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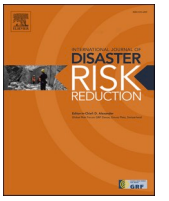

Collaboration is key: Exploring the 2021 flood response for critical infrastructures in Germany

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ABSTRACT

Growing dependence on critical infrastructures and exposure to natural hazards contribute to society's vulnerability to breakdowns, requiring adequate preparedness and a collaborative response during disasters. This study explores collaborative processes in the disaster response of critical water and health sectors following the 2021 floods in Western Germany. It identified key enablers and constraints for successful responses and their interactions. Organizational factors including collaboration, coordination, communication, information management and time management were key, and interacted with physical, human and social factors as well as with the overarching legal frameworks and policies within the disaster context. Lacking many enabling factors, the German flood response was insufficient, showing that critical infrastructures, their interdependencies and collaborative processes need a stronger consideration in preparedness planning.

1. Introduction

The growing number of disasters induced by natural hazards illustrates the dependency of society on functioning infrastructures, such as the supply of clean water, availability of health services and a functioning power supply. Longer outages can have truly disastrous impacts, with the potential for increasing fatalities in the aftermath of disasters.

In theory, critical infrastructures provide basic services for society's needs and functioning, not only enabling safety, security, and health, but also economic prosperity, social well-being, and economic development [1,2]. Essentially, they represent the backbone of a society, as the dependency on such services is increasing. Often overlooked however, is the complexity of providing and maintaining them. Critical infrastructures are highly interdependent across different sectors, for example, functioning health care depends on water and power supply, among others. These interdependencies increase the possibility of cascading impacts, risking a chain reaction of disturbances across various infrastructure sectors [3,4] ultimately exacerbating the impacts of disasters.

Continued functioning of critical infrastructures should hence be a key priority in both disaster preparedness and response. Yet, the sufficient integration of critical infrastructures in general disaster risk management and disaster response planning is still lacking [3,5,6]. Major disasters in countries around the world have demonstrated the potentially devastating impacts on critical infrastructures due to insufficient preparedness. For example, during the response of the 2011 earthquake in Japan, the population's needs for food, water, and sanitation were not met by the municipal governments which were responsible because of the severity of the disaster impacts [7]. After hurricanes Irma and Maria devastated much of Puerto Rico in 2018, many damages and fatalities occurred due to damaged and

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lacking infrastructures where most of the island did not have power supply, affecting other infrastructures severely. One year after the initial count of 64 fatalities, this number was estimated to be as high as 2,975, many of them due to long-term impacts of continued lack of access to proper health care and other critical services [8].

No country seems to be immune from such events, even those which consider themselves well-prepared. In July 2021, Germany was affected by extreme floods. Heavy rainfall in combination with already saturated soils triggered severe flooding in cities and villages within an area stretching from the cities Dortmund through Cologne to Trier in the two federal states North Rhine-Westphalia and Rhineland-Palatinate in the west of the country [9,10]. The floods were sudden and warning chains were disrupted. In many places, the water levels marked historical records much to the surprise of the local population and governments, causing dramatic scenes in the region. It cost over 180 lives, and thousands of people lost their homes [10]. Even a year later, many buildings and infrastructures have not been rebuilt, demonstrating the disastrous impacts and challenges in an adequate response. The event also demonstrated the significance of critical infrastructures during the event, as roads were blocked and power supply was disrupted, people were cut off from information, escape roads, and critical health services for the injured. The flood events showed the importance of infrastructures for survival, as well as crucial organizational and collaborative aspects relevant for preparedness and response planning.

Despite its shift from a rather technical flood defense approach to a more holistic approach with an extended focus on land-use planning and stakeholder collaboration since the major floods of the Rhine in 1995 [11], collaborative disaster response processes were insufficient during the 2021 floods. This led to severe problems in coordination, information management, and disaster response organization, particularly, the collaboration amongst the actors involved [10,12]. During a disaster, a variety of interdependent institutions with varying roles, capacities and work cultures come together to jointly manage the disaster impacts and minimize further risk, a highly challenging and complex undertaking [13,14]. Close collaboration between all stakeholders involved in the response is essential to maximize their effectiveness and requires adequate preparedness and planning [15,16].

Therefore, the purpose of this paper is to critically examine collaborative processes of the disaster response for critical infrastructures in the case of the 2021 floods in Germany. The supply side of the disaster response will be explored through the example of water infrastructure, which was highly needed among the population as well as by other infrastructure sectors. Health care facilities as part of health infrastructure are considered the demand side in this study, not only needing emergency water supply, but also support from the disaster response to cope with the floods and infrastructure failures other than water. Health infrastructure depends on other infrastructures, such as water supply, to carry out its function of providing basic healthcare. The objective is to understand which factors enabled or hindered efficient and effective disaster response as well as to better understand the cumulative impacts on critical health infrastructure, in order to provide insights and recommendations for improved preparedness and response.

2. Theoretical background

2.1. Critical infrastructures and disaster response

Critical infrastructures such as water supply, telecommunications, electricity and also services including health care, emergency response and government administration provide for society's basic needs and functioning [17,18]. This implies a strong dependence of societies on critical infrastructures, referred to as "lifelines" [2,17]. Critical infrastructures are furthermore characterized through high interdependencies and the possibility of cascading impacts [3,4,19]. This means that the performance of one sector influences the performance of other sectors and disturbances in one can cause disturbances and even failures in another [4,17]. For example, power outages will impact water supply as this is necessary for its transportation via electric-powered water pumps [20]. Strong interdependencies therefore increase the vulnerability of critical infrastructures. In parallel, growing dependence on critical infrastructures in combination with cross-sector interdependencies and growing challenges from more frequent and more intense natural hazard-induced events contribute to increased vulnerability [1,2,21]. These challenges must be considered in disaster risk management and continuous functioning of critical infrastructures ensured to support the resilience of communities.

Hence, recent studies have increasingly focused on infrastructure resilience [2,17,19,22,23]. Resilient infrastructures are able to maintain functionality during an emergency, which implies preparedness to minimize the negative effects of a potentially disruptive event, as well as the ability of the system to resist, absorb and recover [4,19,23]. Authors have examined technical and – though to a lesser extent – organizational aspects that influence the functioning and resilience of critical infrastructures [4,19,23,24]. While technology is an important element, organizational mechanisms and collaboration largely define how the emergency is managed [25].

Cross-sectoral interdependencies and shared responsibilities necessitate effective collaboration between various stakeholders to respond to a disaster event [25,26]. Therefore, the successful management of critical infrastructures during a disaster not only depends on individual institutions such as infrastructure providers, but also on their inter- and collective actions with other stakeholders, such as disaster preparedness planners and responders [4,19]. As a result, disaster preparedness planners and responders necessitate a good understanding and consideration of critical infrastructures and their interdependencies to best minimize disaster risk [27,28]. Nevertheless, authors [3,5,6] suggest that critical infrastructure management is yet insufficiently considered in disaster planning and responses, which increases the vulnerability of critical infrastructures even further. To optimize preparedness planning and response for critical infrastructure breakdowns and to enable targeted support, better understanding of stakeholders' requirements for effective collaborative processes during disasters, as well as of the influence of various factors is needed.

Therefore, this study examines critical infrastructures and the key stakeholders responsible for the management of them in the event of a disaster with a focus on collaborative processes, based on the case of the German floods in 2021.

2.2. Disaster response and links to critical infrastructures in Germany

In Germany, disaster response is carried out in accordance to the regulations of the sixteen federal states, which are responsible for crisis response during peace time [29]. During a disaster, when local capacities of communities are exceeded, the respective head of the district, city or regional authority is responsible for coordinating and initiating all response measures [30]. The political authority oversees two separate units which contribute to the overall disaster response. The operative-technical unit, usually led by the head of a fire department, is responsible for initiating all operational-tactical measures to avert the dangers and limit the damage by leading and deploying emergency personnel and equipment. The administrative-organizational unit ensures administrative coordination of the disaster response [30,31] and supports lower authorities and smaller administrative units. In this study, the term "crisis cell" is used to refer to the three components, namely, the political authority and the two units, that are jointly in charge of the formal coordination of the disaster response. Staff members of the different components are referred to according to their relevance and responsibilities.

In addition to the governmental crisis coordination, key stakeholders for the response to critical infrastructure disturbances include infrastructure providers and first responders, such as the fire department and the Federal Agency for Technical Relief (THW) as governmental institutions, as well as other non-governmental aid agencies such as the German Red Cross. Consisting of professional and volunteer fire fighters, the fire department is responsible for day-to-day emergency response and is also a key stakeholder during disaster events. Upon request, additional support can be provided by THW, employing a total of 80,000 volunteers and 2000 full-time staff members [32,33].

Concerning the water sector, first responders will provide resources for alternative water supply, such as vehicles for water transport and packaged drinking water [34]. Health authorities are to be informed about the water quality and will decide whether alternative water supply is needed or if the quality criteria can be lowered for certain uses. Standards are determined by the Drinking Water Ordinance, which also mandates water providers to have contingency plans in case of deviation from the standard [35]. Additionally, water providers can be supported by first responders. Fire departments are able to provide technical and logistical support, such as transporting water with specific trucks. THW can support though additional drinking water supply and emergency repair of critical infrastructures. Other aid organizations can support the THW and fire departments too, for example, the German Red Cross provides support with mobile drinking water treatment plants, laboratories and various transportation assistance from specific local associations [34].

2.3. Collaborative processes in disaster response for critical infrastructures as risk governance

Critical infrastructure management during disasters is essentially a collaborative process which includes inter-institutional collaboration under the influence of various factors [16]. Acknowledging this, this study will apply a risk governance approach to comprehensively investigate the requirements for collaborative processes in disaster response and critical infrastructure management.

The concept of governance describes "*the processes and institutions, both formal and informal, that guide and restrain the collective activities of a group*" [36], and therefore, defines a collaborative process. Risk governance applies this concept to a risk context accommodating the complexity of actors, structures and processes as well as the underlying uncertainty of risk and risk management [37,38]. Furthermore, this "*includes the totality of actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analyzed and communicated and management decisions are taken*" [38] to find joint solutions to certain challenges in a risk context [37,39]. The concept therefore recognizes not only policies and legal frameworks as important elements of risk governance, but also considers the institutions involved and their contextual settings which govern collaborative action in response to risk. Collaborative processes for disaster response are thus governed through decision-making processes and a variety of factors as well as the interactions between them [37]. Overall, an effective disaster response requires the minimization of cascading risks and the provision of targeted and need-based support through rapid needs and capacity assessments as well as timely, informed and flexible decision-making in a collaborative process [25,40,41].

Authors have identified various factors that govern collaborative processes in disaster response based on literature reviews [25,26,39,42], as well as empirical data and case studies from past emergencies [15,16,27,41,43,44]. The most important factors cited across papers can be grouped as follows.

Disaster context. This may include substantial and large-scale destruction, human casualties (depending on the nature of the hazard), preparedness and exposure of communities and territory [26]. Basic infrastructures, such as information and communication technology (ICT) and transport infrastructure can be severely affected [6,41], as well as the availability of staff. This can create significant communication and logistical challenges and also limit staff capacities, which are essential for effective collaborative disaster response [6,41].

Policies and legal frameworks. These determine preparedness and define the stakeholders' roles and responsibilities and formal channels of coordination and communication during the response. Therefore, they govern stakeholders' activities and interactions as well as institutional and staff capacities to deal with the disaster at various administrative scales [4]. Policies further determine bureaucratic structures and processes, obligating stakeholders to adhere to certain rules and regulations which govern such procedures [25].

Physical factors. This includes basics infrastructures such as electricity, ICT, transport, and water supply. They support logistics as well as communication impacting the quality and timeliness of information [16,25,42,43,45]. Furthermore, technological equipment enables operative processes throughout the response [25].

Social factors. Social contexts and culture also play a significant role in how stakeholders communicate, interpret information and collaboratively manage risk and disaster [38,39]. Social factors refer to the relationship between two people or more and thus include the existence of networks and relationships. Further, factors which directly influence relationships such as trust and clarity in role

definitions can be attributed to social factors. They directly influence communication and information management within and between people and institutions [13,14,46–48].

Human factors. This includes staff, expertise, experience as well as other psychological factors at individual level such as stress which can directly influence decision-making and interactions [14,42,44]. For the management of critical infrastructures, authors highlight the need for a certain understanding and expertise of critical infrastructures, which will support coordination, communication and information management [6,25,49]. Experience with previous disasters and similar scenarios enhances awareness of certain patterns and their understanding of the needs of an emergency situation, which is important to support timely and adequate decision-making [45,50–52]. In turn, lack of experience can have counter-productive impacts, for example creating stress and fear, potentially leading to a loss of focus and poor task prioritization [42,51]. It is important to acknowledge that factors at individual level and related issues can also be traced back to other factors, such as the lack of trainings for capacity-building.

Organizational factors. Coordination, communication, information management, collaboration, and time efficiency are factors which directly influence decision-making [41,53]. Formal coordination from public administration as part of the collaborative process directs the stakeholders' activities to ensure organized resource sharing and communication, and can therefore meaningfully enhance efficiency and effectiveness of the collaboration between people and institutions [16,42,43,46,54]. Communication describes the way any kind of information, including facts, assumptions and also feelings, is exchanged between people and institutions [25]. Information management implies accessibility of information and it is important for the assessment of local risks and needs to enable informed decision-making for effective, need-based response and its organization [25]. Collaboration includes joint activities by at least two people or institutions with the intention of working together and joining resources towards a common goal of public value – the disaster response [55]. Time efficiency is essential given the urgency of the disaster context and the necessity for rapid action as people's lives may no longer be ensured [25,54].

Governance and organizational challenges linked to critical infrastructures and risks of disturbances have been addressed in literature [4,17,24,29,56]. Nevertheless, little research exists on critical infrastructures, interdependencies, and collaborative

Table 1
Overview of interviewees.

Interview ID	Interviewee ID	Gender	Institution	Position	Governmental/non-governmental	Volunteer yes/no	Interview type
1	H1	M	Political authority	Mayor	Governmental	No	Group
1	U2	F	Administrative-organizational unit	Head of department for advisory, public work, organization, social affairs	Governmental	No	Group
1	J3	M	Technical-operational unit	Head of fire department	Governmental	No	Group
1	E4	F	Municipal administration	Environmental planner	Governmental	No	Group
2	O5	M	Health department	Head of health surveillance division	Governmental	No	Individual
3	W6	F	Health department	Staff with responsibility for drinking water	Governmental	No	Individual
4	C7	M	Infrastructure provider	Head of department for network planning, documentation and sales	Non-governmental	No	Individual
5	A8	M	Infrastructure provider	Executive director	Non-governmental	No	Individual
6	P9	M	Fire department	Professional firefighter, head of department for staff, operations, control center, training, and civil and disaster protection	Governmental	No	Individual
7	X10	M	Technical relief agency (THW)	Troop leader for special group for drinking water supply	Governmental	Yes	Group
7	Z11	M	Technical relief agency (THW)	Group leader for special group for drinking water supply	Governmental	Yes	Group
7	B12	M	Technical relief agency (THW)	Official (deployment/critical infrastructures)	Governmental	Yes and no	Group
7	D13	M	Technical relief agency (THW)	Group leader for special group for drinking water treatment	Governmental	Yes	Group
7	G14	M	Technical relief agency (THW)	Troup leader for special group for drinking water treatment	Governmental	Yes	Group
8	J15	M	German Red Cross	Head of department for disaster prevention and tracing service	Non-governmental	No	Individual
9	F16	M	German Red Cross	Responsible for drinking water laboratory	Non-governmental	Yes	Individual
10	S17	F	Hospice care facility	Hospice and nursing management	Non-governmental	No	Individual
11	K18	F	Hospital (1)	Head of Quality and Risk Management	Non-governmental	No	Group
11	M19	F	Hospital (1)	Nursing management	Non-governmental	No	Group
11	B20	M	Hospital (1)	Technical management	Non-governmental	No	Group
12	W21	M	Senior's pension	Managing Director	Non-governmental	No	Individual
12	V22	M	Senior's pension	Technical management	Non-governmental	No	Individual
13	I23	M	Hospital (2)	Managing Director	Non-governmental	No	Group
13	R24	M	Hospital (2)	Technical management	Non-governmental	No	Group
13	L25	F	Hospital (2)	Nursing management	Non-governmental	No	Group

processes in practice when risks manifest [19]. Furthermore, the interactions between critical infrastructure stakeholders and first responders are not well researched [1], and no research addressing these interactions based on empirical data from a case study could be found. Research based on case studies interfacing critical infrastructures and preparedness planning and response with a focus on the collaborative processes between key stakeholders during disaster is much needed. This study aims to fill these gaps by studying the collaborative processes of the supply and demand side of disaster response for critical infrastructures with a focus on the water and health sectors the during the 2021 floods in Germany by uncovering answers to the following research questions.

1. How was the disaster response for water supply and health care impacted by the floods?
2. Which factors enabled and constrained the stakeholders in delivering effective and efficient disaster response during the floods?
3. Which conclusions can be drawn to improve future disaster preparedness?

3. Material and methods

A qualitative approach was applied, which allowed in-depth exploration of the collaborative processes based on the interviewees' lived experiences, perceptions, decisions, needs and priorities. A total of thirteen interviews including four group interviews were conducted between October 2021 and June 2022 with a total of 25 representatives from various institutions (Table 1). Group interviews included a minimum of three interviewees. The interviews were conducted through telephone and video calls as well as in person, with a duration ranging from 53min to 2 h 38min and averaging 1 h 17min.

To gain deeper insights into the supply side of the disaster response with the example of the water infrastructure sector, nine interviews (including two group interviews) were conducted with sixteen representatives of key stakeholders of the disaster response for water supply (interview IDs 1–9). Interviewees represented a fire department, the German Technical Relief Agency, the German Red Cross, infrastructure providers, a municipal crisis lead and health departments from different cities within the flood-affected area.

For a more profound understanding of the cumulative impacts on critical health infrastructure, four interviews (including two group interviews) were conducted with various health care facilities affected from the floods. Representing the demand side of the disaster response (interview IDs 10–13) were two hospitals, a retirement home and a hospice care facility. Interviewee identification and selection followed a snowball sampling approach.

All interviews were conducted in German language and interviewees' statements quoted in the results chapter have been translated into English by the authors. Both individual interviews and group interviews followed the same questionnaire with 14 questions and necessary adaptations based on the interviewees' responsibilities, adding up to a total of 16 questions. The questionnaire was designed based on an explorative literature review and included both open-ended and closed questions covering the following subjects: preparedness, risk awareness and experience with disasters or disruptive events, responsibilities, inter-institutional collaboration, communication and interdependencies, requirements and gaps during the response as well as lessons learned and recommendations for better preparedness. This enabled more of a focus on the relevant subjects and also new topics to emerge according to the interviewees' experiences and priorities.

Video and audio recordings amounted to 16 h 51min and were all transcribed verbatim. Coding and analysis were both deductive and inductive, using MAXQDA software. First, interviews from the disaster response and water sector were coded to identify enabling and constraining factors. Coding followed a deductive approach based on the subjects of the questionnaire and those identified in the literature on critical infrastructures, risk governance and decision-making during disaster response. Coding also followed an inductive "data-driven" approach based on observations from the data, thus following a Grounded Theory approach. Acknowledging the contextual influences in governance, this approach was suitable and enabled the analysis of decision-making and collaborative processes with attention to governing contextual and individual factors [57]. New codes were created within the initial coding scheme, which was then re-structured during coding and data analysis. This coding scheme was used to code and analyze the interviews from the health sector in a next step, following the same approach to allow both focus on the relevant subjects to identify the impacts for the health care facilities from the identified factors, as well as for new codes to emerge according to sector-specific needs. The results are presented based on the major themes that emerged from the priorities of the interviewees from the disaster response and water sector, the supply side of the response.

All interviewees were asked for permission to record and transcribe the interviews and to use the content for this research prior to the interviews. All interviewees were anonymized in this study to ensure confidentiality.

The study has some limitations. Representing individual experiences from different flood-affected locations, this research is not a chronological and area-wide representation of the 2021 flood events. Not all potential interview partners were available for an interview, but the number of interviews was considered sufficient as a level of saturation was reached when patterns could be identified across interviews. Furthermore, perceptions of risk and emergency can highly differ between individuals, even if their experience was in a shared location. Therefore, this research does not present an objective and statistical representation of the flood events. One must also acknowledge that every disaster is different and will produce different experiences and lessons learned.

Henceforth, this study does not claim to produce universally valid results for any type of disaster and the results may not necessarily be applicable to other types of disasters. Nevertheless, it provides an overall image of the event and its perceived consequences. The factors identified are rooted in prevalent social and political structures and processes. Their consideration in preparedness planning can thus support collaborative systems and processes in disaster response contexts outside of the event in the focus of this study.

4. Results

The interviewees faced a variety of challenges and constraints, which they often responded to spontaneously. Overall, the

Table 2
Overview of factors based on the analysis of interviews 1 to 9, supply side of the disaster response. Interviewee IDs from interviewees who made respective statements are added from both supply and demand side of the disaster response. *Spontaneous action.

Type of factor	Category	Constraining factors	Interviewees	Enabling factors	Interviewees
Disaster context	Anticipation of floods and impacts	Unexpectedness of the floods	All		
	Flood impacts	Severe flood impacts	All		
	Preparedness	Limited preparedness	All	Preparedness for worst-case scenarios on site*	P9; G14
Physical factors	Electricity	Electricity outages	H1; U2; J3; O5; C7; A8; P9; D13; G14; F16 S17; K18; B20; W21; V22; I23; R24		
	ICT infrastructure	Damaged ICT infrastructure	All	Functional ICT infrastructure	J3; E4; O5; C7; P9; X10
	Transport infrastructure	Damaged transport infrastructure and limited accessibility of places	All	Off-road trucks	A8; P9; X10
	Equipment			Equipment (e.g., for water treatment and transport)	P9; X10; D13; G14 K18; M19; B20
Legal frame-works/ policies	Bureaucracy	Lengthy communication and coordination	H1; U2; O5; C7; A8; P9; D13; G14 S17; K18; M19; B20		
Social factors	Role clarity	Lack of role clarity	U2; O5; W6; A8; P9; D13 V22	Role clarity through preparedness plans and relationships	U2; W6; A8; P9
	Relationships	Lack of pre-existing relationships	O5; A8; P9; X10; D13; G14	Pre-existing relationships	O5; W6; C7; P9; F16 S17, W21; V22
	Trust	Lack of trust in capacities	O5; P9; X10; D13; G14	Trust	P9; X10; D13; G14; J15 S17; K18; I23
				Proof of capacities through legal documents and certificates*	P9; X10; D13; G14
	Social expectations	Diverging social expectations	U2; P9	Common social expectations	U2; P9
Human factors	Staff	Reduced staff	U2; E4; O5; C7; P9 S17; M19; B20; I23		
		Limited availability of volunteers	A8; P9; X10		
	Practical experience for emergency response	Lack of practical experience for emergency response	U2; A8; P9 V22	Practical experience and skill for emergency response	P9; D13 K18; M19; B20; V22
				Ad hoc engagement of experienced staff*	P9
	Technical expertise	Lack of technical expertise (e.g., for water supply)	C7; A8, P9; X10; D13; G14 W21; V22; I23; R24	Technical expertise (e.g., for water supply)	O5; C7 A8; P9; G14 S17; K18; M19; B20
				Ad hoc engagement of technical experts*	P9 S17; K18; W21
	State of mind	Overwhelmed, stressed	U2; P9 S17; K18; W21; V22; I23; L25	Motivation to help (volunteers)	O5; C7; P9; G14; F16
				Awareness of responsibility to provide support (professionals)	H1; U2; J3; E4; O5; W6; C7; A8; P9; J15
Organizational factors	Formal coordination	Poor coordination	O5; C7; A8; P9; X10; Z11; G14; J15; F16 S17; K18; M19; V22	Swift coordination, informal coordination*	C7; A8; D13
	Communication	Communication challenges	All	Informal communication*	H1; U2; J3; E4; O5; C7; A8; P9 S17; W21; W22
	Information management	Lacking accessibility of information	All		
	Time management	Delays	H1; U2; O5; W6; C7; A8; P9; X10; G14; J15 S17; K18; M19; B20; W21; V22	Time efficiency	W6; C7; P9; D13
	Collaboration	Collaboration challenges	All	Good collaboration	All

interviews yielded 40 different factors, 21 of which constrained and 19 of which enabled the collaborative processes during the disaster response (Table 2). All factors are highly interconnected. Organizational factors were central for the disaster response, which was based on timely and effective collaboration, supported through information and communication, and facilitated through formal coordination from crisis cells. Some factors, both organizational and non-organizational, directly impacted institutional collaboration; and some factors directly influenced the coordination from the crisis cell, which then impacted institutional collaboration. Interestingly, there are no sectoral differences, i.e., all sectors are represented almost equally per factor and no pattern could be observed.

The findings will be presented according to the constraining or enabling qualities of the factors in the given contexts and their interactions. Findings in relation to the disaster context will be presented first, followed by physical factors, legal frameworks and policies, social factors and human factors of the collaborative process. Many of these then influenced the formal coordination as organizational factor, which will be presented lastly. Each sub-chapter describes the processes within the disaster response (interviews 1–9) as well as the impacts on health care facilities (interviews 10–13).

4.1. Disaster context

4.1.1. Unexpectedness and severity of the floods and limited preparedness

All interviewees expressed surprise by the severity and scale of the floods and their impacts. The floods caused severe damages to critical infrastructures and even affected many disaster responders personally limiting their availability (P9; U2; E4; O5) while staff for some institutions, which constrained the respective institutions in fulfilling their responsibilities. Additionally, an interviewee from an infrastructure provider company (C7) said that the extensive scale of the disaster required more staff for the response than were available.

With respect to disaster response and infrastructures, interviewees from the fire department (P9) and THW (G14) said that they took all available equipment to the affected sites to ensure utmost preparedness for any scenario. Furthermore, the same interviewee from the fire department (P9) mentioned an innovative system for emergency water supply which he deployed during the response. An interviewee from an infrastructure provider (A8) and an interviewee from a health department (W6) reported to have plans for certain contingencies and disruptions, which were however, of no use given the scale and severity of the disaster.

The severity of the disaster also significantly limited the health care facilities in their ability to maintain operations and keep patients safe. While one interviewee highlighted that they had not been warned by the authorities: *"The warning of the flood is still pending today"* (I23), all respondents emphasized how surprised they were by the severity of the impacts: *"no one could have expected that it would overtake us so massively"* (I23), saying that the first day after the flooding *"was about surviving"* (W21). Damaged infrastructure and failures cut them off temporarily from electricity and water supply, wastewater and sanitation, communication networks, and transportation routes. All facilities had to be completely evacuated, eventually.

Preparedness measures on site were described in all interviews as mainly technical, including torches, radio sets, or emergency electric generators. While the two hospitals had generators on site, which is mandatory for hospitals according to law, one health care facility had a second generator on site which they had purchased proactively (S17), while the other one was able to acquire a second one in the aftermath of the flood (W21). Neither facility was prepared for failures of water or sanitation. At an organizational level, contingency plans were at hand, however, they were perceived as inadequate, described as *"nonsense"* (K18), and *"lapsed"* (W21). The same interviewee criticized that in such contingency plans *"all emergency scenarios are designed to be remedied in the short term"* (W21), and that constrained disaster response and its cascading impacts during larger disasters were not considered.

Overall, preparedness measures were insufficient as these were not designed for disasters of such severity, which required many ad hoc solutions. While many interviewees pointed out the need for spontaneous action to respond to a disaster of such scale, the need for better preparedness within health care facilities was strongly emphasized.

4.2. Physical factors

4.2.1. Transport, electricity, and ICT infrastructure

Damaged roads, bridges, and railway lines impeded accessibility of the affected locations. In one of the most affected areas, the topography was characterized by steep and muddy hills. As a result, not only was the acquisition of information and an overview of the situation to assess support needs a challenge and time intensive, but so too was the restoration of at least provisional water supply. These difficult conditions even caused safety risks for vehicles and their drivers, further constraining effective and timely decisions and action for water supply (P9). Additionally, some interviewees (P9; H1; E4; U2; O5) reported that some staff members were not able to reach their workplace or only with great delay, further limiting staff capacities. "*Places were not accessible; many bridges were torn away. […] There were no experts on site, the water supply companies and the authorities were personally affected. That's why there was no one on the crisis lead team. It was a pure chaos.*" (P9)

Damaged electricity and ICT infrastructure largely constrained communication, information management and thus collaboration during the first few days of the floods. Some interviewees (H1; U2; E4; O5; C7) reported that communication through work email and phones was not possible due to network problems and instead, private communication channels such as WhatsApp and personal phone numbers were used instead. Additionally, due to a lack of electricity, monitoring of the water levels in certain tanks was disrupted, hindering adequate needs-assessment (P9). *"We could not reach our people. We had a person on the other side (of the valley) who came back after hours and reported a condition […] which had perhaps changed and was no longer true, and then to say 'so, we'll do it exactly like this, please drive back.' […] Travel time was enormous*." (A8) In response, the interviewee from the fire department spontaneously established a Geographic Information System to use through a mobile application and monitor real-time water levels for assessment of needs for water supply. An interviewee (A8) from an infrastructure provider strongly emphasized the need for better and continuous functionality of communication infrastructure.

Constrained communication, lack of information and delayed support heavily affected the health care facilities, not receiving up-to-date information about the current situation (S17; W21; V22): *"the biggest problem was […] that we had no communication. That was the be-all and end-all. […] We didn't get any information about what was happening around us."* (V22)

Unable to communicate with first responders, two interviewees stated that they were not informed whether and when support could be expected (W21; V22). This resulted in great uncertainty among staff: "*We were on our own for the next few days. We had to see that we could find a solution"* (V22) *"We were here on an island."* (W21) According to some interviewees, arranging supply of food, water, equipment, and the relocation of patients to other facilities was very challenging and sometimes organized during only a few seconds of phone connection as well as by cycling and walking with rubber boots to the nearby hospital and fire department (S17; W21).

An interviewee said that during the flood, first responders *"couldn't even get here […] The water was too high and the flow rate of the water on the road was so immense that you couldn't have driven here even with a heavy fire truck […] so the hospital could not be approached with heavy equipment at all. […] the access roads were no longer passable at all"* (I21). Being constrained in their support from first responders, also internal response capacities were limited. Hospital staff had difficulties too as some could not reach their workplace at all because roads were full of garbage and debris (S17; M19; I23), so that *"you could hardly drive 100 m"* until "*the tire was flat again"* (B20).

4.3. Legal frameworks and policies

4.3.1. Bureaucracy

Communication with other institutions had to be done very formally through staff, secretaries, and forms, and was therefore described as time-consuming. The use of private communication channels such as WhatsApp was reported to be much more efficient. This was additionally supported by built relationships. "*The theory is that people communicate with each other formally […] and reality showed that people communicated more quickly and directly through private contacts than through official channels.*" (C7) In addition, two interviewees (A8; P9) criticized a first response institution for being too reliant on bureaucratic structures and processes. For example, an interviewee (A8) from an infrastructure provider said he had requested support for water treatment. After over a week's wait for a response, the request was rejected as his institution was found not to meet the legal requirements to receive support. He had to seek support from other institutions, instead.

Formal coordination of support through the crisis cell and the official process of requesting support also required a lot of paperwork and time. Three interviewees (O5; D13; G14) furthermore criticized the lengthy process until support for drinking water was approved as this decision, tied to the drinking water standards, had to be assessed from several authorities.

In response to the bureaucratic and lengthy coordination, an interviewee from an infrastructure provider (C7) made use of an online platform created by two German public associations for energy and water management in the context of the 2021 floods. He said it facilitated "*very non-bureaucratic and fast*" informal coordination of support between those institutions in need of and those which offered technical support, enabling direct contact and action, and supporting effective and efficient disaster response. Moreover, some interviewees (H1; U2; J3; A8; P9) stated that "*no longer asking, and instead, just doing*" (A8) was a common response to avoid lengthy bureaucratic processes given the urgency of the situation, as well as "*using one's human sense instead of strictly following a book*" (H1). Overall, bureaucratic processes and structures hindered organizational factors such as communication, collaboration, and formal coordination.

The interviewees with the health care facilities confirmed the constraining impacts from bureaucratic structures and processes to receive support during the response. For example, an interviewee stated that it was challenging to reach first responders through official ways: *"We couldn't get anyone from the fire department on the phone. They were totally overloaded."* (S17) The interviewee could get in contact with the fire department only "*via private contacts of colleagues who have their husbands working for the fire department"* (S17). Another aspect noted was that health care facilities were not on the list with "*all the important telephone numbers for disasters"* kept by the district administration, whereas it included an animal rendering company, pointing out the lacking effectiveness of certain regulations (K18). Furthermore, one of the interviewees mentioned that, to his surprise, a crisis cell mandated a flood damage assessment in the hospital two weeks after the floods, which was perceived as unnecessary because by that time "*everybody knew who was affected and where"* (M19). Having to deliver comprehensive reports about the current situation every day, the mandate was even perceived as burdensome. In addition, the approval from the crisis cell of sewage disposal collection through a big tank and pumping station was very lengthy, taking "*almost 14 days"* (B20).

4.4. Social factors

4.4.1. Relationships, trust, and role clarity

Almost all interviewees stated that networks and trustful relationships were key enabling factors for quick and efficient collaboration during the disaster response. They enabled clarity of roles, responsibilities, and capacities, which prevented the need to explain oneself as well as prevented lengthy formal communication, further supporting swift collaboration between institutions. "*You have to have a good network. […] My experience is that personal contact usually leads to quicker results and quicker solutions. And if you are a reliable partner and know your counterpart … Then a lot of things can be done on demand, which is difficult under certain circumstances if you try to achieve something anonymously by e-mail.*" (J16) For example, collaboration between health departments and infrastructure providers as well as fire departments went well during the response due to their trustful relationships and clarity of roles, responsibilities, and capacities. This was because they collaborated regularly outside the disaster context (W6; P9).

However, pre-established and trustful relationships between volunteer first responders and other institutions were lacking (O5; A8; P9; X10; D13; G14). As a result, capacities of the first responders were not always clear to those in need, such as the health department and health care facilities (X10; D13; G14). In some cases, this resulted in the lack of trust in the institutions. Frequent shift rotations

among the volunteers due to limited availability and absence from their workplace in combination with insufficient handovers further constrained the stakeholders in building relationships and trust with other institutions. This resulted in the need for permanent and lengthy explanations and confusion about contact persons (O5; A8; P9; X10). "*They always have to explore, they change weekly and there is no proper handover. Every week you have someone of the new squad, […] asking exactly the same questions […] as the predecessor.*" (A8)

Furthermore, the interviewee from the fire department (P9) reported that water providers were often not familiar with the innovative water system and lacked trust in the capacities of the fire department to deliver a reliable water supply. Trust in organizational capacities could be enabled through legal documents and certificates which proved capacities (P9; X10; D13). For example, interviewees from THW showed written proof of their ability to provide drinking water quality with their equipment to a health department (X10; D13). Role clarity was furthermore facilitated through administrative documents for preparedness planning (W6; A8). An interviewee from THW (G14) stated the need for policies from the government to facilitate support and connect stakeholders from the supply and demand side of the disaster response to establish relationships as means for improved preparedness.

Health care facility managers stated that established and trustful relationships enabled them to spontaneously organize support, equipment, and staff around the clock from local companies: *"We're lucky that we have a lot of local companies that we've worked with for years, that we also had the private numbers of"* (V22). Well-established relationships with other health care facilities were also critical to organize support, such as for food, water, and evacuations. For the hospice care facility and retirement home, this was important to enable patient transfers to the same kind of facility to ensure well-being (S17; W21). Another interviewee mentioned that the contact with a nearby hospital was crucial to get "*food and things like that […] We were lucky that [name] hospital was there. […] What would we have done without them? We wouldn't have been able to get anything from anywhere"* (V22).

Furthermore, trusted relationships and cohesion among health care facility staff were crucial factors enabling effective internal response, according to all interviewees: *"What we have learned from this is that cohesion is the most important thing […] only as a team, no matter which professional group, you can survive such a catastrophe, also solve it and move forward together"* (I23). The interviewees reported that the experience of responding to the disaster as a team significantly strengthened the employees' social cohesion (S17; K18; I23). Interviewees said they learned they *"can rely on each individual 100 percent"* (S17).

4.4.2. Social expectations

In such cases when different institutions were used to different modes of work and to the use of different tones and vocabulary, interviewees reported further communication challenges (U2; P9). This resulted in divergent social expectations (P9), constraining swift inter-institutional communication and trust-building during the response. Those who were used to working in a task force were used to communicating in a clear and concise manner, partly at the cost of being considered as rude and impolite by others without this experience, including administrative staff of the crisis cell and volunteers (U2; P9). This created communication challenges also between the crisis cell and the operative component of the governmental disaster response lead (U2).

"*These [disaster response] are systems that the fire department and the Bundeswehr have already practiced very well. For administrations, […] this is much, much newer. Because we normally work in a completely different mode, in a much more partnership-oriented way, and command and obedience are not so common.*" (U2)

As opposed to the administrative staff member of the crisis cell (U2), the interviewee from the fire department (P9) highlighted that communication through command and obedience is part of his daily work. Both interviewees mentioned that while persons with the same or a similar work culture communicate and collaborate smoothly, challenges might arise between those being used to different work cultures.

"*We are used to working in a task force […]. We can deal with command and obedience. We can also yell at each other […] and talk loudly, but we are still aware that we have to function. If someone doesn't know that they are quickly offended, and may say, 'no not with him anymore', 'if he talks to me like that, no thank you'*" (P9)

4.5. Human factors

4.5.1. Practical experience and skill for disaster response and technical expertise

Coordination, as well as collaboration were reported to be most efficient when those with practical experience and skill in working under high time pressure were in charge. According to the interviewees (O5; C7; A8, P9; X10; G14), technical expertise for water supply was essential to assess needs and make informed decisions for need-based support, and was also enabled through practical experience. For example, an interviewee from a health department (O5) pointed out that one needs to know which indicators to analyze in the water when assessing support needs. He said he was aware of this due to his experience in a previous incident during heavy rainfall and it enabled him to make informed decisions for the response.

However, some interviewees (U2; A8; P9), pointed out that crisis cell staff lacked such practical experience and skill, as they were used to an office-based work environment. Additionally, technical expertise for water supply was found to be lacking among crisis cell staff, which constrained swift communication about technical needs and required lengthy explanations before informed decisions could be made (C7; A8, P9; X10; D13; G14). An interviewee (P9) said that water supply was insufficiently considered by the crisis cell. "*When a crisis cell meets up there, they ask questions which you know a water supplier wouldn't ask, and then you're busy explaining basic questions to them. […] The crisis cell didn't have a clear overview of the drinking water situation. […] that was bad, but in my opinion, that's because this topic is not so popular and they didn't have it so much on their radar.*" (P9)

Both insufficient practical experience and skill for disaster response and technical expertise among the crisis cell staff constrained and delayed the coordination of action for support. In response, an interviewee (P9) reported that experienced technical experts were ad hoc engaged to create a professional group to coordinate as well as to support the disaster response for water supply. *"I made the effort to get a retired manager from the water supply company to be a permanent contact in the crisis cell […]. We got someone […] who really*

has good experience. You can see from his CV what he has already done." (P9) His recommendation, in line with other interviewees (O5; P9; X10; D13), was to de-centralize the disaster response coordination and allow sector-based focus for coordination by creating a group of experts representing the respective stakeholders from the respective infrastructure sector.

Interviewees from the health care facilities praised the expertise and experience of the THW volunteers who provided efficient and effective support for water supply, wastewater treatment and sanitation, enabling water supply within three days after the disruption (K18; M19; B20). Wastewater treatment especially was described as major issue, as no other institution provided this support (K18; B20). The hospital was therefore able to resume regular operations after only a few weeks: *"Who really saved us was THW. These guys, what they managed to do here […] I really have to say, they were amazing."* (K18)

When first responders were absent, technical expertise and practical experience were also required internally. Health care facility managers had to prioritize and make ad hoc decisions, however, lacked the relevant expertise and experience. For example, interviewees were not sure if it was necessary to turn off electricity supply in the flooded facility (I23; R24), and at what point it would be too dangerous to enter a flooded basement: *"One problem was also in these situations that there is often a lack of […] physical knowledge […] if you are a technician, you can judge these things"* (W21). Respondents reported that employees with the necessary expertise made relevant decisions such as the house electrician, and that responsibilities emerged according to the needs of the situation (K18; W21). Therefore, one of the interviewees recommended specific trainings for health facility staff to practice disaster response scenarios in disaster situations (V22).

4.5.2. State of mind

Awareness of one's responsibilities to provide for the citizens, to respond to the citizens' expectations as well as to maintain good institutional reputation were important drivers of support for all interviewees. Another great driver of support was the motivation of the volunteers to help, who said they were glad to help and find solutions for the challenges they faced (P9; X10; G14; F16). For example, two interviewees from THW (X10; G14) highlighted that in a challenging situation, their motivation to help was a key driver for their search for a solution, which the severe flood impacts contributed to, as well. "*You saw this misery […] I could've told them [his team] a hundred times to stop, we go to bed. It didn't work. It's just like that, you start and you really want to get things done […] Of course, you want to help, and you have to find a solution.*" (G14) This supported positive collaboration with other institutions during the disaster response, including the health care facilities. For example, the interviewee from the fire department (P9) said they could count on the volunteers' motivation and support. "*We counted on the motivation of the staff, and also on that of the volunteers*." (P9) An interviewee (O5) from a health department stated that "*many pragmatic solutions*" were found by the helpers.

However, awareness of one's responsibilities and of the citizens' expectations to receive support were also reported to contribute to stress, fear and emotional overwhelming, as reported by an administrative staff member of the crisis cell (U2). The same interviewee experienced stress and emotional overwhelming as a result of the lack of experience working in an emergency context. "*Everyone went there [the only available room] to get assignments, information or anything, no office rooms, nowhere to retreat and do something in peace. That was a great stress and burden.*" (U2) Emotional overwhelming constrained an individual's ability to make focused, timely decisions (U2; P9) and to communicate and collaborate adequately. For example, an interviewee from the fire department (P9) explained how the communication with a representative from a water provider was hindered as this representative was emotionally overwhelmed by the situation. The interviewee from the fire department wanted to support the water provider, but because of stress coupled with mistrust in the interviewee's capacities, the representative hindered the interviewee from the fire department in his activities until the representative calmed down and capacities were explained. The interactions were described as such, "*[…] someone who was always extremely upset after three sentences and could no longer be approached because he was simply overwhelmed by the situation […]*." (P9)

Furthermore, interviewees from the health care facilities stated that local fire departments were unable to respond during the first hours and days because they were *"completely overwhelmed"* themselves (S17; W21). In addition, interviewees from three health care facilities felt emotionally overwhelmed with the situation, as well as *"forgotten"* and *"left alone"* (S17; K18; W21) due to the absence of first responders in the first hours and days after the floods. Additionally, some interviewees (S17; V22; I23; L25) stated that it was extremely stressful to reassure and calm patients who experienced high levels of stress and fear, including panic. For some of the staff, such experiences had long-term consequences, and led to one staff member being *"so traumatized she can't work anymore"* (S17).

4.6. Organizational factors

4.6.1. Formal coordination

The majority of the interviewees highlighted the importance of the crisis cells to oversee the situation and local needs, and to make decisions to enable effective collaboration and response. Interviewees from response organizations (P9; X10; Z11; G14) and an interviewee from a health department (O5) stated the need for an overview with regular updates of the damages, support needs and the activities of other responders. The interviewee from the health department (O5) said he required such an overview to be able to ensure that the treated and distributed water from all responders met the drinking water quality standards.

However, coordination through crisis cells was largely constrained. Some interviewees (O5; W6; X10) acknowledged that a certain "chaos phase" was normal after a hazard occurred but stated that the lack of coordination exceeded an acceptable duration. Many crisis cells in the affected area and their coordinating function were affected by a combination of the above factors and their impacts, including limited accessibility of information, limited staff capacities, high levels of bureaucracy, communication challenges due to divergent expectations and stress as well as the lack of experienced and technical experts. These factors hindered effective and timely collaboration among staff of the crisis cells and thus formal coordination. In addition, due to the lack of a crisis cell at the federal level in Rhineland-Palatinate, two interviewees reported that many local crisis cells were "*overwhelmed*" (C7; J15) and did not work together, lacking efficiency.

As a result of the lacking coordination from higher authorities, many interviewees (O5; A8; P9; X10; Z11; G14; F16) described the work of the response organizations as "*microcosms*" (A8; P9), greatly lacking efficient and effective collaboration. With every institution having to organize and orientate individually on site, which was time-consuming, the disaster response was heavily delayed, limiting efficiency of the disaster response and risking that needs for support were not met. "*I can't really say exactly what else was going on around me. […] Coordinating everything somehow and discussing what with whom and where? That was extremely disorganized.*" (Z11)

Interviewees from the health care facilities confirmed the lack of need-based support during the first few days, feeling that response stakeholders *"did not have us on their radar, they did not know that we had problems"* (K18). Interviewees from one health care facility even stated that first responders did not show up at their facility at all, *"there was no one up here, no one from the city, no one from THW, no one from the fire department"* (S17). However, communication with the crisis cell staff was constrained to a large extent as they were unavailable, and information about support was often unclear (K18; M19).

While three of the four health care facilities were evacuated in the first few days (K18; W21; I23), the hospice facility residents remained in their facility for eight days until the crisis cell requested their evacuation (S17). However, an interviewee from the facility stated he did not want to evacuate the dying people: *"The most important thing for us was that we could stay"* (S17). From his point of view, it would have been possible to stay at the facility because it was not flooded and therefore still adequate (S17). Once mandated to evacuate, the hospice staff took charge of the patient transfer to other palliative care facilities, as he said, dying people, requiring special social-psychological care from trained workers, cannot be transferred to other kinds of health care facilities (S17). Additionally, the retirement home reported that, while no one died during the evacuation, around 22% of the patients died in the aftermath (W21). Some patients had to be relocated far away from their familiar environment, care takers, friends, and families (W21). "*And unfortunately, we also learned in the following months that many people were not able to cope, simply emotionally, […] When people give up, then they die.*" (W21)

The diverse needs of health facilities were not met during the disaster response, largely due to inadequate coordination of support, according to the interviewees. This led to a sense of abandonment among the health care facilities, and further constrained their efforts to meet their patients' needs.

5. Discussion and recommendations

This research has identified multiple enabling and constraining factors that enabled or complicated disaster response. By following a qualitative and event-specific approach, the findings revealed the complex and collaborative nature of disaster response. Thereby, it expands the yet rather technical focus in critical infrastructure research by adding a governance perspective. It demonstrates the

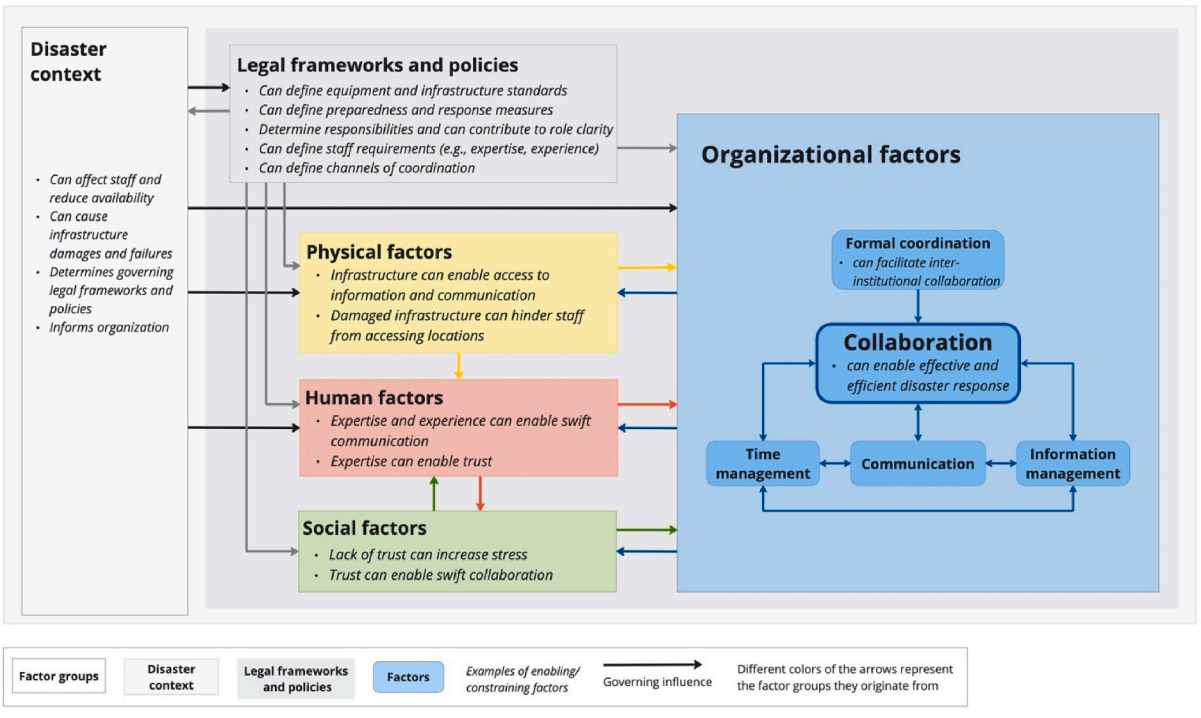

Fig. 1. Overview of factor groups and factors governing collaborative processes in disaster response. Organizational factors are central, governed by other interacting physical, human, and social factors. The disaster context delineates the broader context as well as the legal framework and policies in place, which determine response measures, actors, and responsibilities, as well as organizational processes during the response. Collaboration is governed by time management, communication, and information management. It is an essential process for the efficiency and effectiveness of the disaster response and can be facilitated through formal coordination from governmental crisis cells. The factors within each factor group can be both constraining and enabling. Examples are written in italics.

significant influence of not only physical and technical components, but of a wide variety of factors from different sectors on disaster response.

Furthermore, this research discloses the interconnections between these factors as well as between the people of different institutions and their impacts. The disaster response was essentially based on timely and effective collaboration, supported through information management and communication. This study furthermore showed that collaboration between first responders and other institutions such as health departments can be facilitated through formal coordination from the governmental crisis cell. The efficiency and effectiveness of the latter was fundamentally rooted in the same factors, namely, collaboration, information management, communication, and time management. While formal coordination can facilitate inter-institutional collaboration, this research furthermore demonstrated how first responders and other institutions managed to collaborate and operate despite insufficient coordination from the crisis cells. Therefore, organizational factors were identified as central and dictated by physical, social, and human factors, as well as associated legal frameworks and policies within the disaster context (Fig. 1). The disaster context delineates the general context and requirements of the situation and determines which legal frameworks and policies for the disaster response are in place, which then define response measures, actors, and responsibilities as well as organizational processes. This research addresses a knowledge gap in research, which often focuses on one type of factor or factor group, such as coordination [54], social factors [15,43] and human factors [42,44]. Clear patterns of interconnections between factors could be identified that also help to flesh out recommendations for better preparedness. Given the strong interconnections between the factors, by addressing one factor, multiple other factors can also be addressed, as illustrated in Fig. 1 and outlined in the following.

First, the findings demonstrate the limited preparedness of the disaster response, significantly constraining efficient and effective support. Generally, awareness of the potential impacts of disasters seems to be alarmingly low, and the same is true for knowledge around cascading impacts. Even if actors were aware of such risks, this was not necessarily captured in their organizations' mandates. Hence, better knowledge on disaster contexts as an enabler of preparedness is key, on both an individual basis, and even more so institutionally.

Especially in large-scale disasters, first responder capacities are easily exceeded in cases of limited preparedness or if many critical facilities are in need of support simultaneously. Internal preparedness measures of the disaster response recipients, such as health care facilities, can improve their autonomous response mechanisms for a certain period without relying on immediate support from first responders, to bridge a critical gap until external support is provided. Health care facilities play an essential role as anchor points for life-saving medical care and relief in society [58,59] and overwhelmed or halted functioning in health care must be avoided. Nevertheless, such response must be prepared, requiring the willingness of responsible actors, but also the awareness of current limitations in formal disaster response. In addition, this study shows how strongly technical and organizational measures in health care facilities are interconnected, as technical measures need to be managed, reinforcing the findings from other authors [25,60–62]. A stronger consideration of organizational components, including in the development and continuous revision of emergency plans should be a first step for health care facilities [60]. In addition, this study shows how disruptive supposedly trivial components can be, such as bureaucratic procedures, shift rotation and handovers of staff, which can, at the worst, result in lengthy processes or even in loss of information, causing delays while timely response and support are key. While the great number of volunteer workers are a critical part of the formal disaster response in Germany, its limitations in severe disasters such as insufficient staff handovers and lacking relationships with other institutions, do not seem to be adequately considered. This is not a reflection of their quality of work or motivation, but further demonstrates the inadequate consideration of institutional and inter-institutional preparedness.

With respect to physical factors, this study illustrates how failure of technical basic infrastructures, including electricity, ICT and transport infrastructure, hindered efficient communication and accessibility of information during the response. Apparently, this was inadequately or even never accounted for in preparedness planning and took actors by surprise. This shows once more how much is taken for granted in planning disaster response, and that particularly the interconnectedness of impacts is not considered. Swift communication, however, is key during disasters to minimize their impacts. The lack or failure of technology hinders collaboration and coordination.

This study also identified multiple constraints from legal frameworks and policies, including bureaucratic structures and processes. The mismatch between inflexible bureaucratic policies and the needs of an emergency environment under high time pressure has also been pointed out by other authors [63–65]. In response, several interviewees of this study found innovative and ad hoc solutions, for example informal communication, and de-centralized coordination, such as through an online platform provided by German infrastructure associations to enable quick and need-based action. Such "emergent" behavior aims to meet the needs of the disaster context, including continuity, collaboration and time-efficiency, echoing previous studies [63,66,67]. Standards for efficient workflows during the response could support decision-makers to manage information and resources while avoiding unnecessary delays [68].

The findings also demonstrate the challenges occurring from constraining social factors, such as when organizations from different sectors and with individual culture and policies meet for the first time during a disaster to jointly respond to it, corresponding to the findings from other studies [14,47]. Many interviewees of this study lacked pre-existing relationships with other institutions whose roles and responsibilities were unknown to these interviewees, which apparently limited trust. Such social factors are, however, key enabling factors for effective collaboration between first responders [13,46,48]. Routine collaboration between institutions has shown to be important to build relationships, trust, and role clarity. However, the extent to which such relations enabled swift collaboration for the interviewees during the disaster response was substantial and might be underestimated in formal preparedness mechanisms. Repeated collaborative exercises and trainings for stakeholders involved in disaster response could provide opportunities to increase preparedness by building inter-institutional relationships and become familiar with each other's roles, responsibilities, and capacities [16,48,69,70]. Such activities could have made a significant difference in the German flood event of 2021 and should be prioritized for preparedness planning. Furthermore, this could reduce false expectations occurring from not being familiar with the mandates of other

actors, and to avoid communication challenges, frustration or even reduced willingness to collaborate in the future.

Moreover, the findings highlight the need for clear and continued communication between the crisis cell, first responders and health care facilities as key for efficient and effective response. This can reduce feelings of uncertainty, overwhelmedness and being "left alone" among support recipients. Pre-established relationships enabled informal and quick communication and collaboration between first responders and health care facilities. Thereby, institutional response capacities were strengthened, showcasing the power of social and human factors as well as the lack of considering them in formal preparedness action, as response actions identified in this study considerably relied on individuals' spontaneous initiative or even lucky and unplanned coincidences. In addition, the consideration of individuals as important actors who may themselves be personally affected in the event, mentally or physically, was far from sufficient. Such factors must be taken into account as part of the preparedness planning to enable continued disaster response, for example by developing backup plans in case of lack of staff, and by enabling psychological support for staff.

Lastly, this study identified multiple constraints in coordination from the crisis cell. Coordination of need-based support from interdependent institutions with diverse interests and under high time pressure during an emergency is a highly complex and challenging task. In the flood event, coordination was executed by a centralized and partically administrative institution, the crisis cell, as determined by the German legal framework for disaster response [30]. While authors have pointed out the advantage of such an institution to manage high numbers of various institutions within the governance regime and enable inter-institutional trust [71], the interviewees pointed out many problems in coordination as well as the necessity of a de-centralized approach to the disaster response coordination in enabling need-based support. For example, interviewees from both the water and the health care sector perceived an insufficient consideration of their needs in the crisis cell. Mandated measures from the crisis cell were even perceived more burdensome than supportive, undermining trust in their decisions now and in the event of future disasters.

Various sectors and actors were involved in response efforts, the goals of which were diverse, resulting in the need for partly time-consuming ad-hoc coordination. Reinforcing the findings from other authors [13,14,49,54], this study found that a coordinating institution must be aware of the multitude of needs of the involved institutions and sectors and must be able to understand and communicate these needs. These tasks and responsibilities require professional expertise, which furthermore includes a profound understanding and consideration of cross-sectoral interdependencies which was a major concern. Underlying reasons are likely the unanticipated scale of the event, overwhelmed actors particularly on the municipal scale where the coordinating role is normally not typically a full-time engagement, and the large number of formal and informal stakeholders involved.

This calls for better expertise in the coordinating institution to enhance leadership during disaster response. A stronger focus on sector-based coordination might enhance effective information flow, communication, and collaboration, as demonstrated by the ad hoc creation of a water expert group involving one of the interviewees. Such a solution should be considered in emergency plans for better preparedness to enable targeted and need-based support during crises, particularly in the fields of infrastructures and technology that require a unique skill set. Better representation of experts in coordination would enable consideration of the different needs of various institutions of the corresponding sector that need support, such as health care facilities, as illustrated in this study.

Moreover, the lack of experience and skill to work under high time pressure among crisis cell staff can be related to the fact that emergency trainings for the administrative staff are not mandatory [21,31]. This should be urgently addressed, given that extreme events are expected to occur more often in the future. Such practical trainings should include both administrative and operational staff to enable role clarity, build relationships and trust and furthermore address communication challenges that were a demonstrated constraint in this study and have also been pointed out by other authors [31,68]. This would allow staff to build disaster management skills, as well as to also address emotional challenges such as how to deal with stress and overwhelm. In addition, role clarity and demonstrated expertise have shown to enhance trust, thus supporting collaboration. This means that expertise not only is important for one's own organization to be able to operate, but is also fundamental for the collaboration with others. Its absence can thus create impacts that may significantly disrupt the disaster response.

Overall, the interviewees were well aware of the shortcomings in preparedness and response, that resulted in valuable solutions, ad-hoc action and spontaneous assistance. Nevertheless, it has also revealed various entry points for improvement, particularly of formal and bureaucratic mechanisms which were often found insufficient and even counterproductive.

6. Conclusion

Society's strong dependence on critical infrastructures require efficient and effective response when disasters strike. This implies the need for improving collaborative processes between the multitude of involved stakeholders, as revealed during the 2021 floods in Western Germany where disaster response was inadequate, with disastrous consequences. This study collected enabling and constraining factors that impacted the delivery of critical infrastructure services during disaster response, specifically, for the water and health sector. Assessing both the supply and demand side, this study contributes to closing a crucial knowledge gap in research and practice, as the continued functioning of critical services during crises is too often taken for granted. Unfortunately, the opposite is the case.

Organizational factors were central for the disaster response, which was based on timely and effective collaboration, supported through information and communication, and facilitated through formal coordination from the crisis cell. Key enabling factors identified as critical for the support of stakeholders in disaster response were the availability of ICT infrastructure, equipment, trusted networks, role clarity, informal communication, preparedness, strong motivation to help, awareness of responsibilities, technical expertise for critical infrastructure and practical experience and skill for disaster response. Key constraining factors were the lack of enabling factors, as well as unexpectedness of the floods, the severity of its impacts, damaged transport infrastructure, lengthy communication and bureaucratic processes. They severely constrained organizational factors, leading to lacking accessibility of

information and an overview of the situation and poor coordination from the crisis cell, limiting communication and collaboration between the stakeholders. Negative amplifications from interactions between these factors further hindered effective and timely response.

A key takeaway is the demonstrated necessity to critically assess both enabling and constraining factors and their interactions, and incorporate these into crisis management, and preparedness action plans. Even a solution in accordance with formal mechanisms and policies may fail in reality, which was the case during the 2021 floods. Reasons often included insufficient preparedness and limited consideration of factors and their interactions such as trust, communication and their effects on collaborative processes in the disaster response. Findings also show that critical infrastructures, sector-specific needs, and interdependencies were insufficiently considered in planning and response. This is deeply concerning, considering the growing dependence on the continuous availability of critical infrastructures and the simultaneously increasing risks from natural hazards and climate change.

Improved knowledge of the diverse needs of disaster response stakeholders, and awareness of the role of critical infrastructures in limiting or exacerbating impacts will be key to improved disaster management going forward. It however requires a stronger focus on understanding disaster response as collaborative process, taking into account contextual legal, physical, social, human and organizational factors and their interactions.

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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 that has been used is confidential.

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