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Assessment of two behavioural models (HBM and RANAS) for predicting health behaviours in response to environmental threats: Surface water flooding as a source of groundwater contamination and subsequent waterborne infection in the Republic of Ireland

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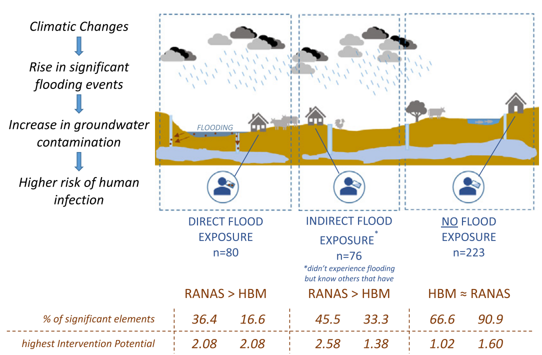
HIGHLIGHTS

- Comparison of two models of "health behaviour" following flooding
- 'Intervention Potential' scoring component to assess the Health Belief Model
- RANAS predicts health behaviours among those with flooding experience.
- RANAS predicts health behaviours among those with indirect flooding experience.
- HBM predicts health behaviours among those with no flooding experience.

GRAPHICAL ABSTRACT



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ABSTRACT

Extreme weather events (EWEs) are increasing in frequency, posing a greater risk of adverse human health effects. As such, developing sociological and psychological based interventions is paramount to empowering individuals and communities to actively protect their own health. Accordingly, this study compared the efficacy of two established social-cognitive models, namely the Health Beliefs Model (HBM) and Risks-Attitudes-Norms-Abilities-Self-regulation (RANAS) framework, in predicting health behaviours following EWEs. Surface water flooding was used as the exemplar EWE in the current study, due to the increasing incidence of these events in the Republic of Ireland over the past decade. Levels of prior experience with flooding were considered for analyses and comparative tools included a number of variables predicting health behaviours and intervention potential scores (i.e. measure of impact of targeting each model element). Results suggest that the RANAS model provides a robust foundation for designing interventions for any level of experience with an extreme weather event, however, use of the simpler HBM may be more cost-effective among participants unacquainted with an EWE and in relatively infrequent health threat scenarios. Results provide an evidence base for researchers and

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Flooding
Extreme weather events

policymakers to appropriately engage with populations about such threats and successfully promote spatiotemporally appropriate health behaviours in a changing climate.

1. Introduction

The rising frequency and severity of extreme weather events (EWEs) such as flooding or drought have myriad implications for human health (Wu et al., 2016). Due to their inherent potential to disturb local and regional hydrological regimes, EWEs represent a significant trigger for contamination of public and private water supplies, directly increasing the risk of human waterborne infections (Shuman, 2010; Semenza et al., 2012; Wu et al., 2016). This issue may be further complicated in the case of private groundwater supplies, due to widespread lack of regulation and the perception that groundwater is a universally safe drinking water source (Hynds et al., 2012; O'Dwyer et al., 2014; Flanagan et al., 2015). In most instances, government or central bodies are responsible for drinking water safety, thus, water treatment and testing are centrally overseen. However, in many areas including high-income regions (Murphy et al., 2016; Flanagan et al., 2018), private domestic (often groundwater) supplies are not covered by governing legislation. As such, the safety of these supplies is the sole responsibility of the private-well owner, including all source-related protective behaviours (e.g. source maintenance, testing and treatment), in order to protect household health and alleviate the burden on public health services posed by waterborne infections (Shreve et al., 2016).

The potential health risks posed by consumption from contaminated waterbodies are substantial (Hynds et al., 2014; Murphy et al., 2017), with 1.31 million deaths worldwide attributed to diarrhoeal diseases contracted through unsafe drinking water in 2015 alone (Troeger et al., 2017). While a majority of global mortality and morbidity associated with inadequate water quality occur in low-income regions, rates continue to persist in high-income countries (Hynds et al., 2013; Andrade et al., 2018). For example, Ireland currently has the highest incidence rate of verotoxigenic *Escherichia coli* in the European Union (EU), with the use of private domestic wells identified as a major transmission route (ÓhAiseadha et al., 2017). A recent review by Andrade et al. (2018) reports that while flood-related groundwater borne infection clusters/outbreaks are understudied, approximately 10,000 suspected individual cases and 1000 confirmed cases of acute gastroenteric infection have been associated with flooding of groundwater systems in the global scientific literature. The review reports that a majority of flood-related infection clusters were associated with high permeability and/or of karstic bedrocks, and thus, direct ingress of contaminated floodwaters represents a significant ingress mechanism as these hydrogeological settings are typically indicative of rapid subsurface pathways, and consequently, bypass of the natural attenuative processes afforded by the unsaturated zone.

In the social and psychological literature, actions intended to promote or maintain health, which in the context of private (ground) water supplies would include regular well water testing, supply inspection, and installing/maintaining adequate water treatment systems, are referred to as health behaviours (HBs) (Kasl and Cobb, 1966). A significant body of research has examined the factors that promote or inhibit them, however, these can be difficult to influence, as they require potentially costly and logistically complex long-term interventions (Blalock, 1979). Several social-cognitive models have been developed to identify the more personal and contextual variables that motivate HBs (Armitage and Conner, 2000). These models draw on various elements of motivational, social, and health psychology to identify the best axes on which to intervene and increase the likelihood that an individual or community will perform a given HB. Within the context of water-related HBs, the Health Belief Model (HBM; Rosenstock, 1974) and Risks, Attitudes, Norms, Abilities and Self-regulation (RANAS) approach (Mosler, 2012) are two of the most commonly applied. Both have been employed to assess risk perception and modify HBs in the field of environmental health (Huber and Mosler, 2013; Straub and Leahy, 2014; Flanagan et al., 2015, 2018; Lilje and Mosler, 2018).

Both the HBM and RANAS frameworks share a number of common features; however, they are characterised by marked practical and theoretical differences (Fig. 1). For example, the HBM, focuses on *personal* perceptions of the barriers, benefits, severity and susceptibility as *individual* responses to environmental stimuli. Conversely, the RANAS approach combines individual perceptions with social, normative, and environmental factors to examine individual behaviour within the socioeconomic context in which it occurs. In essence, the HBM is an individualist psychological model, whereas the RANAS approach accounts for the interaction between individuals, communities, and the environment and is thus defined as an interactionist approach (Turner and Oakes, 1986). These different psychological perspectives may be attributed to the underlaying motivations for each model's creation. The HBM was designed as a tool to assess the factors influencing HBs in relation to infectious disease in the United States (Rosenstock, 1974), while the RANAS approach was created to assist promotion of water-related HBs in the developing world, incorporating elements of previously established models and theories, including the HBM (Mosler, 2012). However, to date, the relative efficacy of these two models in assessing the motivation to perform a behaviour or predicting the likelihood of specific HBs have not been compared.

The overarching aim of the current research is to compare the HBM and RANAS frameworks as tools to i) assess the motivation (s) to undertake (ground)water-related HBs by private supply owners and ii) subsequently predict the performance of HBs in response to EWEs. Additionally, as experience can strongly influence risk perception (Chappells et al., 2015) and subsequent HBs (Severtson et al., 2006), differing levels of personal experience with EWEs was explored as a potential modifier of model efficacy. The authors consider that given the global increase in EWE frequency and severity, their adverse health outcomes, and the growing use of socio-cognitive models, results from the current study will provide an evidence base for researchers and policymakers to appropriately engage with populations about such threats and successfully promote spatiotemporally appropriate HBs.

2. Methods

2.1. Study area

The Republic of Ireland (RoI) has a temperate maritime climate, characterised by persistent rainfall events throughout the year (Met Éireann, 2018) and a highly heterogeneous geological profile (Hynds et al., 2012). Recent climate projections indicate that the incidence, severity and timing of extreme rainfall events and flooding will increase dramatically over the next century, with the RoI projected to be the second most affected European country in terms of the mean population proportion residing in flood-prone areas by 2100 (Arnell and Gosling, 2016; Forzieri et al., 2017). Compounding this, recent work has shown that waterborne VTEC outbreaks are significantly associated with persistent, high-intensity antecedent rainfall in the RoI, particularly

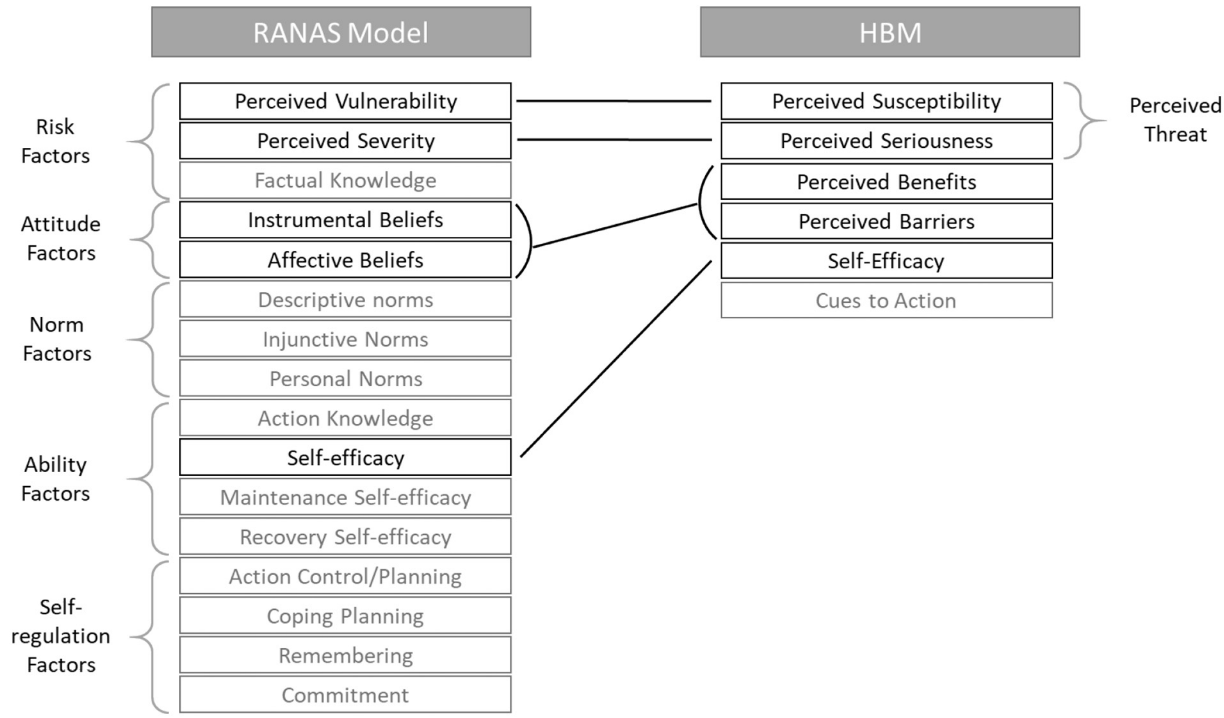

Fig. 1. Schematic representation of the RANAS and HBM frameworks and respective elements, with commonalities between the two frameworks presented in bold text.

among private well users (O'Dwyer et al., 2016). This is of particular concern in the RoI, as approximately 750,000 people (16% of national population) rely on unregulated private wells as their primary source of drinking water (CSO, 2012).

Most private groundwater supplies in Ireland serve <50 persons and/or extract <10 m^3/day, and are thus exempt from the European Commission Drinking Water Directive 98/83/EC, freeing owners and users from the legal compulsion to test or treat their supplies (i.e. primary HBs). Accordingly, primary responsibility for ensuring appropriate water quality falls on the end user. Therefore, implementation of measures to mitigate contamination risks and subsequent health outcomes are entirely voluntary, thus necessitating appropriate levels of knowledge and risk perception by owners/caretakers.

2.2. Data collection

The study dataset was collated via an online questionnaire targeting private groundwater users in the RoI and was conducted between November 2017 and February 2018. The questionnaire comprised 38 questions and was designed with a maximum completion time of 10 min, thus avoiding potential respondent fatigue (Cape and Phillips, 2015). Questions types ranged from multiple-choice ($n = 18$), 5-point Likert scale ($n = 15$), checkbox ($n = 3$), numerical ($n = 1$), and forced preference ranking ($n = 1$), and covered four main themes related to 1) socio-demographical characteristics, 2) flood experience, 3) experiential and conjectural responses to flooding (i.e. HBs taken by those who have experienced floods near their groundwater supply versus intended HBs by those who have not), and 4) HBM and RANAS model questions (Appendix 1). Section 4 comprised a series of Likert scale responses to statements related to each model element, and one ranking question (Table 1). Model statements sought to establish the factors that motivate or inhibit respondents to engage in HBs following significant flooding, with the ranking question used to establish the number of "cues" necessary to prompt a post-hazard HB. All questions include in Section 4 utilised the action of testing the groundwater supply following flooding events as an indicator for all potential HBs, as groundwater testing is the first recommended HB if contamination is suspected (Simpson, 2004), with regular testing a commonly used indicator of general well stewardship practices (Kreutzwiser et al., 2011).

The RANAS model comprises 16 behavioural factors (i.e. elements; Fig. 1), 11 of which were incorporated into the study questionnaire (Table 1). Most EWEs, including significant flood events, are sporadic and relatively unpredictable (i.e. specific event timing and consequences are difficult to establish). Thus, the five excluded RANAS variables (maintenance self-efficacy, recovery self-efficacy, action planning, coping planning, and remembering) were not considered concomitant with overarching study aims. Conversely, the HBM comprises just five elements (Fig. 1), all of which were considered directly relevant to this study, and thus included (Table 1). A brief description of the five HBM and 11 RANAS elements included in this study are shown in Supplementary materials (Appendix 2). The RANAS model was designed to precede and inform the development of community interventions, and as such, includes an additional component, namely, intervention potential (IP). IP scores aim to measure each psychological element in terms of its influence on the studied behaviour in order to identify factors that should be targeted by behavioural interventions (Mosler, 2012).

The survey was initiated in November 2017 and continued over a 4-month period until February 2018, with an online recruitment and completion approach employed. The questionnaire was hosted on a cloud-based survey application and distributed among the rural Irish population via several non-professional interest groups. Respondent recruitment was initiated via distribution of an introductory email, which outlined the overall study objectives and procedure. Prospective respondents were ensured that study participation was entirely voluntary and confidential, with no potentially identifiable data collated. No financial reward was offered to participants, with all private well owners/users over 18 years of age and currently residing in the Republic of Ireland considered eligible to apply. It is important to note that while every attempt was made to ensure both data and overall study quality complied with the highest standards of scientific research, the selected approach comprises a number of inherent limitations which are included in the article discussion (Section 4).

Table 1
Section iv questions belonging to each psychological element that is part of RANAS and/or HBM, question type, response options, effect towards the desired HB and codes used for analyses.

Survey question	Psychological element (Model)	Question type	Response options	Effect towards HB	Code used for analyses
What reasons, in your personal opinion, would lead you to test your well water after floods?	Cues to action (CtA; HBM)	Ranking	Cues to action that would lead to HB (i.e. if there's change in smell, taste, or colour; in well is covered by floodwater, if someone becomes ill, if neighbours and friends do, if it is recommended by local authorities, etc.)	Positive	No cues (0), one cue (1), two or more cues (2)
"My well can become contaminated if flooding occurs within 100 m (110 yards) of it"	Perceived Vulnerability (PV; RANAS) & Perceived Susceptibility (PSu; HBM)	Likert-scale	Strongly Disagree (1), Disagree (2), Neither Agree nor Disagree (3), Agree (4), Strongly Agree (5)	Positive	Strongly Negative (1), Negative (2), Neutral (3), Positive (4), Strongly Positive (5)
"My life would be impacted if I or a member of my household became ill with symptoms of diarrhoea and/or vomiting"	Perceived Severity (PS; RANAS) & Perceived Seriousness (PSe; HBM)				
"You can always tell when well water is contaminated by its taste, colour or smell"	Factual Knowledge (FK; RANAS)	Likert-scale	Strongly Disagree (1), Disagree (2), Neither Agree nor Disagree (3), Agree (4), Strongly Agree (5)	Negative	Strongly Positive (5), Positive (4), Neutral (3), Negative (2), Strongly Negative (1) – *inverted order*
"Wells can stay contaminated for weeks after the flood period has passed"	Factual Knowledge (FK; RANAS)	Likert-scale	Strongly Disagree (1), Disagree (2), Neither Agree nor Disagree (3), Agree (4), Strongly Agree (5)	Positive	Strongly Negative (1), Negative (2), Neutral (3), Positive (4), Strongly Positive (5)
"Testing my well water in a laboratory is the only way to know that it is safe to drink"	Perceived Benefits (PBe; HBM)				
"Getting my well water tested in a laboratory is an easy task"	Instrumental Beliefs (IB; RANAS) & Perceived Barriers (PBa; HBM)				
"After a flood I would worry less knowing that my well water is tested by a laboratory"	Affective Beliefs (AB; RANAS) & Perceived Benefits (PBe; HBM)				
"People I know would test their well water if flooding occurred near their well"	Descriptive Norms (DN; RANAS)				
"People who visit me expect me to ensure my well water is safe to drink and not contaminated"	Injunctive Norms (IN; RANAS)				
"I would feel personally obligated to test my well water after flooding occurred near my well"	Personal Norms (PN; RANAS)				
"if I notice that my well is flooded, I would feel personally obligated to test my well water"	Personal Norms (PN; RANAS)				
"I know who to contact to get my well water tested"	Action Knowledge (AK; RANAS) & Self-Efficacy (SEf; HBM)				
"I am able to get my well water tested if I decide to"	Self-Efficacy (SE; RANAS) & Self-Efficacy (SEf; HBM)				
"I will test my well water if flooding occurs nearby"	Commitment (C; RANAS)				

2.3. Data analysis

All questionnaire responses were numerically coded and analysed using IBM SPSS Statistics 24. A series of independent binary logistic regressions were undertaken for all RANAS and HBM psychological elements (Table 1) to identify their ability to predict HBs following floods. Cronbach's coefficient (α) was calculated as a measure of inter-item consistency when one or more variables were used to define a single psychological element, with the level of consistency for each element subsequently classified as low ($\alpha < 0.7$) or high ($\alpha \geq 0.7$) (Nunnally and Bernstein, 1978). A p-value <0.05 was used by convention to identify statistically significant elements (Agresti, 1996).

Previous studies have shown that experience (Severtson et al., 2006) and knowledge of others having performed healthy behaviours (Sandman and Weinstein, 1993) significantly influence the likelihood of undertaking HBs at the individual level. In order to account for respondents' level of flood experience, three distinct participant groups were developed for analyses (Table 2), with binary logistic regressions undertaken for each group. Undertaking a HB following previous flooding (i.e. experiential HB) was the dependent variable (Yes/No) used when analysing data from group 1 participants, while the intention to perform a HB as a response to future flooding (i.e. conjectural HB) was the dependent value (Would/Would not) for analyses of Groups 2 and 3. Participants that could not be classified into one of the three outlined groups were not included for analyses.

One of the primary features differentiating the RANAS and HBM is the IP score comprised within the RANAS framework (Mosler, 2012). Although IP score is not a component of the HBM framework, its ability to quantify the influence of psychological elements on targeted behaviours makes it valuable for comparing model elements. Thus, values for IP were calculated for all RANAS and HMB elements significantly linked

Table 2
Level of flood experience for each participant group examined using binary logistic analyses and dependent variables employed for each of them.

Participant group	Flood experience	Dependent variable
Group 1	Direct (have personally experienced flood)	Reported Behaviour following past floods (i.e. experiential HB).
Group 2	Indirect (flood has been experienced by a proximal member of social network)	Reported intention to perform HBs following possible flood event in the future (i.e. conjectural HB).
Group 3	None (has no personal experience and is unaware of flood experience in social network)	

to the behaviour (Eq. (1)), and subsequently used to assess model efficacy for targeting behavioural interventions following EWEs.

$$IP = (X_{max} - \mathrm{M}) \times \beta \qquad 1$$

where, X_{max} = Maximum value in range; M = mean value; and β = Regression Coefficient*

**X_{max} equals to 2 for CtA variable and to 5 for all other*

The higher the resulting IP value for a given psychological element, the greater the potential impact of an intervention that targets it in changing future behaviours (Huber and Mosler, 2013). As such, both percentage of significant elements belonging to each model (RANAS and HBM) and higher IPs were used as comparative measures for assessing model appropriateness under the studied circumstances.

3. Results

3.1. Respondent profile and level of flood experience

In total, 405 private water supply users representing all 26 administrative counties in the RoI participated in the study (Fig. 2), of which 41.5% (n = 168) were female. Approximately 40.5% (n = 164) of respondents were in the 35 to 49 age range (16.8% below and 42.7% above), while 72.8% (n = 295) had completed third level education.

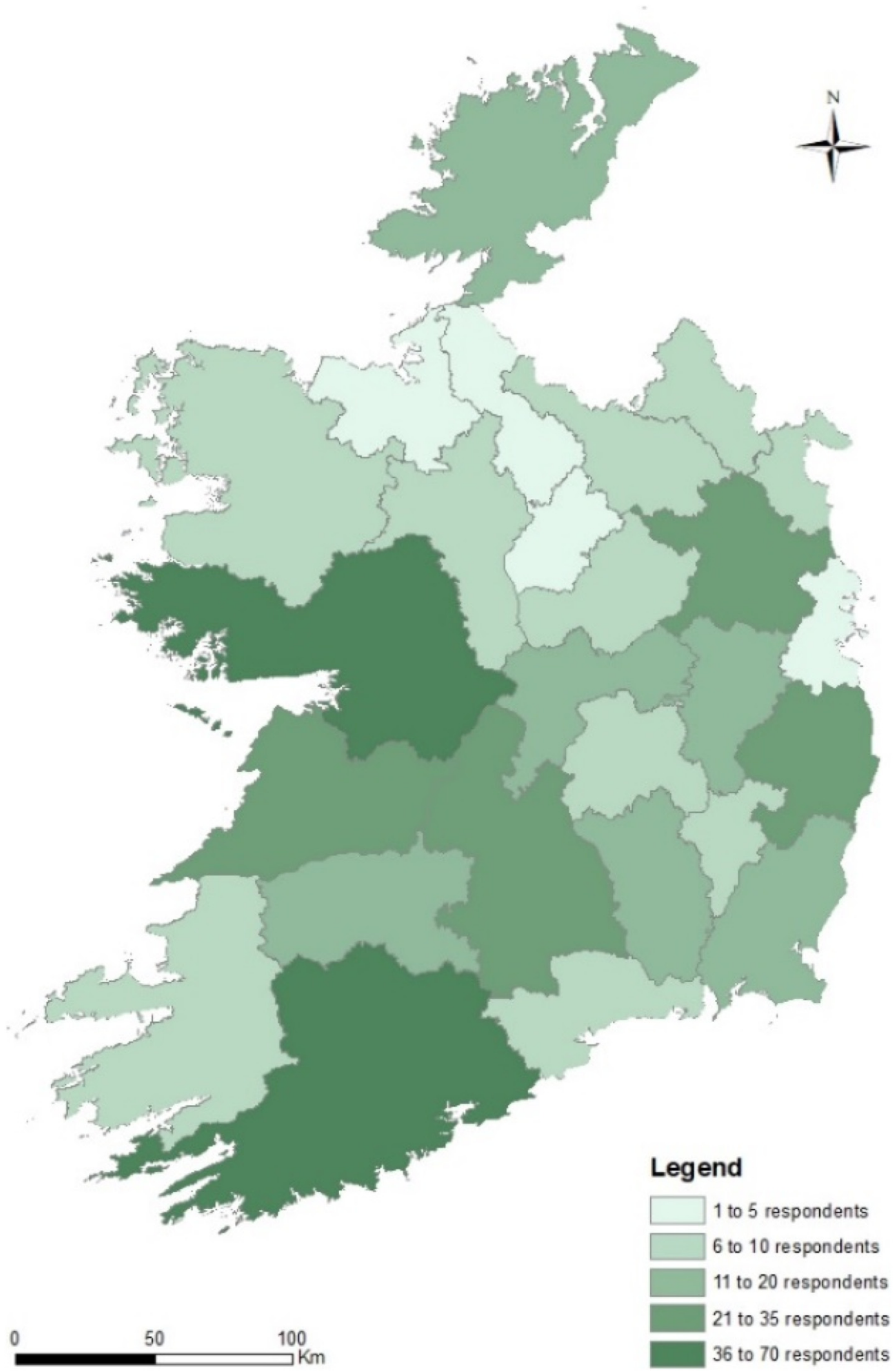

Fig. 2. Survey response distributed by administrative county in the Republic of Ireland.

The majority of participants (88.6%) owned their current residence, with self-reported property location split between rural agricultural (42%), and rural non-agricultural (52.8%) settlements. The remainder of participants reported that they lived in small villages, towns or other (peri)urban settlement (5.2%). Finally, 81.7% of study participants were served by a private household well while 18.3% were members of a private group water scheme.

As per definitions set out in Table 2 (experiential participant delineation), 19.7% of respondents reported previous direct experience with flooding near their groundwater supply (Group 1), 18.8% reported indirect experience (i.e. knew people that have experienced flooding; Group 2), and 55.1% reported no previous experience with flooding (Group 3). The remaining 5.42% abstained from responding to the question and as such were excluded from further analysis. As shown (Fig. 3), when reporting post-flood action, just 27.5% of participants from Group 1 undertook a protective HB following flooding near their personal groundwater supply (Experiential HB). Conversely, a majority of participants in Groups 2 (85.5%) and 3 (83.9%) reported an intention to undertake protective HBs if affected by proximal flooding (Conjectural HB).

3.2. Participant responses to psychological elements

Responses acquired from all 405 respondents to each RANAS and HBM element, discretized from strongly positive to strongly negative, are presented in Fig. 4a and b. The high median values (positive; light green) encountered for a majority of RANAS and HBM statements show that participant responses were typically positive with regard to undertaking post-flooding HBs.

3.3. Psychological elements influencing post-Hazard HBs

3.3.1. Experiential HBs after flooding

The suitability and influence of each RANAS and HBM element in predicting experiential HBs as a response to flooding (i.e. Group 1) is presented in Tables 3 and 4. As shown (Table 3), findings indicate that four of the 11 RANAS elements (36.4%) were significantly associated with performing HBs after flooding. These were, perceiving the threat of floods to personal groundwater supply (Perceived Vulnerability; PV), feeling obligated to undertake a HB after flooding (Personal Norms; PN), believing that others expect the individual to ensure well water safety (Injunctive Norms; IN), and committing to undertake HBs following future flooding (Commitment; C). Of note, as PV is defined by two variables Cronbach's α was calculated, to measure inter-item consistency, and equalled to 0.711, as such it was high enough (i.e. ≥0.7) to justify their combination for analysis (Nunnally and Bernstein, 1978). Analyses of the influence of HBM elements (Table 4) found only one psychological determinant to be significantly associated with undertaking any HBs (16.6%), namely Perceived Susceptibility (PSu). All calculated IPs were > 1, ranging from 1.09 to 2.09, with the aforementioned common (i.e. PV/PSu) exhibiting the highest IP (2.087). Thus, despite having equally higher IPs, the RANAS model has been shown to be more adequate, as it contained a higher percentage of elements significantly affecting the desired behaviour.

3.3.2. Conjectural HBs after flooding

The capability of each RANAS and HBM element to predict intention to undertake conjectural HBs after future flooding events were assessed separately for respondents with indirect (Group 2; n = 76) and no (Group 3; n = 299) previous experience of flooding. Results are presented in Tables 5 and 6, with marked differences found between both RANAS and HBM frameworks, respectively, within each of the two groups.

Within Group 2, five RANAS elements (45.5%) were significantly associated with the intention to perform HBs after flooding (Table 5). These were Factual Knowledge (FK), Descriptive Norms (DN), Personal Norms (PN), Action Knowledge (AK), and Commitment (C). Of those, FK and PN are defined by more than one variable, and Cronbach's α obtained for them were 0.228 (low) and 0.809 (high), respectively. Despite the low found α for FK, analyses were still performed as it still holds comparison value. Results obtained for the HBM show that two of the six (33.3%) factors were significantly associated with conjectural HBs (Table 6), namely Perceived Benefits (PBe) of HB and self-efficacy (SEf). Both are defined by two variables each and α values obtained were 0.191 (low) and 0.730 (high), respectively. Once again analysis for PBe was still performed and IP calculated for comparison. IP values

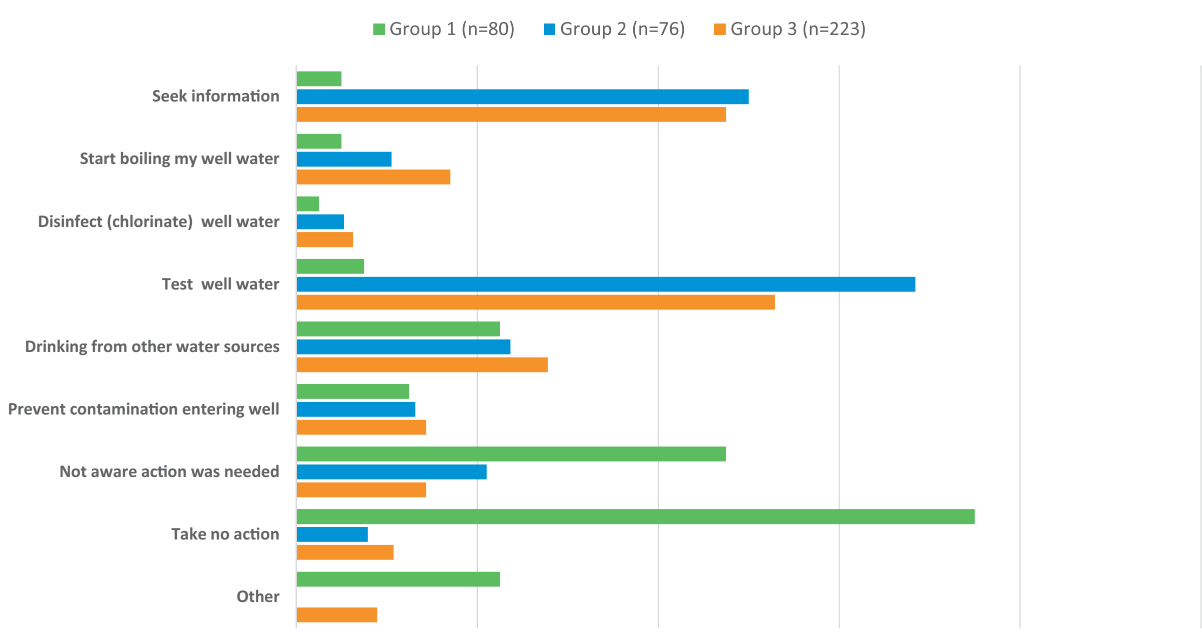

Fig. 3. Actual behaviours in response to flooding by respondents with direct flood experience (Group 1; green) versus intended actions by those with indirect flood experience (Group 2; blue) and no flood experience (Group 3; orange.

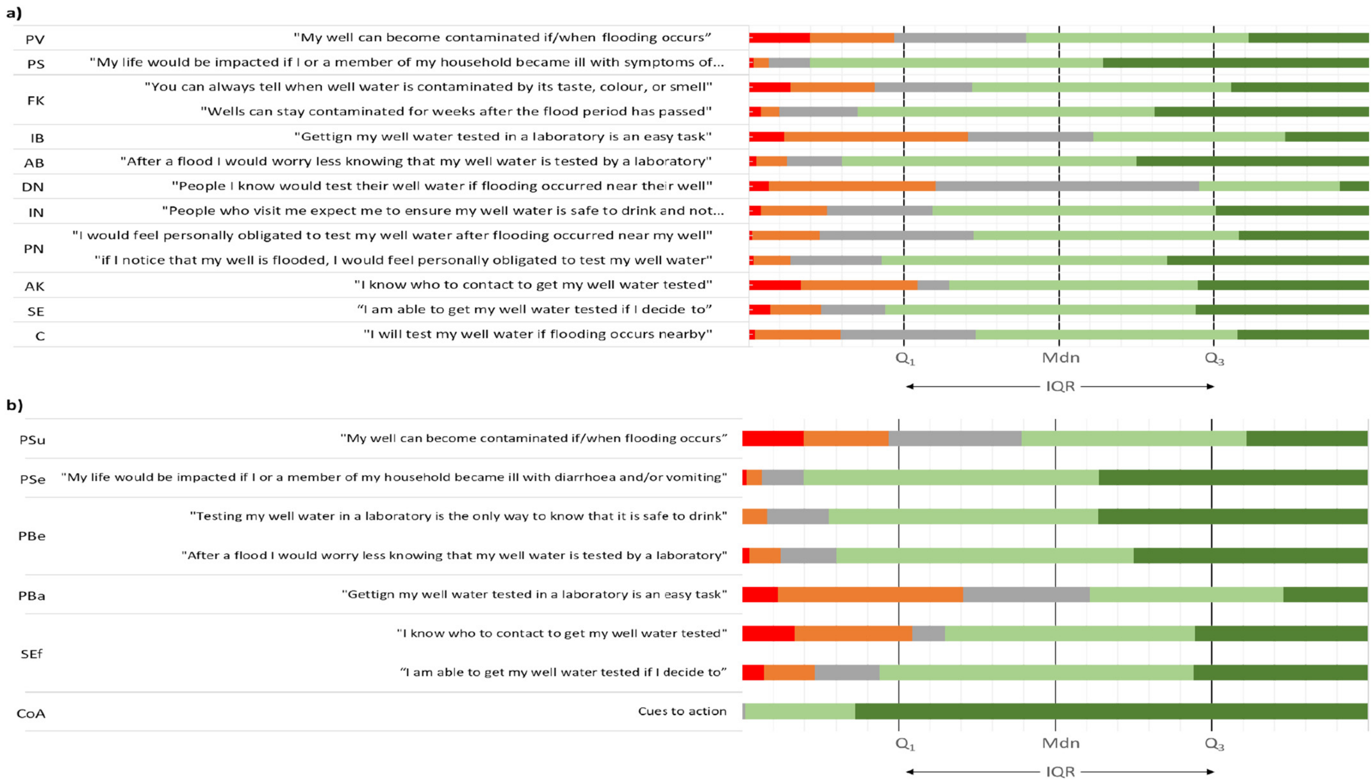

Fig. 4. (a) Responses to Likert-Scale RANAS Statements with Positive Impact on Protective HBs; (b) Responses to Likert-Scale and Ranking HBM Elements with Positive Impact on Protective HBs. Responses to each statement are classified as: Strongly Negative towards HB (1; RED); Negative towards HB (2; ORANGE); Neutral towards HB (3; GREY); Positive towards HB (4; LIGHT GREEN), and strongly positive to HB (5, DARK GREEN). Q_1 = *First quartile*; *Mdn* = *Median*; Q_3 = *Third quartile*; *IQR* = *Interquartile Range*.

for RANAS elements ranged from 0.672 (AK) to 2.577 (DN), while HBM elements scored 0.819 (SEf) and 1.385 (PBe). As such, the RANAS model has both a higher percentage of significant elements and its associated IP values are superior (86% larger) to ones obtained using HBM elements. Moreover, as the highest IP value obtained with the HBM is associated with an element of low inter-item consistency, it suggests that in terms of predictive capacity, the RANAs approach is better defined and applicable to groups across experiential settings.

Analyses of Group 3 participants using the RANAS framework indicated that 10 of the 11 elements (90.9%) were significantly associated with conjectural post-hazard HBs. The only behavioural factor adjudged to be insignificant ($p = 0.183$) was the self-reported perception of the seriousness of adverse health consequences potentially arising from flooding (Perceived Severity; PS). Moreover, FK had a very low (i.e. 0.009) α, meaning very low inter-item correlation. Analogous modelling of the HBM framework resulted in four (66.6%) components which were predictive of conjectural HBs (Table 6), two of which were also found among Group 2 participants (i.e. PBa and SEf). However, for Group 3, both PBa and SEf obtained high α (i.e. ≥ 0.7; 0.733 and 0.795, respectively). The two remaining elements of significance

Table 3
Descriptive statistics of RANAS elements (i.e. Behavioural Factors) within Group 1 (i.e. participants with direct flood experience; n = 80) and binary logistic regression results for Behavioural factors predicting experiential protective HBs towards groundwater supply following the EWE (floods).

Factor blocs	Behavioural factors	Items	Range	Group 1 – direct flood experience (n = 80)						
				M[a]	SD	*B*	OR	95% CI		IP
								Lower	Upper	
Risk factors	Vulnerability	1	1–5	3.50	1.191	**1.391**[**]	**4.018**	**1.988**	**8.122**	**2.087**
	Severity	1	1–5	4.39	0.646	0.232	1.261	0.571	2.785	–
	Knowledge	2	1–5	3.86[b]	0.815	0.461	1.586	0.824	3.051	–
Attitude factors	Instrumental	1	1–5	2.95	1.157	−0.043	0.958	0.625	1.470	–
	Affective	1	1–5	4.18	0.823	0.111	1.117	0.603	2.068	–
Norm factors	Descriptive	1	1–5	2.55	0.855	0.165	1.179	0.661	2.102	–
	Injunctive	1	1–5	3.70	1.072	**0.829**[*]	**2.291**	**1.218**	**4.309**	**1.078**
	Personal	2	1–5	3.57[c]	0.778	**1.410**[**]	**4.095**	**1.751**	**9.578**	**2.016**
Ability factors	Action knowledge	1	1–5	3.39	1.401	0.149	1.160	0.807	1.668	–
	Self-efficacy	1	1–5	3.72	1.201	0.287	1.332	0.851	2.085	–
Self-regulation	Commitment	1	1–5	3.39	0.987	**1.083**[**]	**2.954**	**1.582**	**5.515**	**1.744**

Bold used to indicate statistically significant Odds Ratio (OR) i.e. $p < 0.05$.
[a] <3 = negative effect and >3 = positive effect.
[b] α < 0.7.
[c] α ≥ 0.7.
[*] p ≤ 0.01.
[**] p ≤ 0.001.

Table 4
Descriptive statistics of HBM Elements within group 1 (i.e. participants with direct flood experience; n = 80) and binary logistic regression analysis for HBM Elements predicting experiential protective HBs towards groundwater supply following the EWE (floods).

HBM element	Items	Range	Group 1 - direct flood experience (n = 80)						
			M[a]	SD	*B*	OR	95% CI		IP
							Lower	Upper	
Perceived Susceptibility	1	1–5	3.5	1.191	**1.391**[*]	**4.018**	**1.988**	**8.122**	**2.0865**
Perceived Seriousness	1	1–5	4.39	0.646	0.232	1.261	0.571	2.784	–
Perceived Benefits	2	1–5	4.21[b]	0.655	0.299	1.349	0.619	2.938	–
Perceived Barriers	1	1–5	2.95	1.157	−0.043	0.958	0.625	1.470	–
Self-Efficacy	2	1–5	3.56[c]	1.250	0.223	1.250	0.825	1.892	–
Cues to Action	1	0–2	1.86	0.347	0.013	1.013	0.243	4.227	–

Bold used to indicate statistically significant Odds Ratio (OR) i.e. $p < 0.05$.
[a] <3 means negative effect on average and >3 means positive effect on average.
[b] $\alpha < 0.7$.
[c] $\alpha \geq 0.7$.
[*] $p \leq 0.001$.

were Perceived Susceptibility (PSu) and Perceived Barriers (PBa). IP values for RANAS and HBM elements ranged from 0.550 to 1.606 and 0.633 to 1.023, respectively. Despite results showing that the RANAS model was once again superior, both with regards to percentage of significant elements and highest IP values, the differences between the two models was considerably less.

4. Discussion

The adverse human health effects associated with increasingly frequent extreme weather events (EWEs) are potentially severe and on the rise, with global climate and coupled climate-health models predicting high morbidity and mortality rates in both low/medium- and high-development regions worldwide (McMichael et al., 2006; IPCC, 2012). Historically, management efforts have focused on prevention via structural defence, however this represents a costly strategy which is progressively being replaced by integrated approaches, which seek to promote preparedness at the individual (i.e. bottom up) level (Bubeck et al., 2012). Accordingly, increasingly effective, sociologically- and psychologically-based interventions are required to empower individuals and communities to take an active role in protecting their own health (Tringali et al., 2017). The current study sought to compare the efficacy of two available social-cognitive models in predicting HBs, namely the Health Beliefs Model and RANAS framework, in the context of human health threats triggered by EWEs. Specifically, a case-study approach was used to examine the capacity of these approaches to predict the performance of (ground)water-related HBs as a response to nearby flooding events, both in the presence and absence pf previous personal experience. This study focused on private water supply users in the Republic of Ireland, as a population considered particularly vulnerable to the deleterious effects of climatic events and subsequent groundwater contamination (Hynds et al., 2012; O'Dwyer et al., 2014; O'Dwyer et al., 2016).

The HBM and RANAS framework were selected for comparison due to their relative simplicity and frequency of use in the environmental health sphere. Both approaches share common theoretical roots, drawing from similar social-cognitive constructs to attempt to understand the factors that promote or inhibit health behaviours. However, the differences between them mean that they approach health behaviours from differing perspectives, thus producing different results, making it difficult to compare research findings on similar topics (Altman and Bland, 1983).

As shown, the RANAS approach contains more factors that significantly predict both actual performance of HBs and the intention to perform health behaviours for those with some prior (direct or indirect) experience with EWEs (i.e. 36.4 and 45.5%, respectively versus 16.6 and 33.3% of the HBM elements, respectively). Highest IP values obtained were the same for both RANAS and HBM in Group 1 analyses

Table 5
Descriptive statistics of RANAS elements (i.e. Behavioural Factors) within Groups 2 (i.e. participants with indirect flood experience; n = 76) and 3 (i.e. participants with no flood experience; n = 223), and binary logistic regression results for Behavioural factors predicting experiential protective HBs towards groundwater supply following the EWE (floods).

Factor blocs	Behavioural factors	Items	Range	Group 2 – indirect flood experience (n = 76)							Group 3 – no indirect flood experience (n = 223)						
				M[a]	SD	*B*	OR	95% CI		IP	M[a]	SD	*B*	OR	95% CI		IP
								Lower	Upper						Lower	Upper	
Risk factors	Vulnerability	1	1–5	3.67	1.025	0.322	1.380	0.765	2.489	–	3.30	1.289	**0.602**[***]	**1.825**	**1.372**	**2.428**	**1.023**
	Severity	1	1–5	4.39	0.675	0.079	1.082	0.426	2.751	–	4.22	0.821	0.268	1.308	0.881	1.940	–
	Knowledge	2	1–5	3.96[b]	0.734	**1.450**[**]	**4.263**	**1.470**	**12.361**	**1.508**	3.82[b]	0.731	**0.823**[**]	**2.278**	**1.362**	**3.810**	**0.971**
Attitude factors	Instrumental	1	1–5	3.11	1.102	0.460	1.584	0.869	2.887	–	3.26	1.188	**0.420**[**]	**1.522**	**1.116**	**2.074**	**0.731**
	Affective	1	1–5	4.16	0.849	0.606	1.833	0.928	3.620	–	4.14	0.897	**0.637**[***]	**1.891**	**1.318**	**2.713**	**0.548**
Norm factors	Descriptive	1	1–5	3.04	0.855	**1.315**[**]	**3.725**	**1.391**	**9.975**	**2.577**	3.13	0.868	**0.684**[**]	**1.982**	**1.267**	**3.099**	**1.279**
	Injunctive	1	1–5	3.95	0.862	−0.239	0.787	0.360	1.721	–	3.83	0.95	**0.611**[***]	**1.843**	**1.286**	**2.641**	**0.715**
	Personal	2	1–5	3.95[c]	0.862	**2.281**[***]	**9.783**	**2.870**	**33.347**	**2.395**	4.03[c]	0.79	**1.656**[***]	**5.238**	**2.956**	**9.284**	**1.606**
Ability factors	Action knowledge	1	1–5	3.74	1.226	**0.533**[*]	**1.704**	**1.030**	**2.820**	**0.672**	3.65	1.264	**0.440**[***]	**1.553**	**1.192**	**2.023**	**0.594**
	Self-efficacy	1	1–5	4.09	0.819	0.673	1.960	0.977	3.932	–	3.95	0.948	**0.500**[**]	**1.648**	**1.176**	**2.310**	**0.525**
Self-regulation	Commitment	1	1–5	3.75	0.926	**0.810**[*]	**2.248**	**1.158**	**4.364**	**1.013**	3.84	0.954	**1.264**[***]	**3.539**	**2.302**	**5.441**	**1.466**

Bold used to indicate statistically significant Odds Ratio (OR) i.e. $p < 0.05$.
[a] <3 = negative effect and > 3 = positive effect.
[b] $\alpha < 0.7$.
[c] $\alpha \geq 0.7$.
[*] $p \leq 0.05$.
[**] $p \leq 0.01$.
[***] $p \leq 0.001$.

Table 6
Descriptive statistics of HBM Elements within Groups 2 (i.e. participants with indirect flood experience; n = 76) and 3 (i.e. participants with no flood experience; n = 223), and binary logistic regression analysis for HBM Elements predicting experiential protective HBs towards groundwater supply following the EWE (floods).

HBM element	Items	Range	Group 2 - indirect flood experience (n = 76)							Group 3 - no indirect flood experience (n = 223)						
			M[a]	SD	*B*	OR	95% CI		IP	M[a]	SD	*B*	OR	95% CI		IP
							Lower	Upper						Lower	Upper	
Perceived Susceptibility	1	1–5	3.67	1.025	0.322	1.380	0.765	2.489	–	3.30	1.289	**0.602*****	**1.825**	**1.372**	**2.428**	**1.023**
Perceived Seriousness	1	1–5	4.39	0.675	0.079	1.082	0.426	2.751	–	4.22	0.821	0.268	1.308	0.881	1.940	–
Perceived Benefits	2	1–5	4.20[b]	0.600	**1.731****	**5.649**	**1.680**	**18.988**	**1.385**	4.20[c]	0.760	**0.791*****	**2.205**	**1.427**	**3.407**	**0.633**
Perceived Barriers	1	1–5	3.11	1.102	0.460	1.584	0.869	2.887	–	3.26	1.188	0.420**	1.522	1.116	2.074	0.731
Self-Efficacy	2	1–5	3.91[c]	0.925	**0.751***	**2.119**	**1.082**	**4.149**	**0.819**	3.80[c]	1.018	**0.571*****	**1.770**	**1.270**	**2.469**	**0.685**
Cues to Action	1	0–2	1.84	0.402	−0.616	0.540	0.070	4.162	–	1.79	0.417	0.029	1.030	0.447	2.373	–

Bold used to indicate statistically significant Odds Ratio (OR) i.e. $p < 0.05$.
[a] <3 means negative effect on average and >3 means positive effect on average.
[b] $\alpha < 0.7$.
[c] $\alpha \geq 0.7$.
* $p \leq 0.05$.
** $p \leq 0.01$.
*** $p \leq 0.001$.

(i.e. 2.09) but were considerably greater when using the RANAS framework for Group 2 participants (i.e. 2.6 versus 1.4). Thus, it can be surmised that, in this instance, the RANAS approach provides a fuller description of the factors that are significant to those who have directly experienced flooding (group 1) and more accurately and robustly describes the HBs of those that have indirect experience of flooding (group 2). For participants in the latter group, the factors with the highest IPs included knowing that others had carried out HBs in response to flooding (DN), and the sense that there was a social obligation to do so (PN). This aligns with Sandman and Weinstein (1993), who found that locals who believed that other members of their community were concerned about a threat was a strong predictor of both thinking about and deciding to perform a HB.

Overall, the findings of this study appear to reinforce previous theoretical criticisms of the HBM. For example, the HBM has been critiqued for having vaguely defined relationships between the various constructs (Sheeran and Abraham, 1996). Additionally, previous research suggests that the link between motivations and actual behaviour may be weak (Conner and Armitage, 1998). Consequently, while the HBM has been shown to be useful in measuring intention, evidence indicates that it may be insufficient as a predictor of actual behaviour (Stroebe and Stroebe, 1995). As such, the HBM may be inadequate for developing evidence-based interventions for communities threatened by poor environmental quality (Michie et al., 2008).

Regarding participants with no prior experience of flooding (participants in group 3), while both models contain more statistically significant variables for predicting intentions to perform HBs in response to hypothetical future flooding events, the IP values found were considerably lower when compared to analyses undertaken for other groups. Specifically, the RANAS model resulted in IP values ranging from 0.526 to 1.606, while the HBM had IPs ranged from 0.633 to 1.023. Notably, this could indicate that there is little advantage to employing the more comprehensive RANAS model in favour of the HBM when assessing a participant's motivations in an unfamiliar context. Moreover, the brevity of HBM instruments may reduce the burden on participants (Cape and Phillips, 2015) and make it easier to collect group-level findings at the outset of preventative behaviour change projects. However, the fact that the IPs produced by this analysis are much lower than those returned by the other groups may signify that neither model is accurately identifying the best means of intervention to alter intended behaviour for an unexperienced threat. Furthermore, it may suggest that participants who have no experience with a threat, are less equipped to generate an accurate assessment of their long-term susceptibility, or the instrumentality of a HB (how much doing any of these things will protect them) or to gauge their self-efficacy (Bandura, 1986). Indeed, it may be the case that participants who lack experience with the particular threat are misestimating the threat facing them or their own access to resources.

Finally, it is also worth noting that the intervention potentials generated by this research are lower than those reported in other studies that have used the RANAS approach (i.e. Huber et al., 2012). This may be explained in part by the extremity and relative novelty of the EWE (flooding) as a threat to groundwater supplies. It may also be the case that the majority of participants are displaying an optimism bias (Sharot et al., 2011), as only 19.75% of the sample had directly experienced flooding at the time of data collection and so may not see a need for behaviour change.

The HBM was the first widely deployed model of HBs and represented a significant advancement in the process of connecting communities to promote and support health, and is still a valuable tool for assessing health-related motivations. However, the RANAS approach has built effectively on the HBM and other theories of health-promotion, to create a more holistic picture of the social context in which a given community exists and thus represents a more useful tool for those engaged in health promotion rather than just research. Novel, multidisciplinary tools such as the RANAS approach allows communities to work with central bodies more effectively to create a sustainable, culturally congruent approach to health promotion that could significantly reduce risks in the years and decades to come (Hynds et al., 2018).

Study limitations

While every effort was made to target a representative cross-section of private groundwater users in the Republic of Ireland, and particularly in terms of spatial risk susceptibility (i.e. floodplains, etc.), the web-based nature of the study questionnaire made this difficult, with less than half the participant sample reporting (direct or indirect) experience with previous significant flooding events. Future work will seek to elucidate the number and density of these private supplies in the RoI in order to focus on current and likely vulnerable areas, thus permitting increased data collation and analyses with respect to objective behaviours as opposed to prospective intentions.

Perhaps more fundamentally, the web-based nature of the survey, while effective in terms of acquiring a wide geographical spread, represents an inherent limitation, as some well owners may not have had access to it and/or the capacity to complete it, and particularly older well owners.

In order to increase the survey completion rate and avoid respondent fatigue, five elements (i.e. behavioural factors) present in the RANAS model were excluded), preventing the use of multiple variables to describe each model element, as previously undertaken in other studies (Huber and Mosler, 2013; Flanagan et al., 2015, 2018). As such, the authors consider that the current study could be modified in future to include these missing elements, and thus draw more definitive conclusions as to overall model efficacy.

5. Conclusions

Results suggest that the RANAS approach provided a more complete picture of both actual (experiential) and intended (conjectural) protective behaviours as a response to EWEs, thus providing a more robust evidence-based foundation for design of interventions to promote healthy behaviours. However, the gains acquired from this more comprehensive social-cognitive model were relatively modest among individuals with no previous experience of the environmental threat. Notwithstanding, the RANAS approach is characterised by significant detail and length when compared with the HBM, and thus, its use and completion requires increased resources, both on behalf of the researcher and study participants. Accordingly, utilisation of the simpler HBM may be more appropriate and cost-effective among specific cohorts; more specifically, results suggest that the HBM is ideally suited for use in the early stages of an investigation, in more general studies, and within studies focusing on hypothetical or relatively rare health threats i.e. where there is a general lack of experience among the study sample.

The HBM appears to capture motivation and risk perception with similar clarity, and the degree of granularity provided by the HBM may be sufficient for a general understanding of a specific health context. Conversely, the HBM does not appear to provide adequate information for generation of evidence-based interventions for managing the social, cognitive, economic, and normative barriers to health promotion pertaining to specific and/or previously encountered issues. In this case, the RANAS approach appears to generate more useful information.

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