https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

Performance of the flood warning system in Germany in July 2021 – insights from affected residents

Annegret H. Thieken[1], Philip Bubeck[1], Anna Heidenreich[1], Jennifer von Keyserlingk[1], Lisa Dillenardt[1], Antje Otto[1]

[1]Institute of Environmental Science and Geography, University of Potsdam, Karl-Liebknecht-Strasse 24-25, 14476 Potsdam, Germany

Correspondence to: Annegret Thieken (thieken@uni-potsdam.de)

Abstract. In July 2021 intense rainfall caused devastating floods in Western Europe and 184 fatalities in the German federal states of North Rhine-Westphalia (NW) and Rhineland-Palatinate (RP) questioning their flood forecasting, warning and response system (FFWRS). Data from an online survey (n = 1315) reveal that 35% of the respondents from NW and 29% from RP did not receive any warning. Of those who were warned 85% did not expect a very severe flooding and 46% did not know what to do. Regression analysis reveals that this knowledge is influenced by gender and flood experience, but also by the contents and the source of the warning message. The results are complemented by analyses of media reports and official warnings that show shortcomings in providing adequate recommendations to people at risk. Dissemination of warnings, communication of the expected flood magnitude and adequate responses are seen as entry points for improving the FFWRS in Germany.

1 Introduction

From 12 to 19 July 2021, Western and Central Europe witnessed widespread and intense rainfall caused by the low pressure system "Bernd" that led to severe flooding in Belgium, Germany, Luxembourg, and the Netherlands as well as further European countries in lower intensities (Schneider and Gebauer, 2021; Kron et al., 2022). In the western part of Germany, particularly in the federal states of North Rhine-Westphalia (NW) and Rhineland-Palatinate (RP), rainfall amounts totalled to more than 100 mm in 72 hours over large parts of the two most affected states with local maxima of more than 150 mm in 24 hours (Junghänel et al., 2021). This rainfall led to urban flooding in some cities such as Cologne, Düsseldorf, and Hagen as well as to quickly rising flash floods in small and steep catchments in the middle hills, particularly around the Eifel mountain ranges (Dietze et al., 2022; Kron et al., 2022).

In all of Germany, 189 people lost their lives, thereof 135 in RP, 49 in NW, two in Bavaria, two in Saxony and one person in Baden-Wurttemberg. Two people are still missing (as of 19 April 2022). Severe damage of around € 33 billion occurred in the residential, commercial and industrial sectors as well as in the public sector and at infrastructures (Koks et al., 2021; Munich Re, 2022). Governmental disaster aid of an unprecedented amount of € 30 billion has been provided to support reconstruction and recovery in the affected areas. After floods in August 2002, June 2013 and May/June 2016, this is the fourth flood over the past 20 years that caused damage of more than € 2 billion in Germany (Kron et al., 2022). Even worse, the death toll in July 2021 by far exceeds the number of fatalities caused by former floods, which amounted to 21 in 2002, 14 in 2013 and eleven in 2016. A higher death toll caused by a water-related hazard was only recorded for a storm surge in February 1962 along the North Sea Coast with 347 fatalities in Germany, thereof 318 in the city of Hamburg. Consequently, failures in warning, alerting and evacuation processes have been discussed already shortly after the event of July 2021 (Cornwall, 2021).

Internationally, the substantial reduction of global disaster-related fatalities per 100 000 people by 2030 is the first target of the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR). Since it is the primary goal of early warning systems to save people's lives during a disaster, the SFDRR also aims at increasing the number of countries with multi-hazard early warning systems in its seventh target (UN, 2015).

Flood warning systems are more adequately termed flood forecasting, warning and response systems (FFWRS; Parker and Priest, 2012). As such, they include continuous monitoring and forecasting of precipitation and water levels, the detection of potentially hazardous situations, which should be linked to defined thresholds and rules on when, how and whom to warn in case of expected heavy precipitation or rising water levels including (pre-defined) statements that alert and inform civil protection and potentially affected people. For the overall success of a FFWRS, civil protection and affected parties have to respond adequately and effectively to an unfolding flood situation (Parker et al., 1994; Parker and Priest, 2012). Warning is successful if all components function across spatial and departmental borders. In this process, creation and dissemination of warnings that trigger adequate and effective response is seen as major challenge (e.g. Cools et al., 2016; Kuller et al., 2021), in which various contents and formats of a warning message and different dissemination channels can be distinguished (Kuller et al., 2021). Furthermore, trust among partners and in institutions plays a crucial role (Parker and Priest, 2012; Cools et al., 2016; Morss et al., 2016).

In Germany, flood warning systems have been established since the 1880s (DKKV, 2015). Currently, capacities and responsibilities for forecasting, warning and response are divided between the federal, state and local levels. At the federal level, the meteorological service (Deutscher Wetterdienst – DWD) is in charge of weather forecasting and severe weather warnings, such as heavy precipitation. Flood forecasting and warning is, however, the task of the individual federal states and is organized differently as described by DKKV (2015) and Kreibich et al. (2017). After the severe flooding in August 2002, the DWD introduced a fourth warning level to indicate very extreme weather events. Some federal states reorganized and centralized their forecasting and warning centres, e.g. Saxony, Lower-Saxony, and Thuringia (DKKV, 2015). In addition, data on flood water levels are displayed in a joint nationwide web-portal (www.hochwasserzentralen.de). These changes led to an improved warning situation during the river flood of June 2013 (Thieken et al., 2016; Kreibich et al., 2017).

To warn the general public is primarily the task of the local level, e.g. the district administrations. Since 2017, warnings can be disseminated via a Modular Warning System (Modulares Warnsystem – MoWaS) hosted by the Federal Office of Civil Protection and Disaster Assistance (Bundesamt für Bevölkerungsschutz – BBK) to a wide range of warning multipliers and

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

dissemination channels like media operators and warning apps (e.g. NINA, KATWARN). Some districts and municipalities also use sirens or loudspeaker announcements to warn their population directly. The first nationwide alert day after the German reunification in September 2020 revealed how difficult it is to operate warning systems successfully. The federal ministry of interior declared the test a failure as the MoWaS messages and consequently also messages of warning apps were delayed due to technical reasons (BBK, 2020; Deutscher Bundestag, 2020). Subsequently, the system was improved and was tested successfully in NW in March 2021 (BBK, 2021). However, user data and views were not analysed (BBK, 2021).

Even if alerts function technically, there are many "potential deficiencies at each stage of FFWRS which transfer through their enchained processes" (Parker and Priest, 2012). Eventually, warnings can only avoid flood impacts – primarily fatalities, but also financial losses – if people in flood-prone areas as well as the local disaster management or civil protection receive and notice the warning in time, trust the warning, understand its contents, and know how to respond and behave adequately (Penning-Rowsell and Green, 2000; Párraga Niebla, 2015; Morss et al., 2016). Using German survey data from 2002 to 2013, Kreibich et al. (2021) showed the importance of residents 'knowing what to do' for flood damage reduction. Such factual knowledge is at least partly influenced by the warning message itself that should not only contain information on the hazard process, location, and time, but also some guidance on how to protect oneself (Kuller et al., 2021). Therefore, an evaluation of a FFWRS should include how the targeted population perceived the warnings and whether they were able to respond adequately (Penning-Rowsell and Green, 2000). As part of a broader post-event investigation, this paper aims to analyse how the warning system in July 2021 performed – also in comparison to other flood events in Germany –, and to discuss how to further improve the FFWRS based on views of the population affected in July 2021.

2 Data and Methods

Between 25 August and 17 October 2021, an online survey on the warning situation in July 2021 was conducted. The link to the survey was distributed and advertised via Facebook, primarily in the two most affected federal states of North Rhine-Westphalia (NW) and Rhineland-Palatinate (RP). In addition, a press release was sent to local newspapers in the area and all mayors were informed by e-mail about the survey. In total, 1348 people completely answered the survey, thereof 892 from NW and 423 from RP; Fig. 1 shows the districts with respondents from these two states. The remaining 33 cases could not be located due to missing geographic information, or were located in other federal states and thus omitted from further analyses. In this paper, first analyses of the data set are presented. Results were verified by local media reports that were searched in a newspaper database and official warnings released by MoWaS in July 2021 as well as via the warning app KATWARN.

The questionnaire comprised 22 questions, of which several were taken from similar surveys that have been conducted after floods since 2002 (Thieken et al., 2017; Kreibich et al., 2017) allowing us to compare the data from 2021 to the recent past. The questions address the following topics: how the water entered the building (flood pathway), water level at the building, warning source (dissemination channel), information content, point in time when the first warning was received, assessment

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

of the credibility of the warning on a six-point rating scale, the anticipated intensity of the flood, the perceived impacts of the event in the neighbourhood and for the own household, the perceived knowledge on how to react adequately, types of immediate response actions and an assessment of their loss-reducing effect, as well as the perceived level of surprise. In addition, two questions on previously experienced floods were posed. Finally, people were asked to indicate on a six-point rating scale how much they appreciate currently discussed channels of warning dissemination and how important they regard different pieces of information to be contained in a warning message. As socio-demographic information the postal code and the place of residence, the age and gender of the person as well as the size of their household was elicited. At the very end, respondents could provide further information considered important as open answer.

As data post-processing, the corresponding federal state, as well as the official codes and names of the district and the municipality, were added to each case based on the reported postal code and place of residence. In addition, indicators on the warning source and the information content were calculated in accordance with Thieken et al. (2005). The warning source indicator captures through which channel/by whom respondents received a warning, ranging from 'no warning' and 'own search' to 'official warnings' from authorities or local disaster management (see Table A1 for variable definitions). Although the quality of the warning source is considered to increase with every category of the warning source indicator, the different categories are still entered as dummy variables in the regression models. The warning information indicator reflects the reported pieces of information of the warning message. It ranges from 'no relevant information/no warning' to 'information on how to act and protect oneself' (see Table A1).

The socio-demographic characteristics of our sample are summarized in Table 1 and are compared to the general population per federal state as of 31 December 2020. With regard to gender, the subsample of NW is somewhat biased towards women (Chi-Square goodness of fit test, $p = 0.0003$), while the subsample of RP is slightly, but non-significantly biased towards men. With regard to age, the age group of 41 to 60 years is overrepresented in both subsamples and accounts for almost half of the respondents. Adolescents (15 to 20 years), who were not explicitly addressed by the adverts, and very old people (>80 years), who might not be reached by an online format, are clearly underrepresented in both subsamples (Table 1). However, both samples include respondents from all age classes and hence cover a wide range of ages (NW: 15 to 88 years; RP: 20 to 83 years).

3. Results and discussion

3.1 Receiving, trusting and understanding warnings

As outlined in the introduction, a prerequisite of an effective FFWRS is that warnings officially issued by authorities reach those at risk. In July 2021, 35% of the surveyed residents from North Rhine-Westphalia (NW, $n = 892$) and 29% of those from Rhineland-Palatinate (RP, $n = 423$) stated that they had not been warned. Fig. 2 puts these high numbers into the context of former fluvial (left) and pluvial (right) floods in Germany. Since flood forecasting and warning is the responsibility of the federal state (see Introduction), data in Fig. 2 are distinguished per federal state and event year for fluvial floods, while for pluvial floods, for which the severe weather warnings of the DWD are important, just the name of the city and the year of the event is provided.

Since August 2002, Germany has experienced several fluvial floods, particularly in the southern and eastern parts of the country (see Kienzler et al., 2015; Thieken et al., 2022). Fig. 2 reveals that in 2002, 2005, 2010 and 2016 the share of the affected population that received no warning was more or less comparable to the shares in 2021 with only small differences across different federal states, except for Saxony-Anhalt in 2002. The flood processes of these events are also comparable to the situation in 2021, i.e. they occurred mainly in the middle hills and partly showed a flashy character (Kienzler et al., 2015; Thieken et al., 2022). In 2002, the flood then travelled further downstream and caused inundations along the river Elbe, which had the character of a (huge) fluvial flood in parts of Saxony and Saxony-Anhalt. In contrast to the events in 2002, 2005, 2010, 2016 and 2021, the share of the population that was not warned in most of the affected federal states dropped to around 5 to 10% in 2006, 2011 and 2013 (Fig. 2), which can be seen as a good performance of the FFWRS (Thieken et al., 2016). These latter floods can be primarily characterized as slowly rising fluvial floods (Kienzler et al., 2015; Thieken et al., 2016). Fig. 2 further reveals that during pluvial floods the warning situation is even worse with a share of unwarned people of more than 50% showing, however, some improvements over time (see also Rözer et al., 2016).

Altogether Fig. 2 suggests that the performance of the FFWRS in Germany greatly depends on the type of flooding and is particularly challenged by pluvial and flash floods. For most of the pluvial floods shown in Fig. 2 as well as for the rainfall and subsequent (flash) floods in May and June 2016, lead times of just two hours were reported by Kind et al. (2019, p. 79) based on official warnings. Survey data from affected residents resulted in a median lead time of just one hour in 2016 (Thieken et al., 2022). In addition, the forecasted rainfall amounts underestimated the observed values by far (Kind et al., 2019, p. 79). These analyses illustrate the limits of rainfall forecasts for convective storms. In 2021, however, the flood-triggering low pressure system had been forecasted several days in advance by the European Flood Alert System (EFAS) as well as by the German weather forecasting system since Sunday, 11 July 2021 (DWD, 2021). Hence, the share of residents who received no warning should have been considerably lower than surveyed, although Saadi et al. (2022) illustrate the tendency of radar-based rainfall data from July 2021 to underestimate rainfall amounts and hence flood peaks.

To identify entry points for improvements we examined, whether we can identify factors predicting the receipt of an official warning issued by authorities (or not). Official warnings include warnings from authorities or civil protection, calls to evacuate, messages from weather apps as well as sirens or sound trucks. As potentially related factors, we included socio-demographic information (age, gender, household size and the federal state of the respondents), the number of previously experienced flood events (prior flood experience), the perceived impact of the 2021-event for the respondent's household, as well as different flood pathways, as reported by the respondents.

Table 2 presents the results of the logistic regression explaining the receipt (yes or no) of an official warning as defined above. As regression coefficients are difficult to interpret in logistic regressions, we instead provide odds ratios as effect sizes. In terms of socio-demographic characteristics, we find that men report higher levels of being officially warned than women (increased odds ratio of nearly 67%). No significant effect is shown for age, the household size and the federal state.

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

Having experienced flooding prior to 2021, increases the odds of receiving a warning in 2021 by 23%, while perceived strong impacts of the flood for the household decreases the odds by 18%. In terms of flood pathways, we find that fluvial flooding (marginally significant) and wildly flowing surface runoff increases the receipt of a warning (odds ratio of 36% and 43%, respectively), while a dike or dam breach reduces the odds ratio of an official warning receipt by 36% (marginally significant). Respondents who observed no flooding in their immediate surrounding reported significantly higher levels of being officially warned. While the latter finding might sound counterintuitive at first, it may be explained by the fact that respondents who were not flooded themselves were not surprised by water intrusion and thus had more time to receive an official warning. In addition, they might not have experienced power outages or break-downs of telecommunications which were frequently reported in severely affected areas (e.g. by Koks et al., 2021). Overall, the explanatory power of the model is rather low with an explained variance in official warning receipt of 6.3%.

In many places affected in July 2021, flooding occurred in the evening of 14 July and during the night from Wednesday to Thursday (15 July). 740 respondents (valid answers from NW: n = 474; RP: n = 266) provided the day on which they were warned for the first time (Fig. 3). In both federal states, most respondents, who were warned, did receive the first warning on Wednesday, 14 July 2021, (NW = 40% of valid answers; RP = 61%). The second most frequent day for receiving a warning was Monday, 12 July 2021, (NW = 23%; RP = 16%). Altogether, around 35% of the warned residents from RP had received their first warning before 14 July, while this share amounts to 50% in NW. By the end of 14 July 2021, the cumulative sums rise to 95% in RP and 90% in NW (Fig. 3).

In fact, the heavily affected district of Euskirchen (NW) issued a first warning via MoWaS on 12 July 2021 (around 5 p.m. local time), which was updated twice on 14 July 2021. Most of the other districts issued a first warning via MoWaS in the course of 14 July 2021; this was accompanied by state-wide warnings for NW and RP. The severely affected district of Ahrweiler (RP) issued a flood warning in the early afternoon of 14 July 2021. So, the answers of the respondents in Fig. 3 are basically consistent with the release of official warnings and underline the need to improve warning dissemination.

An investigation of the performance of a FFWRS should involve an assessment of the credibility and comprehensibility of the warning message as these are crucial aspects (Morss et al., 2016; Párraga Niebla, 2015). In July 2021, the credibility of the warning was in general high: on a six-point rating scale (1: “the warning was totally incredible” to 6: “the warning was highly credible”) 48% of the 841 respondents, who had been warned and answered this question, chose a 5 or 6 (NW: 47%, RP: 51%). Just 9% found the warnings incredible, i.e. chose a 1 or 2 (NW: 8%, RP: 11%). This distribution is very different when it comes to the anticipated intensity of the forecasted event – and thus the understanding people got of the upcoming event after having received a warning: on a six-point rating scale (1: “it will rain, but there’s no problem” to 6: “torrential rain will cause widespread inundations, massive damage and life-threatening situations”) just around 15% of the 856 respondents, who had been warned and answered this question, chose a 5 or 6 (NW: 15%, RP: 14%) and 29% (NW: 30%, RP: 26%) chose a 1 or 2. This underlines that the warnings failed to credibly communicate the magnitude of the upcoming event. In many parts of the affected areas, the flood of July 2021 was larger than any flood that had been measured in the continuous discharge series (e.g. Apel et al., 2022; Saadi et al., 2022). Our data underline that its magnitude was largely

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

underestimated by the affected residents. In addition, some respondents complained that too many warnings on Covid-19 were disseminated via the most popular warning app NINA and that in the week prior to the severe flood event warnings for heavy rain had no serious (flood) impacts.

3.2 Knowing what to do after receiving a warning

Warning can only avoid flood impacts – in terms of deaths, but also in terms of financial damage – if people know how to respond and how to behave adequately (Kreibich et al., 2021; Kuller et al., 2021). Thus, an assessment of the factual knowledge needed to avoid dangerous situations or mitigate damage needs investigation. The factual knowledge was again assessed on six-point rating scale (1: "Based on the warning, I didn't know at all how to protect myself and my household from the flooding" to 6: "Based on the warning, I knew very well how to protect myself and my household from the flooding"). Fig. 4 shows the lack of factual knowledge as assessed by surveyed affected people that reported that they had been warned before the flood hazard became relevant and chose a 1 or 2 on the rating scale mentioned above. Similar to Fig. 2, the answers of 2021 can be compared to former surveys and flood events. Again, severe and flashy floods like those in 2002 and 2016 perform the worst and are comparable to the values reported for the flood of 2021. Therefore, communication on how to cope with pluvial and flash flood has to be enhanced.

To identify more specific entry points for improvements, we also analysed the influence of various factors on people's factual knowledge during a flood by means of a regression analysis. Besides information on the warning source and warning information (also referred to as 'channel' and 'content', e.g. by Kuller et al., 2021), we include event characteristics (i.e. perceived impact for respondent's household), the number of previously experienced floods, to what degree the flood of 2021 came as a surprise, as well as age, gender and the federal state as socio-demographic control variables. Variable definitions, coding and summary statistics are provided in Table A1. The results of the linear regression model predicting respondents' knowledge what to do are displayed in Table 3. A corresponding ordered logistic regression model, which considers the ordered nature of the dependent variable is provided in Table A2. As results are largely similar in terms of significant predictors, we report the linear model here since regression coefficients can be interpreted more intuitively.

In terms of the warning source, results show that warnings issued by authorities have a significant positive influence on people's knowledge what to do, when compared with respondents that did not receive any warning (= base), which is in line with the literature review presented by Kuller et al. (2021). The other three warning source categories, i.e. own search, friends and neighbours, as well as nationwide or regional news, had no significant effect when compared to those without warning. A significant but rather weak positive effect is found for the warning information, i.e. if the warning message contains information about adequate behaviour, people tend to perceive to be better informed and able to cope with the situation. A strong positive effect is observed for flood experience. As could be expected, people who had experienced one or more floods before the 2021-event report significantly higher levels of factual knowledge. Interestingly, this effect increases continuously with the number of previous events that people reported (Table 3). In terms of the socio-demographic control variables, men tend to report higher levels of knowing what to do, while age had again no significant effect. We also

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

find that respondents from RP report higher levels of knowing what to do. Significant negative effects are found for the level of surprise and the perceived flood impact at the respondents' household, with surprise having the larger effect (Table 3). Apel et al. (2022) argue that forecasting the impacts, i.e. the potentially inundated areas, would have been helpful to communicate the extent and the deadly potential of the upcoming flood event.

These findings are verified by a first content analysis of media reports on warnings before the event hit and of the official warnings that were disseminated via MoWaS or KATWARN. Some examples from the local press illustrate that even though warnings from the DWD were usually reported correctly, the corresponding advice on behaviour was, however, often too vague and seems – in hindsight – inappropriate given the high intensity of the flood. Moreover, only around a third of media reports that mentioned warnings included recommendations on behaviour. For example, on 13 July 2021, the "Trierischer Volksfreund" (region Trier, RP; Seydewitz, 2021) reported an extreme weather warning from DWD with up to 200 mm rainfall that may also lead to rising water levels in small rivers. The associated advice was that people living along small rivers and streams should monitor the situation and potentially undertake precautionary measures. However, what such measures involve was not specified. Another article published on 14 July 2021 (Ruhr Nachrichten, NW) similarly reported severe weather warnings for the district Unna (NW). The corresponding advice was to keep doors and windows closed and to store objects in cellars on higher shelves. Finally, for the area of Koblenz (RP) the "Rhein-Lahn-Zeitung" (Lindner, 2021) reported on 14 July 2021 a warning of heavy rain and rising water levels that was associated with the advice for campers to be careful alongside rivers. More comprehensive advises on appropriate property-level measures were just found in the "Rhein-Zeitung" (RP) of 14 July 2021 and mentioned backflow preventers, water-proof doors and windows as well as maintenance works.

In contrast, official warnings are usually accompanied by recommendations what to do. However, some recommendations seem not to fit to the situation that unfolded in July 2021. One example illustrating that the recommended protective actions were not adapted to the real situation is taken from the severely affected district of Ahrweiler (RP). Here, the app KATWARN warned against water levels of more than five meters at 14 July 2021 at 7:35 pm, which considerably exceeded the 100-year flood level of around 3.7 meter at the gauge Altenahr. However, the recommended protective actions for affected people were still to avoid cellars and underground car parks, not to drive on inundated streets and to clear drains and wells. These actions were clearly insufficient, since already at 8:30 pm houses in the municipality of Altenahr were reported to be half-way under water and flowing away at 10:40 pm (Frankfurter Allgemeine Zeitung, 15 September 2021; Staib and Steppat, 2021). Only at 11:09 pm the state of emergency was declared and people 50 m on both sides of the Ahr river were requested to leave their homes and evacuate by themselves – an advice which, at that time, was clearly too late and also dangerous.

In principle, the official warning messages seem to contain all necessary information, but were not adapted to the intensity that occurred in July 2021. For extreme scenarios such as the record-breaking flood of July 2021, more warning levels could be an option. Since each (official) warning level is associated with predefined recommendations on what affected parties

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

should do to protect themselves (including translations to other languages), more warning levels could probably lead to a better communication of protective measures and adequate behaviour that are appropriate for the unfolding event.

3.3 Wishes for future warnings

In the online survey, the respondents were also asked about their views on warning contents and their wishes for (new) warning technologies. Fig. 5 displays the mean assessments of the importance of different pieces of information by the respondents on a rating scale from 1 (not important at all) to 6 (very important) for both federal states. The data reveal that almost all information is regarded (very) important with slight compromises with regard to the timing and the expected amount of rainfall, comparisons with past events, potential impacts and information about detours, road closures or train cancellations. It should be noted that timing and height of water levels are considered more important than rainfall, which contrasts the media reports that focus more on severe weather warnings released by DWD than on hydrological forecasts. Moreover, Kuller et al. (2021) found in their literature review inconsistent results on the effectiveness of impact-based warnings (and the provision of uncertainties in warnings). Besides the contents shown in Fig. 5, they further recommend providing contact information.

In the future, affected residents are in favour of a countrywide installation of sirens and cell broadcast accompanied by enhanced media coverage (Fig. 6). There are only small differences between respondents from the two federal states. The lower values in RP for cell broadcast might be due to the fact that many people experienced power outages and a breakdown of telecommunication in July 2021 (Koks et al., 2021).

4. Conclusions

In Germany, the system of severe weather and flood warnings, better called flood forecasting, warning and response system (FFWRS), has been improved over the past 20 years, particularly after the severe flood of August 2002 that primarily hit the catchments of the river Elbe in the Eastern part of Germany and the river Danube in Bavaria. Fluvial floods in January 2011 along the rivers Elbe and Rhine and in June 2013 in almost all of Germany with, however, again hotspots along the rivers Elbe and Danube and their tributaries illustrated its overall good performance (Thieken et al., 2016; Kreibich et al., 2017). However, with regard to pluvial and fast-onset flash floods survey data reveal still crucial weaknesses of the system: 30 to 40% of the residents in areas affected by pluvial or flash floods were not reached by severe weather or flood warnings. This was found across various federal states in Germany and across several fast onset flood events in the recent past (Fig. 2). This shortcoming became fatal during the flood in July 2021 despite a good meteorological forecast several days in advance and recent improvements of the system such as the provision of meteorological warnings per municipality by DWD, the introduction of warning apps (NINA; KATWARN), and dissemination platform MoWaS. Hence, further improvements of the whole FFWRS have to be made. With regard to pluvial and flash floods, the need for implementing local warning systems, e.g., at small creeks, which have not been included in the flood forecasting system so far, has to be checked.

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

Moreover, dissemination channels have to be critically reviewed and improved. The online-survey of 2021 underlines that residents tend to be in favour of sirens (Fig. 6), probably since they do not depend so much on power and telecommunication networks than other dissemination channels.

Our analyses further show that it is important that official warnings reach the residents at risk since this improves their knowledge on how to behave adequately during a flood event (Table 3). This is crucial since warnings are only successful if the recipients know how to effectively protect themselves, their families and their properties. Our survey data reveal that up to 50% of the warned residents did not know what to do in July 2021. Again, similar percentages had been reported earlier for flash and pluvial floods (Fig. 4). The results indicate that flood risk and crisis communication in Germany has focussed much on river, i.e. fluvial, flooding. Hence, efforts to communicate threats, mitigation options and adequate behaviour with regard to flash and pluvial floods have to be considerably enhanced. Given the high death toll of 189 fatalities in Germany in July 2021, life threatening situations and their avoidance should be particularly addressed. Examples from the local newspapers and official warning messages underline that warning messages have to be linked more consistently and regularly with advise on adequate behaviour and should better account for the anticipated intensity of the unfolding flood event. Furthermore, the understandability of warning messages should be better tested and evaluated in future.

In many areas affected in Germany, the flood of July 2021 was larger than any flood that had been measured in the continuous discharge series. The survey data underline that its magnitude was greatly underestimated by the affected residents, probably also due to warning messages that failed to clearly communicate the flood magnitude and potential impacts. This aspect needs more in-depth investigations. However, impact-based forecasts that show the expected extent of the flood (as demonstrated by Apel et al., 2022, for the river Ahr) should be tested although the respondents indicated that they consider other pieces of information more important, e.g. affected places, timing of the flood peak or information on evacuations (Fig. 5).

The magnitude of the upcoming flood was probably underestimated by the responsible authorities, too. In some places, e.g. in the district of Ahrweiler (RP), this resulted in the fact that the state of emergency was declared too late and that evacuations of heavily affected settlement areas were initiated too late. In most German states, the declaration of the state of emergency is the responsibility of the district administrator since in most cases the district also has to bear the incurred costs. However, there is no mandatory training of district administrators in disaster management, who are elected politicians. Whether this is a primary weakness of the system needs some further research and thoughts. However, some federal states, e.g. Saxony, have introduced a risk-averse decision strategy, meaning that there is an automatic declaration of the state of emergency if flood forecasts exceed the highest warning level. In other regions, local warning chains have been established so that a telephone chain is initiated from upstream to downstream along a river in case of flooding or another incident, e.g. pollution. Altogether, a more reliable FFWRS need to be developed together with the affected communities so that they know better in the future where to find information, how to interpret this and how to react.

Acknowledgements

We thank all respondents that they participated in the survey despite the flood impacts they suffered from.

Financial support

The presented work was developed within the framework of the research project 'Urban resilience against extreme weather events—typologies and transfer of adaptation strategies in small metropolises and medium-sized cities' (ExTrass) funded by Germany's Federal Ministry of Education and Research (BMBF, FKZ 01LR1709A1) in collaboration with the Research Training Group "Natural Hazards and Risks in a Changing World" (NatRiskChange) funded by the Deutsche Forschungsgemeinschaft (DFG; GRK 2043/2).

Data availability

The survey data are owned by the authors and can currently be provided upon reasonable request only.

Author contributions

AH, AT, AO, and PB developed the questionnaire and conducted the survey with the support of LD. AT, PB, AH, and LD processed and analysed the data. JvK searched and analysed media reports and official warning messages with support of AO. AT prepared the manuscript with contributions from all co-authors.

Competing interests

The contact author has declared that neither they nor their co-authors have any competing interests.

References

Apel, H., Vorogushyn, S., and Merz, B.: Brief communication – Impact Forecasting Could Substantially Improve the Emergency Management of Deadly Floods: Case Study July 2021 floods in Germany, Nat. Hazards Earth Syst. Sci. Discuss. [preprint], https://doi.org/10.5194/nhess-2022-33, in review, 2022.

BBK – Bundesamt für Bevölkerungsschutz und Katastrophenhilfe: MoWaS-Meldung konnte nur verspätet zugestellt werden, https://www.bbk.bund.de/SharedDocs/Kurzmeldungen/DE/2020/09/1-bundesweiter-warntag.html (last access on 14 April 2022), 2020 (in German).

BBK – Bundesamt für Bevölkerungsschutz und Katastrophenhilfe: Warn-App NINA erreicht Meilenstein ohne Probleme https://www.bbk.bund.de/SharedDocs/Kurzmeldungen/DE/2021/03/nina-erreicht-meilenstein.html

Cools, J., Innocenti, D., and O'Briena, S.: Lessons from flood early warning systems, Environ. Sci. Policy, 58, 117–122, 2016.

Cornwall, W.: Europe's deadly floods leave scientists stunned, Science, 373(6553), 372–373, DOI: 10.1126/science.373.6553.372, 2021.

Destatis: GENESIS Datenbank 12411-0013: Bevölkerung: Bundesländer, Stichtag, Geschlecht, Altersjahre (31.12.1967 - 31.12.2020), https://www-genesis.destatis.de/genesis//online?operation=table&code=12411-0013&bypass=true&levelindex=0&levelid=1642928753644#abreadcrumb (last access: March 2022), 2021.

Deutscher Bundestag: Bundesweiter Warntag 2020, Antwort der Bundesregierung auf die Kleine Anfrage der Abgeordneten Stephan Brandtner und der Fraktion der AfD, Drucksache 19/23413, https://dserver.bundestag.de/btd/19/234/1923413.pdf (last access on 14 April 2022), 2020 (in German).

Dietze, M., Bell, R., Ozturk, U., Cook, K. L., Andermann, C., Beer, A. R., Damm, B., Lucia, A., Fauer, F. S., Nissen, K. M., Sieg, T., and Thieken, A. H.: More than heavy rain turning into fast-flowing water – a landscape perspective on the 2021 Eifel floods, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2022-7, 2022.

DKKV – Deutsches Komitee Katastrophenvorsorge: Das Hochwasser im Juni 2013: Bewährungsprobe für das Hochwasserrisikomanagement in Deutschland. DKKV-Schriftenreihe Nr. 53, Bonn, ISBN 978-3-933181-62-6, 207 pp., 2015 (in German).

DWD – Deutscher Wetterdienst: Bericht zum Ablauf und Umfang der operationellen Warn- und Beratungstätigkeit des Deutschen Wetterdienstes im Vorlauf und während des Unwetters 12. – 15. Juli 2021 in NRW und Rheinland-Pfalz, ausgelöst durch das Tief „Bernd". Offenbach, 10 pp., 2021 (in German).

Junghänel, T., Bissolli, P., Daßler, J., Fleckenstein, R., Imbery, F., Janssen, W., Kaspar, F., Lengfeld, K., Leppelt, T., Rauthe, M., Rauthe-Schöch, A., Rocek, M., Walawender, E., and Weigl, E.: Hydro-klimatologische Einordnung der Stark- und Dauerniederschläge in Teilen Deutschlands im Zusammenhang mit dem Tiefdruckgebiet „Bernd" vom 12. bis 19. Juli 2021. DWD-Report, 16 pp. https://www.dwd.de/DE/leistungen/besondereereignisse/niederschlag/20210721_bericht_starkniederschlaege_tief_bernd.pdf?__blob=publicationFile&v=10 (last access: 23 March 2022; in German), 2021.

Kienzler, S., Pech, I., Kreibich, H., Müller, M., and Thieken, A.H.: After the extreme flood in 2002: changes in preparedness, response and recovery of flood-affected residents in Germany between 2005 and 2011, Nat. Hazards Earth Syst. Sci., 15, 505–526, 2015.

Kind, C., Kaiser, T., Riese, M., Bubeck, P., Müggenburg, E., Schüller, L., Fleischmann, R., and Thieken, A.: Vorsorge gegen Starkregenereignisse und Maßnahmen zur wassersensiblen Stadtentwicklung – Analyse des Standes der Starkregenvorsorge in Deutschland und Ableitung zukünftigen Handlungsbedarfs, UBA-Text 55/2019, Dessau, 2019 (in German).

Koks, E., van Ginkel, K., van Marle, M., and Lemnitzer, A.: Brief Communication: Critical Infrastructure impacts of the 2021 mid-July western European flood event, Nat. Hazards Earth Syst. Sci. Discuss. [preprint], https://doi.org/10.5194/nhess-2021-394, in review, 2021.

Kreibich H., Hudson P., and Merz, B.: Knowing What to Do Substantially Improves the Effectiveness of Flood Early Warning, BAMS, 102(7), E1450–E1463, 2021.

Kreibich, H., Müller, M., Schröter, K., and Thieken, A. H.: New insights into flood warning reception and emergency response by affected parties, Nat. Hazards Earth Syst. Sci., 17, 2075–2092; DOI: 10.5194/nhess-17-2075-2017, 2017.

Kron, W., Bell, R., Thiebes, B., and Thieken, A. H.: The July 2021 flood disaster in Germany, contribution to the HELP Global Report on Water and Disasters 2022, in print, 2022.

Kuller, M., Schoenholzer, K., and Lienert, J.: Creating effective flood warnings: A framework from a critical review, Journal of Hydrology, 602, 126708, 2021.

Lindner, J.: Starkregen erwartet / Wetterexperte warnt vor hohen Niederschlagsmengen, Rhein-Lahn-Zeitung, 14 July 2021 (in German).

Morss, R., Mulder, K. J., Lazo, J. K., and Demuth, J. L.: How do people perceive, understand, and anticipate responding to flash flood risks and warnings? Results from a public survey in Boulder, Colorado, USA, J. Hydrol., 541, 649–664, 2016.

Munich Re: Hurricanes, cold waves, tornadoes: Weather disasters in USA dominate natural disaster losses in 2021, Munich Re, https://www.munichre.com/en/company/media-relations/media-information-and-corporate-news/media-information/2022/natural-disaster-losses-2021.html (last access on 14 April 2022), 2022.

Parker, D. J. and Priest, S. J.: The Fallibility of Flood Warning Chains: Can Europe's Flood Warning be Effective?, Water Resour. Manag., 26, 2917–2950, 2012.

Parker, D. J., Fordham, M., and Torterotot, J. P.: Real-time hazard management: flood forecasting, warning and response, in: Floods across Europe. Hazard assessment, modelling and management, edited by: Penning-Rowsell, E. C. and Fordham, M., Middlesex University Press, London, UK, 135–166, 1994.

Párraga Niebla, C.: 8 – Communication Technologies for Public Warning, Wireless Public Safety Networks 1, 229-260, 2015.

Penning-Rowsell, E. C. and Green, C.: insights into the appraisal of flood alleviation benefits: (1) Flood damage and flood loss information, J. Chart. Inst. Water E., 14, 347–353, 2000.

Rhein-Zeitung: Starke Niederschläge lassen Wasser steigen, 14 July 2021 (in German).

Ruhr Nachrichten: Feuerwehren sind gerüstet für den Starkregen am heutigen Mittwoch, 14 July 2021 (in German).

Rözer, V., Müller, M., Bubeck, P., Kienzler, S., Thieken, A., Pech, I., Schröter, K., Buchholz, O., and Kreibich, H.: Coping with pluvial floods by private households, Water, 8(7), 304, 2016.

Saadi, M., Furusho-Percot, C., Belleflamme, A., Chen, J.-Y., Trömel, S., and Kollet, S.: How uncertain are precipitation and peakflow estimates for the July 2021 flooding event?, Nat. Hazards Earth Syst. Sci. Discuss. [preprint], https://doi.org/10.5194/nhess-2022-111, in review, 2022.

Schneider, D. and Gebauer, P.: Die Flutkatastrophe im Juli 2021 in Mitteleuropa aus meteorologischer Sicht, Beiträge zur Berliner Wetterkarte, Verein BERLINER WETTERKARTE e.V. zur Förderung der meteorologischen Wissenschaft, Berlin, Germany, 2021 (in German).

Thieken, A. H., Kienzler, S., Kreibich, H., Kuhlicke, C., Kunz, M., Mühr, B., Müller, M., Otto, A., Petrow, T., Pisi, S., and Schröter, K.: Review of the flood risk management system in Germany after the major flood in 2013, Ecology and Society, 21(2), 51, DOI: http://dx.doi.org/10.5751/ES-08547-210251, 2016.

Thieken, A., Kreibich, H., Müller, M., and Lamond, J.: Data collection for a better understanding of what causes flood damage – experiences with telephone surveys. In: Flood damage survey and assessment: new insights from research and practice (D. Molinari, S. Menoni, F. Ballio, eds.). AGU, Wiley, Chapter 7, p. 95–106; doi: 10.1002/9781119217930.ch7, 2017.

Thieken, A. H., Müller, M., Kreibich, H., and Merz, B.: Flood damage and influencing factors: New insights from the August 2002 flood in Germany, Water Resources Research, 41(12), W12430, DOI: 101029/2005WR004177, 2005.

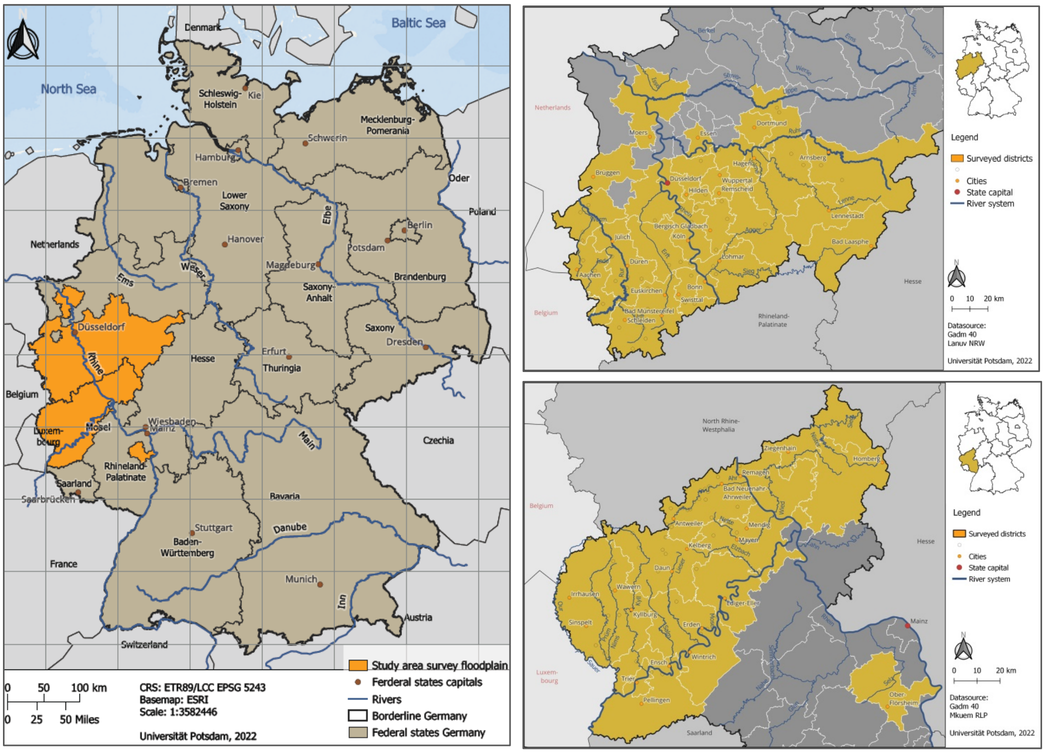
Thieken, A. H., Samprogna Mohor, G., Kreibich, H., and Müller, M.: Compound inland flood events: different pathways, different impacts and different coping options, Nat. Hazards Earth Syst. Sci., 22, 165–185, 2022.

Seydewitz, R.: Meteorologe warnt Region vor Starkregen und steigenden Pegeln, Trierischer Volksfreund, 13 July 2021 (in German).

Staib, J. and Steppat, T.: Flutnacht von Ahrweiler – Rekonstruktion eines politischen Versagens, Frankfurter Allgemeine Zeitung, 15 September 2021 (in German).

UN – United Nations: Sendai Framework for Disaster Risk Reduction 2015–2030, https://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf (last access on 14 April 2022), 2015.

Figures



440 **Fig. 1: Overview map of Germany (left) highlighting the districts with respondents of the online survey in North Rhine-Westphalia (upper right) and Rhineland-Palatinate (lower right).**

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

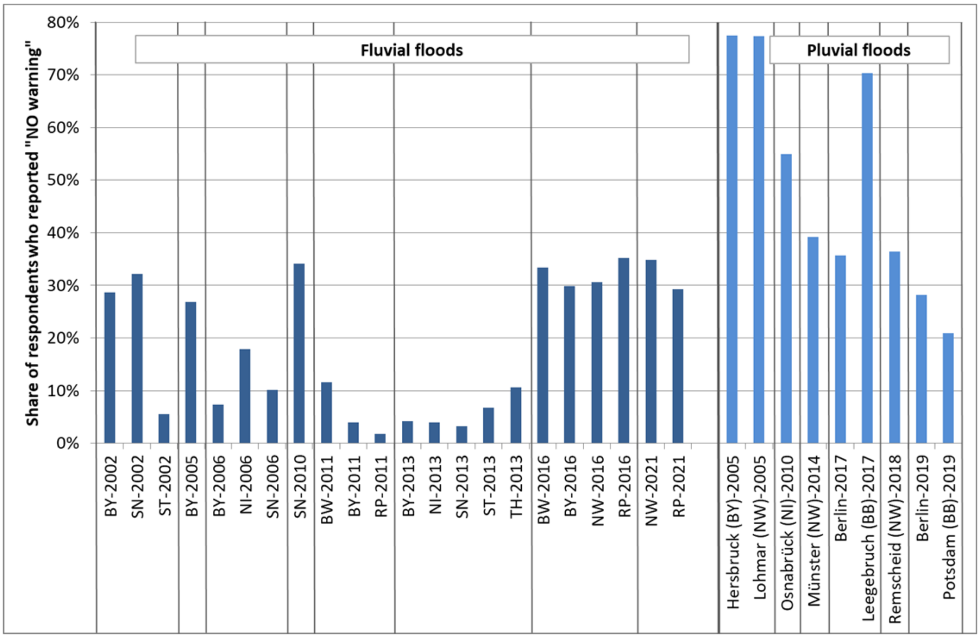


Fig. 2: Share of respondents who reported that they had not been warned before the flood danger became imminent. Data are shown per flood event (year), federal state and flood type; left: fluvial floods from 2002 to 2021, right: some pluvial floods between 2005 and 2019 (abbreviations of the federal states: BB: Brandenburg; BW: Baden-Wurttemberg; BY: Bavaria; NI: Lower Saxony; NW: North Rhine-Westphalia; RP: Rhineland-Palatinate; SN: Saxony; ST: Saxony-Anhalt; TH: Thuringia).

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

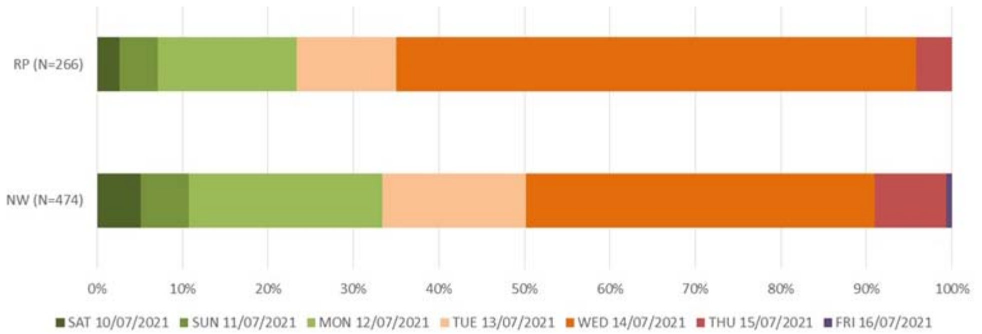


Fig. 3: Day on which 740 respondents from North Rhine-Westphalia (NW) and Rhineland-Palatinate (RP) received a first warning.

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

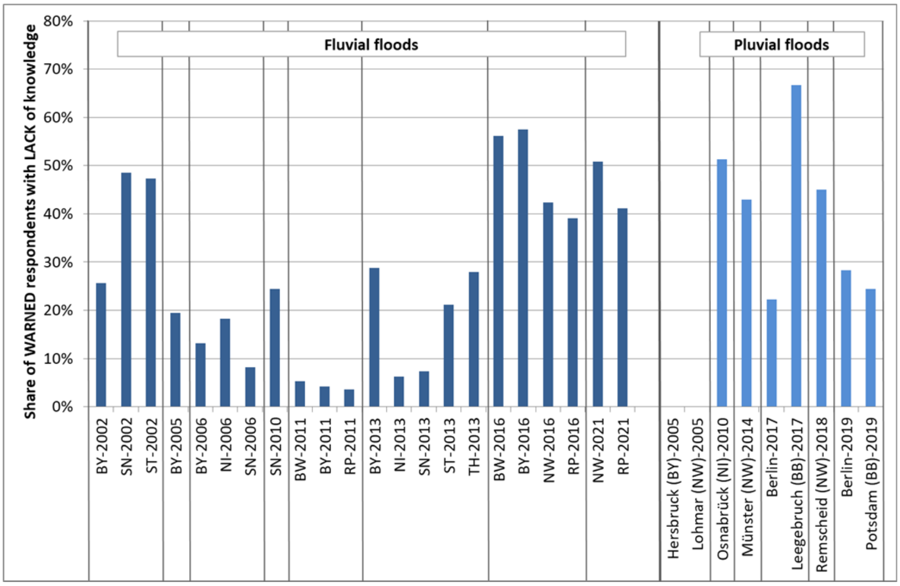
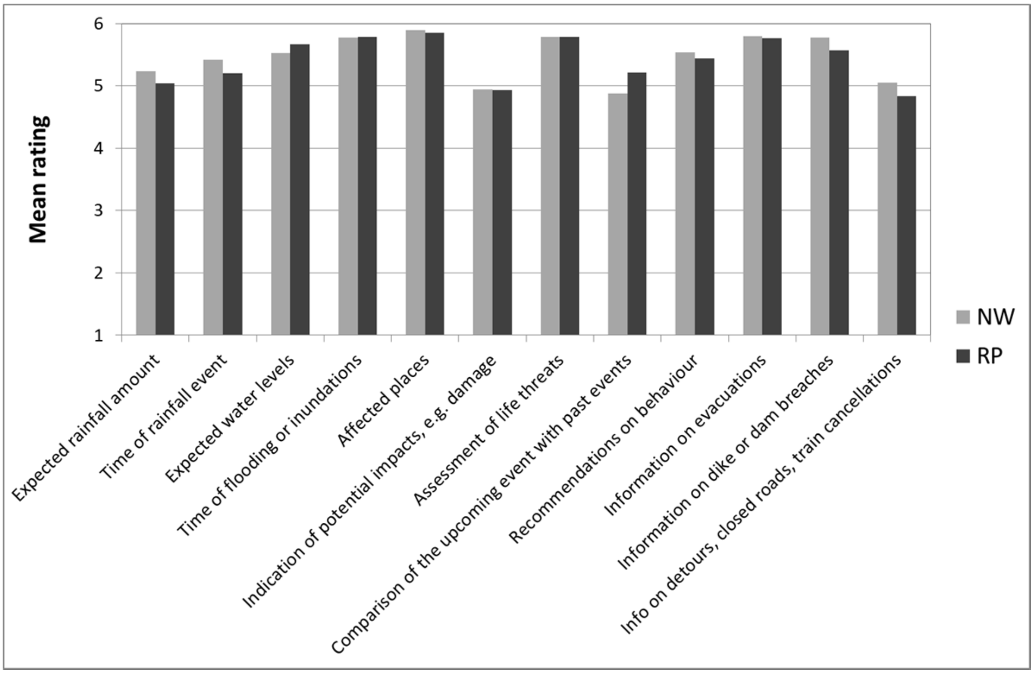


Fig. 4: Share of respondents who were warned, but reported that they did not know (well) how to behave, i.e. how to protect themselves and their household against the flood. Data are shown per flood event (year), federal state and flood type; left: fluvial floods from 2002 to 2021, right: some pluvial floods between 2005 (no data) and 2019 (abbreviations of the federal states: BB: Brandenburg; BW: Baden-Wurttemberg; BY: Bavaria; NI: Lower Saxony; NW: North Rhine-Westphalia; RP: Rhineland-Palatinate; SN: Saxony; ST: Saxony-Anhalt; TH: Thuringia; note that in former surveys the scale was used in a reversed order; for this figure all data were aligned).

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022



465 **Fig. 5: Mean rating of surveyed respondents with regard to the importance of different piece of warning information or content (NW: n = 837 to 882; RP: n = 404 to 418).**

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

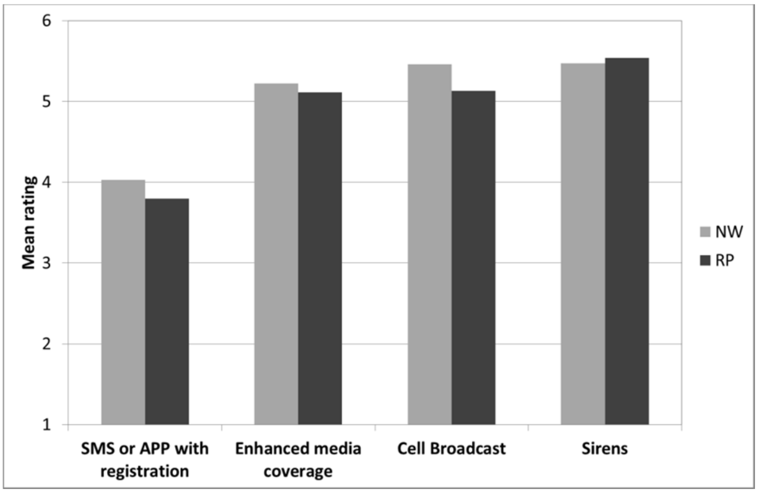


Fig. 6: Mean rating of surveyed respondents with regard to future warning channels (NW: n = 837 to 882; RP: n = 404 to 418).

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

Tables

Table 1: Socio-demographic characteristics of the sample in comparison with the general population per state as of 31 December 2020 according to Destatis (2021).

	North Rhine-Westphalia (NW)			Rhineland-Palatinate (RP)		
Gender	**number of respondents**	**%**	**% population as of 31 Dec. 2020**	**number of respondents**	**%**	**% population as of 31 Dec. 2020**
male	354	42.8%	49.1%	207	52.5%	49.4%
female	474	57.2%	50.9%	187	47.5%	50.6%
subtotal	**828**	**100%**	**100%**	**394**	**100%**	**100%**
diverse	1			1		
missing	63			28		
total	**892**			**423**		
age	**n**	**%**	**% population without children**	**N**	**%**	**% population without children**
15-20 yrs	10	1.1%	6.9%	1	0.3%	6.6%
21-40 yrs	298	33.7%	28.8%	101	24.3%	27.7%
41-60 yrs	435	49.2%	33.0%	235	56.6%	33.1%
61-80 yrs	136	15.4%	24.1%	76	18.3%	25.4%
>80 yrs	5	0.6%	7.1%	2	0.5%	7.2%
subtotal	**884**	**100%**	**100%**	**415**	**100%**	**100%**
missing	8			8		
total	**892**			**423**		

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

Table 2: Results of a logistic regression explaining the receipt of an official warning (n = 1115).

Explanatory Variable	Odds Ratio	Std. Err.	p	95% conf. interval	
Age	1.004	0.005	0.387	0.994	1.014
Gender	1.668	0.216	0.000	1.294	2.151
Federal State	1.075	0.077	0.310	0.934	1.238
Perceived flood impact for household	0.818	0.031	0.000	0.759	0.882
Number of experienced floods prior to 2021	1.235	0.098	0.008	1.056	1.443
Household size	1.003	0.052	0.957	0.906	1.111
No flood in immediate surrounding	2.030	0.643	0.025	1.091	3.776
Overloaded sewage water system	0.816	0.122	0.175	0.608	1.095
Wildly flowing surface runoff	1.430	0.204	0.012	1.081	1.893
Water ingress from toilets, floor drains etc.	0.945	0.168	0.750	0.668	1.338
Overflowing water body (e.g. river)	1.361	0.239	0.079	0.965	1.919
Dike or dam breach	0.639	0.155	0.065	0.398	1.027
Groundwater ingress	1.127	0.168	0.425	0.840	1.510
_cons	0.192	0.151	0.035	0.042	0.893

Pseudo R^2 = 0.063

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

Table 3: Results of the linear regression model predicting respondents' knowledge what to do (n = 1097).

Explanatory Variable	Coefficient	Std. Error	p	95% Conf. Interval	
Age	0.003	0.003	0.285	-0.003	0.009
Gender	0.378	0.082	0.000	0.216	0.540
Federal State					
North Rhine-Westphalia	0.000	(base)			
Rhineland-Palatinate	0.336	0.087	0.000	0.165	0.507
Warning source indicator					
Not warned	0.000	(base)			
Own search	0.113	0.291	0.697	-0.458	0.684
Friends or neighbours	0.036	0.155	0.819	-0.269	0.341
National News	0.273	0.217	0.208	-0.152	0.699
Official warning	0.328	0.150	0.029	0.034	0.622
Warning information indicator	0.107	0.049	0.028	0.012	0.202
Number of experienced floods prior to 2021					
Never before	0.000	(base)			
Once	0.525	0.125	0.000	0.279	0.771
Twice	0.702	0.195	0.000	0.320	1.085
Three times	1.466	0.324	0.000	0.830	2.101
Four times or more	1.510	0.309	0.000	0.903	2.118
Perceived surprise	-0.491	0.045	0.000	-0.580	-0.402
Perceived flood impact for household	-0.065	0.024	0.006	-0.112	-0.019
_cons	4.307	0.345	0.000	3.630	4.984

480 R^2 = 0.33

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

Appendix

Table A1: Variable definition, coding and summary statistics of the data set containing all cases from North Rhine-Westphalia and Rhineland-Palatinate (n = 1315).

Variable	Definition	n	Summary statistics Mean (St. Dev.) OR percentages
Dependent variable			
Knowing what to do (factual knowledge)	Answer to the question: "Did you know how you can protect yourself and your household from flooding before the risk of flooding became acute for you?" 1= it was completely unclear to me to 6 = it was perfectly clear to me. Please note that the scale was reversed for Fig. 2.	1302	2.62 (1.60)
Receipt of an official warning	Dummy variable indicating whether respondents received an official warning from authorities or local disaster response.	1250	Yes = 42.7% No = 57.3%
Independent variable			
Age	Age of the respondents in years	1299	48.0 (13.2)
Gender	Gender of the respondent: 1 = female; 2 = male	1224	Female = 54.0% Male = 45.8% Non-binary = 0.2%
Federal State	Indication of the federal state of the respondent: 5 = North Rhine-Westphalia (NW); 7 = Rhineland-Palatinate (RP)	1315	NW = 67.8% RP = 32.2%
Flood pathway	Description of the flood pathway (multiple answers possible): no flood in immediate surroundings; overload of sewage water system; wildly flowing surface runoff; water ingress from toilets, floor drains etc.; fluvial flood, i.e. overflowing water body (e.g. river); dike/dam breach; groundwater ingress	1315	No flood = 6.6% sewage system = 46.8% Surface runoff = 43.0% Floor drains = 18.6% Fluvial flood = 76.3% Dike/dam breach = 9.2% Groundwater = 28.8%
Warning source indicator	Nominal index that indicates the source of the warning with 0 = no warning; 1 = own search; 2 = friends or neighbours; 3 = national news; 4 = warning issued by authorities. In case of several warning, the most credible source (0<1<2<3<4) was assigned.	1250	No warning = 34.8% Own search = 2.4% Friends = 14.7% National news = 5.4% Authority = 42.7%
Warning information indicator	Index that indicates the quality of the warning content with 0 = no warning/no relevant information; 1 =	1246	0 = 40.9% 1 = 1.8% 2 = 43.7%

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

	information on detours, road blockages and/or train cancellation, evacuation; 2 = information on timing and intensity of rainfall, on (maximum) water levels, potential damage, and/or information on dike breaches; 4 = information on how to behave and protect oneself and/or information on the life-threatening situation.		4 = 13.6%
Number of experienced floods prior to 2021	Answer to the question: How often have you personally - before July 2021 - been damaged by floods? 1 = never; 2 = once; 3 = twice; 4 = three times; 5 = four times or more	1308	1.35 (0.87)
Perceived surprise	Answer to the question: How surprising did you find the intensity of the event in your immediate vicinity? 1 = The intensity of the event didn't surprise me at all to 6 = The intensity of the event totally surprised me.	1313	5.56 (0.97)
Perceived flood impact for own household	Answer to the question: How badly was your household affected by the heavy rain or flood event? 1 = not affected at all to 6 = very badly affected	1313	3.50 (1.78)

485

https://doi.org/10.5194/egusphere-2022-244
Preprint. Discussion started: 29 April 2022

Table A2: Results of the ordered logistic regression model predicting respondents' knowledge what to do (n = 1097).

Explanatory Variable	Coef.	Std. Err.	p	95% Conf. Interval	
Age	0.003	0.004	0.530	-0.006	0.011
Gender	0.493	0.115	0.000	0.268	0.717
Federal State					
North Rhine-Westphalia	0.000	(base)			
Rhineland-Palatinate	0.392	0.122	0.001	0.153	0.630
Warning source indicator					
Not warned	0.000	(base)			
Own search	0.124	0.429	0.773	-0.718	0.965
Friends or neighbours	0.154	0.221	0.485	-0.279	0.587
National News	0.527	0.294	0.074	-0.050	1.104
Official warning	0.571	0.209	0.006	0.162	0.981
Warning information indicator	0.147	0.067	0.028	0.016	0.279
Number of experienced floods prior to 2021					
Never before	0.000	(base)			
Once	0.680	0.173	0.000	0.342	1.018
Twice	0.901	0.271	0.001	0.370	1.432
Three times	2.010	0.448	0.000	1.132	2.888
Four times or more	2.001	0.442	0.000	1.135	2.867
Perceived surprise	-0.648	0.068	0.000	-0.780	-0.516
Perceived flood impact for household	-0.078	0.033	0.019	-0.143	-0.013