Changing Susceptibility of Flood-prone Residents in Germany

Mental Coping and Mitigation Behaviour in the Context of Different Flood Types

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Abstract

Floods are among the most costly natural hazards that affect Europe and Germany, demanding a continuous adaptation of flood risk management. While social and economic development in recent years altered the flood risk patterns mainly with regard to an increase in flood exposure, different flood events are further expected to increase in frequency and severity in certain European regions due to climate change. As a result of recent major flood events in Germany, the German flood risk management shifted to more integrated approaches that include private precaution and preparation to reduce the damage on exposed assets. Yet, detailed insights into the preparedness decisions of flood-prone households remain scarce, especially in connection to mental impacts and individual coping strategies after being affected by different flood types.

This thesis aims to gain insights into flash floods as a costly hazard in certain German regions and compares the damage driving factors to the damage driving factors of river floods. Furthermore, psychological impacts as well as the effects on coping and mitigation behaviour of flood-affected households are assessed. In this context, psychological models such as the Protection Motivation Theory (PMT) and methods such as regressions and Bayesian statistics are used to evaluate influencing factors on the mental coping after an event and to identify psychological variables that are connected to intended private flood mitigation. The database consists of surveys that were conducted among affected households after major river floods in 2013 and flash floods in 2016.

The main conclusions that can be drawn from this thesis reveal that the damage patterns and damage driving factors of strong flash floods differ significantly from those of river floods due to a rapid flow origination process, higher flow velocities and flow forces. However, the effects on mental coping of people that have been affected by flood events appear to be weakly influenced by different flood types, but yet show a coherence to the event severity, where often thinking of the respective event is pronounced and also connected to a higher mitigation motivation. The mental coping and preparation after floods is further influenced by a good information provision and a social environment, which encourages a positive attitude towards private mitigation.

As an overall recommendation, approaches for an integrated flood risk management in Germany should be followed that also take flash floods into account and consider psychological characteristics of affected households to support and promote private flood mitigation. Targeted information campaigns that concern coping options and discuss current flood risks are important to better prepare for future flood hazards in Germany.

Zusammenfassung

Hochwasser zählen zu den schadensträchtigsten Naturgefahren, die in Europa und Deutschland vorkommen. In Deutschland traten in den letzten Jahren einige sehr starke Hochwasser und Überflutungen auf, die die Einstufung von Hochwassern als gefährliche Naturgewalt bestätigten. Private Haushalte leiden unter finanziellen und persönlichen Verlusten und sind sogar teilweise mehrfach betroffen. Folgenreiche Hochwasser, die im Gedächtnis blieben, waren insbesondere das Elbe-Hochwasser im Sommer 2002 sowie Überschwemmungen mit Schwerpukten an Elbe und Donau im Juni 2013. Im Mai und Juni 2016 kam es zu heftigen Unwettern über Zentraleuropa, während insbesondere Süddeutschland von Starkregen und Sturzfluten betroffen war. Hierbei wurden vereinzelte Ortschaften in Baden-Württtemberg (vor allem Braunsbach) und Bayern (vor allem Simbach am Inn) von extremen Sturzfluten beeinträchtigt und Bauwerke stark beschädigt.

Als Reaktion auf die Flusshochwasser 2002 und 2013 wurde unter anderem das aktuelle Hochwasserrisikomanagement in Deutschland so angepasst, dass neben übergeordneten und technischen Hochwasserschutzmaßnahmen auch auf lokaler Ebene Maßnahmen ergriffen werden müssen. Diese umfassen Hochwasservorsorgemaßnahmen, die betroffene Haushalte selbst implementieren sollen. Neben strukturellen Maßnahmen wie z.B. der Verlegung von Heizung, Elektronik und Öltank in nicht-gefährdete Stockwerke sowie dem Schutz des Gebäudes vor Eindringen von Wasser, können auch nichtstrukturelle Maßnahmen, wie z.B. eine angepasste Wohnraumnutzung und das Verwenden von geeigneter Inneneinrichtung, ergriffen werden, um Hochwasserschäden signifikant zu verringern. Bis heute ist es jedoch unklar, aus welchen Gründen sich die betroffenen Menschen für Hochwasservorsorgemaßnahmen entscheiden und wie die individuelle Motivation, Maßnahmen zu implementieren, verstärkt werden kann. Neben dem Wissen um die eigene Hochwassergefährdung ist anzunehmen, dass die Selbsteinschätzung in Bezug auf einen wirksamen Umgang mit Hochwassern ausschlaggebend für die Motivation zur Vorsorge ist. Außerdem kann davon ausgegangen werden, dass verschiedene Hochwassertypen wie Flusshochwasser und Sturzfluten mit ihren unterschiedlichen Dynamiken unterschiedliche Auswirkungen auf die mentale Bewältigung und somit auch auf das Vorsorgeverhalten hervorrufen.

Die vorliegende Arbeit hat demnach zum Ziel, Flusshochwasser und Sturzfluten in Deutschland miteinander zu vergleichen, wobei der Fokus auf schadenstreibenden Faktoren und psychologischen Auswirkungen auf betroffene Haushalte liegt. Weiterhin sollen damit verbundenes Vorsorgeverhalten untersucht und gegebenenfalls Handlungsempfehlungen für das Hochwasserrisikomanagement abgeleitet werden, das einerseits psychologische Charakteristika und andererseits Sturzfluten als signifikante Naturgefahr in Deutschland miteinbezieht. Hierbei werden sozio-ökonomische, zwischenmenschliche und psychologische Variablen von Haushalten ausgewertet, die 2013 und 2016 von Flusshochwassern und Sturzfluten betroffen waren. Dabei kommen verschiedene Methoden (Regressionen, Bayessche Statistik) und Modelle (Protection Motivation Theory) zum Einsatz, um Verbindungen zwischen den Variablen aufzeigen.

Die Ergebnisse veranschaulichen erstens, dass Flusshochwasser und Sturzfluten zwar unterschiedliche Schäden an Gebäuden aufgrund verschiedener Flutdynamiken hervorrufen können, was sich bei Betroffenen jedoch nicht in unterschiedlichen psychologischen Auswirkungen widerspiegelt.

Vielmehr ist die jeweilige Stärke und Schwere des Hochwassers entscheidend für charakteristische Ausprägungen von psychologischen Variablen. In diesem Falle sorgt eine stärkere Flut dafür, dass häufiger an das jeweilige Ereignis gedacht wird, während die Motivation zur Eigenvorsorge in solchen Fällen erhöht scheint. Zweitens sind ein soziales Umfeld, in dem bereits Vorsorgemaßnahmen implementiert wurden, sowie hilfreiche Informationen für geeignete Maßnahmen, deren Kosten und Aufklärung über das aktuelle Hochwasserrisiko förderlich für die Motivation, private Vorsorge zu betreiben.

Ein aktuelles Hochwasserrisikomanagement sollte demnach auch Sturzfluten als mögliches Risiko in Deutschland miteinbeziehen und mehr in die Aufklärung und private Unterstützung bei Hochwassern investieren. Ein besseres Verstehen von psychologischen und mentalen Auswirkungen von verschiedenen Hochwassertypen hat den Vorteil, dass Hilfe und Informationskampagnen individuell und effizient gestaltet, Schäden minimiert und Schadensprognosen aufgrund der genaueren Kenntnisse über Vorsorgeverhalten verbessert werden können.

1 Introduction

1.1 Background and problem definition

Worldwide demographic development, land use change and residential as well as economic expansion into disaster prone areas have led to an overall greater exposure to natural hazards. The severity and frequency of extreme weather events are expected to increase further due to climate change, implying an alteration of risk patterns in affected regions (IPCC, 2012; IPCC, 2014; European Environment Agency, 2017). In the last decades, remarkable efforts have been made to reduce risk and to mitigate direct and indirect damage, framed by international agreements such as the Hyogo Framework for Action 2005-2015 (UNISDR, 2007) and the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2015a,), yet natural disasters are increasingly burdening societies around the globe with widespread economic and social impacts.

Among worldwide natural disasters, flooding represents one of the most costly hazards in economic terms. Especially in recent years, floods simultaneously occurring with storms and hurricanes have been responsible for damages which amounted up to billions of US$ while in 2017, only 41% of overall worldwide losses have been insured. (Munich Re, 2018). In Europe, almost 1500 flood events were recorded between 1980 and 2015, of which 120 events exceeded economic losses of €100 million (EEA, 2017). Only few of the most recent and significant events include the strong winter floods in 2014 in the UK as well as the German river floods in 2002 and 2013 which resulted in 35 fatalities and economic losses of £1.3 billion (EA, 2016), €11.6 billion and €6 to €8 billion, respectively (Thieken et al., 2007; Thieken et al., 2016a).

Floods and strong weather events are potentially enhanced by climate change and are generally expected to increase in frequency and severity in Central Europe. Differences in regional and local climate may lead to variations in local hazards, yet it is expected that a larger overall warming increases the exposure of Southern, Western, Central, Eastern and Northern Europe. (Beniston et al., 2007; Murawski et al., 2015; Forzieri et al., 2016).

Given the diverse European geography, unique settlement patterns and distinct orographic features, different European regions may experience different flood types (i.e. river floods, coastal floods, pluvial flooding and flash floods), of which potential changes in frequency, magnitude and impacts are currently investigated (Kundzewicz et al., 2017, Rözer et al., 2016). In addition to the changing hazard, settlement and economic development inside European flood-prone areas increase the amount and value of the exposed elements and therefore the chance for experiencing economic losses as well as pronounced social impacts (Bouwer, 2011; IPCC, 2012; Fuchs et al., 2013; Alfieri et al., 2016). In 1971 for example, the potential loss of residential assets in the Alpine Lech valley (Austria) amounted only to one-half when compared to 2006, given an annual economic growth rate of 3 per cent (Cammerer et al., 2013). Accordingly, the persistent European flood risk management requires an integrated and constantly updated approach that accounts for changes and development.

On a superior level, the flood risk management in Europe is framed by the European Floods Directive (2007/60/EC) which requires member states to follow a three-step process every six years. First, a preliminary flood risk assessment has to be carried out to identify potential flood risk areas, considering the relevant flood types within the particular member state. In a second phase, flood hazard and flood risk maps have to be created for areas with significant risk. Mandatory are maps with a 100 year flood and a more extreme scenario (more frequent events are voluntary). In addition, it is required that not only the flood extent, but also the inundation depth is shown in the hazard maps. The last step involves the establishment of appropriate flood risk management plans (BMUB, 2007)

In Germany, these regulations have been translated into national legislatives within the German Federal Water Act ("Wasserhaushaltsgesetz"), while the federal states are responsible to meet the obligations (BMJV, 2009). In the recent years, particularly after the severe German river flood of 2002, the focus of flood risk management shifted from mostly technically-oriented (structural) flood protection strategies towards integrated approaches that facilitate risk awareness, flood prevention and alleviation. An integrated flood risk management aims to extend already existing flood protection by involving stakeholders also on local level, considering non-structural measures as an option for flood mitigation (Bubeck et al., 2012a; Hartmann & Albrecht, 2014; Kienzler et al., 2015a; Thieken et al., 2016b). Particularly, changes in the German Federal Water Act ("Wasserhaushaltsgesetz") that have been introduced in 2005 demand flood-prone households to protect themselves in a reasonable manner, leaving the people with several options for private flood mitigation measures in terms of precaution and preparation.

In this context, private precaution comprises several strategies. Buildings can be secured by installing water barriers, elevate structures and improve the flood safety on the property. Dry-proofing aims to seal the building fully against water which requires the use of adequate building materials such as non-permeable concrete and internal drainage systems. Wet-proofing allows water entry into the building while potential damage is prevented by a flood-adapted use, resistant materials and interior fitting. Further securing can be achieved by e.g. safeguarding hazardous materials, avoiding water exposure (Kreibich et al., 2005; Gersonius & Zevenbergen, 2008; Kreibich et al., 2011a). Among these strategies, private precaution measures can be further categorised into structural and non-structural precaution with each distinct features and effects. Kreibich et al. (2005) revealed that structural precaution measures such as waterproof sealed cellars, relocation of heating and electrical utilities reduce the mean damage ratios of buildings by 24%, 53% and 36%, respectively. Non-structural measures, i.e. flood adapted use and adapted interior fitting can reduce the building damage by 46% but also show damage reducing effects on building contents between 48% and 53% (Kreibich et al., 2005) or, according to Hudson et al. (2014), EUR 6700 and EUR 5200 in absolute values. In addition to precaution measures, ad-hoc and emergency measures can be undertaken to help mitigating personal losses by safeguarding documents and personal valuables, turning off electricity, using sandbags, mobile water barriers and pumps as well as staying safe. However, emergency measures also require an early flood warning and general preparedness. In recent years, risk transfer instruments such as insurance gained attention as a meaningful preparation to complement flood protection measures due to an overall increased flood risk awareness (Bubeck et al., 2012a).

Commonly, effective preparation implies a good knowledge about flood risk and coping options. The identification of adequate ways and channels for a stimulating information provision still remains an important and improvable task, since evidence suggests that, in many cases, people even do not know that they live in risk-prone areas and how to prepare themselves in a proper way. (Kreibich et al., 2005; Kreibich et al., 2011b; Lazrus et al., 2016). Moreover, insurance purchasing and further mitigation options are often not undertaken voluntarily (Kunreuther, 1996). Besides the fact that private flood precaution measures can significantly lower the flood damage and play an important role in integrated flood management, the effectiveness of targeted information campaigns and assistance is often unknown. One reason is that it is not yet fully understood which factors influence the individual protective behaviour and to which degree the protection motivation can be facilitated (Bubeck et al., 2013; Bubeck et al., 2018). In general, risk awareness and even lower damage in case of a flood event are strongly connected to prior flood experience, yet experience and knowledge do not fully explain decisions for preparedness and precaution. Therefore, the use of models and assessments that analyse the decision making process is highlighted (Grothmann & Reusswig, 2006; Thieken et al., 2007, Kreibich et al., 2011a).

In summary it can be said that Central Europe is affected by various flood hazards that potentially increase in severity and frequency while the flood risk management aims to make up for constant changes. Against this background, questions arise if the German flood risk management is on the one hand well prepared with regard to changing hazards and on the other hand adequately facilitates the individual mitigation behaviour as a part of an integrated risk management strategy.

It has been pointed out that, among others, a key element of robust flood risk management is to reduce the susceptibility and increase the resilience of flood-prone households through private preparation and precaution (Thieken et al., 2007; Merz et al., 2010a; Kreibich et al., 2011a). Accordingly, this thesis investigates the individual protective behaviour of affected individuals in the light of two different flood types that exist in Germany (i.e. flash floods and river floods) and analyses these flood types with regard to their dynamics and damage driving factors. In the next sections, the current research gaps are described while the following two aspects were particularly important:

First, Germany suffers from various flood types each showing different flood dynamics. Besides regions that experienced severe river floods, German cities (e.g. Hersbruck and Lohmar in 2005, Osnabrück in 2010, Münster in 2014 or Potsdam and Berlin in 2017) were affected by pluvial floods while other cities (e.g. Braunsbach and Simbach am Inn in 2016) were confronted with heavy flash floods. (e.g. Rözer et al., 2016; Bronstert et al., 2017). River floods in Germany emerge as a consequence of various interacting factors. Long-lasting rainfall and/or snowmelt within a large catchment area combined with saturated soils may lead to high surface and groundwater run-off, resulting in slow-rising water levels of receiving waters (Becker et al., 2014). The forecast lead time of riverine floods is usually long, i.e. up to several days, offering the chance for timely reaction and preparation in case of extreme events. In contrast, flash floods are triggered by intense and concentrated precipitation within a small catchment that facilitates strong surface runoff and flow accumulation by distinct orographic features (Gaume et al., 2009; Borga et al., 2014). Accordingly, flash floods are common in mountainous regions and often accompanied by a large amount of suspended material. If the amount of transported and suspended sediments ranges between 60 and 80 volume per cent, the event is denoted as a debris flow (Pierson & Costa, 1987; Gaume et al., 2009; Totschnig et al., 2011; Hungr et al., 2013; Borga et al., 2014). These potentially rough flood dynamics leave people at risk with very short lead time to prepare and take any kind of emergency precaution.

Compared to river floods, flash floods and debris flows are thus associated with a higher number of fatalities (Gaume et al., 2009). Pluvial floods, on the other hand, are characterised by overflowing sewer systems and blocked water discharge after heavy rainfall and describe a costly hazard related to urban areas (Maksimovič et al., 2009).

Other than pluvial floods and river floods, the dynamics of heavy flash floods represent, particularly in Central Germany, a rather unfamiliar flood event. As flash floods can have rapid onsets with high flow velocities and high load of suspended material, distinct damage patterns that vary from those of pluvial floods and river floods may be expected. Countries in alpine regions such as Switzerland, Austria and northern Italy have greater experience with flash floods as well as debris flows, which is reflected by the fact that forecast techniques, warnings, risks, damage driving factors and dynamics are thoroughly investigated (Blöschl et al., 2008; Fuchs et al., 2012, Fuchs et al., 2013). In Germany, however, potential risks of pluvial and flash floods are still underinvestigated outside alpine regions and not yet considered when implementing the Floods Directive. It can be assumed that the demands on risk management are clearly shifted with regard to the preparation and structural protection in comparison to river floods, since each flood type shows distinct origination processes and flow dynamics, leading to different impacts on exposed assets. Thus, potential damage driving factors of flash floods in particular need to be better understood in order to introduce adequate courses of action in future.

Second, private flood precaution measures play a significant role in flood damage mitigation, yet it has been revealed that many hazard-prone households are not well prepared for floods (Kreibich et al., 2005, Thieken et al., 2008; Kienzler et al., 2015a; Kreibich et al., 2017). However, knowing the state of the individual protection as well as the protection motivation is crucial for an improved flood risk management, since the rationale behind an integrated management approach follows the idea of a dynamic adaptation and continuous development. In this context, different perceptions of risk and threat interact with individual coping abilities and character traits and are thus expected to influence the actual implementation of private flood precaution. A large body of literature mainly focused on socio-economic factors and the perception of risk in order to understand the decision making among households that are affected by natural hazards and floods (Perry & Lindell, 2008; Lindell et al., 2009). Perceived risk, which refers to the combination of perceived flood probability and the perceived severity of consequences, has been therefore investigated as one of the most relevant aspects to understand precautionary behaviour. Here it has been revealed that high risk perceptions usually promote the intention to invest in flood mitigation measures. (Botzen et al., 2009a; Botzen & Van Den Bergh, 2012; Zaalberg et al., 2009).

However, several studies also revealed that information about risk perceptions and certain socio economic variables do not necessarily explain the individual protection motivation, which favoured the use of psychological models in that regard (Grothmann & Reusswig, 2006; Baan and Klijn, 2004; Perry & Lindell, 2008; Bubeck et al., 2012a; Morss et al., 2016). A popular theory to explain the risk-reducing behaviour in the context of natural hazards and floods is the protection motivation theory (PMT), which has been introduced by Rogers in 1975 and originated from the health sector. In recent years, the PMT gained attention to understand the cognitive process that people undergo when they are faced with a threat, focusing on the aspects of "coping appraisal" and "threat appraisal" (Grothmann & Reusswig, 2006; Bubeck et al., 2013; Eriksson, 2017). Here, coping appraisal consists of the perceived self-efficacy (feeling able to implement a measure), response efficacy (perceived effectiveness of a measure) and response cost (cost of a measure) while threat appraisal comprises the perceived probability of an event and the expected severity. High coping and threat appraisals encourage protective actions while avoidant and fatalistic thoughts are associated to a lack of protection motivation and thus maladaptive behaviour. In detail, coping appraisals have been identified to be even more important than the perceived threat to comprehend people's protective decisions, also because already implemented precaution measures may affect threat appraisals negatively and thus lead to a bias (Bubeck et al., 2012a; Koerth et al., 2013; Wachinger et al., 2013; Poussin et al., 2014). Yet, specific factors that influence coping appraisals are still unknown and further connections to interpersonal variables remain unclear. A better knowledge of such influencing factors however would strongly benefit the understanding of general protective decisions and could indicate efficient strategies to support flood-prone households.

Apart from the PMT, other methods such as the Impact of Event Scale - Revised (IES-R) (i.e. a survey including a catalogue of specific questions) have been used for psychological assessments to gain better insights into mental impacts and behavioural aspects after natural hazards and floods (Creamer et al., 2003). Evidence suggests that, among others, up to one third of flood-affected people may show signs of the post-traumatic stress disorder (PTSD) accompanied by depression and anxiety while personal losses and high stress further amplify negative mental effects (Mason et al., 2010; Bei et al., 2013). Still, assessments of mental impacts that are caused by different flood types remain scarce although they may contribute to the knowledge of individual protective decisions. In addition to a better understanding of flood-coping appraisals, detailed psychological assessments and their connection to precaution motivation are thus needed to draw a detailed picture of different flood types, their mental impacts and future mitigation behaviour of affected people.

After all, research continues to reveal insights into the decision making of flood-affected residents to protect themselves by shifting more and more to approaches that include psychological and behavioural assessments. External factors such as flood strength, severity and duration as well as personal experience and coping abilities are known to influence future protective actions. Yet, detailed coherences remain unclear, especially concerning different flood hazards in Germany. A better knowledge of such coherences however facilitates an integrated flood risk management and supports affected households with their mental and physical coping.

1.2 Research questions

According to the main aspects expressed in section 1.1, this thesis examines flood-prone households given recent major flood events in Central Europe and particularly Germany. Hereby, the focus lies on the damage patterns that are caused by a severe flash flood in 2016, the difference to river floods as well as the difference in psychological impacts caused by both, river floods, flash floods and pluvial floods. Further, connections of mental characteristics to the precaution motivation and potential implications on flood risk communication and management are identified. In that regard, this thesis analyses the following three research questions:

1. In the context of the PMT, what are the influencing factors on coping appraisals and the related mitigation behaviour of flood-affected individuals? Moreover, do further personality characteristics influence the self-reported ability to take protective actions?

2. What are the damage driving factors of flash floods in Germany and how do they compare to the damage driving factors of river floods? Are there potential implications for national and local risk management?

3. Do different flood types such as river floods and flash floods in Germany induce different psychological responses and do they impact the perceived coping of affected individuals in various ways? Further, are certain psychological characteristics connected to the protection motivation?

The answers to these questions provide evidence for the further development of an integrated flood risk management in Germany that takes different flood hazards as well as private precaution better into account (see section 1.4, Figure 1-1).

1.3 Data and methods

The data which is used as a basis for answering the research question 1 consists of standardized surveys that were conducted as computer-aided telephone interviews (CATI) in 2011 along the Rhine River in Germany and flood-prone regions in France (Bubeck et al., 2012b; Poussin et al., 2014). Further surveys that help answer research question 1 and 3 were carried out after the major river flood of 2013 in Germany (Thieken et al., 2016a) and flash flood events of 2016 in Southern German regions. Those flood events each stood out in terms of severity and monetary losses related to their intrinsic dynamics and properties and are described in greater detail in chapter 4. The telephone surveys comprise questions that were designed to monitor and explain building damage and losses caused by the respective flood event. Besides information about the building itself, the data includes socio-economic characteristics of residents and personal attitudes towards precaution, perceptions of risk, flood experience and questions about psychological behaviour and mental impacts that are, among others, included in the framework of the PMT. The applied surveys and the PMT are thoroughly described in chapter 2 and 4.

To answer research question 2, data is used which was collected in the field, 9 to 10 days after the heavy flash flood of 29 May 2016 in Braunsbach, a small Southern German municipality. The data comprises information about the building damage, estimated inundation depth, building surroundings and contamination as well as precaution levels. The flood event and data collection are described in detail in chapter 3.

As a result of the different survey questions which were designed to cover a broad range of research such as the evaluation of private precaution levels, loss calculations and psychological assessments, it has to be accounted for various data scales (i.e. nominal, ordinal, and interval scaled data). Different data scales demand the use of adequate methods for analysis, since a particular method is only suitable if certain prerequisites are given. Among the surveys that are used, the data consists mostly of self-reported ordinal ratings between 1 and 6. Thus, non-linear methods such as Spearman's Rho correlations, random forests and multinomial regressions are applied. Further applied methods include ordered logit regression models, principle component analysis, cluster analysis, Dunn's test and Bayesian statistics. Table 1-1 in section 1.4 gives a short overview of the used data and methods, connected to the research questions.

1.4 Outline of the thesis

This thesis is structured in five chapters including an introduction and synthesis section. Chapter 1 describes the background and research topic by also embedding the thesis into the current research. Chapter 2 elaborates the PMT and focuses on aspects of coping appraisal, namely self-efficacy, response efficacy and response cost of flood-affected households in Germany and France, which differ in flood experience. Hereby, a key element is to support the idea of coping appraisal being a good predictor of protection motivation itself while revealing socio-economic and other factors that show an influence on coping appraisal (research question 1). Chapter 3 presents a case study of a heavy flash flood event in Braunsbach, Germany. In this chapter, the main difference in damage driving factors between river floods and flash floods is pointed out while the dynamics of both flood typed are compared. Conclusions are drawn with regard to potential implications on future flood risk management (research question 2). Chapter 4 focuses on the comparison of psychological impacts of river floods and flash floods. In this chapter, psychological characteristics are compared among individuals who were affected by different flood types, i.e. river floods, weak flash floods/pluvial floods and severe flash floods, while conclusions are drawn with regard to the relationship of psychological impacts and individual precaution motivation (research questions 1 and 3). Chapter 5 includes a synthesis of the scientific approaches, methods and results of this thesis and formulates recommendations for future research. A general outlook on the topic and potential challenges in data collection and analysis are given. Table 1-1 describes the structure of the thesis with regard to the methods and data. Figure 1-1 illustrates the outline of the thesis in the overall research context.

Table 1-1 Structure and outline of the thesis, applied data and methods per chapter

	Chapter 2	Chapter 3	Chapter 4
Used data	Surveys conducted 2011 in flood-prone regions in Germany and France	Data collected in-field, 9 to 10 days after the heavy flash flood in Braunsbach Germany, 2016	Surveys conducted both around 9 months after the river floods 2013 and heavy rainfalls 2016 in Germany
Applied methods	A, B	A, C	A, D
Treated research questions	1	2	1, 3

A = Correlation, Linear regression,
B = Cluster analysis, Principle component analysis
C = Multinomial regression, Random Forest
D = Bayesian Statistics, Dunn's test

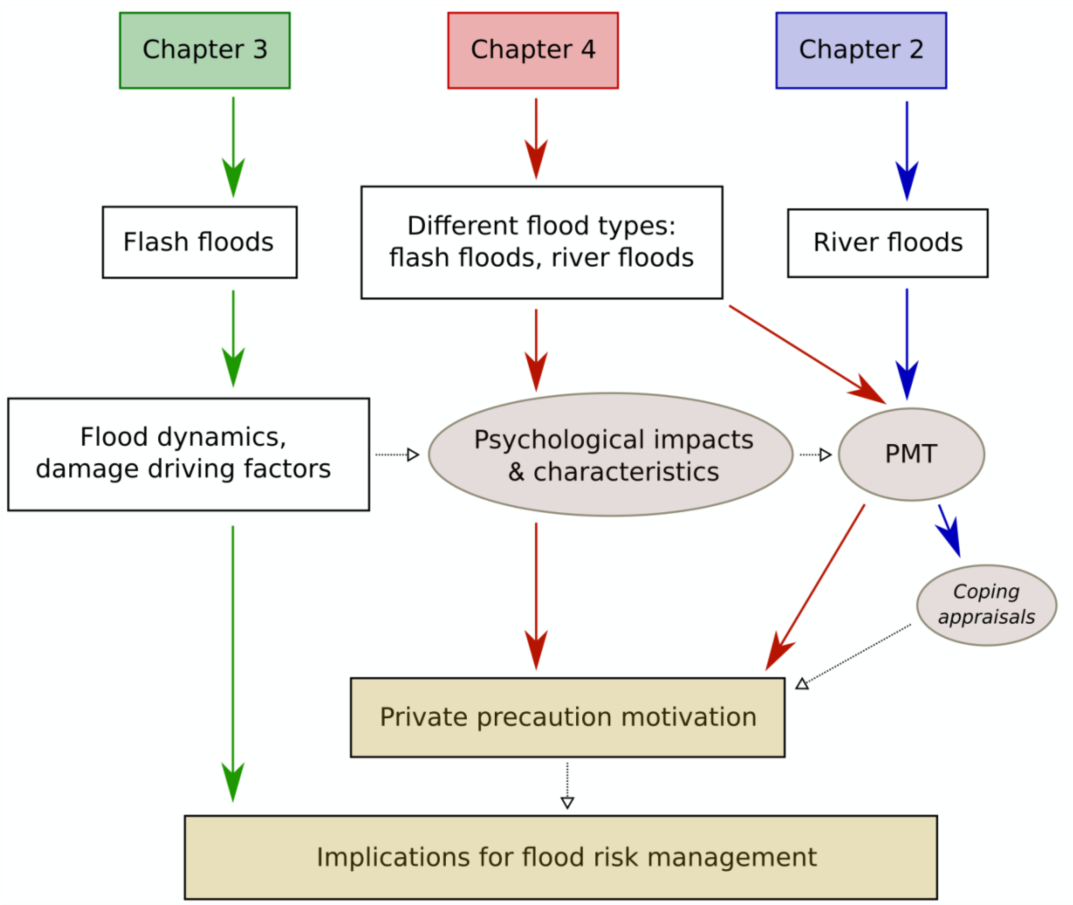

Figure 1-1 Outline of the thesis and connection between the research topics. The dashed arrows represent connections and dependencies which are additionally important in the overall context

2 Insights into Flood-Coping Appraisals of Protection Motivation Theory: Empirical Evidence from Germany and France

Abstract

Protection motivation theory (PMT) has become a popular theory to explain the risk-reducing behaviour of residents against natural hazards. PMT captures the two main cognitive processes that individuals undergo when faced with a threat, namely, threat appraisal and coping appraisal. The latter describes the evaluation of possible response measures that may reduce or avert the perceived threat. Although the coping appraisal component of PMT was found to be a better predictor of protective intentions and behaviour, little is known about the factors that influence individuals' coping appraisals of natural hazards. More insight into flood-coping appraisals of PMT, therefore, are needed to better understand the decision making process of individuals and to develop effective risk communication strategies. This study presents the results of two surveys among more than 1,600 flood-prone households in Germany and France. Five hypotheses were tested using multivariate statistics regarding factors related to flood-coping appraisals, which were derived from the PMT framework, related literature, and the literature on social vulnerability. We found that socioeconomic characteristics alone are not sufficient to explain flood-coping appraisals. Particularly, observational learning from the social environment, such as friends and neighbours, is positively related to flood-coping appraisals. This suggests that social norms and networks play an important role in flood-preparedness decisions. Providing risk and coping information can also have a positive effect. Given the strong positive influence of the social environment on flood-coping appraisals, future research should investigate how risk communication can be enhanced by making use of the observed social norms and network effects.

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2.1 Introduction

In recent years, protection motivation theory (PMT) has become a popular theory to explain the risk-reducing behaviour of residents and farmers against natural hazards (Grothmmann & Reusswig, 2006; Bubeck et al., 2012a; Bubeck et al., 2013; Koerth et al., 2013; Poussin et al., 2014; Bockarjova & Steg, 2014; van Duinen et al., 2015; Gebrehiwot & van der Veen, 2015; Haer et al., 2016; Keshavarz & Karami, 2016; Zheng & Dallimer, 2016; Eriksson, 2017). PMT was originally developed in the 1970s to explain health-related behaviour (Rogers, 1975; Floyd et al., 2000; Milne et al., 2000) and has recently seen a revival in the natural hazard domain due to its good explanatory power (Grothmmann & Reusswig, 2006; Bubeck et al., 2013). The growing interest in the decision making of individuals in response to natural hazards stems from the continuously high losses caused by natural hazards (UNISDR, 2015b) and the related shift to more integrated risk management concepts in many countries (Bubeck et al., 2017; Kreibich et al., 2015). The latter include a more comprehensive approach to natural hazard management, and a focus not only on protection against natural hazards, but also on reducing exposure, lowering vulnerability, and managing residual risks. This requires all stakeholders to contribute to risk reduction, including residents.

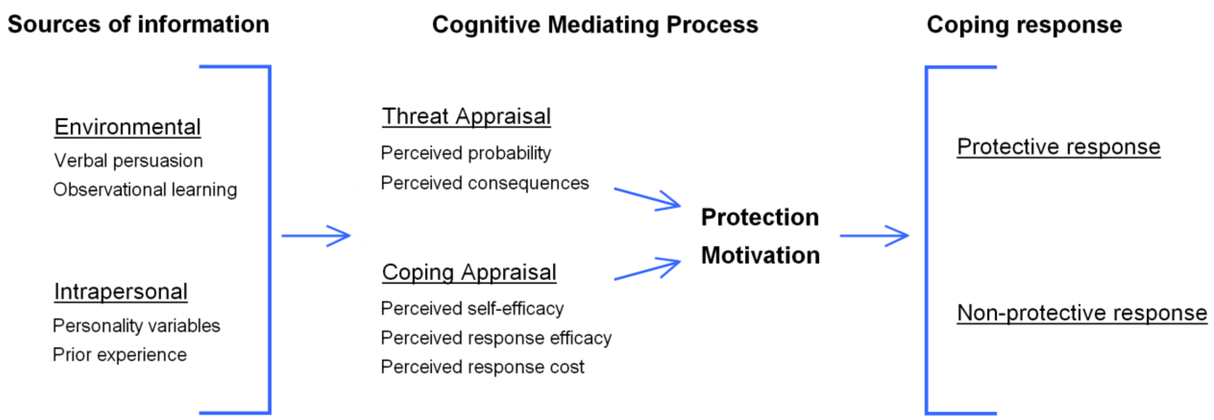

Figure 2-1 A schematic overview of protection motivation theory (adapted from Rogers & Prentice-Dunn, 1997)

According to PMT, the decision of individuals to engage in a protective or nonprotective response is driven by two main cognitive processes, namely, threat appraisal and coping appraisal (Rogers & Prentice-Dunn, 1997). Threat appraisal comprises the two variables of the perceived probability and perceived consequences that an individual associates with a certain hazard. Threat appraisal is, therefore, also referred to as "risk perception" (Grothmann & Reusswig, 2006). Once a certain threshold of threat appraisal is exceeded, contemplation of taking possible response measures to reduce or avert the threat begins, which is referred to as "coping appraisal." Coping appraisal consists of three variables: namely, the perceived effectiveness of a certain measure (response efficacy), the perceived ability to implement the respective measure (self-efficacy), and the perceived costs associated with its implementation (response cost). Note that, according to PMT, the response cost not only reflects financial costs but also the time and emotional effort needed to implement the measure.

The interplay of threat and coping appraisal influences protection motivation, which is considered as an intervening variable that "arouses, sustains, and directs the activity of individuals to protect the self from danger" (Maddux & Rogers, 1983). If high perceived risks are accompanied by high coping appraisals, this can lead to the adoption of a protective response intended to reduce the risk, such as flood-proofing a building. If high perceived risks are accompanied by low coping appraisals, it can result in nonprotective responses, such as fatalism, denial, or wishful thinking (Festinger, 1957). PMT is schematically depicted in Figure 2-1.

According to PMT, different sources of information can trigger the cognitive process of protection motivation (Rogers, 1983). The original version of PMT still focused on fear appeals,[1] which are typically informative communications about a threat and suggested measures to avoid or reduce its negative impacts (Milne et al., 2000). The revised version introduced by Rogers (1983) included additional sources of information referred to as "environmental and intrapersonal sources" (Figure 2-1). Environmental sources (not to be interpreted as geographical factors) include verbal persuasion and observational learning. The latter occurs when an individual observes what happens to others such as friends, neighbours, or family. The intrapersonal source, on the other hand, captures personality variables and prior experience with similar threats (Rogers, 1983). Although intrapersonal variables are in principle broader and can relate, for example, to ideology, they are mainly related to socioeconomic characteristics, like gender, age, and income. Moreover, an emerging literature on the social vulnerability of households to flood hazards has used socioeconomic characteristics as observable proxies for some of the life circumstances, beliefs, and constraints that contribute to vulnerabilities, threat, and coping appraisals (Cutter & Finch, 2008; Montgomery & Chakraborty, 2015; Koks et al., 2015).

When it comes to explaining intentions or actual risk-reducing behaviour, two meta-analyses of the health-related literature on PMT come to the conclusion that the coping appraisal component has a greater predictive validity than threat appraisal (Floyd et al., 2000; Milne et al., 2000). Similar findings have been reported from studies examining protective behaviour in the face of natural hazards (Grothmmann & Reusswig, 2006; Bubeck et al., 2013; Poussin et al., 2014). Grothmann and Reusswig (2006), for example, found that threat appraisal could explain an additional 3–6% of the variance in protective behaviour, while coping appraisal could explain an additional 2–21%.

Given the importance of threat and coping appraisals in influencing protection motivation and subsequent behaviour, it is of interest for policies that aim to improve individual risk preparedness to understand what factors determine the threat and coping appraisals of individuals. A large body of literature exists that examines this aspect in relation to risk perception (called "threat appraisal" in PMT). Several theories have been developed and extensively tested to explain why people perceive a certain event or activity as risky, such as the psychometric paradigm (Slovic, 1987; Slovic, 2000) or

[1] It should be realized that communication policies that focus on fear appeals may be regarded as undesirable because of the negative emotional impacts caused by fear, and that well-designed communication policies can raise risk perceptions without inducing fear, as shown by de Boer et al., 2015

cultural theory, which also seeks to explain individual attitudes towards risk-reducing actions (Douglas & Wildavsky, 1983). Various studies also examined the factors that specifically shape risk perceptions of natural hazards (Lindell, 1994; Mileti & Darlington, 1997; Siegrist & Gutscher, 2006; Botzen et al., 2009b; Kellens et al., 2011; Bosschaart et al., 2013; Kellens et al., 2013; Lo, 2013; Botzen et al., 2015). In contrast, to our knowledge there are no studies that systematically examine which factors influence all three components of coping appraisals related to natural hazards, despite their higher predictive validity in terms of protective intentions and behaviour. While not specifically focusing on PMT, one exception is a study by Lindell et al. (2009) that examines correlations between mostly socioeconomic variables and the perceived attributes of earthquake preparedness measures, such as the perceived protection of persons and property (related to response efficacy) and the required time, effort, and costs (relating to response cost). Self-efficacy, the third component of coping appraisal in PMT, was not included in the analysis by Lindell et al. (2009). Instead, it was elicited more generally whether people thought that specialized skills and knowledge were needed for the implementation of a particular measure. Findings from this study show that especially females, respondents with higher risk perceptions, and those with higher hazard intrusiveness exhibited a higher perceived response efficacy Lindell et al. (2009). Moreover, Hispanics associated higher response costs (captured by the variable "ResAtt" in Lindell et al. (2009)) with implementing measures, while the opposite was the case for whites, older respondents, and homeowners. Babcicky and Seebauer (2017) explicitly investigate factors that influence self-efficacy according to PMT of flood-affected households in Austria, but do not study response efficacy and response cost. They find that self-efficacy is lower for women and respondents facing a higher objective risk, while it is positively influenced by income and cognitive social capital. The latter refers to perceived support, trust, social cohesion, and civil engagement.

Systematic insights into the factors that relate to individuals' flood-coping appraisals are needed to better understand their decision making process in the face of natural hazards in general and floods in particular, and to inform risk communication on how to best stimulate protective behaviour (Haer et al., 2016). To gain a better understanding of these aspects, we empirically explore a wide range of variables capturing environmental and intrapersonal sources of information possibly influencing coping appraisals of more than 1,600 flood-affected households in Germany and France, using multivariate statistics. An important novel contribution of our study is that we provide systematic insights into the factors influencing all three components constituting coping appraisal as given by PMT, namely, response efficacy, self-efficacy, and response cost, in the context of natural hazards. Our empirical assessment for two countries allows for identifying consistent patterns on a large geographical scale.

In addition, we examine whether groups of households can be identified across different types of private flood-damage-reducing measures and the two countries that exhibit identical/similar combinations of ratings for the coping appraisal components and could thus be targeted by tailored risk communication. To this end, we furthermore explore whether this grouping is determined by distinct explanatory variables, such as environmental and intrapersonal characteristics.

The remainder of the article is organized as follows: Section 2.2 describes our hypotheses, the responsibility of households to contribute to flood-damage reduction in Germany and France, and the surveys conducted among flood-affected households, as well as the statistical methods applied in this study. Results of statistical models of the factors that influence flood-coping appraisals of households as well as the grouping analysis based on individual coping appraisal ratings are provided in Section 2.3 Section 2.4 discusses the overall pattern of findings in view of our hypotheses. Section 2.5 concludes and provides policy recommendations for flood risk management and communication.

2.2 Hypotheses, case studies, data and methods

2.2.1 Hypotheses

Our study is structured around a set of five main hypotheses concerning potential factors relating to coping appraisals. These hypotheses have been based on the factors that influence coping appraisals as understood in the PMT framework (Figure 2-1), the literature on social vulnerability to flooding, and the handful of aforementioned studies that examined determinants of selected coping appraisal variables.

Studies on social vulnerability to flooding typically find that socially vulnerable groups have a higher exposure, a lower capacity to prepare for, and cope with, flooding events, and potentially a lower adaptive capacity (Phillips & Morrow, 2007; Adger, 2008; Cutter & Finch, 2008; Thomas et al., 2013; Koks et al., 2015; Montgomery & Chakraborty, 2015). Nevertheless, such groups can also have their own capacities to cope with and manage risk from natural hazards (Lazrus et al., 2012). A variety of indicators have been used to identify vulnerable groups, of which some important variables include a low income, low education level, and older age groups. Moreover, females, older adults, and children may be additionally more vulnerable, that last of which is not relevant for our surveys of only adults. These variables belong to intrapersonal sources according to PMT (Figure 2-1). An examination of some of these sources for which data were available from our surveys is operationalized in our analyses by examining how coping appraisals relate to income, age, education level, and gender. It may be expected that socially vulnerable groups have lower coping appraisals, especially in the form of a high perceived response cost and lower perceived self-efficacy. This leads to the first hypothesis (H1).

H1: Socially vulnerable groups in terms of low income, age, low education, and gender have lower coping appraisals, especially in terms of high perceived response cost and lower perceived self-efficacy.

Several studies have shown that prior flood experience and individual flood risk perceptions are strongly positively related (Kellens et al., 2011), although the effect of experience on risk perceptions declines over time (Bin & Landry, 2013). Past flood experience and high risk perceptions may have the effect that individuals find flood damage mitigation measures appealing. The results of Lindell et al. (2009) and Terpstra and Lindell (2013) suggest this latter effect by showing a positive relation between risk perception and response efficacy. Similar findings are also reported from the literature on hurricanes. Norris et al. (1999) report a positive relation between past hurricane experience and perceptions of response and self-efficacy, referred to as “controllability beliefs.” The finding that the effect of (hurricane) experience on coping appraisals can be ambiguous is reported by Demuth et al. (2016). They also report a positive relationship between hurricane experience and self- and response efficacy, in case hurricane experience is operationalized in terms of evacuation experience. However, if hurricane experience is operationalized in terms of property damage or emotional impact, a negative relationship is found at least for response efficacy and self-efficacy, respectively. It is thus of interest to gain further insights into how prior flood experience and risk perceptions relate to flood-coping appraisals. Based on the flood-related literature, we hypothesize the following:

H2: Prior flood experience and high flood risk perceptions are positively related to flood-coping appraisals (i.e., higher response and self-efficacy and lower response cost).

Moreover, other intrapersonal variables may matter for shaping coping appraisals, as Figure 2-1 suggests. For example, a negative effect on coping appraisals such as perceived response efficacy can arise from fatalism, which corresponds to the belief that nothing can be done to prevent impacts from flooding. A similar effect may be expected from respondents who postpone flood mitigation measures, since these people see less urgency or immediate benefit from flood-proofing their homes (Rippetoe & Rogers, 1987; Steel, 2007). Similarly, according to expected utility theory — the standard economic theory of decision making under risk — protection against a risk (here, flooding) is less valued for individuals with a lower degree of risk aversion (von Neumann & Morgenstern, 1947). This leads to the third hypothesis (H3).

H3: Fatalism, postponement, and low risk aversion are important personality characteristics that are related to lower coping appraisals (i.e., lower response and self-efficacy and higher response cost).

It is commonly expected that having received information about a hazard and ways to protect against it motivates people to better prepare for the hazard. However, only few studies have empirically examined this assumption, as Haer et al. (2016) point out. Here, we empirically estimate whether a positive relation exists between coping appraisals and information about flood risk and coping measures:

H4: Information provision about flood risk and flood-coping measures is related to higher flood-coping appraisals (i.e., higher response and self-efficacy and lower response cost).

Previous research has suggested that individuals are more likely to prepare for disasters (e.g., purchase flood insurance) if their neighbours, friends, and family members, do the same (Kunreuther, 1978; Mileti & Fitzpatrick, 1992; Mileti & Darlington, 1997). For instance, Bubeck et al. (2013) found that a social environment variable, capturing whether respondents believed that friends, family members, or neighbours took flood damage mitigation measures, has a significant positive influence on the number of flood mitigation measures households take. However, it is not well known through which channel the social environment influences mitigation behaviour. This can be related to the verbal persuasion and observational learning sources in PMT (Figure 2-1), in the sense that individuals who learn about mitigation behaviour from others have more positive coping appraisals themselves. This is formalized in our final hypothesis.

H5: Individuals who believe that friends, neighbours, and family members have implemented flood damage mitigation measures (related to observational learning) have more positive coping appraisals (i.e., higher response and self-efficacy and lower response cost).

2.2.2 Private flood-damage mitigation in Germany and France

In both Germany and France, households in flood-prone areas are expected to contribute to flood risk reduction by implementing damage-reducing (also called mitigation) measures. In Germany, the responsibility of households to contribute to risk reduction was increasingly emphasized following major floods along the Rhine in 1993 and 1995 and the Elbe and Danube catchment in 2002, and is also stated in the federal water act as of 2005 (Bubeck et al., 2017; Bubeck et al., 2012a). However, there are currently no clear rules as to what this responsibility encompasses, and no systematic support or financial subsidies are available to households for implementing private flood mitigation measures (Thieken et al., 2013). Flood insurance coverage is available from private insurers that charge risk-based premiums, which is thus more expensive and difficult to obtain in high-risk areas. Market penetration varies considerably between federal states for historical reasons and ranges from 15% to 95% (as of 2015) (Thieken et al., 2006).[2]

In France, private flood mitigation measures are, in principle, stimulated through so-called Risk Prevention Plans (PPR), which delineate areas potentially at risk of flooding. In these areas, PPRs can define obligatory or recommended flood mitigation measures for private households. Moreover, the so-called Barnier fund can provide subsidies for households to implement flood mitigation measures. In practice, however, several studies have shown that both the PPRs and the Barnier fund hardly stimulate private flood mitigation behaviours, which are predominantly enacted at the initiative of the households themselves (Poussin et al., 2013). Property insurance is compulsory and thus reaches a market penetration of 99% in metropolitan France. Flood damage is covered by an additional public–private compensation scheme (the so-called Cat Nat system), which private insurers must provide along with property insurance contracts (Poussin et al., 2013). Insurance premiums are fixed by the government, do not reflect the actual risk, and thus follow the national solidarity principle (van den Bergh & Faure, 2006).

Even though flood risk management systems differ between France and Germany, it can be concluded that households are mostly responsible themselves for implementing and financing flood mitigation measures at the building level. Differences between the two countries exist in terms of flood insurance.

[2] Source: www.gdv.de | Gesamtverband der Deutschen Versicherungswirtschaft (GDV)

2.2.3 Household surveys in Germany and France

To gain insights into the factors that influence flood-coping appraisals of PMT, two surveys were carried out among 752 and 885 flood-affected households in Germany and France, respectively. In addition to details on flood-coping appraisals for different types of private flood mitigation measures, the deployed questionnaires elicited a range of intrapersonal and environmental factors as well as information on risk and coping communication.

In Germany, computer-aided telephone interviews were conducted among households living along the Rhine River by the Umfragezentrum Bonn of the Rheinische Friedrich-Wilhelms-Universität Bonn in early summer of 2011. In France, the survey was administered by mail by IPSOS, which is a French professional survey research company, and distributed to households living in flood-prone areas in the regions of Ardenness, the Var, and the West Coast. For further details on the two surveys in terms of pretesting, sample characteristics, and representativeness of the sample, the reader is referred to Bubeck et al., (2012), Bubeck et al. (2013), Poussin et al. (2014) and Poussin et al. (2015).

Since the characteristics of private flood mitigation measures can substantially differ — for example, flood-proofing a building structure versus purchasing flood insurance — also perceptions regarding these measures can vary. Therefore, flood-coping appraisals were elicited for specific types of measures. In Germany, respondents were asked to indicate coping appraisals for structural measures, non-structural measures, and for purchasing flood insurance. In France, respondents reported their coping appraisals separately for structural and non-structural measures. Insurance was not elicited in France because households are already obliged to buy it (see Section 2.2.2). While postponement was only included in the German survey, risk aversion was only elicited in the French survey, allowing for complementary insights. The variables included in the German and French analyses and their coding are described in Tables AI and AII in the Supporting Information.

One important difference between the two samples exists in terms of the timing of flood experience. German households were mainly affected by the large-scale floods that occurred in the Rhine basin in December 1993 and January 1995 (Chbab, 1995; Bubeck et al., 2012a) even though a number of respondents were also affected by smaller and more recent floods. Flood experience of the French households was more recent: the majority of the respondents who were flooded in the past were affected by the storm Xynthia, which caused large flooding in 2010.

2.2.4 Statistical analyses

2.2.4.1 Factors influencing flood-coping appraisals

Self-reported ratings of response efficacy, self-efficacy, and response cost for structural and non-structural measures, as well as insurance in the case of the German sample, were used as dependent variables in a series of multiple regression models. A separate regression analysis was performed for each type of measure and each country (Tables 2-1 – 2-6). To account for the ordinal scale of the coping appraisal ratings, ordered logit models were applied. For each model, regression coefficients, significance values, and Nagelkerke R^2 values are reported. Differences in the number of observations included in the models stem from missing answers.

In a first step, a set of typical socioeconomic variables (intrapersonal source of information according to PMT), namely, the level of education, number of household members, age, ownership, gender, and income, were used as explanatory variables. These models are referred to as "socioeconomic" models (see, e.g., Table 2-1).

In a second step, the socioeconomic models for the three coping appraisal variables and the different types of measures were expanded with variables capturing additional intrapersonal and environmental sources of information, including previous flood experience and damage, risk perceptions, respondents' social environment, and aspects of risk and coping communication. The resulting models are referred to as "complete" models (see, e.g., Table 2-1).

2.2.4.2 Grouping analysis

In addition to the regression models, we performed a grouping analysis: households with similar combinations of flood-coping appraisal ratings were grouped, and variables influencing this grouping were determined by applying a multivariate grouping analysis that consisted of four steps. All four steps were performed using the software R, version 3.2.2. First, a hierarchical cluster analysis applying Euclidean distance and the Ward.D2 clustering method was performed on the three coping appraisal variables (response efficacy, self-efficacy, and response cost) in order to obtain an algorithm-based grouping for each category of mitigation measure. For instance, all respondents who indicated the highest response and self-efficacy rating and the lowest response cost rating for structural measures were identified as one group. Second, the most prominent groups were manually selected using the hierarchical cluster dendrogram, in which equally sized clusters with similar heights result in the particular groups. Third, an unconstrained principal component analysis (PCA) was conducted with the coping appraisal variables in order to present the Euclidean distance between the combinations in an ordination plot. PCA is a method often used in ecology, but increasingly also in the social sciences, to reduce the dimensionality of the data, extracting its most important information and revealing patterns of similarity (Wold et al., 1987; Legendre & Gallagher, 2001; Abdi & Williams, 2010; Gaotlhobogwe et al., 2011). To display the groups in the most representative way, a group overlay was passed to the plot (Figure 2-2). Fourth, the R package "envfit" module (Oksanen et al., 2008) was used to estimate correlations between explanatory variables that were significant in the regression analysis (see Section 2.2.4.1) and the first two principal components (PCA axes).

Correlations between explanatory variables and the groups are displayed by the brown arrows (see Figure 2-2), which show the correlation strength as well as correlation direction of a variable. In general, longer arrows mean stronger correlations between the particular variable and the two PCA axes. The angles between arrows and axes show how the variable is correlated with each particular axis. The smaller the angle between them, the stronger the correlation (Oksanen et al., 2008). Thus, if the variable arrows point to the same plot region where groups appear, a positive coherence between this variable and the group can be assumed. A negative correlation is indicated by variable arrows pointing in the opposite direction of a group (see Figure S1 for an illustrative example). For readers unfamiliar with PCA and the interpretation of ordination plots, a detailed example and explanation is provided in the supplementary information.

2.3 Results

2.3.1 Factors influencing flood-coping appraisals

2.3.1.1 Response efficacy (RE)

German case study: The results of the socioeconomic models predicting RE for the three damage-reducing measures in Germany show that age, ownership, and income level make a significant contribution to at least one of the socioeconomic models (Table 2-1). In terms of structural measures, we find that older adults are less likely to rate structural measures as effective. For non-structural measures, a positive influence for income is found. As far as the purchase of insurance is concerned, the age of the respondents again has a negative influence on RE, while being a homeowner has a positive influence. Common to all three socioeconomic models is the low level of explained variance, ranging from 3.9% to 5.3%.

The complete models explaining RE reveal that especially the social environment has a positive influence on the perceived effectiveness of the three measures, making a significant positive contribution to all three models (Table 2-1). As far as the complete model for the RE of insurance is concerned, results show that people who believe that they live in an area that is unprotected from flood-defense infrastructure rate the effectiveness of insurance lower. Insurance may be viewed as being a less effective way to cope with flood risk in these high-risk areas because it is more expensive there and more difficult to obtain (Thieken et al., 2006; Bubeck et al., 2013). The same argument holds true for the negative influence found for perceived probability. Also, more educated people perceive insurance to be less effective. In contrast, people who expect a flood's damage to be high exhibit a higher RE rating. The explained variance of the complete models is between 10.5% and 17.2%, which is considerably higher than the socioeconomic models.

Table 2-1 Models of Response Efficacy for Structural and Non-structural Measures and Insurance Purchase in Germany

	Structural Measures		Non-structural Measures		Insurance	
Explanatory Variable	Socioeconomic	Complete	Socioeconomic	Complete	Socioeconomic	Complete
Education	0.11	0.15	0.13	0.05	0.00	−0.18*
Household members	0.05	−0.02	−0.05	0.07	−0.08	−0.07
Age	−0.19*	−0.21*	−0.10	−0.10	−0.24***	−0.16
Ownership	−0.16	−0.28	−0.13	−0.52	0.55**	0.41
Female	−0.14	−0.11	−0.17	−0.42	−0.06	−0.06
Income	−0.43	−0.66	0.23*	0.22	0.18	0.50
Perceived consequence	n.a.	0.13	n.a.	0.07	n.a.	0.29*
Perceived probability	n.a.	−0.10	n.a.	0.21	n.a.	−0.26*
Unprotected area	n.a.	−0.16	n.a.	0.03	n.a.	−0.62*
Satisfaction with flood management	n.a.	0.03	n.a.	0.21	n.a.	−0.07
Past flood damage (ln)	n.a.	0.01	n.a.	0.04	n.a.	−0.02
Fatalism	n.a.	−0.02	n.a.	0.03	n.a.	−0.10
Avoidance	n.a.	−0.00	n.a.	−0.07	n.a.	−0.15
Postponement	n.a.	−0.02	n.a.	0.04	n.a.	−0.03
Risk information	n.a.	−0.09	n.a.	0.25	n.a.	0.04
Coping information	n.a.	−0.35	n.a.	−0.46	n.a.	0.00
Social environment	n.a.	0.29**	n.a.	0.29*	n.a.	0.40***
Nagelkerke R^2	0.04	0.11	0.05	0.14	0.04	0.17
N	478	282	484	280	462	271

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

French case study: The socioeconomic models capturing the RE of French households (Table 2-2) show that women have a significantly higher perceived response efficacy with regard to non-structural measures than men. Contrary to the German model, no positive effect is found for income. In line with the sample from Germany, the socioeconomic variables have little explanatory power, ranging from 2% to 3% of explained variance in RE.

The complete model explaining RE in France indicates that the perceived damage of a future flood is negatively related to the latter (Table 2-2).

Moreover, response efficacy among French households is related to fatalism in the sense that individuals with a low degree of fatalism have a higher perceived RE. Risk aversion and perceived response efficacy are positively related with regard to non-structural measures. In line with the findings from Germany, it appears that the social environment has a strong and significant influence on perceived response efficacy for both structural and non-structural measures. As in the case for Germany, the explanatory power of the complete models for France is, with 12–15% in explained variance, considerably higher than the socioeconomic models.

Table 2-2 Models of Response Efficacy for Structural and Non-structural Measures in France

	Structural Measures		Non-structural Measures	
Explanatory Variable	Socioeconomic	Complete	Socioeconomic	Complete
Education	0.05	0.05	0.10	0.09
Household members	0.05	−0.01	−0.05	−0.05
Age	−0.01	−0.01*	−0.00	−0.01
Ownership	−0.17	−0.08	−0.43	−0.31
Female	0.04	0.04	0.34*	0.33
Income	0.07	0.00	0.08	0.02
Perceived consequences	n.a.	−0.11	n.a.	−0.23*
Perceived flood risk	n.a.	−0.04	n.a.	−0.06
Feeling protected	n.a.	0.15	n.a.	−0.02
Public defenses	n.a.	0.31*	n.a.	0.19
Past flood damage	n.a.	−0.00	n.a.	−0.00
Low degree of Fatalism	n.a.	0.25*	n.a.	0.24**
Risk aversion	n.a.	0.17	n.a.	0.37**
Risk information	n.a.	−0.14	n.a.	0.10
Coping information	n.a.	−0.13	n.a.	0.01
Social environment	n.a.	0.52*	n.a.	1.01**
Nagelkerke R^2	0.02	0.12	0.03	0.15
N	582	545	556	521

*$p < 0.05$, **$p < 0.01$.

2.3.1.2 Self-efficacy (SE)

German case study: With regard to SE, the results show that income, ownership, educational level, and age make a significant contribution to at least one of the three socioeconomic models (Table 2-3). As far as SE for structural measures is concerned, we find a significant positive effect for both income and ownership. As far as non-structural measures are concerned, income again influences the perceived SE positively. Here, no difference is found for ownership in the socioeconomic model. Regarding the perceived SE of insurance, we again find a positive influence for income. In addition, the educational level also exhibits a positive influence on the perceived SE of buying insurance. In contrast, older people consider themselves less able to purchase insurance. The explanatory power of the socioeconomic model predicting SE regarding non-structural measures is again low, with only 4% of explained variance. Somewhat higher explanatory power is found for the models predicting SE in terms of structural measures and insurance, with 10.6% and 13.2% in explained variance, respectively.

The complete models explaining SE reveal the importance of the social environment (Table 2-3). People who believed that friends or neighbours implemented one of the three types of measures feel better able to implement these themselves. People who received information on the risk they faced also indicated a higher SE with regard to insurance. In contrast, nonprotective responses, that is, avoidance of insurance, relate negatively to SE. Respondents with a high perceived probability of future flooding also indicated a lower SE for insurance. In line with the results for RE, the explained variance increases considerably for the complete models predicting SE (namely, 13.8–27.4%) compared to the socioeconomic models.

Table 2-3 Models of Self-efficacy for Structural and Non-structural Measures and Insurance Purchase in Germany

	Structural Measures		Non-structural Measures		Insurance	
Explanatory Variable	Socioeconomic	Complete	Socioeconomic	Complete	Socioeconomic	Complete
Education	−0.05	−0.07	0.07	−0.05	0.25***	0.11
Household members	0.03	−0.23*	−0.05	0.05	0.01	−0.02
Age	0.00	−0.12	−0.09	−0.00	−0.23**	−0.23*
Ownership	0.99***	1.16***	−0.13	−0.61	0.14	0.36
Female	−0.26	0.01	−0.17	0.22	−0.24	−0.26
Income	0.67*	0.72	0.25**	0.38**	0.75**	1.32**
Perceived consequence	n.a.	−0.05	n.a.	−0.05	n.a.	0.15
Perceived probability	n.a.	−0.18	n.a.	0.02	n.a.	−0.48***
Unprotected area	n.a.	−0.15	n.a.	−0.39	n.a.	−0.41
Satisfaction with flood management	n.a.	−0.04	n.a.	0.01	n.a.	0.12
Past flood damage (ln)	n.a.	−0.01	n.a.	0.03	n.a.	−0.03
Fatalism	n.a.	−0.06	n.a.	0.14	n.a.	−0.05
Avoidance	n.a.	−0.02	n.a.	−0.13	n.a.	−0.24*
Postponement	n.a.	−0.17	n.a.	0.17	n.a.	−0.02
Risk information	n.a.	0.11	n.a.	0.31	n.a.	0.72*
Coping information	n.a.	−0.02	n.a.	0.20	n.a.	0.16
Social environment	n.a.	0.25**	n.a.	0.43***	n.a.	0.36**
Nagelkerke R^2	0.11	0.16	0.05	0.14	0.13	0.27
N	457	275	482	281	455	267

**p* < 0.05, ***p* < 0.01, ****p* < 0.001.

French case study: For the French households, we find that education appears to be negatively related to the perceived SE for structural measures in the socioeconomic model (Table 2-4). A lower perceived SE is also reported for females in the model for structural measures. Older adults also indicate a lower SE for both measures, although effect sizes are low. As is the case for the German sample, income is positively related to SE for structural measures, but not significantly in the model for non-structural measures. In line with the findings from Germany, the socioeconomic models for SE have a better model fit than was the case for the response efficacy models, and range from 6% to 9% in explained variance.

The complete models predicting the SE of French households indicate that higher perceptions of flood risk are negatively related to the perceived SE of structural measures (Table 2-4). In particular, perceptions that one's flood risk is higher than average has a negative significant influence, and already feeling well-protected against the flooding has a positive influence on perceived self-efficacy. These effects were not observed for the German case study, where neither perceived probability, perceived consequences, nor past flood damage made a significant contribution to the models explaining SE of structural and non-structural measures. Individual risk aversion, which was not elicited in the German survey, is positively related to the perceived self-efficacy of both structural and non-structural measures. Moreover, individuals who have received or searched for information on flood protection measures have a higher degree of self-efficacy for structural measures. The social environment variable is positively related to the self-efficacy of non-structural measures, which is consistent across the two case studies. The explanatory power of the complete models for SE in France again improves considerably compared with the socioeconomic model and ranges from 13% to 15% in explained variance.

Table 2-4 Models of Self-Efficacy for Structural and Non-structural Measures in France

	Structural Measures		Non-structural Measures	
Explanatory Variable	Socioeconomic	Complete	Socioeconomic	Complete
Education	−0.13*	−0.13*	−0.04	−0.10
Household members	0.11	0.12	0.03	0.05
Age	−0.01*	−0.01*	−0.03***	−0.03**
Ownership	0.31	0.24	0.18	0.15
Female	−0.39**	−0.31*	−0.30	−0.20
Income	0.12*	0.11	0.17**	0.17
Perceived consequences	n.a.	0.00	n.a.	−0.09
Perceived flood risk	n.a.	−0.38**	n.a.	0.18
Feeling protected	n.a.	0.34**	n.a.	0.11
Public defenses	n.a.	−0.03	n.a.	0.16
Past flood damage	n.a.	0.00	n.a.	−0.00
Low degree of Fatalism	n.a.	0.00	n.a.	0.08
Risk aversion	n.a.	0.17*	n.a.	0.20*
Risk information	n.a.	−0.11	n.a.	0.13
Coping information	n.a.	0.52**	n.a.	0.31
Social environment	n.a.	−0.09	n.a.	0.65**
Nagelkerke R^2	0.06	0.13	0.09	0.15
N	666	615	613	572

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

2.3.1.3 Response cost (RC)

German case study: In terms of perceived response cost (RC), education, age, and gender significantly contribute to at least one of the three socioeconomic models (see Table 2-5). Respondents with a higher education level perceive the costs of structural measures to be lower. In addition, older people and women consider insurance to be less costly. The explanatory power of all three socioeconomic models is again low and explains only between 1.6% and 4.8% of the variance in perceived RC.

The complete models predicting RC provide mixed results (Table 2-5). In terms of structural measures, we find that older people perceive this type of measure as more costly. People who believe in greater consequences of future flood events consider structural and non-structural measures to be less costly. A negative coefficient is furthermore found for the variable of fatalism, indicating that people who agree with the general statement that “there is nothing that can be done to prevent flood damage” rate the costs of structural measures as lower. The explained variance significantly increases again for the complete models and ranges between 10.7% and 17.4%.

Table 2-5 Models of Response Cost for Structural and Non-structural Measures and Insurance Purchase in Germany

	Structural Measures		Non-structural Measures		Insurance	
Explanatory Variable	Socioeconomic	Complete	Socioeconomic	Complete	Socioeconomic	Complete
Education	−0.13*	−0.11	0.02	0.03	−0.01	−0.03
Household members	−0.02	−0.12	−0.01	−0.09	−0.06	−0.12
Age	0.09	0.23*	0.04	0.06	−0.16*	−0.22*
Ownership	−0.01	0.14	−0.06	0.28	−0.25	0.02
Female	−0.24	−0.07	−0.32	−0.05	−0.54**	−0.59*
Income	0.36	0.65	0.09	0.04	0.21	0.13
Perceived consequence	n.a.	−0.28*	n.a.	−0.36***	n.a.	−0.18
Perceived probability	n.a.	−0.09	n.a.	0.07	n.a.	−0.32*
Unprotected area	n.a.	0.30	n.a.	0.21	n.a.	0.05
Satisfaction with flood management	n.a.	0.13	n.a.	0.22	n.a.	0.14
Past flood damage (ln)	n.a.	−0.02	n.a.	−0.03	n.a.	−0.03
Fatalism	n.a.	−0.24*	n.a.	0.01	n.a.	−0.00
Avoidance	n.a.	0.02	n.a.	0.08	n.a.	0.00
Postponement	n.a.	−0.08	n.a.	−0.09	n.a.	−0.03
Risk information	n.a.	−0.12	n.a.	−0.26	n.a.	−0.25
Coping information	n.a.	−0.01	n.a.	0.47	n.a.	−0.05
Social environment	n.a.	0.09	n.a.	0.17	n.a.	0.15
Nagelkerke R^2	0.02	0.11	0.02	0.11	0.05	0.18
N	456	267	475	278	437	254

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

French case study: For the French sample, several socioeconomic variables have an important influence on RC (see Table 2-6) in the socioeconomic models. Older people perceive structural and non-structural measures as less costly, but effect sizes are very low. Homeowners perceive structural measures as more costly, which probably reflects the fact that the costs of flood-proofing a house are more obvious for homeowners compared to tenants. We also find that people with higher income consider costs lower in all models, which is a marked difference from the German sample. The explanatory power of the socioeconomic models is again low.

The complete models reveal that the perceived consequences of flooding relate to higher perceived costs for both measures. Also, experience with flood damage in the past relates to perceived higher costs of non-structural measures, but effect size is very low. Respondents who feel well-protected against flooding perceive structural measures as less costly. This could be related to the fact that these respondents believe that only minor investments are needed given the already good protection level. Also, respondents who perceived that their social environment implemented flood mitigation measures consider the cost of non-structural measures to be lower. Explained variance again increases considerably and reaches 15% for RC of structural measures and 13% for non-structural measures.

Table 2-6 Models of Response Cost for Structural and Non-structural Measures in France

	Structural Measures		Non-structural Measures	
Explanatory Variable	Socioeconomic	Complete	Socioeconomic	Complete
Education	0.05	0.08	−0.04	−0.06
Household members	0.01	−0.02	0,03	0.02
Age	−0.01*	−0.01*	−0.03**	0.01
Ownership	0.78**	0.79**	0.18	0.59**
Female	−0.07	−0.07	−0.30	−0.13
Income	−0.19**	−0.18**	−0.17**	−0.22**
Perceived consequences	n.a.	0.19*	n.a.	0.23*
Perceived flood risk	n.a.	0.18	n.a.	−0.20
Feeling protected	n.a.	−0.33**	n.a.	−0.09
Public defenses	n.a.	−0.12	n.a.	−0.07
Past flood damage	n.a.	0.00	n.a.	0.004*
Low degree of Fatalism	n.a.	0.02	n.a.	0.05
Risk aversion	n.a.	−0.02	n.a.	−0.15
Risk information	n.a.	−0.24	n.a.	−0.33
Coping information	n.a.	−0.03	n.a.	0.26
Social environment	n.a.	−0.00	n.a.	−0.58*
Nagelkerke R^2	0.04	0.15	0.09	0.13
N	604	564	613	534

*p < 0.05, **p < 0.01.

2.3.2 Grouping analysis

The results of the grouping analysis show that several distinct groups exhibiting very similar ratings of response efficacy, self-efficacy, and response cost can be identified for the different types of examined mitigation measures. The distinct groups that could be identified based on their similar rating across the three coping appraisal components are described in Table 2-7 and the number or respondents belonging to these groups (% in brackets) for each of the examined measures is provided.

The first result of the grouping analysis is that the identified groups do not appear uniformly across all examined measures (Table 2-7). The group "Low coping appraisal" was only identified for insurance. The group "Only low self-efficacy" was found only as a distinct group for structural measures. The group "Only high response cost" was found for both non-structural measures and insurance. The only group that occurred for all examined measures was "High coping appraisal." Interestingly, while the identified groups are not uniform across the different mitigation measures, we find identical groups for the French and German samples, as indicated in Table 2-7 and depicted in the ordination plots in Figures 2-2 (a) – (d). For "structural measures," the groups "High coping appraisal" and "Only low self-efficacy" are both found within the German and French data (Figures 2-2 (a) and 2-2 (b)), whereas "non-structural measures" consist of the groups "High coping appraisal" and "Only high response cost" (Figures 2-2 (c) and 2-2 (d)). The category "insurance," which was not elicited for the French survey, comprises all groups except for "Only low self-efficacy" (Figure 2-2 (e)).

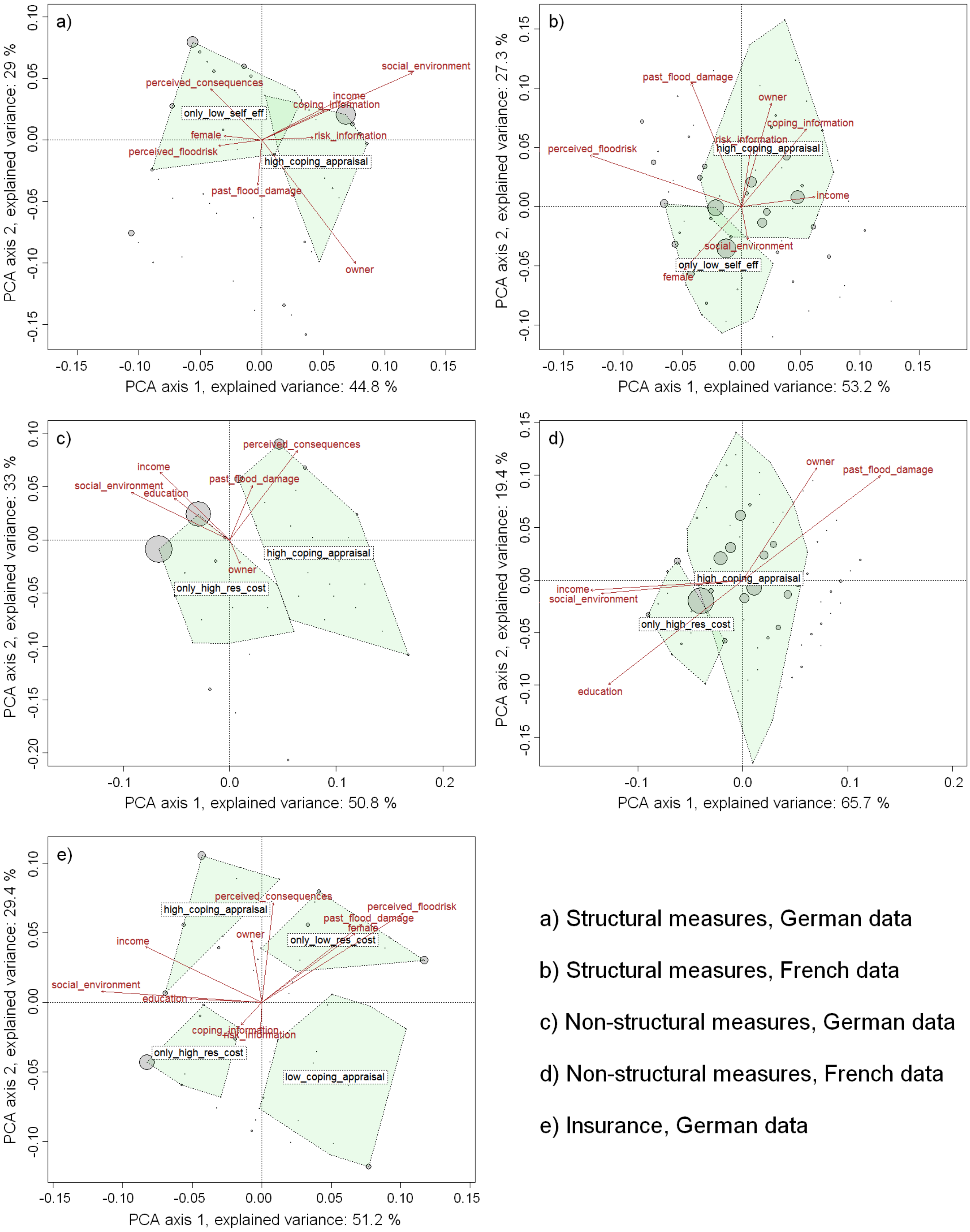

Figure 2-2 PCA ordination plots of the German and French data for different mitigation measure types

Moreover, Figures 2-2 (a) – (e) reveal that the grouping is influenced by different explanatory variables, which is resembled by the brown arrows. In the case of structural measures in Germany, the social environment has a strong significant positive effect on the group "High coping appraisal" (Figure 2-2(a)), while the effect on "Only low self-efficacy" is negative. In addition, being a homeowner also shows a significant positive influence on the "High coping appraisal," group whereas households with worse perceived consequences of flooding tend to show "Only low self-efficacy." Coping information, income, and risk information also show a positive relation to the "High coping appraisal" group, although the significance is relatively low. The same applies for being female and the likelihood of belonging to the "Only low self-efficacy" group. Again, here the significance is low but the tendency is obvious. The French data display a very similar picture (Figure 2-2(b)). The plot indicates that homeownership, income, and coping information have a positive influence on the "High coping appraisal" group. Being female again has a positive — in this case more significant — effect on the "Only low self-efficacy" group. Contrary to the German data, the social environment is not significant and therefore shows no influence on the grouping. As far as non-structural measures are concerned (Figures 2-2 (c) and 2-2 (d)), again very similar patterns are found for the two countries, although the plots differ in their visual appearance. Social environment is significant and shows a positive relation to the group "Only high response cost" in both Germany and France. Besides this, certain other explanatory variables reveal similar trends. High damage incurred in the past, for example, seems to influence the affiliation to "High coping appraisal" positively. Also, higher education and income levels show a positive connection to the "Only high response cost" group and therefore a negative connection to "High motivation." The positive connection between owners and "High coping appraisal" could only be found within the French data (Figure 2-2(d)). In Germany, on the other hand, worse perceived consequences of flooding seem to result in a higher coping appraisal regarding structural measures.

For insurance, which was only elicited for the German sample, Figure 2-2(e) shows that the social environment, income, and education all positively relate to the groups "High coping appraisal" and "Only high response cost." It could be argued that high perceived consequences also lead to a higher motivation. On the contrary, being female, incurring past flood damage, and, especially, perceiving greater flood risks relate to the group showing "Only low response cost."

Table 2-7 Groups Showing Very Similar Coping Appraisal Ratings across Different Mitigation Measures

Group	Group Definition Determined by Coping Appraisal Ratings	Str. (DE)[a]	Str. (FR)[b]	N-Str. (DE)[c]	N-Str. (FR)[d]	Ins. (DE)[e]
High coping appraisal	Households indicating a high response efficacy, high self-efficacy and low response cost	97 (35.8%)	226 (42.2%)	103 (35.9%)	265 (51.2%)	48 (18.9%)
Low coping appraisal	Households indicating a low response efficacy, low self-efficacy, and high response cost					45 (17.7%)
Only low self-efficacy	Households indicating a high response efficacy but low self-efficacy, and low response costs	110 (40.6%)	184 (34.3%)			
Only high response cost	Households indicating a high response efficacy, high self-efficacy, but high response costs			166 (57.8%)	134 (25.9%)	58 (22.8%)
Only low response cost	Households indicating a low response efficacy, low self-efficacy, but low response costs					46(18.1%)
Mixed	Households indicating a combination of response efficacy, self-efficacy, and response cost that occur in a low number of cases and cannot be reasonably categorized; these respondents were therefore excluded from the PCA plots	64 (23.6%)	126 (23.5%)	18 (6.3%)	119 (23.0%)	57 (22.4%)

[a] Structural measure (Germany)

[b] Structural measure (France)

[c] Non-structural measure (Germany)

[d] Non-structural measure (France)

[e] Insurance (Germany)

2.4 Discussion

Below, the results of Section 2.3 are discussed in relation to the hypotheses formulated in Section 2.2.2.

H1: Our results confirm that several intrapersonal characteristics relate to flood-coping appraisals, partly confirming H1. With 16 out of 30 possible instances, age is the intrapersonal variable that contributes most often to all models (socioeconomic [= 9 times] and complete models [= 7 times]). Effects on flood-coping appraisals are mixed, though. While we find negative relations with response efficacy, it is positive in terms of response cost (i.e., older people perceive these measures as less costly) in the French sample and for insurance in Germany. Contrary to this, older adults in Germany consider structural measures as more costly. Regarding self-efficacy, results differ between the two samples, with positive signs in Germany and negative ones in France. While these results confirm that age significantly relates to flood-coping appraisals as stated in our hypothesis, a general direction of that influence could not be established. In addition, concerning the grouping analysis, age was not significantly related to different groups.

In addition to age, we find that especially income relates to flood-coping appraisals, significantly contributing to 11 out of 30 models (socioeconomic [= 7 times] and complete models [= 4 times]). In line with our hypothesis, people with lower income tend to have lower coping appraisals, particularly in terms of self-efficacy. Lower income relates negatively to SE for several measures in both samples. Lower-income groups also consider structural and non-structural measures as more costly in the French sample (Tables 2-3 – 2-6). The grouping analysis also shows that income relates positively to the "High coping appraisal" groups with regard to structural measures and insurance in Germany (Figures 2-2 (a) – (e)). These findings, which are in line with Babcicky and Seebauer (2017), who find that self-efficacy is lower for lower-income groups, indicate that financial support may be needed to overcome the negative influence of low income on coping appraisals. To enable low-income households to invest in flood risk mitigation measures, income support could be provided in the form of subsidies or low-interest loans to help these households pay for the often high upfront investment costs of implementing flood-proofing measures. To address the issue of affordability, also the distribution of insurance vouchers has been discussed (Michel-Kerjan & Kunreuther, 2011). Contrary results are reported by Ge et al. (2011) for a sample of 599 households in Florida, who found that income was not significantly related to respondents' expectations of participating in a mitigation assistance program.

Mixed results are found for education, which contributes to five out of 30 possible models (socioeconomic [= 3 times] and complete models [= 2 times]). It relates positively to the SE of buying flood insurance, which is in line with Atreya et al. (2015) but negatively to implementing structural measures in France. Further, the grouping analysis indicates that education is positively related to high response costs of non-structural measures, both in Germany and France. Our hypothesis that education relates positively to flood-coping appraisals is thus hardly confirmed, given the mixed effects and the small number of models to which it significantly contributes.

Significant gender differences are detected in five out of 30 models (socioeconomic [= 3 times] and complete models [= 2 times]), partly confirming our hypothesis. In the French sample, for instance, women feel less able (= SE) to implement structural and non-structural measures. These findings are generally in line with Babcicky and Seebauer (2017), who also find that self-efficacy is lower for women. As far as insurance purchase is concerned, we find a different result. In our case, women rate the costs of insurance considerably lower than men, as indicated by comparably large effect sizes. The grouping analysis also shows that gender has a significant influence as far as structural measures and purchasing insurance are concerned (Figures 2-2 (b) and 2-2 (e)). These findings are generally in line with Babcicky and Seebauer (2017), who find that self-efficacy is lower for women and low-income groups.

Overall, it has to be noted that almost all socioeconomic models have a very low explanatory power across almost all types of measures and both countries (Tables 2-1 – 2-4). The only socioeconomic models that have a somewhat higher explanatory power are the ones predicting self-efficacy regarding structural measures and insurance in Germany (Table 2-3). The low explanatory power of socioeconomic results is in line with findings indicating that socioeconomic characteristics are only weakly related to flood and also earthquake mitigation behaviour (Lindell & Perry, 2000; Grothmmann & Reusswig, 2006; Bubeck et al., 2012a).

H2: The hypothesis that flood experience positively relates to flood-coping appraisals is generally not confirmed by our results. The experience of flood damage in the past significantly contributes to only one out of 15 possible complete models, that is, RC of structural measures in the French sample. The same is found in the group analysis. The weak influence of flood experience on flood-coping appraisals in our study could be explained by the way in which this variable was operationalized. Demuth et al. (2016) measure hurricane experience in several different ways, such as through property losses, emotional impact, or evacuation experience, and examine the relations of each variable with SE and RE. In line with our study, no significant effect is found for SE and a negative influence for RE is found, if experience is operationalized in terms of property damage. However, if operationalized in terms of evacuation experience, a positive relation with SE and RE is indeed found. This is explained by the fact that prior evacuation experience provides specific knowledge about this action and its utility and thus raises SE and RE.

Risk perception, that is, the perceived consequences and perceived probability (or risk, in the case of France) of a threat, makes a significant contribution to 10 out of 15 complete models, initially confirming our hypothesis. Mixed results are found for the effects of risk perceptions on coping appraisals. In terms of RE, the perceived probability in the German sample relates negatively only to the purchase of flood insurance. This could be explained by the risk-based premiums and the setup of the German insurance system, which previously denied cover to households in high-risk areas (Thieken et al., 2006). The same argument holds true for the negative influence of perceived probability on SE and RC regarding insurance (Tables 2-3 – 2-6).

In contrast, people who expect greater negative consequences of a flood indicate a higher RE for insurance. An analysis of the mean and median values of response efficacy ratings across the three measures, moreover, shows that insurance is generally considered less effective (mean = 2.64; median = 3.0) compared to structural (mean = 3.09; median = 4.0) and non-structural measures (mean = 3.52; median = 4.0). This can be explained by the fact that insurance does not protect lives or property from being damaged and is not useful for any other purposes. Instead, it merely protects the financial replacement value of the property that may have been damaged or destroyed by a flood (Lindell et al., 2009).

For the French sample, perceived consequences relate negatively to the RE of non-structural measures. Inconclusive results are found between the two samples regarding the relation between perceived consequences and RC. While German respondents who believe in greater consequences of future flood events consider structural and non-structural measures to be less costly, the opposite is indicated for the French sample. This could possibly result from the different time periods in which the flood events occurred, where the flooding was more recent in France. More recent negative experiences with high levels of flood damage and greater perceived future consequences may imply that individuals expect that substantial mitigation efforts will be needed to limit future flood damage to their homes, which would trigger high RC. For instance, Bin and Landry (2013) find that individual flood risk perceptions are high right after a flood has occurred, but decline steadily after a flood event. The difference between the two samples could also stem from differences in flood types. In the French sample, some of the households experienced a coastal flood, which is more destructive (Nadal et al., 2009). This could again imply that respondents feel that substantial mitigation efforts will be needed to limit future flood damage, triggering high RC. These findings are generally also further supported by the grouping analysis. For flood insurance, for instance, a higher perceived probability and past flood damage strongly relate to low coping appraisals, in this case "Only low response cost" (Figure 2-2(e)). This is again related to the aforementioned difficulty for households in high-risk areas to obtain insurance in Germany.

The overall rather weak influence of risk perceptions on coping appraisals is in line with findings indicating that high risk perceptions do not necessarily lead to risk-reducing behaviour (Bubeck et al., 2012a; Wachinger et al., 2013).

H3: Hypothesis 3, stating that fatalism, postponement, and low risk aversion are important personality characteristics that are related with lower coping appraisals is partly confirmed. Nonprotective responses, such as fatalism, avoidance, and postponement, make a significant contribution to only four models out of 15 complete models, all in the expected direction (except for fatalism in the model depicting response cost of structural measures in Germany). For instance, French respondents with a low degree of fatalism indicate a higher SE for structural and non-structural measures.

Also, risk aversion is a significant variable in three out of six complete models. It has to be noted, though, that this variable was only elicited in the French survey. In all models, it contributes in the expected way and in line with expected utility theory (von Neumann & Morgenstern, 1947): people with a higher risk aversion indicate a higher level of response and self-efficacy.

H4: Hypothesis 4, stating that risk and coping information positively relates to coping appraisals, is partly confirmed. The two variables only contribute significantly to two out of 15 complete models. Risk information relates positively to the SE of insurance, and coping information relates positively to structural measures in France, indicating that people who received or sought for information on how they could protect themselves indeed reported a higher SE for these measure categories. Since both information provision and seeking for information were elicited in the same question in the French survey, the two different ways how information reached the respondent cannot be distinguished. Although we are not aware of other studies that examined the influence of coping information on changing flood-coping appraisals, a meta-analysis of PMT studies applied to health risk shows that communicating about coping variables can effectively change people's beliefs about coping measures (Milne et al., 2000).

The group analysis reveals a low significant positive relation between risk and coping information and groups with higher coping appraisals concerning structural measures in Germany and France (Figures 2-2 (a) and 2-2 (b)). These results indicate that coping information material can have a positive effect on coping appraisals, especially in terms of self-efficacy, but that this effect is rather modest.

H5: Hypothesis 5, stating that observational learning from the social environment has a positive influence on coping appraisals, is largely confirmed by our results. The social environment variable, which captures whether respondents perceive that friends, neighbours, and family members have taken mitigation measures, significantly contributes to 10 out of 15 complete models in the expected direction. Particularly strong relationships are found in terms of RE and

SE and, to a lesser extent, also RC. In addition, the grouping analysis indicates a strong relation between the social environment and the "High coping appraisal" groups for structural measures and insurance in Germany (Figures 2-2 (a) and 2-2 (e)). These findings are in line with the PMT and other framework as well as previous studies that demonstrated the influence of the social environment on an individual's protective behaviour (Lindell & Perry, 2012; Brenkert-Smith et al., 2013; Bubeck et al., 2013; Haer et al., 2016; Babcicky & Seebauer, 2017). For most people, it can be difficult to evaluate the effectiveness, feasibility, and costs of a measure without prior flood experience and without actually installing the measure. For instance, it can be difficult for someone to tell how hard (or easy) it will be to claim damage from the insurance company or to deploy sandbags. The fact that one's neighbours have implemented a certain type of measure can thus provide an important cue in terms of its effectiveness, practicality, and expected cost–benefit relationship (Kunreuther et al., 2007; Kunreuther & Michel-Kerjan, 2009).

2.5 Conclusion

Our results confirm other studies that also found that several socioeconomic characteristics are related to individual coping appraisals of flood-preparedness measures, although we find that the overall explanatory power of models that include only socioeconomic variables is weak. Significant relationships between coping appraisals and other intrapersonal characteristics have been found, such as with psychological characteristics like fatalism, postponement, avoidance, and risk aversion. These findings suggest that models that focus solely on socioeconomic characteristics to explain coping appraisals and related mitigation behaviour are unlikely to have strong descriptive validity.

Our findings regarding the observed relationships between coping appraisals on the one hand and flood experience and risk perceptions on the other hand can have important implications for policies that aim to stimulate flood-proofing after flood events. In the aftermath of a flood disaster, there are often calls to "build back better" and there may be possibilities to reconstruct damaged properties in such a way that future flood damage is minimized. Risk perceptions are often assumed to be high after a flood and one may expect that a high threat appraisal will result in a high degree of willingness on the part of households to flood-proof their home. However, we find that flood experience and high risk perceptions may not go hand in hand with higher coping appraisals, and that, in contrast, these variables may even have negative relations to coping appraisals. This highlights the need for policies targeted at improving individual coping appraisals following flood events in order to encourage flood-proof rebuilding.

Communication policies can be an effective way to improve individual coping appraisals. We find that risk and coping information contributes to a greater motivation to implement structural measures or to buy insurance. These findings suggest that effective information provision should focus on both creating risk awareness and providing information on coping measures. Still, risk and coping information is found to make a significant contribution in only a few models. A significantly larger influence than information provision is found for the social environment variable, which takes into account whether respondents perceive that friends and neighbours implement flood risk mitigation measures. This suggests that social norms and networks play an important role in flood-preparedness decisions.

One fruitful avenue for future research could be to investigate how the effect of information campaigns on flood risk and coping options can be enhanced by making use of observed social norms and network effects. Moreover, future research can examine whether or not our findings about the determinants of coping appraisal are applicable to other regions. Although we observe several consistent patterns in our French and German case studies, we also find inconsistent results between the two case studies, as could be expected. These differences could also result from the fact that several items were measured in a slightly different way.

A possible limitation of the present study relates to the consideration of the objective risk, which could also be an important determinant of coping appraisals. This is indicated by our results showing that respondents who live in an unprotected area rate the response efficacy of insurance as lower or exhibit a higher degree of SE in terms of structural measures in France. While we accounted for differences in objective risk by including a variable in the regression models that indicated whether or not respondents think or feel that they live in an area that is protected by structural flood defenses, this is only a rather rough indication of the objective risk. Further insights into the relationship between objective risk and coping appraisals could be gained in future studies by including a more detailed differentiation in terms of the objective risk, for example, due to distance from the river, housing type, or elevation.

Given the substantial research efforts that have been devoted to analysing flood risk perceptions around the world, we believe that coping appraisals have received insufficient attention. This is remarkable, given the large influence coping appraisals have on flood-preparedness behaviour. We hope that our study provides a useful starting point for similar studies in other countries.

2.6 Acknowledgments

The authors would like to thank two anonymous reviewers for their valuable comments provided during the review process. The presented work was partly developed within the framework of the Research Training Group "Natural Hazards and Risks in a Changing World" (NatRiskChange) funded by the Deutsche Forschungsgemeinschaft (DFG; GRK 2043/1), the NWO VICI Grant Nr. 453-13-006, NWO VIDI Grant nr 452.14.005, and the EU-ENHANCE FP7 project (Enhancing risk management partnerships for catastrophic natural hazards in Europe) under grant agreement no. 308438.

2.7 Supporting information

Additional supporting information is given in Appendix A

Table A-1 Variable Definitions of the German Survey Analysis

Table A-2 Variable Definitions of the French Survey Analysis

Table A-3 Intercorrelation Table for the German and French Samples

Figure A-1 Example of a PCA ordination plot with hypothetical data.

3 Damage Assessment in Braunsbach 2016: Data Collection and Analysis for an Improved Understanding of Damaging Processes during Flash Floods

Abstract

Flash floods are caused by intense rainfall events and represent an insufficiently understood phenomenon in Germany. As a result of higher precipitation intensities, flash floods might occur more frequently in future. In combination with changing land use patterns and urbanisation, damage mitigation, insurance and risk management in flash-flood-prone regions are becoming increasingly important. However, a better understanding of damage caused by flash floods requires ex post collection of relevant but yet sparsely available information for research. At the end of May 2016, very high and concentrated rainfall intensities led to severe flash floods in several southern German municipalities. The small town of Braunsbach stood as a prime example of the devastating potential of such events. Eight to ten days after the flash flood event, damage assessment and data collection were conducted in Braunsbach by investigating all affected buildings and their surroundings. To record and store the data on site, the open-source software bundle KoBoCollect was used as an efficient and easy way to gather information. Since the damage driving factors of flash floods are expected to differ from those of riverine flooding, a post-hoc data analysis was performed, aiming to identify the influence of flood processes and building attributes on damage grades, which reflect the extent of structural damage. Data analyses include the application of random forest, a random general linear model and multinomial logistic regression as well as the construction of a local impact map to reveal influences on the damage grades. Further, a Spearman's Rho correlation matrix was calculated. The results reveal that the damage driving factors of flash floods differ from those of riverine floods to a certain extent. The exposition of a building in flow direction shows an especially strong correlation with the damage grade and has a high predictive power within the constructed damage models. Additionally, the results suggest that building materials as well as various building aspects, such as the existence of a shop window and the surroundings, might have an effect on the resulting damage. To verify and confirm the outcomes as well as to support future mitigation strategies, risk management and planning, more comprehensive and systematic data collection is necessary.

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3.1 Introduction

Flooding is a common hazard in central Europe, resulting in high economic losses (Munich Re, 2017). To promote and tailor local planning, flood risk management policies such as the European Floods Directive (2007/60/EC) set up framework conditions for member states to implement flood risk management on national, regional and local levels. Risk assessments and policy decisions are expected to take different flood types into account (e.g. coastal floods, riverine floods, pluvial floods, flash floods), according to the local circumstances (BMUB, 2007). In Germany, for instance, storm surge and river flooding are dominant and were therefore considered risks with national significance. Due to recent severe riverine flooding in eastern and southern parts of Germany, particularly in August 2002 and June 2013, the flood risk management system and the relevant legislation have been substantially improved by the Omnibus Flood Protection Act of 2005 and the EU Floods Directive (2007/60/EC) and its implementation in the Federal Water Act of 2009 (e.g. Thieken et al., 2016b). In support, a large body of literature exists that addresses the topic of riverine flooding in Germany and its effects as well as demands on people, policy makers and general planning. In this regard, risk assessment strategies and effects of preparedness decisions are presented and extensively discussed with a strong focus on recent major riverine flood events. (e.g. Bubeck et al., 2013; Kienzler et al., 2015b; Bracken et al., 2016; Osberghaus & Philippi, 2016; Thieken et al., 2016b; Kundzewicz et al., 2017). However, when implementing the EU Floods Directive in Germany, surface water flooding and flash floods were not considered significant risks and were thus neglected. This assessment is currently questioned due to destructive flash flood events in May and June 2016 that caused damages of EUR 2.6 billion (Munich Re, 2017).

Flash floods are defined as rapid flood events as a result of very intense, timely and concentrated precipitation, which is potentially enhanced by orographic features (Gaume et al., 2009; Borga et al., 2014). According to Gaume et al. (2009), flash floods can be triggered by diverse hydrological and meteorological processes and are, compared to riverine and pluvial flooding, associated with a higher number of fatalities. Whereas pluvial floods are related to urban areas and caused by sewage overflow and surface run-off (Maksimovic´ et al., 2009), flash floods usually occur in mountainous regions, where they can trigger debris flows and/or hyperconcentrated flows. Debris flows and hyperconcentrated flows are characterised by the amount of transported and suspended sediment. With a sediment concentration between 60 and 80 volume per cent, the quantity of solid material is often higher for debris flows than for hyperconcentrated flows (Gaume et al., 2009). Both flow types show a variation in grain size distribution and deposition characteristics as well: while debris flows potentially carry large debris, boulders and gravel, hyperconcentrated flows transport finer sediments (Pierson & Costa, 1987; Gaume et al., 2009; Totschnig et al., 2011; Hungr et al., 2013; Borga et al., 2014).

Weather extremes in Europe are expected to occur more frequently, leading to strong storms, droughts and heavy precipitation in various regions (Beniston et al., 2007; Murawski et al., 2015; Volosciuk et al., 2016). More intense and concentrated rainfall in central Europe might increase the hazard of severe flash flood events, not only in mountainous regions but uplands as well, affecting regions which were previously not perceived as flood-prone. Further, an increased risk due to a change in exposed objects and their vulnerability can be detected, which is mainly influenced by urbanisation and economic growth as well as changing land use patterns (Thieken et al., 2016c; European Environment Agency, 2017). As a result, flash floods are progressively perceived as a serious hazard in central Europe. Yet, the implications on elements at risk are poorly understood and assessing their vulnerability, also in comparison to riverine floods, is challenging.

Vulnerability can be defined as the tendency for elements at risk to suffer negative effects and damage if affected by a specific hazard (Cardona et al., 2012). Regarding flash floods, vulnerability and risk estimations were already conducted in several studies. For instance, Papathoma-Köhle (2016) pointed out that vulnerability assessments for flash floods or debris flows need to be reviewed and adjusted constantly. In her study, an indicator-based method was used for assessing the vulnerability of elements at risk which are exposed to debris flows in South Tyrol. In this regard, the relevance of building characteristics and location for vulnerability estimations were highlighted. Similarly, Fuchs et al. (2012) conducted a study which describes the vulnerability of elements at risk, based on clusters of similar damage ratios caused by flood events. This spatial approach revealed that higher damage ratios are not only a result of stronger floods, debris flows or hyperconcentrated flows, but are also dependent on land-use patterns and the characteristics of the elements at risk, such as the type and year of construction. With regard to non-alpine environments, Hlavčová et al. (2016) performed a post-hoc analysis of three strong flash flood events which occurred between 1988 and 2004 in northern Slovakia, focusing on the hydrology as well as hydraulic and topographic properties of the catchment areas. They showed that the modelling of flash flood events is accompanied by major uncertainties due to the lack of data and overall non-linear relationship between precipitation, run-off and catchment properties.

Concerning flash floods in central Europe and particularly non-alpine environments, we are in the early stages of understanding specific and subsequent damaging processes from such floods. Especially in respect to vulnerability estimations of the elements at risk as well as the damage driving factors, flash floods are insufficiently understood. Yet, it can be assumed that damage processes of flash floods differ from those of riverine floods, highlighting the need for elaborate research in this field. Riverine floods commonly emerge on the basis of large catchment areas after long-lasting rainfall or snowmelt, which leads to high surface and groundwater run-off and relatively slow-rising water levels. In contrast to riverine floods, flash floods originate from catchments in which geographical features such as steep slopes and defined channels result in rougher flow dynamics in terms of velocity, sediment transport and discharge (Borga et al., 2014). Here, potential damage to buildings comprises erosion and physical impacts, which, on the other hand, do not seem to be distinct damage patterns in riverine flooding (Kreibich et al., 2009).

To obtain a better understanding of the damage processes of flash floods as well as of effective mitigation options, a comprehensive damage database that links process dynamics and intensities with damage and loss is needed, but is currently not available. Consequently, we present the flash flood in Braunsbach, a town in the district of Schwäbisch Hall in Baden-Württemberg, Germany, as a case study, having collected and analysed data in order to add to the knowledge of damage caused by flash floods and governing factors.

Intense rainfall at the end of May and beginning of June 2016 over central Europe led to severe surface water flooding and flash floods, which were partly accompanied by mud and debris. Several municipalities mainly in the south of Germany were hit, eleven people lost their lives and infrastructure and buildings were heavily damaged (GDV, 2016). The insured losses of these events amounted to EUR 1.2 billion (GDV, 2016) and the overall loss was estimated at EUR 2.6 billion (Munich Re, 2017), an extraordinary monetary loss caused by flash floods in Germany. The district of Schwäbisch Hall in Baden-Württemberg was particularly affected. Moreover, at the beginning of June 2016 the municipality of Rottal-Inn in southern Bavaria was hit by flash flooding, triggered by the same weather conditions (GDV, 2016).

A small village in Schwäbisch Hall named Braunsbach faced an especially severe flash flood on 29 May that caused high damage to buildings and infrastructure. The village of Braunsbach contains just about 1000 residents, yet due to the devastating character and abruptness of this event, the media attention was high and policymakers were interested. The monetary losses for the municipality of Braunsbach (2500 residents) were estimated at EUR 104 million, which is more than 90 % of the estimated EUR 112 million of total damage in Schwäbisch Hall (Landkreis Schwäbisch Hall, 2016). The catchment of the creek primarily responsible for the inundation in May 2016, the Orlacher Bach, is only about 6 km2 in size and characterised by steep slopes, in which the stream descends 180 m over a distance of 3.1 km. Heavy rainfalls in the catchment area between 18:45 and 20:00 of 29 May resulted in an estimated accumulated precipitation of 60 mm, based on radar data which was recorded 70 km south of Braunsbach. Due to inconsistencies and attenuation effects, the data were corrected up to 153 mm after the approach of Jacobi and Heistermann (2016), (see Bronstert et al., 2017). The extraordinary rainfall patterns finally led to the severe flash flood, which was accompanied by massive amounts of debris and rubble. Streets along the main run-off channel were blocked by layers of debris, up to a thickness of 2 to 3 m, while numerous houses in the area showed severe structural damage. Given the town size, event duration and catchment area, the losses were extremely high. Eventually, this event and similar cases of severe flash flooding in Germany triggered a reassessment of local risk and revealed that the processes and impacts of flash floods are insufficiently understood (in Germany), also showing that research on and management of this particular flood type needs to catch up, particularly in comparison to river floods.

Our research paper follows two major objectives. Using the flash flood in Braunsbach as a case study, it is aimed at identifying, analysing, comparing and discussing factors that govern damage caused by this event, applying different linear and non-linear methods. As a second issue, the digital methods used for the ex post damage data collection in Braunsbach and the creation of this database are presented and discussed to demonstrate accompanying challenges as well as successes during the field work.

3.2 Methods

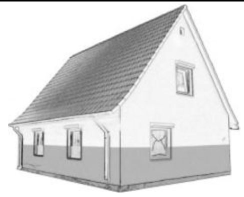
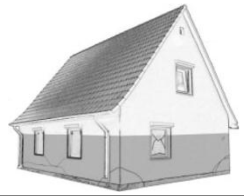
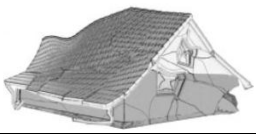
Collecting and analysing data on structural and non-structural damage to buildings is valuable for understanding specific damage processes, helping to design and assess effective mitigation measures and creating damage models which can be used to estimate potential monetary losses ex ante. Thus, a digital survey was designed to collect relevant information in Braunsbach which can be used for detailed post-hoc analysis. The type of recorded information is based on existing literature on flood damage surveys (e.g. Thieken et al., 2005; Schwarz & Maiwald, 2007; Merz et al., 2010b; Molinari et al., 2014)

3.2.1 Contents of the survey

The survey as well as the data collection was implemented with KoBoCollect, a self-explaining and network-based open-source software which was developed by the Harvard Humanitarian Initiative together with the Brigham and Women's Hospital in 2014 (KoBoToolbox, 2016). The software is designed for quick and reliable information collection after natural disasters or in humanitarian crises. Open-source software, as a method for data collection and gaining knowledge, is increasingly becoming important within the field of natural hazards (Eckle et al., 2016; Klonner et al., 2016). For instance, OpenStreetMap (OSM) and other voluntary geographic information services help to create comprehensive databases of up-to-date geospatial data which also can be used for natural risk assessment (Schelhorn et al., 2014; Vaz & Arsanjani, 2015; Yang et al., 2016).

The gathered information in Braunsbach included an estimation of damage grades of the affected buildings ranging from D1 (no structural damage, slight non-structural damage) to D5 (very heavy structural damage, very heavy non-structural damage). For this classification, the scheme developed by Schwarz and Maiwald (2007) was adopted to obtain a consistent database and to ensure comparability with follow-up studies and with data on riverine flood damage (Table 3-1). Since monetary losses could not be recorded shortly after the event, this classification scheme further offers options for potential subsequent loss estimations. Additionally recorded information included the GPS coordinates, the address (for internal computational use only), the inundation depth at the building in centimetres, visible damage caused by debris, visible contamination by oil or sewage, the building material and type, specific precautionary measures at the building, the building usage (residential, commercial, public, etc.), the number of storeys and types of outbuildings, the estimated year of construction, the perceived condition of the building before the event, existing shop windows on the ground floor, the existence of a cellar, the sealing degree of the near surroundings and the exposition (of the building) in flow direction. All variables except for the address, inundation depth, storeys and the estimated year of construction were pre-coded with the option to record open answers or NA values, resulting in a nominal-, ordinal- and interval-scaled data structure. The complete survey with variable descriptions can be seen in Table 3-2. A more detailed description of the data set, as well as the anonymised data, can be found in Vogel et al. (2017a).

Table 3-1 Assignment of damage grades Di to damage cases: examples from the flood in August 2002 (after Schwarz & Maiwald, 2007)

Damage grade	Damage pattern (sketch)
D1: no structural damage, slight non-structural damage − moisture penetration of walls and ceilings	
D2: no structural damage to slight structural damage, moderate non-structural damage − moisture penetration and contamination − small cracks in walls, dented doors and windows	
D3: moderate structural damage, heavy non-structural damage − larger cracks in walls, dented doors and windows − beginning subsidence of the building − replacement of building components necessary	
D4: heavy structural damage, very heavy non-structural damage − collapse of load-bearing walls, large cracks − replacement of load-bearing components necessary	
D5: no structural damage to slight structural damage, moderate non-structural damage − collapse of large building parts − demolition necessary	

3.2.2 On-site data collection

The on-site damage assessment was carried out between 7 and 8 June 2016, i.e. 9 to 10 days after the event. The digital survey was conducted by a team of five researchers who investigated all buildings in Braunsbach affected by the flash flood using mobile tablet computers with an integrated GPS function.

Some of the flooding characteristics, such as flow velocities and grain size as well as the degree of erosion and amount of suspended material, could not reliably be determined in the aftermath of the event. Hence, the exposition of the building was used as a proxy instead. It is assumed that the degree of exposition can be related to flow velocities, hydrostatical forces and (to a certain extent) to sediment/debris load, which in turn leads to different erosion rates at the buildings' foundation. The exposition in flow direction describes the exposition of building walls, corners or parts to the direction and area of the main run-off channel. In this case, a high exposition means that at least one side of the building was fully exposed to water and potential debris flows. A medium exposition was assumed when parts of the building were exposed. Sheltered buildings are characterised by a low exposition.

A thermographic camera (model Testo 876, 160 120 pixels) was used to validate and to derive the inundation depth in such cases, where a reliable estimation through visible traces and marks was not possible. This was done by detecting the remaining moisture in the walls – caused by inundation – through slight differences in surface temperature. A second advantage of the thermographic camera was the detection of different building materials, which may be covered externally (i.e. plastered half-timbered houses could still be identified as such; see Vogel et al., 2017b).

Table 3-2 Features of 94 buildings affected by flooding in Braunsbach, Germany, recorded between 7 and 8 June 2016, and their frequency of occurrence (continues on page 44).

Variable	Characteristics	No.[a]
Damage grade	D1 (no structural damage, slight non-structural damage)	39
	D2 (no to slight structural damage, moderate non-structural damage)	34
	D3 (moderate structural damage, heavy non-structural damage)	5
	D4 (heavy structural damage, very heavy non-structural damage)	6
	D5 (very heavy structural damage, very heavy non-structural damage)	5
	No damage	5
	NA	0
Inundation depth	Integer value	88
	NA	6
House type	Single-family house	46
	Apartment building	25
	Semi-detached house	3
	Terraced house	0
	NA	20
Building material	Masonry	71
	Half-timbered	26
	Wood	10
	Concrete	0
	Steel	0
	Rubber	0
	NA	1
Building usage	Residential	58
	Commercial	8
	Combined/mixed	21
	Public services	6
	NA	1
Near surrounding sealed	Yes	64
	Mainly yes (small areas around not sealed)	21
	Mainly no (larger areas around not sealed)	8
	No	0
	NA	1
Exposition in flow direction	High (at least one side of the building fully exposed to water flow)	34
	Medium (parts of the building exposed to water flow)	34
	Low (sheltered by other buildings/slightly exposed to water flow)	26

	NA	0
Damage caused by debris	Yes	55
	No	37
	NA	2
Building condition before event	Good	45
	Medium	46
	Bad	1
	NA	2
Outbuildings present	Yes	32
	No	59
	NA	3
Type of outbuilding	Garage	11
	Carport	1
	Barn	8
	Shed	7
	Summerhouse	1
	Greenhouse	0
	Conservatory	0
	Other	7
Number of storeys	Integer value	93
	NA	1
Shop window	Yes	18
	No	74
	NA	2
Having cellar	Yes	30
	No	57
	NA	7
Estimated construction year	Integer value	88
	NA	6
Structural precaution	Higher ground floor	19
	Different (building) materials (of cellar and ground floor)	24
	Protection of cellar duct	3
	Other	4
	No precaution	49
	NA	3
Contamination visible	Yes	77
	No	15
	NA	2
Contamination type	Oil	4
	Chemicals	0
	Sewage	0
	Mud	77
	Other	0

NA means not available

3.2.3 Post-hoc data analysis

The data were preprocessed and analysed/prepared in R 3.3.1 and QGIS 2.14.3, using the R packages randomForest, randomGLM and nnet. Since our study aims to identify and analyse damage driving factors of flash floods, the following variables and binary-coded variable expressions were considered and used as predictor variables for the damage grades:

- Building material (binary-coded):
  – masonry (selected also in case of unidentifiable building material)
  – wood
  – half timbered.

- Precaution (binary-coded):
  – different (building) materials (of cellar and ground floor)
  – higher ground floor
  – no structural precaution visible.

- External forces:
  – inundation depth
  – exposition in flow direction
  – contamination visible (binary-coded).

- Resistance parameters:
  – (building) condition before event
  – estimated construction year.

- Various:
  – shop window present (binary-coded)
  – near surrounding sealed
  – having cellar (binary-coded)
  – outbuilding present (binary-coded)
  – private building usage (binary-coded).

The choice of the variables which were specifically analysed was based on both judgements (e.g. if the near surrounding is sealed or if an outbuilding or shop window is present) and the existing literature. Here, Thieken et al. (2005), Merz et al. (2010) and Maiwald and Schwarz (2015) give an overview of important damage-influencing factors in cases of (river) flooding, including building characteristics, precaution measures and contamination.

3.2.3.1 Models and correlation tests

Detecting non-linear and non-monotonic relationships within recorded data becomes increasingly important with regard to flood loss modelling and associated uncertainties (Kreibich et al., 2016). Consequently, a random forest model (RF) (Breiman, 2001) was chosen as a method of analysis due to its potential to display non-linear relationships between variables. The random generalized linear model (RGLM) (Song et al., 2013) was constructed as an alternative model to compare the results of the non-linear RF to a method which implies linear variable coherences. Both models use the same predictor variables and the damage grade as dependent variables (excluding cases where no damage was recorded) in order to identify potential damage driving factors (Figures 3-1 and 3-2).

The RF is calculated with 500 trees and 4 random variables per split. The number of trees represents the default settings of the algorithm. The number of variables per split corresponds to the square root of the total variable count (16 in this case, resulting in 4 random variables per split). The RGLM takes 100 iterations with 50 samples per iteration (bag) and a varying count of variables (2 to 16) per bag. Also, the number of iterations within the RGLM represents the default settings. The number of samples per bag was set to two-thirds of the total number of observations in the data set (73 in this case due to the need to complete observations, resulting in 50 observations selected by bootstrapping). The count of variables per bag is randomly chosen between 2 and the total count of variables. The variable/feature importance of the RF is given by the Mean Decrease Gini, which describes the loss in model performance when permuting the feature values (Breiman, 2001). A higher Mean Decrease Gini indicates higher importance of the particular variable for the RF model prediction. The feature importance of the RGLM is expressed through the selection count of a variable for the model prediction.

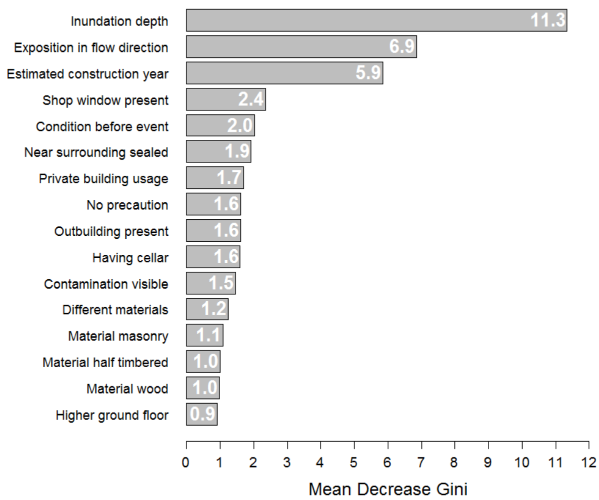


Figure 3-1 Random forest feature importance (Mean Decrease Gini) for the response variable damage grade

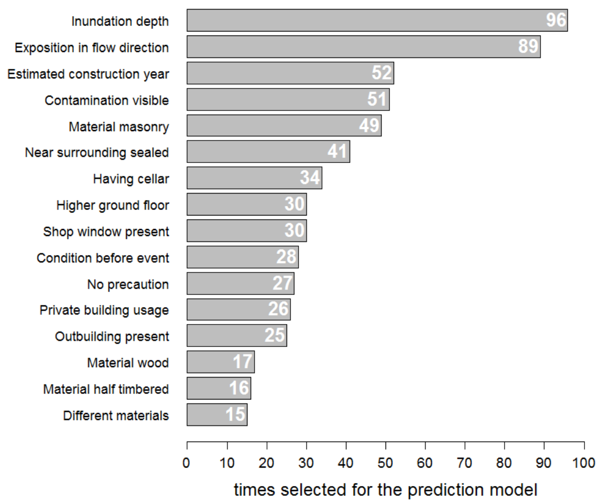


Figure 3-2 Random generalized linear model feature importance (times selected) for the response variable damage grade

By using feature-forward selection, a higher selection count of a particular variable indicates a stronger predictive power within the RGLM model (Song et al., 2013). The performance of both models is given by the rate of false classifications, based on the out of bag predictions. The relative number of cases which were not recognised as the true class is hereby shown in per cent (see Section 3.3.2).

Categories with a nominal variable structure (i.e. building usage, building material and structural precaution measures) exist in a binary format, allowing for basic correlation tests. Thus, the identified feature importance from the models was compared to the results from a Spearman's rank correlation matrix. The Spearman's rank correlation was chosen due to its advantage of being suitable to analyse variables with different scales of measurements and indicates the strength of monotonic relationships. Here, the same variables as in the RF and RGLM models were used (Figure 3-3). An exhaustive list of variable correlations is attached in Appendix B (Figure B-1), which is based on 51 complete observations within the data set.

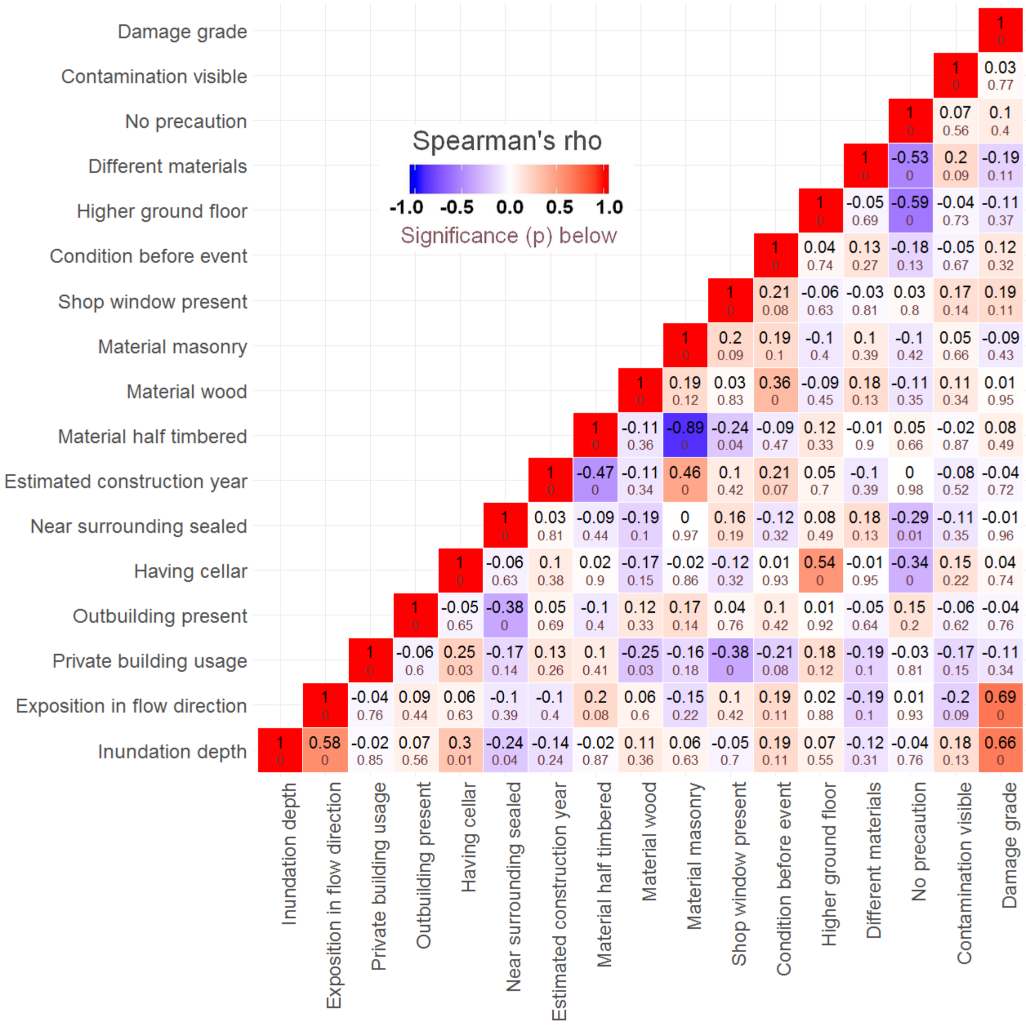


Figure 3-3 Spearman's rank correlation matrix and correlation significance of relevant variables (see Table 2 for a description of the variables). The count of complete cases for the analysis was 73

Furthermore, a multinomial logistic regression was applied to test variable coherences between the damage grades and a local impact indicator (Figure 3-6) which describes a combination of inundation depth and the buildings' exposition in flow direction (the construction of the local impact indicator is explained in Section 3.2.3.2). By treating the damage grade as a categorical variable, the multinomial logistic regression model gives probabilities of category affinity, given a specific local impact. In order to obtain more data points per category and to reduce modelling uncertainties, the damage grades 3, 4 and 5 were combined into a single class (compare Table 3-1). The inherent calculations are based on artificial neural networks (Ripley, 1996; Venables & Ripley, 2002) which again do not require any model-specific assumptions such as linearity.

3.2.3.2 Derivation of a local impact indicator

Maiwald and Schwarz (2015) give an up-to-date overview of factors which influence structural damage to buildings in cases of flooding. The building material, condition (before the event) and age are especially important factors that are related to a building's resistance potential. Factors such as inundation level, flow velocity, fluid density, specific energy and contamination relate to "action" parameters and describe external forces (Maiwald & Schwarz, 2015; Milanesi et al., 2015). Thus, in our study, the inundation depth measured at the building and the building's exposition in flow direction were combined to create a local impact value, which can be seen as a proxy for local flood-related impact and hydrostatical forces at the building. Consequently, we chose a combination of these factors where both contribute to equal extents. While the inundation depth has continuous values which are roughly uniformly distributed between 2 and 360 cm for 88 recorded observations (see Table 3-2), the exposition in flow direction is recorded in three classes (low, medium, high; see Table 3-2). To achieve comparable variable ranges, the exposition classes low, medium and high are transformed into the mean values of the lower (29 observations), middle (30 observations) and upper third (29 observations) of recorded water levels. The derived values 56, 135 and 232 fit into the range of observed water levels, enabling a combination of both attributes (Figure 3-4). The calculated local impact corresponds to the sum of water level and transformed exposition value. Please note that the exposition values are not used to replace water levels but are only transformed into a comparable range.

Furthermore, a local impact map was created in QGIS (Figure 3-5) by calculating Voronoi diagrams for the geocoded data points and solely displaying the area with affected houses. For simpler visual appearance and better distinction of the displayed data, the Voronoi diagrams were smoothed with a Gaussian filter. The local impact map is used for visualisation and comparison of the local impact indicator to the spatial distribution of the damage grades, since potential areas of similar local impact between and around the buildings are shown. However, it has to be noted that the local impact was measured directly at the buildings and is therefore hypothetical for the surrounding areas.

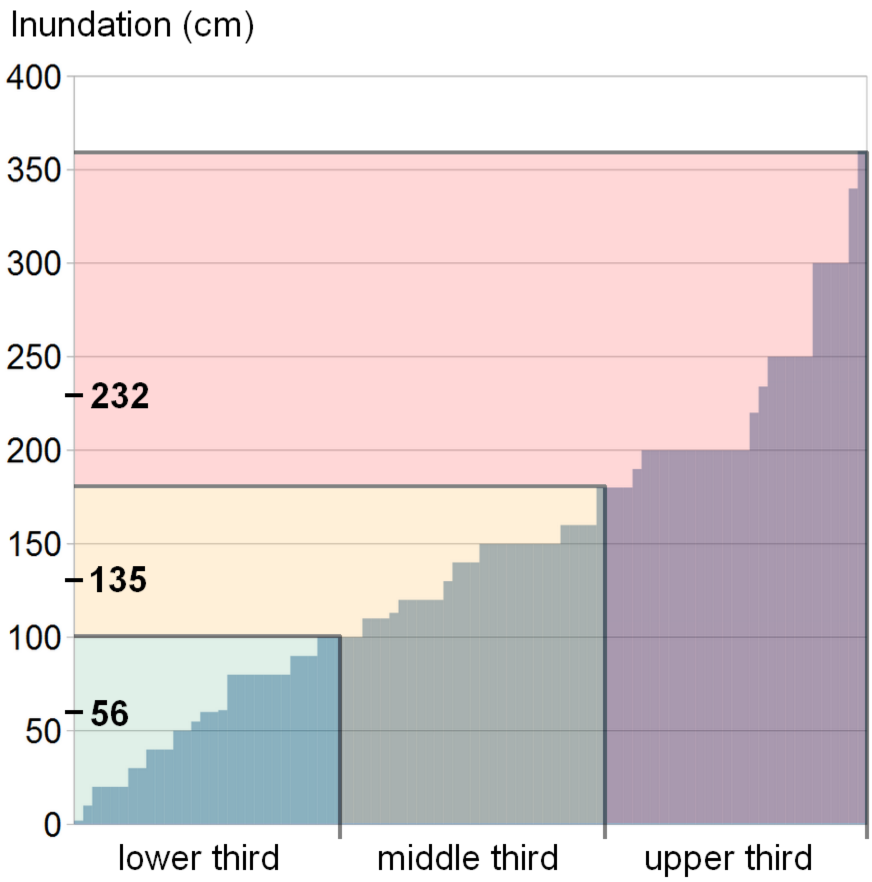


Figure 3-4 Deriving the local impact indicator. The recorded inundation depth is sorted in ascending order. By sorting, the relatively uniform distribution of the inundation values is shown, which allows for the general procedure. On the left, the mean values of the lower, middle, and upper third of the sorted inundation depth (56, 135, 232 cm) are given, which were used to replace the exposition classes, low, medium and high. This step enables a comparable variable range and the derivation of an interval-scaled indicator for further analysis

3.3 Results and discussion

The flash flood in Braunsbach was accompanied by a considerable amount of sediment and building rubble, potentially showing flow characteristics of debris flows such as those defined by Totschnig et al. (2011), Hungr et al. (2013) and Borga et al. (2014). Yet, a clear distinction between flash floods and debris flows is not always straightforward and could not be reliably determined in the field. Throughout our discussion, we will therefore use the term “flash flood” only. The following section begins with a general reflection on the data collection process, limitations and data quality. Thereafter, the damage-influencing factors are identified and discussed by applying different linear and non-linear methods. Finally, features such as the local impact and the damage grades are spatially visualised, helping to discuss our outcomes and illustrating the flash flood processes in Braunsbach.

3.3.1 Data collection and field work; assumptions and limitations

The in-field work load can be estimated at roughly 10 h, in which a team of five researchers was able to survey 96 buildings in Braunsbach (corrected to 94 observations after database checks), each specifying 18 variables. In addition, a picture has been taken along with the coordinates, the address and, if needed, further details regarding the building's usage. Table 3-2 provides an overview of the data types and frequency distributions. One week after the event, the structural damage to buildings and building characteristics were still assessable, since the main work within this period was focused on clearing the roads and establishing paths for large construction machinery as well as removing and cleaning the interior of affected buildings. The progress of the clean-up work was even beneficial for the damage assessment to a certain degree, as a thick layer of debris and rubble previously covered big parts of the damaged buildings. However, a few buildings could not be reliably examined, since debris and rubble were still considerably hampering the access.

When handling the thermographic camera it has to be pointed out that, even 1 week after the event, remaining moisture and visible traces could still be detected without problems. Yet, ascending humidity in the walls is a point to consider when using a thermographic camera for water level estimations. Rising moisture can distort the observation of actual water levels at the building. For that reason the thermal images were checked against estimations based on visible mud contamination and marks caused by water and transported debris as well. Since the thermally derived water levels matched well with visible traces, the inundation depth for buildings derived from thermal images could be accepted without any correction. Still, when using a thermographic camera for water level estimations on buildings, it has to be considered that the type of flood (flash flood, riverine flood) has an effect on the duration of the inundation and thus on the distinctness of visible moisture boundaries. Considering the short inundation times in Braunsbach, the overall good visibility of moisture boundaries was remarkable.

Overall, the in-field data collection was greatly facilitated by the use of KoBoCollect in terms of speed, handling of the gathered data and efficiency of data processing and analysis. However, to create a uniform database and to maintain consistency among the different team members throughout the data collection process, objective criteria for items such as the structural damage had to be defined. Therefore, careful preparations and agreements were carried out prior to the field trip off site as well as on site. In retrospect, we consider the data to be consistent because the team members had very similar opinions, e.g. on the damage grades or exposition in flow direction. Thus, a bias in the data set due to personal variations in expert judgement is expected to be low. This assumption is further supported by the engineering analysis of Maiwald and Schwarz (2016), who applied the same damage classification system to assess the buildings structural damage in Braunsbach. Their report reveals that the distribution of the recorded damage grades after a second inspection (D1: 40, D2: 43, D3: 5, D4: 7, D5: 3) is relatively similar to the distribution presented in this study (D1: 39, D2: 34, D3: 5, D4: 6, D5: 5 as shown in Table 3-2). Although it is not known which damage grade was assigned to which building, it is likely that, even among people with different qualifications (experienced engineer, researcher or student), comparable results can be achieved and data collection can be consistent. This offers interesting options for crowd-sourced information collection using open-source software such as KoBoCollect, which can be helpful for scientific research.

3.3.2 Models and correlation tests

First, the collected data were used to identify damage driving factors by creating a random forest model (RF) and a random generalized linear model (RGLM) with the damage grade as response variable. In a next step, a Spearman's rank correlation matrix was constructed. In the following, the different model and correlation results are discussed and compared to each other.

The post-hoc data analysis revealed that the RF and RGLM both show a relatively poor model performance, based on the false classifications. Here, the percentages of false classifications for the RF are 33.3 % for damage grade D1, 41.9 % for D2 and 100 % for D3 and higher. The RGLM performed slightly better with a false classification of 33.3 % for D1 and 41.9 % for D2, 20 % for D3, 80 % for D4 and 100 % for D5. However, trends and relations of predictor variables with the damage grade can be derived. Both models give the highest feature importance for the damage grade to the inundation depth and the exposition (of the building) in flow direction. Here, the Mean Decrease Gini for the RF were 11.3 and 6.9 (average: 2.7), whereas the RGLM feature selection counts in 100 iterations were 96 and 89, respectively (average: 39) (Figures 3-1 and 3-2). It is further shown that the RGLM compared to the RF indicates a different variable importance hierarchy for variables other than the inundation depth, the exposition in flow direction and the estimated construction year. This is due to different internal calculations of the variable importance, as explained in Section 3.2.3.1. Yet, this issue also suggests that, apart from the inundation depth, the exposition in flow direction and possibly the estimated construction year, differences in variable importance are less distinct in both models and the predictive power is low, which hampers the interpretation of the importance hierarchy when comparing both models.

Regarding the correlation tests, the highest positive (and significant) correlations can be seen between the damage class and the exposition of the building in flow direction as well as the damage class and inundation depth with values of 0.69 and 0.66, respectively (Figure 3-3). Hence the correlation analysis strongly confirms the results of the RF and RGLM. The detected a strong link of the exposition of the building in flow direction and the inundation depth to the caused damage makes sense, given the nature of the event and the mass of debris, water and mud flowing down the main channels within the village of Braunsbach. These results are confirmed by Maiwald and Schwarz (2016) as well, who identified the exposition of a building to the flow direction as an important parameter for potential structural damage. A high exposition in flow direction can be related to a higher flow force of water, higher flow velocities and intensities acting on a building. Investigations on these parameters regarding riverine floods by Kreibich et al. (2009) resulted in weak correlations with recorded damage grades of residential buildings. It is revealed that the exposition in flow direction is an especially significant damage driving factor of flash floods which does not show strong importance in riverine flooding.

The estimated construction year of a building displays a certain importance within the RF as well as the RGLM model with a Mean Decrease Gini of 5.9 and a feature selection count of 52 (see Figures 3-1 and 3-2). In this case, the correlation analysis does not reveal any significant monotonic relationships between the estimated construction year and the damage grade (Figure 3-3). Additionally, the building condition before the event displays only slight importance within the RF and a slight, non-significant correlation with the damage grade. Since the construction year is related to the overall preservation and the building's state of the art in terms of technology, it can still be assumed that newer buildings or buildings in a better condition have a higher resistance to structural damage. This is in line with Maiwald and Schwarz (2015), who consider the building age and condition to have an influence on the expected structural damage.

Further, a positive correlation, but of low significance, can be observed between the damage grade and the existence of a shop window with a value of 0.19 and a p value of 0.11 (Figure 3-3). Accordingly, the RF model shows a certain variable importance with a Mean Decrease Gini of 2.4 (Figure 3-1). Here, it can be assumed that a trend towards higher damage grades caused by shop windows on ground level which – if they break – create debris and water paths into the building. Also Maiwald and Schwarz (2016) underline the fact that broken windows may allow water and debris to accumulate inside the building, causing damage to sustaining building structures. Yet, our results might also be affected by the fact that, in this case study, buildings with shop windows mainly occur along the main street and city centre and are therefore located inside the main flow channels.

No (obvious) precaution at the property level indicates a slightly higher chance of higher damage by displaying a positive correlation of 0.1 with the damage class, although the significance is low (p value 0.4) and there is no remarkable importance within the RF and the RGLM models. Yet, this is in line with the negative correlation between the damage class and the precaution measure "different (building) materials (of cellar and ground floor)" of 0.19 which in fact shows a low significance (p value 0.11) but still allows for meaningful assumptions. This is supported by Thieken et al. (2005) and Merz et al. (2010), who claim that different precautionary measures significantly reduce the damage to buildings in the case of flooding. Still, the question arises as to what degree precautionary measures, which were effective at riverine flooding, are suitable for mitigating structural damage to buildings in cases of flash flooding.

The building material masonry seems to have a slight damage-reducing effect by displaying a negative correlation of 0.09 (p value 0.43) with the damage class, while the half-timbered building material shows a very slight but non-significant positive correlation of 0.08 (p value 0.49) with damage. Interestingly, the RGLM model only considers the building material masonry as relatively important for the damage grade prediction, whereas the RF does not display a significant feature importance for all building materials. Although it is not clearly shown which distinct building material is related to lower structural damage, it can be assumed that if being hit by debris, half-timbered houses are more susceptible to structural damage than houses made of masonry and concrete due to their lower structural stability (Schwarz & Maiwald, 2007).

Overall, when performing detailed analyses such as models and correlation tests it has to be considered that the database of 94 data points is rather small and assumingly insufficient for creating representative and universal results. This fact could also explain the low model performance and low significance in some of the cases discussed above. Nonetheless, it is important to point out the strong correlations in many cases of up to 0.69 (damage class and exposition in flow direction) revealing obvious damage driving factors and showing as well that the data collection within the team of different researchers was consistent.

3.3.3 Evaluation of the local impact

In Figure 3-5, the town of Braunsbach as well as the corresponding local impact during the event and recorded damage grades are illustrated. The map reveals that highly damaged buildings and a strong local impact – which relates to hydrostatical and impact forces at the building (see Section 3.2.3.2) – occurred along the main run-off channels of water and debris during the event. Higher damage grades were also recorded in the lower-lying town regions, where the tributaries Orlacher Bach and Schlossbach flow into the river Kocher, since debris and water accumulated in these areas and caused severe structural damage. Most of the higher damage grades are located in high local impact areas. Yet, especially in those areas, the degree of damage differs strongly, highlighting the complexity of damage driving processes that cannot be explained by the local impact alone. The flow characteristics of debris and rubble during severe flash floods can be unforeseen and influenced by chaotic factors, changing sediment deposition as well as bedload processes (Totschnig et al., 2011; Hungr et al., 2013). Thus, it can be assumed that, during the flash flood in Braunsbach, chaotic factors and deposition of debris led to various damage patterns which remain inexplicable through quantitative analysis and modelling. This is strongly supported by the engineering report of Maiwald and Schwarz (2016), who claim that chaotic flow processes at the building caused by rubble and debris can greatly influence the inundation depth.

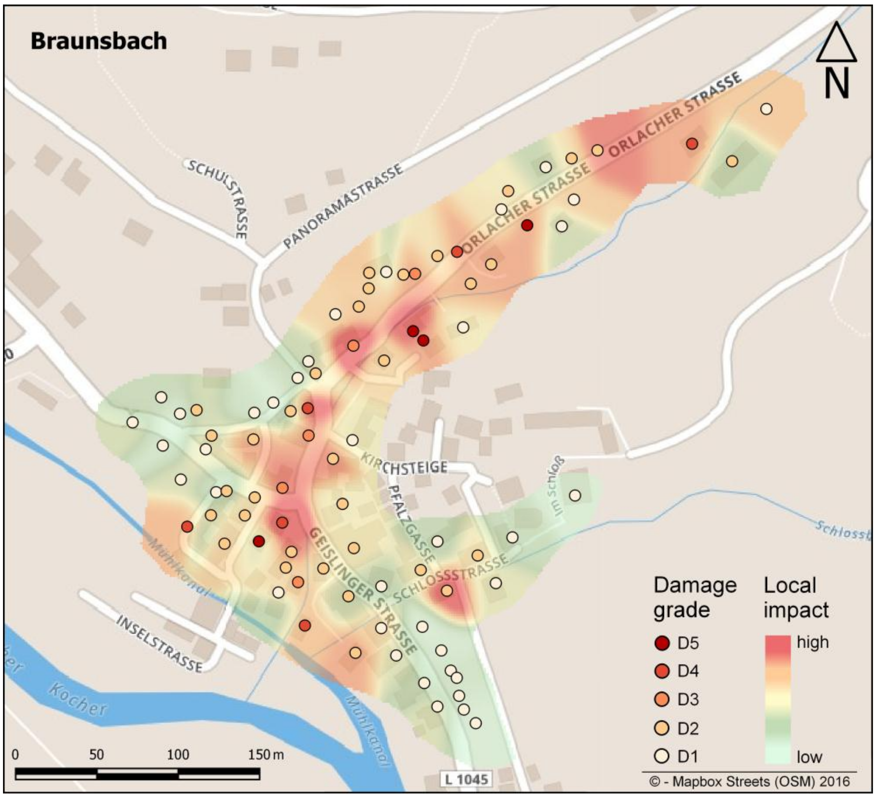


Figure 3-5 Map of the study area with the local impact, which is a combination of the inundation depth at the building and its exposition in flow direction (see text for further details). Further, the damage grades as recorded on site using the classification scheme of Schwarz and Maiwald (2007) are shown; see Table 3-1 for a verbal description of the damage grades

However, it is revealed that buildings with a high exposition in flow direction are more susceptible to severe structural damage, since the probability of large debris colliding with building walls is much higher and erosion of the foundation is more likely to happen. Also Maiwald and Schwarz (2016) stated that the recorded damage patterns differ from damage patterns caused by riverine flooding and appear to be more severe due to higher hydrodynamic stress and collision of debris with the building. Conversely, some buildings can benefit from shadowing effects of neighbouring buildings, which retain debris and suspended material to a certain degree.

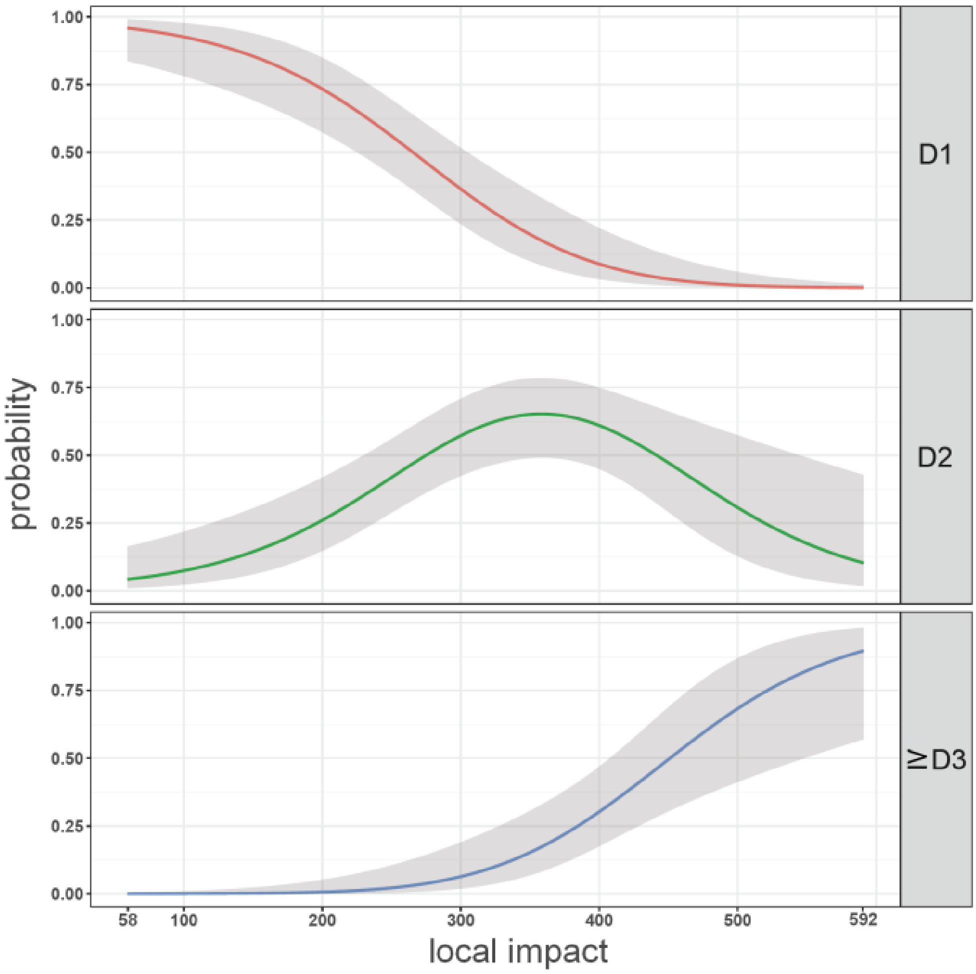


Figure 3-6 Probabilities of the damage grade predicted by the multinomial logistic regression model (see Table 3-2 and Section 3.2.3.2 for details on the damage grades and the local impact indicator). It can be seen how the probability for a specific group affinity changes with an increasing local impact value and shifts towards higher damage grades

To further evaluate the local impact indicator, a multinomial logistic regression was applied. By analysing the dependency between only the local impact indicator and the damage grade, the influence of external forces on the damage grade can be observed separately, since resistance parameters and building characteristics are neglected. As can be seen in Figure 3-6, there is a clear coherence of an increasing local impact and an increasing probability to belong to higher damage grades. However, in accordance with Figure 3-5, Figure 3-6 reveals again that external forces are not enough to explain the complex damage pattern. Especially for moderate impact values (around 300 to 400), non-negligible probabilities are assigned to all damage grades. Further, if higher local impact values are considered, a large model uncertainty has to be taken into account, which is shown by the 95 % confidence interval that covers a probability range of 45 % for the corresponding damage grade affinity. This means that i.e. given a local impact value of 550, the chance of belonging to class D2 ranges from 5 to 50 % and for greater equal D3 from 50 to 95 %. The large variability can be explained by the small number of observed data points with high local impact values. Additionally an increasing complexity of the damaging process for higher local impact values might contribute to the model uncertainty. Still, Figure 3-6 shows that a local impact indicator can be suitable to evaluate the hydrostatical forces of this type of hazard, which, in addition to the characteristics of the element at risk, might allow vulnerability estimations such as performed by Papathoma-Köhle (2016).

It can be summarised that, next to individual flow and deposition processes of the flood, local factors, shadowing processes, and building characteristics shared a certain importance as damage driving factors in Braunsbach, highlighting the complexity of this event. This is supported by the findings of Fuchs et al. (2012), who revealed as well that damage to buildings is not only caused by flood-inherent processes and intensities, but is also influenced by building characteristics and is dependent on the general land use pattern.

According to Varnes (1984), risk reflects the expected damage which is governed by the hazard, exposure and vulnerability. Our results show that the local impact – which stands as a proxy for elements of the hazard processes and the exposure – is a meaningful external indicator of structural damage caused by flash floods, although it does not fully explain the recorded damage grades. It can be used either in multivariable damage models or in future risk maps for flash-flood-prone regions, introducing a valuable parameter for current and future risk and damage assessments. However, questions arise on how to collect necessary data for a reliable calculation of respective values. A feasible option is the derivation of values from aerial images in combination with digital elevation models to identify buildings which are exposed or shielded. Given the specific type of hazard, in this case flash floods, the local impact according to potential inundation depths and a building's exposition in flow direction could be estimated either manually or by algorithms. Prerequisites and challenges, however, comprise the accessibility of data, up-to-dateness, adequate image resolutions and quality checks. Here, further research is needed to evaluate potential uses of indicators such as the local impact, which can be relatively easily derived and hold a proxy character.

An alternative and quantitative approach to assessing hydraulic forces on buildings is the computation of flow fields during flash floods, taking into account local slope and fluid densities. This approach is presented by Milanesi et al. (2015), who introduce a conceptual model which describes the acting forces on humans during rapid floods. However, detailed information about the building shape and geometry, friction coefficients as well as flow dynamics are required for the computation.

Consequently, when performing damage and risk assessments for flash floods in future, compromises must be found on issues such as the robustness and uncertainties of models, data availability and efficient data handling.

3.4 Conclusion

The evaluation and data analysis in this study resulted in important information about the impacts (damage to buildings) of the flash flood event in Braunsbach. It is revealed that not only does the water depth seem to be a risk factor in flash-flood-prone regions, often considered as the only damage driving factor in riverine flood loss modelling, but so does the exposition of a building in flow direction and susceptible building parts like shop windows. This result considerably differs from investigations on damage caused by riverine floods. Yet, the damage driving as well as damage reducing factors of flash floods are complex, often unpredictable, contingent upon the surrounding and dependent on certain building characteristics.

Knowing processes of flash floods and their impacts can help to create awareness for future events and support strategic planning with regard to similar emergencies. Concerning the European Floods Directive 2007/60/EC and its implementation in Germany, implications according to the German Federal Water Act exist. The evaluation of flash floods and surface water flooding as a significant risk would result in the obligation to create new nationwide hazard and risk maps. As a further consequence, the German Federal Water Act intends to place a building ban in all areas that are affected by a 100-year flood event, which would lead to serious consequences for local planning in flash-flood-prone regions. Therefore, flash floods are currently judged as a general risk throughout Germany.

Still, maps such as the presented local impact map could be a supportive and feasible first step in order to update and perform risk and damage assessments. The estimation of the local impact could be used in integrated risk management and strategic planning of mitigation measures against future hazards in Braunsbach or similar villages in that region. Thus, the introduced concept may be beneficial for the identification of potentially vulnerable locations on a small scale and within case studies, helping us to understand the potential future development of flash-flood-prone regions. However, further investigations are needed in order to verify the results and to obtain larger databases.

To facilitate data collection in the future, the case further demonstrates the potential of mobile devices and open-source applications. In the field, the simplicity, speed, quality and handling of information using the open-source application KoBoCollect particularly stood out as a great success. Even in a short time and with a small team of researchers it was possible to gather a fair amount of useful information that could be further processed and analysed. The public availability of the software makes it a fast and ad-hoc tool for assessing different kind of questions, usable in various research fields, not only for scientific but also for private uses. However, further aspects to discuss are whether the quality of crowd-sourced information is suitable for scientific investigations and how to approach and deal with possible limitations, security and copyright issues as well as uncertainties. Still, it can be concluded that open-source data collection software for mobile use has great potential as a scientific tool with which to generate extensive valuable data under challenging conditions. It should be especially considered in time-critical research applications such as ex post disaster analyses, as was demonstrated by the presented case of Braunsbach.

Data availability: The data sets used in this article are available at <doi.org/10.5880/fidgeo.2017.015> (Vogel et al., 2017a).

4 Flash Floods versus River Floods – a Comparison of Psychological Impacts and Implications for Precautionary Behaviour

Abstract

River floods are among the most damaging natural disasters that occur frequently in Germany, causing high economic losses and affecting many residents. In 2016, several Southern German municipalities were hit by flash floods after heavy rainfalls which have been unexpectedly severe and led to total economic losses of EUR 2.6 bn. This study investigates the psychological impacts of river floods and compares them to the impacts of flash floods, using computer-aided telephone interviews that were conducted among flood-affected households 8 to 9 months in the aftermath of the events. By applying Bayesian statistics and negative binomial regressions, the suitability of psychological indicators to predict the precaution motivation of individuals is analysed. The results show that not the particular flood type, but rather the severity and local impact of the event is crucial for different and potentially negative impacts on mental health. Moreover, it is revealed that the derived psychological indicators "coping appraisal", "threat appraisal", "burden" and "evasion" only show a limited usefulness for predictions of the individual precaution motivation, which is displayed by a generally low explanation power and non-significant results. Further research is needed to better address established psychological assessment procedures and to focus on alternative data sources regarding floods and the connected precaution motivation of affected residents.

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4.1 Introduction

In June 2013, eleven years after the severe 2002 flood event in Germany which caused an overall loss of EUR 11.6 billion (Thieken et al., 2006), the country was challenged again by strong river flooding, affecting Saxony, Saxony-Anhalt, Brandenburg and Bavaria. Considering country-wide gauge data and peak discharges, the 2013 flood event can be described as even more severe than the costly river flood in 2002, yet causing less monetary losses of EUR 6 to 8 billion (Thieken et al., 2016a). Again in May and June 2016, heavy rainfall in Central Europe lead to severe surface water run-off, pluvial flooding and flash floods in Southern Germany, especially affecting municipalities in Bavaria and Baden-Wurttemberg and resulting in overall losses of EUR 2.6 billion (Munich Re, 2017).

The flash flood events in 2016 have been remarkably different from the river flood events of 2002 and 2013 in terms of processes, dynamics, duration and the type of induced damage on buildings (Laudan et al., 2017). In contrast to river floods, flash floods are defined as rapid flood events, typically occurring in steep, small catchments shortly after heavy rainfall with no prolonged lead time. The strong surface run-off, transport of large debris (also called debris flows) and the rapidness of the event identify flash floods as an unpredictable and potentially life threatening hazard (Gaume et al., 2009; Borga et al., 2014).

Flash floods are typically associated to regions with a pronounced orography. Therefore, the occurrence of severe flash floods in Germany outside alpine regions in 2016 can be described as unexpected, but yet highlights the topicality, considering the relatively high monetary losses of EUR 2.6 billion (Munich Re, 2017), damage and unfortunately eleven fatalities (four in Baden-Wurttemberg and seven in Bavaria along Simbach am Inn). However, there is a lack of studies that compare impacts of and preparedness to flash and river floods, especially with regard to protection motivation and the influencing factors.

Flood protection in Germany has a long history with several regulations and ongoing programs. Besides national initiatives such as the "Nationales Hochwasserschutzprogramm" (NHWSP) and a national framework legislation regulation, the Federal Water Act of 2009 and its updates, the management of water bodies and flood management are in Germany in principle regulated on state level. Superior regulations such as the European Floods Directive (2007/60/EC) set up framework conditions and thus had to be incorporated into the national legislation by 2010 (e.g. Thieken et al., 2016b). After the severe river flood events in 2002 and 2013, the flood risk management in Germany and the relevant legislation was revised while the focus was shifted to a more integrated flood management, considering structural as well as non-structural flood protection measures (Kienzler et al., 2015b; Thieken et al., 2016b; Laudan et al., 2017). In this context, the German Act on precautionary flood protection in 2005 (Gesetz zur Verbesserung des vorbeugenden Hochwasserschutzes) requires residents in flood-prone areas to take private precautionary actions within the individual bounds of possibility. As an overall result, regions which have been affected by recurrent river floods are now well managed, having tailored flood risk management plans in place, including private precaution. Still, despite the devastating events in 2016, flash floods and strong surface water run-off do not yet count as significant national risks and are therefore not considered in recent flood risk management. As a result, little is known about private precaution measures concerning flash floods in Germany.

In general, private precaution measures can significantly reduce damage to households and thus play a significant role in comprehensive flood management (Kreibich et al., 2005; Thieken et al., 2008; Merz et al., 2010b). The state of private precaution can further be integrated in flood loss estimation models such as the flood loss estimation model (FLEMO) which results in more reliable damage estimations on different scales and therefore contributes to robust risk and vulnerability estimations (Thieken et al., 2008). Hence, understanding and predicting private precaution is essential for future planning and flood risk management not only with regard to river floods, but also with respect to flash floods and rapid surface run-off as an unfamiliar and potentially more frequent hazard in future. Here, the individual protective behaviour it is not yet fully understood, particularly if people are affected by different flood types. Questions must be raised whether affected individuals carry out private protective measures, to what extent they implement measures and what are motivating as well as demotivating factors. In this context, the protection motivation theory (PMT) (Rogers, 1975) has been frequently used as a psychological model to explain the risk-reducing/protective behaviour of affected individuals by analysing the influencing factors on coping strategies and potential positive or negative responses. Main findings suggest that besides socio-economic factors such as income and homeownership, psychological factors – not only in terms of risk perception, but also avoidance, wishful thinking, and the self-rated coping appraisal – can influence protective responses (Grothmann & Reusswig, 2006; Bubeck et al., 2012a). Further, empirical evidence from Germany and France indicates that social norms and networks can be considered as important for better coping abilities after river floods (Bubeck et al., 2018).

Besides structural/financial losses to buildings and contents, severe river floods and flash floods are expected to have strong impacts on the psychology of affected residents. For instance, Mason et al. (2010) reveal that certain criteria for psychiatric disorders such as the post-traumatic stress disorder (PTSD) as well as high scores of anxiety and depression are met within one quarter to one third of flood-affected study participants among different communities in the UK. On the other hand, an increased exposure to floods may also be connected to negative mental health effects due to the disruption of daily routines, financial loss and evacuation stress, especially if social support by family and friends is missing (Bei et al., 2013). Besides negative responses to flood exposure, coping strategies also comprise protective behaviour which is dependent on personal knowledge, multiple socio-economic and psychological factors as well as individual character traits.

Previous studies have further shown that the motivation to protect oneself from flooding cannot be solely explained by risk information, the individual risk perception and/or socio-economic variables (e.g. Baan & Klijn, 2004; Bubeck et al., 2012a; Morss et al., 2016). This suggests that certain psychological characteristics may have an influence on the individual flood protection motivation and may vary with regard to different flood types. Still, few studies consider individual psychology in flood preparedness decisions. Hence, the aim of this work is the identification of psychological impact patterns with regard to differences among individuals affected by either flash floods or river floods and the related protective behaviour. Accordingly, the following hypotheses were raised:

H1: Flash floods, in comparison to riverine floods, show a different psychological impact on affected people in which negative effects such as stress and feelings of being helpless are more pronounced, since flash floods are more dynamic and thus are a bigger threat for life.

H2: Negative psychological impacts are connected to a lower probability for precaution because negative feelings hamper the individual energy and self-confidence as well as the overall motivation to implement precaution measures.

H3: Identified psychological indicators are suitable for explaining precautionary behaviour because certain psychological characteristics are distinctly connected to the protection motivation.

The first hypothesis is tested by comparing psychological characteristics of people which are affected by different flood types and flood strengths. Thus, groups of similar psychological manifestations (psychological indicators) are created first, secondly the distributions are analysed by applying Kruskal-Wallis rank sum test and Dunn's Test. To answer the second and third hypotheses, a "planned precaution" indicator is created first, then the Bayesian approach and negative binomial regressions are applied and resulting probability distributions of conditional variable dependences as well as regression coefficients are evaluated. The Bayesian approach has been frequently used in psychology (e.g. Wetzels et al., 2011) and offers advantages due to the assessment of uncertainties which in general facilitates scientific studies that rely on relatively small datasets. Accordingly, this study considers Bayesian inference as a method to assess variable relations that are based on conditional probabilities and related uncertainties. Preliminary assumptions such as e.g. linear variable coherences are therefore not required. Furthermore, this approach evaluates the specific variable applicability for a potential prediction of a response variable, in this case the "planned precaution" indicator. As an additional advantage, the method enables prior knowledge to be taken into account, for example in following studies. However, to assess the potential direction of the predictor and response variable coherence, the Bayesian approach is supported by a negative binomial regression model. The implementation of all methods is addressed in the next section.

In summary it can be said that gaining insights into the psychological impacts of river floods and flash floods and the related precautionary behaviour is important for the following reasons:

- A good understanding of psychology and precaution motivation might result in an indicator which estimates the probability for a specific precaution level and could be integrated into flood loss modelling.
- The outcome might be beneficial for targeted information campaigns, supporting affected individuals while strengthening their motivation to implement useful private flood precaution measures (e.g. Morss et al., 2016).
- A better understanding of this connection might help to improve future vulnerability and risk estimations and may facilitate the use of alternative data sources to estimate the state of individual precaution. For example, by gathering data from different sources (online surveys, social media, communication platforms), psychological profiles could be created which could then be used to predict the individual precaution motivation in areas which have not been flooded recently.

The results of this study are presented and discussed in section 3. A further outlook on this topic is given in the conclusion.

4.2 Data and methods

In this section, the used data is presented and the applied data preparation steps as well as the methodology are explained.

4.2.1 Description of the river flood and flash flood datasets

The individual datasets consist of computer-aided telephone interviews which were conducted among residents affected by either the river flood of 2013 or the heavy rainfalls and flash floods of 2016. Within this study, the river flood of 2013 and the flash floods of 2016 are considered for comparison, since the two events were very different in terms of the flood dynamics. Still, both events were relevant on the national scale. Finally, the time lag between the particular event and the implementation of the survey is similar, i.e. around nine months after the flood event in both cases. The surveys were equally designed and initially focused on flood damage estimation of affected households and the assessment of damage driving factors. Hence, the biggest part comprised questions about socio-economic characteristics (e.g. age, gender, social status, income, education, homeownership), characteristics of the housing unit (e.g. number of stories or floor space, construction year, number of persons per unit, housing area) and different dimensions of private precaution (e.g. if certain single protection measures are already implemented or planned to be implemented in the near future). Yet, various psychological characteristics addressing the protection motivation theory (threat appraisal, coping appraisal, avoidance, memories of the event, optimism and further questions about the mental well-being) were recorded as well which are – combined with questions about the private precaution – used as the database for this study. An exhaustive list of the analysed psychological variables is given in Table 4-1. All psychological variable ratings were adjusted and equalised to follow a self-reported rating scheme of 1 (not once/I do not agree/very low) to 6(7) (few times a day/I fully agree/very high), which ensures their comparability. In this context, four out of nine variable ratings were reversed (see Table 4-1).

In total, 16 private precaution measures were analysed. They comprise information about flood protection and flood risk as well as information within seminars, insurance, networking, flood-adapted story usage, flood-adapted interiors, relocating heat and electricity, securing heat and oil tanks, improving flood safety, installing backflow prevention, installing water barriers, having no noxious liquids in the cellar, installing pumps, having generators available and anticipatory planning of supplies. For each private precaution measure, individuals were asked to mark them as “implemented before the event”, “implemented after the event”, “will be implemented in near future”, and “not planned to be implemented”.

The dataset of the 2013 river flood comprises 1652 responses in total, the 2016 flash flood 601 cases with an equal distribution of age and gender. This study considers only homeowners for all consecutive analyses, since homeowners – unlike tenants – suffer from flood damage on the building itself to a greater extent and also hold a greater flexibility to take potential protective actions (e.g. Grothmann & Reusswig, 2006). The proportion of homeowners within the river flood and flash flood dataset is 82% and 86% respectively, lowering the valid responses to 1366 (2013-flood) and 517 (2016-floods).

Table 4-1 List and explanation of the psychological variables used in this study

Variable	Original variable scale	Original question or statement (shortened)
Believe in being affected again	6 (I do not agree)… 1 (I fully agree)	**Statement**: It is likely to be affected again by a flood event.
Fear of severe effects again	6 (I do not agree)… 1 (I fully agree)	**Statement**: A future flood event will not be as bad as the recent event.
Self-efficacy	6 (I do not agree)… 1 (I fully agree)	**Statement**: I personally do not feel able to implement at least one private precaution measure.
Response efficacy	6 (I do not agree)… 1 (I fully agree)	**Statement**: Private precaution measures can reduce the flood damage.
Response cost	6 (I do not agree)… 1 (I fully agree)	**Statement**: Private precaution measures are too expensive.
Stress still today	1 (no stress)… 6 (high stress)	**Question**: Do you still feel stress and negative emotions caused by the flood event (at the time of the interview)?
Often thinking of the event	1 (not once)… 7 (few times a day)	**Question**: How often did you think about the event within the last six months (at the time of the interview)?
Avoidance	6 (I do not agree)… 1 (I fully agree)	**Statement**: I do not like to think of future flood events.
Fatalism	6 (I do not agree)… 1 (I fully agree)	**Statement**: One is in general helpless regarding future flood events and the damage.

4.2.2 Separation of weak and strong flash floods

In May and June 2016, several places in Germany were hit by flash floods or surface water flooding that differed, however, in strengths and dynamics as well as with regard to the perceived severity and the resulting damage. In many cases, the heavy rainfall only led to an increased surface water run-off in the vicinity of affected buildings and/or the water entering the basement. Yet, in some municipalities, entire villages (such as Braunsbach and Simbach am Inn) were suffering from enormous flash floods and debris flows with strong flow velocities and a very high suspension of debris – even large rocks – vigorously damaging buildings and infrastructure (Laudan et al., 2017). Therefore, it is crucial to separate severe and weaker flash flood events before comparing the psychological impacts among each other and to the 2013 river flood.

The approach to assess the flash flood strength comprises quantitative and qualitative methods and makes use of rainfall data and press articles which allow an estimation of inundation depths and flow velocities. Here, the hourly rainfall data was downloaded from the "Deutscher Wetterdienst" (DWD) for the days with known heavy rainfalls in May and June 2016. According to the definitions of the DWD, a severe weather alert is given for a particular region if the local rainfall is expected to exceed 25 mm per hour. Thus, if the rainfall exceeded 25 mm per hour at a gauging station, the region was marked to be potentially affected by a strong flash flood. In this context, only the municipalities and cities which were covered by the survey were considered. This was possible since the approximate address of each affected household was provided. In a next step, an online literature and press article review was conducted for each affected city to find a basis for the flash flood strength classification. This procedure can be described as a rather qualitative approach. According to the reported damage, impressions of photos and the level of media attention as well as associated rainfall in the area at the particular time, the surveyed households were classified to weak flash floods (if a low impact was noticed), to medium flash floods (if the impact was considered to between low and high) or strong flash floods (if a high flood impact could be assumed). For the analysis, only weak and strong flash floods among homeowners were considered. The count of cases for weak flash floods is n=293 and for strong flash floods n=116.

4.2.3 Defining main psychological indicators

To answer the first hypothesis, four main psychological indicators were considered within this study. The indicators are combined according to literature such as Creamer et al. (2003), Grothmann and Reusswig (2006) and Bubeck et al. (2012) and were further chosen for reasons of comparability as well as to minimise correlations among the single psychological variables. Subsequently, the four main indicators are defined as "threat appraisal", "coping appraisal", "burden" and "evasion" and are defined as follows.

Threat appraisal and coping appraisal are considered within the protection motivation theory (PMT) and represent two distinct psychological indicators that explain the risk-reducing behaviour of individuals when they are faced with a threat. Threat appraisal consists of the perceived probability of being affected again by a severe event and the perceived impact of such a future event. Coping appraisal comprises self-efficacy, response efficacy and response cost which describes the self-rated ability to deal with a threatening event, the perceived efficiency of a protective measure and the cost of a protective measure in terms of money and effort, respectively (Grothmann & Reusswig, 2006; Bubeck et al., 2012a).

The indicators burden and evasion were developed by following the general procedure in psychology surveys to combine expressive psychological items (e.g. Ware & Sherbourne, 1992; Kroenke et al., 2001) and taking high correlations among psychological variables into account. In this regard, Creamer et al. (2003) for example confirm the usefulness of the Impact of Event Scale - Revised (IES-R), a widely used item-based survey that measures traumatic stress, to assess symptoms of the post-traumatic stress disorder (PTSD) in male Vietnam veterans. However, they also find that the main factors of the IES-R, i.e. "hyperarousal", "avoidance" and "intrusion" do not provide a good account of the data due to correlations among single items and suggest the use of less or diversely composed factors/indicators. Accordingly, the creation of the indicators burden and evasion required pre-processing of the data, correlation tests and the evaluation of preliminary results. Thus the preliminary results are shortly presented in this section.

The correlations among the single psychological variables were assessed using ordination plots (principle component analysis) and correlation tables (Spearman's Rho, corrected after Holm (1979), done in R Studio 1.1.414, using the package "psych"). According to the tests, subjective stress which is still felt at the time of the interview and the frequency of remembrance of the event show a strong correlation of 0.54 (complete cases n=279) for weak flash floods, 0.46 (complete cases n=115) for strong flash floods and 0.50 (complete cases n=1152) for river floods with a p value of <0.05 in all cases. Further, avoidance and fatalistic thoughts reveal a correlation of 0.23 (complete cases n=275, p<0.05) for weak flash floods, 0.29 (complete cases n=113, p=0.34) for strong flash floods and 0.18 (complete cases n=1242, p<0.05) for river floods. Here, the low significance in the case of strong flash floods may be due to the small dataset of 113 complete pairwise observations. See the Appendix C for the correlation tables (Figures C-1, C-2 and C-3).

Based on these results, the subjective stress still felt at the time of the interview and the frequency of remembrance was combined to the indicator burden, while avoidance and fatalistic thoughts constitute the indicator evasion. In this context, burden describes the degree of negative psychological load that is still apparent at the time of interview and evasion resembles avoidant behaviour, e.g. trying to supress the experience.

The distributions of threat appraisal, coping appraisal, burden and evasion were further analysed using the non-parametric Kruskal-Wallis rank sum test and Dunn's Test which may be applied if the data follows an ordinal scale and does not fulfil assumptions of normality and equality of variance. By using these tests, significant differences in psychological impacts can be revealed which were predominantly caused by weak flash floods, strong flash floods and river floods.

4.2.4 Planned precaution indicator

To apply the Bayesian statistics and regression models, an indicator for the planned precaution had to be first derived from the flash flood and river flood datasets which is used as response variable in further analysis. In this context, the planned precaution indicator was created according to existing studies on private flood mitigation in Germany. Here, Kreibich et al. (2005) compared the flood damage mitigation potential of different private precaution measures among German households that were affected by the severe river flood in 2002. The study revealed that flood adapted use, a better interior fitting and the relocation of heat and electrical utilities lower the damage ratio of buildings by 46%, 53% and 36% respectively (Kreibich et al., 2005). Thus, the indicator of already implemented precaution measures and the indicator capturing planned precaution, which is used in this study, consist of single precaution measures that are weighted according to their damage mitigation potential. For further details on the effectiveness of private precaution measures and additional findings see Kreibich et al. (2005), Thieken et al. (2005) and Büchele et al. (2006).

For the planned precaution indicator, the weighted score of measures which were planned to be implemented directly or shortly after the flood event (see section 4.2.1) is summed up and related to the already implemented or non-applicable measures. The data is disregarded if the count of already implemented or non-applicable measures is equal or exceeds the half of the overall measure count of 16 measures (>= 8), since it is hardly possible to obtain meaningful results for the "planned precaution" in such cases, i.e. this value already reflects a very good level of private precaution. Hereby, it is also ensured that there is no bias towards low precaution motivation in the subsequent analysis caused by an already high precaution level, since it can be assumed that people who already implemented many protection measures have a lower planned precaution score. The procedure results in indicator scores ranging from 0 to 48, which are further reclassified into values ranging from 0 (low planned precaution) to 8 (high planned precaution). In the results and discussion section (section 4.3.2), this indicator is compared to the state of precaution, i.e. the weighted score of already implemented precaution measures.

4.2.5 The Bayesian approach

Bayesian statistics can be applied to calculate probability distributions from a limited set of observations and to quantify related uncertainties. The statistical model takes prior knowledge into account (prior) and assesses the likelihood to observe the data, if specific model parameters are given (likelihood). This results in a probability density for the model parameters, conditioned on specific data (posterior) (Puga et al., 2015), where the Bayes theorem is:

$$P(model\ parameter|data) \sim P(data|model\ parameter) * P_0(model\ parameter)$$

The likelihood (L) is based on the binomial distribution for each response variable (planned precaution) and predictor variable value. The binomial distribution was chosen due to the fact that it provides probability estimations solely about the occurrence and non-occurrence of two variable values, as given in the dataset. It resembles a basic probabilistic approach to scientific questions without making preliminary assumptions (e.g. linear variable coherence). The binomial distribution is thus defined as:

$$P(k \mid p, n) = \binom{n}{k} * p^k * (1-p)^{n-k}$$

Where:

- n = count of specific predictor variable value
- k = count of specific response variable value, given n

Here, the estimated parameter (p) resembles the specific combination probability of two variable values. More precisely, it indicates the likeliness to observe a specific response variable value, if a specific predictor variable value is given. To our knowledge, no similar studies exist which are based on comparable datasets and equal psychological indicators, thus, no prior knowledge is taken into account in this study. This means that the prior, which influences the estimation of the parameter (p), was chosen to be uniformly distributed on (0, 1). Eventually, the Bayesian analysis results in posterior distributions that indicate the conditional probability density of the occurrence of two variable manifestations.

4.2.6 Average posterior distributions, Jensen-Shannon divergence and regression tests

In order to test the second and third hypotheses, the psychological indicators as well as the single psychological variables (see Table 4-1) were analysed with regard to their coherence to the planned precaution indicator, using the Bayesian approach, the Jenson-Shannon divergence and a negative binomial regression model. Both, the psychological indicators and the single variables were separately analysed to reveal differences between the general procedure in psychology to combine similar items/variables and studying all variables separately.

First, the weighted arithmetic mean of all posterior distributions (resulting from the Bayesian analysis, see section 4.2.5) was calculated for each indicator and single variable, to reveal variable connections to the planned precaution indicator while excluding all non-existent combinations (Figure 4-1). The weighted posterior combinations allow for the assessment of likely probability distributions at once, giving ideas about the data structure and variability. In a next step, a weighted arithmetic mean posterior is calculated by randomising the respective variable while considering its individual distribution to describe the random occurrence of predictor and response variable. This step is necessary to obtain the particular reference posterior shape, which is exclusively influenced by the distribution of the predictor and response variable. In other words, if e.g. the response variable is not equally distributed, but heavily skewed to low values, these values are overrepresented in any weighted conditional probability calculation of two variables, even if the predictor variable is completely independent. Taking this into account, the difference of each weighted arithmetic mean posterior to the respective reference posterior was measured using a variation of the Kullback-Leibler divergence, i.e. the Jensen-Shannon divergence (JSD). The JSD is defined by:

$$JSD(P, R) = H\big(0.5 * (P + R)\big) - 0.5\big(H(P) + H(R)\big)$$

Where the Shannon-Entropy is defined by:

$$H(p) = -\sum_{i} p(i)\log\big(p(i)\big)$$

The divergence represents the degree of mutual information between both analysed variables and the resulting information gain, if one variable is explained by the other. This resembles the strength of variable connection and thus the overall applicability for predictions. The divergence is presented within a variable ranking.

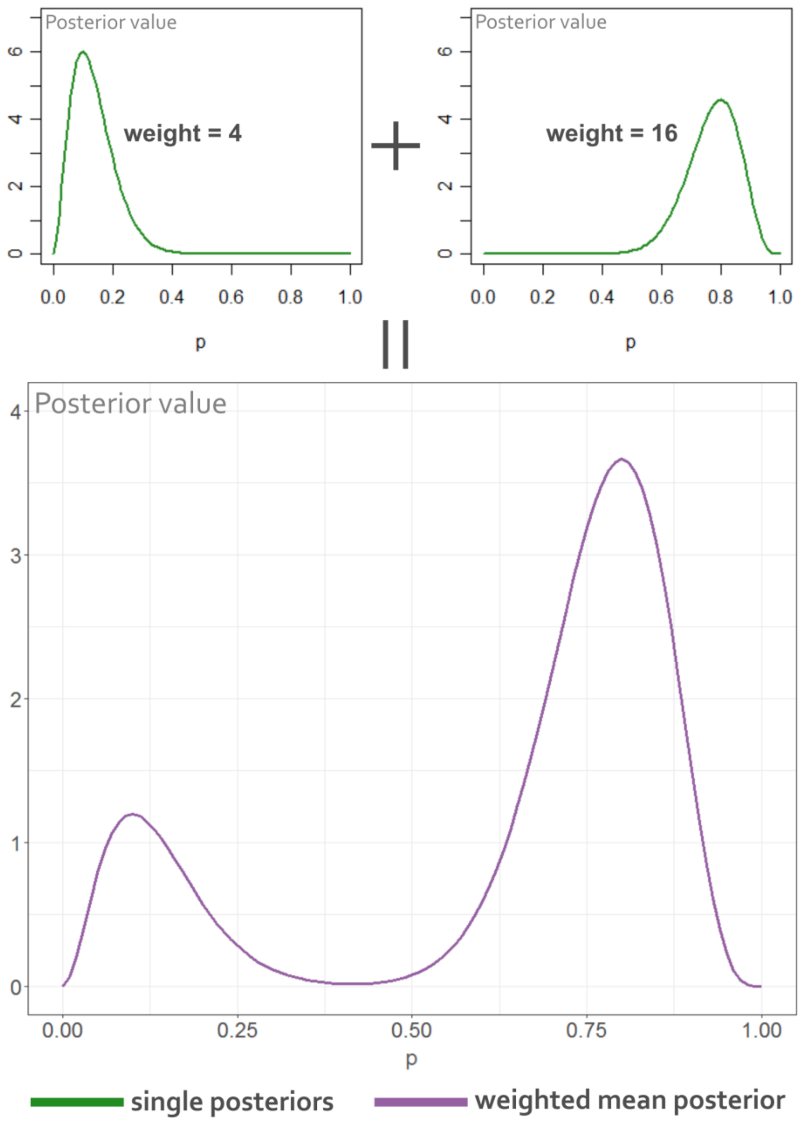

Figure 4-1 Example graphic explaining the creation of the weighted arithmetic mean posterior. The posteriors are weighted according to the sum of occurrences within the dataset. In this case the weighted mean posterior means that, given the example dataset of 20 data points, 80% coherence of the predictor variable with any value of the response variable is most likely to occur, if a random data point is chosen

Complementary to the Bayesian approach (i.e. the combined posterior distributions and divergence), negative binomial regressions were performed for each flood type, using the planned precaution indicator as response variable and the psychological indicators as well as the single psychological variables as predictors. Since the posterior distributions and divergence computations are solely based on probabilities, information gain and prediction applicability can be assessed, yet the direction of coherence with the response variable is not given. Thus it is supported by a negative binomial regression model which indicates significant positive or negative coherences of variables with the "planned precaution" indicator. The negative binomial regression was chosen due to the fact that the "planned precaution" indicator consists of ordinal discrete (count) values which are restricted between 1 and 8 and follow an overdispersed Poisson distribution (tested in R 1.1.414, using the packages "logspline" and "fitdistrplus").

4.3 Results and discussion

In this section, the differences in the distribution of the psychological indicators are presented and discussed first. In a next step, the planned precaution indicator is presented before the indicators and single psychological variables are analysed by evaluating the posterior distributions, the JSD and regression coefficients. Subsequently, the hypotheses are discussed and answered at the end of this section.

4.3.1 Psychological indicator distributions

Figure 4-2 illustrates the distributions of the four psychological indicators, i.e. coping appraisal, threat appraisal, burden and evasion, and also includes the Dunn's Test results.

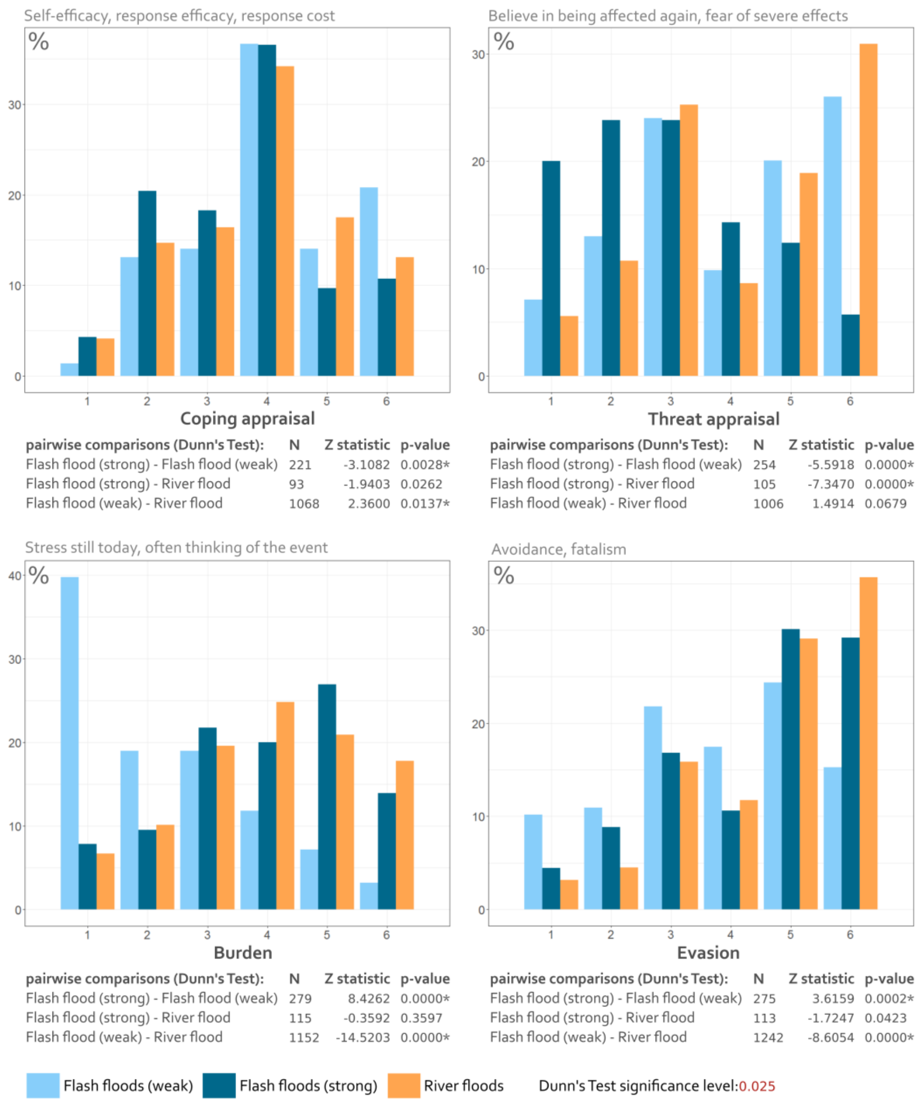

Figure 4-2 Relative distributions of the combined psychological indicators and Dunn's test results

Regarding coping appraisal (Figure 4-2, top left), the indicator distributions and Dunn's Test reveal significant differences between strong flash floods, river floods and weak flash floods. People affected by strong flash floods show generally lower ratings than people who suffered from strong flash floods or river floods while weak flash floods seem to be easier to handle in general. Still, most of the respondents reported medium coping appraisal ratings (Figure 4-2, top left).

The results indicate that people who were affected by strong and rapid flood events feel generally less able to cope with the situation and the implementation of protective measures, respectively. Although the effects are not strongly pronounced, a significant difference to weaker flash floods becomes apparent which might be due to the different (potential) flood impacts. A similar finding is revealed when comparing the difference between strong flash floods and river floods, yet the results are not significant. Although it has not been tested whether a lack of protection information strategies or other effects lead to a lower coping appraisal for strong flash floods in general, the effects could also be explained by the fact that people do not believe in a high efficiency of precaution measures in case of strong flash floods.

Concerning threat appraisal, the significant lower ratings of people affected by strong flash floods are remarkable, since it could be assumed that severe and damaging events lead to stronger feelings of threat in the first place (Figure 4-2, top right). Yet, these results could be explained by the fact that people which were affected by strong flash floods believe similar events to be very unlikely to happen again in near future, resulting in lower feelings of threat. Still, research has shown that there may be increase of severe flash floods in regions which were formerly not perceived as flash flood-prone, highlighting the importance of targeted information campaigns in that regard. Weak flash floods and river floods show a relatively similar distribution (not significantly distinct from each other) with a peak at medium threat appraisal ratings and a peak at the highest threat appraisal rating. This might be due to the weaker nature of the flash flood event and the higher perceived probability to be affected by a similar event again. With regard to river floods, a number of people in Germany have been affected more than three times within a relatively short period between 2002 and 2013, which might also contribute to a pronounced feeling of threat in residents who have been affected by river floods. This is in line with Mason et al. (2010), who find that the fear of reoccurrence of a flood event and anxiety is increased with repeated experience of damaging events.

The ratings of burden are significantly lower for people affected by weak flash floods, which indicates a lower psychological load and feelings of stress (Figure 4-2, bottom left). The distributions of strong flash floods and river floods are on the other hand shifted to higher ratings of burden. This clearly illustrates the connection between the "severity" of an event and the resulting negative psychological impacts, which is in line with Mason et al. (2010) and Bei et al. (2013), who report that a greater impact in terms of daily routine disruption, financial loss and evacuation is associated with significantly worse effects on mental health. In contrast to the "severity" of an event, the type of the event (flash flood or river flood) does not seem to have an effect on burden, since strong flash floods and river floods do not display any significant distribution differences (Figure 4-2, bottom left).

Similarly, the indicator evasion shows a significant difference in the distributions only with regard to weak flash floods (Figure 4-2, bottom right). This could be explained by the same effect that weak events or events leading to less severe impacts in general result in less pronounced feelings of avoidance and fatalism. Here, evasion especially differs between people affected by weak flash floods and river floods which also might be due to the frequent river floods in Germany and their severity which could lead to evasive behaviour of repeatedly affected residents. In fact, evasive behaviour can be described as a particular strategy to cope with severe events, enabling affected individuals to emotionally distance themselves from oppressive situations, as described by Mason et al. (2010).

4.3.2 Precaution indicators

Since the "planned precaution" indicator is used as response variable within all further analyses its distribution will be presented first in this section. Further, the planned precaution is compared to the already implemented precaution (Figure 4-3).

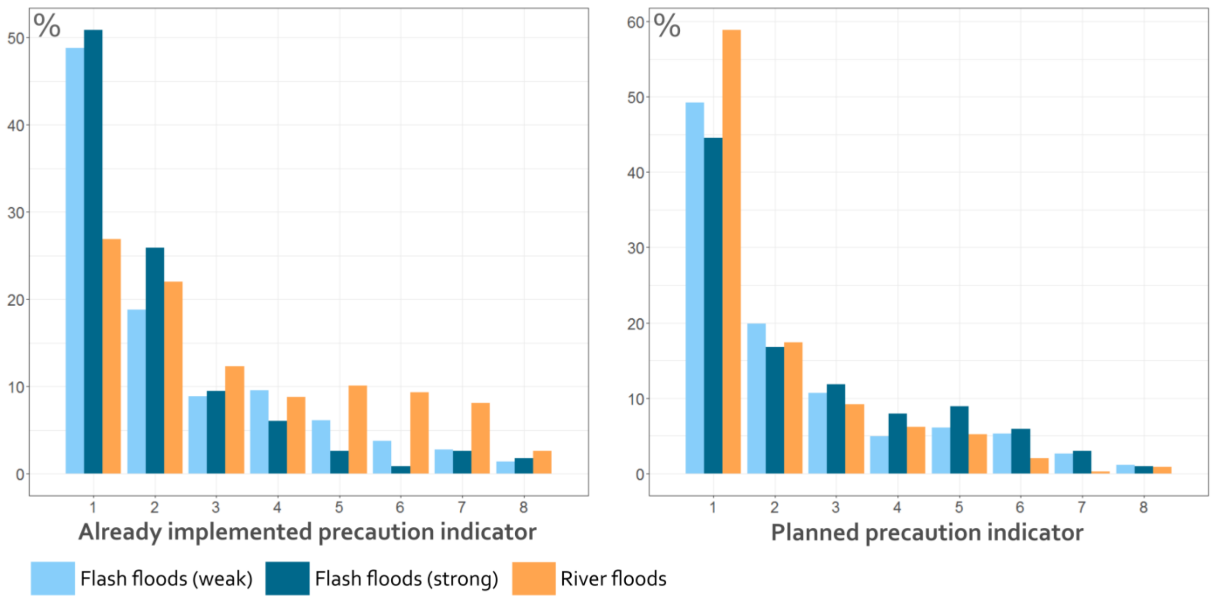

Figure 4-3 Relative distribution of the already implemented precaution indicator (left) and the planned precaution indicator (right) for weak flash floods (n=293), strong flash floods (n=116) and river floods (n=1366)

By evaluating the distributions of already implemented precaution measures (Figure 4-3, left side) and planned precaution (Figure 4-3, right side) it becomes apparent that people who have been affected by river floods show slightly higher scores of already implemented precaution measures. Regarding weak and strong flash floods, the score of already implemented precaution measures is considerably low while it can be noticed that the planned precaution scores are relatively low for all flood types. Especially in the case of river floods, affected people reveal a low motivation for (further) precaution in future. This result might also reflect a certain demotivation for precaution of residents who have been affected several times by river floods, i.e. by the river floods of 2002, 2005, 2006, 2010, 2011 and again 2013 which could be due to avoidant and fatalistic thoughts.

4.3.3 Posterior distributions and regressions of the psychological indicators

In general, the posterior distributions and regression results are based on a low number of data points, especially in the case of weak and strong flash floods (see Table 4-2, N). Yet, the results indicate certain positive and negative connections of the psychological indicators to the planned precaution indicator.

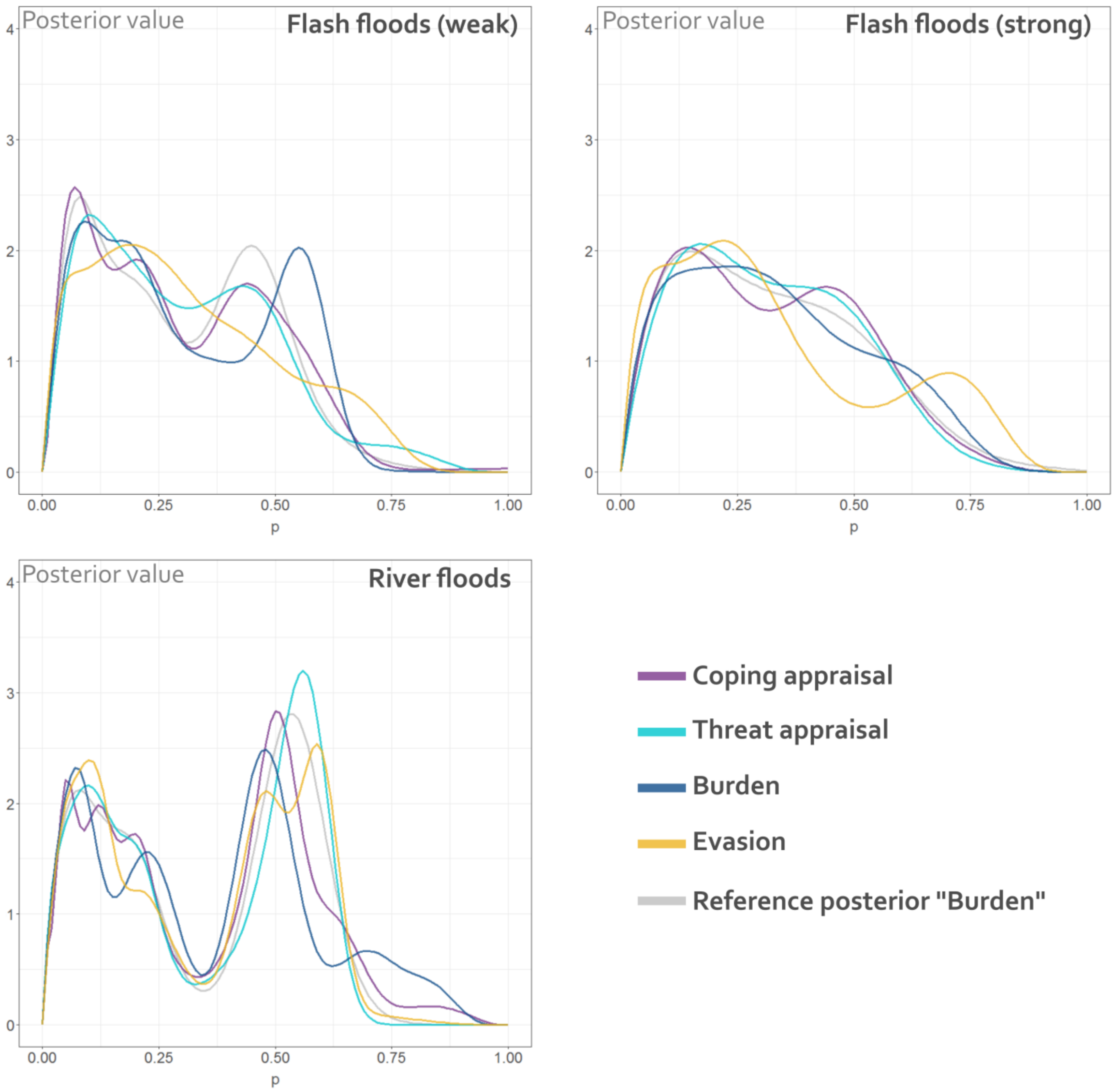

Figure 4-4 Weighted arithmetic mean of all posterior distributions for the psychological indicators “Coping appraisal”, “Threat appraisal”, “Burden” and “Evasion”, given weak flash floods (top left) strong flash floods (top right) and river floods (bottom left). The reference posterior is shown for “Burden” only

The weighted arithmetic means of all posterior distributions reveal in general a wide range of likely probabilities for the conditional dependence of variable ratings. In the case of weak flash floods for example, this means that if a single person who is affected by a weak flash flood is selected and surveyed, 52 per cent coherence of burden and 7 per cent coherence of coping appraisal with the planned precaution is most likely to be observed. For threat appraisal and evasion, the likely coherences are 10 and 19 per cent, respectively (Figure 4-4, top left). Other posterior peaks are however visible, yet less likely. As mentioned in section 2.6., the posterior shapes are greatly influenced by the distribution of the predictor and response variables. Since the planned precaution indicator is Poisson-distributed with the highest value counts among the lowest ratings, similar posterior shapes can be found in all cases with peaks around 10% and 50%. Yet, considering the reference posterior for burden (Figure 4-4, top left), the highest JSD is revealed for burden, respectively (Figure 4-5). The JSD for coping appraisal, threat appraisal and evasion however is low for weak flash floods. Additionally, the regression results indicate a significant positive relationship of burden and the planned precaution for weak flash floods (Table 4-2). It can be concluded that, if anything, burden is the most significant and useful indicator to predict the planned precaution among all indicators. Here, stronger feelings of burden seem to result in a higher precaution motivation. This result is in line with Lindell et al. (2009), who find that often thinking and talking about a hazardous event (earthquakes in that case) is positively correlated with the intention to adapt to the hazard. Our results indicate that this might also be the case for flooding.

The posterior peaks of strong flash floods are less pronounced which is due to the small dataset of 76 observations (Figure 4-4, top right & Table 4-2). In this case, a pattern is observable in which again burden and evasion show distributions slightly shifted to higher probabilities. Yet, the most likely coherence of the psychological indicators and the planned precaution is between 14% and 22% for strong flash floods. Regarding the JSD, Evasion reveals a certain information gain when describing the planned precaution, yet the effect is relatively weak (Figure 4-5). Simultaneously, evasion does not show any significant linear relationship with the planned precaution (Table 4-2). Thus, a distinct nonlinear pattern among the variables can be expected with regard to this dataset. All other indicators show almost no divergence and no information gain. According to the regression results, burden reveals a slightly negative coherence in this case, yet, the significance level is only between 0.1 and 0.05. In general, the results of the strong flash flood analysis should be interpreted with caution due to the low number of observations.

Concerning river floods, all psychological indicators show a peak around 50, up to 60 per cent and a relatively similar posterior shape that is caused by the distribution of the planned precaution indicator (Figure 4-4, bottom). In the case of burden, a posterior peak at 69 per cent is recognizable, which is remarkably different from the reference posterior shape. Accordingly, the JSD reveals a pronounced information gain for burden, while coping appraisal, threat appraisal and evasion reveal weak divergences (Figure 4-5). Yet, the regression results reveal only slight positive and negative coherences for the significant variables burden and threat appraisal (Table 4-2). These facts speak for a distinct, assumingly nonlinear coherence pattern for burden and the planned precaution, while the other psychological indicators show no significant information gain. However, similar to weak flash floods, stronger feelings of burden seem to result a higher protection motivation, which is again in line with Lindell et al. (2009).

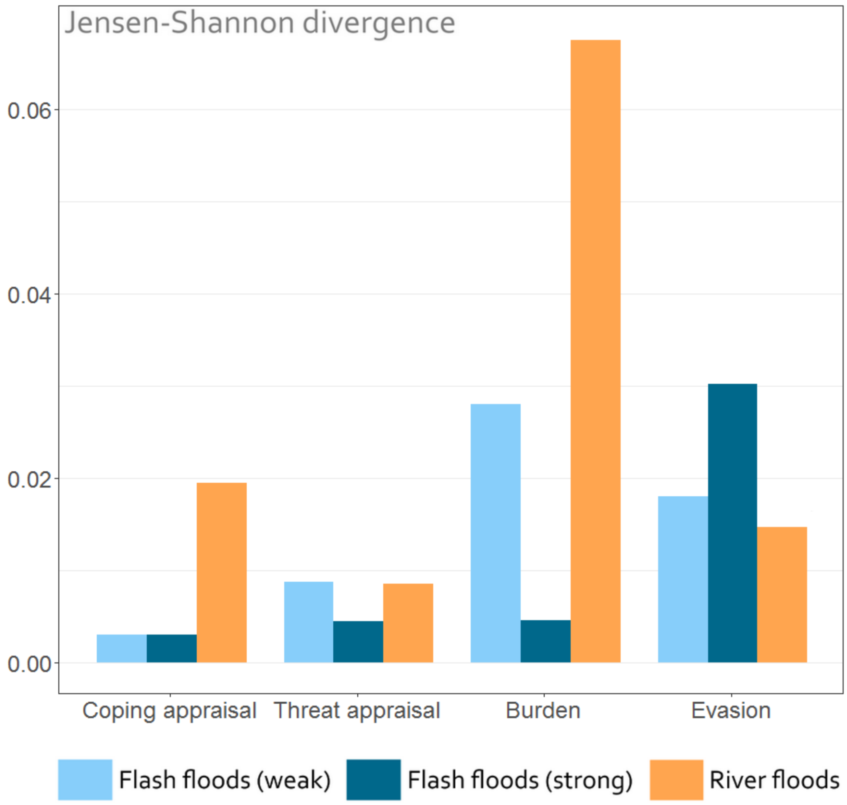

Figure 4-5 Jensen-Shannon divergence ranking of the psychological indicators. Higher values indicate a higher information gain, if the planned precaution is explained through the particular indicator

Table 4-2 Coefficients of the negative binomial logistic regression models for weak flash floods, strong flash floods and river floods with the psychological indicators as predictor variables and the "planned precaution" indicator as response variable

Predictor variable	Flash floods (weak)	Flash floods (strong)	River floods
Intercept	0.67*	1.59**	0.48*
Coping appraisal	0.01	0.01	0.02
Threat appraisal	−0.01	−0.02	−0.04‘
Burden	0.13***	−0.11‘	0.05*
Evasion	−0.02	−0.06	0.02
AIC	667.26	293.01	1422.30
R^2	0.08**	0.06	0.03*
N	177	76	419

‘$p < .10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

4.3.4 Rankings and regressions of single psychological variables

Figure 4-6 shows the JSD of the single psychological variables for weak flash floods, strong flash floods and river floods, indicating the information gain with regard to the planned precaution. In contrast to most of the other variables, the high divergence for "often thinking of the event" is remarkable for weak flash floods and river floods. Only for river floods, a relatively high JSD can be seen with regard to "response efficacy", "response cost" and "fatalism". Compared to Figure 4-5, it has to be concluded that variables which make up the indicators usually do not show an equal JSD. This is especially true for “often thinking of the event” and “stress still today”, which constitute burden. Here, “often thinking of the event” seems to be decisive for high values of burden. In the case of evasion for strong flash floods, however, a combination of the respective variables fatalism and avoidance leads to a higher information gain. The variables that constitute threat appraisal, namely “fear of severe effects again” and “believe in being affected again” do not show any information gain, (Figure 4-6), which is also reflected in Figure 4-5.

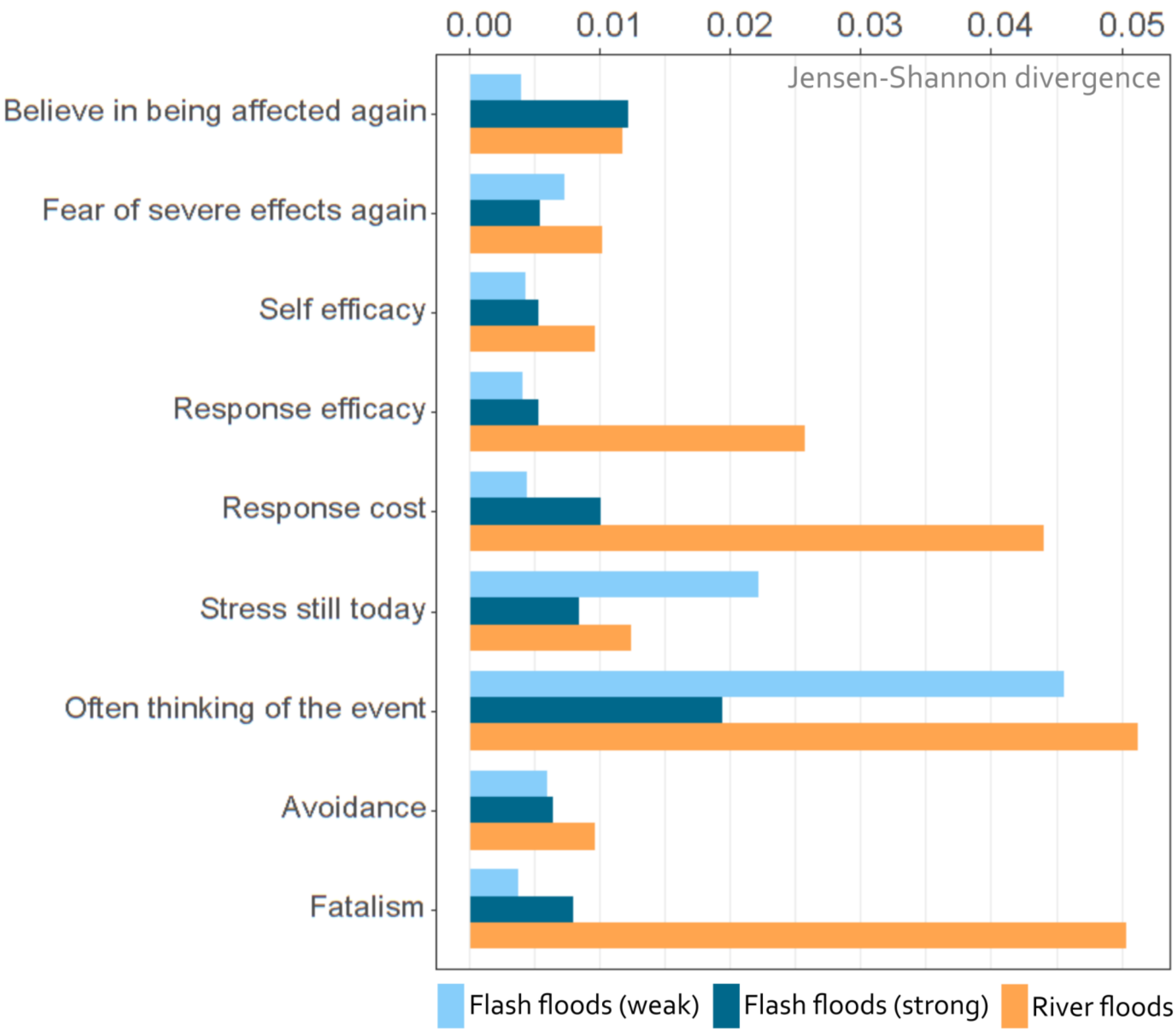

Figure 4-6 Jensen-Shannon divergence ranking of single psychological variables. Higher values indicate a higher information gain, if the planned precaution is explained through the particular variable

Further, the regression results of the single variables indicate almost no significant relationships with the planned precaution indicator (Table 4-3). Regarding weak river floods, “often thinking of the event” is significantly connected to a higher planned precaution while for strong flash floods, “fatalism” reveals a significant negative connection. In the case of river floods, no variables are significant (Table 4-3).

Table 4-3 Coefficients of the negative binomial logistic regression models for weak flash floods, strong flash floods and river floods with the individual psychological variables as predictor variables and the “planned precaution” indicator as response variable

Predictor variable	Flash floods (weak)	Flash floods (strong)	River floods
Intercept	0.62‘	1.64**	0.51‘
Believe in being affected again	-0.03	0.03	−0.03
Fear of severe effects again	0.00	−0.02	−0.02
Self-efficacy	−0.00	0.00	−0.01
Response efficacy	0.04	−0.02	0.03
Response cost	−0.02	0.01	−0.00
Stress still today	0.04	−0.06	0.04
Often thinking of the event	0.10*	−0.05	0.02
Avoidance	−0.04	0.03	0.01
Fatalism	0.02	−0.10*	0.01
AIC	669.34	300.24	1429.10
R^2	0.12**	0.1	0.04
N	177	76	419

‘$p < .10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

When comparing the analysis of the psychological indicators and the single variables, it can be summarised that a combination of items, as it is common practice in psychology, does not lead to more consistent and meaningful results in this case which is mainly reflected by similar JSDs. Moreover, the regression models of the single variables (Table 4-3) reveal a higher explanation power (R^2), especially in the case of weak flash floods, highlighting the importance of particular single psychological items. So the question remains, which method is the most suitable to combine variables. In this study, only few psychological items/variables were available while surveys to assess mental health comprise various indicators with up to 22 items (e.g. Ware & Sherbourne, 1992; Bei et al., 2013). By combining items, the inconsistencies among reported answers can be lowered and the predictive validity of indicators can be raised, facilitating the creation of psychological profiles (Ware & Sherbourne, 1992; Creamer et al., 2003). The analysis in this study follows this idea and indicates a certain importance of basic psychological indicators or variables for the motivation to implement precaution measures in future. However, the surveys which are used in this study primarily focus on direct damage and explanatory variables (see Thieken et al., 2017) and hence only comprise few significant questions which do not necessarily follow the established scheme of psychological surveys such as for example the 36-Item Short Form Survey (SF36), which is widely used to monitor the quality of life among patients. It has to be noted that more meaningful outcomes may be produced by more standardised questions and surveys. Within follow-up studies that rely on surveys, adjusting and adding questions should be considered for better psychological assessments.

4.3.5 Discussion of the hypotheses

H1: Flash floods, in comparison to riverine floods, show a different psychological impact on affected people in which negative effects such as stress and feelings of being helpless are more pronounced, since flash floods are more dynamic and thus are a bigger threat for life.

According to Figure 4-2, not the flood type, but the perceived strength/severity of the flood induces negative psychological effects. Among strong flash floods and river floods, no significant difference in stress becomes apparent except for threat appraisal where the distribution of strong flash floods is based on a relatively small dataset of 76 records (Figure 4-2, top right). Yet, this difference could be explained by the fact that the perceived threat of a strong flash flood event is lower, especially due to the severity and type of the event itself. Affected people perceive a strong flash flood event as less likely than people who have been repeatedly affected by river floods. Thus, future disaster risk management in Germany may also focus on the threat perception of affected residents and promote information campaigns in flash-flood-prone regions, especially if evidence from different sources suggests an increase in severe flash flood events. However, since all remaining burdensome and negative psychological effects vary with regard to the flood severity and do not significantly vary among different flood types, the first hypothesis must be rejected.

H2: Negative psychological impacts are connected to a lower probability for precaution because negative feelings hamper the individual energy and self-confidence as well as the overall motivation to implement precaution measures.

A high level of burden increases the protection motivation instead of affecting it negatively (Figure 4-5 & Table 4-2). Except this effect, no strong connections between strong psychological impacts and planned precaution were found. This may be explained by two reasons. Firstly, the assessment methods of psychological items as well as the items themselves do not follow established psychological assessment routines or surveys, presumably decreasing the data consistency and accuracy. Secondly, because of the relatively small datasets especially regarding flash floods, subtle effects on precautionary behaviour that are caused by psychological aspects may be superimposed by incidental effects. However, it is revealed that the indicator burden and, from a general point of view, thinking often of the event as well as the subjective stress are slightly positively connected to the precaution motivation among different flood hazards. This is contrary to the hypothesis but yet a valuable result, indicating a certain motivation of affected residents to protect themselves even after a severe and burdensome flood event. Here, the perceived "recency" and presence of the event may play a role in preparedness decisions. However, since negative psychological impacts are, if at all, positively connected to the precaution motivation, the second hypothesis must be rejected.

H3: Identified psychological indicators are suitable for explaining precautionary behaviour because certain psychological characteristics are distinctly connected to the protection motivation.

According to the correlation results, weak coherences (JSDs) as well as high uncertainties, the identified psychological indicators are mainly not suitable for explaining precautionary behaviour (see Figure 4-4, Figure 4-5, Table 4-2 & Table 4-3). As already mentioned, by applying standardized and established surveys to assess psychological characteristics, the accuracy and validity of the results may be increased. A very diverse and promising future field might also be the application of data mining techniques and the use of alternative data sources to facilitate the psychological profiling and predicting precautionary behaviour by different methods. Yet, a lot of research still has to be done in that regard. This study, however, reveals that stronger feelings of stress and often thinking of an event (i.e. the perceived burden) are connected to a higher precaution motivation, although the usability as a strong predictor within probabilistic models is limited due to the weak effect strengths. Thus, the third hypothesis can only be partly confirmed.

4.4 Conclusion

The aim of this study was to investigate psychological impacts in flood-affected residents that are caused by different flood types as well as the connection of these impacts to the precaution motivation. Further, the usefulness of psychological indicators and individual psychological variables to predict precaution motivation was evaluated. In this context, four psychological indicators and a precaution motivation indicator were created and differences in psychological impacts among flood types were analysed by using the Kruskal-Wallis rank sum test and Dunn's Test. The connection of these indicators and the individual variables to the precaution motivation was assessed by applying negative binomial regressions and Bayesian statistics as well as evaluating the posterior distributions using the JSD.

The study shows that generally not the flood type, but rather the overall severity of a flood event leads to stronger mental impacts among affected individuals Except threat appraisal, where people affected by strong flash floods report lower values, strong flash floods and river floods result in higher values for the indicators burden and evasion when compared to weak flash floods. The examination of psychological variables reveals that a certain indicator such as burden can be derived which is potentially useful in predicting the planned precaution. Here it is remarkable that people who report stronger negative feelings indicate a higher motivation to implement private precaution measures in future. Yet, the overall strength of different variable connections and the predictive power are generally low, which may be partly due to small sample sizes. When combining psychological variables, or items to derive a more robust indicator of mental health, established procedures which are applied in pure psychological studies should be taken into account. Considering the surveys which are used in this study, the predictive validity can potentially be enhanced by combining items, yet, more specific and standardised questions may lead to more robust results. Therefore, standardised psychological assessments should be considered within follow-up studies. In terms of future development and regarding psychological assessments that are based on publicly available information, further research may also focus on comparisons to established mental health surveys and validity checks to gain knowledge about the usefulness of alternative data sources for predicting individual behaviour. This field of science is rather broad and has already been investigated not only from a scientific perspective. However, useful outcomes may be expected by applying different methods and using different data sources to improve and facilitate information campaigns and damage estimations with regard to flood hazards.

Overall it is indicated that, in particular, the frequency of remembering an event plays a role in preparedness decisions. Therefore, recommendations for disaster assistance and risk communication are difficult to derive, especially with regard to increase the protection motivation of flood-affected individuals and helping with the individual recovery. Further research is required to estimate the predictive power of different psychological models which rely on mental health assessments and aim to quantify protective behaviour in the context of flooding.

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5 Synthesis and conclusion

Overall, the susceptibility patterns of flood-prone residents keep shifting in the context of climate change and economical as well as demographic development. In future, floods will continue to threaten a certain part of the European population, most likely causing financial and personal losses in the case of an event. In that regard, this thesis examined the changing susceptibility of flood-prone residents mainly in terms of influencing factors on private mitigation measures related to different flood types. Analysing and understanding already existing and unfamiliar flood hazards, i.e. river and flash floods, is as important as efficient precaution and preparation strategies, which form the key of an integrated and forward-looking flood risk management. Not only in Germany, also in the whole of Europe, a continuous adaptation of flood management strategies and better information campaigns to reach flood-prone households are needed to prepare for future challenges. Although individual mitigation behaviour is an essential factor in this context, knowledge about the decision making process among homeowners and its connection to various flood impacts remains scarce. To gain better insights into the current flood hazards in Germany and protection motivation of flood-prone households, three main research questions were examined within this thesis, of which the results are summarized and discussed in the next sections.

5.1 Influencing factors on coping appraisals and mitigation behaviour

Certain cognitive processes may influence the individual protective behaviour. A popular model to describe the cognitive process of threatened individuals, which became increasingly important in the domain of natural hazards, is the Protection Motivation Theory (PMT) (Rogers, 1975; Grothmann & Reusswig, 2006). Therefore, the following research question was formulated:

1. *In the context of the PMT, what are the influencing factors on coping appraisals and the related mitigation behaviour of flood-affected individuals? Moreover, do further personality characteristics influence the self-reported ability to take protective actions?*

Especially the coping appraisals of affected people, i.e. the self-efficacy, response efficacy and response cost, are known to be an important factor in the decision making process that leads to either a protective or nonprotective response. The analysis in chapter 2 focused on the influencing factors on coping appraisals and thus revealed insights into related decisions for flood mitigation. It was shown that flood-coping appraisals may not be solely explained by socioeconomic factors such as age, income, gender and education. Combined with psychological characteristics, i.e. risk aversion, avoidance and fatalism, a better picture of flood-coping appraisals is drawn. Avoidance and fatalism are negatively connected to coping appraisals and linked to nonprotective responses, while a higher risk aversion is connected in a positive way, i.e. in increased protection motivation. Coping appraisals are further significantly influenced by better coping information as well as social norms and networks in which positive feedbacks exist, i.e. if people perceive that neighbours and friends actively implement private flood mitigation measures, a general positive attitude towards self-protection and a higher individual protection motivation can be expected. Supporting evidence is revealed in chapter 4

(Appendix C) due to the fact that avoidant and especially fatalistic thoughts have been found to be negatively connected to coping appraisals, too. Overall it is shown that flood-coping appraisals have certain, noticeable influencing factors, however, as with many psychological models, generally low explanation power and fewer significant results were encountered. Further research is needed that includes more variables to understand the protection motivation among flood-prone households and the related coping appraisals, aiming to understand the decision making process in the context of the PMT. Better insights can help to find suitable ways for individual mental and physical support after and before flood events.

5.2 Damage driving factors of flash floods and river floods and potential implications for flood risk management

In Germany, river floods and flash floods occurred frequently in the recent years, causing high economic losses. To better adapt and improve flood risk management the different damage driving factors must be investigated and put into the context of demographic and economic development as well as climate change. Therefore, the next research question is as follows:

2. *What are the damage driving factors of flash floods in Germany and how do they compare to the damage driving factors of river floods? Are there potential implications for national and local risk management?*

Chapter 3 answers this question by analysing one flash flood event in 2016 in Southern Germany and comparing it to river floods in general. This event lead to very high monetary losses and stood as a prime example for the particular flood type. Considering the flood dynamics, flash floods are characterised by a significantly higher flow velocity which allows for the suspension of coarse material, rocks and even large boulders in case of a sufficient inundation depth. The analysed flash flood case study in chapter 3 revealed that the highest structural building damage is caused by large debris and rocks colliding with the building walls and susceptible exterior parts. Thus, the exposition of a building in flow direction plays an important role for the potential damage since shielding effects decrease hydrostatical forces and collisions. The exposition in flow direction is not considered as an important factor in investigations on damage caused by river floods. These floods usually show lower flow velocities (no turbulent flows) with finer suspended materials and damage buildings rather due to high inundation depths and long inundation durations.

The dynamics of flash floods are dependent on the local circumstances and often unpredictable. Still, highly damaging events are likely to increase in future (e.g. Volosciuk et al., 2016). In this context, first important steps of a local risk management include, among others, to increase the risk awareness of people in flash-flood-prone regions since information campaigns in potentially affected areas are still insufficient. National flood risk management may consider flash floods as a significant risk, although comprehensive obligations such as the creation of new hazard and risk maps and adapted local planning exist. In relation to severe weather events and changing risk patterns that are potentially enhanced by climate change, such improvements might be a necessity. However, economic impacts due to implications for local planning in terms of restrictions and new requirements (e.g. building bans in areas that are affected by a 100-year flood event or flood-adjusted construction projects) may also be expected, among others. Therefore, further research should also aim to quantify the potential damage and expected economic losses that may be caused by extreme flash flood events. In that regard, better knowledge helps integrate flash floods as a hazard in Germany, considering aspects that are important for policymakers such as economic and social implications.

5.3 Psychological responses of affected individuals caused by flash floods and river floods and the related protection motivation

Little is known about the mental impacts of river floods and flash floods and their effect on precautionary behaviour. In the overall context however, key strategies for a better understanding of shifting flood risks under climate change include decisions of affected households to protect themselves and the understanding of those decisions. Therefore, the third research question was as follows:

3. *Do different flood types such as river floods and flash floods in Germany induce different psychological responses and do they impact the perceived coping of affected individuals in various ways? Further, are certain psychological characteristics connected to the protection motivation?*

In contrast to river floods, strong flash floods often involve forceful run-off, the transportation of coarse material/debris and high flow velocities. The forecast of such flood events is very difficult and they can develop almost without lead time while having the potential to not only damage buildings and infrastructure, but also to cause serious injuries and fatalities. It can be expected that flash floods are thus perceived as a greater threat for personal health and property, leading to negative psychological responses in people who are aware of the risk and have experience with flooding. However, in chapter 4 it is revealed that not the flood type, but rather the severity of a flood event in terms of inundation depths and duration as well as flow forces and the related impacts can be associated to certain psychological responses and mental coping strategies. Both, strong river and flash floods have the potential to cause feelings of stress as well as avoidant behaviour while weaker flood events usually induce less emotional impacts. In this context, it is remarkable that the perceived threat of a strong flash flood is significantly lower than the threat of weaker flash floods and river floods. This indicates a discrepancy in the perceived probability of a particular event, where people believe that such a severe flood event is not likely to occur again in the near future. Against this background, policymakers may take comprehensive and targeted information campaigns in flood-prone areas into account.

In general, the effects of psychological responses on the protection motivation are either weak or non-linear and thus complex to understand. The most significant result appears to be that people who often think of an experienced event show a greater motivation to implement precaution measures. Yet, only thinking of an event quite often does not necessarily imply a negative psychological impact but could also be part of a coping strategy, which, however, has to be investigated in more detail in future work. In addition to the PMT, which provides first, valuable results, gaining better insights into various psychological responses after floods and the connection to private flood mitigation requires established schemes of psychological surveys such as the 36-Item Short Form Survey (SF36) that can be used to monitor the quality of life among patients (Ware & Sherbourne, 1992).

5.4 Courses of action for policymakers

This research has shown that flash floods and river floods describe serious hazards that remain a factor of risk in many German regions while affected residents follow different mental coping and mitigation strategies. With regard to the research questions, the following facts demand policymakers and flood risk management to review options for an overall improved flood resilience.

After all, strong flash floods are still hard to forecast and not yet assessed as a significant risk in Germany although the flood dynamics can cause high damage and imply a serious danger to life as demonstrated during the flooding in May and June 2016. Local planning should therefore consider flash flood risks in order to mitigate and, in the best case, prevent high economic losses and fatalities. In the light of increasing severe weather events, risk assessments, better communication of scientific results and adequate information campaigns in flood-prone regions could be first steps to raise risk awareness and further sensitise the population. Knowledge about flood risk is known to diminish over the years and, in contrast to the residents in areas prone to river floods, most of the affected residents in 2016 neither did experience a flood before, nor knew how they could protect themselves. Even people who already experienced a severe flash flood perceive the event as unlikely to happen again in a foreseeable timescale. Yet, the overall personal flood coping appraisals and protection strategies are, besides socioeconomic factors, found to be influenced by the social environment, helpful information about coping options and how strong the event is remembered or suppressed. These results suggest that policies should aim to strengthen the social networks and facilitate information provision as well as coping support in relation to flash floods.

After flash floods have been confirmed as a potentially damaging event within a community, programs could be established that strengthen the social networks by e.g. supporting the implementation of self-organised meetings or groups on municipal level to bring together experts and flood-prone homeowners. Current situations and risks could be evaluated and options for damage mitigation as well as expected costs may be discussed. Personal coping abilities could thus be stimulated in an environment that allows for positive feedbacks. In terms of preparation against severe events, insurances should be advertised by also granting premium reductions or similar benefits as a positive incentive. Such initiatives may target both, long-established residents and newcomers.

5.5 Recommendations for future research

With reference to changing flood hazards in Germany that concern flash floods in particular, research should focus deeper on the identification of hazard prone regions and exposed assets, which, together with modern climate models, should be a first comprehensive approach that facilitates adjusted flood risk management and supports the creation of updated risk maps. After the identification of regions that might be affected by a flash flood, assessments of the potential local impact on buildings and infrastructure could follow. Modern technology such as drones or publicly available data could be used to create a detailed 3D environment for hydraulic modelling in order to evaluate superior or private flood protection and mitigation measures. In case that a severe flash flood event happens, data collection and analysis have to be continued. Since severe flash floods are relatively rare in Germany but yet describe a costly and dangerous hazard, it is important to gain more insights into flood processes and the related damage driving as well as damage reducing factors, also as a complement and validation for previously created risk maps or models. Moreover, the effectiveness of certain private mitigation measures against flash floods should be evaluated in order to provide policymakers and affected households with valuable information on costs and benefits of measures.

Apart from better climate modelling and deeper investigations on changing flood-risk patterns in Germany, future research has a lot of potential and various good options to continue within the field of psychology and natural hazards. It is known that modern algorithms offer various possibilities of prediction in many facets of human life. Yet, some aspects of this development are thoroughly discussed in terms of data security, privacy and potential dangers, since modern algorithms often make use of personal and sensitive information, as can be recognised within the advertisement sector, for example. In the context of flood mitigation however, new modelling approaches, machine learning techniques and intelligent algorithms can theoretically be used to identify psychological characteristics that are connected to private precaution and thus analyse the motivation of flood-prone households to protect themselves. As a result, an integrated flood risk management may benefit from a better understanding of behavioural aspects among flood-affected individuals due to the inclusion of future mitigation behaviour into flood damage models and better predictions that focus on potential economic losses. This thesis is a first step in this direction. However, for improvements and deeper knowledge about this topic, several aspects should be considered in future. As an important prerequisite for example, larger databases are generally needed in order to apply new models, machine learning techniques or modern algorithms and gain substantial insights at the same time. First, an important step is to extend the database of flood-affected households in a way that next to psychological characteristics, different regions as well as different flood types are covered to identify behavioural patterns that are generally valid. Since telephone-aided surveys are usually biased towards older survey participants, modern options for a specific data collection that addresses people from all relevant age groups should be considered to obtain a comprehensive, reliable database for further evaluation. In that regard, potential data collection methods comprise targeted online surveys, smartphone applications and contracts with companies. Those techniques may go beyond the findings presented in this thesis and result in predictions that are more precise but go along with certain disadvantages. On the one hand, the prerequisite to have large data amounts available which further show a high quality and consistency is often hard to fulfil. On the other hand, good results should be interpretable in terms of causality and meaning. The application of modern algorithms such as neural networks or random forests involves the risk that results might show a high robustness but are less understandable due to the black box character of the analysis.

Yet, an alternative approach to gain insights into the mental coping and connected mitigation behaviour of flood-prone residents is the use of established psychological assessments after severe flood events to gather robust data and create reliable, interpretable results. In line with the standards, surveys can be conducted that comprise a catalogue of questions to assess the post-traumatic stress disorder (PTSD) or the Impact of Event Scale - Revised (IES-R) as a second option to measure traumatic stress, while relevant aspects of private flood mitigation are included for further analysis. In addition to the protection motivation theory, this approach may reveal insights into negative psychological responses after a flood and their connection to future protective actions. Moreover, ways and options for an effective mental coping after floods may be indicated, especially if personal losses have been experienced. In that regard, longitudinal studies could support the research with analyses that concern the changes in psychological characteristics and the connection to actual precautionary behaviour. This information will be valuable for an integrated flood risk management in terms of updated strategies for a better coping with flood events and support recovery from them.

This thesis showed that the susceptibility of flood-prone residents in Germany could be reduced if various aspects of mental coping and mitigation behaviour are understood and find their way into current flood risk management strategies. It stands out that flood hazards and related psychological impacts both continue to be important fields in science that complement each other and imply promising topics for further research.

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Appendix A

Presentation of structural, non-structural and insurance measures to the respondents when eliciting flood-coping appraisals in the German and French sample:[1]

Please note: the different categories of measures (structural and non-structural) were also introduced previously to the respondents when their implementation level was elicited.

Response efficacy (German Sample):

In the following, I will mention several measures that a person can take to protect the household from flood damage. Please tell me, how effective do you consider these measures to be?

1 Structural measures, such as moving the heating system to the first floor or using flood-resistant building materials
2 Non-structural measures, including avoiding storing valuable items in the cellar or basement, such as personal objects, important documents and other valuables
3 Purchasing flood insurance

Self-efficacy (German Sample):

To what extent are you or a member of your household able to actually carry out the measures listed below? I mention the list of measures here once again:

1 Structural measures, such as moving the heating system to the first floor or using flood-resistant building materials
2 Non-structural measures, including avoiding storing valuable items in the cellar or basement, such as personal objects, important document and other valuables
3 Purchasing flood insurance

Response cost (German Sample):

How much effort would it cost you personally to actually implement the measures listed below? This refers likewise to time, financial and emotional effort. I mention the list of measures once again:

1 Structural measures, such as moving the heating system to the first floor or using flood-resistant building materials
2 Non-structural measures, including avoiding storing valuable items in the cellar or basement, such as personal objects, important documents and other valuables
3 Purchasing flood insurance

[1] Please note that this is a translation from the German questionnaire

Response efficacy (French Sample): [2]

How do you rate the effectiveness of the structural/non-structural measures listed above?

Self-efficacy (French Sample):

Do you feel that you or a member of your household has the capacity to implement most of the structural/non-structural measures listed above?

Response cost (French Sample):

How do you rate the costs of the non-structural measures listed above?

Table A-1 Variable definitions of the German survey analysis

Variable	Definition
Response efficacy	Categorical variable, respondent expects measure to be: 1=ineffective, 2= somewhat ineffective, 3=somewhat effective, 4=effective
Self-efficacy	Categorical variable, how able the respondent expects to be to implement the measure: 1=unable, 2=somewhat unable, 3=somewhat able, 4=able
Response cost	Categorical variable, respondent expects costs of the measure to be: 1=not costly, 2=less costly, 3=somewhat costly, 4=costly
Education	Highest completed education level on a scale of 1-6
Household members	Total number of household members
Age	Age of the respondents grouped into 7 classes
Ownership	Dummy variable, 0=owner, 1=tenant
Female	Dummy variable, 0=female, 1=male
Income	Dummy variable 0=lowest income classes 1=higher income classes
Perceived probability	Categorical variable, expected likelihood the respondent will be affected by a flood again: 1=unlikely, 2=somewhat unlikely, 3=somewhat likely, 4=likely.
Perceived consequences	Categorical variable, respondent expects future damage to be: 1=low, 2=rather low, 3=rather high, 4=high.
Social environment	Categorical variable, how many friends/neighbors implemented the measure: 1=none of them, 2=a few of them, 3=some of them, 4=most of them.
Satisfaction with flood management	Categorical variable, how satisfied respondent is with public flood management: 1=dissatisfied, 2=somewhat dissatisfied, 3=somewhat satisfied 4=satisfied.
Avoidance	Categorical variable, whether respondent agrees with the statement that they simply trust they will not be affected again: 1=disagrees, 2=somewhat disagrees, 3=somewhat agrees, 4=agrees.
Fatalism	Categorical variable, whether respondent agrees with the statement that nothing can be done to protect against flooding: 1=disagrees, 2= somewhat disagrees, 3= somewhat agrees, 4= agrees.
Postponement	Categorical variable, whether respondent agrees with the statement that private flood protection is generally useful but will only be implemented if absolutely necessary: 1=disagrees, 2=somewhat disagrees, 3=somewhat agrees, 4=agrees.
Past flood damage (ln)	Natural log of the damage suffered in the past to contents and building structure
Risk information	Dummy variable, 1=respondent has received or looked for information on his or her risk, 0=otherwise.
Coping information	Dummy variable, 1= respondent has received information on how to implement flood protection measures, 0=otherwise.
Unprotected area	Dummy variable, 1= respondent lives in an area protected by a dike, 0= respondent lives in an area not protected by a dike.

[2] Please note that this is a translation from the French questionnaire

Table A-2 Variable definitions of the French survey analysis

Variable	Definition
Response efficacy	Categorical variable, respondent perceives the measures to be: 1= very ineffective, 2= somewhat ineffective, 3= neither effective nor ineffective, 4= somewhat effective, 5= very effective
Self-efficacy	Categorical variable, how capable a respondent considers him/herself or a member of the household of taking the described measures: 1= totally unable, 2= somewhat unable, 3 = neither able nor unable, 4= somewhat able, 5= totally able
Response cost	Categorical variable, respondent perceives the measures to be: 1= very inexpensive, 2= somewhat inexpensive, 3= neither inexpensive nor expensive, 4= somewhat expensive, 5= very expensive
Education	Highest completed education level on a scale of 1-8
Household members	Total number of household members
Age	Age of the respondent in years
Ownership	Dummy variable, 1=owner, 0=tenant
Female	Dummy variable, 1=female, 0=male
Income	Net monthly household income in €1,000
Perceived consequences	Categorical variable, respondent expects future damage to be: 1=very low, 2= low, 3= medium, 4= high, 5= very high.
Perceived flood risk	Categorical variable of whether respondent thinks that his or her flood risk is 1=lower, 2=equal to, or 3-higher than the average person in France.
Feel protected	Categorical variable, how protected respondent feels against future floods: 1= very poorly protected, 2= rather poorly protected, 3= neither poorly nor well protected, 4= rather well protected, 5= very well protected.
Public defences	Categorical variable, respondent feels protected against future floods by public flood defences: 1= very poorly protected, 2= rather poorly protected, 3= neither poorly nor well protected, 4= rather well protected, 5= very well protected.
Past flood damage	Continuous variable of the total damage to home and contents experienced by the respondent during the last flood in €1,000
Low fatalism	Continuous variable of the extent to which the respondent agrees with the statement "There is nothing that can be done to stop floods from happening or to decrease flood damage" 1=strongly agrees up to 5=strongly disagrees.
Risk aversion	Categorical variable, respondent considers that people avoiding financial risk by purchasing insurance are: 1= very different, 2= somewhat different, 3= neither different nor similar, 4= somewhat similar, 5= very similar to themselves.
Risk information	Dummy variable, 1= respondent has received or looked for information on his or her risk, 0=otherwise.
Coping information	Dummy variable, 1= respondent has received or looked for information on flood protection measures, 0=otherwise.
Social environment	Dummy variable, 1= mitigation measures taken by friends, family, or neighbors, 0=otherwise.

Table A-3 Inter-correlation table for the German and French samples

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Education	1	0.14***	-0.23***	0,05	0.07*	0.47***	na	0.08*	0,04	na	0.09**	na	na	-0.1**	na	-0.09**	0.08*	0,04	na	-0,03
2. Household members	0.09*	1	-0.45***	0.11**	-0.09**	0.42***	na	0,06	-0.07*	na	0.12***	na	na	-0.08*	na	0,02	0.08*	0	na	-0.12***
3. Age	-0.18***	-0.39***	1	0.28***	-0.18***	-0.11**	na	-0.13***	0.09*	na	-0.07*	na	na	0,06	na	0.09*	-0,02	0.09**	na	0.11**
4. Ownership	0,02	0.26***	0.12***	1	-0.12***	0.29***	na	0,02	-0,03	na	0,02	na	na	-0,06	na	0.16***	0.11***	0,05	na	-0,05
5. Female	-0.11**	-0,03	-0,02	-0,06	1	-0.19***	na	-0,02	-0,03	na	-0,05	na	na	0,03	na	-0,02	-0,03	-0,06	na	0,01
6. Income	-0.33***	-0.31***	0.15***	-0.16***	0.18***	1	na	0,02	0,03	na	0.09**	na	na	-0.12***	na	0,01	0.09*	0,06	na	-0,06
7. Perceived probability	-0,01	0	0,02	0,06	0,05	0,01	1	na	na	na	na	na	na	na	na	na	na	na	na	na
8. Perceived flood risk	na	na	na	na	na	na	na	1	-0.38***	na	0,05	na	na	-0.07*	na	0.36***	0.29***	0.12***	na	-0.25***
9. Feeling protected	na	na	na	na	na	na	na	na	1	na	-0,01	na	na	0.2***	na	-0.32***	-0.1**	-0,02	na	0.69***
10. Perceived consequences	-0.09*	0,06	0.08*	0,06	0.09*	0.09*	0.21***	na	na	1	na	na	na	na	na	na	na	na	na	na
11. Social environment	0.19***	0.12**	-0.13**	0,04	-0,02	-0.25***	0,06	na	na	-0,07	1	na	na	-0,01	na	0,02	0.15***	0.14***	na	0
12. Satisfaction with flood magement	-0,02	-0.11**	-0,01	-0.17***	0.08*	0.09*	-0.29***	na	na	-0.11**	-0,01	1	na	na	na	na	na	na	na	na
13. Avoidance	-0.11**	-0,08	0,07	-0.1**	0.09*	0.09*	-0.3***	na	na	-0,03	-0.21***	0.2***	1	na	na	na	na	na	na	na
14. Fatalism	-0.16***	-0,05	0.16***	-0,04	0,04	0.09*	0,08	na	na	0,04	-0.13**	-0,01	0.09*	1	na	-0,06	-0.07*	-0.1**	na	0.23***
15. Postponement	-0.12**	-0,01	-0,07	-0.12**	0,06	0,02	-0.16***	na	na	-0,05	-0.31**	0,06	0.26***	0.13***	1	na	na	na	na	na
16. Past flood damage (ln)	0,03	-0,02	0.25***	0.26***	-0,05	-0.1*	0.38***	na	na	0.18***	0,02	-0.19***	-0.19***	0.08*	-0.21***	1	0.2***	0.13***	na	-0.3***
17. Risk information	0.08*	0.13***	-0,03	0.1**	-0.08*	-0.17***	0,05	na	na	-0,01	0.14**	-0,01	-0.13***	-0,06	-0.17***	0.16***	1	0.45***	na	-0,05
18. Coping information	0.08*	0.14***	-0.09*	0.11**	-0.09*	-0.12**	0,03	na	na	0	0.24***	0,05	-0.09*	-0.09*	-0.14***	0,04	0.43***	1	na	-0,02
19. Unprotected area	0.13***	0,06	-0,04	0,03	-0,02	-0.1*	-0.19***	na	na	-0,06	0,08	0.22***	0,05	-0,04	0.09*	-0.11**	0,01	-0,02	1	na
20. Public defences	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	1

Note: *p-value <.05; **p-value <.01; ***p-value <.001; Method: Spearman's Rho; pairwise complete observations

French data

German data

Appendix A: Supplementary file for review

An example of an ordination plot and an explanation is provided in Figure S1. It shows a plot of a hypothetical dataset with two clearly detected groups (groups 1 and 4) and one group which is less clear (3), indicated by the dispersion and distance between the gray dots within the plot. The closer together and the larger the distance between dot clusters, the more distinct are the groups. Additionally, cases occur outside the green group margins, which implies that these respondents make up a less clearly defined group (formerly group 2) and were thus manually deselected in the plot. The amount of explained variance by the PCA axes 1 and 2 is shown next to the respective axis. The gray dots resemble a particular combination of the variables with which the PCA was conducted. The size of the dots corresponds to the frequency with which the same combination occurred within the data. Coherence values of explanatory variables with the groups are displayed by the brown arrows, which show the correlation strength as well as correlation direction of a variable. Longer arrows mean stronger correlations between the particular variable and the two PCA axes in general. The angles between arrows and axes show how the variable is correlated with each particular axis. The smaller the angle between them, the stronger the correlation (62). Thus, if variable arrows point towards the same plot region in which groups appear, a positive coherence between this variable and the group can be assumed. A negative correlation is indicated by variable arrows, pointing in the opposite direction of a group.

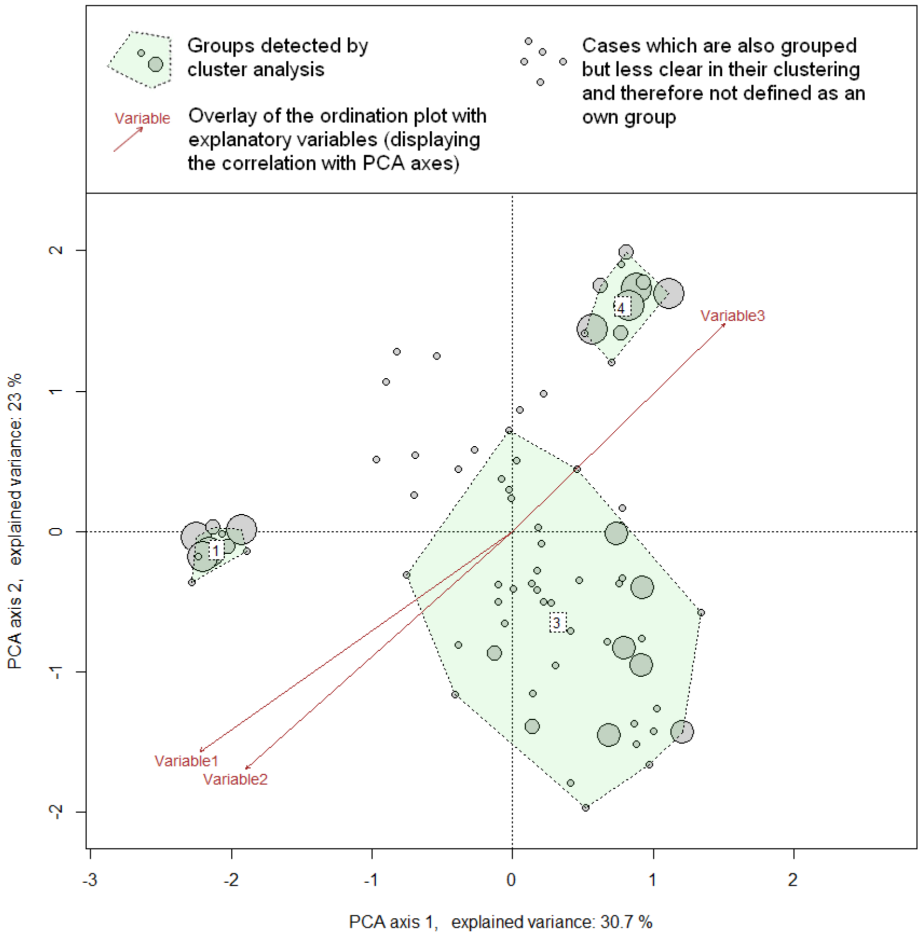

Figure A-1 Example of a PCA ordination plot with hypothetical data

In detail, Figure S1 can be interpreted as follows: Between groups 1 and 4, the relative ‘difference’ is the highest and the cases/combinations of variables within are relatively similar. All three variables are strongly correlated with both PCA axes. While variable 3 is positively correlated with PCA axis 1 and 2, the variables 1 and 2 are negatively correlated with both axes. Further, it is shown that the variables 1 and 2 display a positive correlation with group 1, since they are pointing to the same quadrant – that is, to the negative side of PCA axis 1 – and are relatively close to each other. The same applies for variable 3 and group 4 on the positive side of PCA axes 1 and 2. It can be concluded that variables 1, 2 and 3 have reasonable explanatory power with reference to the grouping of respondents.

Appendix B

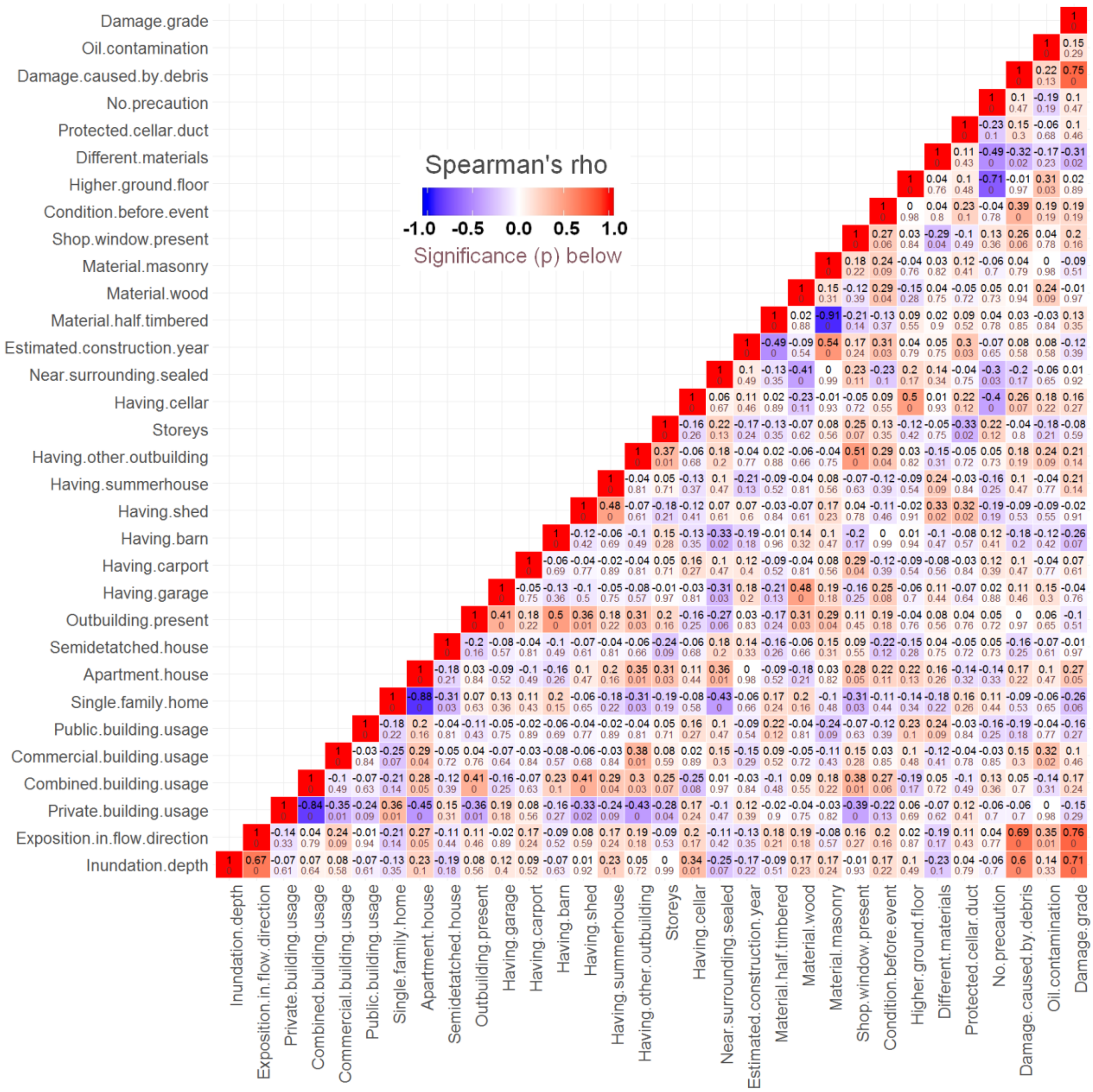

Figure B-1 Spearman's rank correlation matrix and correlation significance of all variables in the data set. The count of complete cases for the analysis was 51

Appendix C

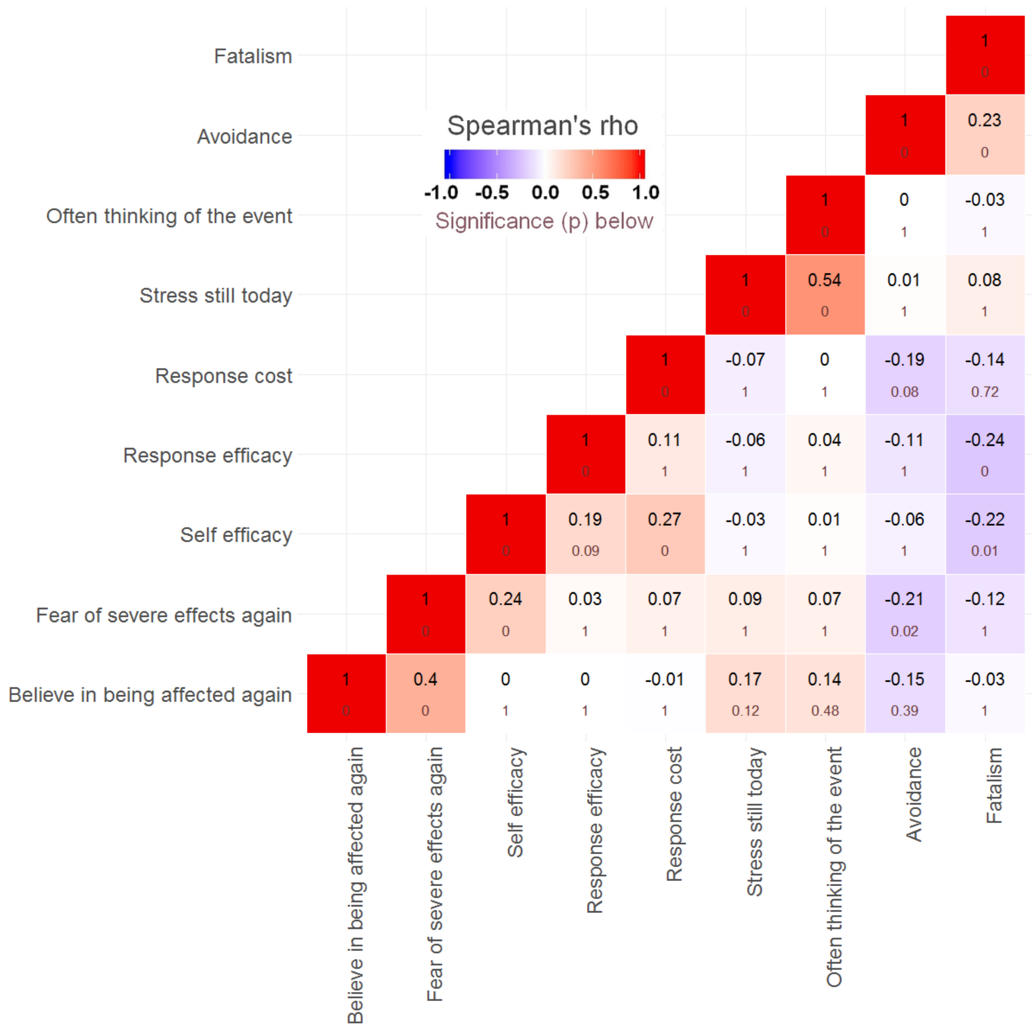

Figure C-1 Correlation table of single psychological variables for weak flash floods

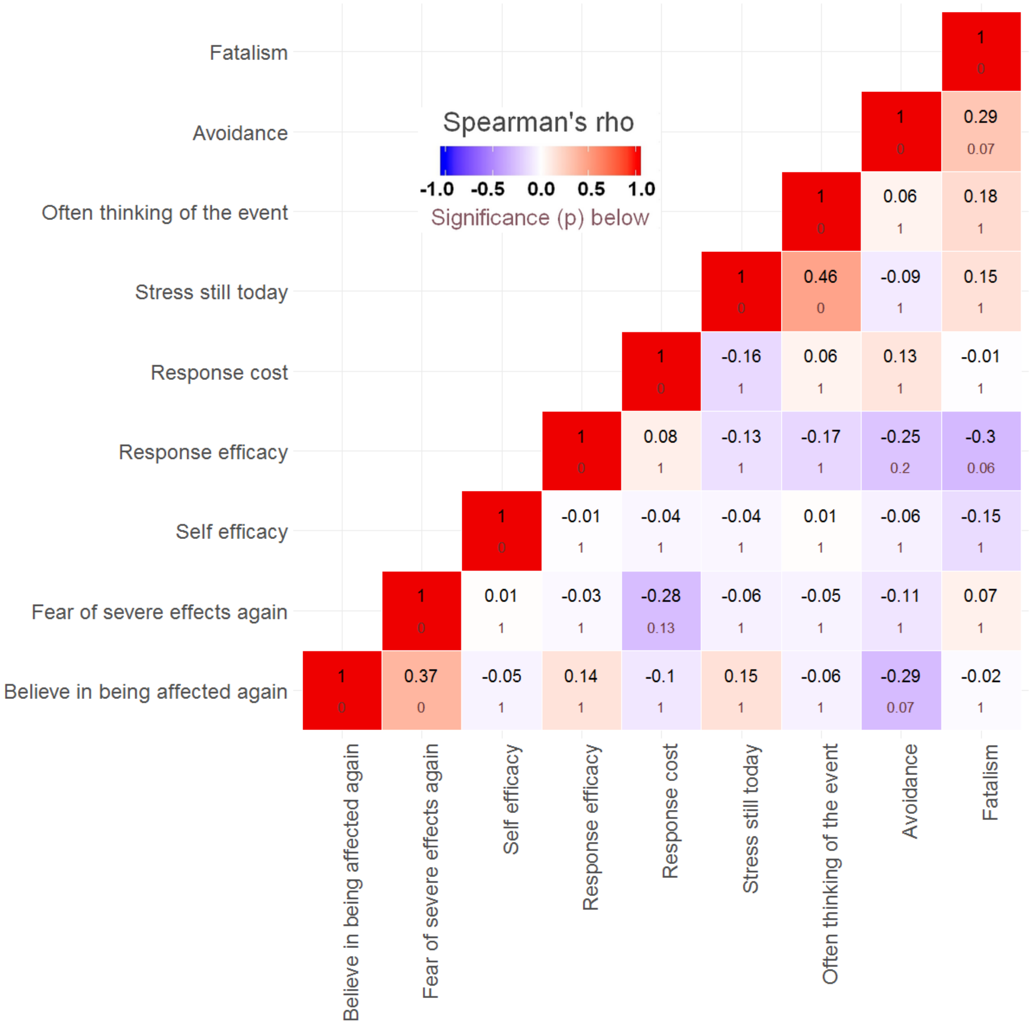

Figure C-2 Correlation table of single psychological variables for strong flash floods

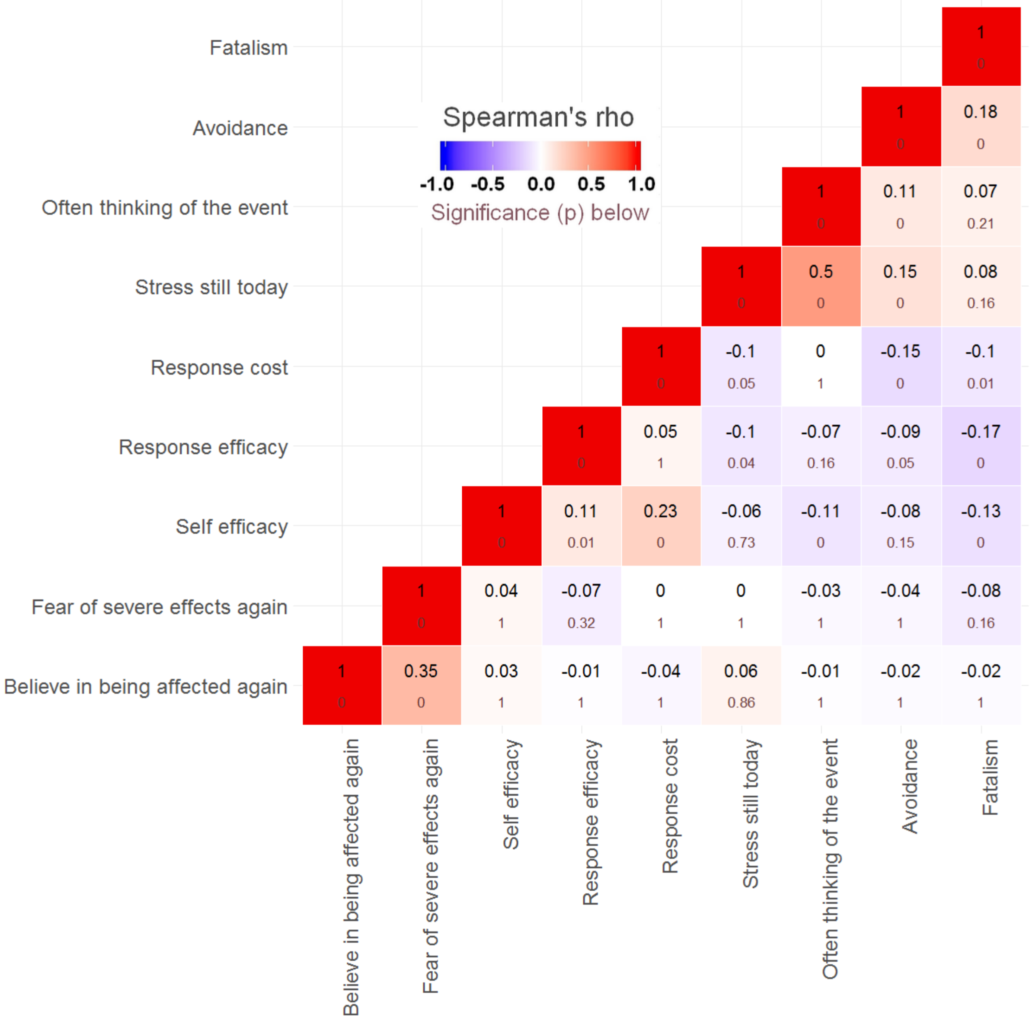

Figure C-3 Correlation table of single psychological variables for river floods

Selbstständigkeitserklärung

Hiermit erkläre ich, dass ich die vorliegende Dissertation selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe. Alle wörtlich oder inhaltlich übernommenen Quellen sind als solche gekennzeichnet.

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