It's not just risk—It's responsibility: changing drivers of home flood protection

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Abstract

Private household adaptation is a critical yet underutilised element of flood resilience. Property-level measures might reduce up to 80% of damage if adopted in a timely manner. However, socio-behavioural factors serve as constraints to adaptation. Among them, a lack of risk awareness is considered a primary barrier. Empirical research typically relies on a single snapshot of data, implicitly assuming these factors are stable over time. Using two nationally representative survey waves from the Netherlands (2020 and 2023), we examine how factors of household intentions to implement six structural home-flood protection measures change. Counterintuitively, despite a major flood in 2021, by 2023, we find lower adaptation intentions (an 11.6 percentage point decline), lower flood worry, and reduced self-efficacy. This coincided with a marked shift in perceived responsibility for flood risk toward the government (12 percentage point increase), while the actual uptake of private adaptation measures remained low (2-5%). Regression analysis reveals a reordering of behavioural drivers: in 2020, prior flood experience, self-efficacy, and flood worry were the most prominent predictors, though perception of responsibility was also consistently significant. By 2023, perception of responsibility emerges as the strongest and most consistent predictor of intention to act (odds ratio 2.4), while the importance of flood experience and worry declines. These results suggest that household drivers for adaptation are volatile, relying not only on a household's experience and capacity to act but also on the understanding of shared responsibility between citizens and the state. "Empowering" households only with information about potential flood risk, while rationally sound, may not result in an intention to protect homes. Climate adaptation policy design that embraces private action must therefore include: clear responsibility framing, support for skills development and the efficacy of measures, targeted financial incentives, and adaptability to account for evolving public attitudes, even over short timeframes.

Author summary

Using two waves of a nationally representative household survey in the Netherlands (2020 and 2023), we examine how the behavioural drivers of household intentions to implement property-level flood adaptation measures change over time. Counter-intuitively, despite a major flood in 2021, we find lower adaptation intentions, decreased flood worry, and reduced self-efficacy by 2023. Most importantly, we reveal a fundamental reordering of behavioural drivers: while prior flood experience and self-efficacy dominated in 2020, perception of responsibility emerges as the strongest determinant of intention by 2023. This suggests the decision to adapt is not merely a rational risk calculation but is shaped by the perceived social contract. Our findings suggest that policies focused solely on risk information are insufficient. An effective adaptation policy must also clearly frame this shared responsibility and provide tangible support to boost self-efficacy for private climate action.

Introduction

Recently, the American real estate giant Zillow introduced a climate risk feature on its platform, displaying a property's flood risk directly to potential buyers [1]. This move coincides with a renewed debate among scholars, policymakers, and the public: when a home is at risk, who is responsible for taking action [2]? While such labels are intended to empower homeowners by raising awareness, they typically focus only on correcting only one private climate change adaptation constraint - information assymmetry, i.e., the biased perception of flood risks held by homeowners and potential buyers.

The private actions in question often concern structural adaptation measures — tangible steps homeowners can take to make their property safer from floods and mitigate potential damage in the face of accelerating climate risks [3]. These can range from relatively simple modifications, like floodproofing doors or windows, to more significant undertakings, such as elevating an electricity meter or reinforcing a home's foundation [4].

There is a growing consensus that government-led, top-down flood protection initiatives are not sufficient on their own [5], highlighting the importance of private adaptation [6]. While government-led public adaptation measures, such as dikes and seawalls, reduce the *probability* of flooding, private actions *reduce damages* and *recovery time* if a hazard event occurs. Research shows that measures taken at the household level can be remarkably effective, reducing flood-related damages by an estimated 40% to 80%, if taken [4]. However, various socio-behavioural factors may serve as adaptation constraints, preventing people from taking timely action to protect themselves and their homes [7].

To understand the drivers behind a homeowner's decision to implement such property-level measures, researchers frequently turn to surveys. Among different social science theories explaining human decisions under risk [8], Protection Motivation Theory (PMT) stands out as one of the best in explaining private climate change adaptation behaviour [9], at least in the "capitalist societies" [10]. According to PMT, our intention to protect ourselves depends on two stages of decision-making: our threat appraisal (how serious is the risk, and how likely is it to affect me, do I worry about it?) and our coping appraisal (how effective is the protective action, am I capable of performing it, how expensive is it for my case?).

Past studies have successfully used PMT to identify critical factors of private flood adaptations, such as personal experience mediated by worry [11], frequent flood experience and loss of control [12], coping appraisal [13], and responsibility [14], that influence a household's intention to adapt. It was also found that the importance of certain factors, such as flood experience, may diminish over time [12] or lead to a downward spiral of distrust and inaction [15]. Longitudinal studies of private property-level adaptation are scarce and show inconclusive evidence on how individual risk perceptions and intentions to adapt change over time [16, 17].

However, what remains unclear is how the key factors of households' adaptation evolve over time, and whether a single survey snapshot delivers a stable value on which policy design can rely. For example, do subjective threat appraisals and perceptions of responsibility - who they believe should lead the charge on flood protection - evolve over time, especially in the wake of a recent flood event? In this context, it is also important to reveal how a sense of responsibility interacts with other motivating factors over time to ultimately shape the decision to adopt or reject various property-level protective measures.

To explore this gap, we draw on two waves of a comprehensive household survey conducted in 2020 and 2023 in the Netherlands, allowing for a comparison of attitudes over time. We first analyse the descriptive statistics to reveal the key trends. Following this, we perform a regression analysis for each survey wave. This allows us to identify the factors associated with the intention to adapt and measure any possible changes in their relative influence, providing a quantitative picture of what motivates — or hinders — household-level climate action, and whether these socio-behavioural adaptation constraints remain stable over time.

Materials and methods

A high-level overview

Our objective is to understand the relative importance of behavioural factors associated with a household's intention to implement structural home-level flood protection measures over time. Here, our focus is on understanding whether subjective risk perception is a decisive and reliable factor which climate adaptation policies could utilise as an effective policy lever. We estimate this for two independent survey waves: 2020 (N = 1,251) and 2023 (N = 420), and compare patterns across years.

We ground the analysis in an extended PMT framework. In its canonical form, PMT explains adaptive behaviour as dependent on two sets of variables: *threat appraisal* (e.g., perceived hazard probability and worry level) and *coping appraisal* (e.g., perceived outcome efficacy, self-efficacy, and costs). Building on this, we add *flood experience* to stress test the recent findings on its importance for Dutch households and *responsibility perception* to capture the role of perceived personal or shared responsibility in motivating private household action.

Within this framework, we examine intentions to adopt six structural measures aimed at reducing flood impacts at the property level: strengthening foundations, reinforcing walls/floors, raising the electricity meter, installing anti-backflow valves, installing pumps/drainage, and fixing water barriers. As the primary analysis method, we perform logistic regression for each wave and measure separately.

Data

We use the SCALAR household climate-adaptation and resilience survey [18], focusing on two samples collected in 2020 (N = 1,251) and 2023 (N = 420) in the Netherlands. The two waves studied opinions in the same geographical areas, specifically the south-west of the country, although they comprised different respondents. However, both waves were designed to be nationally representative with respect to key socio-demographics (e.g., gender, age, education, income, and savings; see Fig. 1).

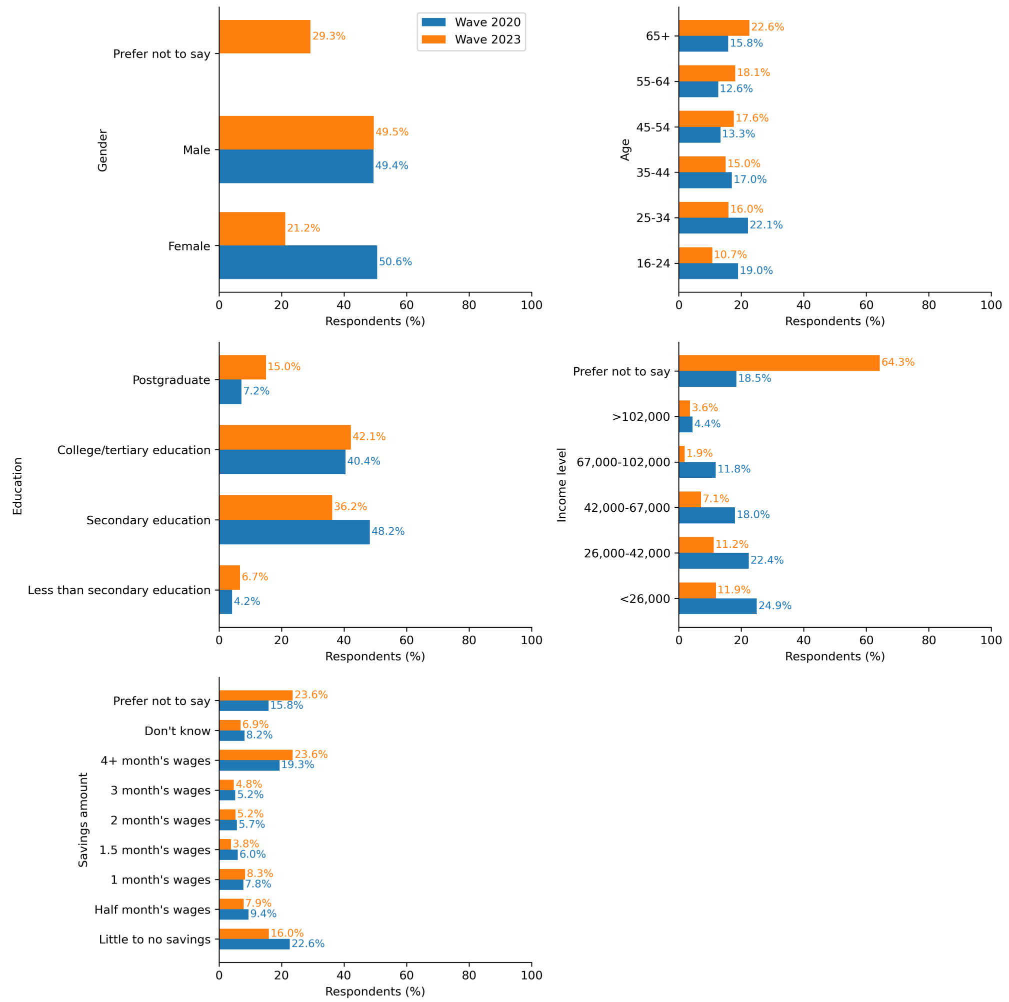

Fig 1. Sample composition by wave (2020 vs 2023). Distributions of gender, age, education, income, and savings for Wave–2020 (N=1,251; blue) and Wave–2023 (N=420; orange). The samples are comparable across demographics and were designed to be nationally representative. Bars show the percentage of respondents in each category and sum to 100% within panel and wave.

Statistical analysis

As two primary groups of methods, we use descriptive statistics with frequency tables and Likert plots and regression analysis with a specific type of logistic regression, the Logit model, which has been demonstrated to be effective with similar tasks [19]. We utilise an implementation of the Logit model in the statsmodels Python package [20].

As the dependent variable, we use the answers to the question: "*Please indicate if you have already implemented any of these structural measures or if you intend to do so in the future*", for each of the six structural measures, resulting in six regression models. In the survey, respondents had an opportunity to indicate when they have already implemented each particular measure, plan to implement it over a specific time horizon (in 6 or 12 months, a year, in two years, or after two years), or do not plan to implement it. For our analysis, we combine all intentions to implement a specific measure irrespectively in the near-future timing - in one year, two or two years - into a single, measure-specific overall intention to adapt. We exclude "Already implemented" answers from the analysis. Hence, our dependent variable becomes binary with 0 corresponding to the respondent's response "Do not plan to implement a measure" — no intention to adapt, and 1 corresponding to the respondent's response "Planning to implement a measure" — intention to pursue one of the six property-level adaptation measures (Table 1).

Table 1. Surveyed property-level flood adaptation measures. Short names and descriptions of the six structural measures included in the survey and used to construct the dependent variable in the regression models.

Short name	Description
Strengthen foundations	Strengthening the housing foundations to withstand water pressures
Reinforce walls/floor	Reconstructing or reinforcing the walls and/or the ground floor with water-resistant materials
Raise electricity meter	Raising the electricity meter above the most likely flood level or on an upper floor
Install anti-backflow valves	Installing anti-backflow valves on pipes
Install pump/drainage	Installing a pump and/or one or more system(s) to drain flood water
Fix water barriers	Fixing water barriers (e.g., water-proof basement windows)

As for the independent variable, we start the analysis of our six measure-specific variables grounded in extended PMT (Table 2). To avoid unstable models, we screen for multicollinearity using the Variance Inflation Factor (VIF>5) and pairwise correlations. We find that response efficacy and perceived costs are collinear with self-efficacy and have high VIF across measures and waves. We therefore excluded them from the final models. The final predictor set consists of perceived flood frequency, flood worry, flood experience, self-efficacy (measure-specific), and responsibility perception.

Table 2. Independent variables based on extended PMT (waves 2020 and 2023). Operationalisation of threat appraisal (worry, perceived frequency), coping appraisal (self-efficacy, response efficacy, perceived costs), and PMT extensions (experienced flood, responsibility perception). Responsibility differs by wave (2020: 5-point scale; 2023: 100-point allocation).

Group	Short name	Question	Type	Values (summary)
Threat appraisal	Flood worry	How worried are you about flooding at home?	Likert 1–5	1 not at all ... 5 very worried
Threat appraisal	Perceived flood frequency	How often do you think flooding occurs at your property?	Ordinal 1–10	Categories from "completely safe" to "> annual"; "don't know"; see Note A
Coping appraisal	Self-efficacy	Do you have the ability to undertake the measure (DIY or by paying a professional)?	Likert 1–5	1 unable ... 5 very able
Coping appraisal	Response efficacy	How effective would this measure be in reducing flood damage?	Likert 1–5	1 extremely ineffective ... 5 extremely effective
Coping appraisal	Perceived costs	Considering your finances, would implementing this measure be cheap or expensive?	Likert 1–5	1 very cheap ... 5 very expensive
PMT extension	Experienced flood	Have you personally experienced a flood?	Binary	Yes / No
PMT extension	Responsibility (2020)	In your opinion, whose responsibility is it to deal with floods?	Likert 1–5	1 completely government ... 5 completely individual
PMT extension	Responsibility (2023)	Allocate responsibility for dealing with floods across actors (sum to 100).	Allocation 0–100	7 actors; see Note B

Table notes: **A**: Full category wording for perceived flood frequency: 1 completely safe; 2 <1/500y; 3 1/500y (0.2%); 4 1/200y (0.5%); 5 1/100y (1%); 6 1/50y (2%); 7 1/10y (10%); 8 annual; 9 > annual; 10 don't know.
B: Actors in 2023 allocation: citizens; private companies/businesses; local NGOs; international NGOs/UN bodies; local/regional/state government; national/federal government; water authorities; other.

We estimate separate logistic regressions (logit link, binomial family) for each wave × measure combination (6 measures in 2020 and 2023; 12 models total) using `statsmodels` and report robust (HC0) standard errors. Because each wave includes many coefficient tests across the six measures, we control the False Discovery Rate (FDR) within each wave using the Benjamini–Hochberg (BH) procedure [21]. The family is defined as *all* coefficient tests across predictors and measures in that wave. We report q-values (BH-adjusted p-values) and consider an effect statistically reliable when $q < 0.05$. To keep tables readable, we show the odds ratio (OR) cells in the cross-measure summary only when $q < 0.05$. Confidence intervals are 95% unadjusted CIs (i.e., CIs are not multiplicity-adjusted), which is standard when FDR is used for inference. Significance markers (stars) reflect q-values; effects with OR< 1 are marked with a dagger to indicate a protective association. For each model, we report pseudo-R^2, ORs with 95% CIs, and FDR-adjusted significance. We also provide VIF summaries by measure and wave in the Supporting Information to document the absence of collinearity.

Results

Household intentions to adapt declined substantially between 2020 and 2023

Our analysis begins by examining the changes in private household flood adaptations between the 2020 and 2023 waves. The actual adoption rates of structural measures remain consistently low in both years, ranging from 2% to 5% depending on the specific measure, with no significant change detected between the survey waves (Table 3).

However, a striking and substantial shift occurred in households' intention to adopt these measures. As shown in Table 3, the proportion of respondents planning to implement a measure dropped across all six actions. In general, the intention to adapt decreased by 11.6 percentage points, from 25.4% on average across six measures in Wave-2020 to 13.8% in Wave-2023. The largest declines (≈ 13 percentage points) were observed for intentions to "Raise the electricity meter", "Install a pump/drainage system", and "Fix water barriers".

Table 3. Intentions to adopt property-level flood measures Wave-2020 and Wave-2023. Shares of respondents reporting no intention, planning to implement, or already adopted each measure in Wave-2020 and Wave-2023. The proportion planning to implement fell on average by 11.6 percentage points (from 25.4% to 13.8%), with the largest declines (≈ 13 percentage points) for raising the electricity meter, installing a pump/drainage system, and fixing water barriers.

Measure	Wave-2020			Wave-2023		
	No intention	Planned	Adopted	No intention	Planned	Adopted
Raise electricity meter	68%	28%	4%	81%	15%	4%
Install anti-backflow valves	70%	26%	3%	81%	15%	4%
Install pump/drainage	70%	27%	3%	83%	14%	4%
Fix water barriers	71%	26%	3%	83%	13%	4%
Strengthen foundations	74%	24%	2%	85%	13%	2%
Reinforce walls/floor	72%	25%	3%	85%	13%	2%

Table notes: Values are percentages of respondents within each wave for a given measure. Rows sum to 100% per wave (subject to rounding).

Shift in behavioural drivers: decreased worry and self-efficacy, and greater reliance on government

To understand this decline in intention, we examine shifts in the key drivers of protective behaviours. While we started our analysis with a full set of six predictors after carefully examining correlations and VIF, we conclude that only three factors could remain as predictors. These factors, which most strongly influence a household's intention to pursue property-level adaptation, are flood worry, self-efficacy, and perceived responsibility.

Surprisingly, despite a major national flood event occurring between the survey waves in July 2021 [22], the overall level of flood worry decreased among our respondents from 2020 to 2023 (Fig. 2). Although the 2021 event impacted another part of the country, a flood in the Netherlands is an extremely rare event and has been extensively discussed in society, on policy forums, and in the media. 2021 was also an unprecedented event, exceeding the expected probability, intensity and timing [23]. Despite this, we observe a decrease in worry among our respondents in Wave-2023 compared to respondents in Wave-2020, with the most notable change being a 16 percentage point increase in respondents reporting they were "Not at all worried", with corresponding decreases in higher worry categories.

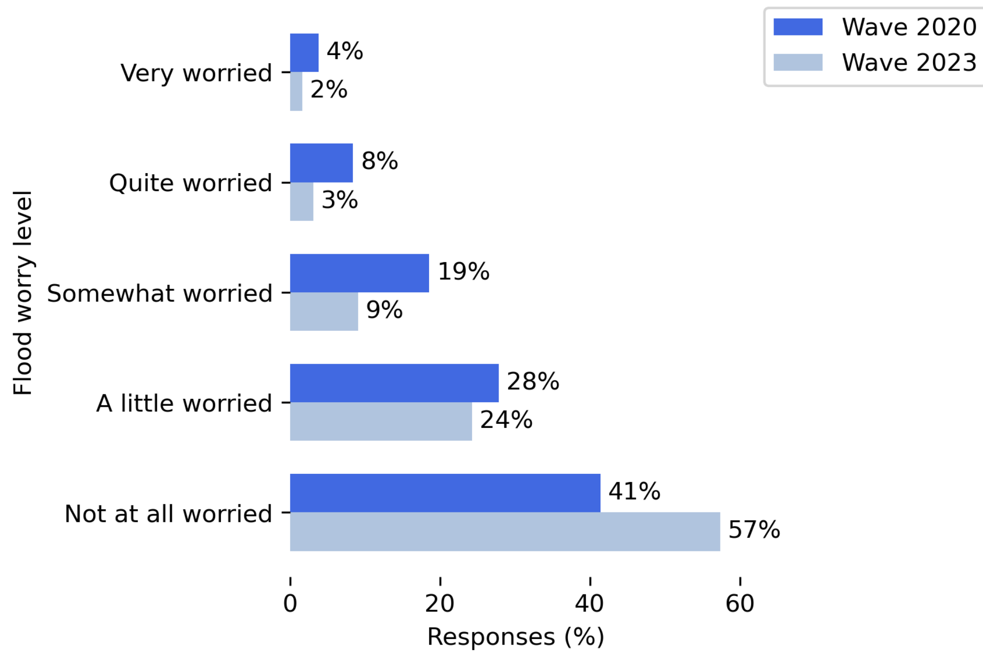

Fig 2. Flood-worry levels declined between 2020 and 2023. Horizontal bars compare worry about flooding in Wave–2020 (dark) and Wave–2023 (light). Despite a major flood occurring nationally in 2021, overall worry is lower in 2023: the share "Not at all worried" rises by about 16 percentage points (41% → 57%), with corresponding declines in higher-worry categories. Percentages label respondent shares and sum to 100% within wave.

In general, between 40%-60% of households - depending on the measure and survey waves - feel they are absolutely unable to implement a property-level flood protective measure, compared to only 4%-9% of households who report very high self-efficacy (Fig 3). Over time, alongside a diminished sense of worry, we observe a significant decline in respondents' perceived self-efficacy — their subjective belief in their own ability to implement protective measures. As detailed in Panel A) and Panel B) of Fig 3, more respondents in 2023 felt they were "somewhat unable" or "unable" to implement these measures, with an average increase of 7.2 percentage points in these categories compared to 2020. This erosion of confidence was most pronounced for "Fix water barriers" (an 11.1 percentage point increase in feeling unable) and least so for "Install anti-backflow valves" (a 3.4 percentage point increase).

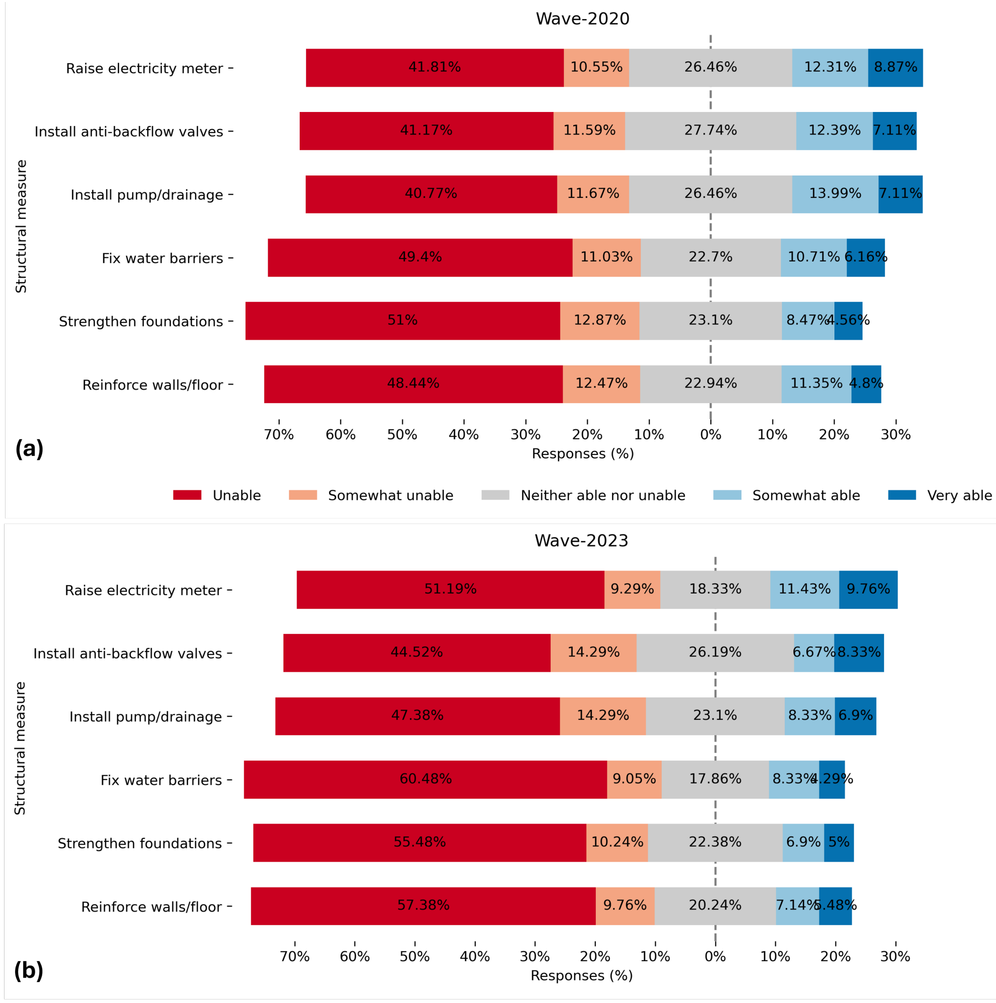

Fig 3. Self-efficacy or perceived ability to carry out structural household flood-protection measures (2020 vs 2023). Panels display diverging stacked bars for seven structural measures, with "unable" responses to the left and "able" to the right; the vertical dashed line indicates the neutral point (0%). *Panel a:* Wave–2020. *Panel b:* Wave–2023. Across measures, many households feel unable to implement these actions, and the unable categories increased on average by about 7.2 percentage points from 2020 to 2023 (largest for "Fix water barriers", smallest for "Install anti-backflow valves"). Percentages are respondent shares; bars sum to 100% per measure.

The final behavioural factor we discuss in detail here, perception of responsibility, revealed a decisive shift away from the individual and toward the government (Fig. 4). In 2020, nearly half of the respondents (49%) believed responsibility was shared equally. By 2023, this figure had fallen to 35%. Conversely, the proportion of respondents believing that flood protection is primarily the government's responsibility increased substantially, from 20% in 2020 to 32% in 2023.

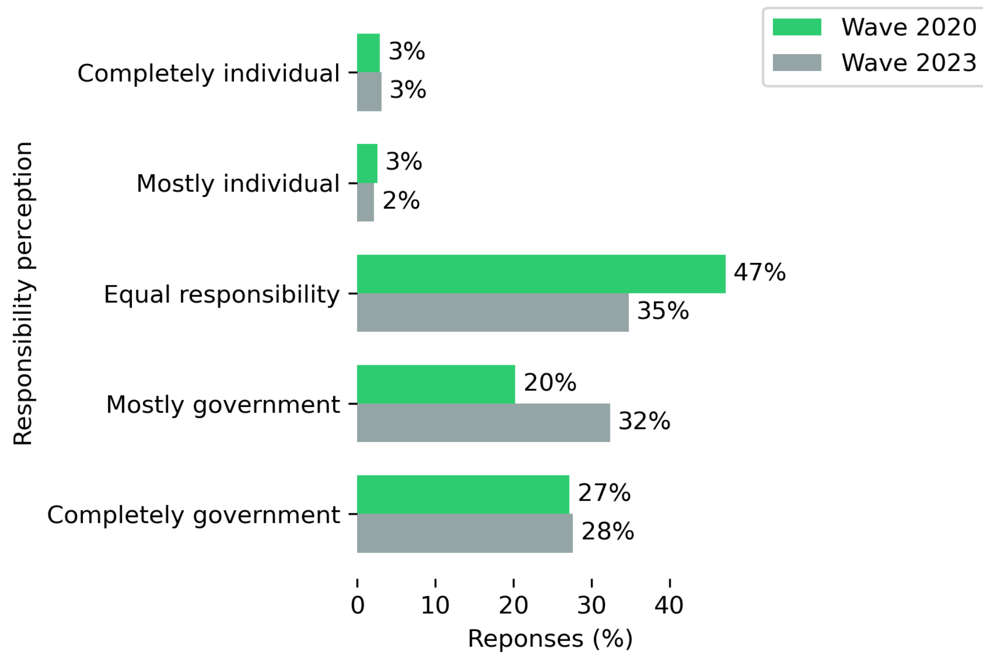

Fig 4. Perceived responsibility for flood risk management shifted toward government (2020→2023). Horizontal bars show how respondents distribute responsibility between individuals and government in Wave–2020 (green) and Wave–2023 (grey). Views move away from "Equal responsibility" (about 47% → 35%) toward greater government responsibility ("Mostly government" increases from about 20% to 32%; "Completely government" remains near 27–28%). For visual comparability, the 2020 item is a five-point scale, while the 2023 allocation task (100 points across actors) is summarised to the same five categories. Bars show percentages and sum to 100% within the wave.

Perception of responsibility becomes the dominant driver of adaptation intention in 2023

To formally identify the factors associated with the intention to adapt in each wave, we conduct a series of six logistic regression analyses. The binary outcome variable is reported intention to pursue a specific measure in the coming years (coded as 1) versus no intention to adapt (coded as 0). After assessing a full set of six potential predictors from PMT (see Table 2) and checking for multicollinearity (VIF > 5), we keep five key predictors for the final models: perceived flood frequency, flood worry, flood experience, self-efficacy, and responsibility perception.

The results, summarised in Table 4 and Table 5, reveal a changing landscape of the influence of these behavioural factors of private adaptation actions. In Wave-2020, four factors — self-efficacy, responsibility perception, flood worry, and flood experience — were statistically reliable for all six adaptation measures after controlling for the FDR with the wave (BH; $q < .05$). Experienced flood had the largest average effect sizes (e.g., ORs $\sim$3–5), while responsibility and self-efficacy were positive and consistent (responsibility ORs $\sim$1.3–1.4).

Most critically, the relative importance of these two core predictors "inverted" between the two waves. By 2023, the influence of flood worry had become selective (significant for four of six measures), and flood experience had largely dropped out (significant for only one measure). In contrast, responsibility perception and self-efficacy remained robust across all six measures and grew in relative importance. Responsibility now shows ORs around 2-3 (e.g., up to 2.69 for Reinforce walls/floor), making it the most consistent and strongest driver of intention in 2023. Perceived flood frequency is generally null and appears protective (OR<1) only for Reinforce walls/floor in 2023.

For the interpretation, one can think of an OR as a multiplier that indicates how much a specific factor (such as "flood worry") increases or decreases the likelihood of an outcome (like "intending to adapt"). An OR of 1.0 is neutral. It means the factor has no effect on the outcome. An OR greater than 1.0 is a "booster". For example, the average OR of 2.69 for responsibility means that for every one-point increase on the responsibility scale, a person's odds of intending to adapt were multiplied by 2.69 (or, seen another way, their odds increased by 169%). An OR less than 1.0 (e.g., 0.74) would be a "reducer", meaning the factor decreases the odds of the outcome. For a simple yes/no variable, such as experiencing a flood, the OR (e.g., 3.48) directly compares the odds of the "yes" group (those who had experienced a flood) to the "no" group (those who had not). In that case, those with flood experience had 3.48 times the odds of intending to adapt.

Table 4. Determinants of adaptation intention in 2020. Measure-specific odds ratios (OR; 95% CI) from logistic regressions (logit; HC0 SEs). Cells appear only when the Benjamini–Hochberg FDR-adjusted $q < .05$ *within wave*; em dashes (—) indicate non-significant effects ($q \geq .05$). Stars reflect q-values; daggers would denote protective effects (OR<1). Across all six measures, self-efficacy, responsibility, flood worry, and prior flood experience are consistently reliable; perceived flood frequency is rarely significant.

Adapt. measure	*Self-efficacy*	*Resp. perception*	*Flood worry*	*Exp. flood*	*Perc. flood freq.*
Raise electricity meter	1.86 (1.67–2.07)***	1.33 (1.13–1.55)***	1.91 (1.67–2.18)***	3.65 (2.38–5.58)***	1.09 (1.02–1.17)*
Install anti-backflow valves	1.82 (1.63–2.03)***	1.33 (1.14–1.56)***	1.71 (1.50–1.96)***	2.94 (1.95–4.43)***	—
Install pump/drainage	1.68 (1.51–1.87)***	1.35 (1.15–1.57)***	1.91 (1.67–2.18)***	3.22 (2.16–4.81)***	—
Fix water barriers	2.04 (1.82–2.29)***	1.32 (1.12–1.55)**	1.94 (1.69–2.23)***	4.05 (2.65–6.19)***	—
Strengthen foundations	2.04 (1.79–2.32)***	1.38 (1.17–1.64)***	1.86 (1.62–2.13)***	2.42 (1.60–3.66)***	—
Reinforce walls/floor	2.29 (2.01–2.61)***	1.27 (1.07–1.50)**	1.95 (1.69–2.25)***	4.59 (3.01–7.00)***	—

Table notes: Cells show OR (95% CI). Entries shown only when FDR-adjusted $q < .05$ (BH within wave). Significance: * $q<.05$, ** $q<.01$, *** $q<.001$. Predictors: *Self-efficacy* (1–5), *Responsibility perception* (resp. perception; 1–5; higher = more homeowner responsibility), *Flood worry* (1–5), *Experienced flood* (exp. flood; 0/1), *Perceived flood frequency* (perc. flood freq.; ordinal). Outcome: intention to adopt the listed *Adaptation measure* (adapt. measure; respondents reporting "already adopted" for that measure are excluded).

Model diagnostics (by measure, in row order): Raise electricity meter: N=1,207, pseudo-R^2=0.250; Install anti-backflow valves: N=1,212, 0.213; Install pump/drainage: N=1,214, 0.215; Fix water barriers: N=1,217, 0.280; Strengthen foundations: N=1,220, 0.259; Reinforce walls/floor: N=1,215, 0.320.

Table 5. Determinants of adaptation intention in 2023. Measure-specific odds ratios (OR; 95% CI) from logistic regressions (logit; HC0 SEs). Cells appear only when the Benjamini–Hochberg FDR-adjusted $q < .05$ *within wave*; em dashes (—) indicate non-significant effects (q≥.05). In 2023, responsibility perception shows the largest and most consistent associations across measures, with self-efficacy remaining robust; flood worry is selective; prior flood experience is largely non-significant; perceived frequency is generally null and protective for one measure.

Adapt. measure	*Self-efficacy*	*Resp. perception*	*Flood worry*	*Exp. flood*	*Perc. flood freq.*
Raise electricity meter	1.67 (1.36–2.04)***	2.12 (1.53–2.94)***	—	—	—
Install anti-backflow valves	1.36 (1.12–1.67)**	2.45 (1.74–3.47)***	1.58 (1.18–2.12)**	3.98 (1.53–10.36)**	—
Install pump/drainage	1.84 (1.47–2.30)***	2.14 (1.48–3.09)***	1.68 (1.24–2.28)**	—	—
Fix water barriers	2.26 (1.71–2.98)***	2.35 (1.54–3.58)***	1.68 (1.19–2.37)**	—	—
Strengthen foundations	2.06 (1.60–2.64)***	2.34 (1.63–3.35)***	—	—	—
Reinforce walls/floor	1.97 (1.52–2.55)***	2.69 (1.82–3.99)***	1.46 (1.04–2.05)*	—	0.74 (0.57–0.96)†

Table notes: Cells show OR (95% CI). Entries shown only when FDR-adjusted $q < .05$ (BH within wave). Significance: * $q<.05$, ** $q<.01$, *** $q<.001$. † OR< 1 (protective association). Predictors and outcome as in Wave–2020.

Model diagnostics (by measure, in row order): Raise electricity meter: N=404, pseudo-R^2=0.226; Install anti-backflow valves: N=404, 0.219; Install pump/drainage: N=405, 0.251; Fix water barriers: N=402, 0.343; Strengthen foundations: N=411, 0.289; Reinforce walls/floor: N=412, 0.309.

Discussion

Our findings reveal an unexpected and critical shift in the drivers of household flood adaptation in the Netherlands between 2020 and 2023. Notably, a major flood event occurred between the two surveys in 2021. Although this flood occurred in another Dutch region, such events are rare in the Netherlands, sending shockwaves through society and sparking public debates nationwide. Therefore, one might have expected to observe heightened risk awareness and motivate action. Yet, our data reveal the opposite: a significant 11.6 percentage point decline in adaptation intentions, accompanied by decreased flood worry and lower self-efficacy. Most importantly, our analysis shows a fundamental reordering of the importance of behavioural drivers, each of which has different implications for what could be a policy lever for inspiring and scaling up private adaptation. While factors like prior flood experience appear to be dominant among our 2020 respondents, by 2023, the perception of responsibility emerges as the most powerful and consistent predictor of a household's intention to protect its home.

Our findings both confirm and challenge existing literature. The strong influence of prior flood experience in our 2020 data aligns with previous work highlighting its role as a "window of opportunity" for encouraging protective action [11, 12]. However, the diminished overall importance of this factor by Wave-2023, alongside a drop in worry, suggests this window may close faster than anticipated or, more provocatively, that a recent disaster or the governmental response to it can trigger a different psychological response. Instead of motivating individuals to act, it may lead to a feeling of helplessness in the face of devastating flood consequences and an increased reliance on the state, a phenomenon where citizens, overwhelmed by the scale of the threat, deny personal responsibility in favour of government intervention [15]. This shift is evident in the 12 percentage point increase among respondents who believe flood protection is primarily the government's duty. An alternative explanation for the observed decline in the effect of flood experience on motivating private property-level adaptation could be the nature of the governmental response to the last hazard event. Following the 2021 flood in the Netherlands, driven by the scale of impact and suffering, the government declared a state of "disaster". In accordance with the law [23]. It made private individuals and businesses eligible for the water damage compensation scheme for noninsured losses. While this was much needed, it may also have caused unintended consequences, such as disincentivising private action, as widely documented globally when public funds are used to compensate for private damages [24, 25].

The change in and the corresponding rise of responsibility perception as the dominant driver of private motivation to adopt all studied property-level measures is striking, especially considering that this shift happened in just three years. Earlier studies have reported the importance of perceived responsibility, also for the Dutch context [14]. However, our longitudinal comparison demonstrates its dynamic and potent nature. In our Wave-2023, a homeowner's belief about who should act became more influential than their personal experience with floods, their level of worry, or even their perceived ability to act (self-efficacy) - factors that are conventionally reported as the key socio-behavioural drivers of private adaptation [9]. This suggests that the decision to protect one's own home from hazards is not merely a rational calculation of expected damages, perceived costs, or even behavioural triggers. Instead, it is fundamentally shaped by institutional arrangements and a social contract — an implicit understanding of the roles citizens and the government play in ensuring safety. While strong institutions are vital for climate adaptation [6, 7], social institutions—both formal and informal—established to suit societies in the past climate might become prohibitive for climate-resilient development in this drastically changing risk landscape. For example, public (flood) protection benefits have forged a unique, comprehensive system of formal flood-protection institutions in the Netherlands and established a strong informal social norm of overreliance on public protection. However, with climate change, even the world's best flood defence infrastructure system cannot guarantee a zero probability of flooding. Therefore, with changing risk regimes, it becomes essential to communicate to private actors that their choices, like property-level adaptations, define whether and how much damage they may suffer should an adverse event occur.

These results have profound policy implications. For a climate-resilient society, a shared responsibility for physical risks becomes unavoidable: with governments responsible for lowering probabilities of floods (e.g. by means of dikes) and reducing exposure (e.g. via spatial planning), with citizens responsible for lowering damages (e.g. dry- or wet-proofing homes and other measures reducing physical vulnerability of own assets) and reducing exposure (e.g. being conscious of physical risks when buying homes), and with the institutions adapting to these shifting responsibilities (e.g. restructuring financial incentives toward climate-smart investments). Our empirical analysis also has implications for the design of specific policy instruments, such as climate risk labels for homes [2, 26]. Our findings suggest that simply informing homeowners of their risk — the primary function of such labels — is insufficient and may even be counterproductive if not accompanied by a clear framework of shared responsibility. A homeowner who learns their property is at high risk may not be empowered to act; instead, they may expect the government to solve the problem. Effective policy must therefore be comprehensive and integrative of the natural science knowledge on physical risks, as well as the behavioural insights on how people understand and act upon risks, and of institutions, including norms, law, and broader financial and economic institutions. It must move beyond mere information provision to:

1. Clearly frame responsibility: Explicitly communicate that reducing flood risks is a shared duty between the state (for hazard protection and exposure) and the individual (for damages and exposure).

2. Enable private action: Couple risk communication with tangible support, such as subsidies, technical guidance, and skill-building workshops, to boost self-efficacy.

3. Embrace adaptive policy process: Recognise that citizens' attitudes, perceptions and public support are not static. Policies must be designed with feedback loops

to monitor and adapt to evolving public sentiment, even over short timeframes, and, possibly, to proactively nudge climate-resilient citizen behaviour.

This study has several limitations that open avenues for future research. First, as is common in literature on private flood protection [9, 10, 13, 27], we focus here on adaptation intention, rather than action. The well-documented "intention-action gap" means that even the intentions we observed may overstate future adaptation rates [17]. Future studies should use longitudinal designs that track individual households to identify the factors that successfully convert intention into an action (implementation). Second, while we document a shift in behavioural drivers, our study cannot definitively establish the causal reasons for this change: the scale and government response to the 2021 flood, or any other factors on the economic or behavioural side. Moreover, the two survey waves in our analysis, though collected in the same geographic area on relatively similar samples, elicit the opinions of different respondents. Further research could focus on qualitative in-depth interviews, behavioural experiments, serious games, randomised control trials or even virtual reality immersion experimental methods to explore the mechanisms behind this evolving public sentiment. Finally, exploring how different framings of responsibility in policy communications affect household intentions would be a valuable next step for designing more effective adaptation strategies.

Conclusion

In the urgent quest for climate resilience, household-level adaptation remains a critical but stubbornly difficult goal. This study aspires to understand if and how the drivers of homeowners' intentions to implement flood protection measures on their homes change over time. Our analysis of two household surveys in the Netherlands, conducted just three years apart, reveals an unexpected and critical insight: citizens' motivation to adapt is not a stable function of risk perception, but is volatile and largely shaped by people's perceptions of responsibility. Between our survey waves in 2020 and 2023, the psychological landscape shifted from one where private intention to adapt is driven by personal experience, worry, and self-efficacy to one where private adaptation is predominantly determined by the perception of who is fundamentally responsible for protection — the individual or the government.

The primary contribution of this work is the demonstration that the social contract can outweigh individual risk calculations and behavioural factors that traditionally explain private adaptation, such as risk perceptions and self-efficacy. Notably, a shocking hazard event occurred in the country in July 2021, between our two survey waves. Although our dataset does not permit us to establish causality, the descriptive evidence is clear: respondents in Wave 2023 are less worried, feel less responsible, and are less capable of taking private flood protection measures compared to respondents in Wave 2020. The clear implication is that policies aiming to "empower" households with risk information alone are built on a fragile assumption. Without a clear and compelling narrative of shared responsibility, such policies may fail to stimulate private action. Ultimately, building a climate-resilient society requires more than just raising citizens' awareness of the risks they face; it necessitates forging a clear and collaborative partnership between citizens and the government to confront those risks together.

Supporting information

S1 Table. Model diagnostics by wave and measure. Sample sizes and pseudo-R^2 for each fitted model.

Wave	Measure	N	pseudo-R^2	LR test p
2020	Raise electricity meter	1207	0.250	$< 10^{-14}$
2020	Install anti-backflow valves	1212	0.213	$< 10^{-14}$
2020	Install pump/drainage	1214	0.215	$< 10^{-14}$
2020	Fix water barriers	1217	0.280	$< 10^{-14}$
2020	Strengthen foundations	1220	0.259	$< 10^{-14}$
2020	Reinforce walls/floor	1215	0.320	$< 10^{-14}$
2023	Raise electricity meter	404	0.226	$< 10^{-14}$
2023	Install anti-backflow valves	404	0.219	$< 10^{-14}$
2023	Install pump/drainage	405	0.251	$< 10^{-14}$
2023	Fix water barriers	402	0.343	$< 10^{-14}$
2023	Strengthen foundations	411	0.289	$< 10^{-14}$
2023	Reinforce walls/floor	412	0.309	$< 10^{-14}$

S2 Table. Full logistic regression results (Wave 2020). Log-odds coefficients (Coef), robust SE (HC0), raw p, Benjamini–Hochberg FDR-adjusted q (computed within wave across all predictors × measures), and odds ratios (OR) with 95% CIs for each predictor and adaptation measure. Significance markers appended to OR use q: * $q < .05$, ** $q < .01$, *** $q < .001$. † indicates OR< 1 (protective association). Households reporting "already adopted" are excluded. VIF checks indicated no multicollinearity concerns (all VIF < 5).

Measure	Predictor	Coef	SE	p	q	OR (95% CI)
Raise electricity meter	Self-efficacy	0.62	0.05	6.9e-30	8.1e-29	1.86 (1.67–2.07)
Raise electricity meter	Responsibility perception	0.28	0.08	0.000379	0.00051	1.33 (1.13–1.55)
Raise electricity meter	Flood worry	0.65	0.07	6.6e-22	3.3e-21	1.91 (1.67–2.18)***
Raise electricity meter	Experienced flood	1.29	0.22	2.45e-09	4.76e-09	3.65 (2.38–5.58)***
Raise electricity meter	Perceived flood frequency	0.09	0.03	0.010	0.012	1.09 (1.02–1.17)*
Install anti-backflow valves	Self-efficacy	0.60	0.06	3.8e-27	2.6e-26	1.82 (1.63–2.03)***
Install anti-backflow valves	Responsibility perception	0.29	0.08	0.000375	0.00051	1.33 (1.14–1.56)***
Install anti-backflow valves	Flood worry	0.54	0.07	8.2e-16	2.05e-15	1.71 (1.50–1.96)***
Install anti-backflow valves	Experienced flood	1.08	0.21	2.40e-07	4.20e-07	2.94 (1.95–4.43)***
Install anti-backflow valves	Perceived flood frequency	0.05	0.03	0.114	0.123	1.06 (0.99–1.13)
Install pump/drainage	Self-efficacy	0.52	0.06	3.9e-21	1.36e-20	1.68 (1.51–1.87)***
Install pump/drainage	Responsibility perception	0.30	0.08	0.000216	0.000315	1.35 (1.15–1.57)***
Install pump/drainage	Flood worry	0.65	0.07	1.5e-21	6.6e-21	1.91 (1.67–2.18)***
Install pump/drainage	Experienced flood	1.17	0.20	1.09e-08	2.01e-08	3.22 (2.16–4.81)***
Install pump/drainage	Perceived flood frequency	0.04	0.03	0.238	0.245	1.04 (0.97–1.11)
Fix water barriers	Self-efficacy	0.71	0.06	5.0e-33	8.7e-32	2.04 (1.82–2.29)***
Fix water barriers	Responsibility perception	0.27	0.08	0.001082	0.00140	1.32 (1.12–1.55)**
Fix water barriers	Flood worry	0.66	0.07	2.8e-21	1.09e-20	1.94 (1.69–2.23)***
Fix water barriers	Experienced flood	1.40	0.22	1.06e-10	2.18e-10	4.05 (2.65–6.19)***
Fix water barriers	Perceived flood frequency	0.07	0.04	0.056	0.0655	1.07 (1.00–1.15)
Strengthen foundations	Self-efficacy	0.71	0.07	4.5e-27	2.6e-26	2.04 (1.79–2.32)***
Strengthen foundations	Responsibility perception	0.33	0.09	0.000140	0.000213	1.38 (1.17–1.64)***
Strengthen foundations	Flood worry	0.62	0.07	3.4e-18	9.1e-18	1.86 (1.62–2.13)***
Strengthen foundations	Experienced flood	0.88	0.21	2.74e-05	4.57e-05	2.42 (1.60–3.66)***
Strengthen foundations	Perceived flood frequency	0.06	0.04	0.116	0.123	1.06 (0.99–1.13)
Reinforce walls/floor	Self-efficacy	0.83	0.07	3.2e-35	1.1e-33	2.29 (2.01–2.61)***
Reinforce walls/floor	Responsibility perception	0.24	0.09	0.006862	0.00858	1.27 (1.07–1.50)**
Reinforce walls/floor	Flood worry	0.67	0.07	3.3e-20	9.6e-20	1.95 (1.69–2.25)***
Reinforce walls/floor	Experienced flood	1.52	0.22	1.46e-12	3.19e-12	4.59 (3.01–7.00)***
Reinforce walls/floor	Perceived flood frequency	0.04	0.04	0.266	0.266	1.04 (0.97–1.13)

S3 Table. Full logistic regression results (Wave 2023). Columns as in S2 Table. Stars reflect FDR significance within 2023; † marks protective associations (OR< 1).

Measure	Predictor	Coef	SE	p	q	OR (95% CI)
Raise electricity meter	Self-efficacy	0.51	0.10	6.8e-07	2.9e-06	1.67 (1.36–2.04)***
Raise electricity meter	Responsibility perception	0.75	0.17	6.2e-06	2.0e-05	2.12 (1.53–2.94)***
Raise electricity meter	Flood worry	0.25	0.15	0.101	0.136	1.28 (0.95–1.72)
Raise electricity meter	Experienced flood	1.13	0.53	0.035	0.0534	3.08 (1.08–8.79)
Raise electricity meter	Perceived flood frequency	-0.20	0.12	0.100	0.136	0.81 (0.64–1.04)†
Install anti-backflow valves	Self-efficacy	0.31	0.10	0.00227	0.00475	1.36 (1.12–1.67)**
Install anti-backflow valves	Responsibility perception	0.90	0.18	3.4e-07	2.0e-06	2.45 (1.74–3.47)***
Install anti-backflow valves	Flood worry	0.46	0.15	0.00231	0.00475	1.58 (1.18–2.12)**
Install anti-backflow valves	Experienced flood	1.38	0.49	0.00458	0.00843	3.98 (1.53–10.36)**
Install anti-backflow valves	Perceived flood frequency	-0.11	0.13	0.429	0.500	0.90 (0.69–1.17)†
Install pump/drainage	Self-efficacy	0.61	0.11	7.2e-08	8.4e-07	1.84 (1.47–2.30)***
Install pump/drainage	Responsibility perception	0.76	0.19	4.6e-05	0.000134	2.14 (1.48–3.09)***
Install pump/drainage	Flood worry	0.52	0.16	0.000907	0.00227	1.68 (1.24–2.28)**
Install pump/drainage	Experienced flood	0.86	0.59	0.144	0.186	2.37 (0.75–7.51)
Install pump/drainage	Perceived flood frequency	0.04	0.12	0.745	0.767	1.04 (0.82–1.33)
Fix water barriers	Self-efficacy	0.81	0.14	7.4e-09	2.3e-07	2.26 (1.71–2.98)***
Fix water barriers	Responsibility perception	0.85	0.22	7.3e-05	0.000195	2.35 (1.54–3.58)***
Fix water barriers	Flood worry	0.52	0.18	0.00341	0.00664	1.68 (1.19–2.37)**
Fix water barriers	Experienced flood	0.85	0.64	0.186	0.232	2.33 (0.67–8.14)
Fix water barriers	Perceived flood frequency.	-0.06	0.12	0.603	0.657	0.94 (0.74–1.19)†
Strengthen foundations	Self-efficacy	0.72	0.13	1.3e-08	2.3e-07	2.06 (1.60–2.64)***
Strengthen foundations	Responsibility perception	0.85	0.18	3.7e-06	1.30e-05	2.34 (1.63–3.35)***
Strengthen foundations	Flood worry	0.33	0.16	0.0389	0.0567	1.39 (1.02–1.91)
Strengthen foundations	Experienced flood	0.45	0.65	0.490	0.554	1.57 (0.44–5.62)
Strengthen foundations	Perceived flood frequency	-0.07	0.14	0.620	0.657	0.93 (0.71–1.23)†
Reinforce walls/floor	Self-efficacy	0.68	0.13	2.5e-07	1.74e-06	1.97 (1.52–2.55)***
Reinforce walls/floor	Responsibility perception	0.99	0.20	7.3e-07	2.85e-06	2.69 (1.82–3.99)***
Reinforce walls/floor	Flood worry	0.38	0.17	0.0306	0.0486	1.46 (1.04–2.05)*
Reinforce walls/floor	Experienced flood	0.76	0.61	0.208	0.251	2.14 (0.65–7.03)
Reinforce walls/floor	Perceived flood frequency	-0.31	0.13	0.0214	0.0375	0.74 (0.57–0.96)†*

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