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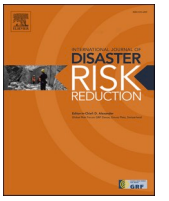

A look into our future under climate change? Adaptation and migration intentions following extreme flooding in the Netherlands

Sem J. Duijndam [a,*], W.J. Wouter Botzen [a,b], Thijs Endendijk [a], Hans de Moel [a], Kymo Slager [c], Jeroen C.J.H. Aerts [a,c]

[a] Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, De Boelelaan 1085, Amsterdam, 1081HV, the Netherlands
[b] Utrecht University School of Economics (U.S.E.), Utrecht University, Kriekenpitplein 21-22, EC Utrecht, Utrecht, 3584, the Netherlands
[c] Deltares, Boussinesqweg 1, 2629 HV, Delft, the Netherlands

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ABSTRACT

Worldwide, increased flood risk from climate change prompts adaptive behavior of households in situ or through migration. Both can be sensible adaptation responses involving tradeoffs, and understanding their drivers is important for effective climate policy. However, in-situ adaptation and migration are rarely studied in combination and research on how extreme events trigger adaptive behavior in originally low-risk areas is lacking. We analyze survey data from residents affected by the extreme summer floods of 2021 in the Netherlands to contribute to fill this research gap. Our results indicate that current low levels of flood-related migration are likely to increase under higher flood risk. Undertaken in-situ adaptation may act as a barrier for further in-situ adaptation or migration behavior. Where in-situ adaptation is mostly related to cognitive factors including risk perceptions, response efficacy and self-efficacy, migration seems to be driven by flood-related emotions. Personal flood experience, mediated by worry, is strongly associated with both types of adaptive behavior. We discuss how policymakers can use these insights to guide and anticipate household adaptation behavior.

1. Introduction

Flooding belongs to the most devastating natural hazards globally, leading to billions of euros in damages annually and disrupting communities and livelihoods [1]. Climate change is expected to increase the frequency and severity of (extreme) flood events in many regions worldwide [2–4]. Adaptive behavior of individuals and households in response to flooding (in-situ adaptation or migration) can play an important role in mitigating flood risk, by reducing vulnerability or exposure to flooding [5,6]. Understanding drivers of adaptive behavior is therefore pivotal. Future extreme flooding, as expected under climate change, may strongly influence adaptive behavior since experience of extremes is known to influence risk perceptions, worry and other behavioral factors driving adaptive decisions [7,8].

A large literature has assessed the drivers of in-situ adaptive behavior, such as flood-proofing buildings [9–12], and a small but growing literature has investigated how flooding may influence migration, elaborated upon in a recent review paper by Duijndam et al. [13]. Empirical studies on the influence of flood extremes on both in-situ adaptation (ISA) and migration are, however, rare (see

* Corresponding author.
E-mail address: sem.duijndam@vu.nl (S.J. Duijndam).

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Buchanan et al. [14] and Schwaller et al. [15] for exceptions). This is partly because of the low likelihood of such events happening in historically low-risk contexts. This lack of understanding limits policymakers in implementing integrative flood risk management policies that consider both adaptation options. To address this research gap, we assess adaptive behavior and its drivers by researching both ISA and migration following a rare extreme flood event. Migration and ISA are both sensible responses for households to adapt to increased flood risk and have distinctive societal and policy implications [13,16–18]. Hence, it is imperative to understand trade-offs between the two choices and to compare their drivers.

We do so by studying a broad spectrum of potential determinants of adaptive behavior (ISA + migration) following the extreme floods that occurred in Belgium, Germany, and the Netherlands in July 2021, taking the lives of more than 200 people and causing billions of euros in damages [19]. The floods were caused by record rainfall and peak discharges of the Rhine and Meuse river systems [20]. For our research, we collected 750 household surveys from areas that were affected by this flood in Limburg, the Netherlands. Data was collected shortly after the flood event. The return period of this event was very low being 1/100 to 1/1000 years [20,21]. The last major flood in the region occurred in 1995 and was constrained to the main Meuse branch, making this event a unique case study of extreme flooding in Europe.

For ISA, we measure intentions for ten ISA measures that can be implemented to flood-proof buildings. We distinguish between low-effort measures (4 measures, e.g. sandbags) and high-effort measures (6 measures, e.g. floor elevation) in our analyses (see Section 2). This was done because they differ in difficulty and costs of implementation as well as effectivity in providing flood protection. Also the decision-making processes for low- and high-effort measures have been found to differ [11,22]. Migration is a more far-reaching decision in response to flood risk than ISA, and is more strongly affected by other drivers than flood risk alone [13,23]. Flood-related migration is also not yet observed at a large scale in many developed countries such as the Netherlands. Therefore, we gauge respondent's migration intentions at present but also under two hypothetical future flood scenarios. These scenarios refer to an increase in frequency of extreme flood events similar to the 2021 flood (see Section 2). In this way, we are able to assess the direct impact of flood risk on migration intentions and how migration behavior may develop under future climate change-induced flood risk.

For our analysis, we developed a conceptual framework based on Protection Motivation Theory (PMT), which is a widely applied and accepted theory to examine in-situ flood adaptation behavior [12,24,25]. To our knowledge, this study is the first to apply a complete PMT framework in the analysis of migration intentions and to test and compare its applicability in this adaptation domain. The PMT framework consists of two components: (1) threat appraisal including perceived likelihood of flooding, perceived damage, and worry about flooding and (2) coping appraisal shaped by response efficacy, self-efficacy and response costs. In our conceptual framework we expand on PMT, based on literature and relevance for the case study at hand, by researching the effects of (1) personal flood experience (of the 2021 flood) [8,10], (2) crowding-out effects (expected flood damage compensation and trust in public flood protection, which can crowd out individual adaptation) [26–28], (3) anticipated regret of not taking protective measures, which can prompt people to adapt as to "buy off" their regret [29,30], (4) previously implemented flood protection measures, which by reducing flood risk can decrease the need for implementing additional adaptation measures [11,16,31], and (5) socio-demographic background. Compensation, trust, regret, and previous adaptation are all relevant factors in the aftermath of extreme flood experience and it is therefore important to assess their role in our research context. In the analysis of migration intentions, we also add life satisfaction as an additional explanatory variable, as people may use migration as a strategy to improve their lives [32].

Empirical (survey) studies on socio-behavioral drivers of in-situ flood adaptation are plentiful, and multiple review and meta-analysis studies on this topic have been published [9–12,33]. These studies show that regarding PMT, coping appraisal is often an important predictor of ISA behavior, while results for threat appraisal are more modest or mixed. Regarding the other factors incorporated in our conceptual framework, previous studies find (1) a positive association of personal flood experience and anticipated regret with the implementation of ISA measures [9,10,29], (2) a negative association of undertaken implementation of ISA measures with further investments in ISA [11], and (3) mixed effects for compensation and trust [26,27,34,33]. Increasingly, studies in their analyses of ISA uptake take into account different types of adaptation and find that drivers of low-effort ISA measures tend to differ from that of high-effort measures [11]. For instance, and relevant for our case study, Osberghaus [8] finds that personal flood experience in most cases has a stronger impact on instigating low-effort behavioral responses than more high-effort structural measures. In contrast to ISA, limited survey research has been done on the socio-behavioral drivers of migration in the context of flood risk. Most empirical research has focused on large-scale, census-type, data in which detailed socio-behavioral factors are not collected [13]. Studies that do collect these data have found mixed results for the impact of flood experience on migration [13], a positive effect of flood-related emotions like worry [35,36], and a negative impact of undertaken ISA implementation [16]. Studies that compare drivers of ISA and migration under flood risk are lacking (US studies by Buchanan et al. [14] and Schwaller et al. [15] are exceptions), which leaves an important knowledge gap on what adaptation choices are more likely under which circumstances, and by whom, and on potential trade-offs between ISA and migration. This study contributes to filling this gap.

To assess the influence of personal experience of extreme flooding on adaptive behavior, we do not only analyze direct effects of experience but also its indirect effects via risk perceptions and worry. Research shows that personal flood experience generally increases risk perceptions (perceived likelihood and perceived consequences of the risk) and worry towards flooding [7,37], while most studies also find that risk perceptions and worry are positively associated with intending or undertaking risk mitigation measures [10,12,33]. Whether rational cognitive assessments (risk perceptions) or emotional reactions (worry) towards risk are most decisive in risk-related behavior has been the subject of a long-standing debate [38–42]. Yet, few studies have assessed empirically how risk perceptions and emotional responses, such as worry, mediate the impact of flood experience on flood adaptive behavior, and those existing studies report mixed results [28,33,43,44]. In our study, we address the call for more research on this topic [33,45], and we are the first to assess and compare this mediation effect for both ISA and migration decisions.

We use regression techniques to analyze drivers of ISA and migration intentions and employ mediation analyses to disentangle the

direct and indirect effects of experience of extreme flooding on adaptive behavior. The remainder of this paper is structured as follows. Section 2 discusses the data and analytical methods employed. Section 3 presents the results of our analyses, and Section 4 provides a discussion and conclusion.

2. Data and methods

2.1. Data collection and sample description

Data for this study were collected from households in the province of Limburg, the Netherlands. The independent research agency Kantar Public distributed letters to 10,143 households in December 2021. These letters contained a request to fill in an online questionnaire. Half of the targeted household addresses were located in areas that were flooded during the July 2021 flood, whereas the other half of the addresses were randomly selected from areas that received an evacuation order during the flood event but that were (officially) not directly flooded. Sampling these latter areas is relevant as these areas were still under threat of flooding which could impact flood adaptive behavior, while it also allows for a useful comparison between flooded and non-flooded areas and households in terms of flood adaptive behavior. In February 2022 reminders were sent to addresses from which no survey response was received yet.

Distributing online questionnaires by postal mail is a useful method to target specific population groups at a local scale, as in our case with flood-affected households. Face-to-face interviews could be employed for this type of research as well, but this was not feasible due to COVID-19 measures still in place during this period. In total, 1513 respondents completed the survey, which is a response rate of 14.9%. This is a higher response rate than generally observed in questionnaires about flood risk distributed by postal mail (e.g. Poussin et al. [46]), which could be due to the high salience of the flood event [47]. However, this may indicate that people who experienced larger emotional and financial impact from flooding are overrepresented, as they would be the most willing to share their experiences in the wake of the flood event. Compared with census statistics from the province of Limburg, males and older people are somewhat overrepresented in our sample. The letters were addressed to all the residents living at the address. As a consequence, if more traditional household customs are followed, this may explain why male and older household members are overrepresented in our sample. Also higher educated respondents are somewhat overrepresented, which perhaps may be explained by higher educated household members (being perceived to) better understand the survey questions and therefore filled in the survey for their household. Endendijk et al. [21] can be consulted for an extensive description of the data collection, sampling, and representativeness. To make sure that the sample distribution for these socio-demographic variables does not bias the results of our analysis, we include gender, age, and education as control variables in all our regression models [11]. Due to the relatively long length of the survey compared with other questionnaire studies, we decided to distribute different topics over different questionnaire versions. Half of the respondents were (randomly) assigned questions about implementation intentions of the individual flood adaptation measures as well response efficacy, self-efficacy, and response costs of the individual measures. As a consequence, half of the total sample is used in our analyses.

2.2. Dependent variables

To measure flood adaptive behavior, we collected data on five low-effort ISA measures, six high-effort ISA measures, and migration. Low-effort measures and high-effort measures differ in difficulty of implementation as well as effectivity in providing flood protection, and it is therefore warranted to analyze them separately [11,48]. The choice and categorization of the low- and high-effort ISA measures is based on a wide collection of previous research [6,46,47,49] as well as applicability to the case study area of Limburg [20,21], and is supported by confirmatory factor analysis (see Section S.2 in Supplementary Information). The low-effort measures included in the survey are the implementation of water-retaining bulkheads, sandbags, a water pump, elevation of valuable possessions, and vehicle relocation to save areas. Because vehicle relocation is dependent on vehicle (car/motor) possession we excluded this measure from our analyses. The six high-effort measures studied include elevation of the floor or entrance level, strengthening the foundation of the house, elevation of electronic devices, implementation of a water-resistant floor, implementation of water-resistant walls, and implementation of other water-resistant building materials.

For each of the measures, respondents were first asked whether they had already implemented the measure. Respondents who had not yet implemented the measure were consequently asked about their intentions to implement the measure in the coming 5 years. We focus on ISA intentions instead of implementation because implementation often influences risk perceptions and possibly also coping appraisals [9], leading to reversed causality where behavior influences attitudes and not vice versa. Intentions were gauged using the following 5 answer options: (1) Certainly not (0% chance), unlikely (1%–39% chance), not unlikely, not likely (40%–60% chance), likely (61%–99% chance), certainly (100% chance). By asking for probabilities of implementation we get richer insights into people's intentions compared to simple yes/no questions. Probabilities are combined with qualitative Likert-scale indicators to improve comprehension of these numerical values [16].

The dependent variables aim to measure intentions to undertake low-effort and high-effort ISA as well as migration. Because intentions of multiple low-effort and high-effort ISA measures are measured, intentions for these measures are grouped to calculate average intentions for both types of ISA measures. Because intentions are not asked for measures that the respondent has already implemented, this has to be accounted for when constructing the dependent variables [11]. This is done by calculating average intention probabilities for measures that the respondent provides intentions for, excluding measures already implemented and missing responses:

$$ISA\ intentions_{Low-effort,i} = \frac{\sum_i Intention\ probability\ of ISA_{Low-effort}\ measures_i}{Nr.\ of\ ISA_{Low-effort}\ measures\ for\ which\ intentions\ are\ provided_i}$$

$$ISA\ intentions_{High-effort,i} = \frac{\sum_i Intention\ probability\ of ISA_{High-effort}\ measures_i}{Nr.\ of\ ISA_{High-effort}\ measures\ for\ which\ intentions\ are\ provided_i}$$

The values of the dependent variables range between 0 and 100, where 0 indicates that the respondent mentions to certainly not implement any of the measures the respondent provided intentions for, and 100 indicates that the respondent mentions to certainly implement all these measures. To calculate the probabilities for the individual measures, we use the average value for answer options that display a range of percentages (i.e. 20 for the answer option 'unlikely (1%–39% probability)', 50 for 'not unlikely, not likely (40%–60% probability)', and 80 for 'likely (61%–99% probability)'. Naturally, respondents who did not provide intentions for any of the measures in the group are excluded from the analysis. We use the continuous percentage values for our main regression models as this allows for a more meaningful interpretation of the regression results. Nevertheless, as a robustness check we also perform all analyses using ordinal answer option values (running from 1 to 5), following the same logic of the calculation of the dependent variable and leading to very similar results (see Table S4). Our approach in estimating the dependent variables for ISA measures is similar to that of Noll et al. [11], except that they use a binary approach to measure intentions. Although measure-specific information is lost, major

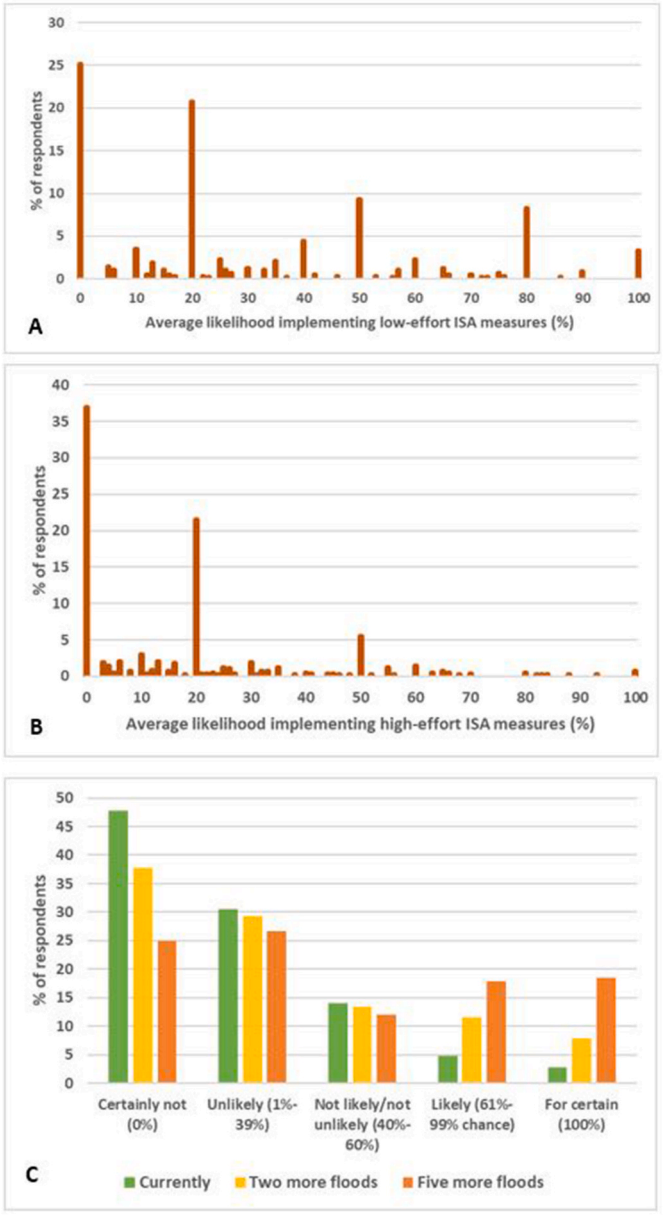

Fig. 1. Distributions of the dependent variables, (A) low-effort ISA intentions, (B) high-effort ISA intentions, and (C) migration intentions (currently and under flood scenarios).

benefits of this approach compared to other strategies to analyze intentions for multiple measures include that it (1) ensures consistency across respondents by accounting for the fact that the number of measures already undertaken varies across respondents, and (2) incorporates information about the number of measures planned to be implemented [11].

Migration intentions for the coming 5 years were asked in the same manner as ISA intentions, with migration being defined as a permanent move to another place of residence (we do not specify whether migration is internal or international). However, we also measure respondent's migration intentions under two hypothetical future flood scenarios. The reason for this is that migration is a more far-reaching decision in response to flood risk than ISA, and is more strongly affected by other drivers than flood risk alone. Migration due to flooding is also not observed yet at a large scale in developed countries such as the Netherlands. Hence, by assessing migration intentions under flood scenarios we get a better idea of how floods directly impact migration intentions and how increased flood risk under climate change may shape migration behavior in the future. The first scenario asks for respondent's migration intentions would *on average* two more extreme flood events like the one of July 2021 occur before 2050. The second scenario asks for migration intentions would *on average* five more extreme flood events like the one of July 2021 occur before 2050. Intentions in these scenarios are measured on the same 5-point scale as for the other behavioral intentions described above. We acknowledge that the flood return periods in the scenarios are not realistic to occur before 2050 [20,50]. Nevertheless, to obtain a more realistic picture of how people in the future may behave would flood risk strongly increase under climate change, it is important to make the scenarios salient and 'imaginable' for respondents. If instead we would refer to such risk occurring in 2100 or 2150, for instance, this would be beyond their lifetime and results may reflect that instead of the increased flood risk. Such an approach for presenting hypothetical scenarios has also been done in previous studies [16,51,52]. Because the answer options are identical for migration intentions in the coming 5 years and for migration intentions under the two hypothetical flood scenarios, we pool the responses to these three migration questions into a single dependent variable for our analyses [16].

Fig. 1 displays descriptive statistics of the dependent variables for both ISA and migration intentions. It shows that, on average, respondents have higher intentions to implement low-effort than high-effort measures. This is not surprising given that low-effort measures are cheaper and easier to implement. Migration intentions are currently low but increase considerably under the scenarios of increased flood risk, with around 35% of respondents reporting that it is likely or certain that they would migrate under the highest flood risk scenario.

2.3. Independent variables

Table S1 in the Supplementary Information shows all variables included in the analyses, the associated survey questions, coding and descriptive statistics. To analyze drivers of household adaptive behavior to flooding we utilize an extended Protection Motivation Theory (PMT) framework as the conceptual framework. PMT is widely applied in research on ISA to flooding in which it is generally found to have substantial predictive power [6,9,11]. In our survey design all six core elements of PMT are incorporated. However, due to a relatively large number of missing values for perceived damage, which is measured as expected monetary damage under future flooding, we omit perceived damage from the main regression specifications and instead incorporate it in additional regressions shown in Section S.3 of the Supplementary Information. The coping appraisal variables 'response efficacy', 'self-efficacy', and 'perceived response costs' are asked per individual ISA measure as well as for migration. Because in our analysis of ISA we combine measures into low-effort and high-effort measures, we calculate average values for the coping appraisals for each respondent (using values for measures for which intentions are provided, excluding undertaken measures), in accordance with previous literature [11]. We expand on the PMT framework by incorporating additional variables that are expected to be relevant in explaining adaptive behavior. Due to the large number of potential variables to be included, we selected variables based on their relevance to the case study at hand, and previous literature that have found them to be influential determinants of adaptive behavior. Besides the variables included in the analyses presented in the main text, we also assessed the influence of household income and risk aversion (Table S7), which according to previous studies may be associated with flood adaptation behavior [10,53]. Due to considerable missing values for these variables and results being insignificant, we decided not to include them in our main specifications. Excluding these variables did not significantly affect the main findings. We include life satisfaction only in the regression models of migration, because for ISA there is no clear theoretical ground for including it as an explanatory variable and results were insignificant (results not shown here).

2.4. Analytical strategy

2.4.1. Regression analysis

To research determinants of low-effort and high-effort ISA intentions we employ the following two linear regression models:

$$Y_{Low-effort,i} = \beta_0 + \beta_1 L_{1i} + \ldots + \beta_k L_{ki} + \varepsilon_i, i = 1, \ldots, N$$

$$Y_{High-effort,i} = \beta_0 + \beta_1 H_{1i} + \ldots + \beta_k H_{ki} + \varepsilon_i, i = 1, \ldots, N$$

where $Y_{Low-effort}$ and $Y_{High-effort}$ represent intentions for undertaking low-effort and high-effort ISA measures, and L and H the respective explanatory and control variables.

To assess determinants of migration intentions, we pool the responses to the three migration intention questions into a single dependent variable. By pooling the data, we now deal with clustered data with the three responses being clustered within individual respondents [16]. To properly account for the clustered nature of the data, we employ the following random effects linear regression model:

$$Y_{Migration,ri} = \beta_0 + \beta_1 F_{1r} + \beta_2 F_{2r} + \beta_1 M_{1i} + \ldots + \beta_k M_{ki} + \mu_i + \varepsilon_{ri}$$

with responses (r) nested within individuals (i). F_1 and F_2 represent dummies for the two flood scenarios showing the effect of increased flood risk on migration intentions ($Y_{Migration,ri}$). M represents the explanatory and control variables. For all employed regression models we conducted a variance inflation factor (VIF) analysis, which showed no problematic signs of multi-collinearity (all VIFs <2).

2.4.2. Mediation analysis

To obtain a more complete understanding of how personal experience of the 2021 extreme flood has shaped respondent's adaptive behavioral intentions we conduct mediation analyses. Besides a direct effect on intentions, personal flood experience may indirectly influence intentions by increasing flood risk perceptions (perceived likelihood and perceived damage) and worry about flooding [7,10,12,37]. Because we control for perceived likelihood and worry in the main specifications, these variables may potentially mediate part of the effect of flood experience in the regressions shown in Table 1. For the mediation analysis, we follow the KHB (Karlson, Holm, and Breen) method which provides an unbiased decomposition of total effects into direct and indirect effects for both linear and non-linear regression models [54,55]. In the mediation analyses, we include the same variables as in the main models in Table 1. We also conduct two additional mediation analyses (Tables S8-S9). In the first, we include perceived damage as a mediator variable, conducted separately due to a high number of missing values for this variable. In the second, we substitute personal experience of home flooding with stress experienced during the flood, which is a more emotional appraisal of how respondents have experienced the flood and may influence adaptive behavior differently compared to objective flood experience [28,56].

Table 1
Determinants of ISA and permanent migration intentions.

Variable	Low-effort ISA	High-effort ISA	Migration
Undergone high-effort measures	0.163	−2.299***	−2.357*
	(1.100)	(0.823)	(1.365)
Undergone low-effort measures	3.867***	−0.356	−0.201
	(1.459)	(0.858)	(1.495)
Perceived likelihood	3.416***	2.299**	0.676
	(1.151)	(0.948)	(1.631)
Worry	3.873***	2.150**	8.158***
	(1.252)	(0.877)	(1.723)
Response efficacy	8.195***	4.878***	1.085
	(1.234)	(0.912)	(1.271)
Self-efficacy (difficulty)	−3.631**	−2.891**	1.021
	(1.463)	(1.197)	(1.609)
Response costs	−0.440	2.263**	0.389
	(1.410)	(1.068)	(1.597)
Home flooded	15.284***	9.861***	17.802***
	(2.889)	(2.190)	(3.710)
Compensation	−1.895	−4.998**	1.136
	(3.474)	(2.377)	(3.987)
Trust in public flood protection	−0.992	−1.304	−0.844
	(1.584)	(1.147)	(1.672)
Anticipated regret	2.663**	1.037	2.137*
	(1.064)	(0.736)	(1.239)
Gender	3.168	3.253*	3.055
	(2.708)	(1.948)	(3.269)
Age	0.011	−0.036	−0.112
	(0.092)	(0.076)	(0.100)
Higher education	−5.787**	−0.268	0.717
	(2.493)	(1.816)	(3.190)
Home owner	4.799	1.563	0.881
	(3.780)	(2.802)	(5.537)
Life satisfaction			−5.403***
			(1.142)
Flood 2 scenario			10.768***
			(1.474)
Flood 5 scenario			25.346***
			(1.699)
Constant	−17.938*	−8.223	22.841
	(10.780)	(8.743)	(18.163)
N observations	401	430	871
N individuals	401	430	294
R^2	0.383	0.263	0.365
F-statistic or Wald χ^2	23.19***	8.65***	619.49***

Note: Robust standard errors in parentheses. The levels of significance are: *p < 0.1, **p < 0.05, ***p < 0.01.

3. Results

3.1. Drivers of in-situ adaptation and migration

Several elements of the PMT framework are significantly associated with adaptive behavioral intentions (Table 1), although there are differences between the type of adaptation (low-effort and high-effort ISA as well as migration). Looking into threat appraisal, perceived likelihood of flooding is significantly positively associated with both low-effort and high-effort ISA intentions, while the association with migration intentions is insignificant. Perceived damage, estimated in a separate regression model due to considerable missing values (Section 2), is only weakly significant for low-effort ISA and insignificant for high-effort ISA and migration (see Table S5). On the other hand, worry is significantly associated with all three adaptation types and most strongly with migration. A one-point increase in the 5-point Likert scale of worry is associated with an 8% point increase in the reported likelihood of migration, compared to 2 and 3% points for low- and high-effort ISA, respectively. Hence, for ISA both cognitive appraisals (perceived likelihood and to some extent perceived damage) and emotional attitudes towards the risk (worry) are important drivers, while for migration emotions seems decisive. A reason for this difference could be that ISA is tailored specifically towards reducing flood risk, causing rational appraisals of the flood risk to be more strongly weighted in the decision [57]. In contrast, migration is a much more emotional decision than ISA because someone has to leave behind their home and neighborhood. Moreover, migration depends on many more dimensions than flood risk alone [23]. Therefore, only strong emotional reactions towards flood risk may trigger migration decisions. This is consistent with Haney [36], one of the sparse studies assessing migration intentions in the wake of extreme flood experience, who also finds that worry is among the strongest predictors of migration intentions.

The effects of the coping appraisal variables are mixed. Response efficacy is a strong and significant predictor of both low-effort and high-effort ISA intentions. This positive relationship is also generally found in past empirical research [12,56]. Self-efficacy is also a significant determinant of both low-effort and high-effort ISA intentions, likewise corresponding with previous literature [11,12]. Response costs is insignificant for low-effort ISA and a weak positive relationship is found for high-effort ISA, which is unexpected. A reason for this could be that people who intend to adopt high-effort measures have looked up information about them and found out that these measures are very expensive, which they often are indeed [5,58]. This 'awareness effect' may be pronounced in our study case due to the recent experience of extreme flooding [59], with information retrieval being very recent. Coping appraisal is not a strong predictor of migration intentions. None of the three coping appraisal variables are significant. A reason for this lack of significance could partly be the complexity of the migration decision, with migration destination also playing a role, making elements such as effectiveness and costs more difficult to appraise [23]. Furthermore, reducing flood risk may again not be the only or main reason for migration, which could explain the lower influence of response effectiveness for migration.

People can adapt in multiple ways to flood risk, but assessing **trade-offs** between adaptation options and potentials for multi-adaptive behavior is rarely done in the literature. In our sample, 58% of respondents had already implemented at least one low-effort ISA measure whereas 38% had implemented at least one high-effort ISA measure. Prior implementation of high-effort ISA is significantly negatively associated with high effort ISA intentions as well as with migration. This can be explained by the fact that high-effort ISA are costly and can provide permanent and substantial protection against flooding. Hence, this may reduce the need and willingness to undertake additional costly protection measures. Furthermore, ISA means an investment in the current place of residence, which may make migration a less attractive option [31]. Effects for prior low-effort ISA are positive and significant for low-effort ISA intentions. Low-effort ISA measures are often not fully protective against flood risk and people may feel the need to implement more of them in order to be sufficiently protected.

Crowding out of adaptive behavior may occur when people feel that they are protected against flood risk by the government or other actors, either through public protection (e.g. large levee systems) or financial compensation (e.g. government disaster funds). Our results show some evidence of crowding out effects. Trust in public flood protection is negatively associated with ISA intentions and migration, although results are insignificant. Respondents who expect to be fully compensated in case of flood damage (e.g. by the government or insurers) are significantly less likely to intend high-effort ISA while we find no significant effect for low-effort ISA. High-effort ISA are more expensive than low-effort ISA and previous research suggests that expectations of generous compensation may prevent people from taking expensive measures [47]. Furthermore, in contrast to ISA, there may be other motives for undertaking migration than reducing flood risk for which compensation would be obtained, which can explain the insignificant effect of expected compensation on migration. Anticipated regret (i.e. anticipated regret of not having taken flood protection measures if a future flood would occur) has a consistently positive impact on adaptation intentions. A reason why regret is most significant for low-effort ISA intentions may be that they are relatively cheap and easy to implement, making it an easy way for people to buy off their regret [29].

Because it is important to take into account the complexity and distinctiveness of **migration** compared to ISA, we extended the PMT framework for our analysis of migration intentions with some additional variables. Firstly, migration intentions are not only measured as they are presently but also under two flood scenarios. This is done only for migration and not for ISA because migration decisions often reflect more than just a desire to reduce flood risk, making it more difficult to disentangle the direct effect of flood risk. Furthermore, environmental migration is not yet observed at a large scale in many higher-income countries, including the Netherlands, and it is relevant to know if this may change in the future. Results indicate that migration intentions strongly increase under scenarios of increased flood risk. The average reported likelihood of migration increases with, respectively, 11 and 25% points would, on average, another two or five extreme flood events like the one of Summer 2021 occur before 2050. This shows that although migration due to flooding is currently very low in developed countries like the Netherlands, this may increase considerably when flood risk increases under future climate change. Research in the developing country context of coastal Vietnam found a similar increase in migration intentions under scenarios of increased flood risk, indicating that this finding may be more universal [16]. Nevertheless, scenarios of flood risk were framed differently in this study due to the regular occurrence of flooding in Vietnam. Secondly, life

satisfaction is included as an additional explanatory variable. As expected, life satisfaction is strongly and significantly negatively associated with migration intentions. People who are less satisfied with their current life can employ migration as a strategy to change and improve upon this [32]. Life satisfaction is often associated with people's experienced (positive and negative) day-to-day emotions [60], and these findings in addition to the findings for worry may further indicate the important role of emotions in migration decisions.

3.2. Disentangling the direct and indirect effects of extreme flood experience on in-situ adaptation and migration

28% of our sample personally experienced home flooding during the 2021 flood, whereas 72% did not. The regression results in Table 1 show that personal experience of the extreme 2021 flood is strongly and significantly associated with higher intentions for both low-effort and high-effort ISA as well as migration. The reported likelihood of implementing these three types of measures is between 10 and 18% points higher for people who experienced home flooding during the 2021 flood, compared to those who did not. The larger effect size for low-effort ISA compared to high-effort ISA is consistent with earlier findings [8]. When substituting experience of home flooding with stress experienced during the flood, a more emotional appraisal of people's flood experience, we find a similar highly significant positive effect on adaptation intentions with again the largest effect sizes for low-effort ISA and migration (Table S6, models I-III; not assessed together due to correlation of 0.45). Having experienced flooding in one's town but not in one's home is not associated with higher adaptation intentions compared to people whose town was not flooded (Table S6, models IV-VI), indicating that only direct personal experience seems to be important. People whose home was not flooded may have less negative feelings associated with the flood experience, which may reduce the perceived need for adaptation [61].

Personal experience of home flooding may have also impacted adaptive behavior by increasing risk perceptions (perceived likelihood and perceived damage) and emotional attitudes towards flooding (worry), which were controlled for in the regression analyses. To investigate these additional pathways we conduct mediation analyses. The mediation analyses (Table 2) show that experience has a substantial and significant indirect positive effect on adaptive behavioral intentions via influencing perceived likelihood and worry. By accounting for these indirect effects, the total effect of flood experience on adaptation intentions is a 12 to 24% point increase in the average reported likelihood (compared to 10 to 18% points when excluding indirect effects, as reported earlier). The indirect effect thus accounts for 15 to 24% of the total effect. The indirect effect can largely be attributed to the impact of extreme flood experience on worry. This holds for both types of ISA as well as for migration, and most strongly for the latter. The indirect effect via perceived likelihood is always insignificant. When including perceived damage as an additional mediator variable (Table S8), the total effect of experience becomes somewhat larger, although the mediation via perceived damage is insignificant in all cases. Substituting experience of home flooding with stress experienced during the flood leads to very similar results compared to the main findings (Table S9). Because we analyze migration intentions using a random effects panel model, the interpretation of the mediation analysis is more challenging due to conflating within- and between-effects [62]. Therefore, we also conducted the mediation analyses separately for the three migration scenarios (i.e. current intentions and under the two flood scenarios). The results (Table S10) show a similar picture as the results in Table 1. Flood experience has a large and significant impact on migration intentions, with the effect being larger under the scenarios of increased flood risk. The indirect effect is substantial and significant for each of the three scenarios, and goes almost completely via worry.

The results of the mediation analyses seem to indicate that emotions (worry) are more decisive in guiding behavior after extreme flood events compared to cognitive risk assessments by the individual (risk perceptions), which corresponds with the risk-as-feelings hypothesis proposed by Loewenstein et al. [39]. The mediating role of flood-related emotions in the impact of flood experience on behavior is in line with empirical studies by Terpstra [28] and Demski et al. [63] who focus on, respectively, in-situ flood adaptation and more general climate-friendly behavior. However, in contrast to our study, Terpstra [28] finds that perceived likelihood of flooding is a more important mediator than flood-related emotions. A reason for this difference could be that the study by Terpstra surveyed respondents in areas for which the experience of severe flooding was at least 10 years ago. It could be that after a long period of time after the flood experience emotions become less influential compared to cognitive perceptions, but longitudinal research on this topic would have to study this further [64,65].

4. Discussion and conclusion

In the Summer of 2021, parts of the Netherlands, Germany and Belgium were hit by one of the worst floods in Europe in decades.

Table 2
Decomposition of the total effects of flood experience on adaptive behavior into direct and indirect effects.

	Low-effort ISA	High-effort ISA	Migration
Total effect	18.680*** (2.637)	11.577*** (1.950)	23.523*** (3.311)
Direct effect	15.284*** (2.756)	9.861*** (2.047)	17.802*** (3.451)
Indirect effect	3.400*** (1.107)	1.717** (0.764)	5.721*** (1.215)
Via perc. Likelihood	*0.599 (0.488)*	*0.177 (0.294)*	*0.040 (0.100)*
Via worry	*2.797*** (0.975)*	*1.540** (0.690)*	*5.681*** (1.222)*
Mediation %	18.18%	14.83%	24.32%
Via perc. Likelihood	*3.21%*	*1.53%*	*0.17%*
Via worry	*14.98%*	*13.30%*	*24.15%*
Observations	401	430	871

Note: Standard errors in parentheses. The levels of significance are: *p < 0.1, **p < 0.05, ***p < 0.01.

This created a unique setting for understanding drivers of ISA and migration after extreme flooding, the latter being expected to occur more frequently under climate change. Both adaptation options can be effective responses for households to protect themselves against future flood risk. However, they have distinctive societal and policy implications, making it important to compare their drivers and assess potential trade-offs between the two adaptation choices, for which studies are currently lacking. We study drivers of ISA and migration intentions in the aftermath of the 2021 floods and disentangle the role of the extreme flood experience herein. For this purpose we use unique household survey data collected in the Dutch province of Limburg, which we analyze by employing regression techniques and mediation analyses.

Using an extended PMT conceptual framework, we find that the more rational elements of PMT including risk perceptions and coping appraisal are strong predictors of ISA but not of migration intentions. Worry, on the other hand, which is an emotional attitude towards the risk, is much stronger associated with migration intentions than with ISA intentions. This may be explained by the fact that leaving behind your home is a more emotional decision than ISA which may outplay rational assessments of risk. We further find that life satisfaction, which is also often associated with people's emotional state [60], is strongly associated with migration intentions as well. The high explanatory power of PMT in ISA behavior is consistent with findings of previous literature [33]. We are the first to apply a complete PMT framework in the analysis of migration intentions and our results suggest that PMT with its focus on a more rational appraisal of flood risk may be less appropriate for understanding flood-related migration behavior. However, a limitation of our approach is that it provides a snapshot in time, in a specific research context. It could be that the specific circumstances in which the survey was held (in the Netherlands, just after a unique flood event) has influenced our results, and for this reason we have to be cautious with generalizations. Further empirical research is, therefore, needed to confirm if this finding also applies in other contexts.

Literature review studies provide mixed findings for the influence of flood experience on migration [13], whereas they report positive, but often modest, effects for ISA [9,10,33]. However, knowledge about the impact of extreme flood events is lacking in historically low-risk contexts like the Netherlands, which witnessed no recent flood experience comparable with the 2021 Summer floods. Our findings show that recent personal experience of a low-probability extreme flood event is statistically significantly associated with higher ISA and migration intentions, alone increasing the average reported likelihood of adaptation with 12–24% points. Mediation analysis shows that 13%–24% of this total effect of flood experience can be attributed to indirect effects, through increased worry about flooding. This illustrates that experience of (recent) extreme flood events can be a major force in shaping flood adaptive behavior, which has important implications for flood adaptation under climate change. It also reinforces the importance of emotional consequences after flood experiences and the added value of incorporating this as indirect effects in analyses of flood experience impacts.

Our future under climate change requires a thorough understanding of the myriad of different adaptation pathways that can help protect us against increased natural hazard risk, of their effectiveness but also their drivers. Within this context, household adaptation plays an important role [5,6]. This study contributes to the need to understand how the experience of (historically) low-probability extreme events shape such household adaptation efforts, and our approach can form the basis for future cross-sectional studies that can research what factors drive migration and ISA in different contexts. To address the limitations of cross-sectional research, longitudinal research can build on this by assessing these developments over time, how intentions translate to actual behavior, and how (the lack of) additional flood experiences may spur or limit adaptation [53]. Although not the focus of the present study, it would also be useful for future research to compare the findings in the Netherlands with those in Belgium and Germany, which were also hard hit by the 2021 floods and, in contrast to the Netherlands, suffered many casualties [66]. Another implication of our study for future research is the importance of worry as opposed to more rational factors like risk perceptions and coping appraisal in people's migration decision-making. Besides implications for survey research on migration and flooding in which emotional factors like worry are rarely included (Haney [36] and Ekoh et al. [35] are exceptions), this also has implications for migration modeling research which often builds on 'rational' economic theories, with agent-based models (ABMs) being the most prominently used models [67]. The tendency to neglect emotions in ABMs is more widespread than in the migration literature alone [68,69], but novel approaches show that it can be done [70,71] and surveys can play an important role in parametrizing such models. Finally, our study has focused on the comparison between ISA and migration behavior, by applying an analytical framework (extended PMT) that is hypothesized to be of merit in studying both ISA and migration decisions in response to flood risk. Due to this focus, our framework does not incorporate several dimensions that previous research has found to be important in migration decision-making specifically, including economic, social, political, cultural and demographic factors [23,72,73]. Future research can extend on our work by considering these factors. Furthermore, research on the concept of climate mobilities, as part of the wider mobilities literature [74], shows that mobility (or immobility) under climate change is complex and multifaceted, and is often a gradual decision that is embedded in already existing patterns of movement [75,76]. It would be an interesting avenue for future research to incorporate such an approach when studying the impact of extreme flood events on (im)mobility and ISA, as this can help to better understand the influence of these events in the wider context in which adaptation decision-making unfolds.

Our results have several important implications for policy. First, we find that migration intentions increase strongly under scenarios of increased flood risk under climate change. Policymakers should plan for this potentially increased flux of migration, while they can also reduce the need for relocation by implementing effective flood risk management policies that limit these risks. In terms of the Dutch policy context, planning is currently focused on flood protection of land and people with no specific out-migration policies being in place, and only some exceptional (local) buyouts have occurred of people in floodplains to create space for nature-based solutions [77]. On a national scale, flood-related migration and managed retreat policies are studied solely in an exploratory manner at the strategic level (e.g. Ref. [78,79]). Second, we find evidence that there are trade-offs between ISA and migration; people who implemented high-effort ISA are less inclined to migrate. Hence, besides increasing flood protection, limiting migration may be another reason for governments to stimulate the uptake of high-effort ISA by households. The PMT components response efficacy and

self-efficacy are important predictors of high-effort ISA. Governments can help enhance these factors by informing people about the effectiveness of flood protection measures and by facilitating the ease of implementation. Related to this, more frequent future flooding under climate change implies more compensation payments for affected households, while we find that compensation crowds out more effective and expensive (high-effort) ISA behavior. Policy solutions for this could be improved building code requirements, ISA subsidies, and linking compensation payments with building back better after extreme flood events. Finally, our findings illustrate the importance of mental and emotional consequences of flood events. Worry is a significant predictor of all adaptation measures but most strongly so for migration. A substantial part of this effect comes from increased worry due to personal flood experience. Consequently, policymakers could put more efforts in offering emotional assistance after extreme flood events. First and foremost to reduce the negative and often traumatic consequences that extreme flood events can have on people's lives [80,81], while it can also be utilized to reduce migration pressures if migration is deemed undesirable.

Statements and declarations

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Author contributions

Sem Duijndam: Conceptualization (lead); data curation (supporting); formal analysis (lead); investigation (equal); methodology (lead); visualization (lead); writing–original draft (lead); writing–review and editing (lead). Wouter Botzen: Conceptualization (supporting); formal analysis (supporting); investigation (supporting); methodology (supporting); writing–original draft (supporting); writing–review and editing (supporting). Thijs Endendijk: Conceptualization (supporting); data curation (lead); investigation (equal); writing–review and editing (supporting). Hans de Moel: Conceptualization (supporting); investigation (supporting); writing–review and editing (supporting). Kymo Slager: Data curation (supporting); investigation (equal); writing–review and editing (supporting). Jeroen Aerts: Conceptualization (supporting); formal analysis (supporting); investigation (supporting); methodology (supporting); writing–original draft (supporting); writing–review and editing (supporting); Funding acquisition (lead).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

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References

[1] B. Merz, G. Blöschl, S. Vorogushyn, F. Dottori, J.C.J.H. Aerts, P. Bates, M. Bertola, M. Kemter, H. Kreibich, U. Lall, E. Macdonald, Causes, impacts and patterns of disastrous river floods, Nat. Rev. Earth Environ. 2 (9) (2021) 592–609, https://doi.org/10.1038/s43017-021-00195-3.
[2] Y. Hirabayashi, R. Mahendran, S. Koirala, L. Konoshima, D. Yamazaki, S. Watanabe, H. Kim, S. Kanae, Global flood risk under climate change, Nat. Clim. Change 3 (9) (2013) 816–821, https://doi.org/10.1038/nclimate1911.
[3] S. Vitousek, P.L. Barnard, C.H. Fletcher, N. Frazer, L. Erikson, C.D. Storlazzi, Doubling of coastal flooding frequency within decades due to sea-level rise, Sci. Rep. 7 (1) (2017) 1399, https://doi.org/10.1038/s41598-017-01362-7.
[4] H.C. Winsemius, J.C.J.H. Aerts, L.P.H. van Beek, M.F.P. Bierkens, A. Bouwman, B. Jongman, J.C.J. Kwadijk, W. Ligtvoet, P.L. Lucas, D.P. van Vuuren, P.J. Ward, Global drivers of future river flood risk, Nat. Clim. Change 6 (4) (2016) 381–385, https://doi.org/10.1038/nclimate2893.
[5] M. Attems, T. Thaler, E. Genovese, S. Fuchs, Implementation of property-level flood risk adaptation (PLFRA) measures: choices and decisions, WIREs Water 7 (1) (2020), https://doi.org/10.1002/wat2.1404.
[6] C. Kuhlicke, S. Seebauer, P. Hudson, C. Begg, P. Bubeck, C. Dittmer, T. Grothmann, A. Heidenreich, H. Kreibich, D.F. Lorenz, T. Masson, J. Reiter, T. Thaler, A. H. Thieken, S. Bamberg, The behavioral turn in flood risk management, its assumptions and potential implications, WIREs Water 7 (3) (2020), https://doi.org/10.1002/wat2.1418.
[7] E. Lechowska, What determines flood risk perception? A review of factors of flood risk perception and relations between its basic elements, Nat. Hazards 94 (3) (2018) 1341–1366, https://doi.org/10.1007/s11069-018-3480-z.

[8] D. Osberghaus, The effect of flood experience on household mitigation—evidence from longitudinal and insurance data, Global Environ. Change 43 (2017) 126–136, https://doi.org/10.1016/j.gloenvcha.2017.02.003.
[9] P. Bubeck, W.J.W. Botzen, J.C.J.H. Aerts, A review of risk perceptions and other factors that influence flood mitigation behavior: review of flood risk perceptions, Risk Anal. 32 (9) (2012) 1481–1495, https://doi.org/10.1111/j.1539-6924.2011.01783.x.
[10] J. Koerth, A.T. Vafeidis, J. Hinkel, Household-level coastal adaptation and its drivers: a systematic case study review, Risk Anal. 37 (4) (2017) 629–646, https://doi.org/10.1111/risa.12663.
[11] B. Noll, T. Filatova, A. Need, A. Taberna, Contextualizing cross-national patterns in household climate change adaptation, Nat. Clim. Change 12 (1) (2022) 30–35, https://doi.org/10.1038/s41558-021-01222-3.
[12] A.M. van Valkengoed, L. Steg, Meta-analyses of factors motivating climate change adaptation behaviour, Nat. Clim. Change 9 (2) (2019) 158–163, https://doi.org/10.1038/s41558-018-0371-y.
[13] S.J. Duijndam, W.J.W. Botzen, L.C. Hagedoorn, J.C.J.H. Aerts, Anticipating sea-level rise and human migration: a review of empirical evidence and avenues for future research, WIREs Climate Change 13 (1) (2022), https://doi.org/10.1002/wcc.747.
[14] M.K. Buchanan, M. Oppenheimer, A. Parris, Values, bias, and stressors affect intentions to adapt to coastal flood risk: a case study from New York city, Weather, Climate, and Society 11 (4) (2019) 809–821, https://doi.org/10.1175/WCAS-D-18- 0082.s1.
[15] N.L. Schwaller, S. Kelmenson, T.K. BenDor, D. Spurlock, From abstract futures to concrete experiences: how does political ideology interact with threat perception to affect climate adaptation decisions? Environ. Sci. Pol. 112 (2020) 440–452, https://doi.org/10.1016/j.envsci.2020.07.001.
[16] S.J. Duijndam, W.J.W. Botzen, L.C. Hagedoorn, P. Bubeck, T. Haer, M. Pham, J.C.J.H. Aerts, Drivers of migration intentions in coastal Vietnam under increased flood risk from sea level rise, Climatic Change 176 (2) (2023) 12, https://doi.org/10.1007/s10584-022-03479-9.
[17] L.M. Hunter, J.K. Luna, R.M. Norton, Environmental dimensions of migration, Annu. Rev. Sociol. 41 (1) (2015) 377–397, https://doi.org/10.1146/annurev-soc-073014-112223.
[18] N.L. Schwaller, T.K. BenDor, Differential residential perspectives on in situ protection and retreat as strategies for climate adaptation, Climatic Change 167 (3–4) (2021) 42, https://doi.org/10.1007/s10584-021-03055-7.
[19] M. Dietze, R. Bell, U. Ozturk, K.L. Cook, C. Andermann, A.R. Beer, B. Damm, A. Lucia, F.S. Fauer, K.M. Nissen, T. Sieg, A.H. Thieken, More than heavy rain turning into fast-flowing water – a landscape perspective on the 2021 Eifel floods, Nat. Hazards Earth Syst. Sci. 22 (6) (2022) 1845–1856, https://doi.org/10.5194/nhess-22-1845-2022.
[20] ENW, Hoogwater 2021: Feiten en Duiding, 2021, pp. 1–158. Expertise Netwerk Waterveiligheid (ENW), https://www.enwinfo.nl/publicaties/.
[21] T. Endendijk, W.J.W. Botzen, H.D. Moel, J.C.J.H. Aerts, S.J. Duijndam, K. Slager, B. Kolen, M. Kok, Experience from the 2021 floods in The Netherlands: household survey results on impacts and responses [preprint]. Preprints. https://doi.org/10.22541/essoar.167591077.75588565/v1, 2023.
[22] J. Koerth, A.T. Vafeidis, J. Hinkel, H. Sterr, What motivates coastal households to adapt pro-actively to sea-level rise and increasing flood risk? Reg. Environ. Change 13 (4) (2013) 897–909, https://doi.org/10.1007/s10113-012-0399-x.
[23] R. Black, W.N. Adger, N.W. Arnell, S. Dercon, A. Geddes, D. Thomas, The effect of environmental change on human migration, Global Environ. Change 21 (2011), https://doi.org/10.1016/j.gloenvcha.2011.10.001. S3-S11.
[24] R.W. Rogers, A protection motivation theory of fear appeals and attitude change, J. Psychol. 91 (1) (1975) 93–114, https://doi.org/10.1080/00223980.1975.9915803.
[25] S. Rufat, M. Madruga de Brito, A. Fekete, E. Comby, P.J. Robinson, I. Armaș, W.J.W. Botzen, C. Kuhlicke, Surveying the surveyors to address risk perception and adaptive behaviour cross-study comparability, Nat. Hazards Earth Syst. Sci. 22 (2022) 2655–2672, https://doi.org/10.5194/nhess-22-2655-2022.
[26] S. Hanger, J. Linnerooth-Bayer, S. Surminski, C. Nenciu-Posner, A. Lorant, R. Ionescu, A. Patt, Insurance, public assistance, and household flood risk reduction: a comparative study of Austria, england, and Romania: insurance, public assistance, and household flood risk reduction, Risk Anal. 38 (4) (2018) 680–693, https://doi.org/10.1111/risa.12881.
[27] C. Kousky, E.O. Michel-Kerjan, P.A. Raschky, Does federal disaster assistance crowd out flood insurance? J. Environ. Econ. Manag. 87 (2018) 150–164, https://doi.org/10.1016/j.jeem.2017.05.010.
[28] T. Terpstra, Emotions, trust, and perceived risk: affective and cognitive routes to flood preparedness behavior: affective and cognitive routes to flood preparedness behavior, Risk Anal. 31 (10) (2011) 1658–1675, https://doi.org/10.1111/j.1539-6924.2011.01616.x.
[29] M. Kesternich, D. Osberghaus, W.J.W. Botzen, The Intention-Behavior Gap in Climate Change Adaptation, ZEW-Centre for European Economic Research Discussion Paper, 2022, 22-055.
[30] P.J. Robinson, W.J.W. Botzen, Flood insurance demand and probability weighting: the influences of regret, worry, locus of control and the threshold of concern heuristic, Water Resources and Economics 30 (2020), 100144, https://doi.org/10.1016/j.wre.2019.100144.
[31] M. Radhakrishnan, H.Q. Nguyen, B. Gersonius, A. Pathirana, K.Q. Vinh, R.M. Ashley, C. Zevenbergen, Coping capacities for improving adaptation pathways for flood protection in Can Tho, Vietnam, Climatic Change 149 (1) (2018) 29–41, https://doi.org/10.1007/s10584-017-1999-8.
[32] V. Otrachshenko, O. Popova, Life (dis)satisfaction and the intention to migrate: evidence from central and eastern Europe, J. Soc. Econ. 48 (2014) 40–49, https://doi.org/10.1016/j.socec.2013.09.008.
[33] S. Bamberg, T. Masson, K. Brewitt, N. Nemetschek, Threat, coping and flood prevention – a meta-analysis, J. Environ. Psychol. 54 (2017) 116–126, https://doi.org/10.1016/j.jenvp.2017.08.001.
[34] P. Babcicky, S. Seebauer, Unpacking Protection Motivation Theory: evidence for a separate protective and non-protective route in private flood mitigation behavior, J. Risk Res. 22 (12) (2019) 1503–1521, https://doi.org/10.1080/13669877.2018.1485175.
[35] S.S. Ekoh, L. Teron, I. Ajibade, S. Kristiansen, Flood risk perceptions and future migration intentions of Lagos residents, Int. J. Disaster Risk Reduc. 83 (2022), 103399, https://doi.org/10.1016/j.ijdrr.2022.103399.
[36] T.J. Haney, Move out or dig in? Risk awareness and mobility plans in disaster-affected communities, J. Contingencies Crisis Manag. 27 (3) (2019) 224–236, https://doi.org/10.1111/1468-5973.12253.
[37] P. Hudson, W.J.W. Botzen, J. Poussin, J.C.J.H. Aerts, Impacts of flooding and flood preparedness on subjective well-being: a monetisation of the tangible and intangible impacts, J. Happiness Stud. 20 (2) (2019) 665–682, https://doi.org/10.1007/s10902-017-9916-4.
[38] H. Kunreuther, R.J. Meyer, E. Michel-Kerjan, Red, The Future of Risk Management, University of Pennsylvania Press, 2019.
[39] G.F. Loewenstein, E.U. Weber, C.K. Hsee, N. Welch, Risk as feelings, Psychol. Bull. 127 (2) (2001) 267–286, https://doi.org/10.1037/0033-2909.127.2.267.
[40] S. Rufat, W.J.W. Botzen, Drivers and dimensions of flood risk perceptions: revealing an implicit selection bias and lessons for communication policies, Global Environ. Change 73 (2022), 102465, https://doi.org/10.1016/j.gloenvcha.2022.102465.
[41] P. Slovic, E. Peters, Risk perception and affect, Curr. Dir. Psychol. Sci. 15 (6) (2006) 322–325, https://doi.org/10.1111/j.1467-8721.2006.00461.x.
[42] A.M. van Valkengoed, W. Abrahamse, L. Steg, To select effective interventions for pro-environmental behaviour change, we need to consider determinants of behaviour, Nat. Human Behav. 6 (11) (2022) 1482–1492, https://doi.org/10.1038/s41562-022-01473-w.
[43] R. Dittrich, A. Wreford, A. Butler, D. Moran, The impact of flood action groups on the uptake of flood management measures, Climatic Change 138 (3–4) (2016) 471–489, https://doi.org/10.1007/s10584-016-1752-8.
[44] C.A. Ogunbode, G. Böhm, S.B. Capstick, C. Demski, A. Spence, N. Tausch, The resilience paradox: flooding experience, coping and climate change mitigation intentions, Clim. Pol. 19 (6) (2019) 703–715, https://doi.org/10.1080/14693062.2018.1560242.
[45] M.R. Sisco, The effects of weather experiences on climate change attitudes and behaviors, Curr. Opin. Environ. Sustain. 52 (2021) 111–117, https://doi.org/10.1016/j.cosust.2021.09.001.
[46] J.K. Poussin, W.J.W. Botzen, J.C.J.H. Aerts, Factors of influence on flood damage mitigation behaviour by households, Environ. Sci. Pol. 40 (2014) 69–77, https://doi.org/10.1016/j.envsci.2014.01.013.
[47] W. Botzen, H. Kunreuther, J. Czajkowski, H. Moel, Adoption of individual flood damage mitigation measures in New York city: an extension of protection motivation theory, Risk Anal. 39 (10) (2019) 2143–2159, https://doi.org/10.1111/risa.13318.

[48] S. Seebauer, P. Babcicky, The sources of belief in personal capability: antecedents of self-efficacy in private adaptation to flood risk, Risk Anal. 40 (10) (2020) 1967–1982, https://doi.org/10.1111/risa.13531.
[49] P. Bubeck, W.J.W. Botzen, H. Kreibich, J.C.J.H. Aerts, Detailed insights into the influence of flood-coping appraisals on mitigation behaviour, Global Environ. Change 23 (5) (2013) 1327–1338, https://doi.org/10.1016/j.gloenvcha.2013.05.009.
[50] F. Kreienkamp, S.Y. Philip, J.S. Tradowsky, S.F. Kew, P. Lorenz, J. Arrighi, A. Belleflamme, T. Bettmann, S. Caluwaerts, S.C. Chan, others, Rapid Attribution of Heavy Rainfall Events Leading to the Severe Flooding in Western Europe during July 2021, World Weather Atribution, 2021.
[51] R. Brouwer, B.D. Tinh, T.H. Tuan, K. Magnussen, S. Navrud, Modeling demand for catastrophic flood risk insurance in coastal zones in Vietnam using choice experiments, Environ. Dev. Econ. 19 (2) (2014) 228–249, https://doi.org/10.1017/S1355770X13000405.
[52] P.J. Robinson, W.J.W. Botzen, Economic experiments, hypothetical surveys and market data studies of insurance demand against low-probability/high-impact risks: a systematic review of designs, theoretical insights and determinants of demand, J. Econ. Surv. 33 (5) (2019) 1493–1530, https://doi.org/10.1111/joes.12332.
[53] P. Hudson, W.J. Wouter Botzen, J. Czajkowski, H. Kreibich, Moral hazard in natural disaster insurance markets: empirical evidence from Germany and the United States, Land Econ. 93 (2) (2017) 179–208, https://doi.org/10.3368/le.93.2.179.
[54] R. Breen, K.B. Karlson, A. Holm, Total, direct, and indirect effects in logit and probit models, Socio. Methods Res. 42 (2) (2013) 164–191, https://doi.org/10.1177/0049124113494572.
[55] R. Breen, K. Bernt Karlson, A. Holm, A note on a reformulation of the KHB method, Socio. Methods Res. 50 (2) (2021) 901–912, https://doi.org/10.1177/0049124118789717.
[56] R.S. Wilson, A. Herziger, M. Hamilton, J.S. Brooks, From incremental to transformative adaptation in individual responses to climate-exacerbated hazards, Nat. Clim. Change 10 (3) (2020) 200–208, https://doi.org/10.1038/s41558-020-0691-6.
[57] T. Haer, W.J.W. Botzen, H. de Moel, J.C.J.H. Aerts, Integrating household risk mitigation behavior in flood risk analysis: an agent-based model approach: integrating household risk mitigation, Risk Anal. 37 (10) (2017) 1977–1992, https://doi.org/10.1111/risa.12740.
[58] J. Aerts, A review of cost estimates for flood adaptation, Water 10 (11) (2018) 1646, https://doi.org/10.3390/w10111646.
[59] R.J. Griffin, S. Dunwoody, Z.J. Yang, Linking risk messages to information seeking and processing, Annals of the International Communication Association 36 (1) (2013) 323–362, https://doi.org/10.1080/23808985.2013.11679138.
[60] P. Kuppens, A. Realo, E. Diener, The role of positive and negative emotions in life satisfaction judgment across nations, J. Pers. Soc. Psychol. 95 (1) (2008) 66–75, https://doi.org/10.1037/0022-3514.95.1.66.
[61] G. Wachinger, O. Renn, C. Begg, C. Kuhlicke, The risk perception paradox-implications for governance and communication of natural hazards: the risk perception paradox, Risk Anal. 33 (6) (2013) 1049–1065, https://doi.org/10.1111/j.1539-6924.2012.01942.x.
[62] D. Tofighi, S.G. West, D.P. MacKinnon, Multilevel mediation analysis: the effects of omitted variables in the 1-1-1 model: multilevel mediation, Br. J. Math. Stat. Psychol. 66 (2) (2013) 290–307, https://doi.org/10.1111/j.2044-8317.2012.02051.x.
[63] C. Demski, S. Capstick, N. Pidgeon, R.G. Sposato, A. Spence, Experience of extreme weather affects climate change mitigation and adaptation responses, Climatic Change 140 (2) (2017) 149–164, https://doi.org/10.1007/s10584-016-1837-4.
[64] P. Bubeck, L. Berghäuser, P. Hudson, A.H. Thieken, Using panel data to understand the dynamics of human behavior in response to flooding, Risk Anal. 40 (11) (2020) 2340–2359, https://doi.org/10.1111/risa.13548.
[65] E. Mondino, A. Scolobig, M. Borga, G. Di Baldassarre, Longitudinal Survey Data for Diversifying Temporal Dynamics in Flood Risk Modelling [Preprint]. Risk Assessment, Mitigation and Adaptation Strategies, Socioeconomic and Management Aspects, 2021, https://doi.org/10.5194/nhess-2021-88.
[66] F. Lehmkuhl, H. Schüttrumpf, J. Schwarzbauer, C. Brüll, M. Dietze, P. Letmathe, C. Völker, H. Hollert, Assessment of the 2021 summer flood in central Europe, Environ. Sci. Eur. 34 (1) (2022), https://doi.org/10.1186/s12302-022-00685-1, 107, s12302-022-00685-1.
[67] A. Klabunde, F. Willekens, Decision-making in agent-based models of migration: state of the art and challenges, Eur. J. Popul. 32 (1) (2016) 73–97, https://doi.org/10.1007/s10680-015-9362-0.
[68] J. Groeneveld, B. Müller, C.M. Buchmann, G. Dressler, C. Guo, N. Hase, F. Hoffmann, F. John, C. Klassert, T. Lauf, V. Liebelt, H. Nolzen, N. Pannicke, J. Schulze, H. Weise, N. Schwarz, Theoretical foundations of human decision-making in agent-based land use models – a review, Environ. Model. Software 87 (2017) 39–48, https://doi.org/10.1016/j.envsoft.2016.10.008.
[69] R. Huber, M. Bakker, A. Balmann, T. Berger, M. Bithell, C. Brown, A. Grêt-Regamey, H. Xiong, Q.B. Le, G. Mack, P. Meyfroidt, J. Millington, B. Müller, J. G. Polhill, Z. Sun, R. Seidl, C. Troost, R. Finger, Representation of decision-making in European agricultural agent-based models, Agric. Syst. 167 (2018) 143–160, https://doi.org/10.1016/j.agsy.2018.09.007.
[70] I. Wolf, T. Schröder, J. Neumann, G. de Haan, Changing minds about electric cars: an empirically grounded agent-based modeling approach, Technol. Forecast. Soc. Change 94 (2015) 269–285, https://doi.org/10.1016/j.techfore.2014.10.010.
[71] K. Zia, A. Ferscha, An agent-based model of crowd evacuation: combining individual, social and technological aspects, in: Proceedings of the 2020 ACM SIGSIM Conference on Principles of Advanced Discrete Simulation, 2020, pp. 129–140, https://doi.org/10.1145/3384441.3395973.
[72] M.E. Hauer, E. Fussell, V. Mueller, M. Burkett, M. Call, K. Abel, R. McLeman, D. Wrathall, Sea-level rise and human migration, Nat. Rev. Earth Environ. 1 (1) (2020) 28–39, https://doi.org/10.1038/s43017-019-0002-9.
[73] S. Seebauer, C. Winkler, Should I stay or should I go? Factors in household decisions for or against relocation from a flood risk area, Global Environ. Change 60 (2020), 102018, https://doi.org/10.1016/j.gloenvcha.2019.102018.
[74] M. Sheller, J. Urry, The new mobilities paradigm, Environ. Plann. 38 (2006) 207–226, https://doi.org/10.1068/a37268.
[75] I. Boas, H. Wiegel, C. Farbotko, J. Warner, M. Sheller, Climate mobilities: migration, im/mobilities and mobility regimes in a changing climate, J. Ethnic Migrat. Stud. 48 (14) (2022) 365–3379, https://doi.org/10.1080/1369183X.2022.2066264.
[76] G. Cundill, C. Singh, W.N. Adger, R. Safra de Campos, K. Vincent, M. Tebboth, A. Maharjan, Toward a climate mobilities research agenda: intersectionality, immobility, and policy responses, Global Environ. Change 69 (2021), 102315, https://doi.org/10.1016/j.gloenvcha.2021.102315.
[77] S. Van Alphen, Room for the river: innovation, or tradition? The case of the noordwaard, in: C. Hein (Ed.), Adaptive Strategies for Water Heritage, Springer International Publishing, 2020, pp. 308–323, https://doi.org/10.1007/978-3-030-00268-8_16.
[78] M. Haasnoot, F. Diermanse, J. Kwadijk, R. de Winter, G. Winter, Strategieën voor adaptatie aan hoge en versnelde zeespiegelstijging: Een verkenning, Deltares Delft, The Netherlands, 2019.
[79] X. Olsthoorn, P. Van Der Werff, L.M. Bouwer, D. Huitema, Neo-Atlantis: The Netherlands under a 5-m sea level rise, Climatic Change 91 (1–2) (2008) 103–122, https://doi.org/10.1007/s10584-008-9423-z.
[80] K. Hayes, G. Blashki, J. Wiseman, S. Burke, L. Reifels, Climate change and mental health: risks, impacts and priority actions, Int. J. Ment. Health Syst. 12 (1) (2018) 28, https://doi.org/10.1186/s13033-018-0210-6.
[81] K. Walker-Springett, C. Butler, W.N. Adger, Wellbeing in the aftermath of floods, Health Place 43 (2017) 66–74, https://doi.org/10.1016/j.healthplace.2016.11.005.