

We group the changes identified and opportunities to strengthen resilience into four broader areas: a) knowledge, b) finance and funding for loss and damage, c) planning and governance as well as d) technology and infrastructure. These categories help systematize information, and at the same time, these broader categories can inform other reconstruction processes and policies.

6.1. Knowledge

A significant shift took place in terms of risk perception within the context of the flood disaster and the reconstruction process. Findings of the household survey (see method section) revealed that prior to the 2021 flood approximately 80% of the households were unaware of their exposure to flooding [44]. This perception changed significantly after the flood. High levels of risk awareness are seen as an important precondition to better prepare for future risks in many studies conducted in Germany, Japan, Belgium, and Ghana (see, e.g., Refs. [23,68–70]). Moreover, a recent research project on extreme precipitation and flooding in Southern Germany revealed that risk communication processes, particularly raising awareness and providing information on exposure, can help people to better prepare for extreme floods [71]. However, there are also studies that point towards the fact that in some cases (see, e.g., Ref. [72]) there is no significant correlation between preventive measures implemented after the extreme event and the level of risk awareness. Limited actions to conduct preventive measures after extreme events, however, might also be influenced by the fact that some households are not yet able to implement preventive measures, since, e.g., they are still living in temporary houses or they live

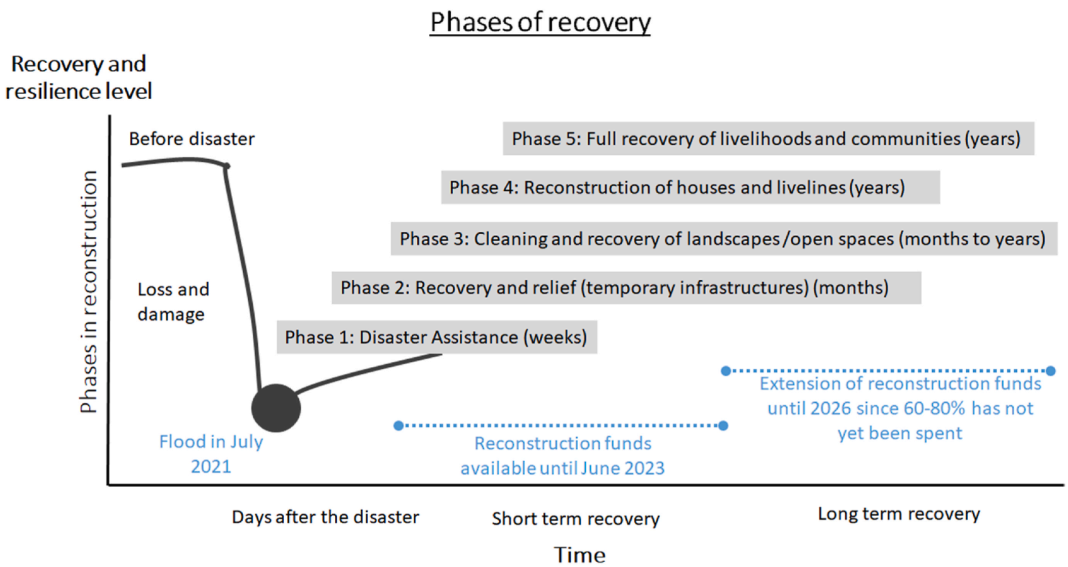

Fig. 2. Phases of recovery observed in the flood affected areas in Germany. Source: own table/figure based on own research and observations.

in rental houses and flats where larger structural measures cannot be implemented without the consent of the house owner. As an illustration, our survey showed that one year after the flood, 12.9% of respondents were still living in temporary housing, with friends or relatives, as mentioned above, and another 14.0% had already moved permanently [44] - making it infeasible or unnecessary to implement precautionary measures. Among the reasons why no precautionary measures were taken after the event, 'living in an apartment building' was cited most often (47.8%), followed by 'lack of knowledge of what they could change and how' (25.1%). In addition, the meta analysis of van Valkengoed and Steg (2019) revealed that self-efficacy, outcome efficacy, negative effects and descriptive norms are the strongest predictors of adaptive and preventive behaviour [72]. This might also point towards the need to modify framework conditions that motivate people and institutions to take action.

6.2. Finance and funding schemes for loss and damage

In the direct aftermath of the disaster event, federal and state governments established a *recovery* fund, providing 30 billion euros for those areas affected in Rhineland-Palatinate and North-Rhine Westphalia [48,73]. However, the reconstruction fund's main objective is to compensate for actual loss and damage rather than to facilitate BBB. In some sectors, improvements have been achieved within the ongoing reconstruction process, particularly when criteria for funding were modified to permit the funding of new standards. According to Art. 4.4.4 of the reconstruction fund, full financial compensation (meaning 80% public funding and 20% private investment) for the reconstruction of demolished private homes in the affected areas in Rhineland-Palatinate can also be granted in case of resettlement to a safer place (see Ref. [48]). The compensation payments for the plot of land and the house of the people affected are based on the loss of values due to the flood (this means a comparison of the value before and after the flood). The requirement is that the new property must be a similar replacement project. There are two obstacles within this process. First, a replacement project must be found, which is difficult in the Ahr Valley itself, since there are hardly any free and buildable areas. Second, 20% of the costs must be borne by the local residents themselves. Payout of the funding and a move to a rental property is not possible. For many people, this presents a substantial barrier to relocation, even if they are willing to move. In contrast, after the floods in Simbach at Inn in Bavaria (Germany) in 2016, a smaller resettlement project was implemented, and residents were given compensation based on the market value before the flood disaster which contributed to the success of the relocation process [54]. Nevertheless, the dynamics of relocation processes differ from one location to another even when there is enough funding and suitable land; for example, in Pakistan the majority of relocation projects after extreme floods (in 2010) failed because of livelihood and cultural issues, the large distance to the place of origin and a lack of participation in the planning and design process of relocation projects [10,74,75]. In Lismore, Australia, relocation was called for but neither planned nor funded properly (see Box).

6.3. Planning and governance

Shifts in regulation and new flood hazard zones: The state of Rhineland-Palatinate, through its regional authority, issued new flood hazard maps (designated flood plain (HQ100) and high risk zone (see in detail [52,53])) a few weeks after the event that includes non-construction zones. These legally binding ordinances influence the way reconstruction is done, but tensions have emerged regarding their interpretation and long-term effects. For example, it is still unclear what kind of flood safety standards need to be applied to sensitive and critical infrastructure reconstructed in the legally defined flood zones. Moreover, the legal consequences of heavy precipitation maps (pluvial flood hazard maps) compared to river flood hazard maps is still an open issue.

Although the rapid development of new floodplains and flood zoning maps is an important element of flood preparedness and resilient urban development, the binding character of these maps is often challenged by exceptions set out in the Federal Water Act [76]. As the regional authority issued two different levels of legally designated floodplains, it can be assumed that a strict building ban is and will be enforced only within the high risk zone [53], which is a small part of the designated floodplains. While the newly designated floodplains cover approximately 65% of the area that was totally inundated in the 2021 flood, the high risk zones amount to only 11% [77].

Flood alliance partnerships: The reconstruction processes are often very local. Individual community flood protection, reconstruction (e.g., bridge reconstruction) and development (e.g., new housing or commercial areas) might influence the resilience and risk profile of downstream communities. Therefore, cooperation at the watershed scale is key. Existing initiatives were reactivated, such as the flood partnership alliance that promotes cooperation between municipalities and various actors. These partnerships are voluntary, and thus, their effectiveness for ensuring new resilience standards is unclear. In addition, funding for loss and damage compensation does not prioritize inter-communal strategies. Thus, cooperation along the entire valley is not sufficiently visible. This is in part also influenced by the fact that the valley contains many small villages and municipalities and each municipality deals with its local concerns (e.g. urban planning), and existing governance structures hamper in part inter-communal cooperation.

Reconstruction agencies: Various cities and villages set up their own reconstruction organisations (see, e.g., the reconstruction agency of the city of Bad Neuenahr-Ahrweiler (https://www.ag-bnaw.de/), the reconstruction agency of the city of Sinzig (https://www.gewi-sinzig.de/) or the reconstruction agency of Dernau, Mayschoss and Rech (https://zukunft-mittelahr.de/)), since the existing administration was often overwhelmed by the additional tasks, and funding for existing staff was not provided by the reconstruction funds. These reconstruction organisations are able to establish additional structures, process recovery funding requests and employ new staff; however, the new organisations often relate to only one city or municipality.

6.4. Technology, planning and infrastructure

Temporary houses were built by municipalities or private initiatives based on private donations [78]. This also changed the fabric of communities significantly. Moreover, some inhabitants, particularly those who lived in rental houses, migrated out of the region

[44]. Hence, the demographic profile and the composition of communities changed. Overall, we observed the following changes in the broader category of technology, planning and infrastructure.

- *Early warning systems* were strengthened, particularly new sirens capable of operating without power for several hours were installed [79]. However, the necessary content of warning messages is rarely discussed, even though it is important for response [45].
- *Changes in land-use planning,* particularly in terms of the reconstruction of *critical and sensitive infrastructure,* are under discussion, such as for electricity networks or water retention areas. In addition, consideration is also being given in some cases to relocating infrastructure that is particularly sensitive and thus worthy of protection (see Levana school, Section 7.2).
- *Heating systems:* In many communities, oil tanks had been used as heating sources for houses and were replaced by other heating systems after the flood (particularly in the HQ-100 flood exposure zones). In both states, these shifts were supported by state activities and funding schemes.

In addition to changes discussed above, we also analysed core challenges for strengthening disaster resilience in reconstruction (see Section 7).

7. Box: post flood reconstruction in lismore (Australia) - disaster resilient recovery

Lismore represents a case from a wealthy developed country, where there have been repeated severe, damaging floods, with many unsuccessful attempts to reduce flood risk through BBB and relocation. This example from the town of Lismore, NSW, Australia, illustrates some opportunities and limitations with recovery processes to support disaster resilient development and BBB, especially in the context of spatial planning. In this regard, it supports some core findings identified in the reconstruction process in the Ahr Valley.

Lismore is the most flood prone town in Australia. Its location, chosen in the mid-1850s for ease of shipping the local timber, has frequent deep flooding with limited warning time. The frequent flooding does not appear to have affected development, with its floodplain home to some 2000 houses and 800 businesses in addition to schools and key infrastructure. Some areas including the CBD flood every few years (since 2005 levee construction the CBD floods about every ten years) [80]. Following the record flood in 1954, an enquiry recommended small levees and related measures, which were implemented. However, the recommended development controls to prevent the risk increasing, were not implemented. Another record flood in 1974 resulted in a minimum floor level requirement and a small-scale property acquisition program targeting the lowest lying areas. Unfortunately, the purchased areas were not rezoned to prevent future redevelopment. However, an alternative flood-free town centre was established at Goonellabah [81]. Flood reports in this period also argued that emergency planning needed to consider the Probable Maximum Flood. There was also indigenous history about extreme floods. However, the focus was on engineered flood risk reduction, and in 2005 a levee was built to provide 1:10 protection for the CBD.

The most effective risk reduction measures have been from individual property owners, especially in the form of house raising with most main floors raised above recorded historic flood levels (up to 4 m above ground level). Over time, the estimated frequency of major floods and the height of extreme floods have both increased. This is due to the influence of climate change and increased understanding of the local hydrology. However, this improved knowledge has had little impact.

By early this century there were many studies and recommendations, generally reiterating earlier work. Government action led to small levees and modest flood protection works. These were effective at reducing the impacts of frequent floods and combined with the widespread practice of house raising – a form of BBB – the result was a community seemingly resilient in the face of historic flood levels. Some flood insurance became available this century. However, a near record flood in 2017 led to much community agitation on the need for better flood risk reduction.

However, in common with many similar areas worldwide, opportunities were missed to deal with the most severely flood prone dwellings, prepare for more extreme events or to consider the implications of climate change. Lismore's long-standing adaptation to flooding was tested, when in February 2022 a flood more than 2 m higher than the previous record occurred. The warning system and preparations by both emergency agencies and the people were overwhelmed. The adaptations for the previous record floods were of little use – even though past recovery was thought to have improved flood resilience - and the results were devastating [82]. The state government has undertaken a public enquiry and created a reconstruction authority with very broad powers [83]. There is public and official discussion about relocation of the most flood prone properties. However, much effort is focused on data collection and catchment analysis, although it is hard to see how this will make a difference.

One lesson is that apparent adaptation incorporating BBB can be overwhelmed by an unexpectedly severe event. Even with best intentions, recovery and risk reduction run into the realities of capacity limits in the construction sector, limited support for those affected, open-ended timelines, and a lack of clarity about the future.

8. Challenges: strengthening disaster resilience in reconstruction

Based on our field research, the larger household survey and workshops with experts and communities affected (see Table A1 in the Annex), we identified six core challenges that hamper resilience building after extreme events or at least need to be considered when developing respective resilience strategies.

8.1. Rapid recovery versus long-term planning

While there is a general agreement among flood affected households that the reconstruction process needs to reduce the level of risk and vulnerability, we found that approximately 60% of the flood affected households interviewed perceive the progress in reconstruction as too slow (see Fig. 3). Affected households often received support from volunteers from all over Germany [84,85] within the first and second phases of reconstruction. This allowed for rapid cleaning and initial recovery (phases 1 + 2), however, it seems that many households are still stuck in recovery phases 4 and 5 (see Table A1 in the Annex).

Even though many people seem to perceive the overall process of recovery as too slow, many households do not want to just rebuild without considering additional resilience measures. A majority of affected households interviewed disagreed with the statement that rapid recovery of houses and infrastructures is more important than a flood-resilient recovery and sustainable reconstruction process (see Fig. 3). Consequently, those affected want a faster recovery on the one hand and a well-coordinated reconstruction process that ensures a higher level of resilience and sustainability on the other. Both views are valid; however, we observe a tension, since in many cases, resilience strategies within reconstruction require more time if they are not already conceptualized before such extreme events or disasters occur. Moreover, previous studies on recovery of flood affected regions along the Elbe and Danube underscored that within these river catchments recovery was mainly defined as the restoration of buildings and the replacement of damaged household inventory without proper resilience measures [22]. However, Thieken et al. (2007) suggested that taking precautions against future flooding in recovery and restoration also depends on the socioeconomic profiles of households [22]. Kreibich et al. (2005) maintained that preventive measures (e.g., flood adapted interior fitting) by households reduced losses from the extreme flooding of the Elbe River in 2002[86]. Nevertheless, the focus on long-term resilience planning was limited.

8.2. Funding schemes: reconstruction to prior status versus resilience building

While reconstruction requires the consideration of new flood protection standards for individual buildings, many structures such as individual houses, schools or sport facilities are rebuilt as before. The government reconstruction fund [28] does not sufficiently support BBB. This is particularly true for partially destroyed infrastructure or buildings that can be rebuilt without additional permission (right of continuance). The funding allows people to rebuild their houses in the same place if allowed; hence, options to support strategic retreat (when houses within the special risk area are not fully damaged) are limited.

The entire reconstruction funding schemes are primarily designed as if the disaster was an insurance case, where direct losses and damages due to the floods in 2021 can be compensated, but further improvements or significant shifts towards more sustainable and resilient development are not foreseen and funded (see regulation [48]). In addition, the recovery funding and compensation focuses strongly on the repair and reconstruction of individual houses, infrastructures, roads or items damaged in the event (see Ref. [48]). However, BBB and climate resilient development requires broader approaches that also consider an entire city or the entire valley (catchment area), due to the fact that the resilience aspects are interconnected and the protection of a specific infrastructure or house might require changes in landscapes upstream rather than solely measures on the individual building damaged before. For example, the enhancement of the resilience of sensitive infrastructures such as schools or hospitals require not only modifications on the individual building, but might also require a new location with additional protection standards in order to avoid future flood risks. These issues are raised by reconstruction agencies (see Ref. [48]); however, the present funding criteria still do not sufficiently capture these issues and challenges (see Table A1, Point 12 in Annex).

Furthermore, applications for reconstruction funding for larger types of infrastructure (schools, bridges, etc.) require a detailed reconstruction plan, which can be difficult to develop rapidly, since many experts and local and regional planning agencies were also severely affected by the flood. Thus, reconstruction plans for larger types of infrastructure requires time and new standards if climate and disaster resilience is the goal. In addition, user needs are changing (schooling concepts, energy transition goals towards renew-

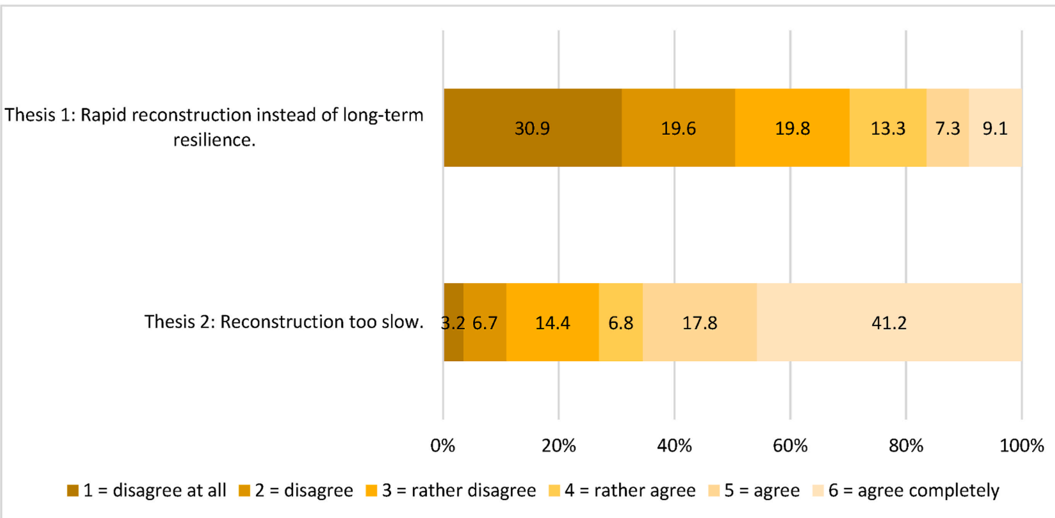

Fig. 3. Agreement on a six-point Likert scale from 1 = disagree at all to 6 = agree completely to two theses (household survey). Thesis 1: Rapid reconstruction of infrastructure and housing is more important to me than a flood-adapted and sustainable reconstruction process. (n = 495) Thesis 2: The reconstruction is happening too slowly for me. (n = 507).

able energy, etc.), and there is a need to better link the reconstruction funding with additional funds that allow such transitions and changes to be implemented at the same time.

8.2.1. The case study: Levana School

A concrete example is the current discussion of the reconstruction of the Levana school that is located directly at the Ahr River (see website Levana School - https://levana-aw.de/). The school encompasses approximately 100 children, all of them are handicapped in terms of intellectual or mental disability and approximately 30% of the children also have physical handicaps [87]. This means that all children are highly vulnerable and most of these children cannot conduct an evacuation order without external help (see Ref. [87]). The reconstruction fund covers the reconstruction costs of the damaged inventory and building structure at the same location. However, from a resilience and BBB standpoint this would be not appropriate, since these children are one of the most vulnerable groups and the present building has only one floor that would be severely flooded in case of an extreme event. The access roads and the evacuation place would already be severely flooded by a HQ-100 flood event (see Refs. [87,88]). A vertical evacuation in the case of an extreme flood is not feasible, due to the fact that the building has only a ground floor. The analysis of the present evacuation plan and documents from the school and the assessment of flood hazard maps and respective exposure patterns, as well as expert interviews with the head of the school, underscore that a rapid and effective evacuation in case of extreme flooding will be a significant challenge. Moreover, the expert interviews also revealed that children and teachers have concerns about returning to the same building that was proven to be quite exposed and vulnerable to flooding in summer 2021 (see Table A1 in the Annex).

8.3. Significant changes versus the right to continue as before

Individual households and infrastructure providers do see the need to significantly modify their own houses or infrastructure (see Table A, Point 5, in the Annex and reference [89]). However, the present federal building regulations (see Ref. [90]), the funding rules for reconstruction (see Ref. [48]) and the lack of alternative land often hamper the opportunity to undertake significant changes. For example, a partially damaged private house or sports facility can be rebuilt based on the legal right of continuance if they are only partially damaged. In contrast, if a building or infrastructure is heavily modified or if a change in location is intended, there is a need to apply for a new building permit. This can take a significant amount of time, particularly if there is no zoning plan for the area where the building is located (e.g., old buildings/settlements or settlements in very rural areas), and a new legal planning basis for the area is needed as a precondition for the later approval of an individual building [91]. Moreover, the relocation of a house or infrastructure to a location less exposed to flooding or the river but still in an area that can potentially be affected by a 100-year flood event also requires a new building permit. This is often difficult to obtain (particularly in the zone that could potentially be affected by a 100-year flood event) since in that case, the new flood zone regulations apply, compared to reconstruction in the same place if the building is not completely destroyed [92]. Overall, the right of continuance is understandable from a legal point of view, but it limits the option to strengthen resilience building within the reconstruction process.

The new flood hazard zones (see Ref. [53]) are an important means to promote resilience. However, at present, they might also enforce a more conservative approach, since the legally binding flood hazard zones for most regions in Germany only consider the 100-year flood risk (HQ-100 flood zone) based on historic data. Unfortunately, these maps disregard other decisive factors, such as velocity and flood depth, and do not consider climate change scenarios that modify return periods in the future. Hence, these regulations (zones) do not sufficiently account for a risk based and adaptive planning process that brings hazard intensity and the vulnerability of the intended land-use into full account (see Table A1, Point 1 and 9 in the Annex).

8.4. New bridges versus the conservation of cultural heritage

Bridges played an important role in affecting flood height and wave generation during the 2021 flood event in Germany. Bridge clogging occurred in approximately 80% of all bridges investigated along the middle reach of the Ahr due to wood, caravans, cars and other debris [93]. This resulted in an overflow at 90% of the investigated bridges. The combination of clogging and overflowing resulted in a significant increase in the water levels (e.g., 2.5–3 m) in the Ahr Valley and an enormous increase in the hydrostatic and hydrodynamic loads on bridges [93,94]. Bridge failures due to overloads generated large and abrupt waves. These “tsunami-like” waves were reported by many people resulting in a sudden increase in the water levels downstream. The problem of bridge clogging and overflow is not new and was previously reported for historic flood events in the Ahr Valley in 1804 and 1910 (see Ref. [95]). From a technical point of view, flood resilient bridges are required that are higher and less susceptible to clogging and overflow or that can be lifted during a flood event. Temporary bridges have been built, but the discussion of standards for permanent bridges is ongoing. In addition, many bridges in the Ahr Valley are historic brick-made bridges under heritage protection. These historic bridges are important landmarks of the cultural landscape, together with vineyards and small villages.

After the Ahr river flood of 2016, an unused former railroad bridge near Brueck that was over a hundred years old was demolished to mitigate the effects of flooding, especially clogging and backwater effects [96]. This suggests that the balancing of different interests and claims allows a prioritisation for flood protection over historic infrastructures such as bridges. However, the demolition of old bridges and their replacement with new flood-proven bridges generally creates tension between different actors (local population, flood protection, heritage protection and others). Flood protection authorities would like to remove those bridges, that increased the flood levels in 2021. Heritage protection would like to protect these bridges [97] and to seek other possibilities to reduce flood water levels and the response of the affected population depends on whether they were flooded during the event or not. Currently, it seems to be very likely that most of those bridges will be removed to give the highest priority to the safety of human lives, see also the discussion about railroad bridges [98]. On the other hand, research has been conducted to identify ways of protecting and preserving cultural heritage sites in the face of growing threats from climate change and extreme weather events [99] showing the importance of cultural heritage.

8.5. Space for the river versus reconstruction close to the river

Flood risk management requires space for both water retention and for the river to flow through a valley and settlement without causing damage. While there is a general consensus that more space for the river and new retention areas are needed, space is limited in such small valleys, and various stakeholders try to push such responsibilities onto those up- or downstream. Intensive discussions are ongoing about retention areas and responsibilities for implementing these measures (see Table A1, Points 3 and 4 in the Annex). Additionally, flood protection infrastructures, such as dikes or retention areas, might be needed for some areas; however, these can cause conflicts with specific nature protection goals in the same place. Two years after the flood disaster, we can still observe that competing approaches do exist. While a river reconstruction plan for the county of Ahrweiler is in the making that aims to provide more space for the river as one important measure, there are at the same time contradictory development processes in some communities along the Ahr river which reduce the space for the river within their ongoing reconstruction (see the interview of Professor Büchs in reference 49). Overall, there is strong competition over space for flood risk management versus economic and settlement development in the reconstruction process (see Table A1, Point 7 in the Annex).

8.6. Multi-functional land-uses versus flood retention outside of settlements

While most flood retention areas will have to be placed in open spaces (agricultural land, forest areas, natural reserve areas), it is important to note that the land-use should also be adapted to a given flood risk in settlement areas. Existing settlement structures are protected by the German constitution law (Art. 14 GG), but almost all settlements undergo change over time, e.g. to higher density or brownfields are revitalised. Multi-functional land-uses for flood prone areas are important, but their implementation in legal frameworks and reconstruction funding schemes is still absent. One option to support appropriate multi-functional land-uses in flood prone areas could be the inclusion of settlements into the designated areas for flood prevention in the Regional Plan [100]; however, that is not yet the case in Rhineland-Palatinate. Flood priority zones in RLP are only defined for open space areas. Spatial planning based concepts to reduce flood damage in urban areas need to be better connected to green and open spaces and to land-uses, such as flood adapted sport fields, that are still within a settlement, but have a low damage potential. This means that new concepts and legal frameworks for multi-functional land-uses are needed, for example in terms of the design and construction of these land-uses and infrastructure. In addition, funding schemes within the reconstruction need to provide incentives to promote and implement such concepts. Moreover, municipalities want to know who would bear the costs of cleaning if a larger urban area (e.g. a sport field) is flooded on purpose (see Table A1, Point 4 in the Annex).

9. Options and measures to strengthen resilience in reconstruction

While every post-disaster process has its specific characteristics, we identified different phases within the recovery process that can also be found in other post-disaster contexts (see Fig. 1). We discussed options and challenges that exist for building resilience. In the following, we explore how specific strategies and measures to promote resilience can be linked to different recovery phases. In contrast to the literature that conceptualises options for policy transitions after extreme events mainly as a short policy window (see Ref. [101]), we find that, based on the research in the Ahr Valley, disaster resilient development and BBB can be supported in different phases of the recovery process and are still feasible months and years after the event. This is particularly the case during long-term recovery, including the reconstruction of sensitive and critical infrastructure such as the Levana School.

Our analysis underscores that various options exist within reconstruction to support disaster resilient development (see Fig. 1 and Table 2), particularly in recovery phases 3 and 4 to promote flood resilience in land use management and urban development practices. The overview of various sectors and areas that can contribute to building resilience during reconstruction processes (see Table 2) goes significantly beyond the past literature that predominantly looked at housing reconstruction.

Within recovery phases 1 and 2, options to strengthen disaster resilience are limited (see Table 2); however, a rapid but also strategic assessment of reconstruction needs considering long-term changes is an important basis for improving BBB in later phases. Moreover, rapid and sound information about options to rebuild houses and businesses in the same community or municipality and the support available, is an important aspect to reduce or influence outmigration. Within phase 3, which deals with the cleaning of landscapes, strategies such as increasing the water retention capacity can be considered as well as approaches to develop strategic retention areas.

Phase 4 offers most of the identified entry points for promoting BBB and building resilience. New flood hazard maps and flood protection zones (see Refs. [53,92]) can be directly applied during reconstruction if available. In addition, the consideration of different vulnerable groups (e.g., elderly people, children with special needs, etc.) in the reconstruction policies is important and could be achieved, for example, if specific protection standards for the reconstruction and location of elderly homes are considered (see Table A1, Point 1 in the Annex; 60). Overall, modified land-use regulations and zoning rules can help to promote resilience building (see Table 2); however - as discussed in expert workshops and policy science-events (see Table A1 in the Annex) -, this requires that robust and continuous information about flood risks and resilience building is provided to different stakeholders engaged in reconstruction and recovery (including companies that undertake reconstruction activities for individual households).

Furthermore, the reconstruction of important infrastructures, such as bridges or railroads, is part of phase 4. Within the ongoing reconstruction in the Ahr Valley, there is, for example, a controversial debate about whether and how bridges should be reconstructed since water clogging under bridges significantly increased flood heights [102]. The integration of flood resilience and adaptation

Table 2
Entry points for resilience building in recovery and reconstruction (+ + +, very high relevance for disaster resilient development, + + high relevance, + moderate relevance, ± moderate to low relevance for disaster and climate resilient development). Source: own table based on own observations, expert interviews, expert workshops and a household survey.

Recovery and reconstruction phases		Actors	Relevance for CRD	Options and measures to strengthen resilience	Hampering factors
Phase 1: Disaster assistance (first weeks after the event)	Damage and site assessment	Civil protection, military, engineers	+/−	The better the assessment, the more suitable the short- and long-term support. Time needed for assessments influences recovery time	Slow response rate in some cases, experts are limited
Phase 2: Recovery and relief support – short term recovery	Migration	Individual households	+ + +	Significant influence on the composition of municipalities (effect can be positive or negative); migration to safer areas possible	Information about migration is often missing, coordination difficult, inclusion may fail
	Mobile infrastructure	Electricity and water provision institutions	+	Cooperation between different actors and people affected	Provision of mobile infrastructures is often ad-hoc – not fully coordinated in the entire Valley
Phase 3: Cleaning and recovery of landscapes and open spaces (ongoing)	Cleaning of landscape	Municipalities, forest and agricultural institutions	+ +	Improve retention capacities of landscapes	The task is often just cleaning, rather than considering resilience issues
	Debris management	Municipalities	+	Avoids long-term contamination	Debris management is urgent and thus resilience is not considered
Phase 4: Reconstruction of houses and liveliness, reconstruction of public infrastructures (ongoing)	Flood hazard maps	SGD Nord/regional authority	+ + +	New flood hazard maps and flood protection zones considering changes in CC and the disaster	Old zoning plans and the right of continuance
	Reduction of vulnerability		+ +	Consideration of vulnerable groups (e.g elderly people) in DRR and reconstruction	Information is missing and vulnerable groups are not on the radar of institutions
	Land-use and urban development	Municipalities and various ministries	+ + +	Reduce damage potential, buffer zones, retention, and settlement standards	Partially limited options in terms of no-build zones and open space conservation in settlement areas
	Mental recovery programmes	Private and public institutions engaged in mental recovery	+ +	Personal security and ability to continue	Access to people is difficult
	Public infrastructures				
	Bridges	Municipalities, state	+ + +	Less bridges and modification of bridge structures	Limited funding, or historic bridges do not allow modifications
	Sports fields	Primarily municipalities	+ + +	Can offer space for flooding, cooperation between municipalities to concentrate those in safe areas	Low awareness of stakeholders, financing issue with planned and regular flooding
	Housing areas	Municipalities and county	+ + +	Location and building standards, e.g. houses on pillars	Space might be limited, lack of coordination, right of continuance
	Critical infrastructures	Critical infrastructure providers	+ + +	Integration of resilience measures (e.g. redundancy), moving facilities out of the floodplain and new planning	Costs and interests
Phase 5: Full recovery of livelihoods and communities (ongoing)	Public information	Information in media and planning	+ + +	Continuous information about flood risks, establishment of a culture of remembrance	Other topics are seen as more relevant
	New standards and norms	New zoning standards, new information tools	+ + +	Up-scaling of good practices	Interest to establish new norms

standards in the reconstruction of bridges and infrastructure are processes that often take time. However, improvements can be made within a reconstruction process without a significant increase in costs, if e.g. alternative sites or respective standards, funding and personnel to implement them are available.

Overall, our research underscores in a positive sense that different phases within the recovery and reconstruction process offer various opportunities and entry points to strengthen disaster resilience and BBB, in terms of risk reduction and adaptation to extreme events.

While the coordination of all actors in post-disaster situations might be impossible, we see a clear benefit in an integrated strategy and a monitoring system that would capture projects and reconstruction approaches that increase the resilience of people, infrastructure and ecosystems. At present, the focus of reconstruction strategies and reporting is often on completed activities and the amount of money spent [48] but less on innovations and resilience measures implemented. A shift towards resilience building, however, would require the definition of goals and criteria for resilience building in the first and second phase of the reconstruction process, which is feasible but rarely done.

Moreover, options to strengthen inter-municipal cooperation can help to join forces and reduce the amount of infrastructure exposed [60]. This can be done when neighbouring municipalities agree on concentrating local infrastructural facilities for joint use (e.g. sport fields) instead of rebuilding in the same place (see Table 2).

10. Conclusions

Reducing risks and vulnerability and strengthening BBB are critical elements of sustainable development. Many researchers and policy-makers still conceptualize disaster resilience after an extreme event as a process that improves a well-ordered and functioning society or community hit by an external stressor. This perspective also guides to a large extent the present funding regulations for reconstruction, where the specific losses due to the flood event 2021 are financially compensated, but pre-existing destabilisation is not sufficiently acknowledged. Consequently, we offer a different perspective in line with earlier research on vulnerability and disaster risk, e.g., by authors in Refs. [103–106]. We suggest that we often deal with systems that are already destabilised, where, for example, low risk awareness, multidimensional vulnerabilities, and high exposure to potential hazards (like flooding) are found. Reconstruction processes after disasters can therefore offer important entry points to build resilience and actually to BBB in the light of ongoing societal and climatic changes - including future changes in extreme events. However, compared to approaches that conceptualize resilience as a characteristic of individuals or that view resilience building mainly as a task of individuals in the sense of self-responsible entrepreneurs responsible for their own protection, we show that context conditions have to change to effectively build resilience after crises, focusing particularly on the issues of land management, planning, infrastructure reconstruction and loss and damage funding schemes. Therefore, we point towards the necessity of creating enabling environments for resilience building that go far beyond the area or region affected and that involve modifications of national laws and funding regulations defined by federal and state institutions.

Our study shows that approaches to strengthen resilient development and BBB strategies need to be adapted to a post-disaster context where many actors are under pressure to recover rapidly. However, just re-establishing the structures that existed before the disaster is not sufficient, since these have proven to be exposed and vulnerable. This is the case even when the reconstruction and recovery processes have addressed the existing hazard, as shown by the case of Lismore in Australia (see Box).

The findings of our study outline how aspects of disaster resilient development and BBB can be implemented during different phases of the recovery process. Changes in land-use and infrastructure reconstruction, for example, in terms of flood-adapted land-uses or bridges or schools, are long-term tasks and these modifications have long-lasting impacts. Consequently, funding schemes for these resilience gains in the medium and long-run are needed that also provide incentives to build back differently. This requires a shift of the focus from compensation of loss and damage to innovations in resilience building after extreme events.

This paper provides new findings in terms of the opportunities and challenges to promote and catalyse disaster resilient development within reconstruction and post-disaster processes – even when significant financial resources for loss and damage compensation are already available, such as in the Ahr Valley. It is important to strengthen strategies and measures that allow and promote resilience building, for example, inter-municipal cooperation in the development of retention areas. Other measures, such as payments for the replacement of oil heating systems with renewable energy, are also important since heating system replacement can have benefits for risk reduction as well as climate change mitigation.

We found that it is not just the funding or technical knowledge that determines whether lessons learned can be implemented but also other factors such as the role of cultural heritage (bridge replacement) or the time needed for the implementation of a specific strategy or measure that needs to be acknowledged. Finally, the findings of this study can also inform the reconstruction and recovery processes of other communities affected by recent floodings in Italy, Spain, Croatia, South Korea and other countries.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data of the household survey (selected parts) can be made available upon request after acceptance of the paper

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Annex

Table A1
List of key events and their outcomes in relation to Ahr Valley reconstruction project

Sr.No.	Name of the event	Date(s) and venue (s) of the event	Key messages/outcome	Type of organisations/ participants involved	Estimated participants
1	Expert meetings on “risk-based spatial planning” (Expert Meeting “Risk Planning” 2022)	June 10, 2022 (NRW) resp. June 28, 2022 (RLP)	- New requirements arose due to the Federal spatial development plan for flood protection (“Bundesraumordnungsplan Hochwasserschutz”) - Worthiness of protection as a politically normative concept - In addition to exposure, it is essential to consider vulnerability in spatial planning	State and regional planners (NRW) resp. State and regional planners as well as planners at the county level (RLP)	40 (NRW) resp. 15 (RLP)
2	Expert workshop on the subject of “retention areas” (Expert Workshop “retention-1” 2022)	December 09, 2022	- Different forms of cooperation can change land use - Technical and natural retention cause different problems and consequences in terms of spatial planning - Retention must happen in many places - Watercourse restoration concept not only eliminates damage, but it also optimizes the river - Further important measures: Cross-section widening of the Ahr; multifunctional areas	Water management experts and practitioners, planners, engineering companies, development agencies, administration, public authorities and scientists of different disciplines	85
3	Expert Workshop on the topic “Retention area potentials” (Expert Workshop “retention-2” 2023	May 12, 2023	- Planning evaluation of potential retention areas can identify conflicts, as well as areas with special suitability, based on different criteria - Only through combination of technical and natural measures significant reduction of flood wave - Consideration of an uncertainty factor and worst-case scenarios - Quantification of costs and benefits, e.g. settlement retreat vs. technical flood protection - Risk-based approach, e.g. prevention of risk accumulation - Necessity of securing areas for the damage-free runoff	Regional planner, administration, planners and practitioners at the county level and scientists from water management and spatial planning	16
4	Workshop “Reconstruction and flood resilience of sports facilities"	January 20, 2023	- Problem of financing measures - Possibilities for cooperation between sports clubs and municipalities in the merging of sports offers and facilities - Personnel capacities represent decisive inhibiting factor for emergency planning at sports facilities - Comprehensive strategy for dealing with flooding necessary (which also includes sports facilities) - Planning law hurdles, e.g. reconstruction of the original sports facility often much faster to realize, thus neglecting flood resilience - Partly inter-municipal projects, but associated with hurdles e.g. in terms of financing	Sports clubs, municipal officials, development agencies, and administration at various levels	30
5	Workshops on resilient power supply	October 18, 2022.February 14, 2023	- If possible, relocation of facilities and cables out of the HQ-extreme (voluntary) - Otherwise, relocate (vertically), build flood-resistant or flood-protected - Vulnerability of “users” to be taken into account more in the future - Resilient power supply essential in today's world, e.g. also for communications	Distribution system operator, administration at county level	20
6	Several Science-Practice Dialogues	June 29, 2022.November 07, 2022.June 15, 2023	- Various foci, including bridges and technical infrastructure, flood protection, spatial planning, and social infrastructure; see, e.g., https://www.youtube.com/watch?v=7sri2SsNLVc and https://www.youtube.com/watch?v=aTrZhr4-ub0	Administration, public authorities, politicians and other stakeholders	70–100
7	Several site visits	March 17, 2022.03 + May 04, 2022.18 + May 19, 2022	- Impressions of the destruction, the continuing impacts as well as the state of reconstruction - Informal one-on-one conversations and interviews	Exchange with practitioners from the ground	15–30
8	KAHR Science Conferences	29 + June 30, 2022.09 + May 10, 2022	- Very wide range of diverse, scientific contributions with space for discussions, see, e.g., https://hochwasser-kahr.de/index.php/de/neuigkeiten/2-kahr-wissenschaftskonferenz-2023-09-10-05-2023-call-for-abstracts?highlight=WyJ3aXNzZW5zY2hhZnRza29uZmVyZW56Il0=	Scientists from different disciplines and countries, administration and public authorities	100

(continued on next page)

Table A1 (*continued*)

Sr.No.	Name of the event	Date(s) and venue (s) of the event	Key messages/outcome	Type of organisations/ participants involved	Estimated participants
9	Expert meetings on "water management in Rhineland-Palatinate"	About every two months since mid-2022	- Discussion of the new floodplains - Flood height and velocity are not taken into account in maps and in the assessment of appropriate land use - Likewise, so far neither the sensitivity nor the worthiness of protection is taken into account - River restoration concept offers rudimentary resilience enhancement through, e.g., slightly more space for the river to flow, redesign of the river bank	Administration and public authorities with regard to water management, e.g. Ministry for the Environment RLP	approx. 20
10	Public Expert Hearing of the Federal Parliament of Germany, Committee on Housing, Development and Municipalities - Speech of Prof. Birkmann	July 06, 2023	- Information such as hazard maps must be incorporated into strategic decisions - Floodplains can change/heavy rain can occur anywhere, so better focus on vulnerability and worthiness of protection - Implementation of model approaches and documentation also important for other regions - Financial support for inter-municipal cooperation for better collaboration in the reconstruction process - Publication of heavy rainfall hazard maps important to better inform property owners and users - Higher protection standards for critical and sensitive infrastructures	Politicians and scientists	68–70
11	State Parliament of Rhineland-Palatinate (Enquete Commission) - Speech of Prof. Birkmann	June 20, 2023	- Importance of precautionary measures with regard to extreme weather events - Recommendation of consideration of different sensitivities and vulnerabilities, e.g. in urban land use planning, as well as of new sites and flood-adapted construction methods - Formulation of climate adaptation goals taking into account social aspects such as climate justice and vulnerability reduction desirable - Ahr Valley offers opportunity for model projects	Politicians, scientists and other experts	
12	Prof. Birkmann Interview	July 12, 2023	- Same reconstruction at the same location often not reasonable, esp. With regard to critical and sensitive infrastructure - Reconstruction fund only designed for damage compensation, but not for climate-resilient reconstruction > Amendment of the funding rules therefore necessary - Overall concept for the entire region necessary - Building infrastructure to meet the challenges of climate change for decades to come	Prof. Birkmann and Axel John (journalist)	2

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