Adapting to the impacts of pluvial flooding: Results of a household survey in three German municipalities

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Abstract. In recent years, German cities have been heavily impacted by pluvial flooding, causing for example losses of ~€70 million in Münster (2014) and ~€60 million in Potsdam and Berlin (2017). Additionally, pluvial flood impacts are projected to increase due to climate change and urbanization. Therefore, it is important to ask how pluvial flood risk management can be improved in urban areas. To understand the current state of adaptation of residents against pluvial flooding, a household survey was deployed in three municipalities. These three municipalities were recently impacted by pluvial flooding. Data was collected from a questionnaire embedded in the scientific literature on household level adaptation to flooding. A hybrid framework based on the Protection Motivation Model (PMT) and the Protection Action Decision Model (PADM) has been used to investigate the possible drivers of adaptive behaviour. Drivers for adaptive behaviour are explored by the means of descriptive, correlation and regression analysis. On this basis we identified (a) self-efficacy, (b) responsibility, (c) risk-awareness and (d) being informed about precautionary measures as drivers for adaptive behaviour. Regarding to integrated flood risk management, our results underpin that it is crucial to inform potentially affected people about their risk, their options to cope with this risk, and to clearly communicate responsibilities.

1 Introduction

In recent years pluvial flooding has caused enormous damage to German municipalities, for instance the city of Münster was heavily affected in July 2014, causing insured damage to private households of ~€70 million (Rözer et al. 2016). From May to June 2016, two weather events in Germany caused together ~€800 million material damage due to heavy rain (GDV 2017). In 2017 a heavy rain event caused ~€60 million material damage in Potsdam and Berlin[a]. These large impacts can be summarised as the result of the interaction between exposure, hazard, and vulnerability (IPCC 2014, 2012). **Exposure** is the value of assets or number of people that can be negatively impacted. This is particularly relevant in urban areas in the context of ongoing urbanization, since in urban areas assets and people are clustered. **Hazard** is the hydrological nature of a pluvial flood. Due to climate change it is most likely that heavy rain events, and as a consequence pluvial flooding, is more likely to occur in Germany (e.g., Müller et al. 2019, Mann et al. 2018). Furthermore, urbanization increases the potential of surface water flooding, since urbanization leads to an increase in sealed surfaces and a reduction of infiltration and retention capacities. **Vulnerability** is the sensitivity of exposed structures and residents to suffer from impacts.

In the case of river flooding it have been found, that the implementation of emergency and precautionary measures can significantly reduce the impacts of flooding at the household-level in a cost-effective manner (Kreibich et al. 2005; DEFRA 2008; Kreibich et al. 2011; Hudson et al. 2014; Poussin, Botzen, and Aerts 2015; Lamond et al. 2018). While this research has focused on fluvial flooding, many of the precautionary measures studied are also applicable to pluvial flooding as well, such as putting furniture and valuables up or setting up transportable water barriers. However, with regard to pluvial flooding little is known what drives the implementation of such measures.

This is particularly relevant within the growing focus on integrated flood risk management concepts (e.g. Kuhlicke et al. 2020, Bubeck et al. 2017). Integrated flood risk management seeks to create an enabling environment whereby all stakeholders actively play a role in managing and reducing risks and work together to provide information and support. For instance, the German Federal Water Act requires homeowners in flood-prone areas to undertake action where possible (Thieken et al. 2016). A pre-requisite for this is that people know that they are at risk and what they can do to reduce their vulnerability and

[a] www.gdv.de/de/themen/news/versicherer-leisten-2-milliarden-euro-fuer-sturm--und-starkregenschaeden-30380

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exposure (and to a lesser extent the hazard). Therefore, we need to have a better understanding of the current adaptive behaviour and the decision process that leads to the implementation of protective measures. This knowledge basis is needed to move from theory to action within integrated flood risk management frameworks.

Two relevant theories in this context are the Protection motivation theory (PMT) (Prentice-Dunn & Rogers, 1986) and the protective action decision model (PADM) (Lindell & Perry 2012), which both aim to explain the adaptive behaviour of affected people.

Both, the PMT and the PADM, have been used in the context of river flooding (e.g. Grothmann & Reusswig 2006, Terpstra & Lindell 2012, Bamberg et al. 2017, Bubeck et al. 2018). In this context it has been found, that flood coping appraisal is, next to socioeconomic factors, significantly connected to operational learning from others (Bubeck et al. 2017). It is essential to communicate the potential consequences of a flood, possibilities to coping measures and strategies, the effectiveness and costs of coping measures and strategies in order to enhance adaptive behaviour (Grothmann & Reusswig 2006). Terpstra & Lindell (2012) divided these attributes into hazard related attributes (e.g. perceived efficiency) and resource related attributes (e.g. perceived costs). Terpstra & Lindell (2012) found that hazard related attributes positively affected adaptive behaviour while they did not find as strong connection between resource related attributes and adaptive behaviour.

Much of the current research on the links between flood adaptive actions and behaviour has been focused on fluvial flood risk. Pluvial flooding, on the other hand, differs in many ways from fluvial flooding, e.g. the forecasting and warning of pluvial flooding is more challenging (Kind et al. 2019) and resulting water levels tend to be lower in case of pluvial flooding compared to fluvial floods (e.g. Mohor et al. 2020). Together with the fact that pluvial flooding can occur everywhere, it most likely creates a different decision-making context.

Therefore, we aim to extend the scientific literature on flood-adaptive behaviour by providing an initial investigation into the factors associated with the implementation of precautionary and emergency measures within the context of pluvial flooding. Our goal is to investigate drivers of adaptive behaviour through studying data collected from a harmonised survey deployed in three German municipalities of varying sizes and socio-environmental contexts. The data collected is then analysed using a hybrid PMT/PADM framework to investigate the possible drivers of adaptive behaviour. This is done in terms of uncovering which precautionary measures respondents implemented before and after a flood event. Followed by a second step in which we analyse, what motivated people to implement those measures A particularly aspect of our survey is that the sample consists of three different sized cities and events of different severity. Therefore, our sample composition allows us to draw more robust and relevant results for Germany as a whole.

In line with findings related to river flooding we hypothesise, that threat and coping appraisal are important drivers of adaptive behaviour also in the context of pluvial flooding.

2 Adaptive behaviour and decision making

2.1 Measures to reduce the impact of pluvial flooding

Pluvial flooding can lead to damage to building structures and/ or contents due to water penetration and contaminated water. Several measures can reduce those impacts at a household level. Those measures can be broadly divided into dry proofing or protective measures (measures that prevent water intrusion, e.g. water barriers) and wet proofing or mitigation measures (measures that limit the impacts if water has intruded the house, e.g. using water proved materials in endangered floors) (Hudson et al. 2016). Both types of measures address potential flood damage by risk reduction. Another way to address potential flood damage is risk transfer (transferring the monetary damage to other stakeholders, e.g. insurances).

Precautionary measures are measures that are implemented, before a flood event occurs. These measures tend to reduce flood risk by acting on vulnerability and exposure (in varying degrees across measures). Emergency measures are measures that are implemented shortly before or during a flood event, such as moving exposed items upstairs or to a flood-safe place. While there is an overlap – e.g. having a water pump available requires action before the flood (preparedness), using it in the event to pump out water is a typical emergency measure, emergency and precautionary measures differ in the time needed to plan and implement them Precautionary measures cover a wider range of possibilities, including low, medium and high costs measures (Rözer et al. 2016), as more extensive preparations can be undertaken. Table 1 indicates the particular precautionary and emergency measures studied in the survey.

Most of the measures listed in Table 1 can be considered as risk reduction (as are all emergency measures) measures in that they aim to directly lower the damage the employer suffers during a flood. Insurance however is a risk transfer mechanism. This means that insurance doesn't directly lower the damage suffered during a flood but allows for the insured to be compensated and recover faster.

2.2. Identifying drivers of adaptive behaviour

In the integrated flood risk management approach for pluvial flooding in urban areas, potentially affected households need to be motivated to undertake adaptive behaviour. This motivation can be internal (e.g. their beliefs) or external (e.g. legal compulsions). In order to achieve sufficient motivation, it has to be understood how people react in the case of a threat and why they do so.

For this study we focus on what can be considered as internal rather than external motivation. The **protection motivation theory (PMT)** is a socio-psychology model that aims to identify drivers of adaptive behaviour

(Grothmann & Reusswig 2006). Although it was not specifically developed for the context of flooding it has been used by several researchers to investigate and better understand why people adapt to (riverine) flooding (e.g. Grothmann &Reusswig, 2006, Bubeck et al. 2018). The PMT assumes that an adaptive response is the last segment of a chain of processes. Firstly, the decision maker assesses the threat itself (threat appraisal). Threat appraisal includes the appraisal of (a) the probability of a flood, (b) the impacts of a future flood and (c) the fear that results from these possibilities. Secondly, the decision maker considers the options to cope with the threat (coping appraisal). Coping appraisal considers (a) how measures could usefully prevent or limit the damage (protective response efficiency), (b) whether one is able to implement necessary measures (self-efficacy) and (c) how much those measures would cost (protective response costs).

The assessment of the situation leads to a motivation to adapt. Once the threat and coping appraisals have reached a sufficient threshold, a sufficient adaptive motivation occurs leading to adaptive behaviours. Otherwise it leads to a non-adaptive motivation and no adaptive behaviours being employed. Whether an adaptive behaviour is taken out further depends on actual barriers, which can hinder the implementation of measures (Grothmann & Reusswig 2006).

However, it has been shown that the PMT rarely explains all aspects of adaptive behaviour in the case of riverine flooding, such as social norms and networks (Bubeck et al. 2018). For instance, the social (normative) context in which a person acts is known to be important (Lo, 2013; Lo et al. 2015; Lo et al. 2017; Bubeck et al. 2018) but is not explicitly mentioned in the PMT framework. However, the inclusion of how people appraise the responsibility of other stakeholders and therefore also appraise their own responsibility (social norms) seems to be crucial to better understand adaptive behaviour. Furthermore, personal resources should be taken into account. For instance we can draw a difference between a person’s perspective of a protective measure is being expensive (as response costs is often formulated) and the ability to pay for the implementation (Hudson 2020).

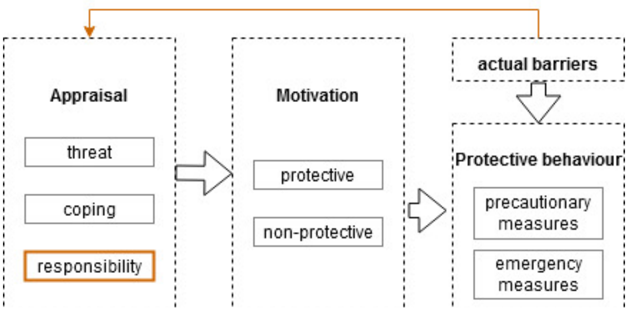

Figure 1: Hybrid PMT/PADM framework based on Grothmann & Reusswig (2006), Lindell & Perry (2012)); in orange interactions and factors derived from the PADM are marked.

The **Protective action decision model (PADM)** (Lindell & Perry 2012**)** creates a wider context around drivers defined by the PMT. The basis for the chain of appraisals, motivation and adaptive behaviour is here seen through a pre-decision process and consideration of the resources available to a person. Furthermore, the appraisal section, while named differently to PMT, is functionally similar and supplemented by stakeholder responsibility (also called Stakeholder perceptions in the PADM). This is important in the context of flooding, since in the integrated flood risk management all stakeholders have to participate to reduce flood risk.

In order to identify drivers of adaptive behaviour we use a hybrid PMT/PADM Framework illustrated in Figure 1. This hybrid framework is based on the PMT but does include factors of the PADM. Figure 1 shows a simplified set up of the hybrid model. By including the appraisal of responsibility, we include the influence of other stakeholders on the decision process of an individual decision-maker. Furthermore, personal barriers, which are describing personal resources from a different point of view, not only affect the implementation of adaptive measures. These barriers influence the chain of decision-making and action much earlier by providing its framework.

On the basis of this simplified model we identified four drivers to which we assigned subcategories from PMT and PADM (Figure 1). The **appraisal of threat** is described by *the perceived probability*: how likely a person thinks flooding occurs (again); *perceived severity*: how severe a person thinks a future flood impact would be; *reliance on public flood protection*: how much does a person trust that public flood protection compensates for the need of private measures. This subcategory also affects **responsibility**, which is further described by *the reliance on disaster relief*: does a person believe that damage will be paid by someone else. We asked for the reliance on disaster relief in the context of precautionary measures. **Actual barriers** hinder the implementation of measures. Subcategories are *self-efficacy*, what is understood as the believe of an affected person, that their actions can significantly reduce the impacts of a flooding, *the response costs*: How expensive will the measures and their implementation be, and *the lead time*: the time between a warning is received and the event occurs (the lead time is solely important for the implementation of emergency measures). The response costs and self-efficacy are further assigned to the category **coping appraisal**, which describes a consideration process of whether measures can and should be implemented or not. It is further described by *protective response efficiency*: does a person believe the possible measures can sufficiently reduce damage and *the intensity* of the last event, which have been derived from the flood duration and inundation. All Categories are affected by *being informed about precautionary measures.* This can be seen as an actual barrier, since a lack of information potentially prevents adaptive behaviour.

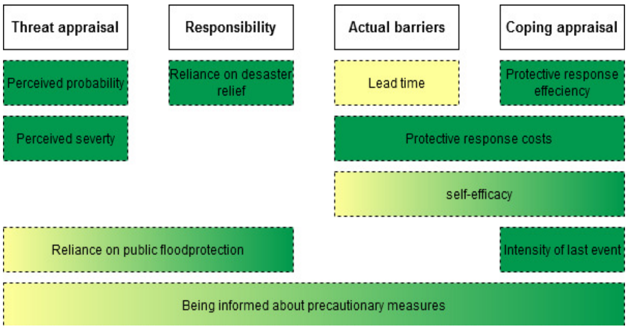

Figure 2: The drivers of our hybrid PMT/PADM framework (white boxes) and their subcategories (coloured boxes); green boxes: used for investigations in the context of precautionary measures; yellow boxes: used for investigations in the context of emergency measures; if boxes share both colours, these subcategories have been used in both contexts: precaution measures and emergency measures.

3 Data and methods

3.1 Survey areas

Affected households in Potsdam, Leegebruch and Remscheid were surveyed between July and November 2019 using paper, telephone, and online surveys following an initial pre-test survey. The demographic information of people surveyed in those municipalities and the official census data can be found in Table 2.

Potsdam is the regional capital of Brandenburg with a total area of approx. 189 km^2 and approximately 200,000 residents. In 2017, 2018, and 2019 several heavy rain events led to local flooding. Many residents were negatively affected by these events by, for example, damage to their property, through interruptions of the public transport system, and other inconveniences. Here, in particular, the event in 2017 has to be noted as the most devastating event in the last three years as a result of a large-scale extreme weather event which impacted large parts of north-east Germany on 29th June 2017.

Leegebruch was also strongly affected by this event in 2017. Leegebruch, a small sized city in Brandenburg with a total area of approx. 6 km^2 and approx. 6800 residents, is located within a topographical depression with a high ground water level leading to a long period of inundation in the case of pluvial flooding.

Remscheid is a city in North Rhine-Westphalia with approx. 109,000 residents and a total area of 75 km^2. Remscheid has been affected by heavy rain events in 2018 that have led to local inundations and the resulting damage and inconveniences.

Overall, the survey respondents display a median age of 53 years. Therefore, the participants are two years older than the average german[b]. The participants also displayed a split of 50 % male, 48 % female, and 2 % non-binary. This is a slightly higher proportion of male participants compared to the Census 2011 (48% male, 52% female)[c]. The surveyed participants are sufficiently representative of the underlying population.

3.2 Sampling and questionnaire

The questionnaire consisted of 64 questions on the main topics (a) warning and media usage, (2) precautionary & emergency measures, (3) damage and inconveniences and (4) social network. Only participants that have had experienced a heavy rain event were eligible to be surveyed.

In order to target a sample of impacted people, the areas affected by pluvial floods were identified on the basis of media reports, fire brigades' operational lists (i.e. where they received call out notifications), and the social media activities of the fire brigades.

The survey was then conducted in two waves. For the **first survey wave** a professional survey company contacted a random sample of 500 households in each municipality within the identified areas. The survey company handed out printed questionnaires solely to households located in the ground floor of buildings. Those households had the chance to answer the questionnaire on paper, online or via telephone in order to maximise potential response rates. After a few weeks reminders were sent out and households were contacted by phone. In the **second survey wave** flyers were distributed within the affected areas in Potsdam and Leegebruch. In Remscheid flyers were instead sent with local newspapers. People had than the chance to participate online via a link or QR-Code. Altogether, data of xxx households were gathered (Table 1).

3.3 Descriptive data analysis

A descriptive analysis is used to investigate the types of precautionary measures households (a) implemented before, (b) after the pluvial flooding and (c) planning to implement in the future. With the descriptive analysis we aim to (a) identify the most common precautionary measures, (b) carve out differences among the three municipalities and for (c) investigate the state of the adaptive behaviour. The latter, in particular, is used to investigate interactions of the precautionary behaviour and personal attitudes and/or characteristics of the participant. In addition to precautionary measures, emergency measures were studied with a similar approach.

3.4 Explanatory statistical analysis

A series of bivariate correlation tests, based on Pearson's correlations is used, to investigate relations between potential drivers and the adaptive behaviour of the participants as represented by the number of measures implemented. We tested the Pearson-coefficients on their two tailed significance. Our intermediate research questions are: (a) Do the drivers, derived by the hybrid PMT/PADM model, have significant links to adaptive

[b] Since all participants are older than 21, we excluded data of younger respondents from the Census 2011 before comparing the datasets.

behaviour and (b) how do precautionary measures and emergency measures differ in these linkages?

We then developed a regression model based on drivers of adaptive behaviour defined by our correlation analysis. With the regression model we aim to identify the (relatively) most important drivers of those investigated.

4 Results and Discussion

4.1 Descriptive analysis

Comparison of flood intensity: Figure 2 shows the average inundation depth and duration in the three survey areas. The impacts in Remscheid and Potsdam are comparable with regard to both, duration and inundation depth, while the event in Leegebruch stands out with higher inundation levels and an almost 9 times longer duration. Residents in Leegebruch suffered a mean flood-duration of approx. 2 weeks.

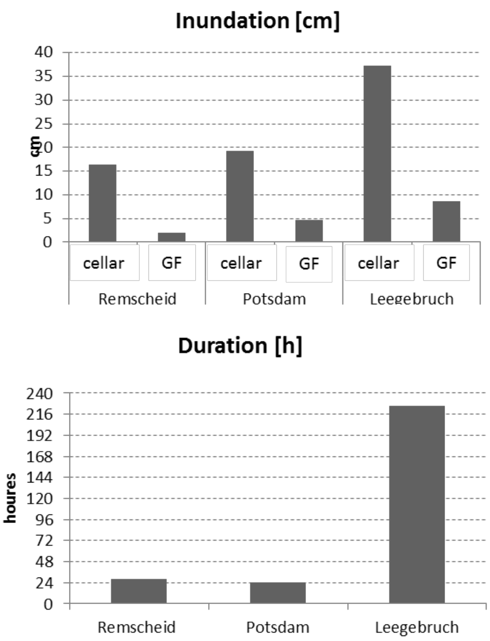

Figure 2: Flood inundation levels (upper panel) and duration (lower panel) in the three municipalities.

Precautionary measures before the event: In all three municipalities high cost measures such as *Barrier systems and/or safety gates* or *Water and pressure resistant windows and/or doors* are the scarcest measures. Those measures are cost-intensive (Rözer et al. 2016), may not be affordable (Hudson 2020), and are probably associated with river flooding more than with pluvial flooding.

The *purchase of insurance against flood damage* is the most common measure in all three municipalities. However, it is more common within Potsdam and Leegebruch than in Remscheid, probably due to historical reasons: In East Germany, until the reunification in 1990, natural hazard insurance was often included in property insurance. Therefore, it is often included in renewed contracts and the awareness regarding this type of insurance is higher in those areas due to the arguable presence of a different historical risk culture (Hudson et al. 2017).

Households in **Potsdam** installed the most precautionary measures before the damaging event. In **Leegebruch**, with the highest percentage of home owners, the clearly most common measure is the driveways dropping in the direction of the streets, so that water is directed away from the building. **Remscheid** stands out with having the lowest number of precautionary measures installed before the flooding. Next to the purchase of insurance, ground sills are the second most implemented precautionary measure in Remscheid.

Precautionary measures after the event: Taken all three municipalities together, pumps have been the most often implemented precautionary measure after flooding.
Households in **Potsdam** installed the fewest number of precautionary measures after the event. Residents from **Leegebruch** installed by far the most measures after the event. This is most likely the effect of the intensity of the event, since the impacts of the flooding in Leegebruch stand out with high water levels and long duration. Hence, the intensity of a last event can be carved out as a driver of adapted behaviour. Backflow preventers have been retrofitted particularly in **Remscheid**.

Emergency measures: In all three municipalities is *protecting the building against water penetration* the most common emergency measure followed by *pumping and mopping out water.* Elaborate measures, such as *dismantle or secure heating, electricals systems, firmly installed segments* or *securing of oil tanks and other hazardous substances* have been less often employed. Differences regarding the implementation of emergency measures among the three municipalities are small. Remscheid, solely, stands out with particular high count in *protecting the building against water penetration*.

4.2 Correlation analysis

The results of the correlation analysis are presented in Table 2 and Table 3. We looked for correlations between the number of precautionary measures and items concerning the drivers of adaptive behaviour defined by the PMT-PADM-hybrid model (Figure 1).

Drivers for implementing precautionary measures before the event: The count of precautionary measures installed before the event is positively correlated with items on self-efficacy and responsibility. These findings support the underlying hybrid PMT/PADM framework, where the basis for adaptive behaviour is defined as the appraisal of whether one can act to limit the effects of flooding and further whether one is responsible to do so in their self-perceived perceptions. Since we surveyed recently flooded people, it is more difficult to establish a link between their current threat appraisal and their behaviour before and during a flood event due to feedback loops between threat appraisals and the implementation of protective measures (Bubeck et al. 2012).

Drivers for implementing precautionary measures after the event: The count of precautionary measures after the event is positively correlated with items included in the categories of responsibility, response efficiency and risk awareness. This is in line with the hybrid PMT/PADM framework, where the appraisal of coping, threat and responsibility leads to adaptive behaviour if each is sufficiently high.

Emergency measures: The results of this correlation analysis are summarized in Table 3 for specific items and the count of the number of emergency measures employed. It has been found, that the count of emergency measures is correlated with responsibility.

Various correlations have been found between the count of emergency measures taken and reduction of damage and on-going inconveniences and impacts. This is a first indicator that the implementation of emergency measures reduces the impacts of pluvial flood events. However, more analysis is needed to delimit the effects of emergency measures of other actions taken.

We have not been able to detect any significant correlations between characteristics of the warning received (lead time, trustworthiness of the warning) and the implementation of emergency measures. However, the medium of how the warning had been received might have an influence on the implementation of emergency measures: A significant correlation was found between using television as a medium for the warning and the implementation of emergency measures. Further we found that the number of emergency measures is correlated with the degree a person still feels burdened by the flood event.

Drivers for adaptive behaviour: The correlation analysis shows that the hybrid PMT/PADM framework is potentially suitable to identity drivers for the implementation of precautionary measures: only if the appraisal of threat, coping and responsibility is sufficiently high, people are likely to develop a protection motivation as they deem themselves to be at risk, can successfully employ measures to limit this risk, and are socially required to do so. This can be seen from the aforementioned correlations presented. From these correlations, it stands out that perceived responsibility as an important driver of adaptive behaviour is missing in the PMT and is therefore one of the enhancements provided by the PADM to better understand adaptive behaviour.

However, we did not find any correlations between the implementation of precautionary measures and the reduction of damage, inundation or duration, unlike with emergency measures.

The number of precautionary measures before the event is not correlated with the number of emergency measures. The survey set up is not suitable to investigate the suitability of our hybrid PMT/PADM framework in the context of emergency measures. However, responsibility is a driver found for both, the implementation of precautionary and emergency measures, and can therefore been seen as an important driver for adaptive behaviour. By comparing the effects of both, emergency and precautionary measures, it stands out, that the count of emergency measures is correlated with the reduction of flood impact such as damage and inconveniences, while the count of precautionary measures does not show those correlations.

4.3. Regression analysis

The results of the correlation analysis show, that (a) the intensity of the flood, (b) self-efficacy, (c) responsibility, (d) risk-awareness and (c) being informed about precautionary measures are drivers for implementing precautionary measures. We further discussed the importance of motivate affected households to implement those measures. By setting up a regression analysis we aim to identify the most important driver out of those mentioned, by comparing their relative strengths. Further research has shown that flood experience affects flood mitigation behaviour (Bubeck et al. 2012). Therefore, we used the sum of precautionary measures implemented (a) before the event, (b) after the event and planned for the future and (c) planned for the future as dependent variable to take this into account. For each driver identified in the correlation analysis we selected the item with the highest correlation coefficient. Solely to represent *responsibility* we used the item that was found with correlation to both, implementation of precautionary measures before and after a flood.

We found that *being informed about precautionary measures* is here the most important driver, no matter which of those three dependent variables was used. This can be interpreted regarding to our hybrid PMT/PADM framework, where the absence of necessary information can be seen as an actual barrier of adaptive behaviour. Hence, it is likely that those barriers are the most important drivers of adaptive behaviour and must be tackled to bring an integrated flood risk management from theory to action.

5. Conclusion

We used a hybrid PMT/PADEM framework to identify drivers of adaptive behaviour on the basis of a household survey conducted in three German municipalities.

By comparing the count of precautionary and emergency measures among those three municipalities using descriptive analysis we found that the intensity of an event is increasing the number of precautionary measures after a flood occurred. We further found that high-cost precautionary measures and elaborate emergency measures are less often implemented.

By investigating correlations between the numbers of precautionary measures implemented before and after a flood with the potential drivers identified by our PMT/PADM-hybrid model we identified (a) self-efficacy, (b) responsibility, (c) risk-awareness and (d) being informed about precautionary measures as drivers for adaptive behaviour. Responsibility was further found to influence the implementation of emergency measures. The number of emergency measures undertaken in the event under study had a more significant influence on the reduction of flood impacts such as damage and inconveniences than the number of precautionary measures.

With a regression analysis we than identified being informed about precautionary measures as the most important driver for adaptive behaviour from those drivers we looked at. This is in line with our PMT-PADM-hybrid model, since the absence of necessary information can be seen as an actual barrier of adaptive behaviour.

Hence, the hybrid PMT/PADM framework is suitable to investigate and identify drivers of adaptive behaviour in the context of pluvial flooding. Regarding to an integrated flood risk management for pluvial flooding in urban areas it can be concluded, that people at risk need to be extensively informed about their risk and their options to cope. Furthermore, responsibilities regarding to adaptive behaviour in the case of pluvial flooding should be clearly defined and communicated.

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Emergency measures	Precautionary measures
Save documents and valuables	upstands (e.g. steps, walls)
Drive car to save place	Ground sills
Move furniture and/or movable objects up or to a safe place	Barrier systems and/or safety gates
Secure oil tanks and other hazardous substances	Driveways dropping in the direction of the streets
Pump or mop up water	Backflow preventer
Save animals	Pumps
protect building against inadvertent influx of water by e.g. sealing of doors or windows	Water and pressure resistant windows and/or doors
Divert water on the property	Window flaps and/or stationary or movable water barriers
Unplug electrical devices, mask sockets	Waterproof foundation
Dismantle or secure heating, electricals systems, firmly installed segments (e.g. doors…)	adapted use of the flood-prone floors
Turn off gas and electricity	adapted use
gas and electricity was turned off by the provider	Heating oil fuse
	insurance against damage caused by natural hazards
	planning and preparing measures for an emergency (e.g. building up stocks, create emergency response plans)

Table 1: Overview of emergency and precautionary measures used in the survey

	Remscheid	Potsdam	Leegebruch	Total
Number of participants	64	119	96	279
Participants [%]	23	43	34	100
Age [years]	57	49	56	53
Age Census2011 [years]	52	49	52	51 (DL)
Gender (m/f/d)	28/20/1	58/44/4	36/53/1	122/117/6
Gender (m/f/d) [%]	57/41/2	55/41/4	40/59/1	50/48/2
Gender (m/f/d) [%] Census2011	(48/52/-)	(47/53/-)	(49/51/-)	(48/52/-)
Number of homeowners	36	66	84	185
Homeowners [%] per subsample	68	60	90	72

Table 2: Demographic information of participants

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No.	X	Scale	category	Correlation coefficient with number of measures implemented before flooding
1	„I personally will do everything possible to protect my house against pluvial flooding“	1 (full agreement) to 6 (no agreement)	Res	-0.155*
2	Post-Traumatic Stress number of Indicator values larger than four	6 (burdened) to 0 (no burden)	PI	0.364**
3	How burdened you were by: repair work	1 (no burden) to 6 (very burdened)	PI	-0.211**
4	How burdened you were by: Loss of things you are personally attached to, e.g. Memorabilia	1 (no burden) to 6 (very burden)	PI	-0.210**
5	How burdened you were by: Damage to sewage system	1 (no burden) to 6 (very burden)	PI	-0.212**
6	How burdened you were by: Damage to content	1 (no burden) to 6 (very burden)	PI	-0.312**
7	How burdened you were by: Damage to building structure	1 (no burden) to 6 (very burden)	PI	-0.293**
8	How burdened you were by: Other financial damages, e.g. due to damage to outdoor facilities	1 (no burden) to 6 (very burden)	PI	-0.211**
9	How burdened you were by: Mental health problems, e.g. Stress, worry, grief or other	1 (no burden) to 6 (very burden)	PI	-0.233**
10	How much of a burden do you have from the last heavy rain event today?	1 (I feel like before) to 6 (burdened)	PI	0.346**
11	Damage content	€	RR	-0.322**
12	Damage building structure	€	RR	-0.280**

Table 3: Results of a correlation analysis between the count of implemented emergency measures and items (Res: Responsibility, PI: Perceived impact, RR: Risk Reduction; significance of correlation: *: 0.05 (two-tailed), **:0.01 (two-tailed).

No.		*Scale*	*category*	*Count measures before*	*Count measures after*
1	„I personally don't feel able to install any measure."	*1 (I fully agree) to 6 (I disagree)*	*SE*	*0.180***	---
2	„There is generally nothing you can do about heavy rain and the damage it causes."	*1 (I fully agree) to 6 (I disagree)*	*SE*	*0.159**	---
3	„Since the state comes up in the event of a flood, it is not worthwhile to make private provision."	*1 (I fully agree) to 6 (I disagree)*	*Res*	*0.155**	---
4	„Everyone is obliged to prevent damage caused by heavy rain."	*1 (I fully agree) to 6 (I disagree)*	*Res*	*-0.186***	---
5	„I personally will do everything possible to protect my house against flooding."	*1 (I fully agree) to 6 (I disagree)*	*Res*	*-0.161**	*-0.201***
6	„The flood management in our region is so good that I do not have to make private provisions.*"*	*1 (I fully agree) to 6 (I disagree)*	*RE*	---	*0.236***
7	„If you now take the effectiveness of all preventive measures together, how much the damage could be reduced*? "*	*1 (measure did not reduce impact) to 4 (measures completely reduced impact)*	*RE*	---	*-0.202***
8	„It won't be as bad as last time. *"*	*1 (I fully agree) to 6 (I disagree)*	*RA*	---	*-0.160**
9	*Intensity of the event (derived from flood inundation and duration)*	*0 (low intensity) to 1(high intensity)*	*RA*	---	*0.220***
10	*Has the ground floor been flooded?*	*0 = no water in ground floor, 1= water in ground floor*	*EF*	*-0.165**	---
11	How much of a burden from the last heavy rain event do you still feel today?	*1 (I feel like before) to 6 (I feel very burdened)*	*EF*	*-0.179***	---

Table 4: Results of a correlation analysis between (1) the count of implemented precautionary measures before flooding and (2) the count of precautionary measures implemented after flooding with items related to (a) SE= Self- efficacy, (b) Res = Responsibility, (c) RA = Risk Awareness, (d) BI = Being informed; RE = Response efficiency, EF = Effects (Significance: *: 0.05 (two-tailed), **:0.01 (two-tailed).

		Regression coefficients (p-values)		
Depending variable	No. of item (compare Table 4)	precaution before event	precaution implemented or planned after event	planned precaution
SE	1	0.185 (0.096)	-0.051 (0.080)	-0.068 (0.056)
Res	6	-0.190 (0.109)	-0.214** (0.090)	-0.086 (0.062)
RA	9	0.098 (0.087)	-0.158* (0.072)	0.024 (0.046)
BI	---	-0.397 (0.420)	-0.531 (0.328)	-0.563** (0.162)
RE	7	-0.106 (0.106)	0.416** (0.088)	0.166** (0.059)
constant	---	2.353	0.946	0.434
Number of cases	---	230	226	230

Table 5: Results of the regression analysis, depending variables are (1) count of precautionary measures installed before the event, (2) count of precautionary measures installed after the event and precautionary measures planned, (3) count of precautionary measures planned; variables are the items with the highest correlation coefficient within the subcategories to (a) SE= Self-efficiency, (b) Res = Responsibility, (c) RA = Risk Awareness, (d) BI = *Being informed about precautionary* measures; RE = Response efficiency (see Table 3 for the items); (Significance: *: 0.05 (two-tailed), **:0.01 (two-tailed)