Final Author comments to:
Referee #1, Tim Harries, RC1: nhess-2018-407-RC1, 2019
Referee #2, Anonymous, RC2: nhess-2018-407-RC1, 2019

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Referee #1

We thank the reviewer for the helpful and constructive comments as well as the reasonable suggestions to improve the paper. Thus, we would like to follow many of the reviewer's hints, addressing all helpful comments.

Comments of the reviewer

Main point 1:

The clarity of the argument is often poor and the logic sometimes flawed/missing

- E.g. P3.29: "This suggests that…" Why does it? Surely there are other, alternative explanations? E.g. the social norms/networks mentioned earlier on the same page. What is the evidence/theory to suggest that psych factors might vary between flood types? Given that this is the main hypothesis of the paper, it requires careful justification.

Answer 1:

Thank you for the hint, we will elaborate more on the explanations, why psychological characteristics might have strong influences on the flood protection motivation and why they potentially vary among flood types. Suggested changes in the text:

"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). 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 while potential effects of protective behaviour such as feelings of safety; anxiety, and the fear of uninsurable impacts are influenced by flood experience. Having analysed flood affected households in Germany and France, Bubeck et al. (2018) identified good social norms and networks as an important factor for better coping abilities after river floods. Especially the trust in its own abilities and the belief in a good measure effectiveness increase with the number of neighbours, who already implemented flood protection measures. Eventually, these results suggest that among influencing factors on protective behaviour, psychological characteristics might play a significant role."

(…)

"River floods usually occur after long-lasting rainfall or snowmelt within large catchment areas and result in slow-rising water levels. In contrast to river floods, flash floods emerge within (small) catchments where slopes are steep and defined, resulting 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 forecast of such flood events is not yet reliable since they can develop with 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.

~~This suggests that certain psychological impacts and characteristics may have an influence on the individual flood protection motivation and may vary with regard to different flood types.~~ After all, only few studies consider individual psychology in flood preparedness decisions although it can be expected that they contribute to the knowledge in that regard."

Main point 2:

The paper is not easy to read/understand E.g. (but there are numerous other instances):

- What is meant by “within the individual bounds of possibility” p2? This needs to be more precisely expressed
- P3 “In general” is too vague.
- Long sentences – e.g.11.

Answer 2:

We will check the manuscript again and increase the readability/clarity of the text at the suggested locations. We will further rewrite sentences and use better expressions to follow the reviewer's suggestions. Suggested changes in the text:

"As a consequence, the 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 ~~within the individual bounds of possibility~~."

(…)

"It has been shown that private precaution measures can significantly reduce the mean damage ratio (flood damage in relation to the total building/content value) to households and household contents 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)"

(…)

"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"

Main point 3 (point 1):

Methods

- The methodology for classifying flash flood strength is opaque and potentially flawed. Was this done for individual homes or for entire areas? The former would be appropriate, but I can't see how it would be possible using online searches and press reports. The latter would be insufficiently fine-grained, because the intensity of impact often varies dramatically between homes in the same street/area. The authors need to justify their reliance on crude estimates of physical damage for an analysis that looks at psych impacts. Are they assuming a close correlation between the two? If so, they should present citations supporting this.

Answer 3 (point 1):

The flash flood strength was assessed on a coarser area since we assume that impressions and effects of the flash flood severity are not particularly dependent on the intensity at the individual house. We rather believe that they are influenced by the overall appearance and effects of the flood within the village, which also includes impacts on neighbours, friends and infrastructure. For example, Bei et al., (2013) describe similar phenomena such as negative mental implications due to the disruption of daily routines with regard to an affected 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.

Moreover, not only the impact, but also the potential to be harmed outside in case of sudden and strong flow forces may influence the mental coping in regions which can experience strong flash floods. Therefore it can be assumed that the mental impacts after a severe event are differing with regard to the severity within an affected area.

In addition, we cross-checked our classification with answers concerning the pathway the water entered the building (data are not shown in the paper). Overall, our classification captures weak flash floods (comprises pluvial flooding), medium flash floods and strong flash floods.

Main point 3 (points 2-7):

Methods

- Justification needed for the exclusion of moderate strength floods.
- The authors need to justify including 'fatalistic thoughts' in a group named 'avoidance' p7
- Is it justifiable to include information-gathering in the same category of response as physical adaptation? Some reflection is needed on this issue and the key concept of precautionary behaviour needs to be defined accordingly.
- It would be helpful to include a power analysis.
- It would be good to clearly label the research as 'secondary analysis', rather than leaving it to the reader to deduce this.
- The authors should discuss the implications of the three years that separate the two surveys.

Answer 3 (points 2-7):

Thank you for these suggestions. We will clarify the different steps of the analysis and discuss the data with regard to the time between the surveys. Suggested changes in the text:

"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 a next step, the psychological characteristics are related to the overall protective behaviour. Accordingly, the following hypotheses were raised:"

(…)

"The regions which were affected by the river floods in 2013 and flash floods in 2016 differ almost completely. Further, 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 also 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."

For clarification: The group in which ‘fatalistic thoughts’ is integrated is not named ‘avoidance’ but ‘Evasion’. See description in paper:

"Evasion comprises the variables "avoidance" and "fatalism" and 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."

We will further define the concept of precautionary behaviour beforehand. Suggested changes in the text:

"The focus was shifted to a more integrated flood management, where also structural precaution measures (i.e. waterproof sealed cellars i.e. dry-proofing, wet-proofing, relocation of heating and electrical utilities) as well as 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)."

For clarification: The category information-gathering and other adaptation measures are combined within the precaution indicator according to their potential to reduce physical damage. The calculation is based on weights that are assigned to each precaution measure that have been derived from analyses mainly done by Kreibich et al. (2005) and Thieken et al., (2005). See description in paper:

"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)."

Regarding the power analysis: We decided to describe the Dunn's test in greater detail instead of including a power analysis. The Dunn’s test generally obviates the need for a power analysis and also helps to understand the related figure (figure 2). Suggested changes in the text:

"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."

Main point 3 (points 8-15):

Methods

- 6.25: "The indicators are combined according to literature…" Requires more explanation.
- The descriptions of the statistical methods, process and results need to be more accessible to readers not expert in stats or the particular methods used
- References needed for the justification for using Bayesian methods (p4)
- The Bayesian approach 'offers advantages'. The authors need to be specific about what these are. P4
- Clearer and more precise language is needed. E.g. 'the specific variable applicability' – what does this (and the rest of the sentence) mean?
- The surveys were 'equally designed'. This needs to be clearer – were they identical or were there differences?
- It makes no sense to speak of 'an equal distribution of age and gender'. 'Balanced'?
- It would be helpful to have more information about the samples. E.g. response rates; social class/occupation; household types; extent of flood damage – and/or some comparison of the German population to highlight ways in which the samples are/are not representative.

Answer 3 (points 8-15):

Thank you for these ideas. We will increase the clarity of our descriptions, justify the applied methods and rewrite certain parts of the text. We will further elaborate the explanation how indicators/items can be combined. Suggested changes in the text:

"The indicators are combined according to literature, i.e. Creamer et al. (2003), who suggest to combine items to create robust indicators. Further, Grothmann and Reusswig (2006) and Bubeck et al. (2012) describe the items that constitute the factors of the PMT, which are especially relevant as 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."

(…)

"The Bayesian approach has been frequently used in psychology (e.g. Wetzels et al., 2011) and other disciplines. It assesses the data uncertainty which is particularly helpful among studies that rely on relatively small data sets, 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. By 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 coherences

are therefore not required. ~~Furthermore, this approach evaluates the specific variable applicability for a potential prediction of a response variable, in this case the "planned precaution" indicator.~~"

(…)

"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."

Additionally, we will include a table in the appendix to provide more information about the samples (age, gender, education, type of housing).

Main point 4 (points 1 & 2):

The scene-setting needs to be done more carefully and the drafting of the hypotheses improved

- More careful use of terminology needed; and some terms need defining.
  - i. E.g. "flood protection" is more commonly used to mean property-level measures, but is not used in this way on p2. Perhaps "flood risk management" is a more appropriate term.
  - ii. On p2 "private precautionary measures" is used before it has been defined.
  - iii. P2: the terms 'structural' and 'non-structural' need defining
- 7.3: I think this should read "perceived cost of a protective measure…"

Answer 4 (points 1 & 2):

See Answer 3 (points 2-7): Important terms will be defined beforehand. As suggested, we will replace the term "flood protection" with "flood risk management". Suggested changes in the text:

"The focus was shifted to a more integrated flood management, where also structural precaution measures (i.e. waterproof sealed cellars i.e. dry-proofing, wet-proofing, relocation of heating and electrical utilities) as well as 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)."

(…)

"Flood risk management in Germany has a long history with several regulations and ongoing programs."

Main point 4 (points 3-5):

- H1:
  - i. 'riverine' refers to the river bank; the term more commonly/accurately used for flooding from rivers is 'fluvial'
  - ii. some fluvial flooding is flashy, so the dichotomy presented is a false one. Are the authors talking about pluvial flashy floods only?
  - iii. what does it mean to say that flash floods are 'more dynamic'? This needs explication.
  - iv. is it an overgeneralisation to say that flashy floods are 'a bigger threat to life'? Where is the evidence for this assertion?
  - v. what is the provenance of this hypothesis: e.g. in theory or the literature?
- H2: like H1, this hypothesis requires anchoring in the literature. It also requires nuancing; after all, some negative psych impacts prompt greater likelihood of precaution.
- H3:
  - i. This is too vague. The reader needs to know which psych indicators are meant, and which psych characteristics
  - ii. Some explanation needed of the distinction between 'indicator' and 'characteristic' (and, later, 'manifestations').

Answer 4 (points 3-5):

These are important suggestions to improve the paper. We suggest the following changes in the text to clarify our motivation and sharpen the hypotheses:

"In contrast to river floods, flash floods emerge within (small) catchments where slopes are steep and defined, resulting 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 forecast of such flood events is not yet reliable since they can develop with 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."

(…)

"H1: Flash floods, in comparison to slowly emerging river 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 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 energy and self-confidence as well as the overall motivation to implement precaution measures.

H3: 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."

(…)

"Thus, groups of similar psychological characteristics (psychological indicators) are created first."

Main point 4 (points 6 &7):

- How is similarity defined when grouping 'similar psych manifestations' p4?
- Lines 24-32 (p4):
  - i. What is meant by 'an indicator'?
  - ii. How can an indicator 'estimate' something? (Did the authors mean 'predict'?)
  - iii. What is meant by a 'precaution level'?
  - iv. The authors need to justify their assumption that a better understanding of psych factors can inform 'targeted info campaigns'. It seems a little simplistic to think that information will make much difference. Plus, how would target groups be identified given that there's no easy way of identifying people with different psych characteristics.

Answer 4 (points 6 & 7):

The phrase "manifestations" will be replaced with "characteristics" since it fits better within this sentence. We will rewrite the respective test passages as follows:

"•A good understanding of psychology and precaution motivation might result in a variable which indicates the probability for a good precaution and could be integrated into flood loss modelling and dynamic risk assessements as suggested by Aerts et al. (2018).

We will clarify our idea of targeted information campaigns. Indeed, the term is a little misleading and the targeting of specific societal groups seems challenging for the mentioned reasons. Here it is important that information campaigns also provide support and information for a broader audience and people who potentially need more help, support and specific info to match their needs. E.g. an information campaign with trained personnel might help to convince people with avoidant tendencies. We will therefore rewrite the respective text passage:

"•The outcome might be beneficial for ~~targeted~~ 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 useful private flood precautionary measures could be strengthened according to the needs of individually affected people (e.g. Morss et al., 2016)."

Main points 5 & 6:

5. The paper would benefit from some critique of Precaution Motivation Theory and a more sophisticated justification of its selection over other theories.

6. The paper needs to draw on literature from outside Germany. E.g. there is much on this topic from the UK. If the situation in Germany is so unique as to make other literature nonsalient (p3), this needs to be explained.

Answer 5 & 6:

Yes, such additions will improve the paper since the explanations and examples are currently too short. We therefore suggest following text changes/additions:

"Originally evolved in the health sector, the PMT gained attention in the domain of natural hazards over the years (Mulilis and Lippa, 1990; Grothmann and Reusswig, 2006; Bubeck et al., 2017). The model 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 an event. 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). Overall the PMT results in reliable estimations of protective behaviour, while particularly coping appraisal has been evaluated as a good predictor (Floyd et al., 2000; Milne et al., 2000; van Valkengoed et al., 2019). 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). 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 while potential effects of protective behaviour such as feelings of safety; anxiety, and the fear of uninsurable impacts are influenced by flood experience. Having analysed flood affected households in Germany and France, Bubeck et al. (2018) identified good social norms and networks as an important factor for better coping abilities after river floods. Especially the trust in its own abilities and the belief in a good measure effectiveness increase with the number of neighbours, who already implemented flood protection measures. Eventually, these results suggest that among influencing factors on protective behaviour, psychological characteristics might play a significant role."

Main points 7 (points 1-4):

Findings

- I do not believe it's appropriate to report as 'findings' correlations that are nonsignificant e.g. 11.4.
- Interpretations of statistical findings should be less speculative i.e. justified from theory/the literature. Presently, much of the interpretation appears no more than supposition. E.g. p11
- Interpretations of statistical findings are best reported separately from the findings themselves.
- Explanation required of some key terms: 'flood adapted use', 'better interior fitting' and 'damage ratio of buildings' (p8); 'coherence' (p9)

Answer 7 (points 1-4):

Thanks for the hints. We will rewrite the respective text passages and explain key terms. Suggested changes and additions in the text:

"A similar ~~finding~~ outcome is indicated when comparing the difference between strong flash floods and river floods, yet the results are not significant."

(…)

"The focus was shifted to a more integrated flood management, where also structural precaution measures (i.e. waterproof sealed cellars, relocation of heating and electrical utilities) as well as 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)"

(…)

"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/content asset value) to households and household contents up to 53 per cent and thus play a significant role in comprehensive flood management (Kreibich et al., 2005; Thieken et al., 2008; Merz et al., 2010)."

(…)

"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 happen again 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 to 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)."

Since the results and interpretation are closely connected within this study, we prefer to keep the section of combined results and discussion.

Main points 7 (points 5-8):

- Figure 2 appears to add little and is hard to understand. I suggest that it be removed or more carefully explained.
- Fig 3 – the x-axis requires more explanation
- 'JSD' requires spelling out p12 etc
- Discussion of the hypotheses:
  - H1: it needs to be made clearer how the suggested 'focus on threat perception' is justified by the findings. At present, the logical argument is weak/hazy.
  - H2: the text is v hard to understand.

Answer 7 (points 5-8):

We will explain all figures in greater detail and also improve the explanation in the paper. We will further define the acronyms and describe the methods in a clearer way beforehand. Suggested changes in the text and within the figure descriptions:

"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. 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."

(…)

Figure 2 description: " 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 description: "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)."

Additionally, we will elaborate on the justifications regarding H1 and rewrite certain text passages regarding H2. Suggested changes in the text:

"Affected people perceive a strong flash flood event as less likely than people who have been repeatedly affected by river floods. Thus, future disaster risk management in Germany may also take into account that 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 (e.g. Murawski et al., 2015)."

(…)

"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."

Main point 8:

- The aim seems incorrectly described (16.11). Wasn't it the connection to precautionary behaviour that was explored, not that to motivation? (See H3)
- It would help if the key findings were foregrounded so that they were easier to pick out.
- The authors should avoid making assumptions of causal direction (17.5). It's possible that preparedness influences frequency of remembering, rather than visa-versa (see Harries, 2008: "Feeling secure or being secure").

Answer 8:

Thanks for the suggestions and hints. We will adapt misleading descriptions. Further, the main results will be highlighted. We will alleviate the description of the overall result regarding the causal direction that was assumed. Suggested changes in the text:

"Further, the usefulness of psychological indicators and individual psychological variables to predict precaution behaviour was evaluated."

(…)

"Overall it is indicated that, in particular, the frequency of remembering an event is positively connected to preparedness intentions."

Referee #2

We thank the reviewer for the constructive comments. We will extend our descriptions analysis and discussion as suggested by the reviewer to improve the paper quality.

Comments of the reviewer

Reviewer quote, paragraph 1:

A general limitation of the study seems to be that the people who experienced river floods experienced them multiple times in the last 10 years. While the people who experienced flash floods seem to have fewer past experiences. Is there a possibility that this frequency of past experiences may be a stronger signal than the flood type? Is there a way to correct your data for the number of flood experiences people have had?

Answer to paragraph 1:

We agree that this is a general limitation of the study since the previous experience of flash floods is very low among the surveyed residents. Yet, the residents who have been affected by river floods experienced several major flood events in recent years (2002, 2006/11, 2013) and therefore show a higher experience in total. However, not all regions that were hit by the 2013 flood, had been affected in 2002 or later, this holds particularly for Thuringia, Lower Saxony and Baden-Wurttemberg. The number of surveyed residents from these regions was, however, lower than aimed at. The correction of flood experience will decrease the flash flood data to a great extent, increasing analysis uncertainty. However, we will analyse the indicator "threat appraisal" with regard to corrected data (all households that experienced a flood for the first time), discuss the results and put a figure (figure D) in the appendix.

Reviewer quote, paragraph 2, 6, 7:

Specific comments: Page 4, line 8-20, these are some very technical sentences, could you explain your approach in a more intuitive way and introduce the technical methods later. Currently this is difficult to read without prior knowledge about the statistical methods that are applied.

2.5 Explain why you use Bayesian statistics, you now just jump into the explanation without first motivating the choice.

2.5 Why did you choose to use Bayesian statistics if no prior is available? What is the advantage of using Bayesian statistics?

Answer to paragraph 2, 6, 7:

Thank you for this suggestion. We will rewrite sentences that are too technical and give explanations of the statistical methods beforehand. We will further elaborate the choice for Bayesian statistics. We decided to include Bayesian statistics without specific prior information since any valuable results from other studies could theoretically be integrated into our analysis in future. Suggested changes in the text:

"Secondly, the differences in the indicator distributions, i.e. shifts to lower or higher indicator ratings, are assessed for each flood type. To answer the second and third hypotheses, a "planned precaution" indicator is created first. In a next step, the Bayesian approach and negative binomial regressions are applied and resulting probability distributions of conditional variable dependences as well as regression coefficients are evaluated. The Bayesian approach has been frequently used in psychology (e.g. Wetzels et al., 2011) and other disciplines. It assesses the data uncertainty which is particularly helpful among studies that rely on relatively small data sets, 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. By 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 coherences are therefore not required. ~~Furthermore, this approach evaluates the specific variable applicability for a potential prediction of a response variable, in this case the "planned precaution" indicator.~~ Bayesian statistics were also chosen due to the fact that the method enables prior knowledge to be taken into account, for example in following studies that use similar Bayesian approaches."

Reviewer quote, paragraph 3:

Page 4 line 24-30: Could you sketch in a bit more detail how you see this being used in the future. We don't know these psychological indicators for everyone when we make a damage model. It might even be easier to ask directly about precautionary measures than to assess their psychology. Using social media information as proxy might be a solution but I like to see these arguments made a bit more thoughtful and if that's the way to apply it I like to see that back in the discussion and maybe a recommendation to study how social media clues can be linked to the indicators used in this paper. You mention several times the "protection motivation theory", please give a brief explanation of this, you can't assume all your readers know about this.

Answer to paragraph 3:

Thank you for the comment, we will elaborate on the topic of alternative data sources as well as new approaches to gather valuable data in the discussion. We will further give a brief outline of the Protection Motivation Theory beforehand. Suggested changes in the text:

"In this context, the protection motivation theory (PMT) (Rogers, 1975) has been frequently used as a psychological model to explain the risk-reducing/protective behaviour of affected individuals by analysing the influencing factors on coping strategies and potential positive or negative responses. Originally evolved in the health sector, the PMT gained attention in the domain of natural hazards over the years (Mulilis and Lippa, 1990; Grothmann and Reusswig, 2006; Bubeck et al., 2017). The model 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 an event. 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)."

(…)

"• 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 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."

(…)

"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, 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 on 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 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."

Reviewer quote, paragraph 4 & 5:

Page 7, line 5, please first explain what burden and evasion are before explaining the motivation behind it.

Give a proper explanation of Kruskal-Wallis rank sum test, Dunn‘s Test, the Jensen-Shannon divergence and regression tests directly after you first mention these methods. Maybe don’t mention them too early in the text. Give both an intuitive and a brief mathematical explanation of the methods.

Answer to paragraph 4 & 5:

As you suggested, we will describe and explain the methods as well as key terms beforehand and in a clearer way. Suggested changes/additions in the text:

"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. 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).

Burden describes a measure for the negative psychological load of the experience and consists of the single variables "often thinking of the event" and "stress still today". Evasion comprises the variables "avoidance" and "fatalism" and can be seen as a measure for the effort to get the experience out of one's mind for various reasons. 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."

(…)

"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."

Regarding the Jenson-Shannon divergence and the negative binomial regression, the respective parts in the text will be converted in a way that the explanation follows directly after mentioning the methods for the first time.

Reviewer quote, paragraph 8:

Figure 2: why is threat appraisal lowest for strong flashfloods? Does it make sense that if something extreme happened to you, you feel the probability that it will happen again to be lower? (your argument on page 11, line 10). Maybe threat appraisal is lower because they only experienced it once while the river floods and weak flash floods were experienced more frequently. If however you would go to another region where only one weak flash flood or river flood was experienced these results may look very different. You should probably discuss that limitation in the study.

Answer to paragraph 8:

We agree with the statement of the reviewer that this means a certain limitation of the study. Therefore, we will add another analysis in the appendix with the corrected data in terms of flood experience for the indicator "threat appraisal" (see also Answer to paragraph 1). The limitation will be discussed in a more elaborate way, yet we believe that our general statement in that case ('it has been such an extreme event that people perceive it as unlikely to happen again') holds true. Suggested changes in the text:

> "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 to 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)."

Reviewer quote, paragraph 9 & 10:

Figure 4: This figure is not very intuitive can you explain a bit more what the reader sees here.

Figure 4: Why do you see the double peaks in the probability distributions?

Answer to paragraph 9 & 10:

Thank you for the hint. Firstly, we refer to the explanation graphic, Figure 1, where we will add more details to the description. We will also describe the method in a better way, changing the respective text passage underneath Figure 4. Suggested changes in the text:

"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 in one plot 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%."

(…)

"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)."

Reviewer quote, paragraph 9 & 10:

Page 14, line 17: You say this is common practice in psychology, can you provide a reference for this?

Answer to paragraph 9 & 10:

A reference will be added. Suggested changes in the text:

"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."

Reviewer quote, paragraph 9 & 10:

Page 15, H2: I think the findings make much more sense than the hypothesis.

Answer to paragraph 9 & 10:

We think that the Hypothesis is justified since personal experience and conversations with flood affected residents indicated a high level of burden after a severe flash flood event, which could also lead to negative responses and low motivation deal with any aspects and implications of the flood event again. Still, we believe that these are interesting negative results which support other studies such as Bei et al. (2013), who reported that affected people with worse mental and physical health show a higher willingness for coping strategies.

List of Changes in the paper, according to all suggestions:

We marked all changes in the document with a reference to the respective point in the list of changes.

The colour green has been associated to changes according to the first reviewer.
The colour blue has been associated to changes according to the second reviewer.

References:

1. Clearer introduction into the topic.
2. Careful terminology, better defining and elaborate explanation.
3. Introduction into the Protection Motivation Theory (PMT).
4. Justification and explanation of psychological factors and related methodologies.
5. Included suggestions for the hypotheses.
6. Intuitive and mathematical explanation of methods.
7. More thoughtful and elaborate discussion.
8. Rewritten sentences for a better understanding.
9. Included samples and tables for additional information.
10. Justification of the applied method.
11. Inclusion of significant literature.

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

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

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

The flash flood events in 2016 have been remarkably different from the river flood events of 2002 and 2013 in terms of processes, dynamics, duration and the type of induced damage on buildings (Laudan et al., 2017). In contrast to river floods, flash floods are defined as rapid, 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 severe flash floods in Germany outside alpine regions in 2016 can be described as unexpected, but yet highlights the topicality, considering the relatively high monetary losses of EUR 2.6 billion (Munich Re, 2017), damage and unfortunately eleven fatalities (four in Baden-Wurttemberg and seven in Bavaria along Simbach am Inn). However, there is a lack of studies that compare impacts of and preparedness to flash and river floods, especially with regard to protection motivation and the influencing factors.

Flood risk management in Germany has a long history with several regulations and ongoing programs. Besides national initiatives such as the "Nationales Hochwasserschutzprogramm" (NHWSP) and a national framework legislation regulation, the Federal Water Act of 2009 and its updates, the management of water bodies and flood management are in Germany in principle regulated on state level. Superior regulations such as the European Floods Directive (2007/60/EC) set up framework conditions and thus had to be incorporated into the national legislation by 2010 (e.g. Thieken et al., 2016b). After the severe river flood events in 2002 and 2013, the flood risk management in Germany and the relevant legislation was carefully revised. The focus was shifted to a more integrated flood management, where also structural precaution measures (i.e. waterproof sealed cellars i.e. dry-proofing, wet-proofing, relocation of heating and electrical utilities) as well as 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, the 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 ~~within the individual bounds of possibility~~. As an overall result, regions which have been affected by recurrent river floods are now well managed, having tailored flood risk management plans in place, including private precaution. Still, despite the devastating events in 2016, flash floods and strong surface water 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 concerning flash floods in Germany.

Kommentar [JL1]: References 1, 4

Kommentar [JL2]: References 1, 2

Kommentar [JL3]: Reference 2

Kommentar [JL4]: Reference 2

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/content asset value) to households and household contents 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). The state of private precaution can further be integrated in flood loss estimation models such as the flood loss estimation model (FLEMO) which results in more reliable damage estimations on different scales and therefore contributes to robust risk and vulnerability estimations (Thieken et al., 2008). Hence, understanding and predicting private precaution is essential for future planning and flood risk management not only with regard to river floods, but also with respect to flash floods and rapid surface runoff as an unfamiliar and potentially more frequent hazard in future. Here, the individual protective behaviour it is not yet fully understood, particularly if people are affected by different flood types. Questions must be raised whether affected individuals carry out private protective measures, to what extent they implement measures and what are motivating as well as demotivating factors. In this context, the protection motivation theory (PMT) (Rogers, 1975) has been frequently used as a psychological model to explain the risk-reducing/protective behaviour of affected individuals by analysing the influencing factors on coping strategies and potential positive or negative responses. Originally evolved in the health sector, the PMT gained attention in the domain of natural hazards over the years (Mulilis and Lippa, 1990; Grothmann and Reusswig, 2006; Bubeck et al., 2017). The model 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 an event. 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). Overall the PMT results in reliable estimations of protective behaviour, while particularly coping appraisal has been evaluated as a good predictor (Floyd et al., 2000; Milne et al., 2000; van Valkengoed et al., 2019). 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). 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 while potential effects of protective behaviour such as feelings of safety; anxiety, and the fear of uninsurable impacts are influenced by flood experience. Having analysed flood affected households in Germany and France, Bubeck et al. (2018) identified good social norms and networks as an important factor for better coping abilities after river floods. Especially the trust in its own abilities and the belief in a good measure effectiveness increase with the number of neighbours, who already implemented flood protection measures. Eventually, these results suggest that among influencing factors on protective behaviour, psychological characteristics might play a significant role.

Kommentar [JL5]: Reference 1

Kommentar [JL6]: Reference 3

Kommentar [JL7]: Reference 3

Kommentar [JL8]: References 4, 11

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

~~Besides negative responses to flood exposure, coping strategies also comprise protective behaviour which is dependent on personal knowledge, multiple socio-economic and psychological factors as well as individual character traits~~. River floods usually occur after long-lasting rainfall or snowmelt within large catchment areas and result in slow-rising water levels In contrast to river floods, flash floods emerge within (small) catchments where slopes are steep and defined, resulting 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 forecast of such flood events is not yet reliable since they can develop with 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.

Kommentar [JL9]: Reference 1, 4

~~This suggests that certain psychological impacts and characteristics may have an influence on the individual flood protection motivation and may vary with regard to different flood types~~. After all, only few studies consider individual psychology in flood preparedness decisions although it can be expected that they contribute to the knowledge in that regard. 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 a next step, the psychological characteristics are related to the overall protective behaviour. Accordingly, the following hypotheses were raised:

Kommentar [JL10]: Reference 4

H1: Flash floods, in comparison to slowly emerging river 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 rough, emerge suddenly and therefore represent an unpredictable danger for health and property.

Kommentar [JL11]: Reference 5

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.

H3: 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.

Kommentar [JL12]: Reference 5

The first hypothesis is tested by comparing psychological characteristics of people which are affected by different flood types and flood strengths. Thus, groups of similar psychological characteristics (psychological indicators) are created first.

Kommentar [JL13]: Reference 2

Secondly, the differences in the indicator distributions, i.e. shifts to lower or higher indicator ratings, are assessed for each flood type. To answer the second and third hypotheses, a "planned precaution" indicator is created first. In a next step, the

Kommentar [JL14]: References 8, 6

Bayesian approach and negative binomial regressions are applied and resulting probability distributions of conditional variable dependences as well as regression coefficients are evaluated. The Bayesian approach has been frequently used in psychology (e.g. Wetzels et al., 2011) and other disciplines. It assesses the data uncertainty which is particularly helpful among studies that rely on relatively small data sets, 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. By 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 coherences are therefore not required. ~~Furthermore, this approach evaluates the specific variable applicability for a potential prediction of a response variable, in this case the "planned precaution" indicator.~~ Bayesian statistics were also chosen due to the fact that the method enables prior knowledge to be taken into account, for example in following studies that use similar Bayesian approaches. However, to assess the potential direction of the predictor and response variable coherence, the Bayesian approach is supported by a negative binomial regression model. The implementation of all methods is addressed in the next section.

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

- A good understanding of psychology and precaution motivation might result in a variable which indicates the probability for a good precaution 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 ~~targeted~~ 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. Morss et al., 2016).
- A better understanding of this connection might help to improve future vulnerability and risk estimations and may facilitate the use of alternative data sources to estimate the state of individual precaution. For example, 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 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.

Kommentar [JL15]: References 8, 6

Kommentar [JL16]: References 4, 6, 10

Kommentar [JL17]: Reference 7

Kommentar [JL18]: References 4, 8

Kommentar [JL19]: Reference 7

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.

2.1 Description of the river flood and flash flood datasets

The individual datasets consist of computer-aided telephone interviews which were conducted among residents affected by either the river flood of 2013 or the heavy rainfalls and flash floods of 2016. Within this study, the river flood of 2013 and the flash floods of 2016 are considered for comparison, since the two events were very different in terms of the flood dynamics. Still, both events were relevant on the national scale. Finally, the time lag between the particular event and the implementation of the survey is similar, i.e. around nine months after the flood event in both cases. The regions which were affected by the river floods in 2013 and flash floods in 2016 differ almost completely. Further, 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 also 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 outline of both surveys was very similar, mainly including the same questions. They were designed and initially focused on flood damage estimation of affected households and the assessment of damage driving factors. Hence, the biggest part comprised questions about socio-economic characteristics (e.g. age, gender, social status, income, education, homeownership), characteristics of the housing unit (e.g. number of stories or floor space, construction year, number of persons per unit, housing area) and different dimensions of private precaution (e.g. if certain single protection measures are already implemented or planned to be implemented in the near future). Yet, various psychological characteristics that address 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 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, insurance, networking, flood-adapted story usage, flood-adapted interiors, relocating heat and electricity, securing heat and oil tanks, improving flood safety, installing backflow prevention, installing water barriers, having no noxious liquids in the cellar, installing pumps, having generators available and anticipatory planning of supplies. For each private precaution measure, individuals were asked to mark them as “implemented before the event”, “implemented after the event”, “will be implemented in near future”, and “not planned to be implemented”.

Kommentar [JL20]: Reference 2

Kommentar [JL21]: Reference 8

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.

Kommentar [JL22]: References 2, 9

Kommentar [JL23]: Reference 9

(Table 1)

2.2 Separation of weak and strong flash floods

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

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

Kommentar [JL24]: Reference 4

2.3 Defining main psychological indicators

To answer the first hypothesis, four main psychological indicators were considered within this study. The indicators are combined according to literature, i.e. Creamer et al. (2003), who suggest to combine items to create robust indicators. Further, Grothmann and Reusswig (2006) and Bubeck et al. (2012) describe the items that constitute the factors of the PMT, which are especially relevant as 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. 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).

Kommentar [JL25]: Reference 4

Burden describes a measure for the negative psychological load of the experience and consists of the single variables "often thinking of the event" and "stress still today". Evasion comprises the variables "avoidance" and "fatalism" and 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. 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), a widely used item-based survey that measures traumatic stress, to assess symptoms of the post-traumatic stress disorder (PTSD) in male Vietnam veterans. However, they also find that the main factors of the IES-R, i.e. "hyperarousal", "avoidance" and "intrusion" do not provide a good account of the data due to correlations among single items and suggest the use of less or diversely composed factors/indicators. Accordingly, the creation of the indicators burden and evasion required pre-processing of the data, correlation tests and the evaluation of preliminary results. Thus the preliminary results are shortly presented in this section.

Kommentar [JL26]: Reference 3

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

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

The distributions of threat appraisal, coping appraisal, burden and evasion were further analysed using the 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.

Kommentar [JL27]: References 6, 10

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).

Kommentar [JL28]: Reference 2

For the planned precaution indicator, the weighted score of measures which were planned to be implemented directly or shortly after the flood event (see section 2.1.) is summed up and related to the already implemented or non-applicable measures. The data is disregarded if the count of already implemented or non-applicable measures is equal or exceeds the half of the overall measure count of 16 measures (>= 8), since it is hardly possible to obtain meaningful results for the "planned precaution" in such cases, i.e. this value already reflects a very good level of private precaution. Hereby, it is also ensured that there is no bias towards low precaution motivation in the subsequent analysis caused by an already high precaution level, since it can be assumed that people who already implemented many protection measures have a lower planned precaution score. The procedure results in indicator scores ranging from 0 to 48, which are further reclassified into values ranging from 0 (low planned precaution) to 8 (high planned precaution). In the results and discussion section (section

3.2.), this indicator is compared to the state of precaution, i.e. the weighted score of already implemented precaution measures.

2.5 The Bayesian approach

Bayesian statistics can be applied to calculate probability distributions from a limited set of observations and to quantify related uncertainties. The statistical model takes prior knowledge into account (prior) and assesses the likelihood to observe the data, if specific model parameters are given (likelihood). This results in a probability density for the model parameters, conditioned on specific data (posterior) (Puga et al., 2015), where the Bayes theorem is (1):

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

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 about the occurrence and non-occurrence of two variable values, as given in the dataset. It resembles a basic probabilistic approach to scientific questions without making preliminary assumptions (e.g. linear variable coherence). The binomial distribution is thus defined as (2):

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

- 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 manifestations.

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 Jenson-Shannon divergence and a negative binomial regression model. The Jensen-Shannon divergence (JSD) is a variation of the Kullback-Leibler divergence and defined by (3):

Kommentar [JL29]: Reference 6

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

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

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

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

Kommentar [JL30]: Reference 6, 10

Both, the psychological indicators and the single variables were separately analysed to reveal differences between the general procedure in psychology to combine similar items/variables and studying all variables separately.

First, the weighted arithmetic mean of all posterior distributions (resulting from the Bayesian analysis, see section 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 a next step, a weighted arithmetic mean posterior is calculated by randomising the respective variable while considering its individual distribution to describe the random occurrence of predictor and response variable. This step is necessary to obtain the particular reference posterior shape, which is exclusively influenced by the distribution of the predictor and response variable. In other words, if e.g. the response variable is not equally distributed, but heavily skewed to low values, these values are overrepresented in any weighted conditional probability calculation of two variables, even if the predictor variable is completely independent. Taking this into account, the difference of each weighted arithmetic mean posterior to the respective reference posterior was measured using 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. Since the posterior distributions and divergence computations are solely based on probabilities, information gain and prediction applicability can be assessed, yet the direction of coherence with the response variable is not given. Thus it is supported by a negative binomial regression model which indicates significant positive or negative coherences of variables with the "planned precaution" indicator. ~~The negative binomial regression was chosen due to the fact that the "planned precaution" indicator consists of ordinal discrete (count) values which are restricted between 1 and 8 and follow an overdispersed Poisson distribution (tested in R 1.1.414, using the packages "logspline" and "fitdistrplus").~~

3 Results and discussion

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

3.1 Psychological indicator distributions

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

(Figure 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 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, respectively. Although the effects are not strongly pronounced, a significant difference to weaker flash floods becomes apparent which might be due to the different (potential) flood impacts. A similar outcome is indicated when comparing the difference between strong flash floods and river floods, yet the results are not significant. Although it has not been tested whether a lack of protection information strategies or other effects lead to a lower coping appraisal for strong flash floods in general, the effects could also be explained by the fact that people do not believe in a high efficiency of precaution measures in case of strong flash floods.

Concerning threat appraisal, the significant lower ratings of people affected by strong flash floods are remarkable, since it could be assumed that severe and damaging events lead to stronger feelings of threat in the first place (Figure 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 happen again 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 to 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, research has shown that there may be increase of severe flash floods in regions which were formerly not perceived as flash flood-prone, highlighting the importance of specific information campaigns in this context. 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 report that a greater impact in terms of daily routine disruption, financial loss and evacuation is associated with significantly worse effects on mental health. In contrast to the "severity" of an event, the type of the event (flash flood or river flood) does not seem to have an effect on burden, since strong flash floods and river floods do not display any significant distribution differences (Figure 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. 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).

3.2 Precaution indicators

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

(Figure 3)

Kommentar [JL31]: References 7, 11

Kommentar [JL32]: Reference 8

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

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 Jensen-Shannon divergence (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, stronger feelings of burden seem to result in a higher precaution motivation. This result is in line with Lindell et al. (2009), who find that often thinking and talking about a hazardous event (earthquakes in that case) is positively correlated with the intention to adapt to the hazard. Our results indicate that this might also be the case for flooding.

The posterior peaks of strong flash floods are less pronounced which is due to the small dataset of 76 observations (Figure 4, 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 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).

(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)

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

(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.

Kommentar [JL33]: Reference 4

3.4 Discussion of the hypotheses

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, 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 strong flash flood event as less likely than people who have been repeatedly affected by river floods. Thus, future disaster risk management in Germany may also take into account that 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 (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.

Kommentar [JL34]: Reference 7

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.

A high level of burden increases the protection motivation instead of affecting it negatively (Figure 5 & Table 2). Except this effect, 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 report 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.

Kommentar [JL35]: References 7, 8

Kommentar [JL36]: Reference 7

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

According to the correlation results, weak coherences (JSDs) as well as high uncertainties, the identified psychological indicators are mainly not suitable for explaining precautionary behaviour (see Figure 4, Figure 5, Table 2 & Table 3). As already mentioned, by applying standardized and established surveys to assess psychological characteristics, the accuracy and validity of the results may be increased. A very diverse and promising future field might also be the application of data mining techniques and the use of alternative data sources to facilitate the psychological profiling and predicting precautionary behaviour by different methods. 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, 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 on 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 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. 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.

Kommentar [JL37]: Reference 7, 11

4 Conclusion

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

Kommentar [JL38]: Reference 2

The study shows that **generally not the flood type, but rather the overall severity of a flood event** leads to stronger mental impacts among affected individuals Except threat appraisal, where people affected by strong flash floods report lower values, strong flash floods and river floods result in higher values for the indicators burden and evasion when compared to weak flash floods. The examination of psychological variables reveals that a **certain indicator such as burden can be derived which is potentially useful in predicting the planned precaution**. Here it is remarkable that **people who report stronger negative feelings indicate a higher motivation to implement private precaution measures in future**. Yet, the overall strength of different variable connections and the predictive power are generally low, which may be partly due to small sample sizes. When combining psychological variables, or items to derive a more robust indicator of mental health, established procedures which are applied in pure psychological studies should be taken into account. Considering the surveys which are used in this study, the predictive validity can potentially be enhanced by combining items, yet, more specific and standardised questions may lead to more robust results. Therefore, standardised psychological assessments

should be considered within follow-up studies. In terms of future development and regarding psychological assessments that are based on publicly available information, further research may also focus on comparisons to established mental health surveys and validity checks to gain knowledge about the usefulness of alternative data sources for predicting individual behaviour. This field of science is rather broad and has already been investigated not only from a scientific perspective. However, useful outcomes may be expected by applying different methods and using different data sources to improve and facilitate information campaigns and damage estimations with regard to flood hazards.

Overall it is indicated that, in particular**, the frequency of remembering an event 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.

Kommentar [JL39]: Reference 2

Competing interests

The authors declare that they have no conflict of interest.

Acknowledgements

This work was developed within the framework of the Research Training Group "Natural Hazards and Risks in a Changing World" (NatRiskChange; GRK 2043/1) funded by the Deutsche Forschungsgemeinschaft (DFG). The surveys were conducted as a joint venture between the GeoForschungsZentrum Potsdam, the Deutsche Rückversicherung AG, Düsseldorf, and the University of Potsdam. The survey on the 2013-flood was conducted in the framework of the research project “Flood 2013” funded by the German Ministry of Education and Research (BMBF; funding contract 13N13017). All survey data are owned by the authors.

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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)	**Statemen**t: 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.

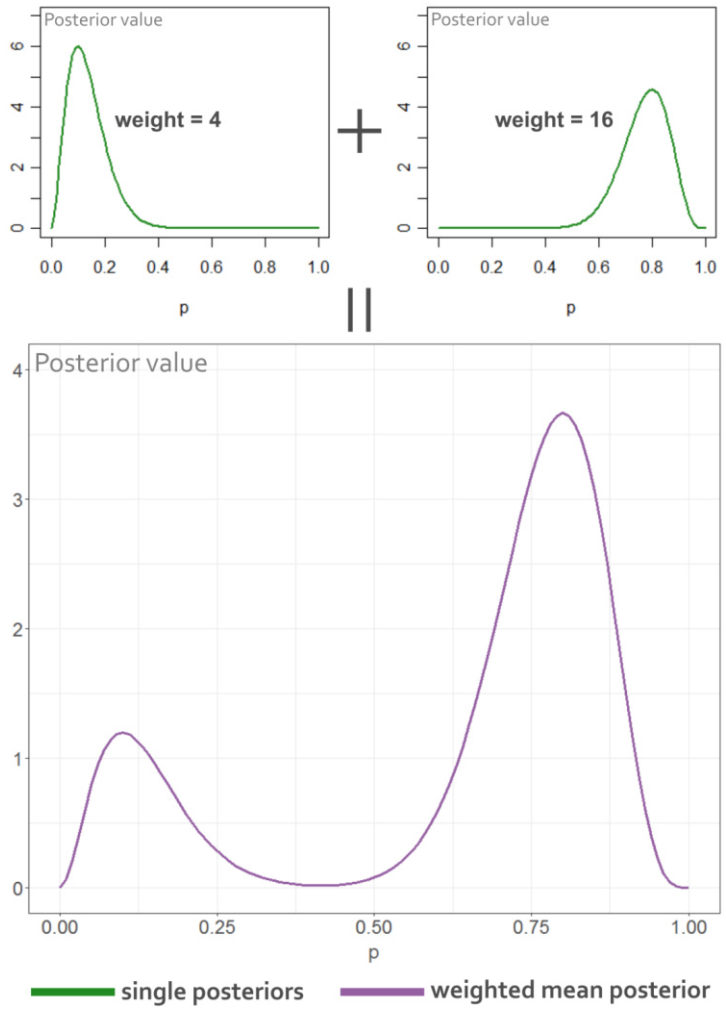

Figure 1: Example graphic explaining the creation of the weighted arithmetic mean posterior. The double peaks are a result of the combination of all posteriors that are calculated for each variable combination. The posteriors are weighted according to the sum of occurrences within the dataset. In this 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%.

Kommentar [JL45]: Reference 6

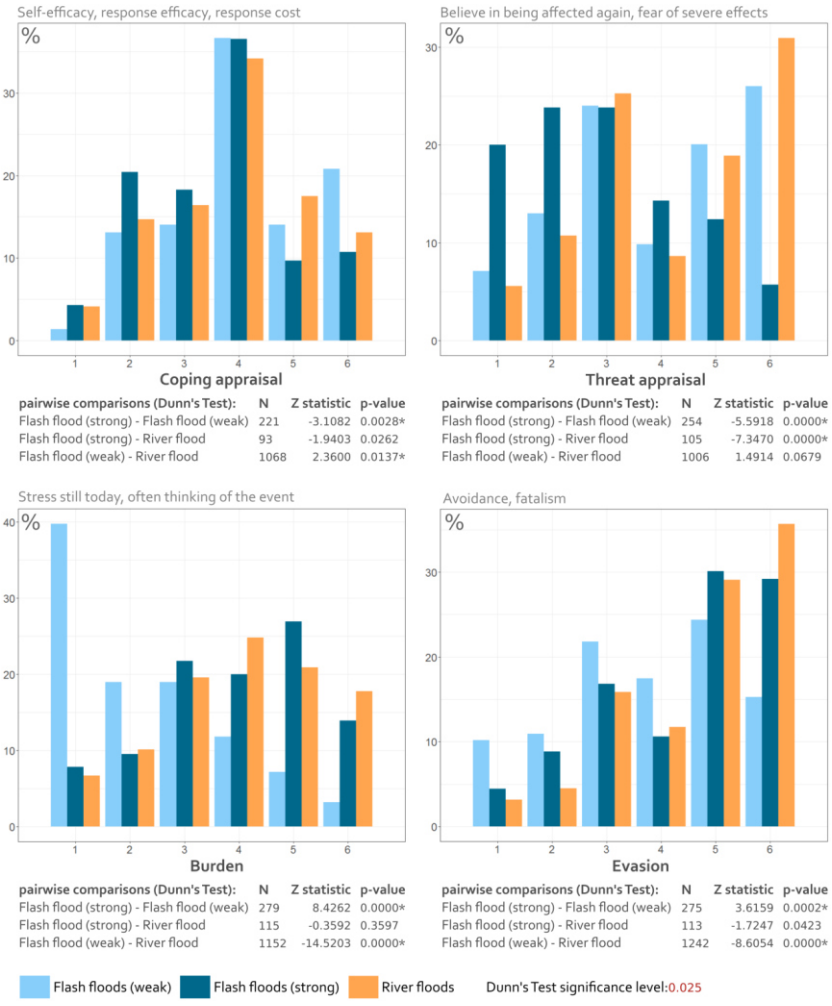

Figure 2: Relative distributions of the combined psychological indicators for each flood type and Dunn's Test results. The results of the Dunn's Test reveal the direction shift of each distribution compared to the other distributions (negative means a shift towards lower values, positive a shift towards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

Kommentar [JL46]: Reference 6

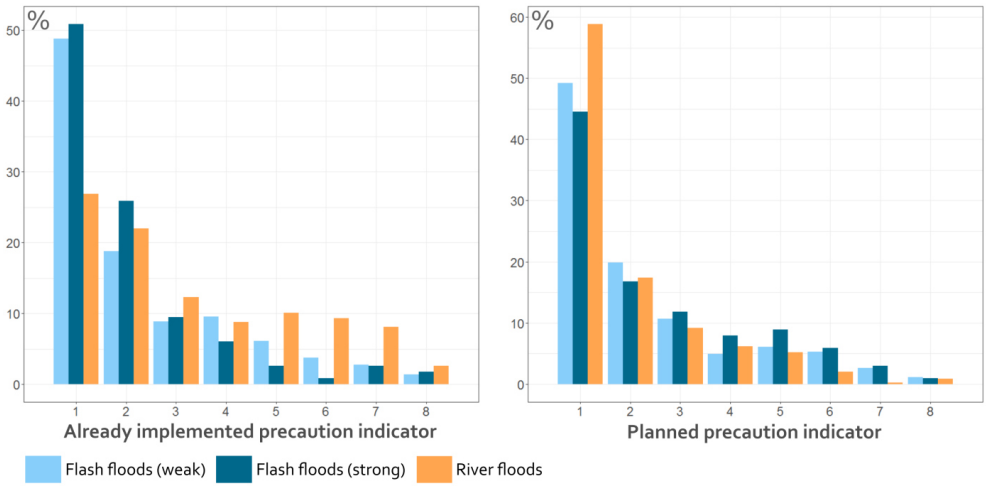

Figure 3: Relative distribution of the already implemented precaution indicator (left) and the planned precaution indicator (right) for weak flash floods (n=293), strong flash floods (n=116) and river floods (n=1366). The X axis represents the implementation of, or the intention to implement effective 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).

Kommentar [JL47]: Reference 6

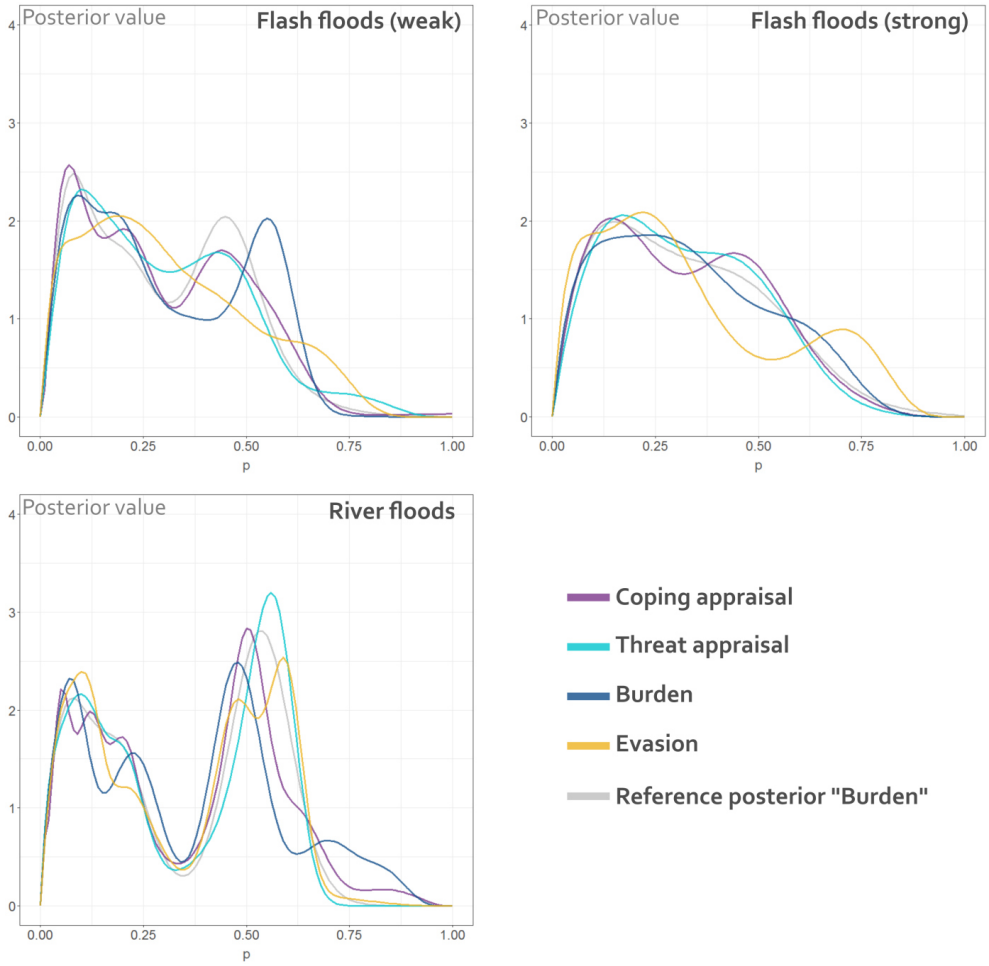

Figure 4: Weighted arithmetic mean of all posterior distributions for the psychological indicators "Coping appraisal", "Threat appraisal", "Burden" and "Evasion", given weak flash floods (top left) strong flash floods (top right) and river floods (bottom left). The reference posterior is shown for "Burden"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

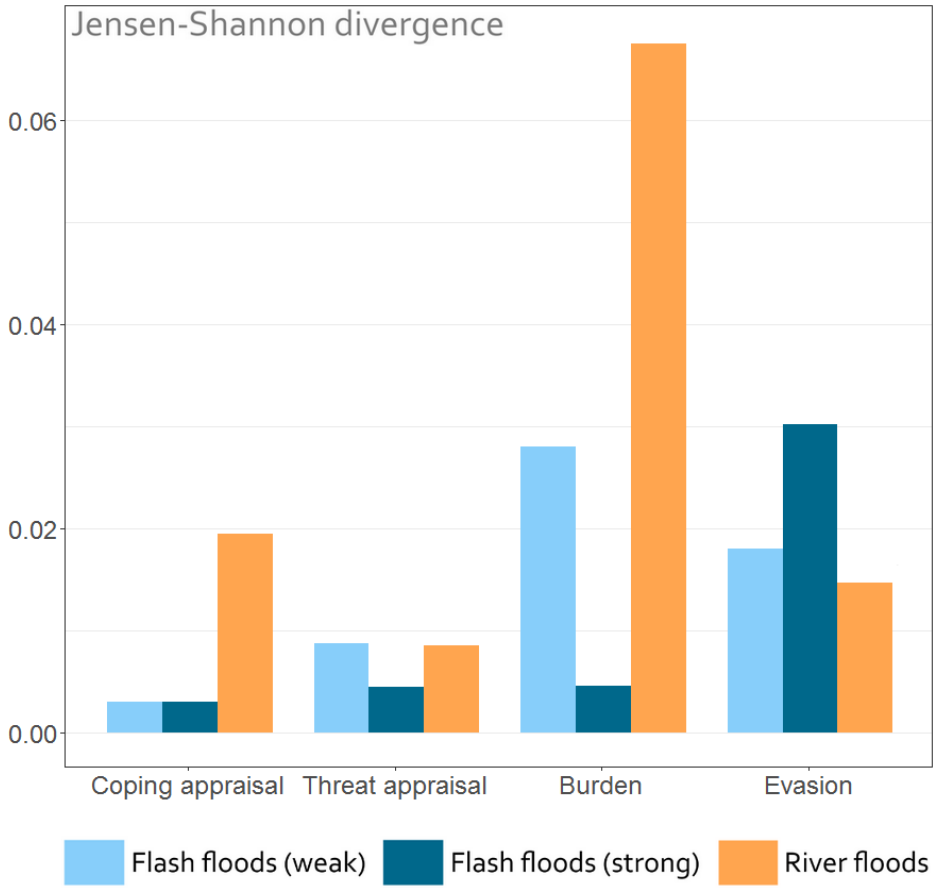

Figure 5: Jensen-Shannon divergence ranking of the psychological indicators. Higher values indicate a higher information gain, if the planned precaution is explained through the particular indicator.

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
Intercept	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.

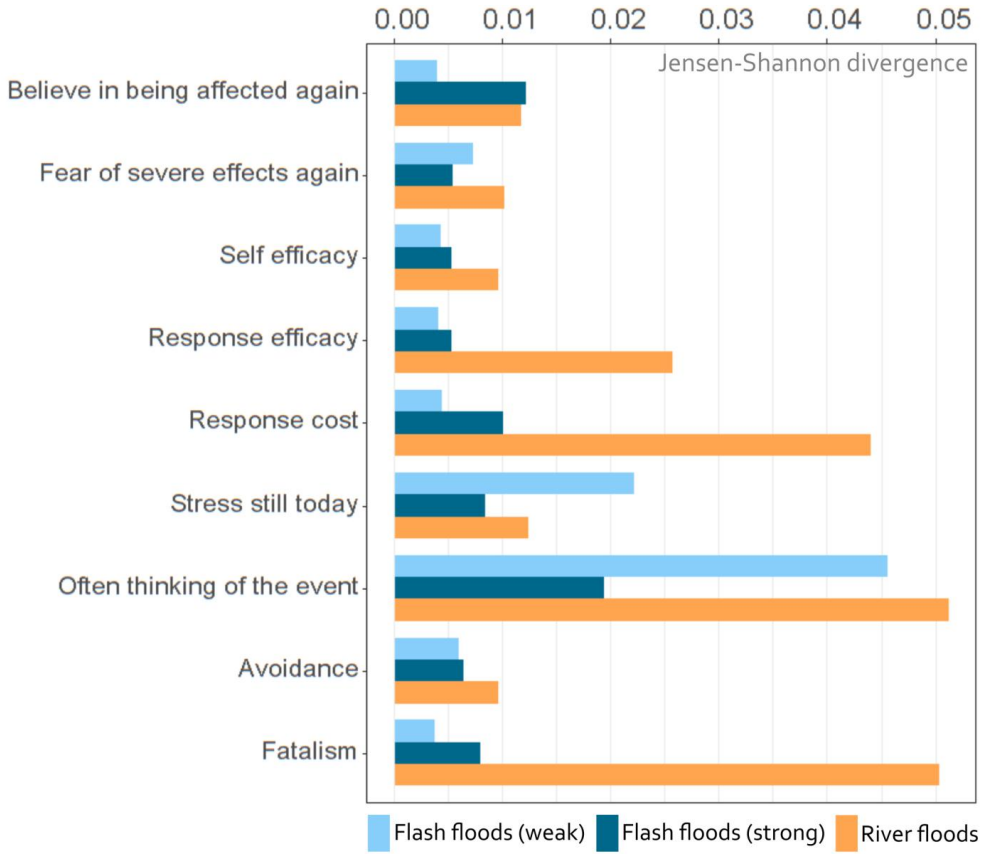

Figure 6: Jensen-Shannon divergence ranking of single psychological variables. Higher values indicate a higher information gain, if the planned precaution is explained through the particular variable.

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
Intercept	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

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

Appendix

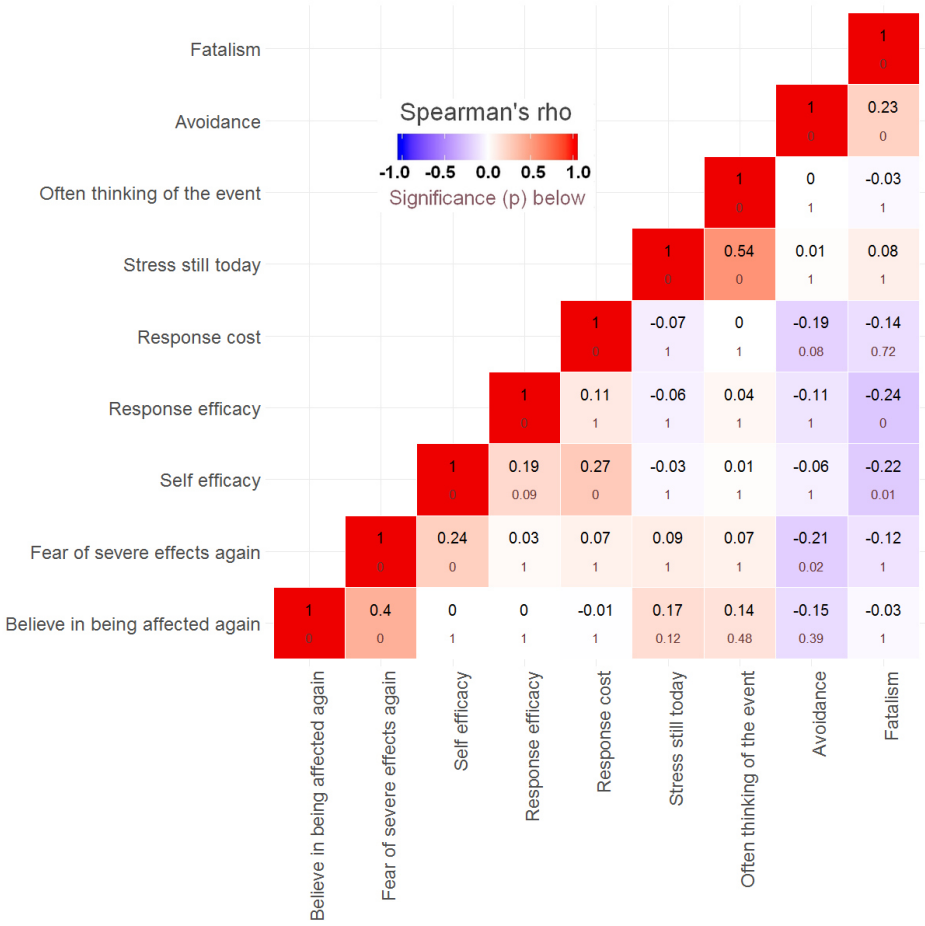

Figure A: Correlation table of single psychological variables for weak flash floods.

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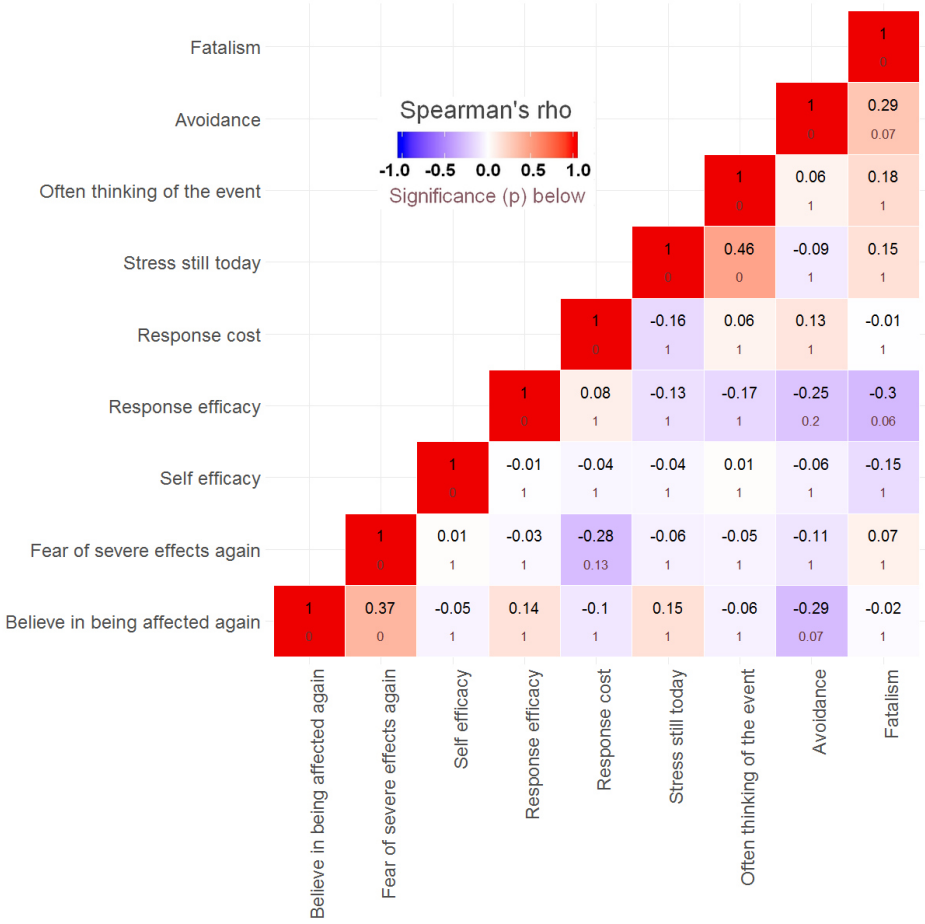


Figure B: Correlation table of single psychological variables for strong flash floods.

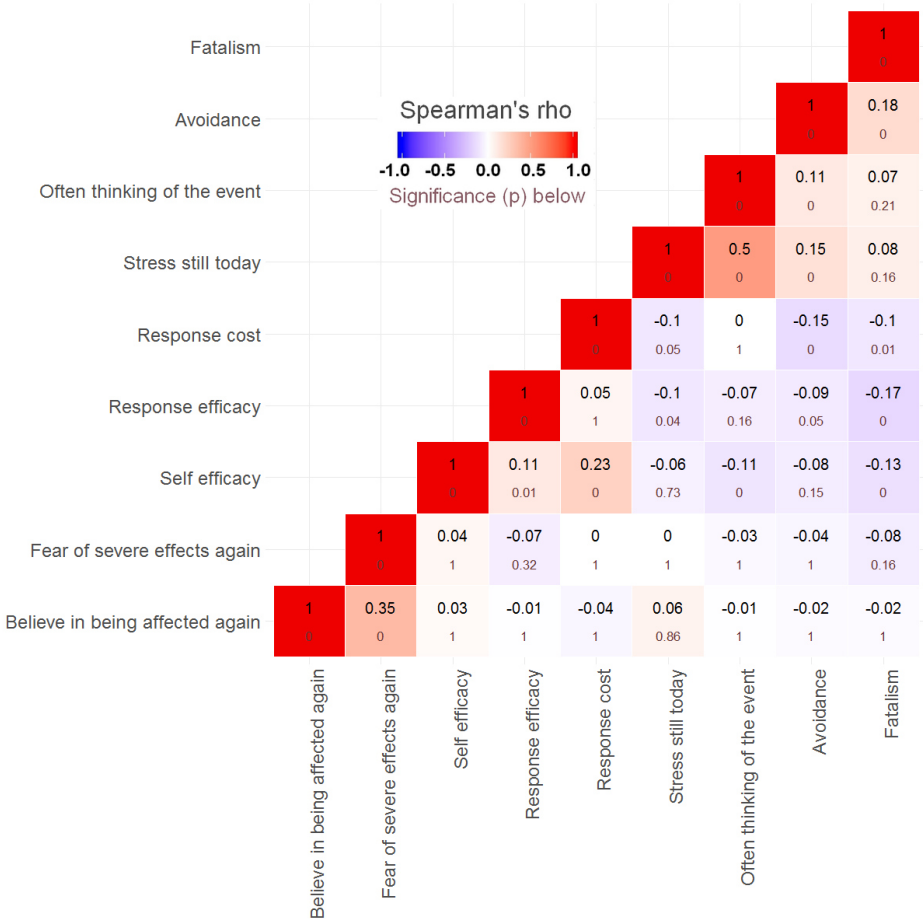
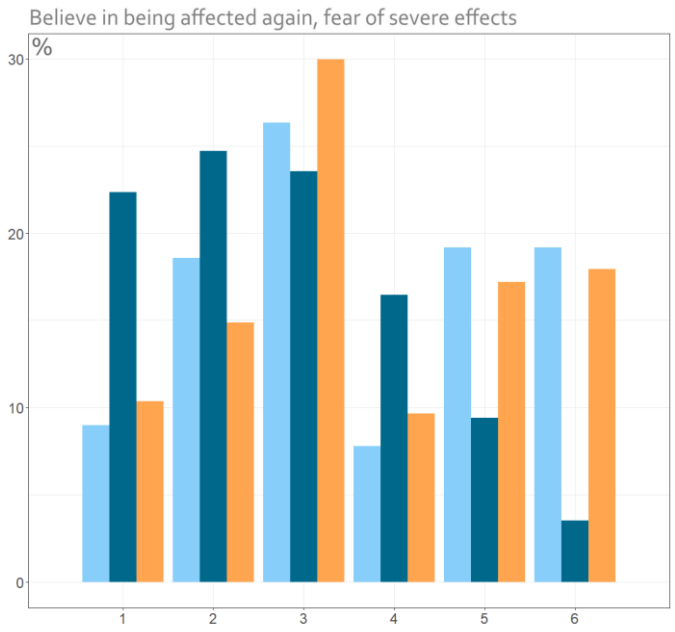


Figure C: Correlation table of single psychological variables for river floods.

5



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

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).

Kommentar [JL48]: Reference 6

Table A: Information about the samples and datasets

Kommentar [JL49]: Reference 9

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

5