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Individual Flood Risk Adaptation in Germany: Exploring the Role of Different Types of Flooding

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Abstract. Whether and how flood-affected people prepare for flooding is commonly assumed to depend on their perception of the risk, coping options, and responsibilities. Furthermore, the influence of different flood types, i.e., fluvial, flash, and urban pluvial floods, is unclear, but might be relevant for effective risk communication. Up to now, risk communication has mainly addressed fluvial flooding situations. We use survey data from more than 3000 households affected by different types of flooding in Germany to investigate the influence of flood type on adaptive behaviour in addition to other influencing factors. We use descriptive statistics, Kruskal-Wallis tests, and single-factor ANOVA to identify differences and similarities between respondents. We use linear regressions to identify factors that influence households' adaptive behaviour in the context of fluvial, pluvial, and flash flooding.

We found that most respondents were motivated to protect themselves, but that there were flood type-specific differences in the factors influencing an adaptive response. For example, those affected by fluvial events had most often implemented measures before the last flooding and had experienced flooding before, but frequently showed signs of emotional coping and were less likely to implement (more) measures. In contrast, those affected by flash flooding showed less confidence in the effectiveness of measures, but were less likely to rate their costs as too high and were most likely to implement measures after the event. We argue that, inter alia, the severity of the flood processes, the experiences of previous flooding, and the management of flooding all shape adaptive behaviour. Regardless of the type of flooding, the perception of the effectiveness of adaptive measures and a positive perception of personal responsibility were found to be crucial for motivating those affected to protect themselves. Further analyses suggest that these two key elements can be strengthened by offering financial support for adaptive measures. We also found that communication on a municipality level enhances residents' sense of personal responsibility. We conclude that communication and management strategies need to involve municipalities and should be tailored to the locally relevant flood type.

Keywords: risk communication, protection motivation, flood type, household, survey

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1 Introduction

Floods were the most damaging climate-related extremes in Europe between 1980 and 2022 (EEA, 2023). To improve flood risk management and reduce flood impacts, the European Floods Directive (2007/60/EC) was launched in 2007 in response to several damaging flood events in the European Union (EU) around the year 2000. The directive introduced a structured and integrated flood risk management plan in all EU member states from 2010 onwards, mainly addressing coastal and fluvial floods. In particular, floods that occur due to an overloaded drainage system can be excluded by member states when adhering to the plan. Germany made use of this option when adapting the Federal Water Act (Wasserhaushaltsgesetz – WHG) in 2009 to the requirements of the Floods Directive. However, in recent years, many German cities have experienced urban pluvial flooding, e.g., the city of Münster in 2014 (Spekkers et al., 2017) and Potsdam and Berlin in 2017 and 2019 (Caldas-Alvarez et al., 2022; Dillenardt et al., 2022). Moreover, fast-onset flash floods in the middle hills in May/June 2016 (Laudan et al., 2017; Piper et al., 2016) and July 2021 (Kreienkamp et al., 2021) had huge impacts, i.e., 11 fatalities and €2.6 billion of damage in 2016 and 190 fatalities and €33 billion of damage in 2021 (Thieken et al., 2023). Such impacts from these flood types were unprecedented in the recent past and again called into question current flood risk management approaches.

Integrated flood risk management is built on a variety of risk-reducing measures involving all possible stakeholders, including the general public. Moreover, residents in flood-prone areas are obliged to contribute to flood risk reduction as stated in the WHG since 2005. Private households can implement property-level flood risk adaptation measures (PLFRAM) (Attems et al., 2020). These measures cover a wide spectrum of effectiveness and implementation costs and thus range from the creation of emergency plans or the sealing of foundations to the implementation of stationary barriers or relocation to a less at-risk area. PLFRAM can reduce damage caused by floods in-situ in a cost-effective manner (DEFRA, 2008; Hudson et al., 2014; Kreibich et al., 2011; Lamond et al., 2018; Poussin et al., 2015). Using the events of 2013 and 2016 as examples, however, Thieken et al. (2022) illustrated that people have to cope with very different flood pathways in terms of hydraulic characteristics. In addition, different coping and adaptive behaviours were observed (Thieken et al. 2022). Still, explanations and conclusions for risk communication are vague. In view of the devastating event of July 2021, there is an urgent need to better understand people's behaviour in different (inland) flood settings. To tackle this issue, we investigate adaptive behaviour of households in the context of three types of flooding: fluvial, flash, and urban pluvial floods (Fig. 1). It should be noted that the distinction between flood types is not always sharp and there may be overlaps (Hunt, 2005; Kaiser, 2021; Thieken et al. 2022).

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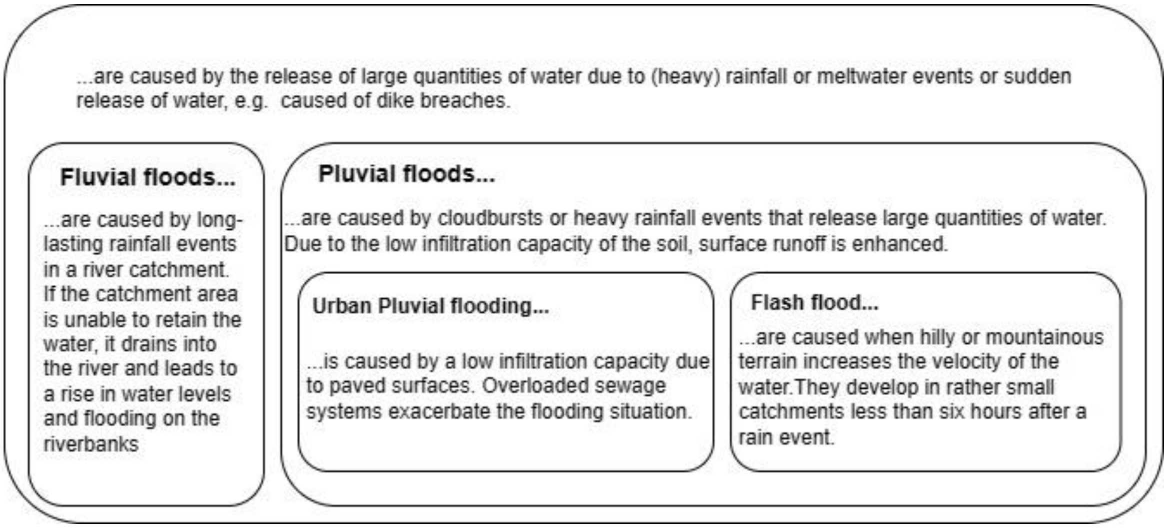

Figure 1: Definitions of the flood types used in this paper based on (Adams et al., 2020; Bruijn et al., 2009; Hunt, 2005; Knocke & Kolivras, 2007; Sweeney, 1992).

All three types of flooding are inland floods. Inland floods are usually caused by a heavy precipitation or melting event or the sudden release of water due to e.g. dike or dam breaches (Bruijn et al., 2009; Hunt, 2005). Fluvial floods in particular are caused by overflowing river courses. This can be distinguished from pluvial events, which are more directly driven by surface runoff and can therefore theoretically occur anywhere (Bruijn et al., 2009). Pluvial floods are triggered by heavy rainfall events or cloudbursts, usually limited in time and space, which are difficult to predict (DWD, 2016). If pluvial events occur in urban areas with low topography, they are intensified by a high proportion of sealed surfaces and are accompanied by an overload of the sewer and/or drainage system. In this paper, we refer to this type of event as urban pluvial flooding. If pluvial events occur in hilly or mountainous terrain, i.e. in steep topography, flash floods with high flow velocities may occur (Adams et al., 2020; Bruijn et al., 2009). They develop in rather small catchment areas – usually less than six hours after a rain event (Arrow et al., 1993; Knocke & Kolivras, 2007).

To investigate households' adaptive behaviour in a structured way, we are using the theoretical frameworks provided by the Protection Motivation Theory (PMT) and the Protection Action Decision Model (PADM). These models identify the appraisals of threat, coping, and responsibility as drivers of adaptive behaviour (Lindell & Perry, 2012; Rogers, 1975, 1983). Various studies have demonstrated the influence of these aspects on the adaptive behaviour of private households in the context of flooding (Bubeck et al., 2013; Bubeck et al., 2018; Dillenardt et al., 2022; Grothmann & Reusswig, 2006).

The PMT and PADM assume that an individual must first recognize a threat by assessing both its severity (perceived severity) and probability of occurrence (perceived probability). In addition to the threat, the individual will assess the options for coping by estimating the costs and effort required to implement suitable measures (perceived response costs), their effectiveness in terms of risk reduction (perceived response efficacy), and their own ability to implement these measures

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(perceived self-efficacy). The PADM adds – among other variables – that individuals assess the extent to which they themselves (perceived self-responsibility) or public institutions (perceived government responsibility) are responsible for the implementation of measures (Lindell & Perry, 2012). It is further assumed that if the appraisals of threat, coping, and responsibility are sufficiently high, a motivation to protect oneself (protection motivation) is encouraged, which will then ideally lead to a protective response within the scope of the person's possibilities. Grothmann and Reusswig (2006) also assume that an assessment of threat that is too low or too high and an assessment of coping strategies that is too low promotes maladaptive thinking or emotional coping mechanisms such as fatalism, denial, procrastination or wishful thinking, which is said to have a negative effect on the motivation to protect oneself. Using a hybrid PMT/PADM framework, Dillenardt et al. (2022) found that in the context of urban pluvial flooding, in addition to negative coping mechanisms, negative responsibility appraisal also promotes maladaptive thinking. Another aspect of adaptive behaviour is trust in public institutions. Terpstra (2011) found that although trust in public institutions is important for (potentially) affected people to be able to believe the complex hazard assessments of scientists and other stakeholders, trust in public flood protection can also lead to a reduction in their own protection motivation. Currently, this aspect is not well accounted for in the theoretical frameworks. Next to threat and coping appraisals, also local flood risk management and previously experienced flooding affect adaptive behaviour (Kreibich et al., 2005; Poussin et al., 2014; Thieken et al., 2006; Wind et al., 1999).

An examination of the interactions between the individual flood types and the factors influencing adaptive behaviour as described above leads to a better understanding of flood management strategies and opens up the possibility to tailor risk communication to prevailing flood situations in potentially affected areas. In order to close this research gap, this study analyses survey data from over 3000 private households that were affected by fluvial, flash or urban pluvial flooding in Germany and asks: How does the type of flooding influence adaptive behaviour? To answer this question, we explore three further questions:

(1) What adaptive responses were reported by individuals impacted by the three types of flooding?

(2) What factors influenced adaptive behaviour in those affected by the three flood types?

(3) What characteristics of these three groups of respondents explain the differences reported?

2. Data & Methods

This study is based on survey data collected between 2014 and 2022 in the course of six surveys among flood-affected households in Germany (see Table 1). A total of 3670 households were questioned about the impacts of recently experienced

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flood events along with questions on adaptive behaviour based on the PMT and PADM. Data were collected by paper/pencil, computer-assisted web interview (CAWI), and/or computer-assisted telephone interviews (CATI).

Data on what PLFRAM were implemented before and after the damaging flood event were collected. However, the questions on PLFRAM were not fully consistent across all surveys due to necessary adaptations to different survey and event contexts. In order to evaluate the implementation of PLFRAM, all measures were assigned to six main groups based on their principal mode of functioning (Fig. 2) as described in the current literature (DEFRA, 2008; Hudson et al., 2014; Kreibich et al., 2011; Lamond et al., 2018; Poussin et al., 2015). Table A1 documents the PLFRAM queried in each survey and their assignment to these six groups. In this paper, we do not assess the number of measures implemented, but only whether at least one measure from a respective group was implemented before or after the flood. It should be noted that this study and the available data cannot clarify the extent to which households adapted appropriately to their local flood situation. This is because the specific PLFRAM or combinations of PLFRAM appropriate to an individual's flood risk depends on many personal and local factors for which no data were collected. On-site visits would be needed for such an evaluation.

Table 1: Information on the surveys and demographic information among surveyed households; CAWI: computer-assisted web interview, CATI: computer-aided telephone interviews.

No.	Place of flood and survey	Flood type	Responses	Flood event	Survey period	Methods	Publications
S-1	More than 160 municipalities across nine federal states	Fluvial flood	1258	June 2013	18 February – 24 March 2014	CATI	(Thieken et al. 2022)
		Levee breach	394				
S-2	Münster, Greven	Urban pluvial flooding	510	July 2014	20 Oct 2015 – 26 Nov 2015	CATI	(Spekkers et al., 2017)
S-3	67 municipalities in South and West Germany	Urban pluvial flooding	448	May – June 2016	28. March 2017 – 28. April 2017	CATI	(Laudan et al., 2020; Thieken et al. 2022)
		Flash flood	153				
S-4	Potsdam, Remscheid, Leegebruch	Urban pluvial flooding	183	2017, 2018, 2019	9 July – 9 September 2019	paper/ pencil, CATI	(Dillenardt et al., 2022)
S-5	Berlin	Urban pluvial flooding	115	2017, 2018, 2019	27 March – 31 May 2020	CAWI	(Berghäuser et al., 2021; Dillenardt et al., 2022)
S-6	North Rhine-Westphalia and Rhineland-Palatinate	Flash flood	609	July 2021	18 Nov. – 31 Dec. 2022	CAWI	No publication yet

For the analysis in this paper, the respondents of the respective surveys were assigned to the urban pluvial flooding, flash flooding, and fluvial flooding flood types according to the definitions in Figure 1 and based on pathways reported in the survey and further event contexts. Urban pluvial flooding was assigned to respondents affected by pluvial flooding in urban areas with no steep topography and possibly accompanied by overloaded sewer systems as a result of temporally and spatially limited heavy rainfall events. This applies to those affected in the city of Münster and the smaller neighbouring city of Greven (Spekkers et al., 2017), as well as to those affected in the cities of Berlin, Potsdam, and Leegebruch (Dillenardt et al., 2022) and 448 surveyed households from S-3 (Thieken et al., 2022). The 64 households affected in the city of Remscheid are not included in the study, as Remscheid's steep topography differs too much from that of the other cities. The respondents to S-1 were assigned to the fluvial flood type, as flooding originated from the rivers Rhine, Weser, Danube, and Elbe (Thieken et al. 2022). In the course of the flooding in June 2013, dike breaches occurred in the federal states of Bavaria and Saxony-Anhalt (Thieken et al. 2022). Respondents who experienced a dike breach were excluded from the analysis of this paper. Following the classification of (Thieken et al. 2022), we separated from S-3 those who were affected by flash floods and assigned them to the flash flooding flood type, while the remaining cases were considered as urban pluvial flooding. All respondents from S-6 were also assigned to the flash flood type, as this was the primary flood type during the flood in July 2021.

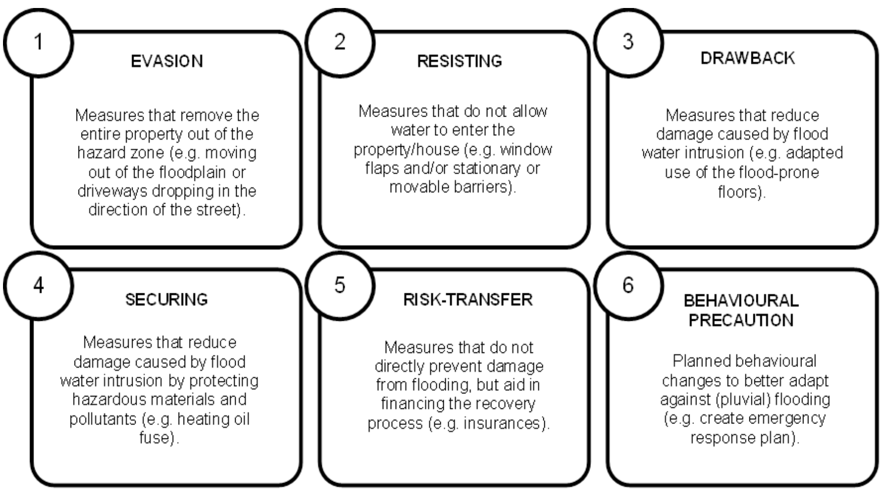

Figure 2: The six main groups to which the surveyed adaptation measures were assigned; more information about the groups can be found in Table A1.

The demographics of the surveyed households are summarized in Table 2. The reported losses to buildings were corrected for inflation to the year 2022 based on the construction price index (DeStatis, 2023a). The losses to household contents were corrected to the year 2022 based on the consumer price index (DeStatis, 2023b). Regardless of the flood type, more women (57%) than men (43%) participated in the surveys. The median age of the respondents was 59, which is approx. 8 years above the average age of the over 18s in the German population (DeStatis, 2014). Mainly home or apartment owners participated in the surveys (82%). On average, 2.6 people lived in the households surveyed. While S-1, S-2, S-3, and S-4 were created by a random sampling in affected areas (based on lists of flooded roads; see Thieken et al. 2017) and considered only landlines, S6 was created in Rhineland-Palatinate with the help of the district Ahrweiler, where every third household who had applied for immediate disaster aid was invited to participate. In North Rhine-Westphalia (as well as in S-5) people from the affected areas were invited for a CAWI via advertisements on Facebook and other media. More than half of those affected by fluvial flooding reported previous flood experience (62%), since similar regions had already been affected in August 2002, whereas fewer had such experience among those affected by urban pluvial (35%) or flash (21%) flooding.

Table 2: Information on demographic characteristics of surveyed households

Flood type	Gender m/f/d [%]	Median age [years]	Homeownership [%]	Median monthly net income [€]	Household size (Mean)	Previously experienced floods [%]
Total	43/57/0.1	59	79.8	2,500	2.6	---
Fluvial N=1258	41/59/---	62	79.7	1,750	2.4	62
Urban Pluvial N=1203	43/56/0.3	60	81.5	2,500	2.5	35
Flash N=762	44/56/0.1	55	76.9	3,100	3.2	21

We analysed the data using the statistical software package IBM SPSS 27. To identify significant differences between the three flood types, the Kruskal-Wallis test was performed. As a post-hoc test, a single-factor ANOVA was performed to better understand identified differences. The flood types were compared in pairs. For each PMT factor, a Kruskal-Wallis test was first performed with all three flood types. If the Kruskal-Wallis test showed that there was no significant difference between the flood types, this was indicated in Table 4 and no post-hoc test was performed.

Linear regressions were carried out with IBM SPSS 27 to examine in the first step which PMT factors influenced the protection motivation of the respondents. In the second step, the PMT factors that significantly influenced protection motivation were examined to determine the framing factors that influenced them. The dependent variable for all regressions was protection motivation, which we derived from the items "I will do everything possible to protect myself from flooding" and the item "I would recommend that others take private precautions" (see Table B1). These two items were combined so that the highest value was always taken for the combined variable. This combined variable enables us to capture protection motivation regardless of whether it relates to the respondent, as in the first item, or to others, as in the second item.

3. Results

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3.1 Comparing the perceived severity of the investigated flood types

In order to characterize the different processes and impacts of the three flood types investigated, key variables are compared in Table 3. Additional data on the perceived flow velocity can be found in Table A1. Altogether, the data reveal that flash floods were particularly severe, since those affected reported the most intense flow velocity, the highest losses to their buildings and building contents, and the highest water depth in their homes, and were most likely to experience floodwater contaminated with fuel oil. In both fluvial flooding and flash flooding, about half of those affected had to be evacuated. Flood duration was particularly high in fluvial floods. Inundation indoors, duration, and contamination with fuel oil were lowest for those who had been affected by urban pluvial flooding; the same holds for the financial losses.

Table 3: Factors used to approximate the severity of the different types of flooding; the reported losses to the building was corrected for inflation to the year 2022 based on the construction price index (DeStatis, 2023a). The losses to the household contents were corrected to the year 2022 based on the consumer price index (DeStatis, 2023b).

	Total	Pluvial	Fluvial	Flash
Total number of cases	3449 (100%)	1203 (37%)	1258 (39%)	762 (24%)
Inundation depth indoors [cm] - median	60	20	90	100
Flood duration [h] – median	60	12	120	24
Flow velocity as assessed on a scale from 1 (steadily flowing) to 6 (turbulent flow) - median	---	3	2	5
Evacuation [%]	43	6	54	54
Oil contamination [%]	16	2	12	34
Losses to building contents [€] – median	3,517	1,749	3,517	30,000
Losses to building structure [€] - median	14,627	4,343	11,251	144,780

3.2 Comparison of the measures taken by those affected before and after a perceived flood

Figure 3 shows the share of surveyed households that implemented at least one measure from a given category (see Fig. 2 and Table A1) of measures before (Fig. 3, left) and/or after a flood (Fig. 3, middle). The results of before and after are summed up in Fig. 3, right.

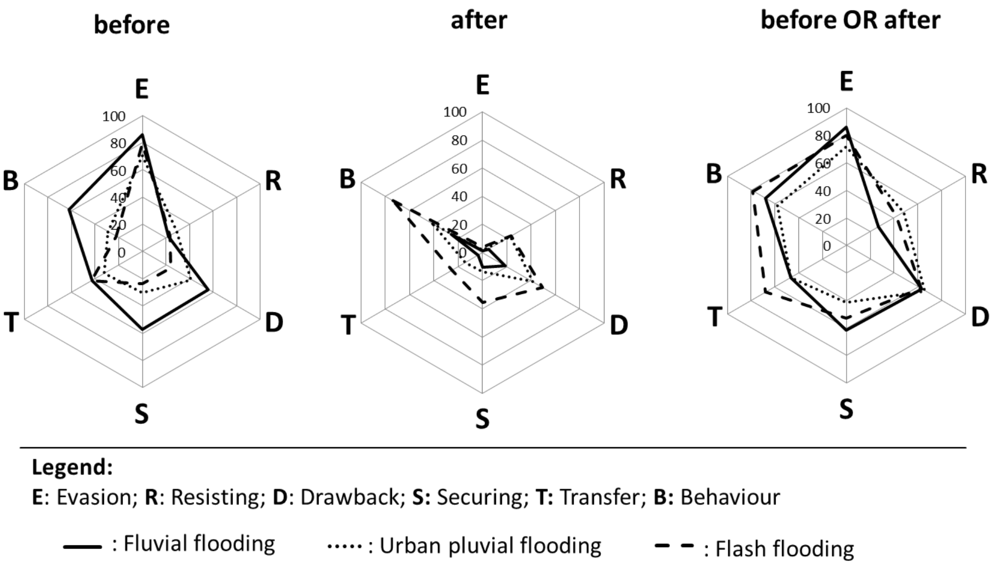

Figure 3: Proportion of respondents per flood type who implemented at least one measure from a PLFRAM group before and/or after a flood; further information on the PLFRAM groups can be found in Fig. 2 and Table A1.

Those affected by fluvial flooding in 2013 had implemented measures most frequently before the event and very few measures after the event, while those affected by flash floods (in 2016 and 2021) had rarely implemented measures before the event, but frequently after the event. Those who were affected by fluvial or flash floods had taken out insurance before the last flood event in roughly equal numbers and more often than those affected by urban pluvial flooding. After the event, those affected by flash flooding were particularly likely to take out insurance, making them the most likely group for this kind of PLFRAM. After the event, roughly the same number of those affected by urban pluvial flooding and flash floods had implemented measures in the categories “Resistance” and “Drawback”. Those affected by flash floods implemented measures in the category “Securing” more frequently after they had been flooded.

Considering together the measures implemented before and after the event, a pattern can be recognized across the flood types. Preparedness measures were implemented quite frequently. Evasion measures were predominantly implemented before the most recent flood event. Drawback measures were implemented before and after with somewhat equal frequency by 60% of respondents. In addition to the above-mentioned similarities, it is striking that those affected by fluvial flooding less frequently implemented resistance measures.

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3.3 Comparing potential drivers of adaptive behaviour

Table 4 compares the flood types in terms of respondents' attitudes towards adaptation to flood risk on the theoretical basis of the PMT and PADM using Kruskal-Wallis tests and post-hoc ANOVA, while Table 5 shows the median and mean values. More detailed information on the answers to the items can be found in Table B1. Percentages show the proportion of respondents who selected either one and two or five and six on a scale from one to six.
With regard to threat appraisal, respondents rate the severity of a future flood as high (median values of 2 for fluvial, 3 for pluvial, and 2 for flash floods on a scale from 1–very bad, to 6–not bad), but often do not believe that such a future event will affect them (median values of 5 for fluvial, 3 for pluvial, and 4 for flash floods on a scale from 1–very unlikely to 6–very likely). The group of those reporting a high perceived severity is comparable and larger among those affected by fluvial or flash (median: 2) flooding than among those affected by urban pluvial floods (median: 3). The proportion of those who rate the probability as low is comparable and higher among those affected by urban pluvial (median: 3) and flash (median: 4) flooding than among those affected by fluvial floods (median: 5).

Coping appraisal is investigated by looking at perceived self-efficacy, perceived response efficacy, and the perceived response cost. Self-efficacy is rather high for around 60% of respondents, and comparable across all samples and flood types, indicating that self-efficacy is person-related rather than event- or flood type-related. Most of those affected by urban pluvial and fluvial flooding tend to have a high and comparable response efficacy (median: 2), while this proportion is lower for those affected by flash floods (median: 3). About 60% of those affected by urban pluvial floods and 56% of those affected by flash floods perceive the response costs as (too) high and are comparable in this respect, while this proportion is higher for those affected by fluvial floods (69%).
Self-responsibility is perceived as high by all respondents. However, the level of self-responsibility is higher among those affected by fluvial (median: 1) than among those affected by urban pluvial or flash flooding (median: 2). At the same time, those affected by fluvial, urban pluvial or flash floods believe that public institutions have a responsibility to implement flood protection measures (median: 3). However, only flash and pluvial flooding are comparable here, see Table 4, and the means in Table 5 reveal that those affected by fluvial flooding stand out in seeing public institutions as slightly more responsible. Yet, most of those affected by flash, fluvial, and urban pluvial floods (median: 5-6) have little confidence in public flood protection measures. Moreover, most people affected by flash, urban pluvial, and fluvial flooding have little confidence in state financial aid (median: 4-5).
In general, most respondents believe that there is enough information available about flooding and flood protection (median: 3). However, fewer respondents affected by urban pluvial (median: 4) and flash flooding (median: 5) believe that there is enough local information available from the municipalities. Those affected by fluvial floods stand out here, as they tend to feel better informed by their municipalities (median: 3).

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Regardless of the type of flooding, over 70% of respondents have a rather high motivation to protect themselves and/or would recommend others do the same. A clear gradient can be seen in the motivation to protect oneself (fluvial - median: 1, pluvial - median: 2 and flash - median: 3, see Table 5). The difference between the motivation to protect oneself and whether protection is recommended to others is most pronounced among those affected by flash flooding (motivation to protect oneself - median: 3; recommend that others protect themselves – median: 1, see Table 5). At the same time, the proportion of respondents showing signs of fatalism is higher among those affected by fluvial and urban pluvial (median: 3) than by flash (median: 4) flooding. The proportion of respondents showing signs of denial is high among those affected by fluvial flooding (median: 1) and less high among those affected by urban pluvial and flash flooding (median: 3). Hence, the group of those affected by fluvial flooding demonstrates that high protection motivation and emotional coping are not mutually exclusive.

Table 4: Results of Kruskal-Wallis and ANOVA post-hoc tests[a]: significance values are adjusted by Bonferroni correction for multiple tests; count = count of cases used for this analysis; more details about items can be found in Table B1; *** p<0.01, ** p<0.05, * p<0.1.

Item	H-Test	ANOVA (pair-wise)		
		Fluvial versus pluvial	**Fluvial versus flash**	**Flash versus pluvial**
Perceived probability	Count: 2856 Test statistic: 279.741***	standardized test statistics: 16.363 Ad. Sig[a].: 0.000	standardized test statistics: 11.204 Ad. Sig[a].: 0.000	standardized test statistics.: -3.621 Ad. Sig[a].: 0.001
Perceived severity	Count: 2641 Test statistic: 248.531***	standardized test statistics: -13.400 Ad. Sig[a].: 0.000	standardized test statistics: -0.589 Ad. Sig[a].: 1.000	standardized test statistics: 12.801 Ad. Sig[a].: 0.000
Perceived self-efficacy	Count: 2634 Test statistics: 1.686	**Retain null hypothesis**		
Response efficacy	Count: 2829 Test statistics: 66.584***	standardized test statistics: 0.460 Ad. Sig.[a]: 1.000	standardized test statistics: -6.878 Ad. Sig.[a]: 0.000	standardized test statistics: -7.610 Ad. Sig[a].: 0.000
Response costs	Count: 2620 Test statistics: 41.416***	standardized test statistics: -5.916 Ad. Sig.[a]: 0.000	standardized test statistics: -5.128 Ad. Sig[a].: 0.000	standardized test statistics: 0.129 Ad. Sig.[a]: 1.000
Responsibility government	Count: 2782 Test statistics: 15.058***	standardized test statistics: -3.820 Ad. Sig.[a]: 0.000	standardized test statistics: -2.464 Ad. Sig.[a]: 0.041	standardized test statistics: 0.957 Ad. Sig.[a]: 1.000
Responsibility self	Count: 2804 Teststatist.: 235.118***	standardized test statistics: -10.447 Ad. Sig[a].: 0.000	standardized test statistics: -14.891 Ad. Sig[a].: 0.000	standardized test statistics: -5.917 Ad. Sig.[a]: 0.000
Trust – public flood protection	Count: 2804 Test statistics: 256.027***	standardized test statistics: 10.780 Ad. Sig[a].:0.000	standardized test statistics -5.088 Ad. Sig.[a]: 0.000	standardized test statistics: -15.203 Ad. Sig.[a]: 0.000

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Trust – financial aid	Count: 2008 Test statistics: 47.959***	standardized test statistics: 0.432 Ad. Sig.[a]:1.000	standardized test statistics: -5.643 Ad. Sig.[a]:0.000	standardized test statistics: -6.460 Ad. Sig.[a]:0.000
Financial support	Count: 2008 Test statistics: 47.959***	standardized test statistics:0.432 Ad. Sig.[a]: 1.000	standardized test statistics.: -5.643 Ad. Sig.[a]: 0.000	standardized test statistics: -6.460 Ad. Sig.[a]: 0.000
Protection motivation self	Count: 2779 Test statistics:319.338***	standardized test statistics: -10.931 Ad. Sig.[a]:0.000	standardized test statistics: -17.674 Ad. Sig.[a]: 0.000	standardized test statistics: -8.623 Ad. Sig.[a]:0.000
Protection motivation others	Count: 2796 Test statistics: 66.818***	standardized test statistics: -7.888 Ad. Sig.[a]: 0.000	standardized test statistics: -5.246 Ad. Sig.[a]: 0.000	standardized test statistics:1.768 Ad. Sig.[a]: 0.231
Emotional coping – fatalism	Count: 2862 Test statistics:102.101***	standardized test statistics: -8.171 Ad. Sig.[a]:0.000	standardized test statistics: -9.187 Ad. Sig.[a]:0.000	standardized test statistics: -2.086 Ad. Sig.[a]:0.111
Emotional coping – denial	Count: 2863 Test statistics:378.274***	standardized test statistics: -15.409 Ad. Sig[a].: 0.000	standardized test statistics: -17.880 Ad. Sig.[a]:0.000	standardized test statistics: -4.565 Ad. Sig.[a]:0.000
Information – general	Count: 2524 Test statistics: 4.637*		**Retain null hypothesis**	
Information - municipalities	Count: 2636 Test statistics: 225.746***	standardized test statistics: -11.489 Ad. Sig[a].: 0.000	standardized test statistics: -14.061 Ad. Sig.[a]: 0.000	standardized test statistics: -4.011 Ad. Sig[a].: 0.000

Table 5: Items asked in the surveys with the scales used and the answers per flood type (median and mean).

No.	topic	Item asked in survey	Scale	Fluvial	Pluvial	Flash
				Data presented as median (above) and mean (below).		
2	Perceived probability	How likely do you think it is that your apartment or house will be hit by flooding again?	1 - very unlikely 6 - very likely	5 4.6	3 3.4	4 3.6
3	Perceived severity	How bad do you expect the consequences of a future event will be?[1]	1 – very bad 6 – not bad	2 2.3	3 3.2	2 2.5
4	Response efficacy	Adaptive measures can significantly reduce flood damage.	1 - I fully agree 6 - I do not agree at all	2 2.6	2 2.5	3 3.1
5	Response	Adaptive measures are far too expensive.	1 - I fully agree	3	3	3

[1] As S-1 was designed as a panel survey and this item was not asked in the first wave of the survey, the results for this item are based on the results of the 2nd wave of the panel survey, in which N=710 households from the 1st wave took part.

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	cost		6 - I do not agree at all	2.9	3.4	3.3
6	Self-efficacy	Personally, I do not feel able to implement any of the measures mentioned above.	1 - I fully agree 6 - I do not agree at all	5 4.3	5 4.3	5 4.4
7	Responsibility public	Flood prevention is the responsibility of public institutions and not of private individuals.	1 - I fully agree 6 - I do not agree at all	3 3.0	3 3.2	3 3.2
8	Responsibility self	Every individual has a responsibility to reduce flood damage as much as possible.	1 - I fully agree 6 - I do not agree at all	1 1.7	2 2.3	2 2.8
9	Fatalism	There is generally nothing that can be done about flooding and flood damage.	1 - I fully agree 6 - I do not agree at all	3 2.9	3 3.5	4 3.7
10	Denial	I don't even want to think about future flood damage!	1 - I fully agree 6 - I do not agree at all	1 1.8	3 2.8	3 3.2
11	Trust	The flood protection in our region is so good, I don't need to take private protection measures.	1 - I fully agree 6 - I do not agree at all	6 5.1	5 4.3	6 5.4
12	Public support	There are enough tax concessions and subsidy programs for financing adaptive measures.	1 - I fully agree 6 - I do not agree at all	5 4.3	4 4.2	5 4.8
13	Information available	There is far too little information and advice on private flood prevention.	1 - I fully agree 6 - I do not agree at all	3 3.4	3 3.3	3 3.2
14		Our municipality provides very good information about flood risks and possible precautionary measures.	1 - I fully agree 6 - I do not agree at all	3 3.2	4 4.1	5 4.5
15	Protection motivation	Personally, I will do everything I can to protect the house I live in from flooding.	1 - I fully agree 6 - I do not agree at all	1 1.6	2 2.1	3 2.7
		I would recommend that others implement adaptive measures	1 - I fully agree 6 - I do not agree at all	1 1.8	2 2.2	1 2.2

3.4. **Results of regression analyses**

The PMT factors and how they affect protection motivation were tested in regressions 1 – 3, see Table 6. After identifying the PMT factors that showed significant influences in the respective flood-type contexts, we investigated which framing factors influence them, see Table 7. Table 7 shows the dependent variables of all linear regressions in the second row, "dependent variables". "Perceived flood inundation/velocity" corresponds to item No. 4, Table B1, "An average person could have stood [...]". In all linear regressions presented here, the flood types were considered, meaning that the datasets presented in Table 2 were used. Each column in Tables 6 and 7 represents a linear regression. All PMT factors examined show significant influences for at least one type of flooding, which demonstrates the suitability of the PMT for discussing the factors influencing protection motivation. Only significant correlations are discussed hereafter. Correlation coefficients are given in brackets.

The influence of threat appraisal on protection motivation is examined through the perception of the flood inundation/velocity of the last flooding and the perceived probability of future flooding. Protection motivation is positively linked to perceived flood inundation/velocity for those affected by fluvial flooding (0.131) and flash flooding (0.128). Hence, a higher perceived severity of the last event may trigger protection motivation. However, only for those who have been affected by pluvial flooding, financial losses are negatively linked to protection motivation (-3.386E-6). This link appears to be minimal. Therefore, the financial loss experienced seems to be less decisive in developing protection motivation. The link between the perceived probability of a future event and protection motivation in the context of pluvial flooding is minimal (-0.096).

The influence of coping appraisal on protection motivation is analysed through perceived response efficacy, perceived self-efficacy, and perceived response cost. Perceived response efficacy is highly significant across all types of flooding, see Table 6, and thus influences the protection motivation regardless of flood type. Perceived self-efficacy positively influences the protection motivation of those affected by fluvial (-0.083) or flash (-0.196) flooding, which is in line with PMT. Response costs are negatively linked to protection motivation in fluvial flooding (-0.066) but positively in the context of pluvial flooding (0.097); however, those linkages are minimal.

The influence of responsibility appraisal on protection motivation is analysed through perceived self-responsibility and perceived government responsibility. A positive linkage between perceived self-responsibility and protection motivation is found across all types of flooding (see Table 6). Thus, the assessment of self-responsibility influences the protection motivation, regardless of the type of flooding. Protection motivation is positively linked to government responsibility for those affected by pluvial (0.109) and flash (0.128) flooding. In conjunction with the positive influence of a sense of personal responsibility, communicating responsibilities in general may positively affect the motivation to adapt.

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Table 6: Results of regression analysis; dependent variable for all four regressions is the protection motivation of households; standard errors in parentheses; significance indicated as follows: *** p<0.01, ** p<0.05, * p<0.1

	regression 0	**regression 1**	**regression 2**	**regression 3**
	general	**fluvial**	**pluvial**	**flash**
	(N=3449)	(N=1258)	(N=1203)	(N=762)
constant	1.383***	1.151***	1.686***	1.876***
	(0.213)	(0.324)	(0.379)	(0.048)
financial loss	3.094E-7*	1.153-6	-3.386E-6**	6.727E-8
	(0.000)	(0.000)	(0.000)	(0.000)
perceived flood inundation/velocity	0.144***	0.131*	-0.068	0.128*
	(0.044)	(0.073)	(0.123)	(0.076)
perceived probability of future floods	-0.019	0.052	-0.096*	0.009
	(0.026)	(0.042)	(0.051)	(0.048)
perceived response efficacy	0.252***	0.240***	0.255***	0.228***
	(0.026)	(0.038)	(0.047)	(0.051)
perceived response cost	-0.064**	-0.066*	0.097**	-0.064
	(0.025)	(0.039)	(0.048)	(0.047)
perceived self-efficacy (reverse item)	-0.089***	-0.083**	-0.013	-0.196***
	(0.026)	(0.037)	(0.048)	(0.052)
perceived government responsibility	0.041	-0.026	0.109**	0.128**
	(0.027)	(0.0.039)	(0.053)	(0.051)
perceived self-responsibility	0.273***	0.246***	0.238***	0.269***
	(0.030)	(0.054)	(0.058)	(0.048)
R-squared	0.243	0.177	0.234	0.262

The financial loss incurred and the flood inundation/velocity were not investigated. In all linear regressions performed, R-squared is generally lower than in the regression analyses of the PMT factors in Table 6. This suggests that the independent variables used do not yet include all framing factors that would reveal influences in these contexts. Nevertheless, the incomplete list of framing factors is used to identify meaningful linkages among PMT and framing factors. Only significant linkages are discussed below.

Increasing age negatively links to respondents' self-efficacy in the contexts of fluvial (-0.030) and flash (-0.020) flooding. Older people, therefore, tend not to feel able to implement adaptive measures. If respondents show a high level of trust in public flood protection, they show a lower perceived self-efficacy in the context of fluvial (0.099) and flash (0.139) flooding.

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The perception that there is sufficient financial aid goes hand-in-hand with a high perceived response efficacy, regardless of the type of flooding (see Table 7). There is, furthermore, a positive link between the perception of financial aid and perceived self-responsibility in the context of pluvial (0.122) and flash (0.126) flooding. Both perceived response efficacy and perceived self-responsibility were identified as the clearest triggers of protection motivation in the analysis of protection motivation (see Table 6). Since they are enhanced by the perceived availability of financial aid, communicating financial aid may be crucial to support the implementation of adaptive measures.

The availability of general information has been shown to influence perceived self-efficacy positively (0.083) and self-responsibility negatively (-0.088) in the case of flash flooding, although those links are minimal. In the context of pluvial (0.204) and flash flooding (0.268), the availability of general information increases the assessment of the government's responsibilities. Perceived response cost is influenced solely by whether the respondents believe that there is enough information in general; in the context of flash flooding, however, there are also negative connections between the assessment of the availability of general information and perceived response efficacy (-0.144). While the availability of general information impacts the perception of the government's responsibility, it is information from the municipalities that might promote the perception of personal responsibility among the respondents, at least in the context of fluvial (0.092) and urban pluvial (0.091) flooding.

There is a negative connection between ownership and self-responsibility, independent of flood type. Hence, homeowners show a greater sense of self-responsibility. Previously experienced floods positively affect the perceived probability of a future event occurring, in the context of pluvial flooding (0.062). This interaction shows that those who have already been affected by flooding are more likely to imagine they could be affected again. However, the flood experience also has a negative effect on the perception of response efficacy in the context of pluvial (-0.061) and flash (-0.151) flooding, suggesting that if households have already experienced flooding, this reduces their positive attitudes towards adaptive measures.

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Table 7: Results of regression analysis for those affected by fluvial flooding; dependent variables (first line) are those variables of TABLE 6-fluvial (column 3) that are significant; standard errors in parentheses, significance is indicated as follows: *** p<0.01, ** p<0.05, * p<0.1

		threat appraisal	**coping appraisal**							**responsibility appraisal**				
	Dependent variables	perceived probability	perceived response efficacy			perceived response cost		perceived self-efficacy (reverse scale)		perceived self-responsibility			perceived government responsibility	
	data set, compare Table 2	pluvial	fluvial	pluvial	flash	fluvial	pluvial	fluvial	flash	fluvial	pluvial	flash	pluvial	flash
independent variabales	constant	2.824 *** (0.402)	0.968 * (0.553)	2.200 *** (0.421)	2.745 *** (0.542)	1.515 ** (0.533)	1.027 ** (0.409)	4.963 *** (0.554)	2.667 *** (0.561)	2.456 *** (0.379)	2.490 *** (0.368)	3.161 *** (0.522)	2.439 *** (0.405)	1.766 *** (0.506)
	age	0.000 (0.004)	0.006 (0.006)	-0.001 (0.004)	0.003 (0.006)	-0.003 (0.005)	0.004 (0.004)	-0.030 *** (0.006)	-0.020 *** (0.006)	-0.001 (0.004)	-0.001 (0.004)	-0.009 * (0.005)	8.681E-5 (0.004)	0.000 (0.005)
	trust in public flood protection	-0.009 (0.038)	0.024 (0.058)	0.031 (0.039)	-0.045 (0.066)	0.088 (0.056)	0.141 *** (0.037)	0.099 * (0.058)	0.139 ** (0.067)	-0.102 ** (0.040	-0.105 ** (0.034)	0.014 (0.063)	0.037 (0.037)	0.144 ** (0.061)
	availability of financial aid	0.041 (0.042)	0.173 *** (0.050)	0.077 * (0.044)	0.104 * (0.054)	0.069 (0.048)	-0.045 (0.043)	0.034 (0.050)	0.054 (0.056)	-0.001 (0.034)	0.122 ** (0.038)	0.126 ** (0.052)	-0.006 (0.042)	-0.105 ** (0.051)
	availability of general information	-0.013 (0.037)	0.023 (0.044)	0.032 (0.039)	-0.114 ** (0.045)	0.222 *** (0.043)	0.379 *** (0.037)	0.135 ** (0.044)	0.240 *** (0.046)	-0.009 (0.030)	0.014 (0.034)	-0.088 ** (0.043)	0.204 *** (0.037)	0.268 *** (0.042)
	availability of local information	0.039 (0.039)	0.043 (0.045)	0.035 (0.041)	0.052 (0.049)	0.024 (0.043)	-0.002 (0.039)	-0.063 (0.045)	0.083 * (0.049)	0.092 ** (0.031)	0.091 ** (0.036)	0.073 (0.047)	-0.007 (0.039)	-0.020 (0.045)
	ownership	0.134 * (0.081)	0.000 (0.099)	-0.094 (0.084)	0.023 (0.093)	-0.036 (0.095)	0.157 * (0.081)	0.075 (0.098)	0.253 ** (0.094)	-0.152 ** (0.067)	-0.189 ** (0.074)	-0.231 ** (0.089)	-0.063 (0.080)	0.143 * (0.086)
	flood experience	0.062 ** (0.028)	0.045 (0.055)	-0.061 ** (0.030)	-0.151 * (0.087)	0.000 (0.054)	0.014 (0.029)	0.061 (0.056)	0.127 (0.088)	-0.028 (0.038)	-0.026 (0.026)	-0.100 (0.084)	0.083 ** (0.028)	-0.001 (0.080)
	R-squared	0.016	0.039	0.018	0.040	0.074	0.126	0.095	0.107	0.044	0.054	0.068	0.060	0.113

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4 Discussion

4.1. Adaptive responses to the different flood types

At 95.6%, most respondents (98.6% of those affected by fluvial, 97.5% of those affected by flash, and 91.5% of those affected by urban pluvial flooding) had implemented at least one adaptive measure before or after the damaging event regardless of flood type. This reflects the generally progressed adaptation of those affected by flooding and the boost in adaptation after damaging events. Respondents were particularly likely to adapt their behaviour by e.g. seeking information, attending seminars and neighbourhood assistance meetings, creating emergency plans, or other preparatory measures (e.g. procuring pumps). This is consistent with the findings of Grothmann and Reusswig (2006), who found that searching for flood-related information is the most frequently performed adaptation. These positive attitudes towards preparedness measures do not directly reduce future damage, but demonstrate the need for information after a flood.

Evasion measures were very rarely implemented after an event (Fig. 3). Since measures in this group are difficult to implement subsequently, such as making driveways drop towards the road, and also require a great effort, such as moving to a less flood-prone area, it is likely that these measures undergo individual cost-benefit assessments. They are much easier to be implemented when planning or constructing a home and should thus be communicated to people involved in construction projects. In contrast, the possibility of taking out insurance could be communicated before and after events. Communicating on this topic is likely to have an impact: in Germany, mandatory flood insurance has been discussed since the devastating floods of 2002 (Thieken et al. 2006). Market penetration has increased from 19% in 2002 to 49% in 2021 (GDV, 2022). Furthermore, our data show that the uptake of insurance policies covering flood losses before the last event was around 40% among all households surveyed. Insurance was purchased after flooding especially by those who were affected by flash flooding. This does make sense, since the amount of flood losses by flash floods is very high (see Table 3) and people with insurance can in general rely on loss compensation based on the insurance contract.

4.2 Appraisal of threat, coping, and responsibility in the context of different flood types

The appraisal of threat is assumed to be a crucial driver in the PMT and PADM. It is formed by the perceived severity and perceived probability (of a future event) and is expected to influence protection motivation positively, if it is not too high (Grothmann & Reusswig, 2006; Lindell & Perry, 2012; Prentice-Dunn & Rogers, 1986). Fluvial floods were perceived as more devastating than urban pluvial floods but less devastating than flash floods. Hence, our analyses illustrate that the flood types examined were perceived very differently by the respondents. These perceptions are confirmed by research on events that were not analysed in this paper: Poussin et al. (2014) found for flooding in France that fluvial floods caused less damage and fewer fatalities than flash floods, and Spekkers et al. (2017) observed rather minor water depth during an urban pluvial flood in Amsterdam and did not report any fatalities. In contrast to flash flooding, the urban pluvial events were perceived as the least severe in our data.

Those who were affected by fluvial floods report both a higher perceived severity and a higher perceived probability of future flooding, which might also be due to repeatedly experienced flooding of this type. Since this group had also implemented the most measures before the event, our data do not allow us to observe the negative feedback loop between the implementation of measures and the appraisal of threat that was described by Bubeck et al. (2012) and confirmed by Poussin et al. (2014) for the context of fluvial events. Our data suggest that the implementation of measures in the past did not lower the respondents' assessment of the threat, or that the assessment of the threat, which may have decreased after the implementation of measures, increased again after experiencing another flood. However, in this context, the fact that those who were affected by fluvial flooding rarely implemented measures after the last flood event may indicate that if those affected by floods implement measures and then experience flooding and losses again, their higher risk assessment will lead not to the implementation of more measures, but rather to higher emotional coping, as emotional coping was particularly pronounced in those affected by fluvial flooding.

For all respondents, the perception of a flood's severity is higher than its perceived probability, showing that many of those affected are already aware that flooding can cause high levels of losses, but that they themselves might not be affected by it (again), which is in line with findings of Netzel et al. (2021) in the context of urban pluvial flooding. Communicating the probability of future events occurring in a particular locality may therefore be a possibility to enhance one's local risk awareness. Return periods may not be the most suitable tool here (Grounds et al., 2017), since they suggest long time periods between flood events. However, neither the perceived probability nor the financial losses experienced by those affected proved to be a strong driver of protection motivation in the regression analyses. Instead, perceived inundation/velocity showed an effect that increased the motivation to protect oneself in the context of fluvial and flash floods, which were perceived as more severe. Future information campaigns should therefore focus on the water levels and flow velocities to be expected near the homes of those affected in order to trigger their motivation to protect themselves through threat appraisal, especially if high flood heights and flow velocities accompanied the last flood event.

In addition to the assessment of the threat, it is the assessment of coping options that shapes adaptive behaviour and is perhaps even the stronger driving force here (Poussin et al., 2014). Therefore, it is a positive aspect that most respondents after an event tend to believe that PLFRAM reduce flood damage and that they can implement these measures, and thus generally tend to perceive both a high sense of self-efficacy and a high response efficacy. Perceived response efficacy has been found to positively influence protection motivation regardless of flood type. The fact that those affected by flash flooding have a lower response efficacy but also less often perceive the costs of measures as too high suggests that this group of respondents experienced particularly severe flooding, which undermined the effectiveness of many measures and put their costs into perspective. This shows that cost-benefit analyses of PLFRAM should be carried out on a flood type-specific basis

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and communicated to those who may be potentially affected. For urban pluvial flood events in particular, it should be investigated which measures can reduce the expected damage in a cost-effective manner, since floods of this type are characterized as less severe (see Table 3). Often, only small changes to the buildings, e.g., the implementation of ground sills, might already help prevent water from entering the building.

Responsibility appraisal is expected to positively influence protection motivation. This study divides responsibility appraisal into one's own perceived responsibility and the perception of the government's responsibility. From the regression analyses, we know that self-responsibility has a positive effect on protection motivation, regardless of the type of flooding, and that perceived government responsibility in the context of pluvial and flash flooding also has a positive influence on protection motivation. Among the flood-affected, the sense of responsibility is generally high (Table 5). Studies have shown that homeowners feel a greater sense of responsibility (Dillenardt et al., 2022; Grothmann & Reusswig, 2006). As over 80% of respondents were homeowners (Table 2), this might explain the high sense of responsibility observed. At the same time, respondents also place responsibility on the public authorities. Thus, those two perceptions are not mutually exclusive. This is in the spirit of integrated flood risk management. However, over 70% of all respondents have little or rather little confidence that the public sector will fulfil the responsibilities they ascribe to it (Table B1). This suggests that clear communication and confidence-building actions among all stakeholders involved in integrated flood risk management should be strengthened in the future.

4.3 Framing factors: A chance to enhance adaptive behaviour?

Framing factors offer the opportunity to discuss the influences of e.g. respondents' age, the availability of general or local information, the perceived availability of financial aid, and flood experience on adaptive behaviour, i.e., the implementation of measures. The influence of framing factors is either indirect via the influence on threat, coping or responsibility appraisals, or direct, if the framing factor prevents the implementation of measures despite a high motivation of those affected and thus acts as a barrier. This study focuses on the indirect effects of the framing factors mentioned.

The regression analysis of the framing factors shows low R-squared values. This has to be kept in mind when interpreting the results, as conclusions derived from those results have to be seen more as starting points for discussions then as hard facts. By analysing the framing factors, we found that the age of affected respondents negatively influenced their self-efficacy. We found this interaction in the context of fluvial and flash flooding. Hence, older people, if they have experienced rather severe flooding, are less likely to see themselves in a position to implement measures. Information campaigns should consider this aspect and pay particular attention to older people in flooded areas by, for instance, identifying who could help them during the implementation process and recommending that they not select measures that require action during an event, such as mobile devices that need to be installed.

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Our data show that those with little flood experience, i.e. those affected by urban pluvial or flash floods, were particularly likely to take action after the last flood. In contrast, those with more flood experience, i.e., those affected by fluvial floods, were particularly likely to have taken action before the last flood that affected them and were less likely to take further measures. In addition, the regression analyses for the context of pluvial and fluvial flooding showed that flood experience may reduce the perceived response efficacy of those affected. Since response efficacy positively influences protection motivation regardless of the type of flooding, this should be addressed. One possibility could be the systematic increase of financial aid, as this positively affects response efficacy, regardless of the type of flooding.

In this context, however, it should be considered that the flood experience is not only characterized by the pure experience of the flood, but also by the experience of the reconstruction process and possibly a subsequent adapted integrated flood risk management, as was the case, for example, after the 2002 and 2013 floods in Saxony (Müller, 2013). Such management, which includes the creation of flood hazard maps and information campaigns aimed at the population, may have a beneficial effect on people's perceptions of the threat, coping options, and responsibilities. While we cannot examine this relationship based on our data, we do find that those who have been affected by fluvial floods – who according to our data are also those who have the most flood experience – have a higher risk perception, a higher perceived response efficacy, a higher sense of personal responsibility, and a higher motivation to protect themselves, and feel better informed by their communities, see Table 5, and had implemented PLFRAM more often before the flood event, see Fig. 3. Future research should focus on these relationships in order to better understand the extent to which integrated flood risk management of fluvial floods has had a positive impact on the precautionary behaviours of households. In the context of different types of flooding, it should then be considered whether similar management approaches should be adapted and applied to other types of flooding.

4.4 Protection motivation and emotional coping: an interaction still not sufficiently understood

Overall, the protection motivation of all respondents is positive or rather positive, and especially those who were affected by fluvial flooding have a high motivation to protect themselves from future events. At the same time, most of the interviewees agree with statements that indicate they will face future events with denial and fatalism. Denial and fatalism are markers of a non-protective response as defined by Grothmann and Reusswig (2006) and which is also referred to as emotional coping in other studies. Grothmann and Reusswig (2006) conclude from their own and other studies that a non-protective response has a negative/hindering effect on protection motivation. Our results show for respondents who were affected by fluvial flooding that high ratings for denial and fatalism and a high protection motivation are not mutually exclusive but can instead coexist, which might be caused by repeated flooding and decreasing resilience, as indicated by Köhler et al. (2023). This may indicate that if the assessments of threat, coping, and (personal) responsibility are high, a protective motivation is promoted regardless of emotional coping. However, we found that those affected by fluvial flooding implemented fewer measures after the event than the other respondents. This might be a hint that a protective response is the result of the interaction between emotional coping and protection motivation. Our data show that, at least in the context of fluvial flooding, the high sense of self-responsibility is not enough to hinder those affected from developing a non-protective response, although self-responsibility was found to have a hindering effect in this sense (Dillenardt et al., 2022). Hence, interconnections among the factors of PMT and PADM are not yet fully understood, in particular in the context of different flood types, and the exact role of emotional coping cannot be conclusively clarified. Further research is needed on this topic. In particular, the items should be selected more carefully.

5 Conclusion

We examined and compared adaptive behaviour of three groups of surveyed households: those that experienced (a) urban pluvial flooding between 2014 and 2019, (b) flash flooding in 2016 or 2021 or (c) fluvial flooding in 2013 in Germany. Our findings are based on several post-event surveys among flood-affected residents that were analysed descriptively, via Kruskal-Wallis tests, post-hoc ANOVA, and linear regressions.

We used the theoretical frameworks of PMT and PADM to structure our analyses and discuss our results in a way that allows us to draw practical conclusions for future risk communication strategies. In such strategies, attention should be paid to ensuring that the threat's communication includes focusing on the probability of future events and communicating high flow velocities and water inundations if those are expected and have occurred during past flooding. In addition, the local context must be established so that those affected can become aware of their individual vulnerability. Equally important as communicating the threat is informing affected individuals about adaptive measures they can take. To this end, flood type-specific recommendations and cost-benefit analyses should be carried out. The results of such analyses should be communicated to specific target groups so that the measures are adapted to the expected severity and hydraulic forces. Care should also be taken to ensure that the communicated measures can be implemented by the respective target group, e.g., evasion measures by those involved in house construction. It may be advisable to incorporate the implementation of measures into the planning and permitting process. As respondents show very little trust in the public sector with regard to dealing with floods, especially after events that are perceived as very severe, communication strategies should include confidence-building strategies. Particularly after a flood event, those affected are open to information campaigns, but those campaigns should be flood type-specific.

Our results suggest that interactions between the factors of PMT and PADM influence adaptive behaviour. In this context, we discussed, for example, the perceived availability of information and financial aid, flood experience, and homeownership as framing factors that promote the development of an adaptive response. We found that the perceived availability of financial aid and information positively impacts coping appraisal and that community-led information campaigns are more likely to increase people’s sense of personal responsibility. However, the interaction of these factors as well as the effect of maladaptive thinking within the development of an adaptive behaviour is not yet sufficiently understood, neither in our study nor in the wider literature. Further research is needed here, as a better understanding can strengthen future risk communication strategies even more.

Competing interests

The contact author has declared that none of the authors has any competing interests.

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Appendix

Table A1: Summary of the measures, their definitions, and which items from the survey were assigned to them, based on Dillenardt et al. 2023, updated; for more information about the surveys, see Table 1.

	Description	Item in survey(-s)	Survey(-s) in which the item was asked
Evasion	Measures that remove the entire building out of the risk zone.	Moving to a less threatened area.	S-3; S-1; S-6
		Upstands (e.g. steps)	S-4; S-5; S-2; S-6;
		Dispensing with a cellar	S-2; S-3; S-1; S-6
		Driveways dropping towards the street	S-4; S-5
Resistance	Measures that do not allow the water to enter the building when it reaches the building.	Ground sills	S-4; S-5
		Barrier systems or safety gates	S-4; S-5
		Backflow flap	S-4; S-5; S-2; S-3; S-1; S-6
		Waterproof or pressure-resistant windows and/or doors	S-4; S-5
		Window flaps or stationary or mobile water stops	S-4; S-5; S-2; S-3; S-1; S-6
		Waterproofing of the foundation	S-4; S-5
		Improvement of the flood safety of the building, e.g. improved structural stability	S-2; S-3
Drawback	Measures that reduce loss caused by water penetration. Measures that reduce loss due to the protection of pollutants are excluded, as these are listed in a separate category "Securing".	I improve the flood safety of my building, i.e. I improve the stability of the building	S-1; S-6
		Low-value use of the floors at risk of flooding	S-4; S-5; S-2; S-3; S-1; S-6
		Low-value use of the floors at risk of flooding	S-4; S-5; S-2; S-3; S-1; S-6
		Buying pumps	S-4; S-5; S-2; S-3; S-1; S-6
Securing	Measures that reduce loss from floodwater intrusion by protecting hazardous materials and pollutants.	Heating oil protection or relocation of the heating system and/or electrical utilities to higher floors	S-4; S-5
		Relocation of the heating system and/or the electrical utilities to higher floors	S-3; S-2; S-1; S-6
		Not storing varnish, paint or gasoline cans in the basement	S-2; S-3; S-1; S-6
		Changing the heating system or providing the oil tank with flood protection	S-2; S-3; S-1; S-6
Risk transfer	Measures that do not directly prevent loss from flooding but transfer the cost of the loss to someone else.	Insurance against flood loss	S-4; S-5; S-2; S-3; S-1; S-6
Behaviour precaution	Measures that cannot be implemented because they are changes in behaviours or the acquisition of new behaviours. Here we also include information seeking, as this can be considered a protective behaviour (Maidl & Buchecker, 2015).	Preparations for the eventuality of a hazard	S-4; S-5; S-2; S-3; S-1; S-6
		Search for information on how affected individuals can protect themselves	S-2; S-3; S-1; S-6
		Participation in seminars	S-2; S-3; S-6
		Participation in neighborhood networks	S-2; S-3; S-1; S-6
		Informing oneself about one’s risk	S-1; S-6
		Acquisition of an emergency generator or a power generator	S-2; S-3; S-1; S-6

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Table B1: Items asked in the surveys, their respective scale, and the respondents' answers in percent.

No.	topic	Item asked in survey	Flood type	Scale	1	2	3	4	5	6
					Values represent the proportion of respondents [%] who rated the respective item with the respective number.					
1	Flow velocity	What best describes the water velocity?	Fluvial	1- steady flow 6- turbulent flow	46	11	14	11	7	10
2			Pluvial		30	14	17	13	10	15
3			Flash		6	8	12	20	21	32
4	Flow velocity and inundation	An average man…	Fluvial	1: …could have stood with no difficulty 2: …could have stood only with difficulty 3: …would have been swept away. 4: Water too deep to stand.	59	20	18	3	---	---
5			Pluvial		75	14	11	0	---	---
6			Flash		22	22	36	20	---	---
7	Perceived probability	How likely do you think it is that your apartment or house will be hit by flooding again?	Fluvial	1 - Very unlikely 6 - Very likely	5	8	16	11	17	44
8			Pluvial		13	16	27	17	14	13
9			Flash		6	14	25	24	14	18
10	Perceived severity	How bad do you expect the consequences of a future event to be?	Fluvial	1 - Very bad 6 - Not bad at all	38	20	21	8	7	7
11			Pluvial		14	17	31	17	11	9
12			Flash		34	22	20	14	7	3
13	Response efficacy	Adaptive measures can significantly reduce flood damage.	Fluvial	1 - I fully agree 6 - I do not agree at	40	16	19	6	6	13
14			Pluvial		37	20	21	7	5	10
15			Flash		24	16	18	17	14	10
16	Response cost	Adaptive measures are far too expensive.	Fluvial	1 - I fully agree 6 - I do not agree at	26	20	24	10	7	12
17			Pluvial		16	18	27	12	11	17
18			Flash		21	14	22	16	12	16
19	Self-efficacy	Personally, I do not feel able to implement any of the measures mentioned above.	Fluvial	1 - I fully agree 6 - I do not agree at	11	8	16	8	15	42
20			Pluvial		9	9	19	9	14	40
21			Flash		8	10	12	15	13	42
22	Responsi-bility public	Flood prevention is the responsibility of public institutions and not of private individuals.	Fluvial	1 - I fully agree 6 - I do not agree at	23	15	34	8	7	13
23			Pluvial		17	17	31	12	10	12
24			Flash		21	16	25	18	8	12
25	Responsi-bility self	Every individual has a responsibility to reduce flood damage as much as possible.	Fluvial	1 - I fully agree 6 - I do not agree at	61	21	12	2	2	3
26			Pluvial		39	25	20	6	5	5
27			Flash		29	22	19	14	8	9

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28	Fatalism	There is generally nothing that can be done about flooding and flood damage.	Fluvial	1 - I fully agree 6 - I do not agree at	31	13	23	9	10	14
29			Pluvial		17	15	22	12	14	20
30			Flash		15	13	15	20	17	20
40	Denial	I don't even want to think about future flood damage!	Fluvial	1 - I fully agree 6 - I do not agree at	72	8	9	3	2	6
41			Pluvial		36	14	19	8	8	14
42			Flash		25	18	17	13	10	17
43	Trust	The flood protection in our region is so good that I don't need to take private protection measures.	Fluvial	1 - I fully agree 6 - I do not agree at	3	4	9	9	20	55
44			Pluvial		9	9	16	12	18	36
45			Flash		2	2	5	7	17	68
46		There are enough tax concessions and subsidy programs for financing adaptive measures.	Fluvial	1 - I fully agree 6 - I do not agree at	8	8	19	12	19	35
47			Pluvial		5	9	20	17	19	30
48			Flash		5	4	7	14	26	43
49	Information available	There is far too little information and advice on private flood prevention.	Fluvial	1 - I fully agree 6 - I do not agree at	21	14	21	10	13	21
50			Pluvial		17	20	24	11	11	18
51			Flash		21	16	21	17	12	13
52		Our municipality provides very good information about flood risks and possible precautionary measures.	Fluvial	1 - I fully agree 6 - I do not agree at	26	19	19	9	10	18
53			Pluvial		9	12	17	13	17	32
54			Flash		8	6	12	14	21	39
55	Protection motivation	Personally, I will do everything I can to protect the house I live in from flooding.	Fluvial	1 - I fully agree 6 - I do not agree at all	76	11	5	2	1	5
56			Pluvial		48	24	15	6	3	5
57			Flash		31	19	21	16	7	6