

Response to Referee #1, Tim Harries, 2019

Author: Jonas Laudan¹

Co-authors: Gert Zöller², Annegret H. Thieken¹

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

²University of Potsdam, Institute of Mathematics, Karl-Liebknecht-Strasse 24–25, 14476 Potsdam, Germany

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We thank the reviewer again for his review and comments how to improve the manuscript.

Comments of the reviewer

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My thanks to the authors for their efforts to take on board the recommendations made by myself and the other reviewer. In particular, the description of the methods has improved considerably and some of the text has become easier to read. Unfortunately, I still have a number of serious reservations, especially regarding the scientific significance of the paper, the attribution of participants to groups (weak, medium and strong) and the clarity of the writing.

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Main point 1:

1. Hypotheses. In order to contribute to the extant literature and have scientific significance, the study needed to have drawn on that literature for its hypotheses. I do not feel this has been done/done sufficiently.

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- H1: I am not aware of any empirical evidence to suggest H1. Neither I am convinced by the common-sense justification provided by the authors. Hence, I do not see the value of expending so much effort (and reader time) on conducting a test that fails to support it.

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- H2 is more interesting but poorly described and, like other Hs, not grounded in the literature. Where is the research evidence to suggest that negative psych impacts will reduce the motivation to implement precaution? I would have liked to see a presentation of the literature on this issue. On p17 the authors themselves cast doubt on the scientific value of the way they tested this hypothesis - when they assert that the sample size was insufficient for H2 and that established processes were not followed.

- H3 remains poorly described. The reader needs to know which psych indicators are being tested rather than just being given examples. It is not clear what is meant by 'are suitable' and this cannot be tested with statistics. What does 'distinctly connected' mean?

5 **Answer 1:**

- To our knowledge, Bei et al. (2013), Gaume et al. (2009) as well as Mason et al. (2010) already provide evidence that severe flash floods describe a danger not only to property but also to physical and mental health and therefore justify hypothesis 1. Additional empirical evidence is now given in the paper for a better grounding of all hypotheses.

Paper changes:

10 (Page 14, line 30) This effect is further described and underpinned by Hudson et al., (2019), who found out that flood experience is connected to a loss in subjective well-being among flood affected residents in Vietnam, while females tend to recover slower than males. This was also found by Bubeck and Thieken (2018) for Germany. Additional evidence for negative mental health effects after floods is given by Wagner (2007), who suggests that models of anxiety and coping can be related to fears of different hazard types. Those models describe reactions and coping strategies of people whichwho are guided by vigilance (i.e. actively searching for threat-related information) and avoidance (i.e. denial & distraction). Moreover, a comprehensive review of Fernandez et al. 15 (2015) on flood related mental health issues as well as Foudi et al. (2017) strongly support the assumption that, in case of flood exposure, especially water depth and high flow velocities have a negative impact on mental health in terms of increased levels of PTSD, anxiety, as well as depression. This is also supported by Lamond et al. (2015) 20 who suggest that psychological symptoms such as stress and anxiety remain as a result of severe flooding and flood damage. Further they reveal that mental health issues are related to post-flood mitigation actions, where especially relocating seems to be a suitable measure.

- By mentioning problems and methodological challenges, we do not intend to disqualify our work, but suggest valuable improvements and giving thoughts to an improved design of future studies.

25 • For clarification we rewrote H3 in the following way:

(Page 15, line 29) Psychological indicators such as e.g. the feelings of stress and burden that people still perceived at the time of the interview or self-reported coping abilities can be used as a proxy to explain precautionary behaviour because such mental feelings and attitudes are connected to the motivation and intention to protect oneself in future as highlighted e.g. by the Protection-Motvation-Theory and others.

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Main point 2:

There is no shame in producing a negative result, yet the authors seem to try to hide this. E.g. if you have 'low explanatory power' and 'non-significant results' this suggests that the psych indicators have no usefulness rather than 'limited usefulness'.

5 **Answer 2:**

We agree that there is no shame in producing negative results and support the approach to avert post-hoc hypothesis adjustments in general. We rewrote the mentioned paragraphs in a way that any concerns about alleged hiding intentions may be eliminated.

Paper changes:

- 10 (Page 11, line 15, Abstract) According to the used data, however, predictions of the individual precaution motivation should not be based on the derived psychological indicators, i.e. "coping appraisal", "threat appraisal", "burden", and "evasion", since their explanatory power was generally low and results are, for the most part, non-significant. Only burden reveals a significant positive relation to planned precaution regarding weak flash floods. A remarkable difference to weak flash floods and river floods can be seen with regard to strong flash floods, where the perceived threat is significantly lower although feelings of burden and lower coping appraisals are pronounced.
- 15

Main point 3:

- 20 The non-significance (rather than 'low significance') of the relationship between avoidance and fatalism amongst those experiencing strong flash floods seems to call into question the validity of combining avoidance and fatalism when looking at strong flash floods. Yes, this 'may' be due to the sample size, but where is the statistical evidence to support this suggestion?

25 **Answer 3:**

The variable combinations and resulting indicators have been chosen to remain the same among different flood types to ensure a certain comparability. Therefore we also combined avoidance and fatalism among those who experienced strong flash floods. To gain insights into single variable connections we performed a correlation analysis of the planned precaution and all separate psychological variables. Here it is revealed how they perform as predictors on their own.

- 30 In fact, we accidentally reported a wrong p-value regarding the correlation between avoidance and fatalism of strong flash floods. The new corrected p-value is 0.07 and therefore significant at a <0.1 level.

Still, for a better clarity we will include a power analysis to test the correlations.

Paper changes:

(Page 20, line 34) and a power of 1.0 in all cases. Further, avoidance and fatalistic thoughts reveal a correlation of 0.23 (complete cases n=275, $p < 0.05$, power=0.97) for weak flash floods, 0.29 (complete cases n=113, $p = 0.34$, $p = 0.07$, power=0.88) for strong flash floods and 0.18 (complete cases n=1242, $p < 0.05$, power=1.0) 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.~~ Therefore, we combined avoidance and fatalistic thoughts as two different strategies of maladaptive behaviour

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10 **Main point 4:**

The categorisation used within the study aim and the paper title remains problematic. Flash floods and river floods are not mutually exclusive categories. Rivers can themselves produce flash floods (e.g. when their catchment has a low absorptive capacity). I may be wrong, but I think that it would be more accurate to distinguish "flash" floods from "slower onset" floods and that the source of the flooding (pluvial or fluvial) is irrelevant to their question.

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Answer 4:

It is true that the boundaries of flash floods and river floods can be rather fluid. However it is also true that orography describes an important aspect to consider in potential flash-flood-prone regions. Our flood data is based on two different datasets after two different events. One survey has been conducted after a strong river flood event in 2013 with slow onset times, the other contains only persons affected by heavy rainfall and following floods with a short lead time, a more or less forceful runoff (pluvial floods/urban flooding) and high flow velocities. According to this, we distinguished the flood types as described in the paper.

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Main point 5:

Large parts of the text remain hard to read and, in many instances, hard to understand even after repeated reading. E.g. lines 25-32 on p4; 29-31, p7. It is not uncommon for the former to indicate that authors themselves do not fully understand what it is that they are trying to express, so the lack of clarity makes me particularly nervous. There are two main issues here: logical clarity (i.e. in the construction of sentences and paragraphs) and use of English. Terminology. "Flood dynamics" needs to be defined before it is used.

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Answer 5:

Additional proofreading by a native English speaker was performed before the resubmission of the revised paper. Changes are included in the revised version but not detailed in this response letter. We hope that this process has improved the readability of the paper.

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Main point 6:

Methods

- 10 • In an ideal world, all other factors should be kept constant in a test of the impacts of type of flood on psych. The confession that the two regions “differ almost completely” is therefore a peculiar one; it seems to invalidate the whole exercise.
- The two surveys are described as “very similar”. I would want some reassurance that none of the differences impact on the validity of the analysis.
- 15 • Was “information gathering” aggregated with other precautionary measures in the outcome variable used? Why? My reading of the overall text suggests that the intended/actual precautions variables refer to tangible measures and not to information seeking. This should perhaps be made clearer.
- The attribution of weak, strong and medium to the flash floods is key to the analysis, so needs careful explanation. I find this a particularly vulnerable aspect of the research design and need reassurance and greater clarity. I suggest more detail on this aspect.
- 20 • The authors should make it explicit that weak, strong and medium relate to impacts on the areas and do not necessarily reflect levels of physical impact on particular homes/residents.
- Given that online literature and the press usually report only the most dramatic floods, I wonder how the authors were able to identify “weak” floods. It would not be safe to assume that any flood not mentioned in the press was “weak” as it is unlikely that all strong/medium floods were actually reported on.

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Answer 6:

- It is theoretically correct, but practically questionable to assume that regions as well as the flood types should not differ, since the characteristics of flood types we considered are -besides rainfall intensity- also influenced by orography and catchment sizes. Despite the fact that river floods and flash floods are not mutually exclusive, they rarely affect the same region and therefore different regions and residents are affected by different floods within a reasonable time span. As stated by Wagner (2007), we agree that the region, or more precise the local condition, is a relevant factor of risk perception. However after being affected by a flood, behavioural aspects and individual mental coping are influenced much more by the recent event itself and depend on personal character traits, rather than the particular region. Of course, longitudinal studies

with the same persons being repeatedly affected by different flood types would be desirable but yet, data scarcity is an issue and panel data are challenging to collect as recently outlined by Hudson et al. (2019).

- Yes, we are confident that none of the differences impact on the validity of the analysis and we clarified this within the paper.

5 • Information gathering, too, factors into the 'planned precaution indicator' and it is true that not only tangible measures have been considered. We clarified this that in the paper, as well.

- We further elaborated on the fact that the flash flood strength is considered for a larger area, in most cases a whole municipality, and not at particular houses.

- To not rely solely on press articles we compared the reported event with rainfall data from DWD (Deutscher Wetterdienst)

10 - as described in the paper - for a better judgement of the local flood severity.

Paper changes:

(Page 17, line 27) The outline of both surveys is identical regarding all questions that were chosen for this study. In general, the questionnaires (...)

15 (Page 19, line 5) The flash flood strength was assessed on the municipality scale. It can be assumed that impressions and effects of the flash flood severity are not particularly dependent on the intensity at the individual house but are rather influenced by the overall appearance and effects of the flood within a village/town, which also includes impacts on neighbours, friends and infrastructure. It makes sense that mental coping, especially after strong flash floods, is not solely influenced by the individually experienced damage but dependent on experiences gathered in the local neighborhood.

20 Moreover, not only the impact, but also the potential to be harmed outdoor in case of sudden and strong flow forces may influence the mental coping in regions which can experience strong flash floods. In this context, Morris et al. (2016) showed that people who perceive flash floods as a risk to their life tend to protect themselves if they receive a flash flood warning. Therefore it can be assumed that the mental impacts after a severe event are differing with regard to the severity within an affected area (eg. Bei et al., 2013).

25 (Page 19, line 25) as well as associated rainfall in the area at the particular time based on data from DWD, (...)

30 (Page 21, line 28) It resembles a score of precaution in which information gathering, non-structural precaution structural precaution and preparation are included and weighted according to their effectiveness (see section 2.1 for the private precaution measures).

Main points 7:

5 Given that the paper places such emphasis on the role of denial, it seems strange that the authors do not utilise 'denial' to explain lower feelings of threat amongst those experiencing strong floods and that they treat respondents' answers to survey questions as beliefs – p12. On p14 (line 21), the authors make the cardinal error of reading causal direction into correlation.

Answer 7:

10 "Denial" is a variable that we cannot derive from our dataset with absolute certainty and we also did not record it as a standalone item. For this reason it is not possible to utilise it in such ways. However, the role of denial should definitely be considered in follow-up studies.

Concerning Threat appraisal, we mention in the text that the given ratings are based on perceptions. More specifically it is asked, how people perceive the probability to be impacted again by a flood and if they think that the event will be severe again. See text in paper:

15 (Page 13, line 32) PMT relies on two main cognitive processes - "threat appraisal" and "coping appraisal" - to describe the mental response to a specific threat. Threat appraisal is composed of the perceived consequences and probability of a specific threat. Coping appraisal comprises the variables "self-efficacy" (perception of how well a person is able to carry out protection measures), "response efficacy" (how effective the measures are believed to be) and "response cost" (the perceived cost in terms of money and effort) (Rogers, 1975; Bubeck et al., 2012).

20 (Page 28, line 26) Here, perceived feelings of burden ~~seem to result in~~ are positively related to a higher precaution motivation.

Main points 8:

25 To make section 3.3 more accessible to readers not familiar with Bayesian analysis, the authors might want to explain to readers the meaning and significance of the term 'posterior distribution'.

Answer 8:

We will elaborate on that to highlight the significance of the Bayesian analysis.

30 Paper changes:

(Page 23, line 4) This means that a given variable value (e.g. score 3 out of 6 possible scores among planned precaution) occurs with a particular value of another variable (e.g. score 6 out of 6 possible scores among avoidance) to most likely e.g. 45 per cent (peak of parameter p).

(Page 23, line 19) In detail, this means that the combined posterior distribution shows the likeliness of the likeliness of all mutually occurring variable scores (or values) in a single graph. Here the distribution shape of parameter p (i.e. its highest peak) resembles the most likely probability of mutual occurrence, in the dataset at hand.

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Main points 9:

Conclusion section

- “Individual threat perceptions differ from evidence based hazard estimations” p16. This seems obvious and is certainly not a new finding.
- The recommendation of ‘information campaigns’ seems naive given the sophistication of the psychology in this paper. Given the complex emotion regulation that characterises the response to flooding and flood risk (e.g. denial), it is hard to imagine that it will be enough to simply tell people that they might be flooded again. See my 2008 and 2018 papers in Health, Risk & Society and International Small Business Journal for some additional insights.
- I’m afraid I find little in the Conclusion section that adds to existing knowledge of this topic.

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Answer 9:

Of course, only information does not necessarily lead to an adaptive response of flood affected individuals. This is already included in psychological models. Therefore we refer to information campaigns in a more comprehensive way.

20 Paper changes:

(Page 16, line 27) The outcome might be beneficial for information campaigns that better support flood affected individuals in different flood prone regions. Various mental coping approaches could be considered in such campaigns, since they may vary among different flood types and affected regions. The motivation to implement suitable private flood precautionary measures could be strengthened according to the needs of individually affected people (e.g. Morss et al., 2016) This could be achieved by strengthening the beliefs in precautionary measures, informing about the risk and offering mental support. For heavy rainfalls that lead to pluvial floods as well as for river floods, examples on precaution from the neighborhood could be communicated in combination with risk maps for specific areas. Regarding strong flash floods it could be meaningful to include affected people in strategies that can be realised on municipality level (e.g. retention areas), highlighting the dangers of such events and informing about specific private precaution measures that could lower building damage.

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Response to Anonymous Referee #2 RC2, 2019

Author: Jonas Laudan¹

Co-authors: Gert Zöller², Annegret H. Thieken¹

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

²University of Potsdam, Institute of Mathematics, Karl-Liebknecht-Strasse 24–25, 14476 Potsdam, Germany

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We thank the reviewer again for the constructive comments that helped to further improve the paper.

Comments of the reviewer

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In general I'm very happy with the revisions and think the paper is almost ready for publication. Just the following three points need some attention:

Reviewer main point 1:

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In the introduction you mention "negative binomial regressions", maybe add a sentence explaining what that is.

Answer to main point 1:

Thank you for the overall positive response to our revisions.

A short explanation regarding the "negative binomial regression" is now provided in the revised version.

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Paper changes:

(Page 16, line 9) Negative binomial regression can be used to model ordinal count data where variance and mean are not equivalent.

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Reviewer main point 2:

Throughout the paper the Jensen-Shannon divergence is applied. I think the explanation of this method is still a bit weak, the connection to the Kullback-Leibler divergence that is not explained isn't very useful.

Also not all parameters in formulas 3 and 4 are defined.

Answer to main point 2:

Thank you for this hint, we carefully revised the whole methods section and hope that it is more accessible for readers now.

Paper changes:

(Page 24, line 2) P = posterior distribution, R = reference posterior distribution

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(Page 24, line 9) The divergence represents the degree of mutual information between two or more variable distributions and the strength of their connection (or to which degree they are distinguishable). Consequently, the JSD was used to assess the similarity of each posterior distribution and its reference posterior distribution to reveal if they differ from each other. The JSD can take any value between 0 and 1. If the JSD of the reference posterior and the calculated posterior is 0, both underlying variables (e.g. the planned precaution indicator and burden) are independent from each other and do not show any relation apart from random effects. If the JSD is greater than 0 however, these variables show a certain information gain if one is explained by the other. If the JSD is 1, both underlying variables are identical.

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Reviewer main point 3:

Figure D in the appendix, please provide a legend indicating what color is what flood type.

20 **Answer to main point 3:**

Thank you for this hint. A legend was added.

Flash floods versus river floods – a comparison of psychological impacts and implications for precautionary behaviour

Jonas Laudan¹, Gert Zöller², Annegret H. Thieken¹

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

²University of Potsdam, Institute of Mathematics, Karl-Liebknecht-Strasse 24-25, 14476 Potsdam, Germany

Correspondence to: Jonas Laudan (jlaudan@uni-potsdam.de)

Abstract. River floods are among the most damaging natural hazards that frequently occur in Germany. Flooding causes high economic losses and impacts many residents. In 2016, several Southern German municipalities were hit by flash floods after unexpectedly severe heavy rainfall, while in 2013 widespread river flooding had occurred. This study investigates and compares the psychological impacts of river floods and flash floods. Data was collected using computer-aided telephone interviews that were conducted among flood affected households around 9 months after the damaging event. This study applies Bayesian statistics and negative binomial regressions to test the suitability of psychological indicators to predict the precaution motivation of individuals. The results show that it is not the particular flood type, but rather the severity and local impacts of the event that are crucial for the different, and potentially negative, impacts on mental health. ~~Moreover According to the used data, however, it is revealed that predictions of the individual precaution motivation should not be based on the derived psychological indicators, i.e. “coping appraisal”, “threat appraisal”, “burden”, and “evasion”, since only show a limited usefulness for predictions of individual level precaution motivation. This is because these indicators displayed generally low their~~ explanatory power ~~was generally low and results are, for the most part, non-significant results.~~ Only burden reveals a significant positive relation to planned precaution regarding weak flash floods. A remarkable difference to weak flash floods and river floods can be seen with regard to strong flash floods, where the perceived threat is significantly lower although feelings of burden and lower coping appraisals are pronounced. Further research is needed to better include psychological assessment procedures and to focus on alternative data sources regarding floods and the connected precaution motivation of affected residents.

Kommentiert [JOL1]: Changes, main point 2, RC1

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., 2006a), the country was challenged again by strong river flooding, affecting 12 out of the 16 federal states, in particular Saxony, Saxony-Anhalt, and Bavaria. Considering country-wide gauge data and peak discharges, the 2013 flood event can be described as even more hydrologically severe than the 2002 flood, yet caused a lower monetary losses of EUR 6 to 8 billion (Thieken et al., 2016a). Additionally, in May and June 2016, heavy rainfall in Central Europe lead to severe surface water runoff, pluvial flooding, and flash floods in Southern Germany. Municipalities in Bavaria and Baden-Wurttemberg were especially affected, resulting in overall losses of EUR 2.6 billion (Munich Re, 2017).

The flash flood events in 2016 were 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). River floods usually occur after long-lasting rainfall or snowmelt within large catchment areas and result in slow-rising water levels. On the other hand, flash floods emerge within (small) catchments where slopes are steep and defined. This results in rapid, unpredictable flow dynamics that can be rough in terms of a high sediment transport, high flow velocities and forceful discharge (Borga et al., 2014). The forecasting flash floods is not yet reliable since they can occur within a very short lead time. Apart from potentially high damage on buildings and infrastructure, flash floods can also cause serious injuries and fatalities (Gaume et al., 2009). Therefore it can be assumed that flash floods are perceived as a threat for personal health and property and induce negative psychological responses in flood experienced people. In contrast to river floods, flash floods are defined as rapid, unpredictable flood events, which are typically associated to regions with a pronounced orography (Gaume et al., 2009; Borga et al., 2014). Therefore, the occurrence of the severe flash floods across Germany in 2016, outside alpine regions, can be described as unexpected. Still, they are important events to study when the comparatively high monetary losses of EUR 2.6 billion (Munich Re, 2017), and eleven fatalities (four in Baden-Wurttemberg and seven in Bavaria along Simbach am Inn) are considered. However, there is a lack of studies comparing the impacts of and preparedness to flash and river floods, especially with regards to protection motivation and its influencing factors.

Flood risk management in Germany has a long history with several regulations and ongoing programs, e.g. the “Nationales Hochwasserschutzprogramm” (NHWS) that was launched after the 2013-flood and national legislation regulation, e.g. the Federal Water Act (WHG). The WHG was first introduced in 1957, revised in 2005, of renewed in 2009 and again revised in 2018 to consider gaps that became obvious after damaging flood events. Additionally, regulations such as the European Floods Directive (2007/60/EC) required additional frameworks to be incorporated into the national legislation by 2010 (e.g. Thieken et al., 2016b). However, despite this, the management of water bodies and flood management are in principle regulated at the state level rather than the national or federal level. After the severe river flood events in 2002 and 2013, flood risk management in Germany and the relevant legislation was carefully revised. In addition to structural precaution measures on a higher level such as dikes and retention areas and non-structural measures such as early warning systems, the focus was shifted to a more integrated flood management approach, in which where potentially affected residents are

encouraged to prepare themselves. In this context, private structural precaution measures (i.e. waterproof sealed cellars i.e. dry-proofing, wet-proofing, relocation of heating and electrical utilities) as well as private non-structural flood protection measures (i.e. adapted interior fitting and flood-adapted use such as avoiding water-sensitive furniture in the cellar) became increasingly important (Kienzler et al., 2015; Thieken et al., 2016b; Laudan et al., 2017). As a consequence Accordingly, the 2005 revision of the WHG designated private precaution as mandatory which thus German Act on precautionary flood protection in 2005 (Act to Improve Preventive Flood Protection) requires residents in flood prone areas to undertake appropriate private precautionary actions. As an overall result, regions which have been affected by recurrent river floods are now better 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 runoff 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 in Germany concerning flash floods and also pluvial floods to a degree, which describe low velocity floods associated to urban areas after heavy rainfalls. This is mainly in Germany due to the strong focus on fluvial flooding in recent years.

It has been shown that private precaution measures can significantly reduce the mean damage ratio (i.e. the financial flood damage in relation to the total building or content asset value) to households and household contents by up to 53 per cent and thus play an important role in comprehensive flood management strategies (Kreibich et al., 2005; Thieken et al., 2008; Merz et al., 2010; Hudson et al., 2014). Yet, 15% (in 2002) up to 65 per cent (in 2011) of residents affected by river floods use or furnish their home in a flood-adapted manner (Kienzler et al. 2015; Thieken et al. 2016b), this percentage is lower for residents affected by pluvial floods, i.e. just 7 per cent (in 2014; Spekkers et al 2017), but around 20 per cent (in 2005 and 2010; Rözer et al. 2016). Moreover, the overall state of private precaution can also be integrated into flood loss estimation models such as the flood loss estimation model (FLEMO). This further integration results in more reliable damage estimation at different scales, therefore, contributing to more robust risk and vulnerability estimations (Thieken et al., 2008). Hence, understanding and predicting private precaution is essential for future planning and flood risk management (Aerts et al. 2018). This is not only with regard to river floods or pluvial floods, but also with regard to flash floods and rapid surface runoff. These flash floods and rapid surface runoff are currently relatively rare, but due to climate change are potentially more frequent in Europe in future (e.g. Murawski et al., 2015). However, individual precautionary behaviour it is not yet fully understood, particularly if people are affected by different flood types. Questions must be raised as to whether affected individuals carry out private precautionary measures and what are motivating and demotivating factors for this behaviour. 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 individuals. PMT does so by analysing the influencing factors on coping strategies and potential positive or negative responses to a risky event. Originally evolved in the health sector, PMT has gained attention in the domain of natural hazards over recent years (Mulilis and Lippa, 1990; Grothmann and Reusswig, 2006; Bubeck et al., 2017). PMT relies on two main cognitive processes - "threat appraisal" and "coping appraisal" - to describe the mental response to a specific threat. Threat appraisal is composed of the perceived consequences and probability of a specific threat. Coping appraisal comprises the variables "self-efficacy" (perception of how well a person is able to carry

out protection measures), “response efficacy” (how effective the measures are believed to be) and “response cost” (the perceived cost in terms of money and effort) (Rogers, 1975; Bubeck et al., 2012). ~~Main findings suggest that psychological factors—not only in terms of risk perception, but also avoidance and wishful thinking—can influence protective responses (Grothmann and Reusswig, 2006; Bubeck et al., 2012).~~

Kommentiert [JOL2]: Hint (no changes), main point 7, RC1

- 5 ~~It~~Here it has further been shown that the motivation to protect oneself from flooding cannot be solely explained by risk information, risk perceptions and socioeconomic factors such as income and homeownership (e.g. Baan and Klijn, 2004; Bubeck et al., 2012; Morss et al., 2016). ~~Overall and that~~ the PMT results in reliable estimations of protective behaviour. ~~In particular, while particularly~~ coping appraisal has been evaluated as a good predictor (Floyd et al., 2000; Milne et al., 2000; Bubeck et al., 2012; van Valkengoed et al., 2019). ~~It has further been shown that the motivation to protect oneself from~~
- 10 ~~flooding cannot be solely explained by risk information, risk perceptions and socioeconomic factors such as income and homeownership (e.g. Baan and Klijn, 2004; Bubeck et al., 2012; Morss et al., 2016).~~Supportive evidence is given by Hopkins and Warburton (2015), who revealed that flash flood experience among UK citizens does not necessarily lead to higher risk perceptions. Yet, Harries (2012) shows that protective behaviour of flood affected UK citizens is significantly associated with the perceived probability to be flooded again. Moreover, the potential effects of protective behaviour such as feelings of
- 15 safety, reduced anxiety, and the fear of uninsurable impacts were also influenced by flood experience. ~~This suggests that apart from risk perception, different psychological factors influence protective responses which can also result in maladaptive behaviour.~~ Further, Bubeck et al. (2018) study flood affected households in Germany and France and identified good social norms and networks as an important factor for better coping abilities after river floods. In particular, Bubeck et al. (2018) found that perceived self-efficacy and response efficacy increased with the number of neighbours who already
- 20 implemented flood protection measures. When taken together these results suggest that among the influencing factors on protective behaviour, psychological characteristics ~~such as perceived coping abilities, anxiety, burden or stress as well as avoidant thoughts~~ might play a significant role.
- ~~It became clear that private flood precaution might be influenced more by psychology than it has been taken into account, raising questions about psychological impacts of flood events in general. Furthermore~~Here it can be expected that, severe
- 25 river floods and flash floods ~~are expected to~~ have strong impacts on ~~the psychological~~ mental health of affected residents in addition to financial losses. 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. Additionally, an increased exposure to floods may also be connected to negative mental health effects due to the disruption of daily routines, financial loss and
- 30 situational stress, especially if social support by family and friends is missing (Bei et al., 2013). ~~This effect is further described and underpinned by Hudson et al., (2019), who found out that flood experience is connected to a loss in subjective well-being among flood affected residents in Vietnam, while females tend to recover slower than males. This was also found by Bubeck and Thieken (2018) for Germany. Additional evidence for negative mental health effects after floods is given by Wagner (2007), who suggests that models of anxiety and coping can be related to fears of different hazard types. Those~~

models describe reactions and coping strategies of people ~~which~~who are guided by vigilance (i.e. actively searching for threat-related information) and avoidance (i.e. denial & distraction). Moreover, a comprehensive review of Fernandez et al. (2015) on flood related mental health issues as well as Foudi et al. (2017) strongly support the assumption that, in case of flood exposure, especially water depth and high flow velocities have a negative impact on mental health in terms of increased levels of PTSD, anxiety, as well as depression. This is also supported by Lamond et al. (2015) who suggest that psychological symptoms such as stress and anxiety remain as a result of severe flooding and flood damage. Further they reveal that mental health issues are related to post-flood mitigation actions, where especially relocating seems to be a suitable measure.

Kommentiert [JOL3]: Changes, main point 1, RC1

Therefore, it is important for an integrated flood risk management to consider how river and flash floods differ and how their occurrence might lead to different subjective impacts. River floods usually occur after long-lasting rainfall or snowmelt within large catchment areas and result in slow rising water levels. On the other hand, flash floods emerge within (small) catchments where slopes are steep and defined. This results in unpredictable flow dynamics that can be rough in terms of a high sediment transport, high flow velocities and forceful discharge (Borga et al., 2014). The forecasting flash floods is not yet reliable since they can occur within a very short lead time. Apart from potentially high damage on buildings and infrastructure, flash floods can also cause serious injuries and fatalities (Gaume et al., 2009). Therefore it can be assumed that flash floods are perceived as a threat for personal health and property and induce negative psychological responses in flood experienced people.

However, only a few studies consider individual psychology, outside of PMT concepts, in flood preparedness decisions although it can be expected that they ~~contribute to the knowledge in that regard~~play an important role. Thus, the aim of this work is to identify patterns of psychological impact with a focus on differences among people affected by either flash floods or river floods. In the following step, the psychological characteristics are related to the overall protective behaviour. Accordingly, the following hypotheses were raised:

H1: Flash floods, in comparison to slowly emerging river floods, show a different psychological impact on affected people, ~~in which a~~Negative effects such as stress and feelings of being helpless are more pronounced, since flash floods are rough, emerge suddenly and therefore represent an unpredictable danger for health and property.

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

H3: ~~Psychological indicators such as e.g. the feelings of stress and burden that people still perceive today or self-reported coping abilities can be used as a proxy to explain precautionary behaviour because such mental feelings and attitudes are connected to the motivation and intention to protect oneself in future. Psychological indicators such as the level of stress and coping appraisals are suitable for explaining precautionary behaviour because those psychological characteristics are distinctly connected to the protection motivation.~~

Kommentiert [JOL4]: Changes, main point 1, RC1

The first hypothesis is [based on the evidence given by Gaume et al. \(2009\), Mason et al. \(2010\), Lamond et al. \(2015\) and Foudi et al. \(2017\) and is](#) tested by comparing psychological characteristics of people which are affected by different flood types and strengths. Thus, groups of respondents with similar psychological characteristics (psychological indicators) are created. Then the differences in the indicator distributions, i.e. shifts to lower or higher indicator ratings, are assessed for each flood type for these sub-groups.

To answer the second and third hypotheses [which is based on evidence given by Wagner et al. \(2007\), Mason et al. \(2010\), Lamond et al. \(2015\) and Bubeck et al. \(2018\)](#), a “planned precaution” indicator is created first. In the next step, a Bayesian approach and negative binomial regressions are applied and the resulting probability distributions of conditional variable dependences as well as regression coefficients are evaluated. [Negative binomial regression can be used to model ordinal](#)

[count data where variance and mean are not equivalent.](#) The Bayesian approach has been frequently used in psychology (e.g. Wetzels et al., 2011), ~~and medicine and various~~ other disciplines. ~~It~~ [The Bayesian approach can](#) assess data uncertainty which is particularly helpful for studies that rely on relatively small data sets. ~~This is achieved by allowing~~ ~~while~~ prior information independent of the data can be included (Van de Schoot et al., 2015). Since this study relies on small data sets, using the Bayesian approach as a supportive analysis helps to interpret main results. In revealing data and model uncertainties, the reliability of future prediction models that are based on these data sets can be evaluated in advance. 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 ~~relations~~ ~~coherences~~ are therefore not required. Bayesian statistics were also chosen due to the fact that the method enables prior knowledge to be taken into account from other studies that use similar Bayesian approaches. However, to assess the potential direction of the predictor and response variable ~~coherence~~ ~~correlation~~, 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 related precautionary behaviour is important for the following reasons:

- A good understanding of psychology and precaution motivation might result in a variable which indicates the probability for a good precautionary outcome and could be integrated into flood loss modelling and dynamic risk assessments as suggested by Aerts et al. (2018).
- [The outcome might be beneficial for information campaigns that better support flood affected individuals in different flood prone regions. Various mental coping approaches could also be considered in such campaigns, since they may vary among different flood types and affected regions. The motivation to implement suitable private flood precautionary measures could be strengthened according to the needs of individually affected people \(e.g. Harries et al., 2008; Morss et al., 2016\).](#) [This could be achieved by strengthening the beliefs in precautionary measures, informing about the risk and offering mental support. For heavy rainfalls that lead to pluvial floods as well as for river floods, examples on precaution from the neighborhood could be communicated in combination with risk maps](#)

Kommentiert [JOL5]: Changes, main point 1, RC2

Kommentiert [JOL6]: Changes, main point 9, RC1

[for specific areas. Regarding strong flash floods it could be meaningful to include affected people in strategies that can be realised on municipality level \(e.g. retention areas\), highlighting the dangers of such events and informing about specific private precaution measures that could lower building damage.](#)

- 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, data from online surveys, social media and communication platforms offers a lot of potential to assess individual mental coping strategies such as evasive behaviour or the active remembering after severe events. With the help of advanced intelligent learning algorithms (e.g. random forests, neural networks and deep learning), psychological profiles could thus be created. Those might be used to develop sophisticated models and predict the state of precaution in areas which have not been flooded recently, all based on data given voluntarily by residents. Surveys that capture the state of precaution are still an alternative option.

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

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.

15 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 ~~flash floods~~ heavy rainfalls in ~~of~~ 2016 [that led to strong flash floods in some cases](#). 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. Additionally, both events were relevant at the national scale. Finally, the time lag between the particular event and the implementation of the survey is similar, i.e. data collection took place around nine months after the flood event. It should be noted that the regions which were affected by the river floods in 2013 and flash floods in 2016 do not overlap. [The floods in 2013 were mainly recorded in Saxony Anhalt Saxony along the Elbe river and partly in Bavaria along the Danube river. The heavy rainfalls in 2016 mainly led to flash floods and pluvial floods in Bavaria, Baden-Wurttemberg and North Rhine-Westphalia.](#) ~~Furthermore, apart from an increase in insurance density regarding river floods, no specific developments concerning flood risk management and flood precaution are indicated during these years.~~ Given the fact that both surveys cover two different flood types, the time lag between the two surveys, i.e. three years, is not expected to cause any effect on the following analysis. The underlying questionnaire of both surveys ~~was is identical regarding all questions that were chosen for this study, very similar, mainly including the same questions.~~ [In general, the questionnaires](#) were designed to improve flood damage estimation of affected households and the assessment of damage driving factors. Hence, the biggest part comprised questions about the flood impact at the affected property), socio-economic

Kommentiert [JOL7]: Changes, main point 6, RC1

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), warning and emergency measures (see Thieken et al. 2005; 2017). Yet, various psychological characteristics that address elements of 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. These 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 1. All psychological variable ratings were ~~transformed, 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 1).

In total, 16 private precaution measures were analysed. They comprise information about flood protection and flood risk as well as information within seminars (~~which was combined to overall “information”~~), insurance, networking, flood-adapted story usage, flood-adapted interiors, relocating heating and electricity, securing heat and oil tanks, improving flood safety, ~~a combined “water barriers” variable that consist of installing backflow prevention and/or installing water barriers as well as a combined “emergency preparation” variable which consists of~~ having no noxious liquids in the cellar, installing pumps, having generators available and/or 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 similar distributions of age (average 59 years) 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 and 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). More information about the samples (type of housing, age, education, and gender) can be found in the appendix, Table A.

(Table 1)

2.2 Separation of weak floods 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 intensity 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 runoff in the vicinity of affected buildings and/or the water entering the basement due to the fact that the sewer system could not cope with the water volume, ~~i.e. pluvial floods~~. 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 [rainfall events that led to weak floods or strong flash floods](#) ~~severe and weaker flash flood events~~ before comparing the psychological impacts among each other and to the 2013 river flood.

5 ~~The flash flood strength was assessed on the municipality scale a relatively coarse area. It can be assumed that impressions and effects of the flash flood severity are not particularly dependent on the intensity at the individual house but are rather influenced by the overall appearance and effects of the flood within the village, which also includes impacts on neighbours, friends and infrastructure. It makes sense that mental coping, especially after strong flash floods, is not solely influenced by the individually experienced damage but dependent on broader impressions.~~

10 ~~Moreover, not only the impact, but also the potential to be harmed outdoorside in case of sudden and strong flow forces may influence the mental coping in regions which can experience strong flash floods. In this context, Morris et al. (2016) showed that people who perceive flash floods as a risk to their life tend to protect themselves if they receive a flash flood warning. Therefore it can be assumed that the mental impacts after a severe event are differing with regard to the severity within an affected area (e.g. Bei et al., 2013).~~

15 The approach to assess the flash flood strength comprises quantitative and qualitative methods and makes use of rainfall data and press articles to estimate inundation depths and flow velocities. Therefore, 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

20 ~~affected by a severe weather event. In this context, only the municipalities and cities which were covered by the survey were considered.~~ An intersection with the survey data was possible since the approximate address of each affected household is provided in the data set. In the next step, an online literature and press article review was conducted for each affected area to find a basis for the flood’s intensity. 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

25 particular ~~time based on data from DWD~~, the surveyed households were classified to weak flash floods ([covering pluvial floods](#)) (if a low impact [in terms of damage and severity](#) was noticed), to medium flash floods (if the impact was considered to be 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 ~~and all medium impacts were excluded~~ to reduce the noise of poorly classified data and to increase the effect of flash flood intensity. The count of cases for weak flash floods is n=293 and for

30 strong flash floods n=116.

2.3 Defining main psychological indicators

[In this study, indicators and single variables are defined as follows. A single variable describes a standalone question within the survey \(also called item\). An indicator stands for a newly created variable that consists of two or more single variables](#)

Kommentiert [JOL8]: Changes, main point 6, RC1

Kommentiert [JOL9]: Changes, main point 6, RC1

(or items). To answer the first hypothesis, four main psychological indicators were considered. The indicators were created by combining variables according to what is described in the literature, i.e. Creamer et al. (2003). This is because the literature suggests that combining relevant items such as e.g. "I had trouble staying asleep" and "Any reminders brought back feelings about it" (or variables) can create robust indicators such as e.g. "intrusion", that reduce information to the core content. Furthermore, Grothmann and Reusswig (2006) and Bubeck et al. (2012) describe the items that constitute the factors of the PMT, which are especially relevant as the main psychological indicators. Subsequently, the four main indicators are defined as "threat appraisal", "coping appraisal", "burden" and "evasion", which also show low intercorrelations and offer a certain comparability to other studies such as Bubeck et al., (2017) for example. The four indicators are thus defined and created as follows.

According to the PMT, threat appraisal consists of the perceived probability of being affected again by a flood 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 implement a protective measure, the perceived efficiency of a protective measure and the perceived cost of the protective measure, respectively (Grothmann and Reusswig, 2006; Bubeck et al., 2012).

Threat appraisal and coping appraisal are defined according to the PMT (see Section 1 Introduction) Threat appraisal consists of the perceived probability of being affected again by a flood event and the perceived impact of such a future event. Coping appraisal comprises self-efficacy, response efficacy and response cost. Burden describes a measure for the negative psychological load of the individual experience and can be used to reveal differences among residents affected by different flood types. 'Burden' is measured via the responses to the questions regarding "often thinking of the event" and "stress still today". Evasion comprises of the responses to the variables "avoidance" and "fatalism". We argue that 'Evasion' can be seen as a measure for the effort to get the experience of a damaging flood out of one's mind in order to cope with the threat (maladaptive behaviour). Burden and evasion were developed by following the general procedure in psychology surveys to combine expressive psychological items (e.g. Ware and 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). This scale is a widely used item-based survey that measures traumatic stress in order to assess symptoms of the post-traumatic stress disorder (PTSD). 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 fewer, or more 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 items 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" and "pwr"). 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 and a power

of 1.0 in all cases. Furthermore, avoidance and fatalistic thoughts reveal a correlation of 0.23 (complete cases n=275, p<0.05, power=0.97) for weak flash floods, 0.29 (complete cases n=113, p=0.34, p=0.07, power=0.88) for strong flash floods and 0.18 (complete cases n=1242, p<0.05, power=1.0) for river floods. Therefore, we combined avoidance and fatalistic thoughts as two different strategies of mal-adaptive behaviour. 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 for the correlation tables (Figures A, B and C).

Kommentiert [JOL10]: Changes, main point 3, RC1

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 perceived at the time of interview and evasion resembles avoidant behaviour, e.g. trying to suppress the experience.

The distributions of threat appraisal, coping appraisal, burden and evasion were further analysed using the Dunn's Test, which is based on the non-parametric Kruskal-Wallis rank sum test results. These tests are suitable for assessing the differences among the distributions of ordinal-scaled data, which does not fulfil assumptions of normality and equality of variance. Here, the Kruskal-Wallis rank sum test is preliminary to the Dunn's Test and calculates discrepancies among the rank sums of all values within the compared indicators. The derived Kruskal-Wallis statistic is then compared to the expected average difference among the sum of ranks via Dunn's Test. Similar to a power analysis, the effect size and significance are revealed for a given sample size. The outcome represents a measure for the disparity and shift of compared distributions. This approach reveals significant differences in psychological impacts which were predominantly caused by weak flash floods, strong flash floods and river floods.

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 as found in Kreibich et al. (2005), Thieken et al. (2005) and Büchele et al. (2006). It resembles a score of precaution in which information gathering, non-structural precaution structural precaution and preparation are included and weighted according to their effectiveness (see also section 2.1 for the private precaution measures).

Kommentiert [JOL11]: Changes, main point 6, RC1

For the planned precaution indicator, the weighted score of measures which were directly implemented during the event (presumably in connection with emergency measures), or planned to be implemented directly or shortly (up to 6 months) after the flood event (see section 2.1.) is summed up and related to the measures implemented already before the event or

~~non-applicable-measures~~ as well as ~~missing answers (NA)~~. The data is disregarded if the count of already implemented ~~or non-applicable-measures or missing answers~~ 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 ensured that there is no bias towards low precaution motivation in the subsequent analysis caused by an already high precaution level prior to the event, since it can be assumed that people who already implemented many protection measures have a lower planned precaution score (*saturation effect*). 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 3.2.), this indicator is compared to the state of precaution, i.e. the weighted score of already implemented precaution measures.

10 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). The underlying principle is Bayes theorem, which given the above is show in equation (1):

$$P(\text{model parameter}|\text{data}) \sim P(\text{data}|\text{model parameter}) * P_0(\text{model parameter}) \quad (1)$$

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 on 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 (2):

$$P(k | p, n) = \binom{n}{k} * p^k * (1 - p)^{n-k} \quad (2)$$

- 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 ~~manifestationscores~~. This means that a given variable value (e.g. score 3 out of 6 possible scores among planned precaution) occurs with a particular value of another variable (e.g. score 6 out of 6 possible scores among avoidance) to most likely e.g. 45 per cent (peak of parameter p).

Kommentiert [JOL12]: Changes, main point 8, RC1

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 1) were analysed with regard to their connection to the planned precaution indicator, using the Bayesian approach, the Jensen-Shannon divergence (JSD) and a negative binomial regression model. Both, the psychological indicators and the single variables were analysed to reveal differences between the general procedure in psychology to combine similar items/variables and studying all variables separately.

First, the planned precaution indicator was used as the dependent variable and ~~the all weighted arithmetic mean of all posterior distributions for each psychological indicator (coping appraisal, threat appraisal, burden and evasion) as well as all single psychological variables (resulting from the Bayesian analysis (see section 2.5.) were calculated according to the Bayesian approach for each indicator and single variable, to reveal variable connections to the planned precaution indicator while excluding, excluding all non-existent combinations (Figure 1).~~ Next, the posterior distributions were combined per variable by applying the weighted arithmetic mean (Figure 1). In detail, this means that the combined posterior distribution shows the likeliness of the likeliness of all mutually occurring variable scores (or values) in a single graph. Here the distribution shape of parameter p (i.e. its highest peak) resembles the most likely probability of mutual occurrence, given the dataset. Yet, it is not specified which variable scores occur mutually. In the next step, a weighted arithmetic mean posterior is calculated by randomising the analysed variable to obtain a random occurrence of predictor and response variable. This step is necessary to get the particular reference posterior shape, which is exclusively influenced by the distribution of the predictor and response variable.

Kommentiert [JOL13]: Changes, main point 8, RC1

(Figure 1)

The combined, weighted posterior distributions combinations were allow for the assessment of likely probability distributions at once, giving ideas about the data structure and variability, further evaluated using the JSD. The JSD can also be expressed by the more known is a variation of the Kullback-Leibler divergence (which gives the same information) and is defined by (3):

$$JSD(P, R) = H(0.5 * (P + R)) - 0.5(H(P) + H(R)) \quad (3)$$

- P = posterior distribution
- R = reference posterior distribution

Kommentiert [JOL14]: Changes, main point 2, RC2

5 Where the Shannon-Entropy is defined by (4):

$$H(p) = -\sum_i p(i) \log(p(i)) \quad (4)$$

- p = probability distribution of a discrete random variable

10 ~~The divergence represents the degree of mutual information between two or more both analysed variables variable distributions and the resulting information gain, if one variable is explained by the other. This resembles the strength of variable their connection (or to which degree they are distinguishable), and thus the overall applicability for predictions. The divergence is presented within a variable ranking. Consequently, the JSD was used to assess the similarity of each posterior distribution and its reference posterior distribution to reveal if they differ from each other. The JSD can take any value between 0 and 1. If the JSD of the reference posterior and the calculated posterior is 0, both underlying variables (e.g. the~~
 15 ~~planned precaution indicator and burden) are independent from each other and do not show any relation apart from random effects. If the JSD is greater than 0 however, these variables show a certain information gain if one is explained by the other. If the JSD is 1, both underlying variables are identical.~~

Kommentiert [JOL15]: Changes, main point 2, RC2

20 ~~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”).~~

~~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.~~

25 ~~First, the weighted arithmetic mean of all posterior distributions (resulting from the Bayesian analysis, see section 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 1). The weighted posterior combinations allow for the assessment of likely probability distributions at once, giving ideas about the data structure and variability. In the 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~~
 30 ~~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 the JSD.

(Figure 1)

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. 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 (variance is greater than the mean) Poisson distribution (tested in R 1.1.414, using the packages “logspline” and “fitdistrplus”). Since the posterior distributions and divergence computations are solely based on probabilities, information gain and prediction applicability can be assessed. ~~Yet it is not clear how both variables relate to each other (i.e. positively or negatively) 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 ~~correlationseherences~~ of variables with the “planned precaution” indicator.

3 Results and discussion

In this section, the differences in the distributions of the psychological indicators are presented and discussed first. In the 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 at the end of this section.

3.1 Psychological indicator distributions

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

(Figure 2)

Regarding coping appraisal (Figure 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-weak~~ 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 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. Although the effects are not strongly pronounced, a significant difference to weaker flash floods [or pluvial floods](#) becomes apparent which might be due to the different (potential) flood impacts. [In this context, our data shows higher structural damage on building substance for strong and rapid events \(38 per cent, 13 per cent and 2 per cent smaller cracks, bigger cracks and collapsed elements respectively\) than for weaker events \(25 per cent, 4 per cent and 1 per cent smaller cracks, bigger cracks and collapsed elements respectively\).](#) A similar outcome is indicated when comparing the difference between strong flash floods and river floods. However, the results are not significant [which might be due to the fact that different flood processes are covered by the 2013 data set](#). Although it has not been tested whether a lack of [awareness regarding precautionary strategies, missing protection information campaigns](#) ~~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 significantly 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 2, top right).

Yet, these results could be explained by the fact that people who were affected by strong flash floods believe similar events to be very unlikely to recur in near future, resulting in lower feelings of threat. Although Hopkins and Warburton (2015) showed that flash flood experience does not necessarily lead to higher risk perceptions, it is unknown, to which degree lower feelings of threat are caused by a lower flash flood experience itself. Since almost all surveyed households experienced a strong flash flood for the first time (82%), they may not believe that they will be affected again. However, an analysis of threat appraisal with corrected data in terms of flood experience (all households that experienced a flood for the first time) reveals a similar picture, i.e. threat appraisal is significantly lower for people who were affected by a strong flash flood in comparison to people who were affected by weak flash floods and river floods (see appendix, Figure D). This again supports the findings of Hopkins and Warburton (2015).

Still, [e.g. Murawski et al. \(2015\)](#) ~~research~~ [has](#) ~~shown~~ [shown](#) that there may be increase in severe flash floods in regions which were formerly not perceived as flash flood-prone. This further highlights the importance of specific information campaigns in this context [to counteract mal-adaptive behaviour](#). 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 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 reported 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 2, bottom left).

Similarly, the indicator evasion shows a significant difference in the distributions only with regard to weak flash floods (Figure 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 (i.e. in less mal-adaptive behaviour). Here, evasion especially differs between people affected by weak flash floods and river floods. One reason could be the comparatively high frequency and severity of river floods in Germany 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).

In summary, the indicators are particularly insightful in case of strong flash floods. The combination of feeling less able to cope with such an event as well as a low perceived threat but yet an increased burden means that people feel an emotional pressure and do not see efficient ways to deal with the situation on their own. A comforting thought then might be the assumption that a similar event will not happen again soon. It can be expected that this leads to mal-adaptive behaviour, although damages on buildings after rapid and strong flood events are usually high. This is a contrast to weaker flood events and river floods, where risk communication, insurance and private precaution measures are more established. These results again highlight the importance of information campaigns in regions potentially affected by strong flash floods outside alpine environments.

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. Furthermore, the planned precaution is compared to the already implemented precaution (Figure 3).

(Figure 3)

By evaluating the distributions of already implemented precaution measures (Figure 3, left side) and planned precaution (Figure 3, right side) it becomes apparent that people who have been affected by river floods show slightly higher scores of already implemented precaution measures. This is in line with Kienzler et al. (2015), Rözer et al. (2016) and Spekkers et al. (2017). 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 is also true for people who were flooded the first time. 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.](#)

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 2, N). Yet, the results indicate certain positive and negative connections of the psychological indicators to the planned precaution indicator.

(Figure 4)

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, it is second most likely (second highest posterior peak) that a particular burden rating is always reported together with a specific rating of the planned precaution to 52 per cent (most likely to 9 per cent due to the highest posterior peak at this point). For coping appraisal, the most likely percentage would be 7 per cent. For threat appraisal and evasion, the most likely percentages are 10 and 19 per cent, respectively (Figure 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, top left), the highest JSD is revealed for burden, respectively (Figure 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 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, [perceived stronger feelings of burden seem to result in are positively related to](#) a higher precaution motivation. This result is in line with Lindell et al. (2009) [and Lamond et al. \(2015\)](#), who find that often thinking and talking about a hazardous event [as well as mental health issues \(earthquakes in that case\) is are](#) positively correlated with the intention to adapt to the hazard. Our results [indicate confirm](#) 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, top right & Table 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

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describing the planned precaution, yet the effect is relatively weak (Figure 5). Simultaneously, evasion does not show any significant linear relationship with the planned precaution (Table 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, 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 5). Yet, the regression results reveal only slight positive and negative coherences for the significant variables burden and threat appraisal (Table 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) and Lamond et al. (2015).

[The results contradict studies on coping appraisals to a certain degree, which claim that higher coping appraisals are connected to preparation and precaution intentions \(Floyd et al., 2000; Milne et al., 2000; Bubeck et al., 2012; van Valkengoed et al., 2019\). Thus, better insights into the factors of PMT and the actual connection to intended precaution as well as longitudinal studies are needed with regard to flooding. Further, the PMT could potentially be expanded with relevant variables that cover mental health and behaviour.](#)

(Figure 5)

(Table 2)

3.4. Rankings and regressions of single psychological variables

Figure 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 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 6), which is also reflected in Figure 5.

(Figure 6)

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Furthermore, the regression results of the single variables indicate almost no significant relationships with the planned precaution indicator (Table 3). Regarding weak flash 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 3).

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(Table 3)

When comparing the analysis of the psychological indicators and the single variables, it can be summarised that a combination of items, as it is practised by e.g. Ware and Sherbourne (1992) and Bei et al. (2013), 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 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 and 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 and 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.

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3.4 Discussion of the hypotheses

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H1: Flash floods, in comparison to fluvial 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 2, it is 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 2, top right). Yet, this difference could be explained by the fact that the perceived threat of a strong flash flood event is lower due to the severity and type of the event itself. Affected people perceive a (future) strong flash flood event as being less likely than people who have been ~~(repeatedly)~~ affected by river floods. Thus, future disaster risk management in Germany may also take into account that the individual threat perceptions of affected residents may differ from evidence-based hazard estimations, ~~potentially leading to higher damage~~. Therefore, information campaigns in flash flood prone regions should be promoted, especially if various studies suggest an increase in severe flash flood events due to climate change and a change in weather patterns such as strong precipitation events (e.g. Murawski et al., 2015). 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 might hamper the individual energy and self-confidence as well as the overall motivation to implement precaution measures.

The most surprising result is that a high level of burden increases the protection motivation instead of affecting it negatively (Figure 5 & Table 2). However, otherwise no strong connections between strong psychological impacts and planned precaution were found. This may be explained by two reasons. First, the assessment methods of psychological items as well as the items themselves do not follow established psychological assessment routines or surveys, what potentially decreases data consistency and accuracy. Second, subtle effects on precautionary behaviour that are caused by psychological aspects may be covered by incidental effects, due to the small sample sizes. This is particularly true for strong flash floods, leading to high uncertainties. 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. This result further supports Bei et al., (2013), who reported that affected people with worse mental and physical health show a higher willingness for coping strategies. However, since negative psychological impacts are slightly positively connected to the precaution motivation, the second hypothesis must be rejected.

H3: ~~Psychological indicators such as e.g. the feelings of stress and burden that people still perceive today or self-reported coping abilities can be used as a proxy to explain precautionary behaviour because such mental feelings and attitudes are connected to the motivation and intention to protect oneself in future. Identified psychological indicators are suitable for explaining precautionary behaviour because certain psychological characteristics are distinctly connected to protection motivation.~~

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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, Figure 5, Table 2 & Table 3). [Here it is remarkable that this result contradicts studies on PMT which confirm a positive relation of high coping appraisals and the willingness to implement precaution measures \(Floyd et al., 2000; Milne et al., 2000; Bubeck et al., 2012; van Valkengoed et al., 2019\).](#) As already mentioned, [further reliable insights could be obtained](#) by applying standardized and established surveys to assess psychological characteristics, ~~the accuracy and validity of the results may be increased.~~ [In this regard, Creamer et al. \(2003\), for example, confirm the usefulness of the Impact of Event Scale - Revised \(IES-R\). This scale is a widely used item-based survey that measures traumatic stress in order to assess symptoms of the post-traumatic stress disorder \(PTSD\). 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 fewer, or more diversely composed, factors/indicators.](#)

A very diverse and promising future field might also be the application of data mining techniques and the use of alternative data sources to [increase data amounts, to](#) facilitate the psychological profiling and predicting precautionary behaviour by different methods. An issue of telephone surveys is that the data is becoming biased towards older participants when based on landlines (Greenberg and Weiner 2014). Alternatively, by implementing and making use of online surveys, smartphone applications and contracts with companies, [larger amounts of](#) valuable data could be collected accounting for people from all age groups. For further use, algorithms such as Neural Networks or deep learning algorithms may be applied to this data to create or categorize psychological aspects such as the expected level of burden or evasion in case of an event. Those techniques might result in good predictions of psychological behaviour and the connected precaution motivation and can theoretically be transferred to other regions but yet imply certain challenges. Firstly, large amounts of consistent and high quality data have to be collected on the condition that data security and personal rights are considered. Secondly, the interpretation of results in terms of causality and meaning is hampered due to the black box character of the analysis, even though potential results might show a certain robustness. [In this context, established routines of mental assessments have the advantage of a better transparency and will continue to play an important role in future.](#)

Eventually, 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 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 influence of these impacts on precaution motivation. Furthermore, the usefulness of psychological indicators and individual psychological variables to predict precautionary behaviour was evaluated. In this context, four

psychological indicators and a precautionary 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.

5 The study shows that **generally it is not the flood type, but rather the overall severity of a flood event** leads to stronger mental impacts among affected individuals. The exception is threat appraisal, where people affected by strong flash floods report lower values. Here it is indicated that people are under emotional pressure but do not know how to cope with the situation and probably do not believe in a good efficiency of private precaution measures. In terms of mental coping they rely on a lower probability for such an extreme event again, all potentially leading to mal-adaptive behaviour.

10 In general, Sstrong 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 **potentially useful indicators of planned precaution, such as burden, can be derived**. Here it is ~~remarkable-revealed~~ that **people who report a strongerhigher mental load (indicator: burden) –negative feelings– indicate a higher motivation to implement private precaution measures in future, hinting the importance that mental health might have for precaution.** Yet, the overall strength of

15 different variable connections and the predictive power are generally low, which may be partly due to small sample sizes. Additionally, the fact that the planned precaution is heavily biased towards low values, i.e. generally not intended in future among all flood types impairs the clarity of results. 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

20 combining items based on more specific and standardised questions on mental health 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~~

25 ~~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 is positively connected to preparedness intentions**. 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.

Competing interests

The authors declare that they have no conflict of interest.

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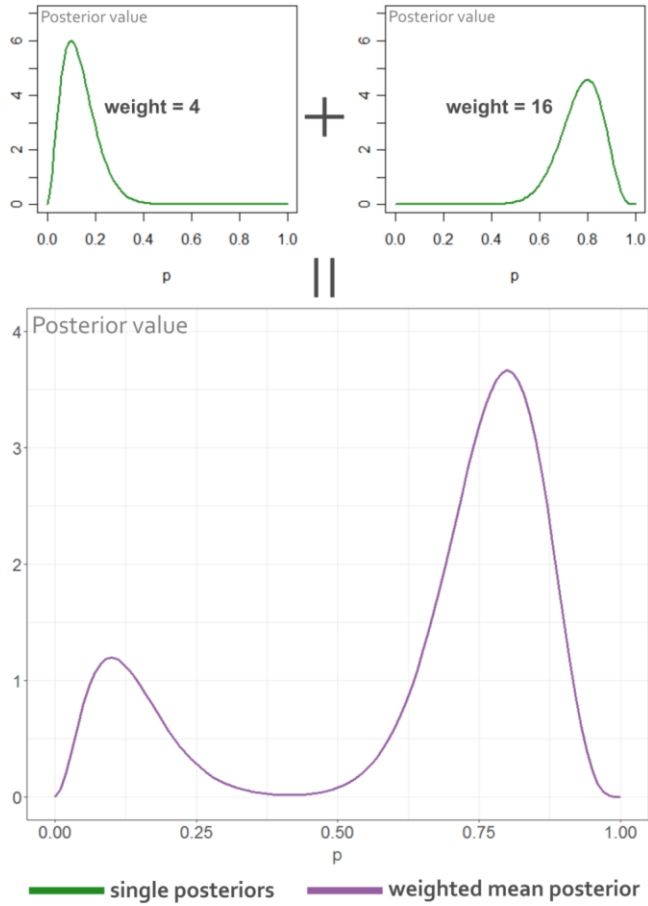
Table 1: List and explanation of the psychological variables used in this study.

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.

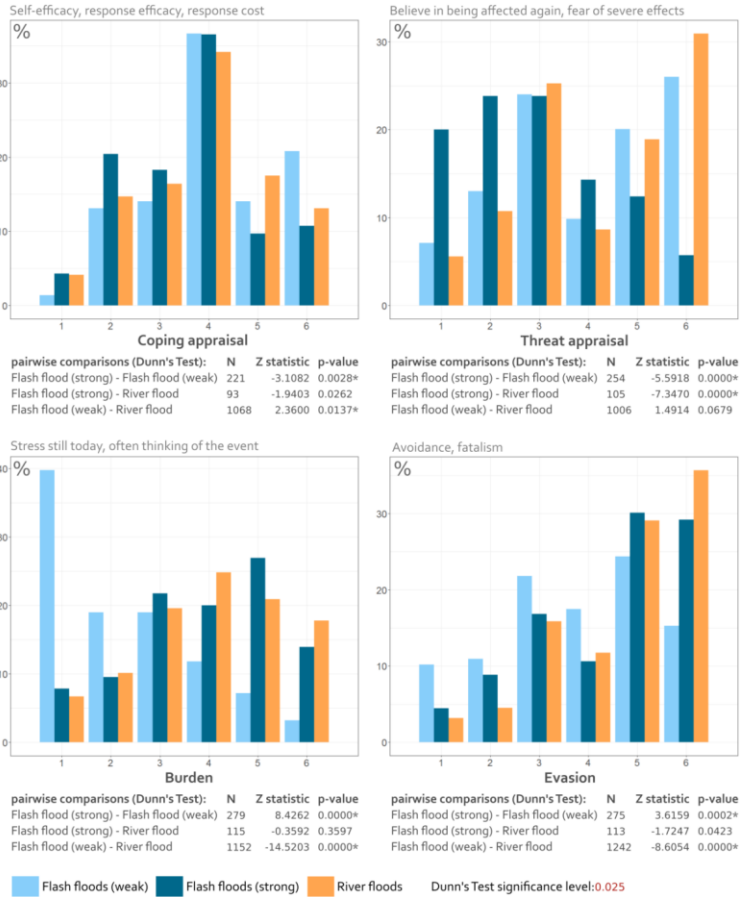
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5 **Figure 1:** Example graphic explaining the creation of the weighted arithmetic mean posterior. The double peaks are a result of the combination of all posteriors that are calculated for each variable combination. The posteriors are weighted according 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, it is most likely that a specific predictor variable rating occurs together with only one specific response variable rating to 80%.



5 **Figure 2: Relative distributions of the combined psychological indicators for each flood type and Dunn's Test results. The results of the Dunn's Test reveal the direction shift of each distribution compared to the other distributions (negative means a shift towards lower values, positive a shift towards higher values), by also indicating the strength and significance of the shift (Z-statistic and p-value).**

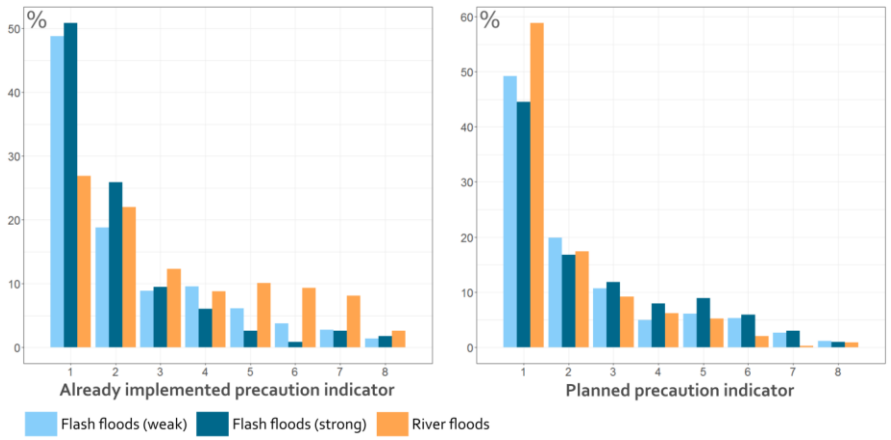


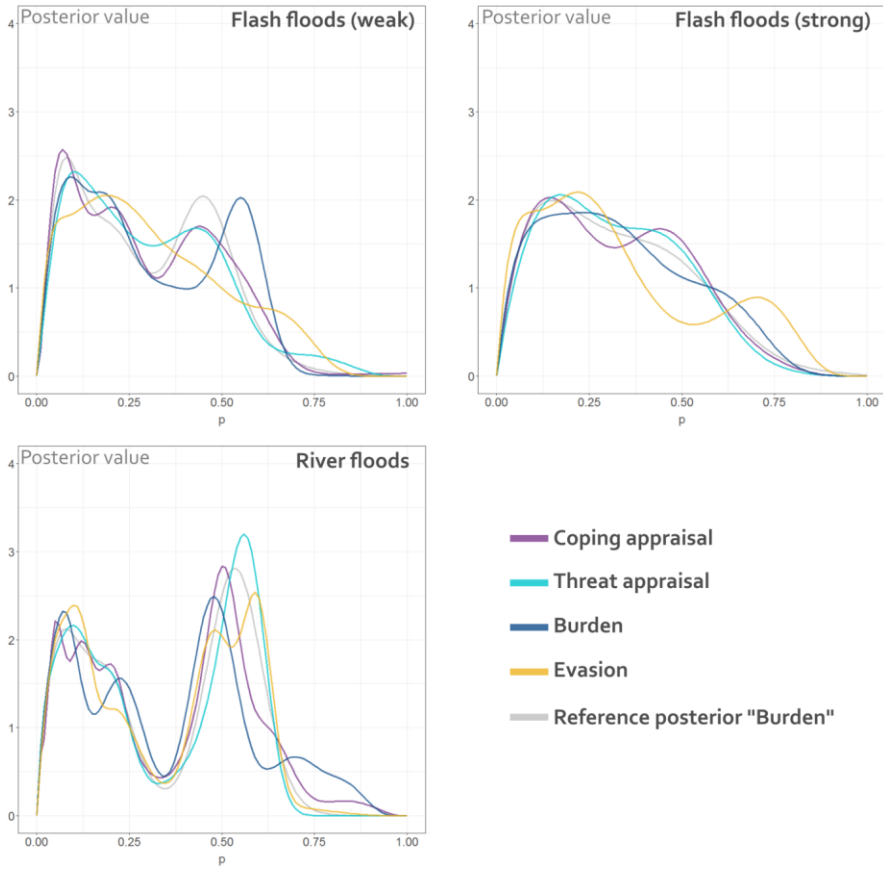
Figure 3: Relative distribution of the already implemented precaution indicator (left) and the planned precaution indicator (right) for weak flash floods (n=293), strong flash floods (n=116) and river floods (n=1366). The X axis represents the implementation of, or the intention to implement effective precaution measures. The higher the value, the more effective measures have been implemented, or will be implemented in near future. The indicator was based on results from Kreibich et al. (2005) and Thieken et al. (2005).

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5 **Figure 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.**

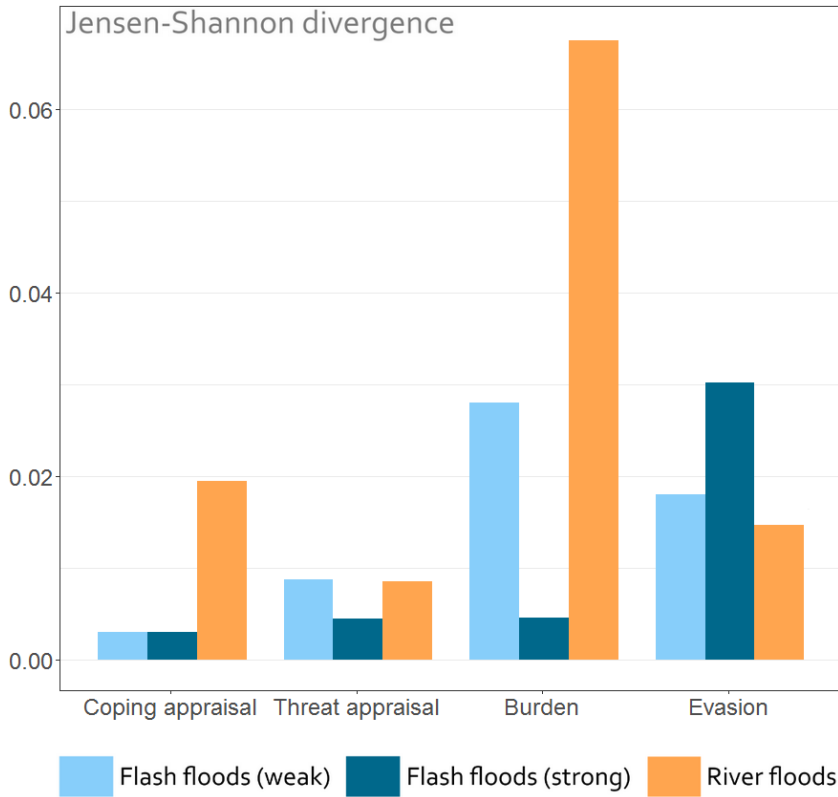


Figure 5: Jensen-Shannon divergence ranking of the psychological indicators. Higher values indicate a higher information gain, if the planned precaution is explained through the particular indicator.

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Table 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
<i>Intercept</i>	0.673 *	1.585 **	0.483 *
Coping appraisal	0.012	0.011	0.024
Threat appraisal	-0.013	-0.016	-0.038 †
Burden	0.134 ***	-0.105 †	0.054 *
Evasion	-0.024	-0.059	0.020
AIC	667.26	293.01	1422.30
R ²	0.08 **	0.06	0.03 *
N	177	76	419

Note: †p-value <.10, *p-value <.05, **p-value <.01, ***p-value <.001.

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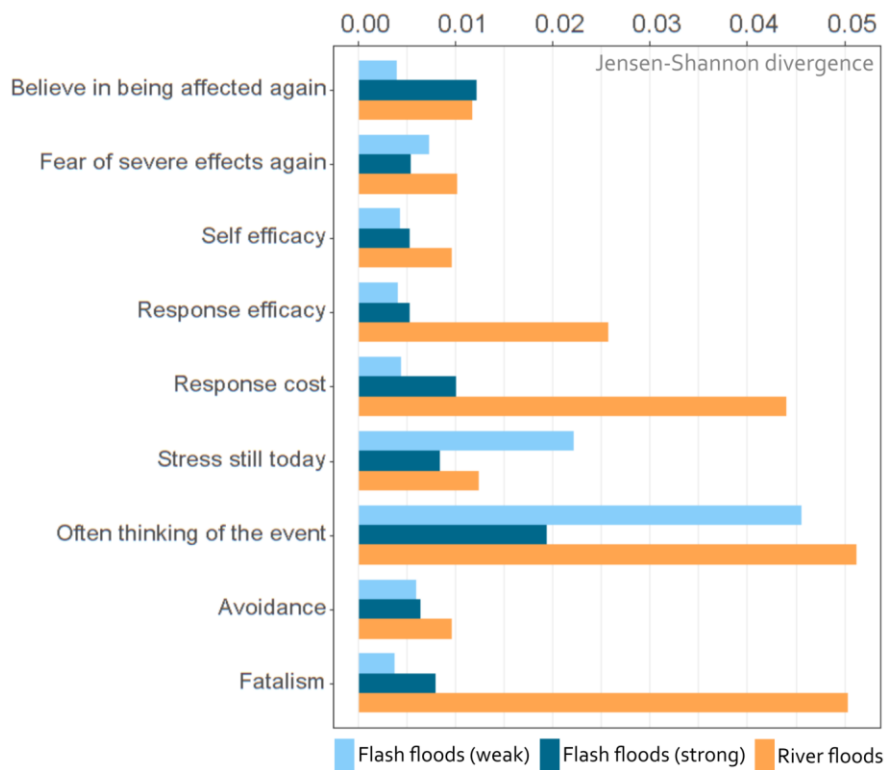


Figure 6: Jensen-Shannon divergence ranking of single psychological variables. Higher values indicate a higher information gain, if the planned precaution is explained through the particular variable.

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Table 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
<i>Intercept</i>	0.619 ‘	1.644 **	0.510 ‘
Believe in being affected again	-0.031	0.032	-0.028
Fear of severe effects again	0.002	-0.024	-0.020
Self-efficacy	-0.003	0.002	-0.007
Response efficacy	0.042	-0.019	0.027
Response cost	-0.017	0.006	-0.002
Stress still today	0.040	-0.056	0.036
Often thinking of the event	0.102 **	-0.047	0.022
Avoidance	-0.044	0.030	0.012
Fatalism	0.020	-0.103 *	0.009
AIC	669.34	300.24	1429.10
R ²	0.12 **	0.10	0.04
N	177	76	419

5 Note: ‘p-value <.10, *p-value <.05, **p-value <.01, ***p-value <.001.

Appendix

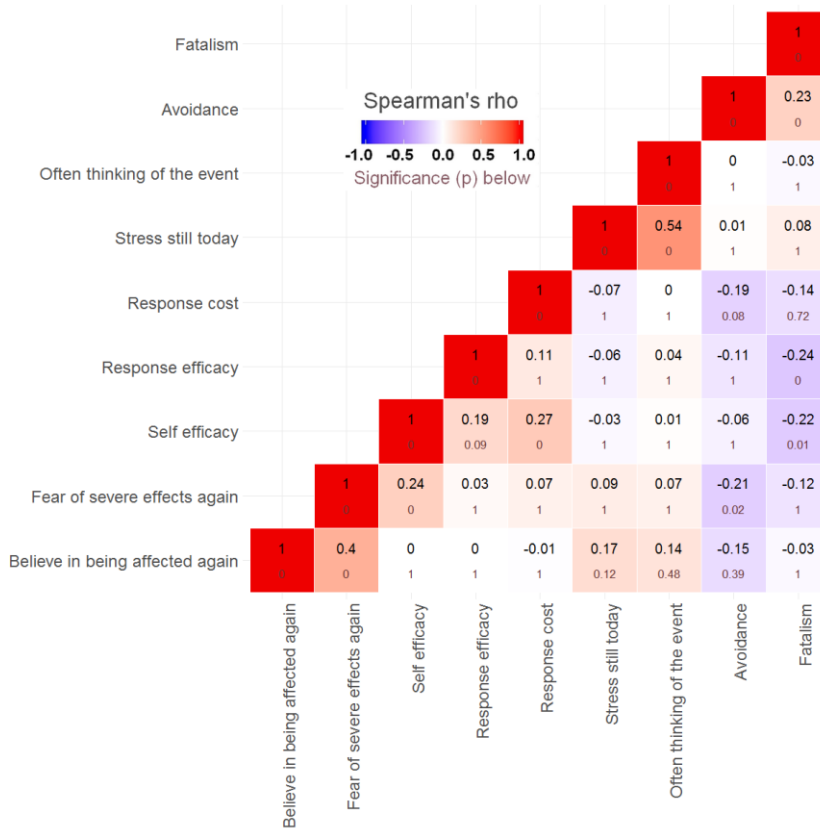


Figure A: Correlation table of single psychological variables for weak flash floods.

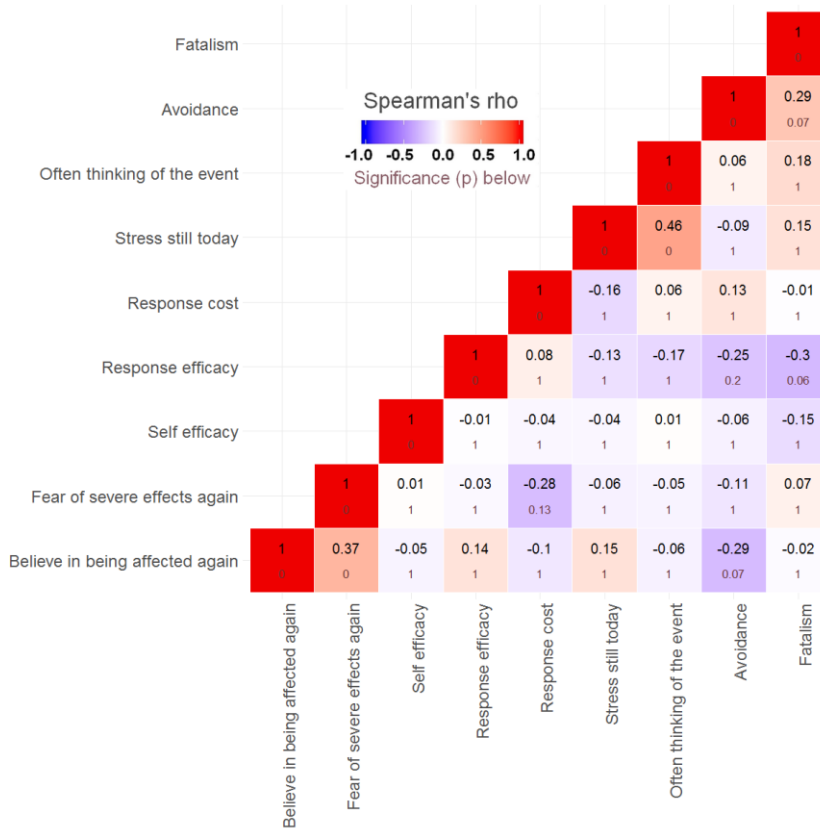


Figure B: Correlation table of single psychological variables for strong flash floods.

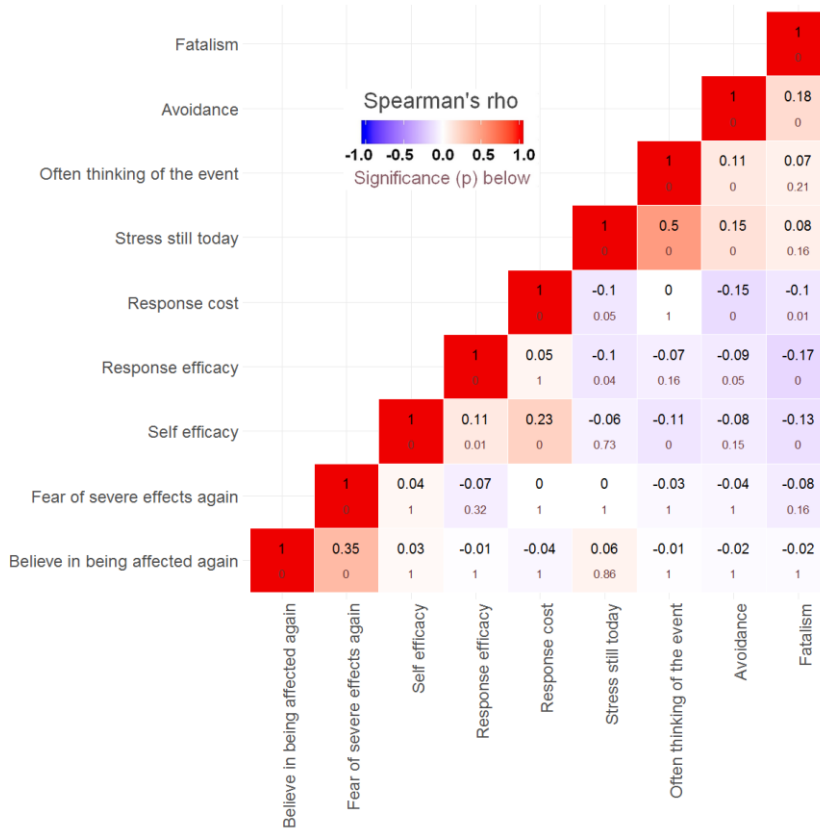
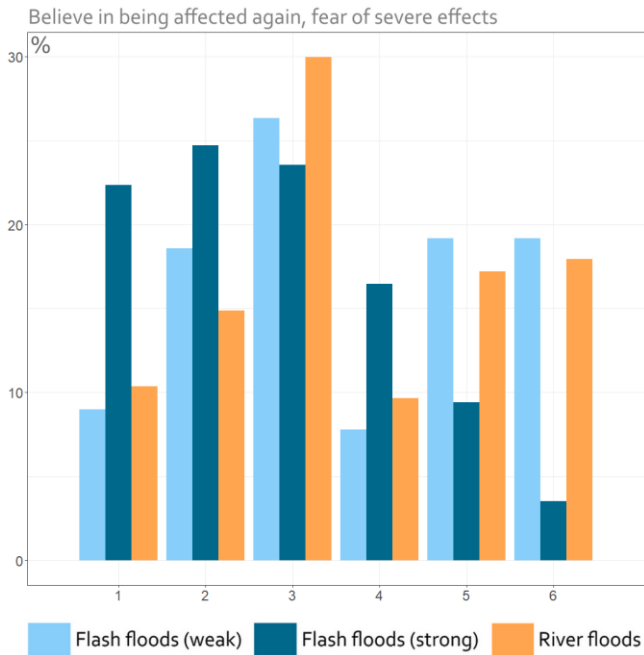


Figure C: Correlation table of single psychological variables for river floods.



Threat appraisal

pairwise comparisons (Dunn's Test):	N	Z statistic	p-value
Flash flood (strong) - Flash flood (weak)	195	-4.1112	0.0000*
Flash flood (strong) - River flood	94	-4.4440	0.0000*
Flash flood (weak) - River flood	558	0.2149	0.4149

Kommentiert [JOL18]: Changes, main point 3, RC2

5 **Figure D: Relative distribution of Threat appraisal among each flood type and Dunn's Test results. The data was corrected for flood experience, i.e. all households which only experienced a flood once. The results of the Dunn's Test reveal the direction shift of each distribution compared to the other distributions (negative means a shift towards lower values, positive a shift towards higher values), by also indicating the strength and significance of the shift (Z-statistic and p-value).**

Table A: Information about the samples and datasets

Variable	Flash flood dataset 2016 (n=517)	River flood dataset 2013 (n=1366)
	n	n
Type of housing		
Single-family house/duplex house	293	778
Semi-detached houses	45	124
Terraced houses	50	116
Farm houses	17	72
Other	16	18
NA	96	258
Age		
16-30	20	31
31-50	104	281
51-70	257	642
>70	99	280
NA	37	132
Education		
No school graduation	3	13
Secondary modern school	82	289
Middle school/apprenticeship	200	483
AVCE/technical diploma	35	82
University degree	164	419
NA	33	80
Gender		
Male	229	581
Female	288	785