*Journal of Flood Risk Management*

WILEY

CIWEM Chartered Institution of Water and Environmental Management | Journal of Flood Risk Management

SPECIAL ISSUE PAPER OPEN ACCESS

# Design Flaws at the Interface of Flood Forecasting, Early Warning and Disaster Response in the Disaster in Western Germany in July 2021—An Interdisciplinary Analysis

Jens Reinert[1] | Cordula Dittmer[2] | Daniel F. Lorenz[2] | Elena-Maria Klopries[1]

[1]Institute of Hydraulic Engineering and Water Resources Management, RWTH Aachen University, Aachen, Germany | [2]Disaster Research Unit (DRU), Freie Universität Berlin, Berlin, Germany

**Correspondence:** Jens Reinert (reinert@iww.rwth-aachen.de)

**Received:** 11 July 2024 | **Revised:** 23 June 2025 | **Accepted:** 24 June 2025

**Keywords:** crisis communication | disaster | disaster response | flood response | flood risk management | flood warning | July 2021 flood event

## ABSTRACT

Extreme heavy rainfall in Western Europe on 13–15 July 2021 caused severe flooding, notably in Germany's Rhineland-Palatinate and North Rhine-Westphalia. This study examines Flood Forecasting, Early Warning, and Disaster Response weaknesses during this event, focusing on the city of Stolberg. An interdisciplinary mixed-methods approach integrated meteorological, hydrological, and social science research. Data included river gages, precipitation measurements, warnings, and 300 documents, with 30 expert interviews. Weaknesses included imprecise meteorological forecasts due to dynamic weather, leading to general warnings without specific impact guidance. Limited flood forecasting hindered local preparation and response, exacerbated by an emergency response system unprepared for the event's scale. The top-down approach of Flood Forecasting and Early Warning conflicted with the bottom-up processes of Disaster Response, hampering effective crisis management. The study reveals critical weaknesses and calls for improved forecasting, integrated response plans, communication protocols, and crisis channels to enhance flood resilience. Future research should explore these issues in other extreme flood events and compare international Flood Forecasting, Early Warning, and Disaster Response systems.

## 1 | Introduction

Western Europe experienced extreme heavy rainfall events from 13 to 15 July 2021, with subsequent floods and flash floods. In addition to Germany, Belgium, the Netherlands, France, and Luxembourg were affected (Thieken, Bubeck, and Zenker 2023). In Germany, the most significant damage occurred in the federal states of Rhineland-Palatinate (RLP) and North Rhine-Westphalia (NRW). In RLP, 136 fatalities were recorded, including one person who had initially been reported missing but was later officially declared dead after human remains were found. Of these, 135 deaths occurred in the Ahr valley, 49 in NRW, and 5 in other federal states (Thieken, Bubeck, Heidenreich, et al. 2023). The overall economic loss is estimated to be around €30–40 billion, while insurance companies anticipate insured losses of approximately €8.2 billion (Szönyi et al. 2022). The questions that the public, as well as various parliamentary investigative commissions, were discussing are whether many lives could have been saved with an earlier warning and a subsequent evacuation, and who takes responsibility for the many deaths (Mathiesen et al. 2021; Thieken, Bubeck, and Zenker 2023).

There have been consistent analyses from a meteorological and hydrological perspective to understand the factors that contributed to this extreme weather event and subsequent floods and flash floods (DKKV 2022, 2024; Fekete and Sandholz 2021). Many weak points that led to partially severe disaster response and maybe fatal errors have also been identified by disaster research and disaster management organizations themselves. These included a lack of crisis management team training due to the SARS-CoV-2 pandemic, dependency on destroyed technical infrastructure, inaccurate situational awareness, and false expectations, as well as insufficient training for such an extremely fast and dynamic situation (Dittmer et al. 2024; Fekete and Sandholz 2021; THW 2021).

In the following, we will deal with the specific interface of flood forecasting, early warning, and disaster response, which has hardly been considered in previous studies. We combine hydrological, meteorological, and disaster sociological perspectives, and argue that a central weakness lay in the almost opposite structure and functioning of flood forecast, early warning, and disaster response.

Section 2 will present an overview of the structure of flood forecasting, early warning, and disaster response during heavy rain events and floods in Germany, along with the research question. Section 3 will outline the different methods used. Next, we will introduce the case study of the city of Stolberg in Section 4. Stolberg in NRW was selected as a case study due to the good data availability and, unlike other affected areas, the absence of fatalities and legal proceedings, which made access to involved actors easier. In Section 5, we will show how each system functioned in the case of Stolberg and the results of the joint weak point, followed by a discussion in Section 6 that explores the common underlying factors of these weak points. A brief conclusion will summarize the main findings of the paper.

## 2 | State of Flood Forecasting, Early Warning and Disaster Response in Case of Heavy Rain and Floods

In this section, we will give a brief overview of the functioning of flood forecasting, early warning, and disaster response system in Germany as different sub-areas of flood risk management and disaster management systems that both are complex systems in themselves.[1]

The timing and content of a warning are generally based on the information about the hazard and the perceived risk (McLuckie 1970; Scolobig et al. 2022). In the case of (extreme) weather phenomena with a high potential for damage, the responsibility for issuing official early warnings that could lead to a threat to public safety and order lies with the German Meteorological Service (DWD). Based on a four-stage warning system, the meteorological warning center in Offenbach, Germany, is informed about significant weather phenomena and warns accordingly. The warnings are based on the expected intensity of precipitation being exceeded and are disseminated via various channels, such as radio and television, the internet, and the DWD app.

The hydrological assessment, including the forecasting and reporting of flood situations, is the responsibility of the federal states' ministries of environment. The responsible water management authorities receive the model results of the meteorological model forecasts via special information systems. This is followed by a hydrological assessment of the impending severe weather, indicating increased water levels and expected warning value exceedances. Based on the meteorological forecast data and other measurement data such as soil moisture, precipitation-runoff models are used, the results of which form the necessary basis for the operation of dams and flood retention basins. In addition, presumed exceedances at flood warning levels can be predicted. The federal states operate flood forecasting and reporting services for this purpose. The flood reporting process is based on the constant monitoring and modeling of precipitation and runoff events, the regular information of relevant stakeholders, and the dissemination of hydrological situation reports. The reporting process is defined in the flood reporting regulations of the respective water bodies. It is based on forwarding water levels, e.g., to relevant stakeholders in disaster prevention (MULNV 2021). The exact interpretation for managing the situation is left to local emergency response authorities.

The German disaster response system, in general, relies on the cooperation of governmental and civil society actors. While a small group of paid professionals handles daily emergency response tasks, the majority of official disaster response personnel consists of formal volunteers ("Ehrenamtliche") (Merkes et al. 2024). These volunteers engage through organizations such as the Federal Agency for Technical Relief (THW), local fire brigades, and relief organizations like the German Red Cross (GRC). The whole system is a strongly formalized bottom-up process where responsibility for everyday emergencies lies as long as possible at the municipal level (emergency response by local administrations and local fire brigades). Only if the local structures are overwhelmed can the district assume responsibility by declaring a disaster (Wissenschaftliche Dienste—Deutscher Bundestag 2021; Wolf and Pfohl 2015). In such cases, local emergency response becomes part of the district led disaster response. This formal shift of responsibilities in times of disaster reflects the fundamental differences of emergencies, disasters, and catastrophes as they are discussed in international disaster research (Fischer 2003; Montano and Savitt 2023; Quarantelli 2000).

In case of flood or heavy rain events, emergency and disaster response authorities receive warnings from the DWD or flood warning centers much earlier than the media or the population, but with a higher uncertainty level. It is now up to the responsible local emergency response authorities at the municipal level to decide whether they want to take initial hazard prevention measures, such as the preparation of protective structures and sandbags, informing the population, or, if necessary, setting up crisis management teams for extraordinary events (SAE). SAEs are command-and-control structures that are established below the district at the municipal level. They primarily work with the existing local fire brigades. The assessment criteria used to decide on appropriate measures in the face of an impending extreme weather event are the precipitation forecasts issued by the responsible authorities, water levels, and site-specific experience from previous extreme weather events. These are compared with mostly known vulnerable infrastructures (bridges, hospitals, retirement and nursing homes, emergency operations, etc.), and appropriate hazard prevention measures are initiated in accordance with the available resources. This also includes warning and informing the population, for which various warning tools are available (Fischer-Preßler et al. 2021; Frische et al. 2021).

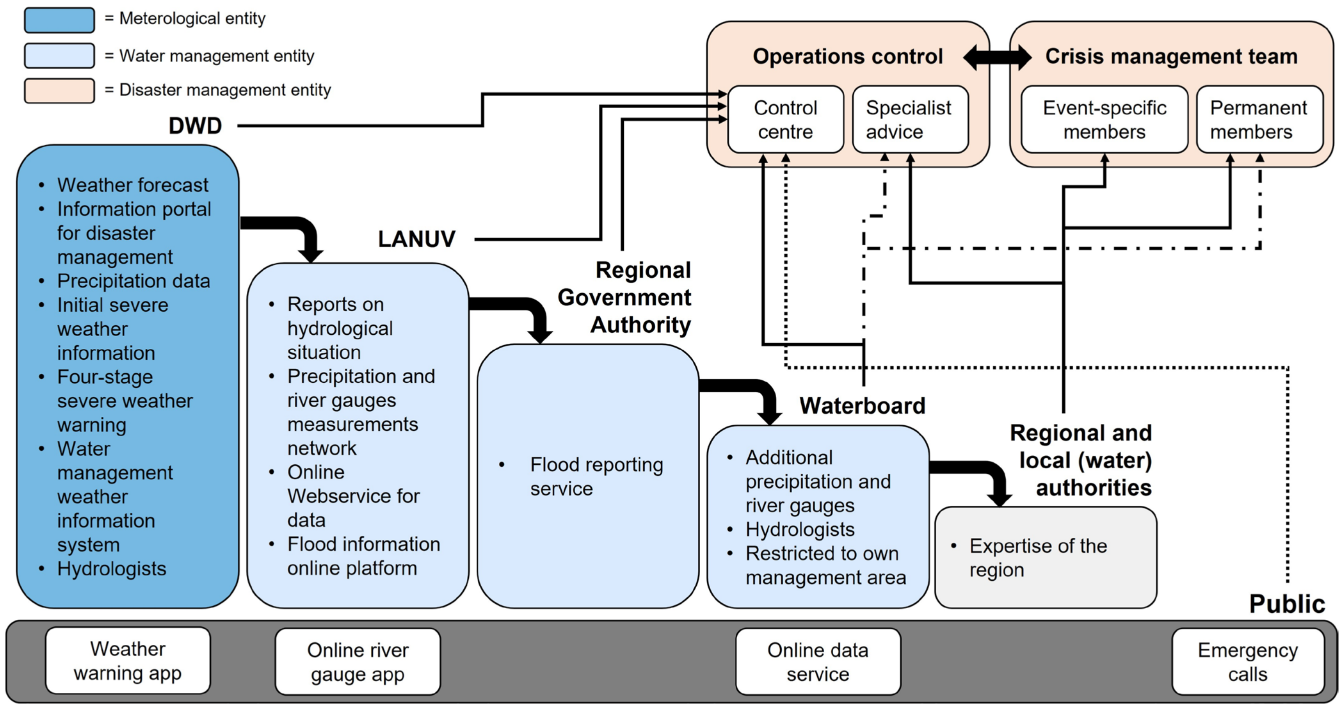


**FIGURE 1** | Information flow from water management to disaster response entities during the July 2021 flood event with a focus of NRW, StädteRegion Aachen. Figure adapted from Wingen (2025).

In summary, it can be said that the flow of information has to undergo a transition from Flood Forecasting and Early Warning to emergency and disaster response (see Figure 1). The process begins with the DWD providing weather forecasts and warnings, which are passed on to the State Office for Nature, Environment and Consumer Protection of North Rhine-Westphalia (LANUV) for hydrological assessments. These reports, along with local expertise from regional water authorities, inform the crisis management teams. The fire brigade's central control center coordinates the response, while emergency calls from the public also contribute to real-time updates. This collaborative system ensures that expert analysis and local knowledge guide disaster management decisions (Wingen 2025). Figure 1 of the transition of the information flow refers to NRW as an example for the case study Stolberg.

On an international level, the United Nations initiative 'Early Warnings for All' (World Meteorological Organization 2022) defines a global framework to enhance early warning systems. It focuses on disaster risk knowledge, monitoring and forecasting, warning dissemination and communication, as well as preparedness and response planning. This internationally recognized framework provides valuable benchmarks, which we later use to structure and contextualize the identified design flaws.

In principle, floods and heavy rainfall events are well-known hazards for emergency response in regions that are repeatedly affected by these natural hazards (Jann et al. 2019). As long as they do not significantly exceed the magnitude of previous events, they are dealt with in a largely standardized reactive manner using appropriate resources. In many places, supra-local aid concepts exist so that resources can be requested from neighboring municipalities or districts. If the situation can no longer be managed on the municipal level with the available resources and different management structures are required, the district (as lower disaster response authority) can declare a disaster and, thus, assume formal responsibility (not operational implementation) using a district crisis management team under the district chief executive and request additional resources from other districts, state, or federal authorities (Wissenschaftliche Dienste—Deutscher Bundestag 2021; Wolf and Pfohl 2015). Specialist advisors (e.g., from transportation or critical infrastructure) can also be called into the crisis management team if required. This is helpful insofar as the local emergency response at the municipal level with voluntary fire departments only has limited knowledge of specific hazards and their effects, as they have to deal with a large number of different hazards (Geier 2022).

Despite the highly advanced flood forecasting, early warning, and disaster response, it is puzzling why the information and forecasts in 2021 failed to reach the relevant disaster response structures on time to avert losses and prevent the disaster (Dombrowsky 2022). As a result, an effective disaster response was delayed (Dombrowsky 2022) and warnings were issued too late or not at all, with disastrous consequences (Thieken, Bubeck, and Zenker 2023).

Studies about bottom-up and top-down approaches at the interface of flood forecasting, early warning and disaster response (Serra-Llobet et al. 2016) already pointed to the problem of combining flood risk decision analysis (Knighton et al. 2018) and water management in general (Klassen and Evans 2020) with bottom-up approaches due to locally set-up flood warning systems and disaster response (Geddes et al. 2024). Becker (2020, 289) states "an evident problem of fit between the hydrology of the catchment area and the regime of practices of individual actors governing flood risk mitigation within it".

Thus, the paper addresses the following research question: Which weak points can be identified at the interface of flood forecasting, early warning and disaster response in the 2021 disaster, and do they relate to a “problem of fit”?

## 3 | Materials and Methods

Addressing the research question necessitates an interdisciplinary mixed-methods approach that combines methodologies from meteorology, hydrology, and social science disaster research to cover the diverse systems with unique structures and processes. We decided to use a triangulation approach referring to multilevel research combining quantitative and qualitative data for an overall analysis and interpretation of the very complex processes of the July 2021 flood event (Creswell 2021; Headley and Plano Clark 2019; Tashakkori and Teddlie 2006).

The starting point of the analysis of weak points is an investigation of the meteorological and hydrological course of the July 2021 flood event. This is mainly based on the evaluation and processing of data recorded during the event and provided by the federal state environmental agencies and flood forecasting centers of RLP and NRW. The data is used to analyze critical points in time during the flood event in the affected catchment areas. This involves a total of 41 data sets from river gages and 40 data sets from precipitation measuring stations in the period between 10 and 16 July 2021.

A comprehensive description of the meteorological and hydrological data sets as well as the methods applied for their analysis can be found in Reinert et al. (2025), which serves as a companion paper to this study in the same special issue.

Another basis for the analysis is the DWD's warnings and published information. Although the forecasting operation is based on numerical models for meteorological forecasting, they will not be included in their detail level for the present analysis. Instead, the analysis focuses on the summarized warning reports as an end product of the DWD that the emergency and disaster response authorities use for their information.

Finally, defined flood information thresholds complete the analysis from a water management perspective. Their exceedance times can be used to derive critical phases and points during the flood event.

To analyze the processes in disaster response, three different qualitative methods were used: (1) content analysis of documents, (2) interviews with experts and affected people, and (3) participant observations (Corbetta 2003).

(1) A total of 300 documents were collected, including government reports, disaster response organization mission reports, inquiry committee materials, academic publications, and policy papers. The analysis of newspaper reports played a significant role, as the event was extensively covered for weeks, and reputable media outlets conducted their own investigations into the unfolding events. (2) Extensive empirical research was conducted in the field to explore the response of emergency and disaster management, focusing on the timing, approach, and knowledge base utilized. Data collection took place in May 2022 and September–October 2022. A total of 30 people were surveyed in 25 interviews, with both individual and group interviews being conducted in German. These were carried out with experts, individuals affected by the events, and local residents (Table 1 provides an overview). The saturation point was reached before concluding the interviews. The selection of experts involved in emergency and disaster response at various levels was deliberate, and additional contacts were made using the snowball system and recommendations. Interviewees were selected in affected areas based on news reports and recommendations. The interviews lasted between 45 and 300 min and averaged approximately 70 min. They were either recorded and transcribed or summarized in meeting minutes. (3) Additionally, passive participant observations were conducted (Corbetta 2003). These observations were recorded in memos and contributed to a better understanding of the situation on-site. The interviews, meeting minutes, document analyses, and memos were analyzed via rule-based qualitative content analysis following Mayring (2000), Schreier (2012). These data were coded using the data analysis software MAXQDA.

Based on the hydrological and disaster sociological analyses, the interdisciplinary collaboration resulted in a minute-by-minute reconstruction of the 2021 events in the city of Stolberg (NRW), referring to the available information and responses. To this end, the interviews that showed explicit references to the situation in Stolberg, the overarching StädteRegion Aachen level and NRW were selected and analysed in more detail for the following analysis (in particular nr. 4, 6, 8, 12, 13, 14, 16, 17, 18, 21, 22, 23, 25). The other interviews provided further background knowledge that is relevant for understanding the overall disaster context of the 2021 flood events. The data was compiled in different figures that helped to identify weak points at the interface of the different systems.

## 4 | Case Study: Stolberg

The municipality of Stolberg, located in the district StädteRegion Aachen, is situated in the southwest of the state of NRW within the Aachen city region and presents an excellent opportunity for research and analysis. With its narrow valleys, the topography corresponds to the edge of the low mountain region of the Eifel. Furthermore, Stolberg is known as a former mining region. The large number of industrial companies, particularly metal processing companies, brought the town some prosperity. However, due to economic change and the move away from copper processing, the town has been undergoing structural change for years. With around 56,000 inhabitants, it is the largest municipality in the StädteRegion Aachen. The city's development has been aligned with the watercourse and runs along the valley axis. The river Vicht, which has its source about 20 km from Stolberg near Roetgen, flows through the town. There is also a water gage in Mulartshütte, approximately 12 km upstream of Stolberg. Downstream of Stolberg, the Vicht flows into the Inde river and then crosses the town of Eschweiler, 2 km away, where there is another gaging station. In the Vicht catchment

**TABLE 1** | Overview of all interviews conducted.

| Number | Date | Interview type | Interviewee/Organization | Location |
|---|---|---|---|---|
| 1 | May 2022 | Group | Disaster response | Bitburg-Prüm |
| 2 | October 2022 | Group | Crisis team | Mayschoss |
| 3 | May 2022 | Individual | Mayor | Kirchsahr |
| 4 | February 2022 | Individual | ASB district disaster unit | Worms-Alzey |
| 5 | February 2022 | Individual | Municipal administrator | Trier-Ehrang |
| 6 | May 2022 | Individual | THW management and coordination staff lead | Bonn |
| 7 | November 2021 | Individual | Fire brigade Mühlheim | Mühlheim |
| 8 | May 2022 | Individual | THW staging area lead | Bonn |
| 9 | February 2022 | Individual | GRC HQ Flood operation evaluation coordinator | Berlin |
| 10 | January 2022 | Individual | ASB regional branch head of operations | Bad Windsheim |
| 11 | May 2022 | Group | Distribution grid operator emergency staff head | Trier |
| 12 | February 2022 | Individual | ASB NRW state civil protection advisor | Köln |
| 13 | June 2022 | Individual | Fire brigade Erftstadt | Erftstadt |
| 14 | February 2022 | Individual | ASB NRW state managing director | Köln |
| 15 | September 2022 | Individual | Fire brigade Puhlheim/Erftstadt | Puhlheim |
| 16 | May 2022 | Individual | District Düren hazard prevention head | Düren |
| 17 | March 2022 | Individual | DWD basic forecasting department head | Bonn |
| 18 | May 2022 | Individual | District StädteRegion Aachen disaster response admin | Simmerath |
| 19 | May 2022 | Group | Malteser flood relief | Trier |
| 20 | May 2022 | Individual | Mayor | Waxweiler |
| 21 | September 2022 | Individual | Coordinator flood risk management StädteRegion Aachen | Simmerath |
| 22 | June 2022 | Individual | State Agency for Nature, Environment and Consumer Protection (LANUV), NRW | Recklinghausen |
| 23 | March 2022 | Group | Federal Office of Civil Protection and Disaster Assistance (BBK) | Bonn |
| 24 | March 2022 | Individual | Rhineland Palatinate State Office for the Environment (LfU) | Mainz |
| 25 | April 2022 | Individual | West German broadcasting (WDR) | Köln |

area, precipitation stations are operated at the Eschweiler and Zweifall sites. (See Figure 2).

The StädteRegion Aachen has been very active in the field of disaster response in recent decades. For around 10 years, siren installation projects have been initiated (Dittmer et al. 2023); cross-border cooperation, in particular, the EMRIC network (Euregio 2024) as a Belgian–Dutch–German network of administrations in the areas of fire protection, technical assistance, and rescue services and administration have been expanded and consolidated. In such an extreme water-induced situation as in 2021, the StädteRegion can rely on the forecasts and programs of the DWD and the State Agency for Nature, Environment, and Consumer Protection (LANUV), and there are also contracts with engineering consultants that can continuously assess the situation to provide support. The local volunteer fire department and rescue services provide local emergency response. Disaster response organizations in the region are primarily manned by the German Red Cross (GRC), with a few units from other disaster relief organizations.

Stolberg has a history of dealing with floods and has implemented various flood protection measures such as levees and expansion of the riverbed. In December 1966, an unprecedented combination of factors, including snowmelt, heavy rain on frozen ground, and overflow of the Dreilägerbach dam, led to a devastating flood, causing significant damage as the Vicht and Inde rivers rose to almost 2.50 m (Eschweiler Filmpost 2018). Due to the nearby Belgian nuclear power plant Tihange, which had a number of INES safety incidents in the past (StädteRegion Aachen 2024b), flood response planning played a rather subordinate role in the StädteRegion Aachen in the years leading up

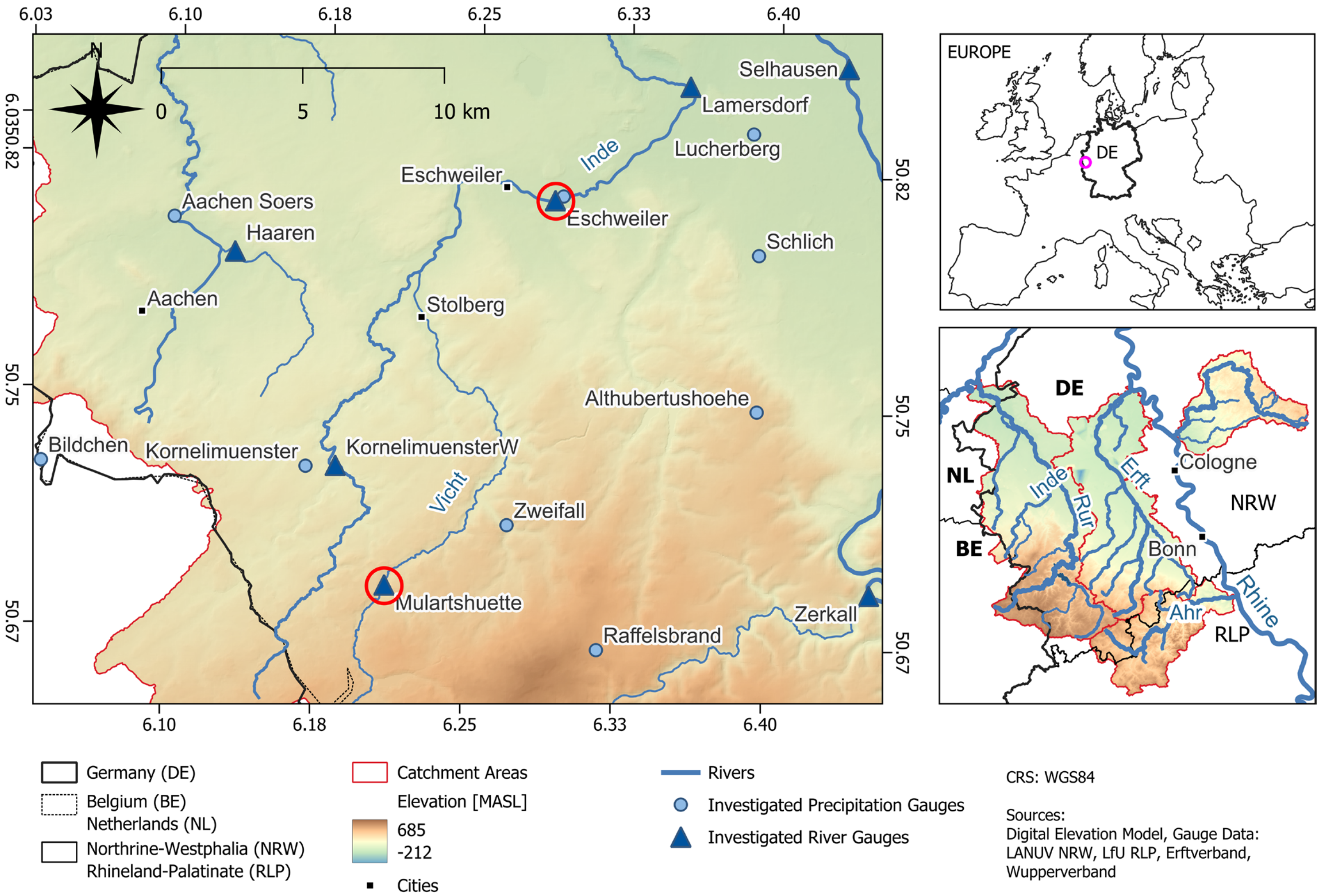


**FIGURE 2** | Investigated catchment area of Inde and Vicht with highlighted flood gages Mulartshütte and Eschweiler.

to the event of 2021; instead, disaster response rather focused on preparations for CBNRE events (StädteRegion Aachen 2024a).

## 5 | Analysis: Weak Points at the Interface of Flood Forecasting, Early Warning and Disaster Response in the Disaster 2021 in Stolberg

In the following section, the operation of the different systems of flood forecasting, early warning, and disaster response in Stolberg is first described. In the joint analysis, weaknesses are identified that (a) result from the other studies on the topic known to date, (b) result from the water management and hydrological data, (c) were identified in the expert interviews themselves, and (d) emerge as complementary opposites in the synopsis of the two systems.

### 5.1 | Analysis of Flood Forecasting and Early Warning

Due to the lack of a water level measuring station, the water level profile in Stolberg can only be depicted to a limited extent using water level data. Nevertheless, to obtain as complete a picture as possible of the flood course, the water level course in Eschweiler is used. The gage in Eschweiler is located about eight river kilometers downstream of Stolberg and measures the water level of the Inde, into which the Vicht flows after passing Stolberg. The Mulartshütte and Eschweiler gages are about 14 km apart from each other. With a certain time delay, the rapid rise in the water level can also be measured in Eschweiler from around midnight until the provisional peak at 05:45 a.m. on the morning of 14 July 2021 at 2.23 m. From this, a similar flood course can be derived in Stolberg between around 02:00 a.m. and 05:00 a.m. of 14 July 2021.

It should be mentioned that no flood forecast was published for either the gage in Mulartshütte or the gage in Eschweiler, as the forecasting system for the gages in NRW was in the test phase at the time of the July 2021 flood event.

The exceedances of the flood reporting values 1–3 as defined occurred at the Mulartshütte gage for the first time on the night of July 14 2021 in the period between 00:15 a.m. (value 1) and 0:55 a.m. (value 3). 15 h after the DWD issued the highest flood reporting value on 13 July 2021 at 09:40 a.m., all options for reporting the impending flood with the help of gage-related flood reporting values were surpassed within 40 min. The rapid rise in the water level continued after midnight and culminated at 01:40 a.m. on 14 July 2021 with a provisional peak of 2.16–0.56 m above warning level 3 (see Figure 3).

### 5.2 | Analysis of Emergency and Disaster Response

In Stolberg, the first forecasts of the DWD regarding an impending heavy rain situation arrived as early as 10 July 2021,

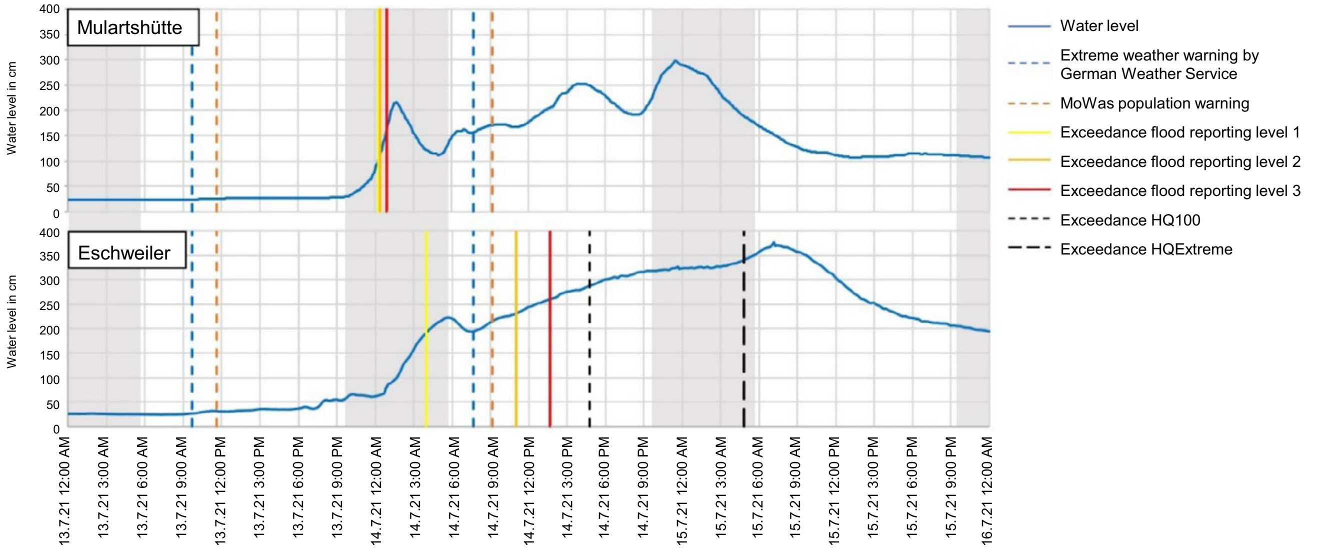


**FIGURE 3** | Water levels of the flood gages Mulartshütte and Eschweiler during the July 2021 Flood Event; Exceedance times of flood reporting values.

although these were still very unspecific. On 12 July 2021, the emergency response organizations were alerted with the incoming DWD warnings, and many disaster response units in NRW were informed. In the StädteRegion Aachen, the first regions were defined as risk areas (e.g., Kornelimünster) (Interview (I) 21). The precipitation that began on 12 July 2021 already led to an increased frequency of operations by the local fire brigades and the initiation of flood protection measures. In the neighboring district of Düren, the situation was already much worse, and all locally available emergency response resources in the district were deployed for operations at this time (I 16). Since there is generally little communication between the districts beyond the request for supra-local assistance during the management of the situation and is also not formally institutionalized, the extent of the looming disastrous situation in Stolberg was not anticipated (I 16, 18, 13).

On 13 July 2021, the first flood protection measures were taken in Stolberg and Roetgen, and the SAE of the city of Stolberg became operational as the municipal crisis management team during the night from 13 to 14 July 2021. On the morning of 14 July 2021, the crisis management team of the district StädteRegion Aachen was manned in a 24/7 shift operation but without assuming formal responsibility as a disaster had not been declared yet (I 18). On 14 July 2021, at around 01:00 p.m., a situation briefing took place in the SAE, in which it was assumed that the city center would be flooded, and the population was requested to evacuate to higher floors (Mein Stolberg 2021). A special focus of the warning communication was on industrial facilities located directly on the Vicht, some of which work with hazardous materials. During this time, the district crisis management team prepared the basis for a (possible) declaration of a disaster for the municipalities (Voss et al. 2022).

At around 04:00 p.m., loudspeaker vehicles of the fire brigade began to drive through the city center, demanding that people evacuate their homes. From 07:00 p.m., emergency shelters and a citizens' hotline were set up, and supra-local help was requested. At 08:10 p.m., the city's mayor addressed the citizens via Instagram with a statement from the Stolberg Fire station (Instagram-Account Stadt Stolberg 2021). He pointed out that water levels continue to rise and demanded that citizens evacuate to safe locations—either to higher floors or leave the area to be inundated. He named emergency shelters, urged people to think about the neighborhood, and communicated that the situation was still under control. From 09:30 p.m., the loudspeaker announcements had to be stopped, as the villages of Zweifall, Vicht, the city center, and Atsch were no longer accessible by road—but still, the SAE managed the situation as no disaster had been declared up to this point (Schreiber 2023).

There are few statements about water levels or water level forecasts for Stolberg in the available data set. In a case study on the nearby city of Eschweiler, also lying at the banks of the Vicht, the emergency services report strongly fluctuating water levels and repeated flood waves (Voss et al. 2022). At 10:25 p.m., the DWD forecasted no further precipitation and a (supposed) stagnation of the water levels led to the expectation of easing the situation in Eschweiler. Nevertheless, in consultation between the municipality of Stolberg, the municipality of Eschweiler, and the district of StädteRegion Aachen, a disaster was declared on 15 July 2021 (00:41 a.m.) and, thus, the responsibility shifted from local emergency management at the municipal level to disaster response at the district level (I 18). From 02:00 a.m., a flood wave rolled toward Eschweiler, which the water gages could no longer pick up, as they were not designed for these heights, and thus hit the city of Stolberg, too (Voss et al. 2022). It was not until early morning that the first reconnaissance flights could be carried out by requested police helicopters. The town hall and its branch offices were not usable due to the inundation in the entire city center—and the city administration was thus initially unable to act. Around noon, the armed forces and other supra-local aid from other districts arrived; disaster response measures started quickly, as the surrounding area was little affected, and it was relatively easy to supply emergency forces (I 4, 14). Spontaneous help from citizens emerged as well (Schreiber 2023).

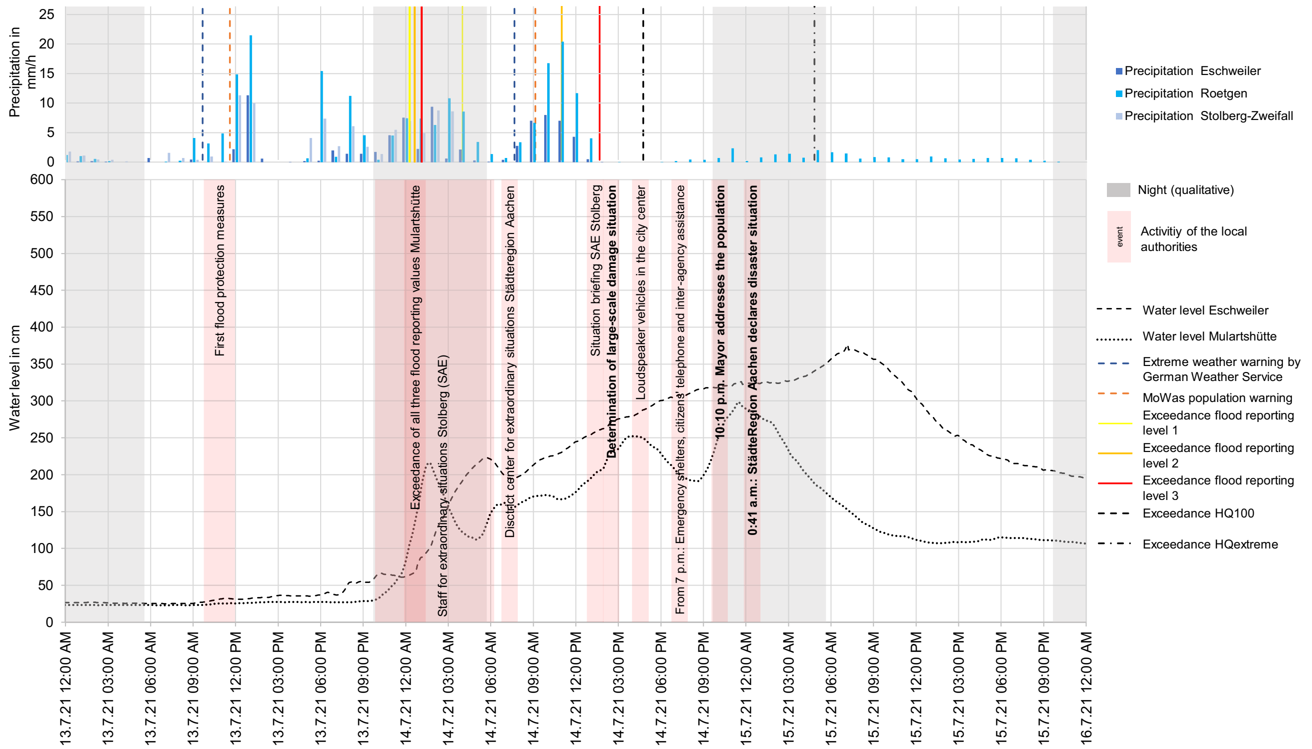


**FIGURE 4** | Actions and reactions at the interplay of weather warnings, flood information, emergency and disaster response during the July 2021 Flood Event in the region of Stolberg between 13 and 16 July 2021.

The situation's development can be illustrated differently. Figure 4 and Table 2 combine the analysis of Flood Forecasting, Early Warning, and emergency and disaster response. Figure 4 primarily shows hydrological and meteorological data, the specific water level trends, forecasts, and exceedances of the various flood warning levels. Table 2 builds mainly on the qualitative data. It shows the different actions and reactions at the interplay of weather warnings, flood information, emergency, and disaster response.

### 5.3 | Joint Analysis of Weak Points in Flood Forecasting, Early Warning and Disaster Response

The flood event at the focus location of Stolberg can be divided into the following phases compared with the meteorological and hydrological processes and the disaster response actions (see Figure 3). Critical interlinked weak points in both Flood Forecasting, Early Warning, and disaster response systems can be identified in different phases:

#### 5.3.1 | Phase 1—Preliminary Phase (Until 13 July 2021 10:00 p.m.)

In this phase, the forecast of the DWD contained amounts up to 80 mm/day, but only a few initial precipitation events were recorded near Stolberg (about 23 mm/day in Eschweiler; about 34 mm/day in Zweifall). The meteorological forecasts lacked precise temporal and spatial data due to dynamic weather patterns, and the DWD provided general weather warnings but without guidance on potential flood impacts. Here, two weak points can be identified. The first weak point is the *inaccuracy of meteorological information* for approaching flood situations. Furthermore, the uncertainty associated with the weather forecasts and warnings was only limitedly mentioned, additionally reducing their effectiveness as early warnings for flood situations. Secondly, there was *insufficient model-based flood forecasting* regarding the predicted rainfall amounts for the catchment area. Instead, LANUV provided only general hydrological situation reports without detailed projections of flood rise or peak levels. This lack of detailed forecasting information impeded adequate preparation and response actions, including flood protection measures such as filling and distributing sandbags or closely monitoring the water level and weather forecasts. While the situation in Stolberg (Instagram-Account Stadt Stolberg 2021; Mein Stolberg 2021) and the StädteRegion Aachen (I 18, 21) was only beginning to develop, information about the potentially disastrous effects of the extreme weather event was already available in other districts (I 6, 8, 16). However, this information did not reach the local emergency response in Stolberg and the disaster response of the StädteRegion Aachen, as cross-district communication and the exchange of situation assessments before a disaster declaration are not part of the formally defined *chain of communication* (I 18; Voss et al. 2022). Thus, if the information reached those responsible, it would have been based on informal personal contacts (I 18; Voss et al. 2022).

#### 5.3.2 | Phase 2—First Heavy Rainfall and Rapid Water Level Rise (Night of July 13–14)

The first heavy rainfall event occurred on the evening of 13 July 2021 in the catchment area of Inde and Vicht, which led to a rapid rise in the water level, as well as the exceeding of all defined flood reporting values at the Mulartshütte flood gage and

**TABLE 2** | Phases of flood forecasting, early warning, emergency, and disaster response with identified weak points during the July 2021 flood event.

<table>
<tr><th></th><th>Phase 1</th><th>Phase 2</th><th>Phase 3</th><th>Phase 4</th></tr>
<tr><td>Time</td><td>Until 13 July 2021 at 10:00 p.m.</td><td>Night of 13 July 2021 to 14 July 2021</td><td>Course of the day on 14 July 2021 until the night of 15 July 2021</td><td>Night and morning of 15 July 2021</td></tr>
<tr><td>Flood Forecasting, Early Warning (FFEW)</td><td>• Preliminary phase in which precipitation has been forecasted<br>• But only a few initial precipitation events were recorded</td><td>• First heavy rainfall<br>• Rapid rise in the water level, as well as the exceeding of all flood reporting values at the Mulartshütte flood gage and the exceeding of flood reporting value 1 in Eschweiler</td><td>• Intense precipitation, which occurred variably and spontaneously<br>• Direct hydrological response in the catchment area and water bodies of the Vicht in the area with the mid-mountain character upstream of Stolberg near Mulartshütte<br>• In Eschweiler, a continuous increase in water levels up to the point where the specified information values, i.e., the $HQ_{100}$, are exceeded</td><td>• End of precipitation and subsequently reached the maximum water levels and flood waves in Mulartshütte and Eschweiler<br>• $HQ_{Extrem}$ exceeded in Eschweiler in the morning hours of 15 July 2021</td></tr>
<tr><td>Weak points FFEW</td><td colspan="3">Inaccuracy of meteorological forecasting information</td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Insufficient model-based forecasting</td></tr>
<tr><td></td><td></td><td colspan="2">Missing link between warning values and response measures</td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Flood warnings are not issued by flood experts</td><td></td></tr>
<tr><td>Municipal Emergency Response (ER)</td><td>• Increased frequency of operations by the local fire brigades and the initiation of flood protection measures by local emergency response</td><td>• Crisis management team for extraordinary events (SAE) in Stolberg was set up<br>• Massive damage became apparent in Stolberg</td><td>• SAE assumed that the city center would be flooded<br>• Warning of industrial facilities<br>• Evacuation order for affected areas<br>• Emergency shelters and a citizens' hotline were set up<br>• Request for supra-local help<br>• Loudspeaker announcements stopped, as roads were no longer accessible</td><td>• Town hall and its branch offices became unusable due to the inundation in the entire city center</td></tr>
</table>

(Continues)

**TABLE 2** | (Continued)

| | Phase 1 | Phase 2 | Phase 3 | Phase 4 |
|---|---|---|---|---|
| District Disaster Response (DR) | • First disaster response organizations were alerted with the DWD warnings<br>• Deployment of all disaster response resources in the neighboring district | • District crisis management team was manned in a 24/7 shift operation | • District crisis management team prepared a disaster declaration | • District declared a disaster<br>• Disaster response assumes responsibility<br>• First reconnaissance flights requested<br>• Supra-local aid arrived<br>• Aid measures started quickly and effectively |
| Weak points ER/DR | Chain of communication | | | |
| | | Interpretation and communication of the situational picture | | |
| | | Supra-local aid concepts | | |
| | | | Disaster declaration | |

the exceeding of flood reporting value 1 in Eschweiler, followed by a subsiding in the early morning hours of 14 July 2021. Again, the *absence of a published model-based flood forecasting* can be identified as a weak point regarding the rapid rise of the water level on the night of 13–14 July because a definition of lead time is completely missing without knowledge about emerging and peak of flood waves as a consequence of predicted rainfall.

On 14 July 2021, significant damage was recorded in the city center of Stolberg during the day and in the neighboring district. Nevertheless, gaps in the SAE's *interpretation and communication of the situational picture* were an additional weak point as the severity, disastrous consequences, and necessary disaster relief measures were not fully anticipated (I 18; Voss et al. 2022). Although the fire brigade expected floods and also called for people to leave the buildings, people could hardly be persuaded to leave their homes, and the flood protection measures were insufficient due to inappropriate forecasts and the communicative framing of the situation by the SAE and political leadership of Stolberg (Instagram-Account Stadt Stolberg 2021; Mein Stolberg 2021). At this point, *supra-local aid concepts*—without a disaster declaration and thus without disaster relief forces—were already ineffective. Due to the heavy rainfall in a large area on 12 July 2021 and the need for local flood protection measures, requests within the framework of supra-local aid were hardly possible anymore as the majority of the fire brigades in the StädteRegion were already involved in local emergency response measures themselves and, hence, could not support the municipality of Stolberg (I 18; Voss et al. 2022).

### 5.3.3 | Phase 3—Second Heavy Rainfall Event and Alternating Spontaneous and Constantly Rising Water Levels (Daytime of 14 July Till the Evening of 15 July 2021)

Periodic variable and spontaneous recurrence of heavy rainfall in combination with saturated ground led to quick runoff and formation of flood waves, particularly recognizable by the water level of the Vicht in the mid-mountain region upstream of Stolberg at gage Mulartshütte. Simultaneously in Eschweiler, a continuous increase in water levels could be observed. A *missing link between warning values and response measures* downstream can be identified. The flood reporting values currently defined at the flood gages in NRW are not integrated into a level-related warning concept but serve as threshold values above which automatic messages are triggered.

It can be stated that the inadequate *interpretation and communication of the situational picture* and the impracticality of *supra-local aid concepts* still had massive implications for the development of the situation in Stolberg. Even though the SAE, at this point, assumed that the city center would be flooded and initiated more response measures, such as the warning of industrial facilities, evacuation order for affected areas, and request for supra-local help, these measures only had limited impact as roads were no longer accessible and supra-local aid was not available (see phase 2).

A *disaster declaration* and, thus, the shift of responsibility to the district level could have been issued earlier, e.g., on 14

July 2021, as stated by different experts in the aftermath (I 12, 18, 21, 22). However, the municipality of Stolberg, especially the political leadership, assumed and communicated until the night of 14 July 2021 that the situation was under control (I 18, Voss et al. 2022). Without the disaster declaration, the response measures remained limited as additional disaster response resources, such as disaster relief units or aerial reconnaissance, were unavailable and evacuations could not be legally enforced.

#### 5.3.4 | Phase 4—Peak of Heavy Rainfall and Water Level (Night and Morning of 15 July 2021)

The peak of the water level at gage Mulartshütte was reached around midnight of 14 July 2021 and at gage Eschweiler, including exceeding the level of defined extreme discharge ($HQ_{Extrem}$) in the morning of 15 July 2021. Information about the level or time of the respective peaks was not available. After the DWD's information on subsiding rainfall was published, local relief forces, using this information as a guide, presumably misjudged the situation and the upcoming flood situation during the night of 15 July. Another weakness can be identified here. The LANUV is not a responsible authority for flood warnings but informs and reports that defined flood reporting values are exceeded at water bodies in NRW, which cannot be seen as a warning. This discrepancy between the provision of information and actionable warnings impairs the effectiveness of flood response in the Stolberg region.

Still, even though delayed due to an improper situation assessment in Stolberg, it can be summarized that the disaster declaration proved to be highly effective when it was issued. First, more information about the situation could be processed, leading to a more accurate situational assessment. Second, on the basis of the disaster declaration and the updated situational assessment, additional resources, for instance, disaster relief units and aerial reconnaissance, were requested by the StädteRegion Aachen and deployed timely (Voss et al. 2022).

## 6 | Discussion

The analysis revealed weak points in both Flood Forecasting, Early Warning and disaster response, but more importantly, at their interface. It shows that the information regarding the water levels was not translated sufficiently and, above all, not in time with a view to potential damage. Disaster response did not act based on flood forecasting but rather in response to the water levels in Stolberg and the associated damage. This led to a practice of the disaster response that was disconnected from the forecasts with a severe time delay. With the high overall dynamic of the event, the disaster response measures were established too late (Dombrowsky 2022). The explanation for this lack of coherence at the interface of Flood Forecasting, Early Warning and disaster response is described as "design flaws" that led to a "problem of fit".

The Executive Action Plan of the UN Early Warnings for All Initiative aims to ensure that every person worldwide is protected by early warning systems by 2027. It focuses on four key areas: improving disaster risk knowledge by integrating scientific and local insights, strengthening global observation and forecasting networks, ensuring that warnings reach vulnerable populations through effective communication, and developing response plans that can be quickly activated when warnings are issued (World Meteorological Organization 2022). Compared to the UN Action Plan, several design flaws could be identified (Table 3):

In Germany, the DWD and the federal state water management structures are responsible for monitoring and deriving information on severe weather situations and flood events. These authorities provide technical information regarding hazards through weather warnings and hydrological situation reports, made available directly to emergency and disaster response authorities. This is where the responsibility of assessing hydrological situations ends, and a gap between warning values and response measures can be identified. In contrast to that, an optimal flood warning system would integrate water level predictions with information on the anticipated effects of the flood and with advice to people as to how to prepare before or during the event (Keys and Campbell 1991). Ultimately, during the July 2021 Flood event, the technical expertise of the situation assessment from a water management perspective is strongly designed as a top-down system and is not located within the area of responsibility of issuing flood warnings and the responsibility of suitable measures for dealing with floods, as is assigned to disaster response authorities.

Conversely, disaster response in Germany is designed as a strongly formalized bottom-up system that allows the district only to assume responsibility when municipal emergency response is overwhelmed (Wissenschaftliche Dienste—Deutscher Bundestag 2021; Wolf and Pfohl 2015).

**TABLE 3** | Summary of foreseen and missed actions during the July 2021 event regarding the UN early warnings for all initiative.

| Phase | Design flaws analysed in this paper |
|---|---|
| Monitoring | Lack of integration between meteorological forecasts and hydrological models. Insufficient spatial precision in weather forecasting |
| Detection | Missing link between water level measurements and direct warnings for the public and decision-makers |
| Forecasting | Inadequate hydrological modeling to forecast water levels and flood peaks with sufficient lead time |
| Communication | Delayed communication of warnings and situational assessments among actors (e.g., municipalities and districts) |
| Response | Late disaster declarations delaying resource mobilization and measures like evacuations |
| Adaptation and Learning | Lack of systematic integration of lessons learned into existing plans and legal frameworks |

The processes established for warning of and coping with flood events within Flood Forecasting, Early Warning and disaster response are structured in very different ways: the warning process in flood forecasting is thought of as a relatively clearly structured top-down process in contrast to the locally specific disaster response bottom-up process—which not only includes warning processes, but also decisions on protective measures, evacuations, etc.—in disaster response. In other words, where it seems "perfectly clear" from the point of view of flood forecasting and warning based on the data available how water courses will develop and that specific measures should be necessary, actors in local emergency response and disaster response are already involved in a complex process of decision-making and actions, in which hydrological modeling and forecasts are only one building block among many others (Curnin et al. 2020).

The opposed processes of Flood Forecasting, Early Warning, and disaster response were even more disastrous because the established disaster response system is oriented toward its past experiences with hazards and disasters in terms of scope, dynamics, degree of complexity, severity of damage, etc. (Hsu 2019; Yamori and Goltz 2021). If hazards and disasters exceed past events by far—as the July 2021 flood event did—it is possible that disaster response operates based on inapplicable fundamental assumptions regarding its capabilities, lead time, etc. In international comparison, many ideas and good practices are described regarding how a holistic system should be implemented (Grothe-Hammer and Berthod 2017; Kapucu and Hu 2016; Nohrstedt 2016; Sandoval et al. 2023). It will be critical to integrate the preparedness phase into disaster response and, therefore, shift from disaster response to a system of Disaster *Risk* Management. In Germany, the authorities responsible for monitoring and deriving information on exceptional situations such as severe weather situations and flood events are, on the one hand, the DWD and, on the other, the water management structures of the federal states (like LANUV). The DWD also organizes, in consultation with the federal states and, depending on individual needs and constraints, the range of information relating to the meteorological forecast and flood-potential events. The hydrological assessment, including the forecasting and reporting of flood situations, is the responsibility of the ministries of environment of the federal states. Technical measuring networks (like precipitation and water level) for identifying floods and operation of flood models for forecasting are also located at the level of environmental authorities of the federal states. These authorities provide information products in the form of hydrological situation reports, which are published or made available directly to other specialist authorities (such as disaster management).

Studies in communication science and disaster research point out that warning is not only sharing information, communicating probabilities and thresholds as a basis for decision-making, but rather it has to be viewed as a "process that is the product of a system," and this system is not only "the units that comprise the system, but also with their interrelatedness and with the larger system of which warning is a part" (McLuckie 1970, 1). The warning process involves establishing a strong relationship between the different systems and their units; it is about a multilevel risk governance system that was missing during the July 2021 flood (Šakić Trogrlić et al. 2022; Scolobig et al. 2022).

Several implications arise from the findings regarding the problems and, above all, the structural design flaws at the interface of Flood Forecasting, Early Warning, and disaster response. It is crucial that in the future, the different functional logics in the other system will be mutually observed in Flood Forecasting, Early Warning, and disaster response. In flood warning processes, for example, it is important to understand how disaster response operates, its lead times, and how decisions must be made under uncertainty. To this end, it is essential to prepare people from Flood Forecasting and Early Warning specifically for tasks in the context of the crisis management team in disaster response, for example, in the form of a specific advisor for flood warnings.

In disaster response, it is important to focus more on the possibilities of flood forecasting and warning and to take preparatory measures for disaster response operations at an early stage based on the warnings of flood forecasting. This often fails due to the disaster laws of the states in Germany that are, in most cases, like in NRW, designed as a response to damages that have already occurred or are about to occur (Geier 2022). In some states in Germany, e.g., Saxony, however, the state disaster laws allow for disaster pre-alarms, which make it possible to carry out some disaster response measures based on forecasts and to be able to fall back on them in the event of a disaster. In addition, disaster response must integrate expertise in Flood Forecasting and Early Warning more strongly into its crisis management work and find suitable procedures to transfer the knowledge of flood warnings into meaningful preparatory measures. On the other hand, no "blind" belief in water levels and gages should be taken, as gages can fail and give a false picture.

Several limitations accompany the paper. Firstly, the multilevel triangulation method combining disaster sociological qualitative data and quantitative forecasting models and data is challenging because each data point has to be given similar weight, expertise is required, and the different data might not agree (Creswell 2021). The paper is the result of a 2-year collaboration of an interdisciplinary team seeking to understand and integrate each other's viewpoints to address this challenge. Secondly, generalizability is limited because this paper examined just one case study within the context of the 2021 flood event, although there are other analogous analyses pertaining to the July 2021 flood (Dittmer and Lorenz 2024; Dittmer et al. 2024; DKKV 2024). Thirdly, the findings are limited in their transferability to other past flood-related disasters in Germany because the July 2021 flood was a dynamic heavy rainfall event in the low mountain regions of Germany. This type of event can only be compared to a very limited extent with other more common flood events in Germany, such as river floods along the rivers Rhine, Elbe, or Oder (Dombrowsky and Ohlendieck 1998; Jann et al. 2019; Jüpner 2018). River floods develop much more slowly, allowing disaster protection measures to take effect earlier despite the reactive nature of disaster response in Germany. But given more intense and more frequent heavy rain events due to climate change (Kotz et al. 2024) similar events are to be expected in the future that may result in major disasters if the described problem of fit persists.

It is important to examine whether the issues and design flaws described can also be observed in other instances of intense rainfall in Germany or similar European or non-European contexts. International research is necessary to compare other countries' flood forecasting, early warning, and disaster response systems. Enhancing interdisciplinary collaboration using a mixed-methods approach to address increasingly complex developments is also essential for future research.

## 7 | Conclusions

The interdisciplinary analysis of Flood Forecasting, Early Warning and disaster response systems during the July 2021 flood event in Germany highlights critical design flaws at their interface. Authorities responsible for monitoring and predicting severe weather and flood events in Germany provide crucial information for disaster response. However, the gap between hydrological assessments and the implementation of disaster response measures is evident. The study reveals that translating meteorological forecasts and hydrological information into actionable measures was insufficient and delayed, impeding timely disaster responses. The disaster response's reactive measures, initiated only after observing water levels and associated damage, were significantly hampered by the event's intense dynamics.

The analysis emphasizes that the effective processing of risk information and warnings is not merely about disseminating information but involves a comprehensive process that integrates multiple systems and their interrelated components. The current disaster response system in Germany, structured as a formalized bottom-up approach, shows a "problem of fit" with the top-down process of Flood Forecasting and Early Warning, leading to a disjointed response during extreme flood events in catchment areas with fast-reacting tributaries. This disparity underscores the need for improved coordination and mutual understanding between Flood Forecasting, Early Warning and disaster response in areas like the semi-mountainous regions affected in July 2021.

The study identifies structural design flaws in the existing systems, where disaster response operates based on past experiences, potentially rendering it ineffective during unprecedented events like the July 2021 flood. International comparisons suggest that holistic, integrated approaches are essential for effective flood risk mitigation and disaster response. The research recommends that future efforts focus on fostering mutual awareness between Flood Forecasting, Early Warning, and disaster response, emphasizing the need for early preparatory measures based on forecasts and integrating Flood Forecasting and Early Warning expertise into disaster response operations. At the same time, regional differences in response effectiveness highlight the potential for learning. As shown by Heidenreich et al. (2025), the warning of the population was more effective in the StädteRegion Aachen than in other affected districts, illustrating that proactive communication strategies can mitigate systemic shortcomings when well implemented at the local level.

This study's limitations include the challenges of multilevel qualitative and quantitative data triangulation, the case-specific nature of the findings, and the limited transferability to other types of flood events. Future research should explore whether similar issues exist in other intense rainfall events in Germany or comparable international contexts, necessitating international comparative studies and enhanced interdisciplinary collaboration.

Overall, addressing the identified design flaws and fostering better integration between Flood Forecasting, Early Warning, and disaster response systems is crucial for improving early warning and disaster response, thereby enhancing sufficient response to future flood events. An interdisciplinary analysis is key to understanding these complex processes and should be part of analyzing such extreme events.


#### Acknowledgments

The analyses were performed within the framework of the project "Governance and Communication during the Crisis of the Flood Event in July 2021" (HoWas2021), which was funded by Germany's Federal Ministry of Education and Research (FKZ 13N16227 and FKZ 13N16230).


#### Conflicts of Interest

The authors declare no conflicts of interest.

#### Data Availability Statement

The water management data were kindly provided by the responsible authorities LANUV and Landesamt für Umwelt Rheinland-Pfalz as well as the water management authorities Was-serverband Eifel-Rur, Wupperverband, and Erftverband. We would like to thank you very much for this and hope that the findings of the study can serve as starting points for the further development of the flood process. Restrictions apply to the availability of these data, which were used under license for this study. The data supporting this study's social science disas-ter research findings are available on request from the corresponding author. The data are not publicly available due to privacy.

#### Endnotes

[1] Because of word limitations and because it is not necessary for further argumentation, a comprehensive explanation of the whole flood risk management and disaster management systems is not provided here. However, please refer to Domres et al. (2000) for additional information.

#### References


Becker, P. 2020. "The Problem of Fit in Flood Risk Governance: Regulative, Normative, and Cultural-Cognitive Deliberations." *Politics and Governance* 8, no. 4: 281–293. https://doi.org/10.17645/pag.v8i4.3059.

Corbetta, P. 2003. *Social Research: Theory, Methods and Techniques*. SAGE Publications.

Creswell, J. W. 2021. *Designing and Conducting Mixed Methods Research and the Mixed Methods Research Workbook*. SAGE Publications.

Curnin, S., B. Brooks, and C. Owen. 2020. "A Case Study of Disaster Decision-Making in the Presence of Anomalies and Absence of Recognition." *Journal of Contingencies & Crisis Management* 28, no. 2: 110–121. https://doi.org/10.1111/1468-5973.12290.

Dittmer, C., and D. F. Lorenz. 2024. "Emergent, Extending, Expanding and Established Citizen Disaster Desponse in the German Ahr Valley Flood in 2021." *International Journal of Disaster Risk Reduction* 105: 104394. https://doi.org/10.1016/j.ijdrr.2024.104394.

Dittmer, C., D. F. Lorenz, and M. Voss. 2024. “Bevölkerungsschutzgovernance im Hochwasser 2021.” In *DKKV-Schriftenreihe: Vol. 63. Governance und Kommunikation im Krisenfall des Hochwasserereignisses im Juli 2021*, 53–68. DKKV.

Dittmer, C., D. F. Lorenz, H. G. Goersch, M. Cremer, and S. Siehoff. 2023. “Warnung und Vorsorge in der StädteRegion Aachen: Erste Ergebnisse eines wissenschaftlichen Begleitprojekts.” *Notfallvorsorge* 54: 21–31.

DKKV. 2022. “Die Flutkatastrophe im Juli 2021.” In *Ein Jahr danach: Aufarbeitung und erste Lehren für die Zukunft*. DKKV.

DKKV. 2024. *DKKV-Schriftenreihe: Vol. 63. Governance und Kommunikation im Krisenfall des Hochwasserereignisses im Juli 2021*. DKKV.

Dombrowsky, W. R. 2022. “Learning From the Catastrophe in the German Ahr Valley.” *D+C Development and Cooperation* 6, no. 6: 31–32.

Dombrowsky, W. R., and L. Ohlendieck. 1998. “Flood Management in Germany.” In *Flood Response and Crisis Management in Western Europe: A Comparative Analysis*, edited by U. Rosenthal and P. Hart, 153–187. Springer.

Domres, B., H. H. Schauwecker, K. Rohrmann, G. Roller, G. W. Maier, and A. Manger. 2000. “The German Approach to Emergency/Disaster Management.” *Medicinski Arhiv* 54, no. 4: 201–203.

Eschweiler Filmpost. 2018. “Hochwasser vor 50 Jahren: Als Inde und Vicht ihr Bett verließen.” https://www.filmpost.de/aktuell/archiv/2016/hochwasser-vor-50-jahren-als-inde-und-vicht-ihr-bett-verlie%C3%9Fen.html.

Euregio. 2024. “Euregio Maas-Rhein.” EMRIC. https://euregio-mr.info/de/themen/sicherheit/emric.php.

Fekete, A., and S. Sandholz. 2021. “Here Comes the Flood, but Not Failure? Lessons to Learn After the Heavy Rain and Pluvial Floods in Germany 2021.” *Water (Basel)* 13, no. 21: 3016. https://doi.org/10.3390/w13213016.

Fischer-Preßler, D., D. Bonaretti, and K. Fischbach. 2021. “Understanding Failures of Emergency Warning Systems from a Representation Perspective: A Case Study from Germany.” https://www.researchgate.net/publication/354613010_Understanding_Failures_of_Emergency_Warning_Systems_from_a_Representation_Perspective_A_Case_Study_from_Germany.

Fischer, H. W. 2003. “The Sociology of Disaster: Definitions, Research Questions, & Measurements Continuation of the Discussion in a Post-September 11 Environment.” *International Journal of Mass Emergencies and Disasters* 21, no. 1: 91–107. https://doi.org/10.1177/028072700302100104.

Frische, A. K., J. F. Kirchner, C. Pawlowski, S. Halsbenning, and J. Becker. 2021. “Leave no One Behind: Design Principles for Public Warning Systems in Federalism.” In *Lecture Notes in Information Systems and Organisation. Innovation Through Information Systems: Volume II: A Collection of Latest Research on Technology Issues*, edited by S. Stieglitz, R. Schütte, and F. Ahlemann, vol. 47, 673–686. Springer.

Geddes, A., A. R. Black, and M. Cranston. 2024. “Integrating Direct Messaging With Flood Alerts and Warnings: Insights Into Effectiveness From a Registered Public User Population.” *Journal of Flood Risk Management* 18: e12972. https://doi.org/10.1111/jfr3.12972.

Geier, W. 2022. “Strukturen, Akteure und Zuständigkeiten des deutschen Bevölkerungsschutzes.” *Bundeszentrale Für Politische Bildung*. https://www.bpb.de/shop/zeitschriften/apuz/bevoelkerungsschutz-2021/327989/strukturen-akteure-und-zustaendigkeiten-des-deutschen-bevoelkerungsschutzes/.

Grothe-Hammer, M., and O. Berthod. 2017. “The Programming of Decisions for Disaster and Emergency Response: A Luhmannian Approach.” *Current Sociology* 65, no. 5: 735–755. https://doi.org/10.1177/0011392116640592.

Headley, M. G., and V. L. Plano Clark. 2019. “Multilevel Mixed Methods Research Designs: Advancing a Refined Definition.” *Journal of Mixed Methods Research* 14, no. 2: 145–163. https://doi.org/10.1177/1558689819844417.

Heidenreich, A., H. J. Murdock, and A. H. Thieken. 2025. “Does Warning Performance Vary Between Administrative Districts and Across Watersheds for Rapid Onset Flood Events? A Case Study of the 2021 Flood in Germany.” *Journal of Flood Risk Management* 18, no. 1: e70021. https://doi.org/10.1111/jfr3.70021.

Hsu, E. L. 2019. “Must Disasters Be Rapidly Occurring? The Case for an Expanded Temporal Typology of Disasters.” *Time & Society* 28, no. 3: 904–921. https://doi.org/10.1177/0961463X17701956.

Instagram-Account Stadt Stolberg. 2021. “20:10 Uhr: Ansprache von Bürgermeister Patrick Haas zur aktuellen Lage.” Bitte passt auf euch auf! | Instagram. https://www.instagram.com/p/CRUVjc7InOH/?utm_source=ig_web_copy_link.

Jann, W., B. Jantz, A. Kühne, and L. Schulze-Gabrechten. 2019. “The Flood Crisis in Germany 2023.” In *Societal Security and Crisis Management: Governance Capacity and Legitimacy*, edited by P. Lægreid and L. H. Rykkja, 75–114. Palgrave Macmillan.

Jüpner, R. 2018. “Coping With Extremes – Experiences From Event Management During the Recent Elbe Flood Disaster in 2013.” *Journal of Flood Risk Management* 11, no. 1: 15–21. https://doi.org/10.1111/jfr3.12286.

Kapucu, N., and Q. Hu. 2016. “Understanding Multiplexity of Collaborative Emergency Management Networks.” *American Review of Public Administration* 46, no. 4: 399–417. https://doi.org/10.1177/0275074014555645.

Keys, C., and B. Campbell. 1991. “Preparing Communities for Flooding: Some Recent Lessons and Some Ways Forward.” *Macedon Digest* 6, no. 3: 1–5.

Klassen, S., and D. Evans. 2020. “Top-Down and Bottom-Up Water Management: A Diachronic Model of Changing Water Management Strategies at Angkor, Cambodia.” *Journal of Anthropological Archaeology* 58: 101166. https://doi.org/10.1016/j.jaa.2020.101166.

Knighton, J. O., O. Tsuda, R. Elliott, and M. T. Walter. 2018. “Challenges to Implementing Bottom-Up Flood Risk Decision Analysis Frameworks: How Strong Are Social Networks of Flooding Professionals?” *Hydrology and Earth System Sciences* 22, no. 11: 5657–5673. https://doi.org/10.5194/hess-22-5657-2018.

Kotz, M., S. Lange, L. Wenz, and A. Levermann. 2024. “Constraining the Pattern and Magnitude of Projected Extreme Precipitation Change in a Multimodel Ensemble.” *Journal of Climate* 37, no. 1: 97–111. https://doi.org/10.1175/JCLI-D-23-0492.1.

Mathiesen, K., H. von der Burchard, and L. Gehrke. 2021. *Over 100 Die in Germany, Belgium Floods Despite Early Warnings*. POLITICO.

Mayring, P. 2000. “Qualitative Content Analysis.” *Forum: Qualitative Social Research* 1, no. 2: 20.

McLuckie, B. F. 1970. *The Warning System in Disaster Situations: A Selective Analysis*. Disaster Research Center.

Mein Stolberg. 2021. “Teile der Altstadt könnten laut Feuerwehr überschwemmt werden.” https://www.meinstolberg.de/teile-der-altstadt-koennten-laut-feuerwehr-ueberschwemmt-werden/.

Merkes, S. T., T. Zimmermann, and M. Voss. 2024. “Whose Disaster? Disaster Response as a Conflicted Field Between Cooperation and Competition.” *International Journal of Disaster Risk Reduction* 106: 104459. https://doi.org/10.1016/j.ijdrr.2024.104459.

Montano, S., and A. Savitt. 2023. “Revisiting Emergencies, Disasters, & Catastrophes: Adding Duration to the Hazard Event Classification.” *International Journal of Mass Emergencies and Disasters* 41, no. 2–3: 259–278. https://doi.org/10.1177/02807270231211831.

MULNV. 2021. *Zweiter fortgeschriebener Bericht zu Hochwasserereignissen Mitte Juli 2021 (zu Landtags-Vorlage 17/5485).* Ministerium für Umwelt.

Nohrstedt, D. 2016. "Explaining Mobilization and Performance of Collaborations in Routine Emergency Management." *Administration & Society* 48, no. 2: 135–162. https://doi.org/10.1177/0095399712473983.

Quarantelli, E. L. 2000. *Emergencies, Disasters and Catastrophes are Different Phenomena (Preliminary Paper No. 304).* Disaster Research Center.

Reinert, J., E.-M. Klopries, and H. Schüttrumpf. 2025. "Meteorological and Hydrological Data as a Basis for Issuing Flood Warnings During the July Flood 2021 in Rhineland-Palatinate and North Rhine-Westphalia (Germany)." *Journal of Flood Risk Management* 18, no. 2: e70078. https://doi.org/10.1111/jfr3.70078.

Šakić Trogrlić, R., M. van den Homberg, M. Budimir, C. McQuistan, A. Sneddon, and B. Golding. 2022. "Early Warning Systems and Their Role in Disaster Risk Reduction." *Towards the "Perfect" Weather Warning*: 11–46. https://doi.org/10.1007/978-3-030-98989-7_2.

Sandoval, V., M. Voss, V. Flörchinger, S. Lorenz, and P. Jafari. 2023. "Integrated Disaster Risk Management (IDRM): Elements to Advance Its Study and Assessment." *International Journal of Disaster Risk Science* 14, no. 3: 343–356. https://doi.org/10.1007/s13753-023-00490-1.

Schreiber, H. 2023. *Jahrhundertflut in Stolberg*. S. H. G. Stolberger Heimat-und Geschichtsverein e.V.

Schreier, M. 2012. *Qualitative Content Analysis in Practice*. SAGE Publications.

Scolobig, A., S. Potter, T. Kox, et al. 2022. "Connecting Warning With Decision and Action: A Partnership of Communicators and Users." In *Towards the "Perfect" Weather Warning: Bridging Disciplinary Gaps through Partnership and Communication*, edited by B. Golding, 47–85. Springer International Publishing.

Serra-Llobet, A., E. Conrad, and K. Schaefer. 2016. "Governing for Integrated Water and Flood Management: Comparing Top-Down and Bottom-Up Approaches in Spain and California." *Water* 8, no. 10: 445. https://doi.org/10.3390/w8100445.

StädteRegion Aachen. 2024a. Aktuelle Infos zu Tihange | StädteRegion Aachen.

StädteRegion Aachen. 2024b. Tihange-1 störanfällig | StädteRegion Aachen.

Szönyi, M., V. Roezer, T. Deubelli, et al. 2022. PERC Floods Following "Bernd". Zurich: Zurich Insurance Group. https://www.newsroom.zurich.de/documents/zurich-perc-analysis-bernd-english-version-423750.

Tashakkori, A., and C. Teddlie. 2006. *Mixed Methodology: Combining Qualitative and Quantitative Approaches*, Applied Social Research Methods Series. Vol. 46. SAGE Publications.

Thieken, A. H., P. Bubeck, A. Heidenreich, J. von Keyserlingk, L. Dillenardt, and A. Otto. 2023. "Performance of the Flood Warning System in Germany in July 2021—Insights From Affected Residents." *Natural Hazards and Earth System Sciences* 23, no. 2: 973–990. https://doi.org/10.5194/nhess-23-973-2023.

Thieken, A., P. Bubeck, and M.-L. Zenker. 2023. "Fatal Incidents During the Flood of July 2021 in North Rhine-Westphalia, Germany: What Can Be Learnt for Future Flood Risk Management?" *Journal of Coastal and Riverine Flood Risk* 2. https://doi.org/10.59490/jcrfr.2023.0005.

THW. 2021. Bericht zur Einsatznachbereitung. Starkregenereignis Bernd 2021. THW.

Voss, M., A. Rüger, N. Bock, C. Dittmer, and S. T. Merkes. 2022. "Die Evakuierung des St.-Antonius-Hospitals Eschweiler während der Flutereignisse im Juli 2021." *KFS* Working Paper Series 25. https://doi.org/10.17169/REFUBIUM-35269.

Wingen, M. 2025. "Hochwasservorsorge und Hochwasserbewältigung 5.0—drei ausgewählte Beiträge zur Verbesserung des Hochwasserschutzes." Dissertation, RWTH Aachen University.

Wissenschaftliche Dienste—Deutscher Bundestag. 2021. "Nationale Systeme des Bevölkerungsschutzes. Ein Vergleich Deutschlands mit den Anrainer- und Partnerstaaten." Deutscher Bundestag. https://www.bundestag.de/resource/blob/822416/d69abe14a5bc0c510c408086b1a24545/WD-3-239-20-pdf-data.pdf.

Wolf, F., and T. Pfohl. 2015. "Bevölkerungsschutz im Mehrebenensystem: Horizontale und vertikale informelle Governance-Muster in Deutschland." In *Zeitschrift für vergleichende Politikwissenschaft Special Issue: Vol. 4. Von Government zu Governance: Informales Regieren im Vergleich*, edited by S. Bröchler and H.-J. Lauth, 259–285. Springer VS.

World Meteorological Organization. 2022. "EARLY Warnings For All—The UN Global Early Warning Initiative for the Implementation of Climate Adaptation: Executive Action Plan 2023-2027." https://library.wmo.int/idurl/4/58209.

Yamori, K., and J. D. Goltz. 2021. "Disasters Without Borders: The Coronavirus Pandemic, Global Climate Change and the Ascendancy of Gradual Onset Disasters." *International Journal of Environmental Research and Public Health* 18, no. 6: 3299. https://doi.org/10.3390/ijerph18063299.