Experience From the 2021 Floods in the Netherlands
Household Survey Results on Impacts and Responses

Endendijk, Thijs; Botzen, W.J. Wouter; de Moel, Hans; Aerts, Jeroen C.J.H.; Duijndam, Sem J.; Slager, Kymo; Kolen, Bas; Kok, Matthijs

DOI
10.59490/jcrfr.2023.0009

Publication date
2023

Document Version
Final published version

Published in
Journal of Coastal and Riverine Flood Risk

JOURNAL OF COASTAL AND RIVERINE FLOOD RISK

Vol. 2, 2023, 9

Experience From the 2021 Floods in the Netherlands: Household Survey Results on Impacts and Responses

Thijs Endendijk,[1] W.J. Wouter Botzen,[1,2] Hans de Moel,[1] Jeroen C.J.H. Aerts,[1,3] Sem J. Duijndam,[1] Kymo Slager, [3] Bas Kolen,[4,5] Matthijs Kok[4,5]

Abstract

This study provides an overview of the impact of the 2021 Summer floods in the Netherlands and the assessment of the effectiveness of various adaptation measures, evacuation strategies, and their impact on society. The floods were characterized by record rainfall in the cross-border region of the Meuse and Rhine basins and resulted in devastating losses in the Netherlands, Germany and Belgium. The study reports on a household survey conducted with 1,509 households in the wake of the 2021 flood event in the southern part of the Netherlands (province of Limburg). Using a descriptive approach, we present household experiences during several stages of the disaster management cycle, reporting on experienced flood hazard and impacts, evacuation, flood damage mitigation measures, the compensation progress, risk perceptions, and stress. Our findings highlight the role of early warnings and flood risk information provision in flood risk management. Risk perceptions influence both adaptation and evacuation behavior, as respondents who were aware of flood risks beforehand took significantly more flood damage mitigation measures compared with those who were not aware. Flood damage mitigation measures, such as building with water-resistant materials and elevating valuables, reduced flood damage by 20% to 50%. Our survey shows that of those who received warnings, the majority actually evacuated. However, residents not aware of any evacuation advice evacuated significantly less. Additionally, the majority (75%) of respondents experienced high or very high stress during and after the flood, which is most likely related to the destructive flood impacts and the slow and uncertain compensation experienced by many respondents. This paper describes the flood event and its consequences to provide insights into Dutch disaster management and what can be learned for potential future disasters in other contexts.

Keywords

Flooding, Netherlands, Preparedness, Damage Mitigation, Survey

[1] t.endendijk@vu.nl, wouter.botzen@vu.nl, hans.de.moel@vu.nl, jeroen.aerts@vu.nl, sem.duijndam@vu.nl, VU Amsterdam, Amsterdam, the Netherlands
[2]Utrecht University, Utrecht, the Netherlands
[3] kymo.slager@deltares.nl, Deltares, Delft, the Netherlands
[4] b.kolen@hkv.nl, m.kok@hkv.nl, HKV Consultants, Lelystad, the Netherlands
[5]TU Delft, Delft, the Netherlands

Please send correspondence to Thijs Endendijk at t.endendijk@vu.nl

This paper was submitted on November 28, 2022. It was accepted after double-blind review on 12 December 2023 and published online on 22 December 2023.

DOI: https://doi.org/10.59490/jcrfr.2023.0009

Cite as: "Endendijk, T., Botzen, W., de Moel, H., Aerst, J., Duijndam, S. ., Slager, K., Kolen, B., & Kok, M. Experience From the 2021 Floods in the Netherlands: Household Survey Results on Impacts and Responses. Journal of Coastal and Riverine Flood Risk. 2, p. 9. https://doi.org/10.59490/jcrfr.2023.0009"

1 Introduction

Floods remain one of the most damaging natural hazards worldwide (Merz et al., 2022). In the summer of 2021, parts of Germany, Belgium and the Netherlands were affected by record rainfall in the cross-border region of the Meuse and Rhine basins (ENW, 2021), which resulted in devasting financial losses, injuries and casualties (Dietze et al., 2022). In a changing climate, it is likely that the intensity and frequency of extreme flood events will increase, which leads to increased flood risk in absence of additional adaptation strategies (IPCC, 2021). To effectively manage flood risks, it is relevant to have prior understanding of the impact of flooding on society, including the response of affected households and communities. The disaster management cycle offers a valuable framework for an analysis of how flooding affects society. This cycle is set in motion by a trigger event, to which society responds (FEMA, 2010). The disaster management cycle consists of five elements: disaster prevention, mitigation, preparation, response and recovery (de Moel & Aerts, 2008). In each stage, different actors, including households, communities, and governments, play critical roles in minimizing the impact of floods and enhancing resilience to future flood events. Effective flood risk management involves all stages of the disaster risk cycle (Thieken et al., 2007).

Disaster prevention is aimed at reducing flood hazard, where governmental bodies take measures to enhance protection standards for a region (de Moel & Aerts, 2008). To determine such flood protection standards, it is important to have prior understanding of the impact of flooding (Kind, 2014). To facilitate such knowledge, flood damage models or catastrophe models have been developed (Gerl et al., 2016). The reliability of such models—including the use of damage curves or data-driven approaches—strongly depends on the availability of empirical data or expert knowledge. Empirical loss data from households during extreme floods can offer insights for improving flood risk assessment models (e.g., Barendrecht et al., 2019). Moreover, empirical data on flood preparedness behavior during and after floods informs policies that contribute to improving individual flood preparedness, such as communication strategies and emergency management activities (Aerts et al., 2018).

The mitigation phase covers households that take measures to reduce flood damage in case flood prevention fails. Concerning private disaster risk reduction, studies on the German Elbe floods in 2002, 2005, and 2006 show the effects of households' flood damage mitigation (FDM) measures on damage reduction (Kreibich et al., 2005; Kreibich & Thieken, 2009). Bubeck et al. (2012) discuss private FDM in the Rhine basin and how risk perception influences households' investments in FDM. Wind et al. (1999) present a case from the Netherlands in which risk awareness (due to flooding experience) may influence the uptake of FDM by households and reduce flood damage for subsequent events. This is elaborated by Poussin et al. (2014, 2015), who show that socioeconomic and psychological factors (e.g., worry, risk perception) influence flood preparedness behavior in France, and that policies, such as insurance, may provide incentives for implementing FDM measures.

During the disaster preparation phase, society braces itself when a disaster is coming soon. Emergency preparations can be triggered by multiple factors, such as warnings from an individual's social network, environmental cues and early warning systems. A priori, extreme flood scenarios are used to map vulnerable locations and to find the correct target group for information provision (Godlewski et al., 2022). Early warnings promote emergency preparation when warning lead times are sufficiently long and the content of the warning is comprehensible (Penning-Rowsell et al., 2005). These warnings can call for evacuation or preparation (e.g., uptake of emergency flood damage mitigation (FDM) measures. The response phase takes place directly after the flood event, where an emergency reaction takes place after an area has already been flooded, these can also include emergency actions, such as evacuation or FDM, such as elevating personal possessions to higher floors or using a water pump.

The Sendai Framework for Disaster Risk Reduction describes recovery as society 'building back better' towards a state of higher disaster preparedness (United Nations, 2015). The disaster functions as an opportunity for society to act and institute recovery for more resilience than before the disaster. Efforts are made to restore essential services and infrastructure, and support affected households and businesses, where flood damage will be repaired. Households and businesses may be assisted in their recovery process through insurance and/or government compensation (Tesselaar et al. 2020). The recovery phase provides an opportunity to enhance society's resilience to future flood events, where the disaster prevention and mitigation phase follow again.

Surveys provide detailed insight into local conditions during flood events as well as households' responses to floods. However, the local context limits the transfer of these findings to other areas with different contexts and to other flood events with different water depths, flow velocities, and rates of water rise. This relates to problems associated with transferring empirical information in space and time from one case study area to another. Wagenaar et al. (2018) illustrate the necessity of collecting more data on flood losses by showing that a flood damage model based on heterogeneous data (six separate flood events) performs better when transferred to another region than a model that is based on only one flood event. However, high-quality empirical data is scarce regarding the effects of and response to floods (Molinari et al., 2017). There have been various efforts to collect such empirical survey data either for purposes of compensation or to study post-disaster mechanisms. Due to the rare opportunity to collect empirical post-disaster data, these surveys cover a wide range of topics at the same time. Studies on these surveys first offer a descriptive overview of the flood event (e.g., Kreibich et al., 2005; Kreibich & Thieken, 2007; Kreibich et al., 2009; Thieken et al, 2016; Chinh et al., 2016), only to use the same survey in later papers to zoom in on more specific topics, such as adaptation behavior, flood experiences, damage compensation or flood damage mitigation effectiveness (e.g., Thieken et al., 2005, 2006; Kreibich & Thieken, 2009; Merz et al., 2013; Hudson et al., 2014). Despite these existing studies, there remains a need to gather empirical data on impacts from extreme floods and FDM dynamics because of the heterogeneity of flood events and differences in the geographic and socioeconomic contexts of affected areas. Collecting survey data and comparing it with previous flood events is crucial to enhance our understanding of the impacts and responses to extreme floods, as it enables the identification of common patterns, variations, and best practices across diverse contexts, facilitating the development of more effective flood management strategies and policies.

A large share of post-disaster flood surveys have been conducted in Germany. As every flood event is unique, a descriptive overview gives new information in a different flood context and allows for comparison of the 2021 Summer floods in the Netherlands with other flood events. We report on a survey conducted with 1,509 households in the wake of the 2021 flood event in the southern part of the Netherlands (province of Limburg). The goal of this paper is to gain more insights into Dutch disaster management and what can be learned for potential future disasters in other contexts by taking a broad descriptive approach. The main research question is, therefore: “What lessons for flood risk management policy can be learned from the impacts on households during the 2021 Summer floods in the Netherlands by analyzing the stages of the disaster management cycle?” Strategies from the disaster management cycle are assessed using experiences and impacts of flooding on the household level. Figure 1 below visualizes all stages of the disaster management cycle and the corresponding section where this stage is discussed in this paper. Included topics are related to the flood hazard itself, the evacuation, the damage caused, FDM measures undertaken by residents, compensation for inflicted damages, early warnings, risk perceptions, and stress experienced by affected people.

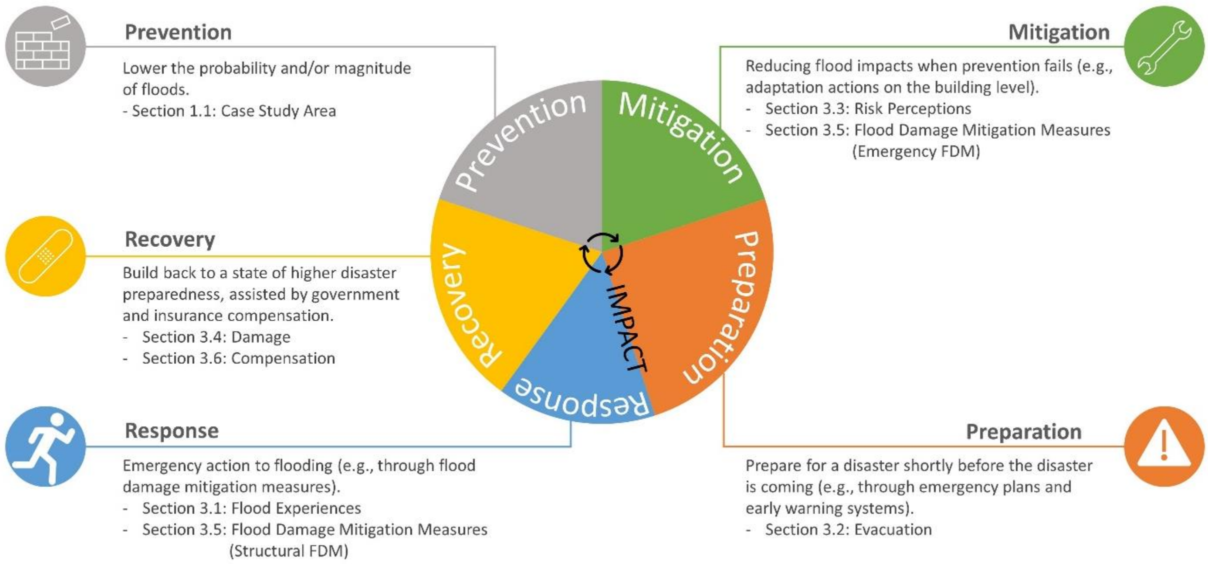

Figure 1: Overview of the disaster management cycle framework, where each stage is matched with the corresponding section from this paper. Adapted from De Moel & Aerts (2008).

1.1 Case Study Area

The context of this flood event in the Netherlands is uncommon. Rainfall and peak discharge occurred during the summer; historic peak flow events of this magnitude have previously only occurred in winter months. Rainfall and discharge for this event were the highest ever recorded in the Meuse, and damages were higher than the most recent flood events in the Meuse in 1993 and 1995. However, current damages were confined to the unembanked area and the tributaries, including the Geul, Roer, and Geleenbeek Rivers, rather than to the main branch of the Meuse as in 1993 and 1995 (ENW, 2021). The Meuse is protected by embankments, and a recent river widening project included high protection standards. Nevertheless, this flood event has sparked a renewed discussion regarding how to protect the tributary rivers (de Jong & Asselman, 2021), where large-scale protection is more difficult to implement.

Figure 2 shows the case study area and flood extent, which covers a portion of the Meuse basin in the province of Limburg in the southern part of the Netherlands. Draining from the Belgian and French Ardennes region, the Meuse River enters the Netherlands from the south and continues in a northern direction. The main river branch is joined by several tributaries, of which the Geul, Geleenbeek, and Roer were most severely affected by the flood (ENW, 2021). The Meuse in Limburg is the downstream area of a considerable catchment. The Geul flows through a relatively small, v-shaped valley, and the river responds rapidly to upstream precipitation. People living along the Geul were generally caught off guard by the flood event, while those living near the Meuse had considerably more time to act because the peak flows arrived later and the national forecasting system provided flood alerts.

In the Netherlands, flood protection standards and maintenance of flood protection measures are differentiated between the main water system (the Meuse and Rhine Rivers and coast) and the so-called regional water system. Dike maintenance along the Meuse falls under the responsibility of Rijkswaterstaat, a subdivision of the Ministry of Infrastructure and the Environment. A recent large-scale investment in river widening, flood protection, and channel deepening (called *Maaswerken*) resulted in the establishment of a flood protection standard of 1/250 years at that time[1] along the Meuse (Rijkswaterstaat, 2022). However, the protection standards along the tributaries are determined by the province of Limburg and the regional water authority (called *Waterschap Limburg*). In a recent policy document (Waterschap Limburg, 2021), protection standards for built-up areas along the tributaries were set to 1/25 years and 1/10 years in some areas, which is lower than in the rest of the Netherlands. The Dutch flood insurance program is also differentiated between these water systems. For regional water systems and heavy rainfall, flooding is insured through a household's home and contents insurance, which has a relatively high penetration rate in the Netherlands (Dutch Association of Insurers, 2018). Meanwhile, Dutch insurers cannot insure against failure of main water defense systems because of challenges with attracting enough capital to cover losses from low-probability high-impact flood events at affordable insurance premiums.

Precipitation accumulated to between 160 mm and 180 mm in two days over a large region, including parts of Belgium and Germany. Return periods for precipitation ranged from 1/10 to even 1/1000 years in some areas along the Meuse. This began a record-high discharge in the Meuse, estimated at ~3300 m^3/s, with a return period of around 1/100 years. However, since most historical discharge extremes have been recorded during the winter, extreme value analysis shows return periods > 1/600 when considering only summer months (ENW, 2021). Return periods for water levels reached 1/200 years near the Belgian border to 1/50 and 1/15 downstream in more northern areas near Venlo (ENW, 2021; de Jong & Asselman, 2021). Return periods of peak discharges along the tributaries Geul, Geleenbeek, and Roer have varied between 1/100 and 1/1,000 years, with water level return periods of 1/100 years (de Jong & Asselman, 2021).

With significant parts of the area under water during the event, substantial economic losses occurred as well as direct damage to buildings and infrastructure and indirect economic losses from business interruptions. Total damage was estimated between €350 and €600 million shortly after the event (ENW, 2021). This is substantially higher than the previous record flood losses during the 1993 and 1995 flood events, which were approximately €201 million and €126 million,[2] respectively (ENW, 2021). There were no direct casualties from flooding in the Netherlands. Most insurance claims were submitted by residents along the Geul and Geleenbeek; 90% of the claims pertained to damage to buildings and cars.

[1] Nowadays, safety standards are differentiated for different dike segments, instead of entire dike rings.
[2] Corrected for inflation and converted to euros.

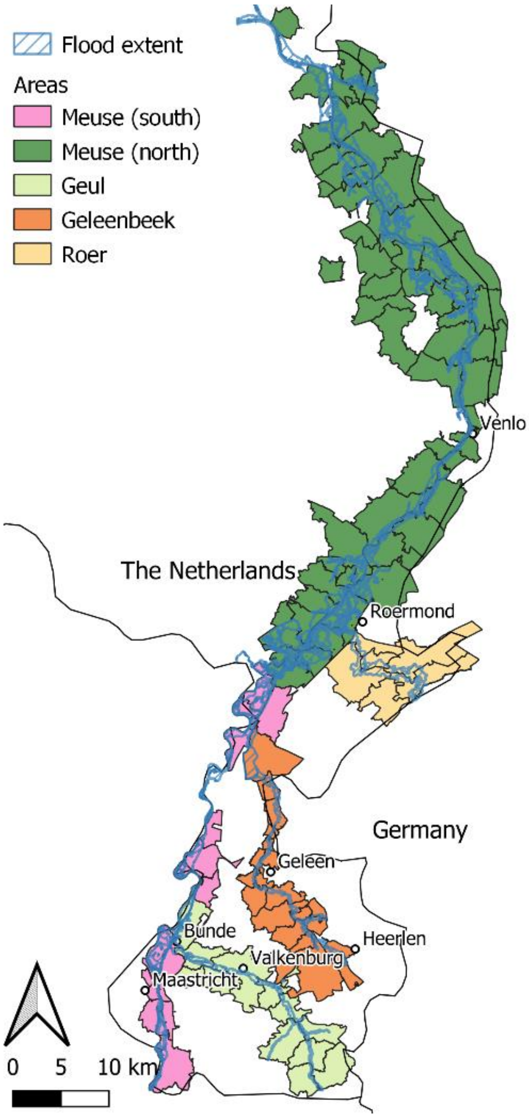

Figure 2: Overview of the case study area, displaying postal code (PC4) areas and the flood extent along the main branch of the Meuse River and its tributaries, the Geul, Geleenbeek, and Roer.

2 Methodology

2.1 Survey Setup

Letters were distributed in December 2021 via postal mail to 11,000 addresses of both firms and households. The letter was addressed to either the residents living at the address or the firm being located there and contained a request to complete the survey online. It is not expected that the online design of the questionnaire results in a lower response rate, as 98% of all households in the Netherlands have internet access (CBS, 2018). Firms and households received a different survey.[3] Exactly half of the 11,000 addresses were located in flooded areas, as defined by the ENW (2021) study. Using a random number generator, the other half were randomly selected from areas that were not directly flooded. Addresses in these areas did not flood, but residents received evacuation orders during the flood event. Sampling these latter areas was useful since some flood impacts may have occurred at these locations due to potential inaccuracies in the initially defined flood extent. Moreover, these areas were threatened by flooding, so it was relevant to examine residents'

[3] In this study, only results of the household survey are reported.

evacuation and risk-reduction behavior. A reminder was sent in February 2022 to addresses from which no response to the survey request had been received. This eventually resulted in 10,143 households and 857 firms being sampled.

Respondents from 1,509 households completed the survey, which indicates a response rate of 14.9%. Although this response rate seems low, it is higher than response rates to other surveys about flood risks with a similar setup (e.g., Poussin et al., 2014). Our higher response rate may have been caused by the survey's timing, which was shortly after a severe flood event; this may have increased respondents' willingness to participate. Nevertheless, the response rate was lower than the response rates associated with face-to-face interviews. The sample composition was as follows: 13% of respondents were between 18 and 44 years old, 37% of respondents were between 45 and 65 years old, and 50% of respondents were older than 65. Additionally, 64% of the sample was male, and 53% finished higher education; 167 respondents did not report their education. The average annual net income of respondents was €51,000; 406 respondents did not report their income.

The geographic distribution of the respondents was as follows: 40% lived near the Meuse, 20% lived along the Geul, approximately 33% did not indicate their location, and the remainder lived along the Geleenbeek or Roer. Because of Dutch privacy laws, the exact location is not known for all respondents, as they were able to refuse to share their home location. In the 1,509 completed surveys, approximately two-thirds of the respondents (*N* = 971) provided their location, with their six-character postal code. Figure 3 shows the geographical distribution of the response rate using four-character postal codes. Panel A gives the absolute number of respondents, and Panel B shows the number of respondents relative to the total number of addresses to which invitation letters were sent; one can see that a considerable share of respondents was located in the southern part of the Limburg province. The responses along the Geleenbeek were relatively low. Panel C indicates the share of respondents who experienced water in their homes during the flood event, which comprised 28% of respondents. The results revealed that a relatively high percentage of residents experienced water intrusion in their homes in the southern part of the Limburg province as well as in Roermond and its surroundings.

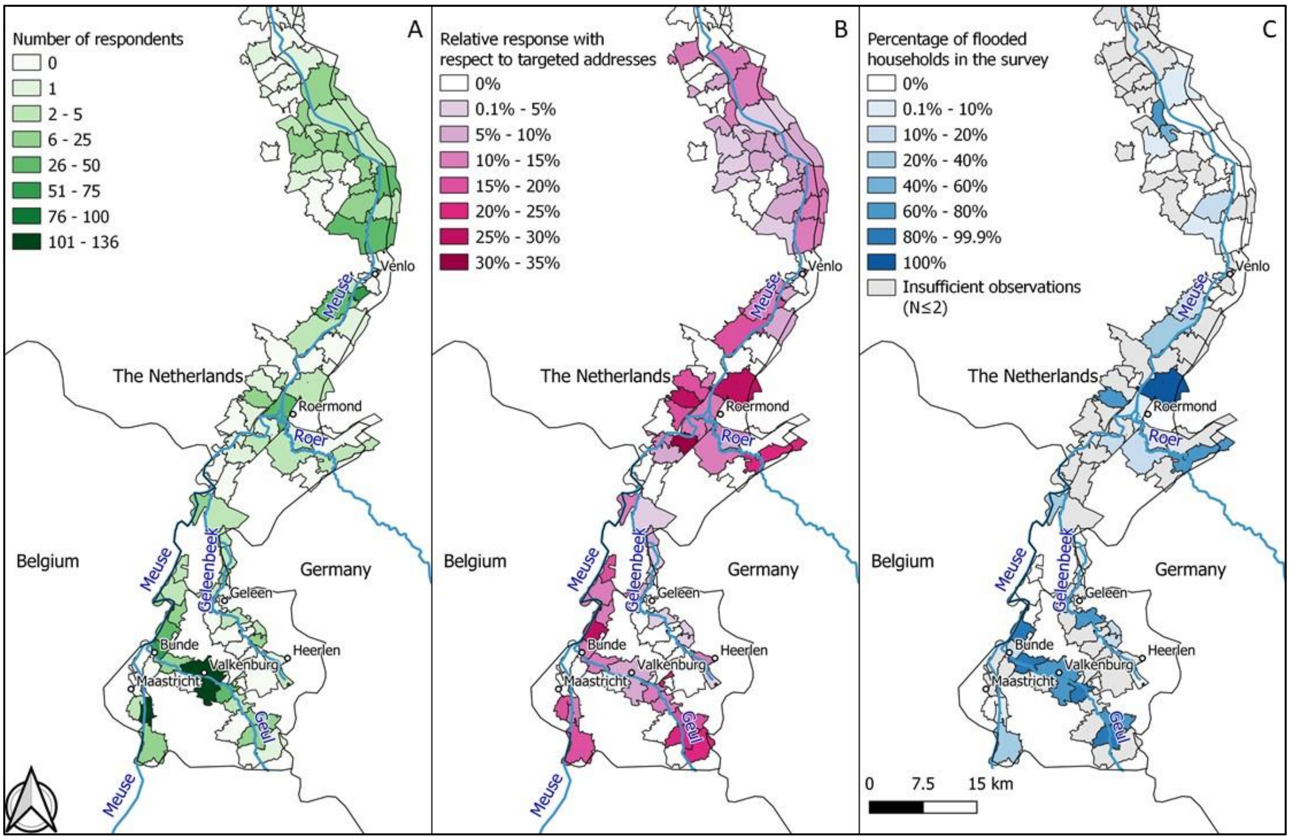

Figure 3: Total responses to the questionnaire (Panel A), response percentage relative to survey invitation letters sent per postal code area (Panel B), and percentage of respondents who experienced water in their homes during the flood (Panel C).

Note: All estimates in the figure are based on data from residents who shared their postal code information (*N* = 971).

The online questionnaire was structured as follows. The survey began with attitudinal questions, such as individual perceptions of flood risks. Several questions requested information about the flood hazard experienced, such as whether respondents experienced water near or in their homes and the maximum water level. Both flooded and non-flooded households received the same set of survey questions. Respondents who experienced flooding were asked three additional questions regarding water entry, water rise rate and water withdrawal rate in their homes. To assess the impacts of the flood event, respondents were questioned about the type of flood damage they experienced, as well as the monetary damage amounts and psychological stress. We also inquired whether respondents implemented various measures to reduce flood damage. This allowed us to evaluate the level of flood preparedness among the respondents and estimate, whether, on average, employing these measures reduced flood damage. Additionally, damage compensation received from the government and insurers was requested; this provided insights into compensation progress at the time of the survey, which was conducted approximately six months after the event.

To reduce the risk of attrition and respondent fatigue, we divided the respondents into two groups for different sets of questions. Roughly half of all respondents (N=764) answered questions about the evacuation process, while the other part (N=745) responded to questions about attitudes towards FDM uptake. The remaining questions were the same for all respondents. The division of questions reduced the time required to complete the survey from 45 to 30 minutes for both groups. The final number of respondents is 1,509. The entire survey is included in the Supplementary Material.

2.2 Analysis

As the goal of this paper is to give a broad overview of multiple topics of the 2021 Summer Floods in the Netherlands, we report mainly descriptive statistics related to the survey results. Descriptive statistics give a cross-section of flood impacts and household behavior during the flood event. To define whether different subgroups (e.g., geographic, with/without warning) of the sample significantly differ from each other, we apply independent two-sided t-tests[4]. The case study areas featured a geographic spread of respondents along the rivers; therefore, we report some results from the entire sample, but in many cases, we also differentiate between households along the Meuse and along the Geul. This is particularly relevant, as the setting (geographic, hydrological, legislative) is considerably different, as described in Section 1.1.

The effect of the FDM measures on reducing flood damage is expressed using the ratio between the cost of damages and the rebuilding value of the property. Rebuilding values have been composed based on building characteristics using approaches from two contractors (iTX Bouwconsult, 2022; BMVV; 2022). Household contents damage ratios have been composed using contents replacement values, determined using an approach insurance companies apply in the Netherlands (Dutch Association of Insurers, 2022). Inputs for this approach are household income, respondent age, dwelling size and home living area. Scaling flood damage to actual property values allows for comparison between households of different income categories.

3 Results

3.1 Flood Experiences

The respondents had varied experiences during the flood event. Approximately 28% experienced water intrusion in their home, 13% had flood water in their streets (but not in their home), 25% saw flooding only in their neighborhoods, 14% mentioned flooding in their municipality but not in their neighborhoods, and 20% did not have any flood water in their hometown. The flow velocities were experienced as relatively high by respondents. As an illustration, only 44% of the respondents answered that an average man could easily stand up straight in the water, while 31% stated that it was difficult to stand up straight, and 25% noted that this was not possible due to flow velocity or water depth. We decided to use these reference categories to estimate flow velocity in line with the surveys of Thieken et al. (2005) and Merz et al. (2013). Although this approach is not fully accurate and dependent on the respondent's perception of an average man, we

[4] The statistical software package STATA17.0 has been used for inferential statistics. Data visualization has been performed using QGIS3.28 and Spyder 5.3.3.

believe that this approach yields more reliable results than asking for flow velocity in m^3/s, which is often harder to assess from individual experiences.

Water entered respondents' homes primarily over the surface (66% of all flooded respondents indicated that water entered the home through doors and walls), with a smaller share of groundwater entering the building (indicated by 22% of flooded respondents). The sewer was mentioned as a source of flood water in only 4% of flooded cases. Additionally, respondents reported substantially different water depths between homes. Figure 4 shows the water depths in different parts of their homes for those who reported water against the outside wall. Water depth was measured from the floor of the room in question and varied from several centimeters to more than two meters, which is approximately the same range as estimated from aerial photographs and a digital elevation model in the ENW (2021) report. 45% of all flooded respondents reported inundation depths higher than 50 cm on the ground floor. The results of the questionnaire are in line with the findings from the ENW (2021) report that more households were flooded by the Geul than by the Meuse (234 versus 96, respectively). The households that were flooded by the Meuse are located in areas outside the dikes, and losses are thus not due to dike failures or dike overtopping. Compared to the Meuse, the inundation depths in buildings along the Geul were significantly ($p<0.05$)[5] higher. Half of the flooded respondents living along the Meuse experienced a water depth of less than 20 centimeters. 90% of all survey respondents who lived along the Geul had water in their basement, where some of the reported water levels were higher than two meters. Water intrusion was mainly experienced on the ground floor, although in a few houses, water reached the second floor.

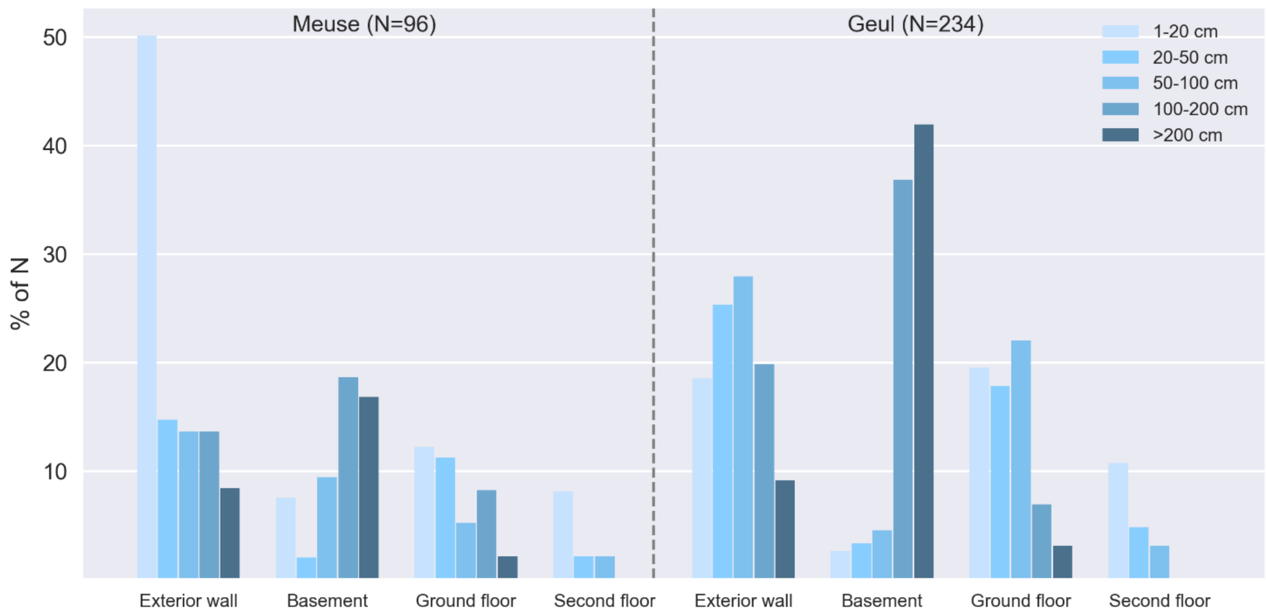

Figure 4: Fraction of respondents with several water depths in different parts of respondents' houses (exterior walls, basement, ground floor, and second floor) based on the data for respondents who provided postal code data and reported water at the outside wall of the house.

For most of the respondents, especially those living along the Geul River with already high water levels, the flood water reached its maximum level shortly after entering their homes, which implies a lack of time to perform last-minute emergency measures. Specifically, 33% of flooded respondents experienced the maximum water depths within one hour, 35% between one and five hours, 20% between five and 24 hours, and 8% more than 24 hours; 4% reported that they did not know this information. Some regional variations were seen in the water's rate of rise: 75% of flooded homes along the Geul experienced the maximum water level in less than five hours, where average water levels were higher as well (Figure 4), while along the Meuse, this estimate was 45%. Furthermore, in 78% of all cases, water remained in the homes for longer than 24 hours.

[5] $t(334)=2.29$

3.2 Evacuation

Overall, approximately a bit more than half of all respondents were warned in advance about the possibility of flooding. Residents received warning messages from various sources and media. The municipality was the most frequently mentioned source (by almost half of all warned participants), but personal networks (neighbors, family, and friends) were another important source of information (indicated by 25%, 20%, and 13% of warned respondents, respectively), as was the safety region. The local government institutions water boards and the national institution Rijkswaterstaat were not often quoted as information sources (only indicated by approximately 5% of all warned respondents). Media through which residents were warned were also diverse: social media, followed by news websites, television, and radio.

These warning fractions differ substantially between the different flooded regions (Figure 5). It stands out that especially along the Geul, relatively few households were warned (around 25% of all respondents along the Geul). Of the group along the Geul that has received a warning, around 10% received a warning after their home already flooded. It is observed that households in areas with shorter warning times took fewer emergency FDM measures, such as placing barriers or moving their vehicle (Figure A1 in the Appendix). Additionally, the rate of rise in these homes was rapid: the highest flood level was reached within an hour for one-third of respondents who did not receive a warning.

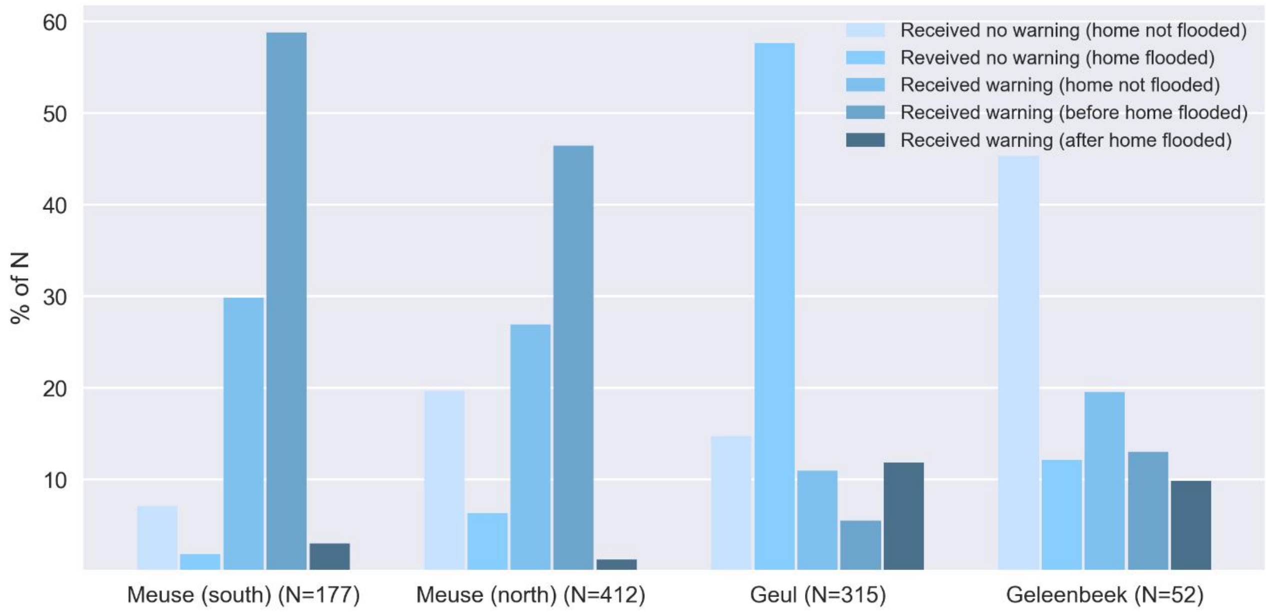

Figure 5: Percentage of respondents along the Meuse, Geul, and Geleenbeek who were or were not warned of the possibility of flooding as well as whether a flood occurred.

Half of the participants were asked about the evacuation process. Overall, 56% of respondents who provided their location and had water in their neighborhood evacuated; this number is strongly connected to receiving evacuation advice. Respondents who received an evacuation advice evacuated significantly[6] ($p<0.01$) more during the flood event[7]. While the number of evacuees was high for residents along both rivers, it was slightly higher for those along the Geul (82%) than the Meuse (72%) (Table 1). Of those who did not receive evacuation advice, approximately 19% still evacuated; the numbers were almost the same for the Geul and Meuse. It is important to note that some people living along the Geul River were warned to stay at home during the flood event, which may have resulted in fewer preventive evacuations. The vast majority of people who evacuated went to friends or family (81%), with designated evacuation centers playing only a minor role, as approximately 4.5% of evacuees used these facilities. Of the people who did not evacuate (regardless of advice), the most frequently stated reason was a lack of perceived threat (45%), a lack of information (7%) about the potential flood and associated evacuation, and fear of burglary and looting (6%). Of the people who evacuated, a considerable number (38%) did not receive any help, whereas 45% received help from friends and family, and 12% were

[6] $t(719)=17.11$

[7] This includes both preventive and responsive evacuation.

assisted by neighbors. A minority of evacuated respondents were helped by aid workers (12%; note that respondents could select more than one answer).

Table 1. Number and percentage of respondents who did or did not receive evacuation advice and their evacuation status. Data is based on answers from respondents who provided their location and experienced flood water in their neighborhood.

	All		Geul		Meuse	
Total	Did not evacuate 135 (44%)	Evacuated 173 (56%)	Did not evacuate 69 (47%)	Evacuated 78 (53%)	Did not evacuate 66 (41%)	Evacuated 95 (59%)
No advice to evacuate (according to respondent)	86 (81.1%)	20 (18.9%)	54 (81.8%)	12 (18.2%)	32 (80%)	8 (20%)
Received evacuation advice (according to respondent)	49 (24.3%)	153 (75.7%)	15 (18.2%)	66 (81.8%)	34 (28.1%)	87 (71.9%)

Of the surveyed evacuees, 44% were able to return to their homes within 24 hours. An additional 26% went home within 48 hours after evacuation. Only 6% of the respondents had not yet returned to their homes at the time of the survey, six to eight months after flooding. Most participants who evacuated during the 2021 floods stated that they were willing to evacuate during a future flood event (Table 2). An independent t-test ($t(716)=18.9$) reveals that respondents who evacuated are significantly ($p<0.01$) more willing to evacuate during a future event. No respondents who evacuated during this flood stated that they would not be willing to evacuate in the future. Conversely, there is a group who consistently refuses to evacuate; 28.9% of those who did not evacuate during the 2021 flood stated that they would not evacuate during a future flood event.

Table 2. Respondents who did or did not evacuate and their intentions to evacuate during future flood events. Data is based on answers from respondents who provided their location and experienced flood water in their neighborhood along the Meuse or the Geul.

	All		Geul		Meuse	
Total	Did not evacuate 135 (44%)	Evacuated 173 (56%)	Did not evacuate 69 (47%)	Evacuated 78 (53%)	Did not evacuate 66 (41%)	Evacuated 95 (59%)
Certainly not evacuating	39 (28.9%)	0 (0%)	18 (26.1%)	0 (0%)	21 (31.8%)	0 (0%)
Probably not evacuating	74 (54.8%)	34 (19.7%)	42 (60.9%)	13 (16.7%)	32 (48.5%)	21 (22.1%)
Probably evacuating	18 (13.3%)	83 (48.0%)	6 (8.7%)	38 (48.7%)	12 (18.2%)	45 (47.4%)
Certainly evacuating	4 (3.0%)	56 (32.4%)	3 (4.4%)	27 (34.6%)	1 (1.5%)	29 (30.5%)

3.3 Risk Perceptions

The flood experience also influenced individual perceptions of the probability of future floods. Around 20% of respondents indicated that they believed flood risk to be high to very high in their region. Figure 6 shows the results of several t-tests. The outcomes of the tests indicate that information regarding flood risks is associated with a higher level of individual flood preparedness by inspiring respondents to undertake FDM measures. 45% of all respondents informed themselves beforehand about the risk of flooding near their homes through various websites. These respondents were better prepared for the flood event because they employed significantly ($p<0.01$) more emergency preparedness actions as well as other measures to reduce flood risk (Figure 6). These emergency FDM measures include, for instance, placing flood shields and sandbags in front of the homes, installing a water pump, moving furniture above potential flood water levels, and moving vehicles to areas that are safe from flooding. Respondents who visited various websites to acquire information about flood risks answered twice as often that they thought the flood probability was high or very high compared to respondents who did not visit such websites. Subsequently, the group with higher awareness of the flood risk protected themselves against flooding with specific measures 23%-100% as often compared to their peers (Figure 6). This found effect in these t-tests is significant at the 1%-level for all FDM measures, with the exception of moving to a less flood-prone location.

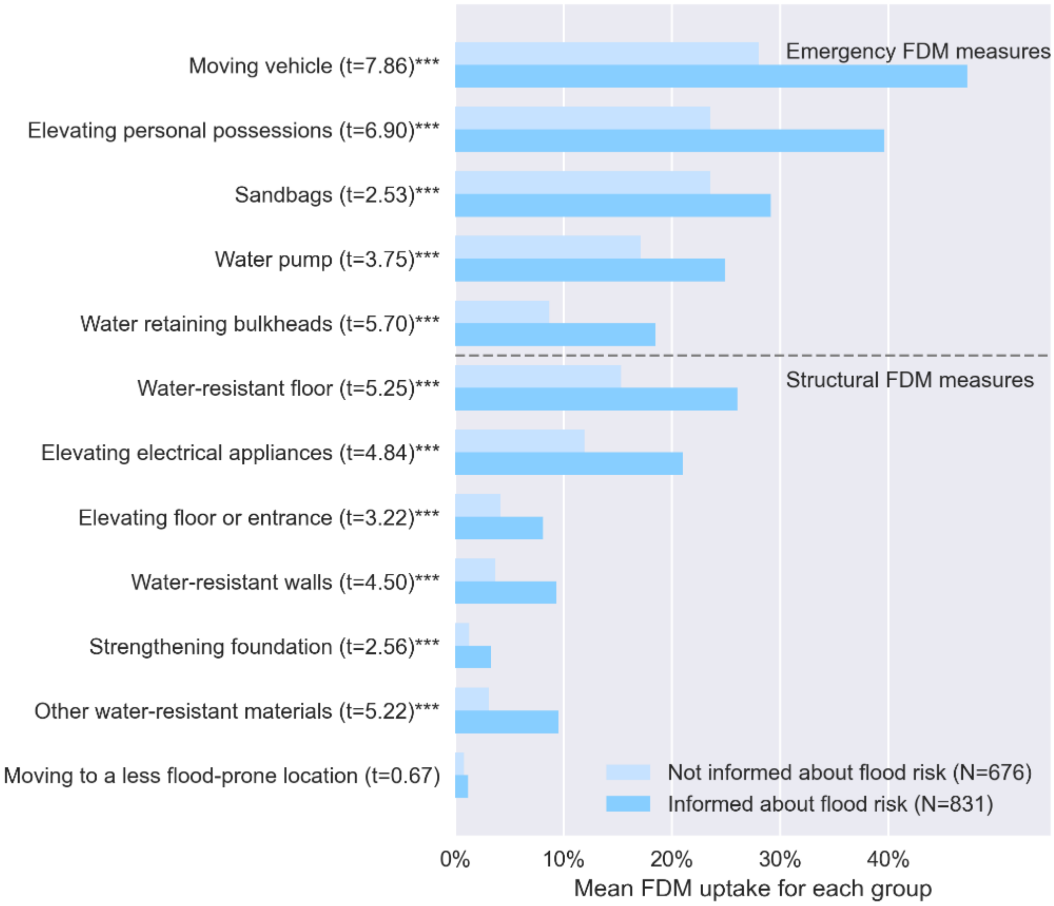

Figure 6: Results of independent t-tests examining whether individuals who were informed about flood risk in their neighborhood take FDM measures more often compared to uninformed individuals.
Note: (*** p<0.01, ** p<0.05, * p<0.1, df=1,507)

3.4 Damage

Panel A in Figure 7 shows the share of households with damage per postal code area. Most flood damage was concentrated along the Geul and Roer Rivers. A large share of surveyed households along the Geul experienced damage (40%-100%, depending on postal code). Overall, one-third of the respondents experienced flood damage. Panel B provides insight into the average damage, which in the south of the flooded amounted to €100,000 per household or higher in some cases. This damage distribution is right-skewed, as there are various outliers with high economic damage. In the northern area, a smaller share of homes experienced flood damage, and the extent of the damage was also lower compared to the south.

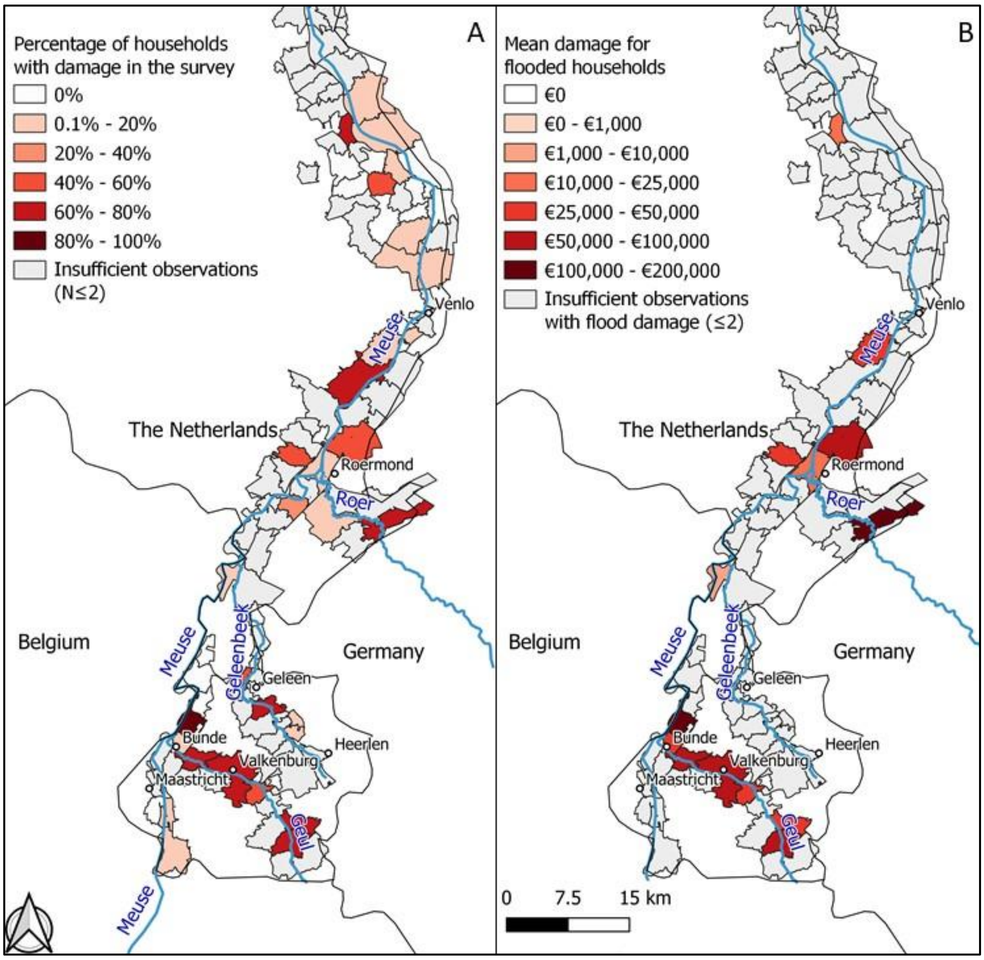

Figure 7: Share of households with damage (Panel A) and average damage for these flooded households (Panel B) based on data for households per postal code area (N = 971).

Figure 8 shows how often respondents mentioned damage in various categories. These results illustrate the diverse categories of building damages. Of other property damages, personal belongings were damaged in more cases than cars and other vehicles. Moreover, gardens were often damaged. Damages because of burglaries and looting were a regular concern in the media but occurred for only seven out of 494 respondents with damage after the flood event. Of the non-property damages, evacuation and cleaning costs were common.

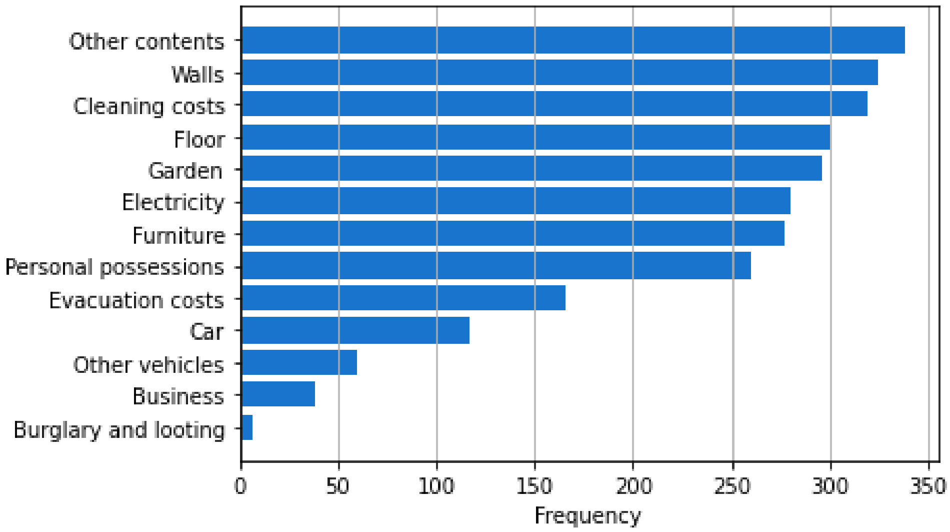

Figure 8: Frequency of damage in specific categories (N = 494).

Table 3 shows the median financial cost of damage (estimated by residents) for the main damage categories. Households without damage are not included. A distinction is made between households along the Meuse, the Geul, and those without postal code information.

Table 3: Median damage to buildings, floors, household contents, and cleaning costs, categorized by source and based on data for households with damage for which the postal code was known.

		Median damage per location		
Category	Full sample	Geul	Meuse	Location unknown
Building	€25,000 (362)	€35,000 (192)	€5,000 (55)	€25,000 (106)
Floor	€8,000 (176)	€8,000 (106)	€5,000 (17)	€10,000 (45)
Household contents	€17,000 (260)	€20,000 (171)	€6,000 (17)	€14,500 (67)
Cleaning costs	€2,500 (199)	€2,500 (119)	€1,500 (21)	€2,000 (53)

Note: Number of responses in parentheses.

The median damage for the Geleenbeek and Roer Rivers is not shown, as only five and six damage cases, respectively, were reported along these tributaries. However, these cases are included in the damage for the full sample. One can see that a larger proportion of respondents along the Geul experienced damage in comparison with the Meuse. Additionally, the damage in each category (building, floor, contents, and cleaning costs) for surveyed households along the Geul was higher than for the group near the Meuse, mostly driven by higher water levels (Endendijk et al., 2023). This larger damage is significant for the building ($p<0.01$) and household contents ($p<0.05$)[8]. Of all respondents who experienced damage during the flood, the estimated damage to the property was €25,000 (median). Median damage for floors, household contents, and cleaning were €8,000, €17,000, and €2,500, respectively. Furthermore, respondents with more property damage generally lived upstream in the Geul area and experienced significantly ($p<0.01$)[9] shorter periods between flood warnings and actual flood impact.

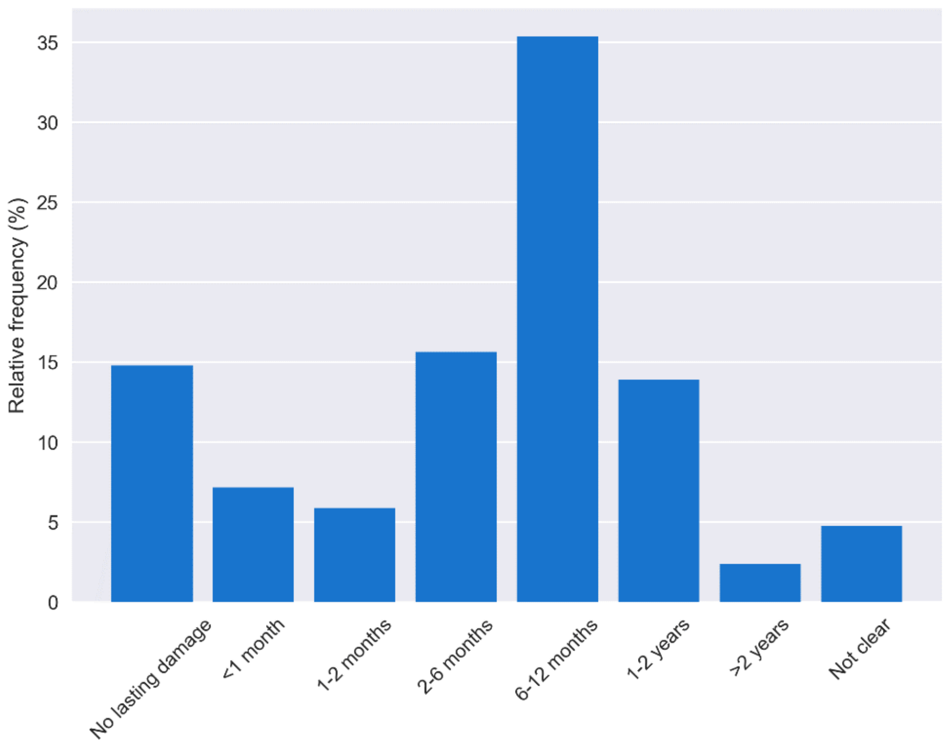

Figure 9: Estimated recovery time in months for households with flood damage with the percentage of households in each category (N = 460).

[8] $t(414) = 2.70$ and $t(306) = 1.83$ respectively
[9] $t(62) = 3.00$

Figure 9 presents the amount of time required to repair the homes of respondents with flood damage; if damages had not yet been repaired at the time of the survey, then respondents provided repair time estimates. Around 15% of respondents who experienced flood damage indicated that their home did not face any lasting damage. Some respondents noted that this time was less than one month or between one and two months; however, for many, this time stretched to between two and six months or between 6 and 12 months. Moreover, 16% of respondents stated that their repairs were expected to take more than a year. The median and average recovery time estimated by respondents at the time of the survey was nine months.

3.5 Flood Damage Mitigation Measures

Our results show that households prepared for flooding by taking both emergency FDM measures and structural FDM measures to reduce flood damage. Structural FDM measures are implemented before a flood event and are relatively expensive and more time-consuming to implement compared to emergency measures. Examples include installing water-resistant floors or raising the entrance to the house. Emergency measures are taken shortly before a flood occurs. Figure 10 gives insights into the geographical distribution of FDM measures (Panel A) and for emergency (Panel B) and structural FDM measures (Panel C) separately. It stands out that there is a relatively large uptake of FDM measures in general more downstream along the Meuse. The explanation behind this can be found in Panel B, where this higher uptake of all FDM measures is explained by the higher uptake of emergency measures. The residents in the areas more downstream had significantly ($p<0.01$)[10] more time to prepare for the flood and took measures accordingly. What also stands out is that the uptake of structural FDM measures is relatively low in all areas (Panel C). Near the confluence of the Roer and Meuse Rivers, there are a few areas with higher uptake of structural FDM measures. More insight into the average number of FDM measures taken in each area can be found in the Appendix (Figure A2).

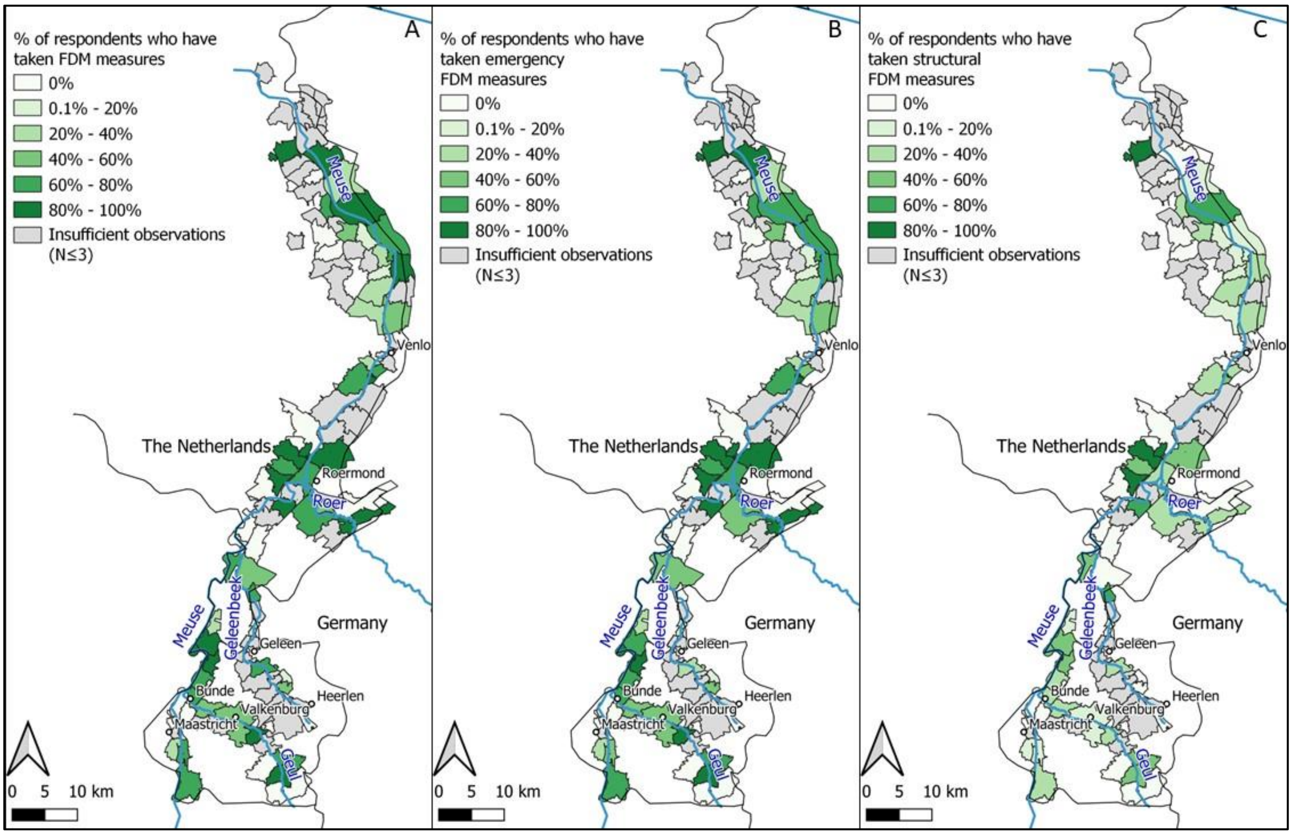

Figure 10: Share of households who have taken at least one FDM measure (Panel A), emergency FDM measure (Panel B) and structural FDM measure (Panel C) based on data for households per postal code area (N = 971).

Table 4 provides an overview of the risk reduction effect of the FDM measures included in the survey. The average rebuilding home value over all data is €257,000, which means that a damage ratio of 0.01 (1% of the home's value), on

[10] $t(1,472)=4.87$

average, is approximately equal to damages totaling €2,570. Table 4 also shows the difference in damage ratios between the groups who did or did not take a particular FDM measure. These numbers pertain only to residents who had water at the outside wall of their houses (*N* = 486). Undertaking the measures is associated with lower damage ratios across all measures. It is important to note that the effectiveness of FDM measures is highly dependent on water level. For example, in two-thirds of all cases, respondents stated that the placed sandbags or flood shields were either not high or strong enough to prevent the water from entering the building. Homeowners who elevated their home contents to higher areas within the building experienced approximately half as much damage compared to homeowners who did not take this action.

Table 4 also shows how often specific measures were taken by respondents. Measures that can be taken relatively quickly after an early warning has been given are applied the most. Examples of these measures are placing sandbags, elevating possessions or using a water pump. Of the structural FDM measures, installing a water-resistant floor and elevating electrics are commonly taken measures. Homeowners took between 60% and 160% more of these measures compared to tenants, which is significant at the 1%-level for all measures, except building with water-resistant materials, which is significant at the 5%-level. Duijndam et al. (2023) have further explored the various drivers of FDM uptake, where it is found that flood experience and cognitive factors (e.g., risk perceptions, self-efficacy) drive future adaptation behavior.

Table 4: Percentage of respondents who employed a specific FDM measure and the average damage ratio (relative damage compared to the actual value of the asset) for groups who did or did not take the specific measure. Data is based on answers from respondents who had water standing against the outside wall of their houses.

		Damage ratio				
FDM measure	% of respondents with measure	Measure not taken	Measure taken	Difference		t-value
Placing sandbags	35.4	0.24 (0.05)	0.19 (0.03)	-0.05	(0.06)	*t*(337)=0.90
Elevating possessions	34.1	0.41 (0.07)	0.23 (0.05)	-0.18**	(0.10)	*t*(236)=1.73
Installing a water pump	32.1	0.25 (0.04)	0.19 (0.03)	-0.06	(0.06)	*t*(337)=1.04
Installing a water-resistant floor	24.7	0.26 (0.04)	0.13 (0.02)	-0.13**	(0.06)	*t*(337)=2.00
Elevating electrical appliances	19.5	0.24 (0.04)	0.15 (0.03)	-0.09*	(0.06)	*t*(337)=1.32
Placing shields or beams	16.0	0.23 (0.03)	0.18 (0.04)	-0.05	(0.07)	*t*(337)=0.71
Elevating floor or entrance	9.9	0.24 (0.03)	0.08 (0.02)	-0.16**	(0.09)	*t*(337)=1.75
Using other water-resistant material	9.5	0.24 (0.03)	0.07 (0.02)	-0.17**	(0.10)	*t*(337)=1.81
Building water-resistant walls	8.8	0.23 (0.03)	0.12 (0.04)	-0.11	(0.09)	*t*(337)=1.14
Strengthening foundations	4.1	0.23 (0.03)	0.08 (0.02)	-0.15	(0.14)	*t*(337)=1.10

Standard errors in parentheses for mean damage ratios, degrees of freedom in parentheses for t-values
*** p<0.01, ** p<0.05, * p<0.1

Note: Damage ratios for the measure of elevating possessions are based on the damage to household contents divided by the actual value of household contents. All other damage ratios represent the damage ratio between building damage and building value.

In addition to economic damage, the flood event caused a diverse range of impacts on people. Figure 11 portrays respondents' stated sources of dominant impact, which illustrates the range of issues, including evacuation, stress, inability to return home, fear of future floods, cleaning, and burglary. Of particular interest are the psychological impacts caused by the flood event. For example, almost 75% of respondents who experienced standing water in their streets stated that they experienced high or very high stress during and after the flood event. During evacuation, almost all participants indicated that they experienced at least some degree of stress, and 28% experienced a great amount of stress while evacuating. More than 35% of respondents noted that even six months after the flood, they continued to suffer substantial stress from the event. Contributors to this stress include building damage, the compensation process, uncertainty and fear during the flood, and the flood's impacts on others.

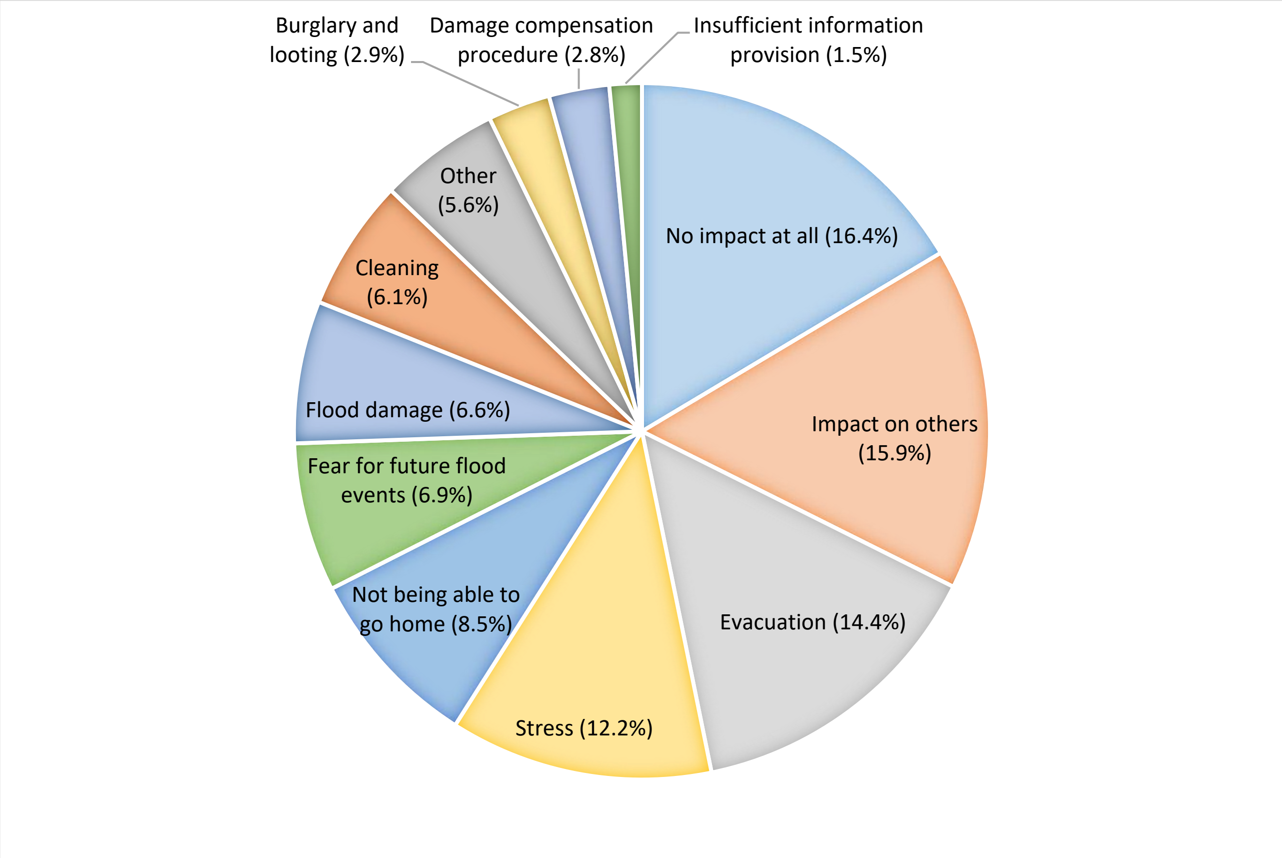

Figure 11: Percentage of respondents who indicated a specific category as the predominant impact experienced during or after the flood event compared to the total number of participants (N = 1,430).

3.6 Compensation

Depending on the type of insurance contract, flood damage to households may be compensated through homeowner's insurance or home contents insurance. After the advice of the Dutch Association of Insurers in 2018, most national insurers included compensation for local flooding in their homeowner’s insurance policies (Dutch Association of Insurers, 2018). This compensation concerns damage that results from flooding in regional waterways, which includes the tributaries of the Geul, Geleenbeek and Roer but not the main waterways. Next to this, the Dutch government applied the Calamities and Compensation Act (CCA), which allows for partial compensation of otherwise uninsurable flood damages. Additionally, the foundation of the National Disaster Fund accepted private donations to be disbursed to residents who experienced severe flood impacts.

Figure 12 illustrates respondents' total compensation received as well as pending compensation from insurance (left) and other sources (right) at the time of the survey (i.e. six to eight months after the event). Approximately 70% of respondents who experienced flood damage received or expect to receive compensation from the CCA. 80% of respondents expect compensation from insurance or the disaster fund. The largest source of compensation was homeowner's insurance, from which 62% of all expected compensation originated. The home contents insurance delivered 22.9% of the total expected compensation, while these estimates were 3.7%, 9.8%, and 1.7% for car insurance, CCA, and the disaster fund, respectively. On average, respondents received or expect to receive compensation for approximately 60% of their total damages, which means that respondents expect that 40% of the damages will not be compensated.

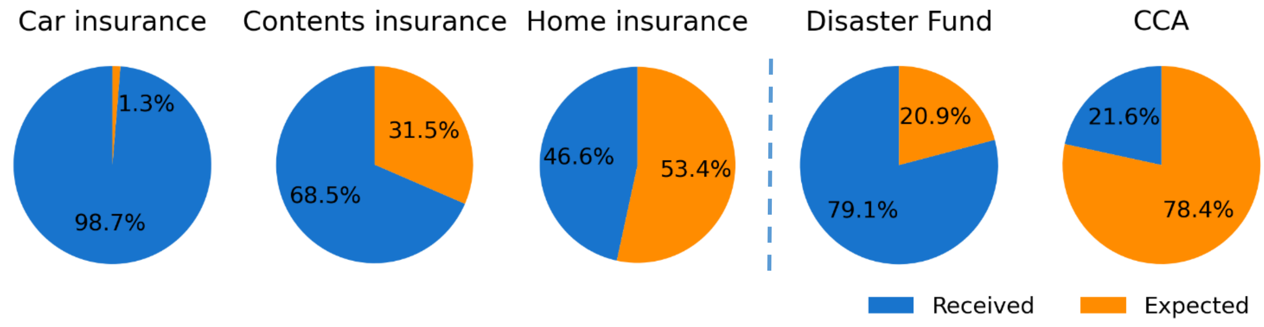

Figure 12: Percentage of total compensation received (in blue) and expected compensation (in orange) from various private (car, home contents, homeowner's) insurances and public compensation arrangements (Disaster Fund and Calamities and Compensation Act (CCA)) for respondents who experienced flood damage; data is based on all households with flood damage (N = 486).

The amount of expected compensation reflects that respondents were still waiting for insurance or government payments six to eight months after flooding. However, respondents' expectations may be overly optimistic, as some participants may not be eligible for this compensation in reality. As Figure 12 illustrates, car insurers had already reimbursed the majority of damages that fell under this insurance type at the time of the survey. From the other insurers, the largest share of compensation still needed to be paid by the homeowner's insurance companies, and these claims may be the most difficult to assess. From the public compensation arrangements, over 75% of expected compensation from the disaster fund had been disbursed, but less than 25% of CCA funds, which are the main source of public funding for 2021 flood damages, had been paid.

4 Discussion

4.1 Comparison with literature

This section will discuss our findings in relation to the broader literature on disaster management. The comparison of different flood disasters from multiple local contexts provides insights into the variations in the impacts of flooding across different case studies for post-disaster surveys. Other major post-flood surveys have been distributed by Thieken et al. (2005) after the German 2002 Elbe floods, Kreibich and Thieken (2007) following the 2005/2006 Elbe floods, Poussin et al. (2015) following several flood events throughout France and Chinh et al. (2016) examining the 2011 flood in the Mekong Delta, Vietnam. Inundation depth is the main driver of flood damage to buildings (Merz et al., 2013), which is in line with reported flood damages across flood events. Our study shows that the Geul area with the highest observed inundation depths also experienced highest the economic damage. Another major indicator for flood damage is economic exposure, where higher economic value at risk implies higher economic damage.

Our survey results indicate that people who received flood warnings evacuated significantly more often (in 75% of all cases). Meanwhile, Dutch standards assume the evacuation fraction for unembanked areas to be around 90%, and between 50% and 82% for embanked areas (Kolen et al., 2013; Dutch Ministry of Infrastructure and the Environment, 2016). The flooded area was not protected by major dike rings, which suggests that the actual evacuation rate for both preventive and responsive evacuation is lower than what current policy assumes. These policies may be overestimating the number of people evacuating during a riverine flood event for unembanked areas, although evacuation fractions may be higher during a more severe event. Furthermore, these findings align with Meyer et al. (2013), who noted that evacuation intentions often do not emerge until actual warnings are received in the US. However, it should be noted that a large share of respondents along the Geul river did not receive a warning, which highlights the need for an improvement of early warning systems. In terms of operational communication and evacuation, people received information from a wide range of sources and through a wide range of media. While social media were mentioned most frequently, more traditional media (radio and television) and formal outlets (such as NLalert) remained important for people. As such, using the whole suite of communication outlets continues to be relevant to warn and communicate with people. However, there is a group structurally unwilling to evacuate, regardless of flood experiences or information provision. Almost half of the respondents who did not evacuate listed a lack of perceived danger as the main reason they were unwilling to evacuate, which is in line with the findings of Nozawa et al. (2008) and Thompson et al. (2017). Moreover, our survey results indicate the presence of a group of people who were flooded but did not receive warnings (either because no warning was provided or because the warning did not reach them).

Besides evacuation, our survey results indicate that information provision and early warnings significantly contribute to the uptake of FDM measures. Longer lead-time warnings are associated with higher adoption of emergency FDM measures, such as placing barriers, moving vehicles to safe locations, or elevating personal possessions to higher floors. 41% of all respondents implemented emergency measures, whereas respondents in more downstream areas were more often able to implement these measures. These findings are in line with the findings from Kreibich et al. (2017), where it is shown that households in areas with longer lead times took more emergency measures during the 2013 floods in Germany.

Individual risk perceptions are shown to often deviate from actual risk levels (Botzen et al., 2015). The share of respondents who thought that the probability of a future flood was high or very high was three to four times higher than respondents of previous Dutch surveys that were conducted in the absence of a recent flood event (Botzen et al., 2009; Mol et al., 2020). These findings are not surprising, as flooding is often a trigger that causes households to update their risk perceptions, after which they decline again (Haer et al., 2017; Bubeck et al., 2020; Mondino et al., 2020). In line with Kreibich et al. (2017), our results indicate an association between prior flood awareness and household preparedness for flooding. It also stands out that household preparedness against flooding in the Netherlands is low compared to other countries. Around 6%-18% of participants added a structural measure to their homes, a number that is substantially lower compared to France, Germany and New York City (Poussin et al., 2014; Kreibich & Thieken, 2007; Botzen et al., 2019). Mol et al. (2020) offer an explanation for this relatively low household preparedness in the Netherlands; there is a high confidence in flood protection standards, even though the majority of the flooded area was unprotected. Another reason for the higher uptake in Germany compared to the Netherlands is that previous flood experience contributes to household preparedness through the uptake of additional FDM measures (Kreibich & Thieken, 2007). As the previous flood events in Limburg were relatively long ago (1993 and 1995) compared to the two consecutive floods studied by Kreibich and Thieken (2007), the uptake of FDM measures may be lower. Flood risk perceptions increase shortly after flood events, but tend to decrease within a few years (Bubeck et al., 2020; Mondino et al., 2020).

The analysis of damages to houses with and without FDM measures (both emergency and structural), yields valuable insights into the effectiveness of these measures. The data reveal significant variations in average damage reduction for both buildings and contents, ranging from approximately 25% (e.g., installing water pumps) to as much as 50% (water-resistant building, elevating valuable household contents), although it is important to note that some measures are dependent of the local impact (e.g., sandbags only work at lower inundation depths). Some measures are relatively cheap to implement for residents and still lead to large damage reductions (e.g., water pumps, elevating possessions and electrical appliances). Other European studies find damage reductions of a similar magnitude. Existing studies have used the same methodological approach to determine the effectiveness of such measures, an independent t-test (e.g., Bubeck et al., 2012; Kreibich et al., 2005; Kreibich & Thieken, 2009), where only some studies performed multivariate analyzes (e.g., Hudson et al., 2014; Poussin et al., 2015). Future research could look more into the effectiveness of such measures at different hazard levels. Taken together, these findings show that the substantial damage savings from household-level flood risk reduction measures observed in other European countries also apply to the Netherlands.

Looting and burglary during flood events regularly make headlines and often cause emotional reactions. Our survey indicates that this indeed happened during the 2021 floods, though at a small scale: only seven respondents noted damage due to burglary. Generally, crime rates drop during extreme weather events (Lemieux, 2014; Yu et al., 2017). However, we also find that looting and burglary influenced behavior and experiences to a larger degree: 41 respondents indicated that burglary was the largest impact of the flood, and a non-trivial number of people indicated that fear of burglary was a motivation not to evacuate.

It stands out that impacts on human health and economic damage were considerably lower in the Netherlands compared to flood impacts experienced in Belgium and Germany during the same flood event in July 2021 (ENW, 2021). The death toll in Germany was over 180 people (Kreienkamp et al., 2021), while in Belgium, the floods claimed the lives of at least 39 individuals (Dewals et al., 2021). In Germany, insurance losses added up to more than €7 billion, of which €450 million of damage to motor vehicles and €6.5 billion to residential buildings, household contents and businesses

(Fekete & Sandholz, 2021). As almost all bridges in the Ahr Valley were destroyed, significant major critical infrastructure losses occurred, which led to further business losses (Fekete & Sandholz, 2021). Economic losses in Belgium were estimated at €1 billion, of which insurance claims are €350 million and losses to infrastructure were estimated at €650 million (Szönyi et al., 2022). Multiple factors play a role in these damage differences between countries. First, in Belgium and Germany much larger areas were affected with higher precipitation levels (ENW, 2021). The highest (very locally) recorded two-day sum of precipitation in the Netherlands amounted to 140 to 160 mm, whereas the same level of precipitation was faced in much larger areas in Germany and Belgium (ENW, 2021). In some areas, this number was 200 mm, which corresponds to roughly double the monthly precipitation normally observed in these areas. (Dewals et al., 2022). It is estimated that the same precipitation levels would have caused at least €2 billion of economic damage in the Randstad area, the large metropolitan area in the western part of the Netherlands (de Bruijn et al., 2023). This expected damage is still lower compared to the observed damage of more than €7 billion in Germany, which can be explained by the fact that the Randstad area is relatively flat, which results in lower inundation depths over a larger area. In contrast, the areas with extreme precipitation in Germany and Belgium had a much steeper topography compared to the Netherlands. The narrow and often steep valleys led to rapid surface runoff on slopes, which led to fast-rising water, high water levels and high flow velocities (Lehmkuhl et al., 2022). Water levels in Belgium often reached over two meters (Dewals et al., 2022), where water reached the second floor for a large share of buildings in the Ahr Valley in Germany (ENW, 2021). In comparison, most observed inundation depths in our study were below one meter.

Comparing disaster management, the German flood management was characterized by failures in the warning chain (Fekete & Sandholz, 2021). A lack of coordination between different authorities resulted in ambiguous warnings for residents of the flooded area. However, these warnings differed in timing, content and the number of issued corrections, which has led to different interpretations by the recipients. Moreover, the issue of missing information was more often quoted in July 2021 compared to the floods of 2013 in Germany (Fekete & Sandholz, 2021). According to our survey, multiple authorities issued warnings as well, but there have been few reports of information ambiguity. However, similar to Germany, some residents were not warned at all. Additionally, precautionary information provision about areas in danger was incorrect in some cases in Germany and Belgium (Szönyi et al., 2022). Some areas were not identified as flood-prone in any Belgian flood scenario but still experienced severe flooding with more than two meters of inundation depth, which surprised both local authorities and residents (Dewals et al., 2022). These inaccuracies in determining flood prone areas have not been observed in the Netherlands (ENW, 2021).

4.2 Limitations

Concerning the representativeness of our sample, it is important to note that older people were overrepresented in our sample compared to population statistics from Statistics Netherlands (CBS, 2022). Population statistics also show that males were overrepresented; in Limburg, they comprise only 50% of the population compared to 64% in our study. This phenomenon is also observed in other flood risk perception surveys in the Netherlands, these studies have shown a skewed gender distribution towards males and older people (e.g., Terpstra & Gutteling, 2008; Botzen et al., 2009). A potential explanation for this overrepresentation may be that the oldest male in the household may have felt more responsible for answering the survey, where letters were addressed to the entire household.

Another limitation of this study is the overrepresentation of households that were directly affected by flooding compared to households that only experienced indirect effects (e.g., through evacuation). A t-test has shown that postal code areas where flooding has occurred have significantly ($p<0.01$)[11] higher response rates than areas where households did not experience water intrusion. To account for this, we only report physical flood impacts for directly impacted households. Moreover, to make sure we only report on individuals who faced some kind of flood threat, we only include individuals where flood water entered their neighborhood for our analysis of evacuation behavior. However, our findings on flood risk perceptions and psychological impacts should be interpreted with caution due to the overrepresentation of flooded households, as we report these findings for all respondents.

[11] $t(113)=6.07$

4.3 Policy Implications

Our findings have several implications for disaster risk management policies. Our survey suggests that Dutch policies currently overestimate the number of people evacuating during a flood event. We also note that a vast majority of people who evacuated did not need help from authorities and did not use central evacuation centers. Many people evacuated to the homes of friends or family and received help from them (or neighbors) during the evacuation. While central shelter and aid remain important, social capital is essential during crises. Leaders in emergency management and aid organizations should capitalize on this finding by facilitating these informal activities during the evacuation process. Considering these findings, there is a need to adjust Dutch flood evacuation policies to better reflect real-world behavior, including a reassessment of preventive and responsive evacuation procedures, communication strategies and resource allocation. Additionally, it became apparent that early warnings play a significant role in the respondent's evacuation decision. Respondents who were not aware of an evacuation advice, evacuated significantly less, while there also is a group structurally unwilling to evacuate. These results highlight the importance of improving emergency management policies that focus on early warnings, concrete evacuation advice and increasing compliance with this evacuation advice.

The number of respondents who indicated that the perceived threat of burglary is substantially higher than the actual reported occurrences of burglary. Additionally, respondents also indicated that this threat was a reason for them not to evacuate. Looting does not occur at a significant scale, although a lot of media attention is given to this topic (Helsloot & Ruitenberg, 2004). As such, the objective threat of burglary seems to be relatively small, but its impact on people and their behavior warrants attention and action from crisis organizations and law enforcement during such events. The objective and subjective threat is burglary is, therefore, a component to include in evacuation and crisis management.

The uptake of structural FDM measures is higher in the US, Germany and France compared to the Netherlands. The reason for these higher numbers is, among other factors (e.g., flood experiences), the proactive governmental programs that incentivize residents in flood zones to invest in flood-proofing measures. These programs raise awareness (e.g., provide flood risk information) and offer subsidies. Moreover, US residents who elevate their homes are eligible for lower flood insurance premiums. The regional water authority in Limburg addresses the importance of structural flood-proofing measures in their water management plan for 2022-2027. However, they do not specifically indicate how this will be facilitated (Waterschap Limburg, 2021). Policies should further create awareness about objective flood risks, as these are sometimes higher than subjective flood risks because of high confidence in Dutch flood protection standards, even though protection standards along the tributaries of the main rivers are substantially lower compared to the main waterways[12] (Mol et al., 2020). Previous attempts in to update perceptions have proven to be ineffective (Kolen, 2013), which calls for a more structural approach to address flood risk awareness. This awareness should also address more extreme flood scenarios that are currently not always considered by regional water authorities, as it is the intensity and frequency of flood events are increasing (IPCC, 2021). It is worth noting that flood events often serve as a catalyst for residents to adopt more FDM measures. Our research findings underscore the pivotal role of increased awareness about flood risks in driving the uptake of these adaptive actions, which has also been confirmed with the regression analyzes by Duijndam et al. (2023). This heightened awareness not only promotes individual preparedness but also serves as a driving force behind community resilience. Moreover, the positive effect of flood-proofing measures at the building scale and the experience seen in other countries (including the positive benefits of cost ratios of flood-proofing measures; Poussin et al., 2015) require that a more proactive policy is recommended.

In addition to the substantial damages experienced by our respondents, we observe that high levels of stress were experienced by respondents following the floods. This high stress is most likely related to the destructive local impact of the flood event, and respondents also indicated that the process of receiving compensation is an important contributor to stress. These topics need further attention during the aftermath of a flood event (HKV, 2009). Our survey results illustrate that residents may receive compensation from a variety of sources, including insurance and government compensation arrangements. However, six months after the flood event, many respondents were still waiting for their compensation, especially government compensation; this observation may add to the stress that residents experience after a flood event. Quick and indisputable damage compensation arrangements will help reduce such post-disaster impacts. One way to achieve this is by creating one central point for residents to quickly claim their compensation, after which insurers and the government together share these costs. Dutch insurers do not allow insurance against flooding from main waterways

[12] For instance, the Geul river has a protection standard of 1/25 years (Waterschap Limburg, 2021).

(Meuse, Rhine and the sea) in the Netherlands because of challenges with attracting enough capital to cover losses from low-probability high-impact flood events at affordable insurance premiums. If the protected area along the Meuse had been flooded, a lot of households would not have received any form of insurance compensation. It is worthwhile for Dutch insurers to explore if it is possible to insure flooding from these main waterways, potentially using a similar public-private partnership approach already present in the UK.

4.4 Research Implications

This study provides an overview of survey results regarding the experienced flood and its impacts, evacuation responses, undertaken FDM measures and their impact on flood losses, compensation, risk perceptions and stress. This enables us to present an overall picture of individuals' experiences of and responses to the 2021 flood event in Limburg. The following four topics for future research would allow more detailed insights into some of the themes covered in this paper.

First, the effectiveness of FDM measures highly depends on water level, which is not controlled for in this study. Performing a multivariate statistical analysis can provide an estimate of the various factors that influence the experience of flood damage, including exposures, hazards, and vulnerabilities. Regarding the latter, such an analysis can offer more robust insights into the effectiveness of FDM measures while controlling for other drivers of damage (e.g., Hudson et al., 2014).

Second, we observe that substantial variations exist between respondents in whether they undertook specific FDM measures, which allows an examination of the factors that explain individual decision-making about preparing for flood events. Based of those results, more specific recommendations can improve individual preparedness for flooding.

Third, in addition to the households sampled for this paper, a substantial number of firms experienced direct and indirect economic losses from the 2021 Limburg flood, which is relevant to analyze in future research because few empirical studies cover the impacts of natural disasters on firms (e.g., Zhou & Botzen, 2021). Data on flood impacts for firms has been collected as well. The aim of this additional data collection is to accumulate a sufficiently large sample to obtain detailed insights into how firms were impacted by and prepared for the flood event.

Fourth, individual flood risk perceptions and levels of flood preparedness are inherently dynamic and often increase in response to flood events, after which they decline again (Haer et al., 2017). Repeated surveys over time in areas affected by floods may offer insights into these dynamics.

5 Conclusion

The goal of this study was to document and investigate the experiences of residents during and after the July 2021 floods in the southern part of the Netherlands, with a focus on disaster management. Respondents from 1,509 households completed the survey, of which about one-third experienced flood damage. This survey was conducted to answer the main research question: “What lessons for flood risk management policy can be learned from the impacts on households during the 2021 Summer floods in the Netherlands by analyzing the stages of the disaster management cycle?”

First, it stood out that disaster prevention was effective during the flood, as only households located outside the dikes have been flooded. For disaster mitigation, it stood out that flood risk awareness is a determinant of the adoption of both emergency and structural FDM measures. Respondents who informed themselves about flood risk employed significantly more flood damage mitigation measures (e.g., placing barriers, building with water-resistant materials, elevating electrical appliances). We found that these measures have the potential to reduce flood damage by 20% to 50%. Moreover, it is found that flood risk perceptions directly after flooding are higher compared to respondents of other surveys in the Netherlands, an increase that often fades away over time. These higher flood risk perceptions offer a window of opportunity for policymakers to enhance mitigation and preparation for future flood events by stimulating FDM adoption.

With respect to disaster preparation, it is found that a large share of respondents was caught by surprise by flood waters, especially those living in the more upstream flooded area along the Geul River, where water levels and economic damage were considerably higher compared to other flooded areas along the Meuse, Roer and Geleenbeek rivers. Flood response was characterized by relatively short warning times along the Geul River, if respondents were warned at all. These warnings contribute to disaster response in the form of both adaptation and evacuation behavior. Respondents who were aware of an evacuation advice evacuated significantly more often compared to respondents who were not aware. Generally, little centralized help was needed with evacuation, with few respondents noting assistance from aid workers and few moving to central evacuation centers. Most respondents received help from friends and family for evacuation and accommodation. Moreover, respondents who had more time between the flood warning and flooding were able to take more emergency flood damage mitigation measures, calling for more coordinated transboundary early warning systems, long lead times and warnings that give residents perspective on how to act (e.g., evacuating, safeguarding personal possessions, placing barriers, moving vehicles).

Recovery from flood damages generally took more than six months for just over half of the respondents, although some expected repairs to take more than a year. Compensation for damages came from private insurance (car, home contents, or homeowner's insurance), the National Disaster Fund, and the CCA. Overall, respondents expected 60% of damage to be compensated; hence, 40% was not expected to be compensated. Compensation through private car insurance had been almost fully paid at the time of the survey (six to eight months after the event). In addition to economic damage, a diverse range of impacts were experienced. About one-third of all respondents were still undergoing impacts six months after the flood event; these were mainly related to building damages, compensation, and uncertainty or fear about future floods.

The descriptive approach in this study also forms the basis for follow-up studies that support flood damage modeling as well as investigations into individual decision-making and perceptions related to flood events and taking risk reduction measures. The results of this study can guide risk assessments (e.g., by considering more extreme flood scenarios) and inform emergency management planning. For example, the sources and media used for communication and the self-reliance observed herein should be considered, as should factors that disproportionally affect people (such as fear of burglary). Particularly, the compensation system deserves some attention, as the diverse sources of compensation, their specific eligibility criteria and insufficient speed of reimbursement cause substantial stress among respondents even half a year after the event.

Acknowledgements

This research was supported jointly by the Dutch Ministry of Infrastructure and Water Management, Strategic Research of Deltares and the REACHOUT project. The REACHOUT project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101036599.

Author contributions (CRediT)

TE: Conceptualization, Data curation, Formal Analysis, Methodology, Visualization, Writing – original draft,. WB: Conceptualization, Data curation, Resources, Supervision, Writing – review & editing,. HM: Supervision, Writing – review & editing,. JA: Supervision, Writing – review & editing,. SD: Data curation, Writing – review & editing,. KS: Resources, Supervision, Writing – review & editing,. BK: Supervision, Writing – review & editing., MK: Supervision, Writing – review & editing.

References

Aerts, J.C.J.H., Botzen, W.J., Clarke, K., Cutter, S.L., Michel-Kerjan, E., Surminski, S., Mysiak, J., Merz, B., Hall, J., Kunreuther, H. (2018) Including Human Behavior in Flood risk assessment. Nature CC. 8, 193-199

Asselman, N., van Heeringen, K-J, de Jong, J., Geertsema, T. (2021) . Juli 2021 overstroming en wateroverlast in Zuid-Limburg. Deltares report nr. 11207700-000-ZWS-0019 (in Dutch).

Barendrecht, M. H., Viglione, A., Kreibich, H., Merz, B., Vorogushyn, S., Blöschl, G.. (2019) The Value of Empirical Data for Estimating the Parameters of a Sociohydrological Flood Risk Model. Water Resour Res.55(2):1312-1336. https://doi.org/10.1029/2018WR024128.

BMVV. (2022). *Bouwkosten per m2 berekenen met handige tool I BMVV Bouwmanagers*. BMVV Bouwmanagers. https://www.bmvv.nl/rekentool (in Dutch).

Botzen, W.J.W., Aerts, J.C.J.H., van den Bergh, J.C.J.M. (2009). Dependence of flood risk perceptions on socio-economic and objective risk factors. *Water Resources Research*, 45: W10440.

Botzen, W.J.W., Kunreuther, H.C., Czajkowski, J., de Moel, H. (2019). Adoption of individual flood damage mitigation measures in New York City: An extension of Protection Motivation Theory. *Risk Analysis*, 39(10): 2143-2159.

Bubeck, P., Botzen, W. J. W., Kreibich, H., & H. Aerts, J. C. J. (2012). Long-term development and effectiveness of private flood mitigation measures: an analysis for the German part of the river Rhine. *Natural Hazards and Earth System Sciences*, *12*(11), 3507–3518. https://doi.org/10.5194/NHESS-12-3507-2012

Bubeck, P., Berghäuser, L., Hudson, P., & Thieken, A. H. (2020). Using panel data to understand the dynamics of human behavior in response to flooding. *Risk Analysis*, *40*(11), 2340-2359.

CBS [Centraal Bureau voor de Statistiek]. (2018). Nederland koploper in Europa met internettoegang. https://www.cbs.nl/nl-nl/nieuws/2018/05/nederland-koploper-in-europa-met-internettoegang(in Dutch).

CBS [Centraal Bureau voor de Statistiek]. (2022). Regionale kerncijfers Nederland. https://opendata.cbs.nl/#/CBS/nl/dataset/70072ned/table (in Dutch).

Chinh, D. T., Bubeck, P., Dung, N. V., & Kreibich, H. (2016). The 2011 flood event in the Mekong Delta: preparedness, response, damage and recovery of private households and small businesses. *Disasters*, *40*(4), 753-778.Copernicus. (n.d.). *Flooding in Europe | Copernicus*. Retrieved August 18, 2022, from https://climate.copernicus.eu/esotc/2021/flooding-july

Copernicus. (n.d.). *Flooding in Europe | Copernicus*. Retrieved August 18, 2022, from https://climate.copernicus.eu/esotc/2021/flooding-july

de Bruijn, K. M., Slager, K., & Juch, S. E. (2023). *Case studie Zuid-Holland: "Analyse grootschalige wateroverlast"*. Deltares. https://pub.kennisbank.deltares.nl/Details/fullCatalogue/1000021120

de Jong, J. & Asselman, N. (2021) Analyse overstromingen Geulmonding. Watersysteemevaluatie Waterschap Limburg. Rapport nr. 11207700-000-ZWS-0013. https://www.waterschaplimburg.nl/publish/pages/7013/analyse_overstromingen_geulmonding.pdf (in Dutch)

De Moel, H., & Aerts, J. C. J. H. (2008). Integration of Spatial Planning in Flood Management in European Research. In *The Adaptiveness of IWRM: Analysing European IWRM research*. Lightning Source.

Dewals, B., Erpicum,S., Pirotton, M., Archambeau, P. (2021): Extreme floods in Belgium. The July 2021 extreme floods in the Belgian part of the Meuse basin. *In: Hydrolink 2021/4*. Madrid: International Association for Hydro-Environment Engineering and Research (IAHR). S. 104-107.

Duijndam, S. J., Botzen, W. W., Endendijk, T., de Moel, H., Slager, K., & Aerts, J. C. (2023). A look into our future under climate change? Adaptation and migration intentions following extreme flooding in the Netherlands. *International Journal of Disaster Risk Reduction*, *95*, 103840.

Dutch Association of Insurers. (2018). *Adviesrapport Overstromingen 2018*. https://www.verzekeraars.nl/media/5105/adviesrapport-overstromingen-2018.pdf

Dutch Association of Insurers. (2022). *Inboedelindex en Herbouwwaardemeter*. https://www.verzekeraars.nl/branche/data-analytics-en-onderzoek/cijfers-statistieken/indexcijfers-inboedels-en-gebouwen (in Dutch)

Dutch Ministry of Infrastructure and The Environment. (2016). *Technisch-inhoudelijke uitwerking van eisen aan primaire keringen*. https://www.helpdeskwater.nl/publish/pages/132791/bijlagen_normering_primaire_waterkeringen_28juni2016.pdf (in Dutch)

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., & Thieken, A. H. (2022). More than heavy rain turning into fast-flowing water – a landscape perspective on the 2021 Eifel floods. *Natural Hazards and Earth System Sciences*, *22*(6), 1845–1856. https://doi.org/10.5194/nhess-22-1845-2022

Endendijk, T., Botzen, W. W., de Moel, H., Aerts, J. C., Slager, K., & Kok, M. (2023). Flood vulnerability models and household flood damage mitigation measures: An econometric analysis of survey data. *Water Resources Research*, *59*(8), e2022WR034192.

ENW (2021) Hoogwater 2021: Feiten en Duiding. Expertiese Netwerk Hoogwater (ENW), https://www.enwinfo.nl/publicaties/ (in Dutch)

Fekete, A., & Sandholz, S. (2021). Here comes the flood, but not failure? Lessons to learn after the heavy rain and pluvial floods in Germany 2021. *Water*, *13*(21), 3016.

FEMA (Federal Emergency Management Agency). (2010) The Federal Emergency Management Agency: Publication 1. FEMA, Washington, DC.

Gerl, T., Kreibich, H., Franco, G., Marechal, D., & Schröter, K. (2016). A Review of Flood Loss Models as Basis for Harmonization and Benchmarking. *PLOS ONE*, *11*(7), e0159791. https://doi.org/10.1371/JOURNAL.PONE.0159791

Godlewski, G., Jonkman, S. N., Moll, J. R., Rutten, M. M., ter Horst, W. (2022). Improvement of the Flood Early Warning System for Valkenburg along the Geul River. *Delft University of Technology.* http://resolver.tudelft.nl/uuid:332ade91-a7ab-4ca0-8dcd-6ada1e6aeeca

Haer, T., Botzen, W.J.W., de Moel, H., Aerts, J.C.J.H. (2017). Integrating household risk mitigation behaviour in flood risk analysis: An agent-based model approach. *Risk Analysis,* 37(10): 1977-1992.

Helsloot, I., & Ruitenberg, A. (2004). Citizen response to disasters: a survey of literature and some practical implications. Journal of contingencies and crisis management, 12(3), 98-111.

HKV Consultants. (2009). *Evacueren kun je leren*. http://www.evacuerenkunjeleren.nl/ (in Dutch)

Hudson, P., Botzen, W.J.W., Kreibich, H., Bubeck, P., Aerts, J.C.J.H. (2014). Evaluating the effectiveness of flood damage mitigation measures by the application of Propensity Score Matching. *Natural Hazards and Earth System Sciences,* 14: 1731- 1747.

iTX BouwConsult. (2022). *Bouwkosten per m2 en per m3. iTX Bouwconsult geeft inzicht.* https://www.itx-bouwconsult.nl/diensten-particulier/gemiddelde-bouwkosten-per-m2 (in Dutch)

IPCC. (2021). AR6 Climate Change 2021: The Physical Science Basis. Cambridge University Press: NY.

Kind, J. M. (2014). Economically efficient flood protection standards for the Netherlands. Journal of Flood Risk Management, 7(2), 103-117.

Kolen, B. (2013). Certainty of Uncertainty in Evacuation for Threat Driven Response [PhD Thesis]. Radboud University.

Kolen, B., Maaskant, B., & Terpstra, T. (2013). Evacuatieschattingen Nederland: addendum. Rijkswaterstaat WVL. (in Dutch)

Kreibich, H., Thieken, A.H., Petrow, T., Muller, M., Merz, B. (2005). Flood loss reduction of private households due to building precautionary measures: lessons learned from the Elbe flood in August 2002. Nat. Hazards Earth Ecosyst. 5, 117–126.

Kreibich, H., Thieken, A.H. (2009). Coping with floods in the city of Dresden, Germany. Nat. Hazards 51, 423–436.

Kreibich, H., Thieken, A. H., Grunenberg, H., Ullrich, K., & Sommer, T. (2009). Extent, perception and mitigation of damage due to high groundwater levels in the city of Dresden, Germany. *Natural Hazards and Earth System Sciences*, *9*(4), 1247-1258.

Kreibich, H., Müller, M., Schröter, K., & Thieken, A. H. (2017). New insights into flood warning reception and emergency response by affected parties. *Natural Hazards and Earth System Sciences*, *17*(12), 2075-2092.

Kreienkamp, F., Philip, S.Y., Tradowsky, J.S., Sarah, F.K., Lorenz, P., Arrighi, J., Belleflamme, A., Bettmann, T., Caluwaerts, S., Chanal, S.C., et al. (2021). Rapid Attribution of Heavy Rainfall Events Leading to the Severe Flooding in Western Europe during July 2021; World Weather Attribution: 2021; p. 54. Available online: https://www.worldweatherattribution.org/wp-content/ uploads/Scientific-report-Western-Europe-floods-2021-attribution.pdf

Lehmkuhl, F., Schüttrumpf, H., Schwarzbauer, J., Brüll, C., Dietze, M., Letmathe, P., ... & Hollert, H. (2022). Assessment of the 2021 summer flood in Central Europe. Environmental Sciences Europe, 34(1), 107.

Lemieux, F. (2014). The impact of a natural disaster on altruistic behaviour and crime. *Disasters*, *38*(3), 483-499.

Merz, B., Kreibich, H., & Lall, U. (2013). Multi-variate flood damage assessment: A tree-based data-mining approach. Natural Hazards and Earth System Sciences, 13, 53–64. https://doi.org/10.5194/nhess-13-53-2013

Merz, B., Aerts, J.C.J.H., Bates, P. Blöschl, G., Dottori, F., Kreibich, H. Lall, U. & Vorogushyn, S. (2021) Causes, impacts and changes of extreme river floods. Nature Reviews Earth & Environment. https://doi.org/10.1038/s43017-021-00195-3.

Meyer, R., Broad, K., Orlove, B., & Petrovic, N. (2013). Dynamic simulation as an approach to understanding hurricane risk response: Insights from the Stormview lab. *Risk analysis*, *33*(8), 1532-1552.

Mol, J.M., Botzen, W.J.W., Blasch, J., de Moel, H. (2020). Insights into flood risk misperceptions of homeowners. *Risk Analysis*, 40(7): 1450-1468.

Molinari, D., Menoni, S., & Ballio, F. (Eds.). (2017). *Flood Damage Survey and Assessment: new insights from research and practice* (Geophysica). John Wiley & Sons Inc. https://www.bookdepository.com/Flood-Damage-Survey-Assessment-Daniela-Molinari/9781119217923

Mondino, E., Scolobig, A., Borga, M., Albrecht, F., Mård, J., Weyrich, P., & Di Baldassarre, G. (2020). Exploring changes in hydrogeological risk awareness and preparedness over time: a case study in northeastern Italy. Hydrological Sciences Journal, 65(7):1049–1059. https://doi.org/10.1080/02626667.2020.1729361

Nozawa, M., Watanabe, T., Katada, N., Minami, H., & Yamamoto, A. (2008). Residents' awareness and behaviour regarding typhoon evacuation advice in Hyogo Prefecture, Japan. International nursing review, 55(1), 20-26.

Penning-Rowsell, E., Johnson, C., Tunstall, S., Tapsell, S., Morris, J., Chatterton, J., & Green, C. (2005). The benefits of flood and coastal risk management: a handbook of assessment techniques. *ISBN 1904750516*.

Poussin, J. K., Botzen, W. J. W., & Aerts, J. C. J. H. (2014). Factors of influence on flood damage mitigation behaviour by households. *Environmental Science & Policy*, *40*, 69–77. https://doi.org/10.1016/J.ENVSCI.2014.01.013

Poussin, J.K., Botzen, W.J.W., Aerts, J.C.J.H. (2015) Effectiveness of flood damage mitigation measures: Empirical evidence from French flood disasters. Global Environmental Change 31, 74-84

Rijkswaterstaat (2022). Project Maaswerken. https://www.rijkswaterstaat.nl/nieuws/archief/2021/02/dijkversterkingen-maaswerken-zijn-gereed

Schade en Slachtoffer Module - Helpdesk water. (n.d.). Retrieved August 17, 2022, from https://www.helpdeskwater.nl/onderwerpen/applicaties-modellen/applicaties-per/aanleg-onderhoud/aanleg-onderhoud/schade-slachtoffer/

Slager, T. en Wagenaar, D. (2017) Standaardmethode 2017. Schade en slachtoffers als gevolg van overstromingen. Deltares report nr. 11200580-004. https://www.helpdeskwater.nl/publish/pages/132789/11200580-004-hye-0002-r-standaardmethode_2017_schade_en_slachtoffers_als_gevolg_van_overstroming.pdf

Szönyi, M., Roezer, V., Deubelli, T., Ulrich, J., MacClune, K., Laurien, F., & Norton, R. (2022). *PERC Flood event review "Bernd"*. Flood Resilience Portal. https://floodresilience.net/resources/item/perc-flood-event-review-bernd/

Terpstra, T., & Gutteling, J. M. (2008). Households' perceived responsibilities in flood risk management in the Netherlands. International Journal of Water Resources Development, 24(4), 555-565.

Tesselaar, M., Botzen, W. W., & Aerts, J. C. (2020). Impacts of climate change and remote natural catastrophes on EU flood insurance markets: An analysis of soft and hard reinsurance markets for flood coverage. *Atmosphere*, *11*(2), 146.

Thieken, A. H., Müller, M., Kreibich, H., & Merz, B. (2005). Flood damage and influencing factors: New insights from the August 2002 flood in Germany. Water Resources Research, 41, W12430. https://doi.org/10.1029/2005WR004177

Thieken, A. H., Petrow, T., Kreibich, H., & Merz, B. (2006). Insurability and mitigation of flood losses in private households in Germany. *Risk Analysis: An International Journal*, *26*(2), 383-395.

Thieken, A. H., Kreibich, H., Müller, M., & Merz, B. (2007). Coping with floods: preparedness, response and recovery of flood-affected residents in Germany in 2002. *Hydrological Sciences Journal*, *52*(5), 1016-1037.

Thieken, A. H., Bessel, T., Kienzler, S., Kreibich, H., Müller, M., Pisi, S., & Schröter, K. (2016). The flood of June 2013 in Germany: how much do we know about its impacts?. *Natural hazards and earth system sciences*, *16*(6), 1519-1540.

Thieken, A. H., Kreibich, H., Muller, M., & Lamond, J. (2017). Data collection for a better understanding of what causes flood damage – experiences with telephone surveys. In D. Molinari, S. Menoni, & F. Ballio (Eds.). Flood damage survey and assessment: New insights from research and practice (Chap. 7, pp. 95–106). Washington, DC: AGU. ISBN 978-1-119–21792-3. Retrieved from http://onlinelibrary.wiley. com/book/10.1002/978111921793. https://doi.org/10.1002/9781119217930.ch7 0, 2017.

Thompson, R. R., Garfin, D. R., & Silver, R. C. (2017). Evacuation from natural disasters: a systematic review of the literature. *Risk analysis*, *37*(4), 812-839.

United Nations. (2015). Sendai Framework for Disaster Risk Reduction 2015-2030. https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf

Wagenaar, D., Lüdtke, S., Schröter, K., Bouwer, L. M., & Kreibich, H. (2018). Regional and Temporal Transferability of Multivariable Flood Damage Models. *Water Resources Research*, *54*(5), 3688–3703. https://doi.org/10.1029/2017WR022233

Waterschap Limburg (2021) . Waterbeheerprogramma 2022-2027. Limburgs water in een veranderend klimaat. https://www.waterschaplimburg.nl/publish/library/6/ontwerp_waterbeheerprogramma_2022-2027.pdf. (In Dutch)

Wind, H. G., Nierop, T. M., De Blois, C. J., and De Kok, J. L. (1993) Analysis of flood damages from the 1993 and 1995 Meuse floods, Water Resources Research., 35, 3459–3465, 1999.

Yu, C. H., Mu, J. E., Ding, J., & McCarl, B. A. (2017). Relationships between typhoons, climate and crime rates in Taiwan. *Natural hazards*, *89*(2), 871-897.

Zhou, F., Botzen, W.J.W. (2021). Firm level evidence of disaster impacts on growth in Vietnam. *Environmental and Resource Economics*, 79: 277-322.

Appendix

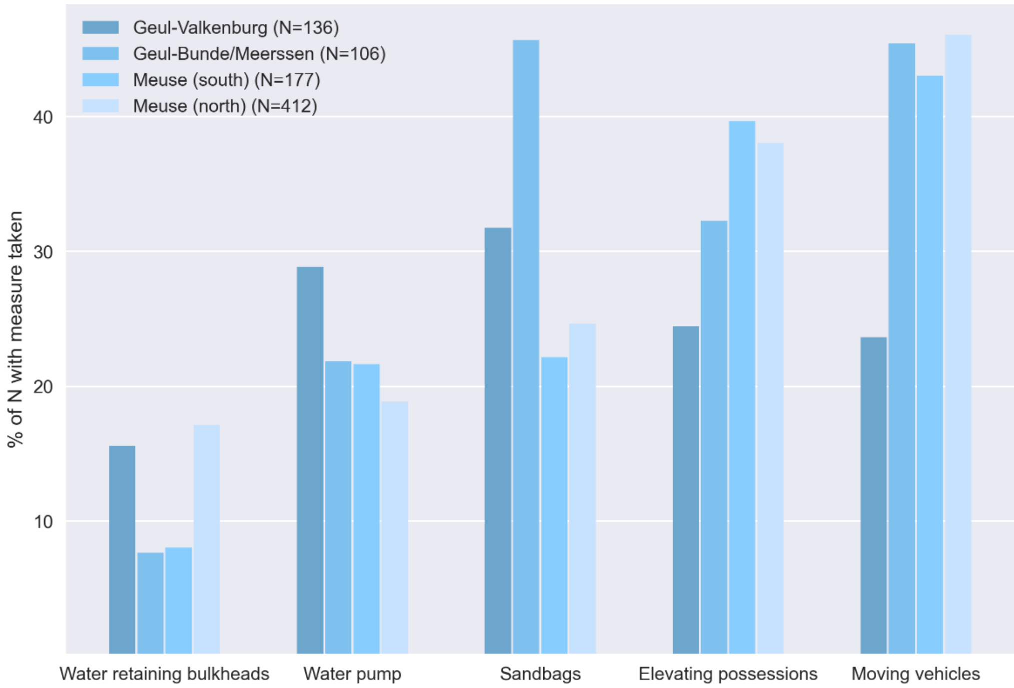

Figure A1: Percentage of respondents who employed several emergency measures; regional data is based on answers from respondents who provided postal code data.

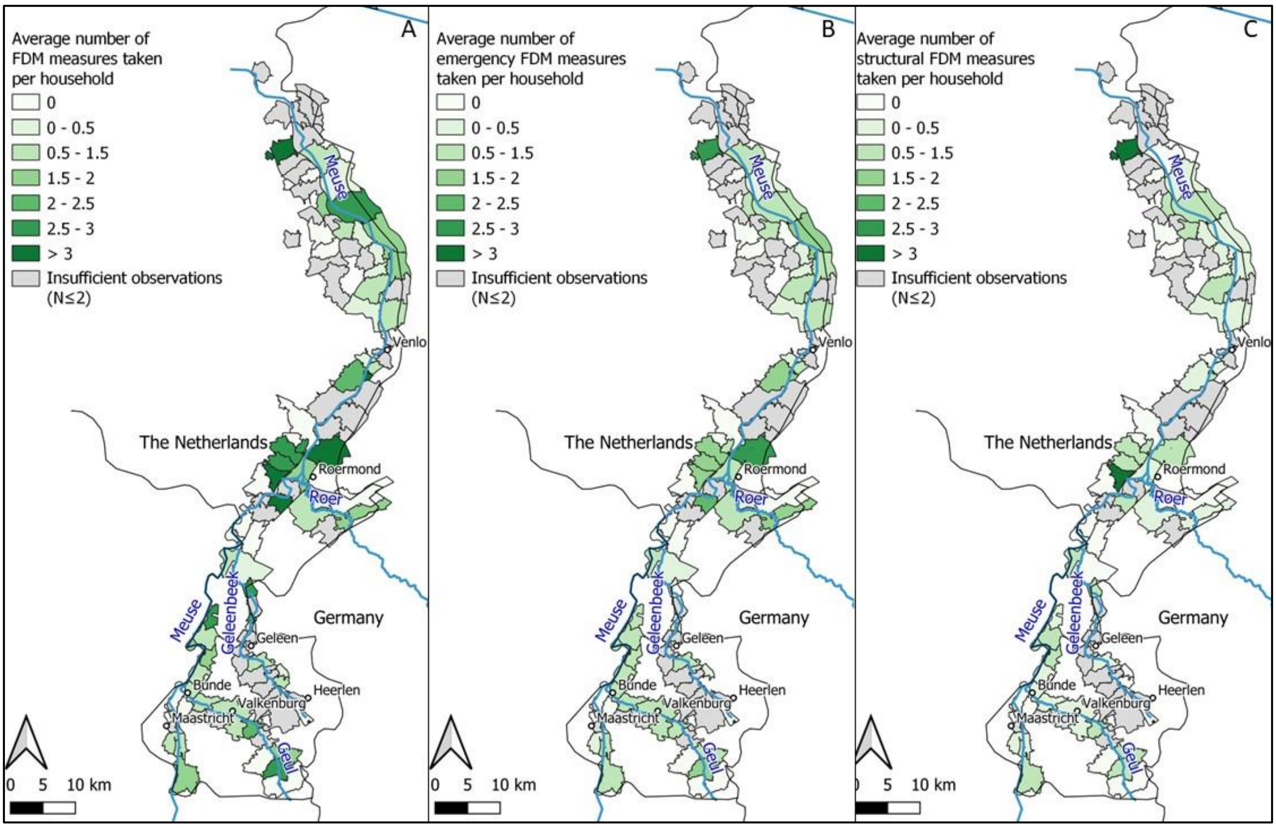

Figure A2: Average number of FDM measures taken per household (Panel A), also shown for emergency FDM measures (Panel B) and structural FDM measures (Panel C) based on data for households per postal code area (*N* = 971).