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Planning for the health impacts of climate change: Flooding, private groundwater contamination and waterborne infection – A cross-sectional study of risk perception, experience and behaviours in the Republic of Ireland

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ABSTRACT

The frequency and severity of flooding events will increase over the coming decades due to global climate change. While close attention has typically been paid to infrastructural and environmental outcomes of flood events, the potential adverse human health consequences associated with post-event consumption from private groundwater sources have received minimal attention, leading to a poor understanding of private well users' preparedness and the drivers of positive behavioural adoption. The current study sought to quantify the capacity of private well users to cope with flood-triggered contamination risks and identify the social psychological determinants of proactive attitudes in the Republic of Ireland, using a cross-sectional questionnaire incorporating two distinct models of health behaviour, the *Health Belief Model* and *Risk-Attitude-Norms-Ability-Self Regulation* model. Adoption of healthy behaviours prior to flooding was evaluated with respect to respondents' risk exposure, risk experience and risk perception, in addition to systematic supply stewardship under normal conditions. Associations between adoption of protective behaviours and perception, experience and socio-demographic factors were evaluated through multinomial and multiple logistic regressions, while a multi-model inferential approach was employed with the predictors of health behaviour models. Findings suggest that floods are not considered likely to occur, nor were respondents worried about their occurrence, with 72.5% of respondents who reported previous flooding experience failing to adopt protective actions. Prior experience of well water contamination increased adoption of proactive attitudes when flooding occurred (+47%), with a failure to adopt healthy behaviours higher among rural non-agricultural residents (136%). Low levels of preparedness to deal with flood-related contamination risks are a side-effect of the general lack of appropriate well stewardship under normal conditions; just 10.1% of respondents adopted both water treatment and frequent testing, in concurrence with limited risk perception and poor awareness of the nexus between risk factors (e.g. floods, contamination sources) and groundwater quality. Perceived risk, personal norms and social norms were the best predictors of protective behaviour adoption and should be considered when developing future awareness campaigns.

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1. Introduction

Flooding events have the potential to inflict major societal, infrastructural and environmental damage, and account for almost one third of natural disasters over the last century (Adikari and Yoshitani 2009; O'Neill and Scott 2011). Global climate change models indicate that both the severity and frequency of these events will increase over coming decades (Pall et al., 2011; Arnell and Gosling 2016). Traditionally, efforts to mitigate the consequences of these events have focused on prevention, however, due to inherent financial and material resource requirements associated with these approaches, the focus has shifted towards management (Schanze 2006; Butler and Pidgeon 2011; Scott et al., 2013). As such, an increased capacity for accurately predicting flood occurrence and the associated infrastructural risks are essential, in concurrence with broadening our understanding of potential societal outcomes (McGahey 2009; Birkholz et al., 2014). Nevertheless, not all flood outcomes are as widely acknowledged as they could be; typically, coverage of flood events in mainstream media, and particularly in economically developed regions, have tended to place an emphasis on infrastructural damage and associated costs (Devitt & O'Neill 2017), with appreciably less attention given to the adverse human health consequences (Semenza et al., 2012).

Significant flood events can cause widespread mobilization of microorganisms, including enteric pathogens (i.e. viruses, bacteria, and protozoa), within the environment via overland flow, short circuiting of natural attenuation processes, subsurface saturation, and wellhead inundation (Muirhead et al., 2004; Weber et al., 2009; Andrade et al., 2018). A recent review by Andrade et al. (2018) reports that little is known regarding the specific contribution of flooding events to the incidence of private groundwater contamination and subsequent waterborne infection, including the dominant contamination pathways, geological and hydrogeological factors influencing source susceptibility, contamination lag, and infection latency and severity. However, little doubt remains as to the potential health impacts arising from contaminated private groundwater systems; for example, Risebro et al. (2012) report that the incidence of infectious intestinal diseases among households served by private supplies in England was significantly higher than in the UK population as a whole.

Individual perception of risk has been shown to shape responses to the occurrence of natural hazards including flooding (Bradford et al., 2012), with risk perception, in turn, deeply grounded in an individual's level of knowledge pertaining to the hazard in question (Chappells et al., 2015). As such, a paucity of appropriate information may be responsible for a decline in societal awareness, resulting in low or absent flood preparedness (Raaijmakers et al., 2008; Shen 2010; Bradford et al., 2012). Previous studies suggest that private well-owners are frequently ill-equipped to prevent or manage the effects of sporadic contamination events, which compounded by a general lack of well stewardship (i.e. water treatment, continuous maintenance, and well water testing) (Hynds et al., 2013; Malecki et al., 2017; Mooney et al., 2020a), results in this rural sub-population being acutely vulnerable to significant flooding events.

Action aimed at reducing risk exposure, safeguarding drinking water quality, or preventing infection at the national, regional, community or household (individual) level may be classified as a "health behaviour". However, numerous actions, such as groundwater testing, fail to directly reduce the risk of contamination, and consequently are more difficult to understand in terms of perception and promotion (Flanagan et al., 2016b). The use of relevant psychological models in health behaviour studies has been shown to result in increasingly effective interventions (Prestwich et al., 2015). The *Health Belief Model* (HBM) and "*Risk-Attitude-Norms-Ability-Self Regulation*" (RANAS) model represent two previously employed frameworks for examining social psychological determinants of private well users' behaviours. The HBM was developed in the early 1970s and has been widely employed in interventional design and assessment studies, including environmentally-based interventions relating to natural hazards (Semenza et al., 2011; Akompab et al., 2013) and analysis of well water testing behaviours (Straub and Leahy 2014). It uses several components to predict health-behaviours, i.e. Perceived Susceptibility and Severity, Perceived Benefits and Barriers, Self-efficacy, Cues to Action (Devitt et al., 2016), of which all but one ("Cues to Action") are included in the RANAS framework (Figure S1, Supplementary Materials). The RANAS model was originally developed by Mosler (2012) to evaluate *water, sanitation and hygiene* (WASH) interventions in developing regions, and recently applied by Flanagan et al. (2016a) in their analysis of arsenic testing behaviours among private well owners in the United States. The overarching RANAS approach seeks to identify and measure behavioural determinants ("Factor Blocks") relating to specific environmental exposures or events within a defined population to design evidence-based "behaviour change interventions" (Mosler and Contzen 2016).

To date, however, few studies have sought to quantify the capability of private groundwater-reliant communities to avoid supply contamination induced by flooding, identify population sub-groups systematically neglecting protective behaviours, or explore social psychological determinants to adopting these behaviours (Hamilton et al., 2020). Accordingly, the current study sought to address this knowledge gap via a cross-sectional questionnaire incorporating HBM and RANAS, thus permitting a comprehensive analysis of behavioural barriers and motivators. The self-protection capacity of individuals and communities, in addition to their perception of risk and their risk exposure to well water contamination in a flooding scenario is evaluated.

2. Methods

2.1. Study area

The study was undertaken in the Republic of Ireland (RoI), a temperate maritime region characterised by increasingly recurrent flood frequency and severity (McDowell et al., 2020). The RoI represents a highly pertinent case study, with high annual precipitation (from 750 to 2000 mm per year), diverse geological and agricultural profiles, and significant levels of reliance on private groundwater supplies and domestic wastewater treatment systems in rural areas (Hynds 2012; Naughton and Hynds 2014). Recent estimates suggest that approximately 720,000–750,000 Irish residents (≈15% of national population) are supplied by an unregulated groundwater source, with private well users up to six times more likely to contract an acute gastrointestinal infection (AGI) (Hynds et al., 2014). In RoI, private well users are entirely responsible for the quality of their well water, with no legislation in place regarding private groundwater system and no regulated obligations existing with respect to well testing and maintenance. Authorities recommend that the wellhead be checked with respect to an appropriate seal, ingress of surface water runoff, and the adjacency of potential contamination sources (i.e. septic tanks, chemical storage, fuel storage tanks, slurry land-spreading, animals access to or near wellhead, abandoned boreholes). Private well users are also advised to test their well water at least once a year for microbiological contamination, ideally after periods of extensive rainfall, and to install treatment systems when contamination signs are detected, however as mentioned, this is not formally regulated (EPA 2020).

Over the past three decades, precipitation volumes have increased by approximately 5%, with climate change projections predicting a marked increase in the number of "very wet days" (>20 mm); when applied to river flows, these figures point to a significantly increased risk of fluvial flooding and short duration 'flash' flood events, while measured sea level rises will make low lying coastal areas more prone to flooding, particularly from storm surges (Met Éireann 2018). Ireland has developed flood management plans in line with the EU Floods Directive (EU 2007) but due to frameworks connecting flood management with structural defences and the absence of a national flood forecasting and early warning system, dominant flood management in the RoI is principally aimed at urban areas (Clarke and Murphy 2019), while the majority of households supplied by a private well are located in rural regions.

2.2. Questionnaire design

To ensure survey brevity, promote completion rates, and collate a homogeneous, analytically comparable dataset, closed-ended questions and response choices were favoured, with open-ended options only presented when multiple choice alternatives did not represent respondent's experiences, attitudes, or opinions. The final questionnaire comprised 38 questions, and included multiple-choice, checkbox, Likert scale, numerical, and forced preference ranking style questions. Survey flow included two primary filters according to respondent's previous experience of groundwater quality analysis and previous adjacent (≤100 m) flooding (Fig. 1). Survey design targeted a maximum completion time of 10 min to minimise respondent fatigue (Cape and Phillips 2015), and was delineated into four distinct sections, namely i) respondent characteristics, ii) groundwater supply characteristics, iii) perception, behaviour and experience, and iv) health psychology (Table S1). To avoid order-effect bias (Perreault 1975), survey questions and available responses were presented in random orders where possible.

2.2.1. Section I: respondent characteristics

Section I comprised demographic and background questions, including respondent age range, gender, level of education, and yearly household income. Participants were also questioned about residential ownership, number of years living at current residence, administrative location, and settlement type (i.e. rural agricultural, rural non-agricultural and urban). The age of all household members was also collated to identify the presence of potentially vulnerable sub-populations (i.e. <5 years, >65 years).

2.2.2. Section II: groundwater supply characteristics

Respondents awareness of their domestic water source was examined, with persons supplied by surface waters, public sources, or bottled water excluded from further questioning. To establish source (and consumer) susceptibility to flood-triggered contamination and associated protective behaviours, the presence of basic well design features (i.e. casing, cap, cover), source proximity (<100 m) to potential hazards (e.g. septic tank, animal grazing, etc.), and the presence of water treatment prior to consumption (e.g. chlorination, UV treatment, reverse osmosis) were examined.

2.2.3. Section III: previous experience and perception of risk

Respondent's perception of flooding events as a potential risk to household water quality and health were investigated using two major components of risk perception: the cognitive component (i.e. likelihood estimates of well water contamination from future flooding) and the affective component (i.e. the feelings of worry associated with the occurrence of contamination from future flooding) (Slovic et al., 2004; Miceli et al., 2008), with each measured on a four point Likert scale.

Respondent's previous experience(s) of local flooding were examined using visual aids (Figure S2). Choice options allowed answer filtering by degree of familiarity with flood experience and flood frequency. Experiential (i.e. "when") and conjectural (i.e. "if") responses to flood events were subsequently quantified, in addition to individuals' awareness of potential adverse human health impacts of groundwater contamination and if flooding events were historically correlated with these impacts. To establish engagement with associated behaviours, respondents were questioned regarding previous well water testing (frequency, barrier(s), motivator(s), and outcomes, where applicable).

2.2.4. Section IV: health psychology

2.2.4.1. Risk-Attitude-Norms-Ability-Self Regulation (RANAS). Five-point Likert scale questions were used to measure RANAS "Factor Blocks" relating to (experiential or conjectural) post-flood groundwater mitigation measures via a series of positive and negative impact statements (Table S1). A "Do Not Know" option was not provided as statements were based on both opinion and existing knowledge. As shown (Figure S1), the RANAS model is based on 16 "Behavioural Factors" corresponding to "Factor Blocks"; due to the infrequent and sporadic nature of flooding, five behavioural factors were not examined, as they deviated from the study objective, namely: i) maintenance self-efficacy, ii) recovery self-efficacy, iii) action control/planning, iv) coping planning, and v) remembering. Remaining factors (n = 11) were each represented with a minimum of one statement, with 14 statements presented in total.

2.2.4.2. Health Belief Model (HBM). Within the Likert scale questions included as part of the RANAS model framework, survey statements on Perceived Vulnerability, Perceived Security, Instrumental Beliefs, and Self-efficacy are also comprised within the HBM (Figure S1; Table S1). Accordingly, the primary HBM element included for investigation was "Cues to Action", with respondents asked to rank the main reasons that would (did) lead them toward undertaking "healthy behaviours" (e.g. post-flood well testing), from a list of alternatives obtained from previous studies (Imgrund et al., 2011; Kreutzwiser et al., 2011; Malecki et al., 2017).

2.3. Survey completion

In accordance with best practice (Cape and Phillips 2015), a small-scale pilot study (n = 21) was carried out before final survey initiation to refine the survey instrument and completion method. Pilot study participants were asked to provide input on questionnaire structure, order and clarity, language, potential bias, and overall survey length. All pilot participant input was considered, with the final survey receiving approval by University College Dublin (UCD) Human Research Ethics Committee (Ref: HS-17-47-deAndrade-O). Surveying was undertaken between November 2017 and February 2018, with all surveys completed via an internet-based questionnaire. The questionnaire was hosted on an online cloud-based survey application (SurveyMonkey) and circulated to the target population through several non-professional interest groups and institutions with established rural connections. Prospective respondents were briefed about study objectives via an introductory webpage and informed that survey participation was entirely voluntary and confidential. All Irish residents over 18 years of age and supplied by a private domestic well or a private group water scheme were targeted for participation. No financial incentive was offered.

2.4. Data preparation and statistical analysis

Respondents' capacity to manage the risk of waterborne infection, under normal conditions, was measured through adoption of two primary protective behaviours, namely implementation of an effective water treatment system and periodic water quality testing (Table 1). Accordingly, respondents were grouped into four categories: (i) adopted both behaviours, (ii) water treatment only, (iii) testing only, (iv) no behaviours adopted. Based on the experiential and conjectural responses of study participants to flood events, respondents were also grouped into two categories, representing their capacity to deal specifically with a flood-induced contamination risk: (i) respondents adopting any action revealing a proactive attitude (i.e. seek information, boil water before consumption, chlorinate well water, test well water, use other sources for drinking purposes, try to prevent contamination ingress into the

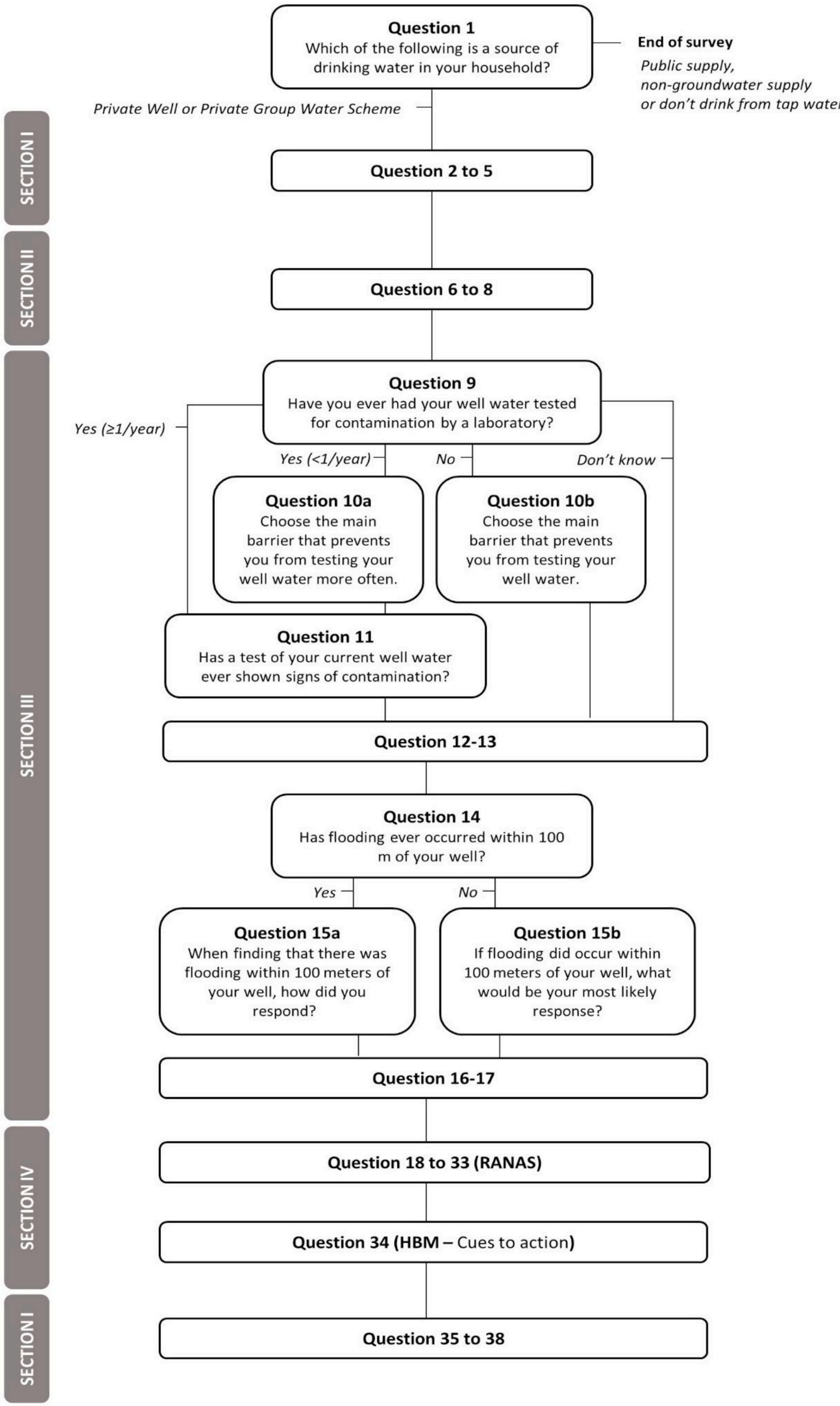

Fig. 1. Survey scheme and sectioning. All questions/answer options are reported in Table S1.

Table 1
Primary variables used for analysis. For each variable, we present: the type of variable (C: categorical, Cn: continuous, D: dichotomous, Ds: discrete), the survey item(s) used to define it, the survey question (in parenthesis the type of answer provided to respondents), and preparation of variables/categories' preparation). The extended version of this table, including all survey items, is presented in Supplementary Materials (Table S1).

Variable (type)	Categories	Survey items	Survey question	Data preparation
Management of ordinary risk (C)	•Water treatment •Water testing •Water treatment and testing •No actions	Water treatment	Do you apply any of the following to your well water before consuming it?(Checkbox)	Water softener, jug or Cartridge filters were not considered as effective water treatment system, according to the study aim.
		Well testing	Have you ever had your well water tested for contamination by a laboratory? (Multiple choice)	Only respondents that performed water test with annual frequency are considered as adopting a water testing behaviour.
Management of flood-inducedcontamination risk (D)	•Protective actions •No actions	Conjectural responses to flood events	If flooding did occur within 100 m (110 yards/330 feet) of your well, what would be your most likely response? (Multiple choice)	Conjectural and experiential responses were jointly considered, unless otherwise specified. All answer options (Seek information, Boiling, Chlorinate, Testing, Drink from other sources, Try to prevent contamination) except "Not aware", "No action", "Other", were considered as suitable protective actions.
		Experiential responses to flood events	When finding that there was flooding within 100 m (110 yards/330 feet) of your well, how did you respond? (Multiple choice)	
Floods experience (D)	•Yes •No	Flood experience	To the best of your recollection, has flooding (as shown in the following pictures) ever occurred within 100 m of your well? (Multiple choice)	Only direct experiences of floods (i.e. within the household) were considered as prior experience of flood. Answers by respondents with indirect experience (i.e. that know someone who experienced flood) were not included in the model.
Risk exposure (C)	•High and Intermediate risk •Low risk •Not aware	Presence of adjacent contaminant sources	To the best of your knowledge, is your well located less than 100 m (110 yards/330 feet) from any of the following? (Checkbox)	•**High risk**: presence of at least one contamination source and lack of well design protective features •**Intermediate risk**: presence of at least one contamination source or lack of well design protective features •**Low risk**: absence of adjacent contamination sources and presence of at least one well design protective feature •**Not aware**: lack of information on at least one of the two survey items High and intermediate risk were considered together in the model.
		Presence of well design protective features	To the best of your knowledge, does your well have any of the following features? (Checkbox)	
Risk perception (Cn)		Likelihood of well water contamination for future flooding	In your opinion, how likely is it that your well water quality could be negatively impacted by future flooding? (4-point Likert-scale)	The mean value of the two items was calculated and used as summary estimate of the overall risk perceived.
		Worry about well water contamination caused by future flooding	Are you worried that your well could be contaminated by future flooding? (4-point Likert-scale)	

Table 2
Description and summary statistics of RANAS and HBM psychological elements, as they were reported in the survey and coded for multi-model inference.

RANAS/HBMPsychological elements	Acronym	Question type	Survey question	Variable type	Coding	Mean (std. dev.)	Frequency
Perceived vulnerability/ Perceived susceptibility	PV_PSu*	5-point Likert-scale	"My well can become contaminated if flooding occurs within 100 m (110 yards) of it"	Continuous	1 (Strongly Disagree) to 5 (Strongly Agree)	3.50 (1.19)	
Perceived severity/ Perceived seriousness	PS_PSe*		"My life would be impacted if I or a member of my household became ill with symptoms of diarrhoea and/or vomiting"		1 (Strongly Disagree) to 5 (Strongly Agree)	4.39 (0.65)	
Factual knowledge/	FK1		"You can always tell when well water is contaminated by its taste, colour or smell"		5 (Strongly Disagree) to 1 (Strongly Agree)	3.55 (1.22)	
Factual knowledge/	FK2*		"Wells can stay contaminated for weeks after the flood period has passed"		1 (Strongly Disagree) to 5 (Strongly Agree)	4.18 (0.84)	
/Perceived benefits	PBe*		"Testing my well water in a laboratory is the only way to know that it is safe to drink"		1 (Strongly Disagree) to 5 (Strongly Agree)	4.24 (0.80)	
Instrumental beliefs/ Perceived barriers	IB_PBa		"Getting my well water tested in a laboratory is an easy task"		1 (Strongly Disagree) to 5 (Strongly Agree)	2.95 (1.57)	
Affective beliefs/Perceived benefits	AB_PBe		"After a flood I would worry less knowing that my well water is tested by a laboratory"		1 (Strongly Disagree) to 5 (Strongly Agree)	4.18 (0.82)	
Descriptive norms/	DN*		"People I know would test their well water if flooding occurred near their well"		1 (Strongly Disagree) to 5 (Strongly Agree)	2.55 (0.86)	
Injunctive norms/	IN*		"People who visit me expect me to ensure my well water is safe to drink and not contaminated"		1 (Strongly Disagree) to 5 (Strongly Agree)	3.70 (1.07)	
Personal norms/	PN1**		"I would feel personally obligated to test my well water after flooding occurred near my well"		1 (Strongly Disagree) to 5 (Strongly Agree)	3.28 (0.89)	
Personal norms/	PN2**		"if I notice that my well is flooded, I would feel personally obligated to test my well water"		1 (Strongly Disagree) to 5 (Strongly Agree)	3.86 (0.88)	
Action Knowledge/Self-efficacy	AK_Sef*		"I know who to contact to get my well water tested"		1 (Strongly Disagree) to 5 (Strongly Agree)	3.388 (1.40)	
Self-efficacy/Self-efficacy	SE_Sef		"I am able to get my well water tested if I decide to"		1 (Strongly Disagree) to 5 (Strongly Agree)	3.73 (1.20)	
Commitment/	C		"I will test my well water if flooding occurs nearby"		1 (Strongly Disagree) to 5 (Strongly Agree)	3.39 (0.99)	
Cues to action	Cta*	Rating (Most important and second most important cues to action)	"To determine that it is safe to drink","If there is a change in smell, taste, or colour","If my well is covered by the floodwater","If family members or visitors become ill","If it is affordable for me to do so","If my neighbours and friends decide to test theirs","If I learn that some wells in my local area have become contaminated","If it is recommended by the local authorities","If that practice is advertised in the media (TV, internet, newspapers, etc.)"	Categorical (Most important cues to action)	Safe to drink Organoleptic changes Flood occurrence Illness Feasibility Friends behaviour Near contamination Authorities Media		0.38 0.11 0.15 0.18 0.04 – 0.09 0.05 0.01

*variables included in the *a priori* generalized linear model.
**variables combined in a unique variable (PN) to be included in the *a priori* generalized linear model, due to their internal consistency ($\alpha > 0.70$).

well), and (ii) respondents not adopting any protective actions.

Respondents individual perception of flooding as a potential trigger for waterborne infection within their household was evaluated considering both the cognitive and affective components of risk perception (Slovic et al., 2004). Accordingly, the mean composite value of (i) perceived likelihood of contamination due to future flooding and (ii) the associated feelings of worry, both measured on a 4-point Likert scale (Table 1), was calculated and used as a summary estimate of overall risk perception. Current risk exposure to well water contamination was evaluated based on the presence of basic well design features and occurrence of contaminant sources within 100 m of the respondents well, by defining four risk levels (Table 1): (i) high risk (i.e. presence of adjacent contamination sources and lack of well design protective features), (ii) intermediate risk (i.e. presence of adjacent contamination sources or lack of well design protective features), (iii) low risk" (i.e. absence of adjacent contamination sources and presence of well design protective features), and (iv) respondents unable to provide information about at least one of these features. It has been reported that a lack of awareness pertaining to self-risk exposure represents a risk in itself (Mohammed and Zungu 2015; Anthonj et al., 2018).

Multinomial and multiple logistic regression were used to identify sub-populations within the survey cohort that systematically failed to adopt protective behaviours against "ordinary" (non-event) and extraordinary (event) contamination risks, by examining the association between protective behaviours and respondent socio-demographic, perceptual or experiential characteristics (Cohen et al., 2013). Effect sizes are presented as Relative Risk Ratios (RRRs). One-way ANOVA and Kruskal Wallis tests were applied to identify the presence of associations between explanatory (independent) variables, followed by Bonferroni post-hoc comparisons ($\alpha < 0.05$). Regarding the adoption of protective behaviours in case of flooding, as a notably higher adoption of protective behaviours was observed among respondents that never experienced flooding ($\text{adoption}_{\text{no experience}}$: 83.0%; no $\text{adoption}_{\text{no experience}}$: 17.0%; n = 223), compared those that previously experienced flooding within 100 m of their well ($\text{adoption}_{\text{flood-experience}}$: 27.5%; no $\text{adoption}_{\text{flood experience}}$: 72.5%; n = 80), conjectural responses were examined for social desirability bias (Syme and Williams 1993). Specifically, reliability prior to logistic regression was ascertained via verification of the presence of consistency between risk perception and adoption of protective behaviours against normal groundwater contamination risks (i.e. non-flood conditions), with both variables expected to exhibit higher values compared to experiential responses. Thus, risk perception and adoption of ordinary behaviours were compared within respondent cohorts using one-way ANOVA and Chi-squared tests, respectively. The relationship between adoption of protective behaviours and prior experience (singular and plural) of flooding was determined using Chi-squared and Fisher's exact test, respectively, with the strength of association evaluated using Cramer's V (Cohen 1988). Due to the bias detection in conjectural responses, logistic regression was undertaken using only experiential responses (n = 80), while multinomial logistic regression comprised all respondents.

A multiple linear regression was fit comprising an (exposure * experience) interaction term (Cohen et al., 2013), to investigate the effect (lack) of risk factor awareness on respondents' risk perception and if these effects differed based on prior experiences of flooding events, well water contamination or water-related gastroenteric symptoms. Effects were evaluated both individually and concurrently (i.e. occurrence of any prior experience related to well water).

To identify the psychological elements that best predict the adoption of proactive behaviours during flood events, multi-model inference was performed with RANAS and HBM predictors, using an information theory approach based on the corrected Akaike Information Criterion (AICc; Bumham and Anderson 2002). Multi-model inference was used to account for uncertainty in model selection as a range selected variables may be associated with the behaviour of interest (Mundry 2011), as in the case of RANAS and HBM health models. Specifically, an *a priori* generalized linear model, with a binomial error term and logit link function, was employed using all combinations of selected predictors. Subsequently, the subset of best-fit models was selected based on the AICc criterion (ΔAICc <1) and used to estimate coefficients and standard errors by weighted model averaging. To provide improved evidence for the relevance of each predictor in the context of considered model subsets, the Relative Importance Value (RIV) was calculated by

Table 3
Respondents characteristics compared to national population.

Demographic Characteristic	Sample (n = 405)	National population
Median Age (yrs)	35–49	36.8[a]
Gender Ratio (M/F %)	58.5/41.5	49.7/50.3[a]
Elderly (>65 yrs) Pop (%)	12.8	13.07[a]
Homeownership (Own %)	88.6	82[ac]
Median Household Income	€40,000 - €60,000	€57,184[a]
Mean Household Size	3.4	2.84[ac]
Median Education	Primary (3rd Level) Degree (72.8%)	Primary (3rd Level) Degree (52%)[b]

a CSO, 2017; b OECD, 2017, c Rural areas.

Table 4
Prior experience and risk exposure of respondents, and statistical associations with their risk perception degree. Mean number of adjacent contaminant sources (<100 m) for respondents with high and intermediate risk is reported. Percentage are calculated on the entire study sample (n = 405).

	%	Risk perception (mean score)	Test Statistic	p-value	Contaminant sources (median)
Prior experiences					
Flood	19.8	2.41[a]	104.4[c]	<0.001	
Contamination	23.7	2.02[a]	9.284[c]	0.002	
Gastroenteric infection	3.7	2.73[a]	16.273[d]	<0.001	
Risk exposure			19.161[d]	<0.001	
High	5.4	1.90			2
Intermediate	64.0	1.66			2
Low	11.6	1.66			–
Not aware	19.0	2.12[b]			1[e]

[a] Significantly higher compared to respondents without prior experience, neither direct nor indirect.
[b] Significantly higher compared to respondents with intermediate or low risk.
[c] One-way ANOVA.
[d] Kruskal-Wallis.
[e] Only based on those respondents aware about the occurrence of adjacent contamination sources (67.5% of 'Not aware').

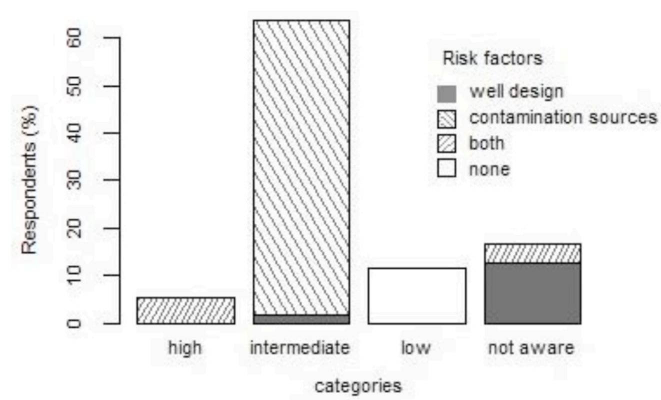

Fig. 2. Percentage of respondents associated with each risk exposure category and the related risk factors: lack of specific well design features, presence of contamination sources, both threats or none. For "not aware" category, legend classes refer to the lack of knowledge of these risk factors by respondents.

summing the AICc weights of models in which the predictor was included (Giam and Olden 2016).

Based on prior analysis of social desirability bias, conjectural responses were not considered reliable, thus multi-model inference was only undertaken for respondents with a prior experience of flooding events (n = 80). RANAS and HBM variables included in the *a priori* model (Table 2) were selected based on previous analysis, thus avoiding multi-collinearity, overfitting and ensuring an appropriate balance between case (80) and variable (9) number within the model (Harrell 2001). Internal consistency between survey items used to define the same psychological element was identified using Cronbach's alpha; variables exceeding the 0.7 cut-off were averaged (Nunnaly and Bernstein 1978). Multicollinearity was assessed using Spearmans' Rho, for continuous predictors, and the Generalized Variance Inflation Factor (GVIF), for all predictors, with 0.5 and 3 cut-offs, respectively (Coolican 2017). To permit comparison of GVIFs across dimensions, squared $GVIF^{(1/2 \times df)}$ values were calculated (df = degrees of freedom) (Fox and Monette 1992). Finally, further selection was carried out for those variables defining the same psychological element not averaged according to Cronbach's alpha, by running single-variable models and retaining the variable with the lowest AIC value, i.e. most notable effect on the dependent variable (Akaike 1973).

All statistical analyses were performed within the R statistical environment (R Core Development Team 2020).

3. Results

3.1. Respondent characteristics

In total, 464 respondents finished the survey. However, 59 of them were not considered suitable for the analysis, as they were supplied by other sources (e.g. surface waters, public sources, or bottled water), resulting in a study sample of 405 private well owners/users. Based on current estimates (Median 735,000 well users nationally), this survey sample size provides a 4.87% confidence interval (CI). In all, 58.5% of study participants were male, with a median age of 35–49 years (40.5%), a median educational attainment of "Primary (3rd Level) Degree", and a median income range of €40,000 - €60,000 (Table 3). All administrative counties within the RoI were represented within the sample population (Figure S3); no data currently exist pertaining to private well reliance at the administrative county level, thus geographical representativity could not be ascertained. Approximately four out of ten respondents (38.7%) reported the presence of a resident from a vulnerable sub-population in their household, 20% of which included ≥1 child <5 years old. Just under 70% (n = 280) of respondents had resided at their current household location for >10 years (≥25th and 75th percentile periods of 2–5 years and 6–10 years, respectively). Almost all respondents' residences were situated in rural areas (52.8% in rural non-agricultural and 42.0% in rural agricultural areas); the remainder were situated in small villages, town and other (peri)urban settlements (5.2%).

3.2. Risk perception, risk exposure and prior experiences

Approximately one fifth of study participants reported having previously experienced flooding in the vicinity of their groundwater source (n = 80; Table 4), with 4.7% experiencing flooding on an annual or near-annual basis. A similar proportion of respondents (18.8%), knew someone (family member or friend) that had previously experienced flooding, thus representing a level of indirect flood experience. Approximately one quarter (23.7%) of those respondents that reported testing their well water at least once (73.8%) had detected faecal contamination (17.5% of all respondents), with the proportion of wells exhibiting a positive faecal indicator organism (FIO) test rising to 30.7% among respondents that test their well water for microbial contamination once per year, i.e. comply with current (Irish) EPA recommendations (EPA 2020). Direct experience of gastroenteric symptoms within the household as a supposed result of drinking well water were reported by just 3.7% of study participants. One quarter of reported infections (n = 8), occurred during or shortly after a local flooding event.

Overall, 64% of respondents reported exposure to an intermediate level of risk, with their household source adjacent to recognized sources of microbial contaminants (median: 2.0, max: 7), albeit in the presence of basic wellhead design features (Fig. 2; Table 4). A lack of both contamination sources and protective features occurred infrequently (2.7% of respondents with intermediate risk). Low risk exposure was reported by 11.6% of participants and high risk by 5.4%. Respondents associated with a "high risk" classification reported a median of 2 adjacent (<100 m) contaminant sources. Almost one fifth of respondents (19.0%) were not able to provide the information required to evaluate their risk exposure, most of whom (67.5%) did not know if their well is/was protected, while 24.7% were not aware of the presence of both adjacent contaminant sources and well-specific protective features.

Well water contamination by future flood events was not generally perceived as a tangible risk; 69.7% of study participants considered this event unlikely or very unlikely (Fig. 3a). Similarly, a low level of concern was reported, with 85.6% of study participants stating they are only slightly or not at all worried (Fig. 3b). The mean calculated risk perception score was 1.75 (25th percentile: 1.00; 75th percentile: 2.00; Fig. 3c). Risk perception changed significantly based on prior respondent experiences (Fig. 4; Table 4). Study participants with at least one previous positive FIO test perceived a significantly higher risk (mean:

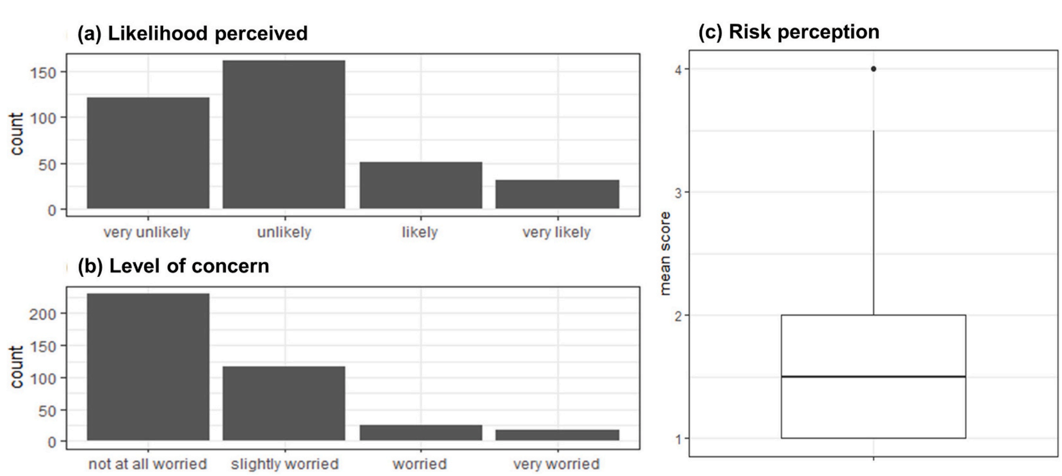

Fig. 3. Risk likelihood perceived (a) and level of concern (b) for well water contamination caused by future flooding. Overall risk perception distribution (c).

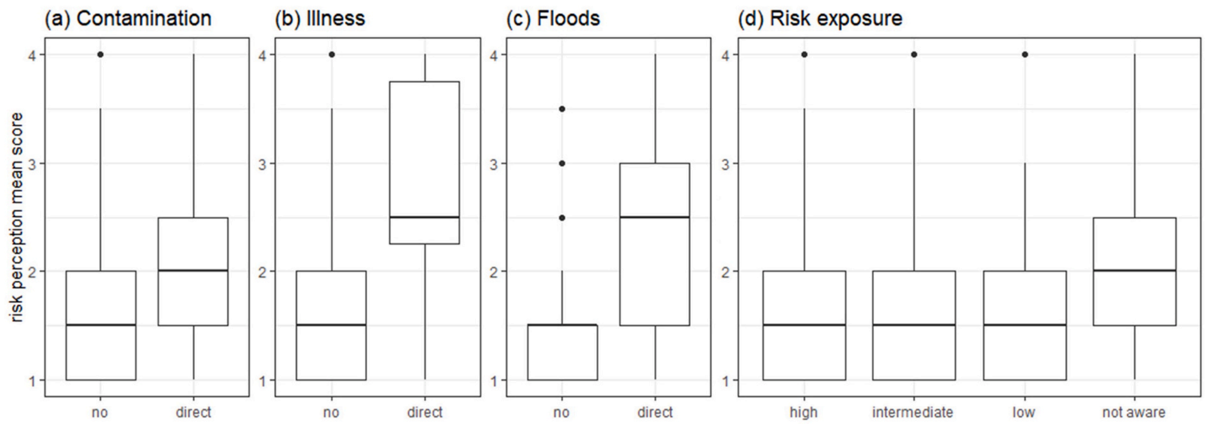

Fig. 4. Risk perception distribution by prior experience of contamination (a), gastroenteric infection for drinking well water (b) and floods (c). Risk perception score by risk exposure category (d).

2.02) compared to those that had not (mean: 1.68) ($p = 0.0025$). Similarly, mean risk perception was higher among respondents that experienced flooding or infection ($mean_{floods}$: 2.40; $mean_{illness}$: 2.73) compared to those that had not ($mean_{floods}$: 1.46; $mean_{illness}$: 1.68) ($p < 0.001$). Risk perception was significantly higher among participants not able to provide information required to evaluate their current risk exposure, compared to those with intermediate and low risk exposures ($mean_{low}$: 1.66; $mean_{intermediate}$: 1.66; $mean_{not\ aware}$: 2.12; Table 4) ($p\text{-}value_{low\text{-}notaware}$: 0.020; $p\text{-}value_{intermediate\text{-}not\ aware}<0.001$). Risk perceived was also slightly higher, although not significantly, among respondents structurally exposed to a higher risk ($mean_{high}$: 1.90).

3.3. Protective behaviours against "non-event" contamination risk

Findings indicate that 62.7% of respondents do not adopt any protective measures to prevent day to day (i.e. non-event) contamination, irrespective of flooding, with annual water testing and effective water treatment systems adopted by just 10.1% of respondents; individually, water treatment and annual testing were employed by 18.5% and 8.6% of participants, respectively.

Based on results of multinomial logistic regression (Table 5), no specific population sub-groups were significantly associated with lower adoption of basic protective behaviours, compared to levels of implementation observed within the total sample. Conversely, specific respondent groups exhibited a higher likelihood of undertaking protective measures, including older respondents, respondents associated with higher incomes (Table 5) and those previously experiencing well water contamination via test confirmation (Table 6). Among those respondents associated with an FIO positive groundwater test, the risk of missing all protective measures was significantly lower than that observed within the total survey cohort (RRR: 0.24; p-value: 0.003); overall, 43.7% of respondents that had prior evidence of contamination opted for the use of a water treatment system while 23.9% did not adopt any protective behaviour. Annual income was the only socio-demographic variable significantly associated with concurrently adopting both water treatment and annual water testing. The likelihood of failure was reduced by approximately 30% as the income of respondents increased ($RRR_{no\ measures}$: 0.692; $p\text{-}value_{no\ measures}$: 0.030; $RRR_{annual\ test}$: 0.652; $p\text{-}value_{annual\ test}$: 0.072; $RRR_{treatment\ system}$: 0.632; $p\text{-}value_{treatment\ system}$: 0.017). A majority of study participants that did not adopt any baseline protective measure (64.7%) or only adopted water treatment (78.7%) reported having performed at least one previous well test, but not regularly testing their well water. The primary reason for not testing well water or not testing more frequently within both groups was a lack of concern about water quality (35.3% of respondents not adopting any measure; 20.0% of respondents adopting water treatment only; Fig. 5). Notably, "normality" (i.e. FIO negative) of a previous test was the second most important reason among respondents not currently adopting any protective measure (23.8%). The cost of testing was also selected as a barrier within both groups (12.7% of respondents not adopting any measure; 17.1% of respondents adopting water treatment only).

3.4. Adoption of event-based healthy behaviours

Overall, 71.9% of respondents stated that they undertook (experiential) or would undertake (conjectural) some form of protective action. However, adoption of healthy behaviours was significantly lower among respondents with prior experience of flooding ($p < 0.001$; Cramer's V: 0.53): 72.5% of those with flooding experience stated that they did not adopt protective behaviours, compared to 17.0% of respondents that never experienced floods. This trend was also confirmed among respondents regularly affected by floods (i.e. annual or near-annual) with a failure to adopt healthy behaviours significantly higher compared with other respondents (89.5%; $p < 0.001$; Cramer's V: 0.30). Over-reporting of proactive behaviours when respondents cannot refer to a personally experienced event (i.e. conjectural responses) was notable in this case, with 83% of respondents stating that they would adopt some protective action. However, the lack of a consistent pattern in both their risk perception and adoption of protective behaviours against the "ordinary" (non-event) risk of well water contamination points to the presence of a desirability bias, thus conjectural responses were adjudged as being unreliable for further analysis. Two primary contradictions were identified: (i) adoption of protective behaviours against non-event contamination risks by respondents providing a conjectural answer concerning floods is not significantly higher, but instead lower (65.0% do not adopt behaviours compared to 55.0% of respondents that experienced floods), and (ii) risk perception was significantly lower (mean: 1.46; p-value<0.001) compared to respondents with flood experience (mean: 2.40).

Logistic regression models for respondents with direct experience of floods show that those residing in a rural non-agricultural area exhibited an increased likelihood (136%) of having never implemented protective behaviours (Table 5). Conversely, among respondents reporting experience of both well water contamination and flooding (albeit independently of each other), respondents' behaviour was significantly changed, insofar as they were 47% more likely to adopt protective behaviours (RRR: 0.53; $p = 0.007$; Table 6). Overall, as observed for the implementation of protective behaviours against non-event contamination risks, in the event of flooding, a high percentage of private well users failed to adopt a proactive attitude (47.6%). The primary actions undertaken by these respondents when floods occurred were the use of other sources for consumption (e.g. bottled water), well water testing and prevention of contamination ingress to the well (Fig. 6).

Table 5
Multinomial logistic regression (MLR) and logistic regression (LR) models predicting the adoption of protective behaviours for non-event and flood-induced contamination risks, respectively, by socio-demographic characteristics. Estimated relative risk ratios are reported; p-values are in parentheses. For categorical explanatory variables the analysed and reference levels are reported in parenthesis in that order: "analysed level: reference level".

	Ordinary risk(MLR)			Flood-induced risk(LR)
	n = 405			n = 80
	Response variables[a]:			Response variable[b]:
	No behaviours	Annual test	Treatment system	No behaviours
Age [c]	0.969*(0.096)	0.970(0.239)	0.982(0.410)	0.999(0.842)
Gender(Female: Male)	1.868(0.132)	2.270(0.140)	1.510(0.377)	0.829(0.325)
Income [c]	0.692**(0.030)	0.652*(0.072)	0.632**(0.017)	1.015(0.832)
Education(Technical: Secondary)	0.942(0.925)	2.160(0.552)	0.581(0.476)	0.992(0.973)
Education(3rd level: Secondary)	1.742(0.322)	5.844(0.128)	1.705(0.340)	0.836(0.493)
Residential duration(6–10 years: 0–5 years)	3.677(0.135)	0.711(0.769)	2.046(0.466)	—
Residential duration(>10 years: 0–5 years)	1.345(0.605)	0.337(0.137)	0.709(0.591)	—
Settlement Type(Rural: Rural on a farm)	1.079(0.849)	0.881(0.823)	2.006(0.137)	1.361*(0.073)
Settlement Type(Urban: Rural on a farm)	0.990(0.991)	2.435(0.405)	1.903(0.510)	—
Property Ownership(Owner: Other)	0.562(0.475)	1.864(0.576)	1.190(0.850)	—
Residents [c]	1.025(0.849)	1.223(0.257)	1.169(0.276)	0.980(0.710)
Presence of children(yes: no)	0.217*(0.066)	0.564(0.694)	0.344(0.253)	0.810(0.664)
Presence of vulnerable population(yes: no)	2.579(0.131)	0.401(0.460)	2.104(0.296)	1.116(0.678)

[a] compared to the ordinary adoption of both protective measures against contamination risk.
[b] compared to the adoption of healthy behaviours in case of floods.
[c] variables included in the model as discrete variables. More details in Table S1.
*p < 0.1, **p < 0.05, ***p < 0.01.

3.5. Behavioural barriers and motivators

Based on Cronbach's alpha diagnostic, the two variables measuring personal norms (i.e. PN1, PN2) were combined into a unique predictor, i.e. PN, as they exhibited high internal consistency (α: 0.71). Conversely, the variables used to define the relevance of factual knowledge (i.e. FK1, FK2) and those measuring perceived benefits (i.e. PBe and AP_PBe) captured different nuances of the same construct ($\alpha_{FK1\text{-}FK2}$: 0.37; $\alpha_{PBe\text{-}AP\_PBe}$: 0.46). However, according to single-variables models, FK1 (AIC_{FK1}: 98.07; AIC_{FK2}: 91.15) and AP_PBe (AIC_{AP_PBe}: 97.98; AIC_{PBe}: 97.32) were not retained for multi-model inference. Similarly, the variables related with Commitment (C), Self-efficacy (SE_Sef), and Instrumental beliefs (IB_Pba) were not included in the *a priori* generalized linear model due to multicollinearity with other psychological elements (Table S2). No multicollinearity was detected via the GVIF collinearity diagnostic (Table S3). The *a priori* GLM model comprised 9 variables (Table 1), with 512 possible variable permutations tested. Based on AICc, four best-fit models were selected, with five variables included (Table S4).

Among the variables included in the best models, RIVs and full averaged coefficients (Fig. 7) identified two main psychological elements as the best predictors of adopting protective behaviours in the case of flooding, namely perceived vulnerability (i.e. knowledge of the contamination risk associated to flooding events; PV_PSu) and personal norms (i.e. the feeling of being personally obligated to test personal water source when flooding occurs; PN). Both elements were present in all best-fit models (RIV: 1.00). The expectation of safe water by people visiting well owners' residence (IN), although less relevant, may also have a positive effect on adoption of healthy behaviours in some cases (RIV: 0.24). Conversely, both perceived severity (symptoms of gastroenteric infection; PS_PSe) and perceived benefits (PBe) were weakly associated with the failure to adopt protective behaviours (RIV_{PS_PSe}: 0.22; RIV_{PBe}: 0.23).

4. Discussion

Human-groundwater relationships are complex, particularly when faced with sporadic interferences like flooding, thus further knowledge

Table 6
Multinomial logistic regression (MLR) and logistic regression (LR) models predicting the adoption of protective behaviours for ordinary and flood-induced contamination risk, respectively, by risk exposure and prior experience. The number of observations in LR model varies according to the presence of missing values in one or more variables. Estimated relative risk ratios are reported; p-values are in parentheses. For each variable the analysed and reference levels are reported in parenthesis in that order: "analysed level: reference level".

	"Ordinary" risk(MLR)			Flood-induced risk(LR)
	n = 405			n = 62
	Response variables[a]:			Response variable[b]:
	No behaviours	Annual test	Treatment system	No behaviours
Risk exposure(High or intermediate: Low)	0.985(0.980)	1.234(0.780)	0.803(0.757)	1.343(0.202)
Risk exposure (Not aware: Low risk)	2.551 (0.328)	3.836 (0.242)	1.324 (0.794)	1.031 (0.935)
Contamination experience (Yes: No)	0.240*** (0.003)	0.512 (0.258)	1.837 (0.219)	0.525*** (0.007)
Floods experience (Yes: No)	1.036 (0.942)	1.313 (0.644)	1.290 (0.631)	–

a compared to the ordinary adoption of both protective measures against contamination risk.
b compared to the adoption of healthy behaviours in case of floods.
*p < 0.1, **p < 0.05, ***p < 0.01.

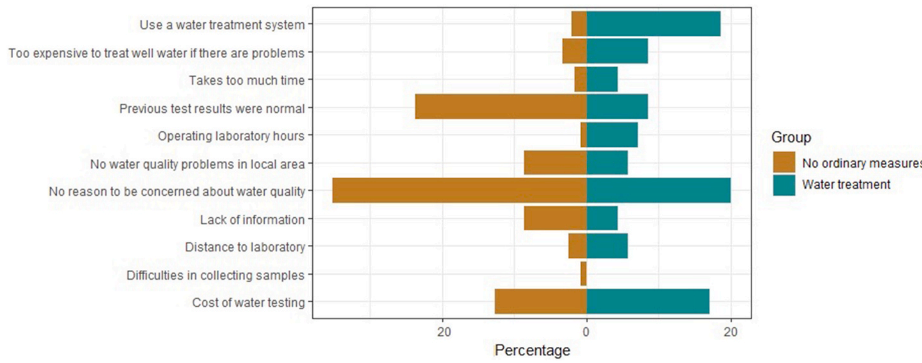

Fig. 5. Reasons for not testing well water or not testing it more often from respondents that currently do not adopt any ordinary protective measure or only adopt water treatment.

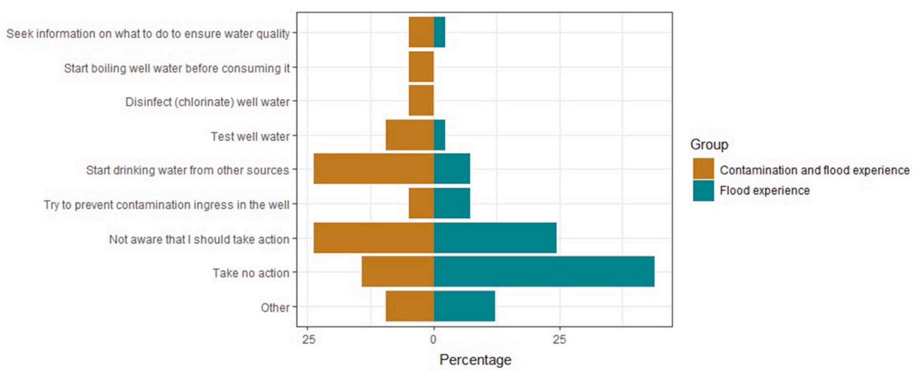

Fig. 6. Health behaviours adopted by respondents that experienced floods in the past or experienced both floods and contamination.

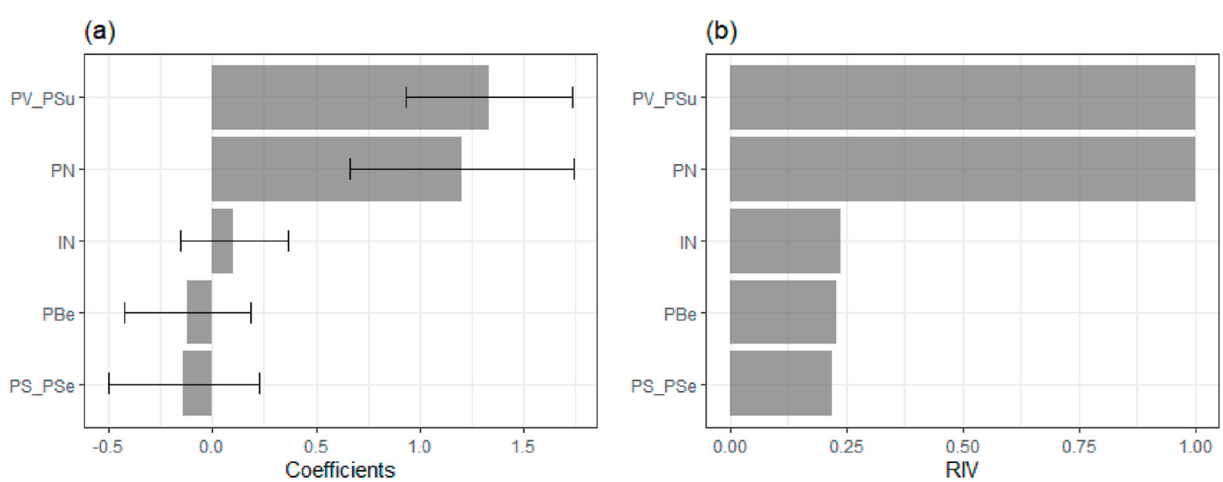

Fig. 7. Model averaging of predictors included in the best-fitting models (ΔAICc $<$ 1; n = 80). Full averaged coefficients ± their standard errors (a), and Relative Importance Values (RIV; b) are shown (IN: Injunctive norms; PBe: Perceived benefits; PN: Personal norms; PS_PSe: Perceived severity; PV_PSu: Perceived vulnerability). The estimation of full averaged coefficients assume that a predictor is included in every model, but in some models the coefficient is set to zero (Bartoń 2020).

pertaining to the internal and external factors driving risk perception and protective behaviours are required for developing appropriate interventions (Hamilton et al., 2020; Schuitema et al., 2020). Compounding this, the likely increase in the frequency and severity of future flooding events due to anthropogenic climate change means that bottom up (i.e. "buy-in") intervention strategies rooted in knowledge-driven custodianship are paramount to reducing the potential public health burden of flooding, particularly among private groundwater users. Understanding people's perception of risk, their susceptibility, and assessing their willingness and promptness to take individual actions, is therefore a fundamental prerequisite (Munene and Hall 2019).

Results from the current study reveal that, from a behavioural perspective, the surveyed cohort exhibited a limited adoption of proactive behaviours even within households characterised as being located in areas prone to flooding (Fig. 6). Accordingly, this lack of self-protection against waterborne infection represents a concrete threat to private well users, with neither prior nor repeated experience shaping or affecting respondents' behaviours; this primarily rural population is thus highly susceptible to the risk of contamination induced by flood events. Moreover, while the incidence of adopting proactive behaviour in case of flooding was shown to increase in the presence of previous experiences of both flood events and source contamination (+47%), it should be noted that the percentage of private well users reporting a proactive attitude is still low in absolute terms (52.5%), with FIO testing remaining an infrequently adopted action (9.5%; Fig. 6). Findings indicate that rather than undertaking "recurrent" measures such as periodic monitoring and quality control, respondents reported a preference for alternative drinking water sources, thus favouring "avoidance coping" (i.e. placing a physical or psychological distance between themselves and the stressor) to (pro)active coping (i.e. taking action to manage the problem via information and support) strategies (Krohne 1993; Duhachek 2005).

Findings suggest that the risk of not adopting suitable behaviours is greater among well users residing in non-agricultural rural contexts and those physiologically more vulnerable to groundwater contamination exposure, thus highlighting population sub-groups characterised by higher levels of susceptibility (i.e. systematically neglecting protective behaviours against flood-induced contamination risk). Previous studies have shown that both opinions and behaviours frequently diverge with respect to settlement pattern type, with individuals and communities from increasingly urban settlements tending to perceive groundwater as being of lower quality (Hu and Morton 2011), while rural agricultural communities are more likely engaged in proactive behaviours in case of extreme climate events, given their typically enhanced awareness of human-environment interactions (Boronyak-Vasco and Jacobs 2016). With respect to the greater levels of risk attributable to non-agricultural residents in rural areas, while no clear causative rationale was found, the authors consider that this may be due to a "simplified" perception induced by the perceived lack of contamination sources in the immediate vicinity i.e. lack of knowledge pertaining to livestock density, livestock vicinity, and hydrological cycling. Moreover, it is both notable and concerning that households associated with physiologically vulnerable residents with respect to waterborne infection (i.e. <5 years, >65 years) did not exhibit increased adoption of event-based healthy behaviours (Table 5). According to a recent review of factors influencing well water testing behaviour (Colley et al., 2019), the presence of vulnerable residents constitutes a "testing trigger" only when associated with the perception of risk and consequences of well water contamination. Thus, given the low risk perception in the surveyed population (Fig. 3) and, more generally, the limited attention given to post-flood health risks, by both mainstream media and the scientific community (Andrade et al., 2018; Hamilton et al., 2020), low adoption of proactive behaviours among physically "susceptible households" would appear to be widespread. Identification of population sub-groups systematically failing to adopt protective behaviours (i.e. physiologically vulnerable people and rural residents) represents a first step to prioritising local-scale behavioural interventions (Mooney et al., 2020a) and, in the longer term, implementing socio-environmental risk management strategies that combine both flood risk projections and social susceptibility data (Karagiorgos et al., 2016).

The general lack of proactive attitudes and ensuing behaviours during and after flood-induced contamination risks occur is perhaps unsurprising given that a high proportion of respondents do not mitigate against "ordinary" (non-event) contamination risks. In fact, periodic (i.e. non-event) stewardship, including both water treatment and frequent testing, was adopted by just 10.1% of the surveyed cohort, while over half of the survey sample adopted neither approach. Moreover, adoption of water treatment by well users seems to play a counterproductive role, as it was associated with lower implementation of water testing (Fig. 5), with water treatment alone not sufficient to ensure groundwater potability (Lothrop et al., 2015). Findings suggest that this lack of stewardship also applies to that portion of the population with previous flood experience. It should be noted that even within the portion of the population that reported having previously received evidence of contamination (23.7%), the percentage of respondents that did not attempt to put protective measures in place remained high (23.9%). As such, while positive FIO tests have been shown to increase retesting behaviours (Qayyum et al., 2020), the opposite is also true, representing a concern.

According to presented findings, several factors would seem to contribute to low adoption of suitable behaviours during and immediately after flood-induced contamination, as follows:

i) *Lack of awareness of flooding as a contamination driver*

Mirroring previous studies (Munene and Hall 2019), results show that risk awareness, when present, is undoubtedly associated with a proactive well stewardship (Fig. 7). However, both low risk perception and a lack of capacity to assess one's own risk exposure based on risk factor occurrence and/or proximity (Fig. 3, Table 4) indicate that a majority of the population do not possess adequate knowledge of the contamination risk and, specifically, of the cause-effect relationship between flooding and potential contamination of well water. Nevertheless, according to recent risk perception literature, to effectively promote adoption of appropriate behaviours, stakeholders' risk perception must be rooted in "relevant knowledge", i.e. knowledge that enable individuals to clarify and connect the causes and consequences of the risk (Visschers and Siegrist 2018). Conversely, when risk perception is based on non-specific knowledge, as generic information about floods or groundwater, misconceptions, complacency and/or adoption of irrelevant behaviours are expected (Kaiser and Fuhrer 2003; Wallquist et al., 2010).

ii) *Lack of belief regarding the general risk of contamination to which a source may be susceptible.*

Results (Fig. 5) point to some noteworthy dominant attitudes - among respondents that never tested their well water or tested it with insufficient frequency (<once per year), a high degree of confidence in well water quality (i.e. "no reasons to be concerned about water quality") was exhibited, thus resulting in the belief that testing was not required, with similar findings previously reported by Chappells et al. (2015). This attitude may be supported by the aforementioned "avoidance coping" strategy, according to which high confidence allows individuals and communities to maintain a psychological distance between themselves and the stressor (i.e. the prospect of having to deal with unfamiliar issues), in addition to the low reported incidence of confirmed waterborne infections among respondents (3.7%). However, it is widely recognized that many enteric infections (and particularly those associated with waterborne transmission) are under reported or misdiagnosed (Hynds et al., 2014).

Conversely, when adequate testing is being undertaken, there would seem to be a general sense of long-term "trust" in terms of its validity when negative FIO test results are obtained (i.e. if no contamination was observed, this situation will remain in place indefinitely). This may be due to the perception of water quality as being a "static" property (Qayyum et al., 2020), while in reality the risks associated with well water consumption may change seasonally and in some cases, rapidly due to unforeseen, uncontrollable events/factors. For example, Latchmore et al. (2020) report that *E. coli* detection rates among private wells in Ontario significantly differed with respect to sampling season and aquifer properties, thus appropriate testing frequency should be defined according to this variability.

iii) *Barriers to private groundwater quality testing*

One of the primary reasons reported for failing to undertake water quality testing was financial cost (Fig. 5), with an increase in annual income associated with an increase in the probability that a well user will take protective measures against contamination (Table 5). These findings are consistent with prior investigations conducted in North America, where income has been identified as a significant predictor of adopting both water testing and treatment (Colley et al., 2019; Munene and Hall 2019). However, while several regions provide free testing services or incentives with some success (Flanagan et al., 2016b), well testing in the RoI is privately undertaken, even if financial costs are widely recognized by local experts from different fields of expertise (Mooney et al., 2020b). Future studies should seek to more accurately assess if this problem is *de facto* of an economic nature or a widely held perception based on summary or second-hand information, and thus, if removing the (potentially perceived) economic barrier would increase the likelihood of periodic source monitoring. Nevertheless, given the many evidences of their effectiveness, financial subsidies should be promoted as a valid support, at least in flood-prone areas. More generally, in light of study findings, the authors consider that the current approach in RoI which is based entirely on "self-responsibility" should be reconsidered, by providing a legislative framework in which private well stewardship is regulated. Specifically, a new policy should consider both ordinary and flood-induced contamination risk, by providing or supplying well water testing on an annual basis as well as during or immediately after extreme weather events. Beyond the practical advantages of exercising controls on groundwater quality and thus public health, the introduction of well testing as both a routine and an extraordinary practice, depending on weather conditions, represents a communication campaign in and of itself, indirectly improving the perception of risk and the need for behavioural adoption.

Overall, results highlight the significant effect of knowledge on risk perception. The latter, being the perceived probability that a flood event potentially causes groundwater contamination and the concerns derived from it, is lower among those who know they are exposed to a greater risk and higher among those who are unaware of the level of risk they are exposed to (Table 4). This pattern may seem counterintuitive, as one would expect risk perception to increase concurrently with awareness of factors associated with an elevated risk of contamination and subsequent infection. However, according to the Psychometric Paradigm by Slovic (1992), the "unknown risk" (i.e. risk unknown to science or to those exposed, a new risk or a risk producing unobservable or uncontrollable outcomes) is a major psychological determinant in shaping risk perception. A lack of familiarity with a hazard, or the link between the hazard and risk pathway or consequence, here measured through knowledge of their own risk exposure, has been shown to enhance its importance in respondents' perception (Visschers and Siegrist 2018). Conversely, a higher awareness of risk factors potentially affecting their own domestic source, in conjunction with the erroneous and/or misleading ideas or beliefs about groundwater contamination (e.g. potability, contamination mechanisms, groundwater occurrence and transport) (Fig. 5), may lead to a decrease in risk perception and resulting complacency. In this respect future investigations should aim to accurately assess the different knowledge types underlying risk perception, thus supporting the adoption of healthy behaviours (e.g. subjective and objective knowledge, concrete and generic knowledge; Kaiser and Fuhrer 2003).

Finally, from an integrated (ground)water management perspective, it is important to account for the influence of personal and social norms in defining behaviours (Fig. 7). According to presented analyses of the HBM and RANAS frameworks, beyond risk perception the second most effective factor influencing adoption of suitable behaviours when flooding occurs, was a feeling of moral obligation (i.e. Personal norms); a minor, but relevant, role is also played by the expectations of respondents' interpersonal network regarding water quality (i.e. Injunctive norms). Overall, these results associated with socio-psychological drivers of health behaviours, together with aforementioned findings regarding risk perception and knowledge, shed light on the essential features of future communication campaigns aimed to enhance the resilience of groundwater-reliant communities in the face of the increasing flood-related contamination risk. Findings clearly indicate that future strategies should be based on interventions at a very local scale, in such a way as to intercept common values and personal morality supporting proper well stewardship. Interestingly, these types of interventions are less common in economically developed regions, where large-scale, top-down communication campaigns are generally favoured (Hynds et al., 2018; Mooney et al., 2020a). As regards the practical implementation of these findings for future campaigns, unfortunately, to our knowledge, little is known regarding mechanisms of behavioural change based on personal norms activation when direct implications for stakeholders' health are at stake, as most studies are instead focused on promoting pro-environmental behaviours (e.g. outdoor water use, product consumption; Van Der Linden 2015; Landon et al., 2017; Joanes 2019). Thus, further work should seek to appropriately develop locally implemented interventions comprising normative factors in economically developed regions. In this regard, quali-quantitative social network approaches may provide a wider understanding on who the "specific audience" and the "knowledge brokers" are within well users networks, together with the characterization of normative factors within local communities, thus addressing both personal and injunctive norms (Mackie et al., 2015; Musacchio et al., 2019). In the interim, dissemination efforts should be based on relevant, evidence-based knowledge, underlining the nexus between cause(s) and consequence(s), in such a way that risk perception is increased.

5. Conclusions

The susceptibility of private well users to flood-triggered waterborne infections has received limited attention in economically developed regions. Findings from the current study indicate that the private groundwater-reliant population is not adequately prepared to cope with sporadic, meteorological contamination risks, highlighting its acute susceptibility to current climate change scenarios. On one hand, low levels of preparedness are a side effect of the limited adoption of proper well stewardship to deal with "ordinary" (i.e. under normal conditions) contamination risks, strengthened by several misbeliefs and misconceptions on groundwater quality and contamination dynamics. Conversely, a general lack of background knowledge of the nexus between floods and groundwater quality undermines the perception of the additional risk of waterborne infections conveyed by flooding. Within this framework of limited awareness and risk perception, direct experience of flooding events does not represent a relevant driver for behavioural change, even if experienced somewhat regularly. Dissemination of relevant knowledge and activation of both personal and social norms should be the cornerstones of future interventions, that in turn should be implemented at local scale. Simultaneously, the current legislative gap should be filled by providing or supplying well water testing to private well users on an annual basis as well as concurrently with extreme weather events.

The authors consider that presented findings may be used by multiple stakeholders to inform evidence-based guidance for flood risk mitigation and preparedness in areas characterised by high levels of reliance on private groundwater sources, and particularly areas at risk of pluvial, fluvial or coastal surge flooding. Moreover, study findings may be internationally transferable and through improved communication, intervention development, and health-based behaviours, can be used to avert the global incidence of climate-related endemic and epidemic waterborne gastroenteric infection.

Since the survey was administered between 2017 and 2018, it would be relevant to replicate it to assess whether individual perceptions have changed as a result of the SARS-CoV-2 pandemic, and in particular, if the current sanitary emergency has increased the risk perception of waterborne infections. Future research developments should also include the replication of the research in other countries that mainly rely upon groundwater for drinking and domestic purposes and are experiencing increasing flood events. Since flood events are becoming an issue of concern worldwide, a broader assessment would permit to unveil its impacts regardless to geographical region or economic asset.

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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.

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Appendix A. Supplementary data

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