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Exploring Risk Perception and Behaviours at the Intersection of Flood Events and Private Groundwater Supplies: A Qualitative Focus Group Study

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Abstract: Flooding events can inflict major disruption on society and cause significant infrastructural and environmental damage. However, the adverse health impacts of flooding, particularly as they pertain to private groundwater resources used for consumption, are frequently overlooked. Whilst the literature has previously found a lack of well stewardship among private well owners under 'normal' conditions, our understanding of private well owners' perceptions of and preparedness for the risks posed by flooding to their domestic well-water supply is limited. This study advances the qualitative literature on this subject. It is amongst the first qualitative studies employing focus groups to examine private well owners, and the first in an Irish context. Six focus groups were conducted in four counties in Ireland, with the themes emerging from the focus groups refined, organised, and interpreted in the context of the Health Belief Model. Most focus group participants expressed awareness of the potential severity of well contamination following flooding, but many did not consider their local area "at risk" of it, notwithstanding the occurrence of previous local flooding events. All focus group participants shared the view that owners were primarily responsible for their own wells. However, their capacity to undertake appropriate actions was reduced by reliance on visual and olfactory evidence to assess water quality, and concerns regarding the financial cost and accessibility of water testing facilities. The phenomenon of misperception was also evident among participants. In light of the increasing frequency and severity of extreme weather events including flooding, these findings provide direction for future socio-hydrogeological interventions. Targeted communication strategies highlighting the risks posed by flooding, mitigation measures that promote well stewardship, and protective behaviours are required. The provision of access to free well water testing would also promote protective actions.

Keywords: private wells; focus groups; socio-hydrogeology; flooding; health belief model

1. Introduction

As one of the most devastating naturally occurring environmental hazards, flooding events have the potential to inflict major disruption on society and cause significant infrastructural and environmental damage [1,2]. During the 35-year period 1980 to 2015, flooding caused at least €164 billion of economic losses in Europe alone [3]. Compounding this, it is now widely accepted that climate change will exacerbate the frequency and severity of flooding arising from increases in extreme precipitation [4,5]; increases of up to 87% have been forecast with respect to future flood risks for various return periods across Europe [6]. Seeking to reduce the adverse consequences of flooding, flood management efforts have traditionally focused on flood prevention; however, these strategies tend to be costly, reliant on hard infrastructure, and are progressively being replaced by integrated approaches, including soft measures that aim to promote flood preparedness at an individual level [7–9]. Nonetheless, most interventions tend to focus on the infrastructural and environmental damage associated with significant flood events [10–12], often overlooking the human health impacts [10,13], which, due to their capacity to trigger and/or exacerbate serious health outcomes, cannot be ignored.

Floods can generate unexpected pathways for enteric pathogens (i.e., viruses, bacteria, and protozoa) via mobilisation within the natural aquatic environment [14,15], resulting in higher risks of human exposure and the consequent onset of infection. A recent global review by Andrade et al., (2018) [16], for example, has highlighted the understudied nexus between flooding, drinking groundwater contamination, and the occurrence of gastrointestinal infections among groundwater consumers. Across fourteen studies identified from 1980 to 2017, approximately 10,000 suspected individual cases and 1000 confirmed cases of acute gastroenteric infection were associated with flooding of or adjacent to groundwater supplies. With approximately 2.2 billion people relying on groundwater as their main drinking resource, the infection pathways triggered by floods represent a significant global health issue [17]. This is further exacerbated by small-scale domestic extractions (i.e., private wells) remaining largely unregulated [18–21]. Thus, the primary responsibility for ensuring potability rests with the supply user. Moreover, a general lack of well stewardship among private well owners has been repeatedly identified under 'normal' (i.e., non-event) conditions [22–25]. Accordingly, private well owners and users may be acutely susceptible and ill-equipped to prevent and manage the health effects of sporadic groundwater contamination events due to significant flooding.

Ireland represents a notable case study, with an estimated 750,000 private well users comprising about 16% of the national population. Private wells remain a largely unregulated source of drinking water, deemed as 'exempted supply' under Ireland's European Union (Drinking Water) Regulations 2014, which implements the EU Drinking Water Directive. Moreover, Ireland consistently reports the highest incidence rates of verotoxigenic *Escherichia coli* (VTEC) enteritis in the European Union [26], with the use of private domestic wells identified as a major transmission route [27]. Indeed, concern about private well water quality in Ireland has been subject to a growing body of research attention [27–33].

However, few studies have sought to qualitatively deepen our understanding of private well owners' perceptions and protective behaviours regarding their drinking water source [34]. Perhaps this should not be a surprise, as the dearth of social science contributions to human–water dynamics in the international socio-hydrology literature has been highlighted [35]. Therefore, this study will seek to provide a deeper qualitative contribution to the existing body of knowledge by utilising focus groups from a number of case study areas. It also represents the final piece of a wider mixed-method set of studies developing Ireland's socio-hydrogeology literature on this topic. For example, Boudou et al. 2021 [36] have shown a link between flooding, groundwater, and human health in Ireland, and Musacchio et al., (2021) [33] has shown major gaps in awareness concerning the nexus between risk factors (e.g., flooding, sources of contamination) and groundwater quality, and, consequently, the need to further improve understanding of this nexus to promote well stewardship. Figure 1 highlights the three primary protective actions for successful well stewardship.

Figure 1. Primary protective actions for successful well stewardship and health protection.

To date, few (if any) studies have sought to assess the perceptions and capability of private groundwater-reliant communities to avoid supply contamination induced by flooding. Accordingly, the current study sought to address this knowledge gap via a series of focus groups carried out across a number of rural Irish communities considered to be relatively representative of Irish hydrogeology, flood risk, topography, and land-use, allowing for novel insight into well users opinions, concerns, and perceptions of flooding as it pertains to their unregulated domestic water supply. The study findings will inform future socio-hydrogeologically-based interventions [37,38] by seeking to enable individuals and communities to take an active role in protecting their health by appropriately managing their private well water supplies. The findings will also deepen the social science-related literature around groundwater management as it pertains to individual users, households, and communities, in addition to providing a formalised, transferable approach which may be replicated irrespective of hydrogeological setting, socio-demographic profile, or local traditions.

2. Methods

2.1. Participant Recruitment and Data Collection

As there is no registry of private well owners in Ireland, areas characterised by high private well reliance were determined by identifying areas served by a public/municipal authority and contacting local community centres/organisations in unlisted (i.e., un-serviced) areas to confirm that the area was primarily supplied by private household wells. Figure 2 presents the focus group locations, with an overview of the selected case study area characteristics (topography, flood history, (hydro)geology) presented in Table 1. As shown (Table 1), all four selected study areas were associated with a history of recurrent localised flooding. All areas are predominantly agricultural with some boglands and forestry, and typically underlain by limestones, sandstones, and shales characterised by a range of groundwater vulnerability classifications, from moderate to extreme (karst), apart from the study area located in Co. Wicklow, which is underlain by granites. Accordingly, the authors consider the selected study areas relatively representative of private groundwater reliant rural regions in Ireland, based on previous studies [27–29].

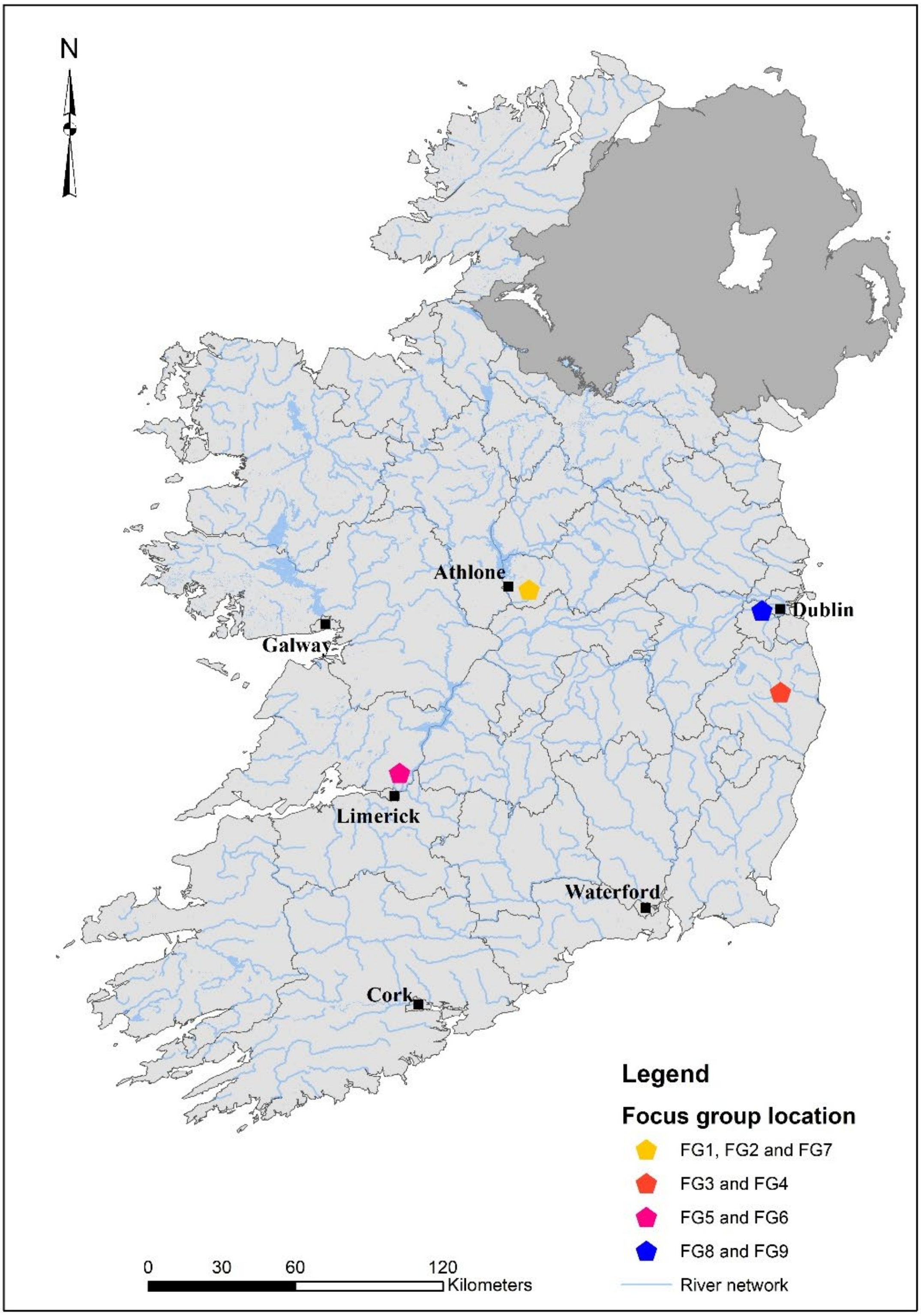

Figure 2. Location of qualitative focus groups (including rivers and principal urban centres).

Table 1. Hydrogeological profile of rural districts in selected study areas.

County	Host Venue	Coordinates & Elevation	District Flood History	Hydrology, Geology and Topography	Primary Land Use
Wicklow	Moneystown Community Centre	53°00′08.1″ N 6°11′55.5″ W Elevation: 220 m	Small-scale localised flooding	Foothills of Wicklow Mountains. District within Avonmore and Vartry catchments. Principal bedrock: slates and shales, granites GW Vulnerability: High	Forestry and Agriculture
Westmeath	Kilcleagh National School	53°22′27.8″ N 7°48′29.1″ W Elevation: 50 m	Recurring localised flooding from River Boar in Upper Shannon catchment and at low lying adjacent land (South) after heavy rainfall	Located in low lying terrain of Upper Shannon catchment Principal bedrock: limestones, sandstones, mudstones GW Vulnerability: Variable (Medium, High)	Bogland and Agriculture
Dublin	Larch Hill Scout Centre	53°15′14.0″ N 6°17′03.6″ W Elevation: 225 m	Recurring fluvial flooding from stream Incidences of small-scale localised flooding	Foothills of Dublin Mountains and primarily within River Dodder. Principal bedrock: granites GW Vulnerability: High	Forestry and Agriculture
Clare	Clonlara GAA Club	52°43′13.2″ N 8°33′31.4″ W Elevation: 19 m	Extensive & recurring fluvial flooding in Lower Shannon.	Located in low lying terrain in Lower Shannon catchment Principal bedrock: limestones GW Vulnerability: Variable (Medium, High, Extreme (Karst))	Agriculture

Participants aged ≥18 years who used a private well were subsequently recruited by mailing recruitment letters to between sixty and one hundred households in selected areas or via local institutions (e.g., local parish, school, or community centre). Recruitment documents included information on: (i) the overarching research project; (ii) participant requirements; (iii) data use; (iv) date, location, and time of the focus group meeting; (v) data protection and privacy; (vi) benefits and risks of study participation; (vii) dissemination of research results; and (viii) contact and background details of the research team. Potential participants were advised that they would be offered a supermarket voucher and a free basic microbial assessment of well water quality for their contribution. Instructions on how to collect a water sample were provided. Potential participants were encouraged to contact the researchers with questions and to confirm their willingness to attend.

Nine focus groups were attempted from April to July, 2018. Good practice techniques were followed during recruitment and reminder stages [39]. Five sessions met the minimum number of participants typically required to be considered successful i.e., four participants [39,40]. One further focus group was successfully completed despite a lower participant number as the achievement of a group dynamic enabled collation of different perspectives from attending participants. No data were collected for the remaining three sessions due to insufficient participant numbers. Thus, a total of six focus group sessions with a total of 35 participants were facilitated. Data collection should continue until data saturation, the point at which no new insights are generated by the data. Typically, this is between four and six focus groups [41]. A high degree of consensus was noted in this study, suggesting saturation was reached.

Organisation and moderation of each focus group closely followed the approach of Fox-Rogers et al. [42] and Devitt et al. [43]. In line with the approach of McLafferty [44], the moderators (LA and/or EO'N) began the sessions by discussing basic ground rules, while participants were assured that the research team were seeking to learn from the participants [39] and were encouraged to share their views and experiences without repercussion or judgement. Participants were also reminded that an observer was present and, upon their verbal consent, sessions would be recorded for analysis. As self-censorship and social desirability can influence views expressed by participants in a focus group setting, the moderators were cognisant of the importance of seeking verification and validation from participants during the focus group sessions. Techniques included, for example, repeating viewpoints back to the participant group to see if they were shared by all members of the group, which has been shown to help ensure interpretive validity and research rigor [45]. Additionally, and similar to the approach of Fox-Rogers et al. [42], the moderators applied what Nyamathi and Shuler [46] refer to as 'mild, unobtrusive control' to avoid group domination and facilitate a group dynamic.

Focus groups were steered by a topic guide that closely followed the Health Belief Model (HBM; [47]) framework, and broadly considered:

(i). water quality perception;
(ii). flood vulnerability and severity;
(iii). public awareness and health-protection resources.

Subtopics, follow-up questions, and probes (e.g., pictures, option lists, maps) were also used.

Focus group members also completed a short survey developed specifically for individual participants (Appendix A, Table A1) comprising twelve multiple-choice questions. Questions examined ages of participants and all household members, gender, residential ownership, number of years living in current household, and household location. Participants were also asked to state whether they drank from their private household well and if they used any treatment before consumption (e.g., chlorination, UV treatment, reverse osmosis). Finally, questions were asked on previous experience with well water testing and flooding events near ($\leq$100 m) their groundwater sources. To avoid order-effect bias [48], both survey questions and available responses were presented in random orders where possible. In recognition of their contribution to the study, each participant received a supermarket voucher worth €20 (by way of context, the minimum wage in Ireland is €10.20 per hour) and a free assessment of their well's basic microbial quality. Research ethical approval was granted by the University College Dublin Human Research Ethics Committee (Ref: HS-17-47-deAndrade-O).

2.2. Data Analysis

Initial screening of the focus group audio recordings and raw text transcriptions was performed by two co-authors (CMcD & LA) to identify broad themes common across focus groups [49]. Secondly, the questions used during data collection were applied to the dataset to help organise responses. Next, in line with Nicholls (2009) [50], a form of naïve coding, or categorisation of broad themes (e.g., "flooding experience and perceived threat" and "cues to action"), was applied, signifying the first coding interpretations of the researcher. Then, the recordings and text were reviewed more closely, and more detailed coding was used (e.g., identification of specific cues to action repeatedly identified, such as change in "smell", "taste", and "colour"), in line with the thematic descriptors, elaborated in Table 2. Next, the coding was reviewed by a third team member (EO'N) for validation. Finally, consistent with approach of Fox-Rogers et al. [42], obvious patterns emerging in the focus groups were detected from basic categorisations which were refined, organised, and interpreted in the context of the HBM [47].

Table 2. Themes and Thematic Descriptors.

Themes	Thematic Descriptor
General Thoughts on Well Water Quality	Participants' perceptions regarding their own well water quality and factors influencing their relative confidence in their well water
Flooding Experience and Perceived Threat	Participants' past flood experience and their perception of the level of flood risk that their well is exposed
Cues to Action	Factors that mobilise participants to take action to protect themselves from waterborne health risks

Table 2. *Cont.*

Themes	Thematic Descriptor
Perceived Benefits and Barriers	Benefits that participants perceive from protecting themselves against waterborne health risk from well-contaminants; and the barriers they report hindering them in protecting themselves against those risks
Self Efficacy	Participants' confidence in their ability to test their well water and/or install water treatments
Health Behaviours Following Floods	Participants' intentions and responses after flood water inundation of their well

2.3. Health Belief Model

There is growing interest in the use of socio-cognitive theories to study perceptions of risk and motivation for adaptation to flood-related risks, since knowledge and perceptions can drive behaviour change [51]. A recent Irish study compared the efficacy of two established social-cognitive models, namely the HBM and Risks-Attitudes-Norms-Abilities-Self-regulation (RANAS) framework, in predicting health behaviours following flooding [31]. This study found that there may be little advantage to employing the more burdensome RANAS model in favour of the HBM when assessing a participant's motivations in an unfamiliar context. Whilst previously there were limited applications of HBM beyond health sciences, it is increasingly being applied in settings where environmental behaviours have health consequences [43,52,53]. Moreover, this includes the application of HBM to the management of domestic wastewater treatment systems [43] and private well water testing [21,51,52,54]. Therefore, the HBM was utilised for this study.

The HBM was designed to assess factors potentially influencing health behaviours in relation to infectious diseases in the United States [47] by combining perceptions and beliefs as a way of understanding and predicting prevention behaviours. It is comprised of several elements, as follows: perceived susceptibility to a negative event; perceived severity of the event; perceived benefits associated with a particular preventive action; perceived costs and barriers associated with performing the action; and, self-efficacy, i.e., confidence in one's ability to perform a particular action. The framework is augmented by "cues to action" whereby individual preventive behaviours are triggered by other stimuli. Internal (e.g., sickness) and external (e.g., media communications) triggers motivate beliefs into behaviour [43]. The HBM suggests that individuals must feel vulnerable to a threat, believe the possible consequences of the threat to be severe, and believe in their own ability to bring about beneficial change without excessive costs, in order for behavioural change to occur [47,55]. A principal benefit of the model is its applicability and flexibility in explaining the cognitive aspects of social behaviour and as a basis for advancing behavioural interventions [56,57]. To help understand the householders understanding of the connection between risk factors (e.g., flooding, sources of contamination) and groundwater quality, and the need to foster well stewardship (well water testing, well maintenance, water treatment; see Figure 1), we used the constructs of the HBM. Notably, these constructs, individually or in combination, have previously been used to explain health behaviours [57]. In this study, similar to Munene et al. [52], perceived susceptibility and severity combine to create the perceived threat to waterborne health risks from well-water contaminants, while perceived barriers and benefits, cues to action, and self-efficacy refer to the adoption of well water testing and water treatment as mitigation to reduce waterborne health risks (as portrayed in Figure 3).

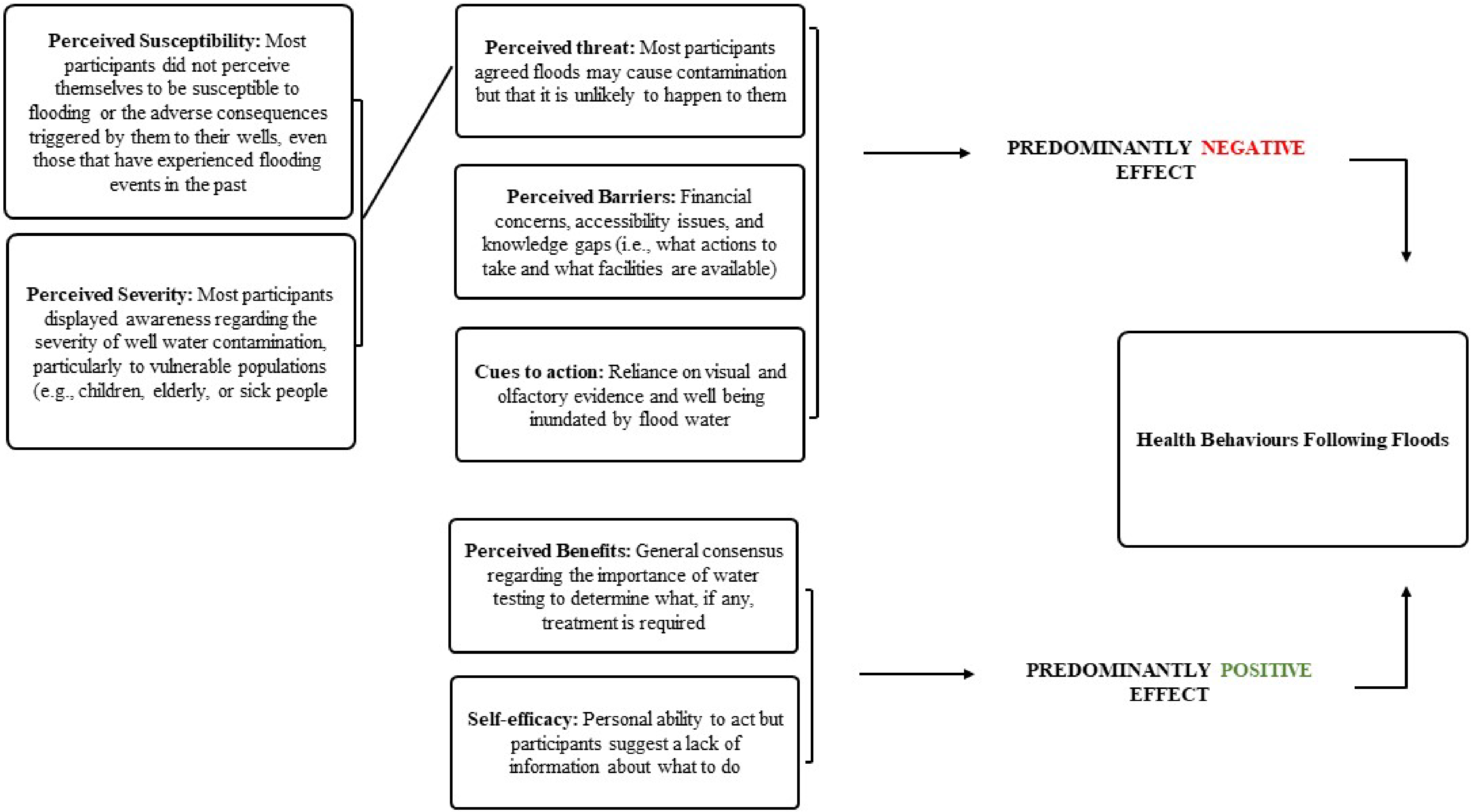

Figure 3. Application of study results to the Health Belief Model.

3. Results

3.1. Focus Group Characteristics

Initially, nine focus groups were planned in rural communities across Ireland (Figure 2). Of those planned, six focus groups sessions (FG1, FG2, FG3, FG5, FG7, and FG8) were successfully completed (Table 3). Results from the short survey are presented in Table 4. In total, 35 (19 male, 16 female) people participated in the study across the six focus groups. Thirty-four participants (97.1%) owned the property in which they lived. Twenty-seven (77.1%) of these were aged fifty years or older, and children aged ten years or younger were present in six (17.1%) participant households. Thirty-two participants (91.4%) reported drinking water from their private wells, with just 14.3% employing a water treatment system (i.e., UV, reverse osmosis or chlorination). Eight participants (22.7%) had previously experienced flooding events near their own well (direct experience), while nine (25.7%) knew other well owners that had experienced flooding (indirect experience). Thirty-one participants presented well water samples for testing and lab results indicated that five (16%) subsequently tested positive for *E. coli.*

Table 3. Planned focus group description, including code, date, location, recruitment strategy, number of participants, length of each session, and the level of flood experience in the area.

Focus Group	Date (2018)	Location (See Figure 2)	Recruitment Strategy	*n* (Targeted Households)	*n* (Participants)	Session Length (mm:ss)
FG1	28/04	Westmeath	Letters	100	9	71:25
FG2	28/04	Westmeath	Letters	100	2	24:07
FG3	05/05	Clare	Letters	100	6	62:25
~~FG4~~	~~05/05~~	Clare	Letters	100	-	-
FG5	07/06	Wicklow	Local recruiter	-	6	64:27
~~FG6~~	~~07/06~~	Wicklow	Local recruiter	-	-	-
FG7	23/06	Westmeath	Local recruiter	-	4	73:47
FG8	18/07	Dublin	Letters	60	8	44:23
~~FG9~~	~~17/07~~	Dublin	Letters	60	-	-

Table 4. Participants profile per focus group meeting, including gender, property ownership status, presence of kids in the household, well water consumption, usage of well water treatment, and flood experience (direct and indirect).

Focus Group	*n* (Male/Female)	Own the Property They Live on	Children <10 Years in Household	Drink Well Water	Well Water Treatment Installed	Experienced Floods near Their Wells in the Past	Total
FG1	6/3	9	0	9	0	3	9
FG2	0/2	2	0	2	0	0	2
FG3	3/3	6	2	5	2	0	6
FG5	3/3	6	3	6	2	4	6
FG7	3/1	4	0	2	1	0	4
FG8	4/4	7	1	8	0	1	8

3.2. General Thoughts on Well Water Quality

In general, participants in each focus group reported satisfaction with their own well water, referencing factors such as good taste, lack of issues, praise from visitors, and overall quality. Common words used to describe water included "lovely," "fresh," and "no chlorine". Complaints of excess "lime" (i.e., hardness via excess $CaCO_3$) (FG1, FG2, FG3, FG7, FG8) and iron (FG1, FG5, FG7) were common; however, concerns largely focused on damage to appliances, plumbing, and clothing, rather than drinking water safety.

Most focus group discussions highlighted awareness of infections that could be caused from drinking contaminated water. *Cryptosporidium* spp. was cited in some focus groups, referring to a large outbreak in the west of Ireland (Galway City) in 2007 which garnered considerable media attention. *E. coli* was also mentioned during several focus groups (FG1, FG3, FG7). Nevertheless, many participants expressed quite limited concerns regarding drinking water safety. One participant related a case of gastroenteritis in the household, but did not believe it was related to the well:

FG5: "My son had gastroenteritis a couple of weeks ago, not that, like I think it's probably nothing to do with the [well], just something but it's just in the back of my mind"

When asked, some focus group participants stated that they would change to a public supply if offered the choice. The main reasons for doing so were:

FG1: "[It would be] far cheaper [less expensive]"

FG3: "I'd say the public water is way safer"

FG5: "I have to get it (my well) serviced twice a year. It would be cheaper for me to pay water charges"

FG7: "I might as a second ... just to have as a backup"

However, there was agreement throughout most of the focus groups that they would prefer to continue using their own supplies, primarily citing the taste, freshness, and knowledge of what (if any) chemicals have been added:

FG1: "One doesn't know exactly what chemicals are being put in, I know they're probably ok, but you don't know that",

FG1: "I suppose the main thing is that you'd like to know what is in your water",

FG7: "I can taste the chlorine in town water, even when it's boiled I can still taste it"

FG8: "I like the idea, I think, of the well, I do think like it's fresh, it has no additives and things like that".

3.3. Flooding Experience and Perceived Threat

As shown (Table 4), most participants (77%) reported no direct flooding experienced near their supplies. Additionally, there was broad consensus across all focus groups that participants did not consider themselves at risk of flooding, the primary reason being that most of them reported living on high ground:

FG1: "Mine couldn't, I'm on a hill"

FG2: "No, I'm high up"

FG7: "I would say (other participant's name) if you or I flood, the rest of the country will be under six feet of water"

Notably, even participants that lived in close proximity to areas affected by extreme flooding events in the past (FG3), or who had already experienced local flooding (FG5, FG8), did not consider themselves at risk of flooding. Participants that had experienced small-scale floods tended to associate flooding and flood-related contamination to large scale events:

FG5: "Sort of, I wouldn't call it flooding, just it came around like and just took a while to [dissipate]"

FG8: "I think once we might have had sort of a heavy flood, actually the water was ok, it's a good few years ago now"

Nonetheless, it was widely agreed throughout the focus groups that wells would be at risk of contamination if flooding did occur, particularly if the well was inundated. In the case of adjacent flooding (i.e., <100 m radius) some participants reported that they would not be concerned about contamination:

FG3: "If it wasn't very close, if it was a hundred metres away, I don't think I'd think of it".

Additionally, cases of optimism bias were identified as some participants believed their source was characterised by a lower risk of becoming contaminated by floods compared to others in their area:

FG1: "Now every other well could be contaminated in that field, mine can't. Because mine is higher than theirs"

FG5: "Mine certainly would be [less likely to become contaminated], no matter what because I'm there 45 years so it never happened, and it would be very unlikely to happen, that's just my own personal experience".

FG5: "Personally my own well compared to other wells in the area, I would classify as low risk".

Notwithstanding, many participants reported that they would be "*somewhat*" or "*very*" concerned about their water quality if flooding happened near their wells. When asked about their reasons for concern, the issue of nearby agricultural run-off, including chemical and animal (faecal) contamination was frequently raised, with human sources (e.g., domestic wastewater (septic) treatment systems) only acknowledged upon further probing. The potential for illness and becoming "*very sick*" if this happened was widely recognised, while some participants noted the potential increased severity when potentially vulnerable people (e.g., children, elderly, people with underlying health conditions) are exposed to contaminated drinking water. On the other hand, some considered that having control over some activities reduced their exposure:

FG7: "And you have your own land around so nobody can be doing anything. Perfect circumstances".

FG3: "At least with a septic tank you can control it yourself, you know".

3.4. Cues to Action

There were several recurring themes in people's cues to action. Change in "*smell*", "*taste*", and "*colour*" (i.e., organoleptic parameters) were brought up in all focus groups as the main potential causes for concern regarding their private well. However, one of the participants, after having experienced a change in water colour, related that the concern didn't result in long-term protective action:

FG8: "After the snow, our pipes froze and then when we got it all back working. And after that then for a good while there was a lot of dirt coming out in the water. I stopped using it. I stopped using it for a while, but we let it run and then after a while, then considered getting it tested and then after a while it seemed fine".

This was jokingly referred to as "*the look test*" by another participant, which was received knowingly by the rest of the group. The point that "*you know your own water*" was raised by multiple groups, and this belief may explain lack of action.

Other frequently mentioned cues to action included whether many people in a household became sick with no obvious cause and if the well(head) was submerged by floodwater; however, some people believed that this would be the same water that was in the well already and so did not perceive this to be a problem. Neighbours getting their water tested was mentioned as a potential cue to action in two focus groups (FG2, FG3).

3.5. Perceived Benefits and Barriers

Across each focus group, many participants only had their well water tested when they "*got it bored*", "*built the house*", "*moved into*" their property, or when they had filters or treatment systems installed, with some reported having never had their well water tested. Paradoxically, many, although not all, participants were aware that "*they recommend you test it every year*" and considered testing the well water important:

FG2: "You need to see whether you need treatment"

FG2: "Just to see is it contaminated and that, you know?"

FG5: "Unless you know what's in the water you can't deal with it".

People in each focus group believed that there is a lack of information currently available and identified this as the primary barrier to getting their water tested. They reported that they would be most likely to get their information online from a source "*without a vested interest*," such as the local county council or the Environmental Protection Agency. It was common that participants were unaware of where they could go to get their water tested and, among those who knew, they cited cost and inaccessibility as significant barriers to testing. Primary reasons given by participants for not testing more often included elevated costs, fear of negative results, distance to laboratories, not knowing a "*reputable testing place*", "*lack of knowledge*" on where to go to get it done, and putting it "*on the long finger*" by indefinitely postponing action:

FG2: "It was quite dear; I remember at the time being a lone parent. I thought: 'Gee €150 or something'. I do remember it being very dear [expensive], and I thought 'Not this week, maybe next week. Not next week, maybe the week after . . . "

FG5: "It kind of slipped down the list of priorities".

When discussing who they would trust to test their water, participants again reported wanting someone without a "vested interest". The most frequently mentioned source of information was scientists, followed by the local county council, and then a government department. However, for many, there was also a degree of mistrust in various public authorities, with some negatively mentioned including Irish Water [public utility], county councils, or the Health Service Executive (HSE) as sources of information:

FG3: "No, I wouldn't go near them, not in a million years".

3.6. Self Efficacy

Self-efficacy (i.e., peoples' confidence in their own ability to implement appropriate mitigation measures) has been shown to be strongly predictive of protective behaviours towards groundwater supplies following flooding events. As for the perceived barriers highlighted above, absence of knowledge, poor accessibility to services, and high cost were mentioned across focus groups as factors that impacted whether participants tested their well water and/or installed water treatments.

FG2 "Q: If your well flooded would you know what to do? Or where to find the information out?

A: Wouldn't have a clue".

FG 5 "(I would be) prepared to do it if I knew what I had to do . . . "

Participants generally believed that if they were provided with the relevant information and knowledge, and if the financial cost was not too high, they would be able to implement the suggested protective actions.

3.7. Health Behaviours following Floods

Regarding post-flood action, there was consensus across most focus groups that participants would get their well water "*checked*" or "*tested*", with some also reporting that they would boil the water before drinking. With regards to protective behaviours after floods in general, one participant stated:

FG5: "The highest risk to all wells is lack of information and lack of knowledge. People not even understanding how, where the water comes from, let alone what to do with it. If people understand the risk of flooding, 90% of them would get a remedy fairly quick, it's just that they're not aware of the risks".

However, amongst the few participants that experienced prior flooding, only one pursued protective action, installing a treatment system. Similar to reasons given for not testing well water regularly, other participants attributed lack of action to postponing action and "*putting on the long finger*". Nonetheless, participants at all focus groups seemed in agreement that it should be the well-owner's responsibility to test their water, including after extreme events such as flooding:

FG1: "The man who owns the well"

FG1: "The way I look at it if it's my well it's my job"

FG3: "I would see it as our own responsibility, but I'd like to get a bit more help from council as regards testing, you know, if you're supposed to get it tested but if they had the facilities to test it, which they probably do because they're testing their own water all the time".

FG7: "You bored your well, it's up to you to keep it"

FG8: "The owners first".

However, many reported that "*it would be nice*" to be alerted to nearby flooding and given a recommendation to get their well water tested, and regretted that local authorities were not more actively involved:

FG1: "They should yeah, but they don't"

FG7: "It's a pity the local authority hasn't a board of some kind there that you can run in to a place and say 'could I get that tested please' and [get] a charge, a small charge, now not astronomical money, but I'm sure fifty euro would cover a water test, it would be a great service, but it'll never happen . . . "

FG8: "I wouldn't expect someone knocking on the door saying did your well flood, it would be nice to have somebody to contact if it did".

4. Discussion

4.1. Overview

Whilst hydrogeological literature on the integration of social research and groundwater management is increasing, there has been very limited research examining the social and cognitive factors that influence risk perception and behavioural response to flooding among private well users, despite the risks posed by flooding to private wells. To the authors' knowledge, this is the first qualitative study employing focus groups to examine the perceptions of Irish private well owners. From six successful focus groups, comprising thirty-five participants, findings suggest that although participants were aware of the potential threat of well contamination following flooding, most did not consider themselves to be at risk. Perhaps it is this lack of a perceived threat that resulted in relatively low levels of interest amongst residents targeted for participation in each case study area.

A variety of behaviour change models exist that could be used to examine how knowledge and perception can influence behaviour modification in relation to health risks [58]. Figure 3 applies the research findings to the HBM. Although this model is traditionally applied to understanding behaviour in the health sciences, there are commonalities between behaviours undertaken to ensure positive health and behaviours undertaken to maintain water quality to protect people's health [43,51]. Additionally, environmental behaviours conceptualised as health behaviours have the potential to offer new insight into pro-environmental behaviour change [51].

In the event of flooding, participants indicated a belief that they were responsible for their own wells. However, their capacity to engage in appropriate protective actions—water treatment, well monitoring and well water testing—was reduced by unsupported optimism regarding their perception of reduced risk of exposure to flooding and subsequent contamination. Misperception is not unusual in relation to perceived flood exposure [59]. However, as noted by Boudou et al. (2021) [36], there can be a considerable time-lag effect between flooding and the experience of contamination, up to 2–3 months, depending on the time of year and hydrogeological setting, so it would be very challenging for a non-expert well owner to predict contamination. Moreover, we found: a failure by some participants to conceive that prior negative health experiences might be linked to contaminated well water—cognitive dissonance; overall reliance on visual and olfactory evidence to assess water quality; concerns regarding the financial cost and accessibility of water testing facilities; and a degree of mistrust by some in public bodies, albeit the fact that recent water policy reforms in Ireland have been controversial [60,61].

Presented findings suggest that although most participants report an awareness of the potential health risks associated with flooding near private wells, these beliefs lack depth of awareness to inform subsequent actions. Instead, in line with recent research [24,34], where potential behaviour change is motivated, in most cases this is simply responding to visual and olfactory evidence. Analogous to findings reported by [43], such exclusive reliance on sensory mechanisms to detect water contamination can result in non-sensory risks such as intangible water quality and related health risks being ignored and, in the absence of any visual cues to action, reduce the potential for necessary preventative behaviour [62,63].

This reliance on sensory mechanisms to “detect” water contamination also suggests that well owners’ awareness and actions may be overly focused on addressing physical water characteristics rather than an overriding concern about potential threats to health; however, participants in the current study did display a reasonable understanding of the potential severity of well contamination and several participants mentioned the importance of water testing when there were vulnerable members in the household (e.g., children, elderly, or people with underlying health conditions). Most participants did not consider themselves to be at risk of flooding or contamination, even those that lived adjacent to areas previously affected by extreme flooding events or who had already experienced localised events. Participants’ beliefs that well water is a natural source free from intervention (e.g., chlorination), unlike water from the public supplies, and the failure of some participants to understand the hydrological cycle or differentiate between the water in their wells and flood water, may strengthen their idea that the chance of potential contamination is relatively small.

Whilst there was not a lack of confidence expressed by participants about their personal ability to implement protective actions, the informational knowledge gap about what these measures were and associated financial costs were identified as barriers that would inhibit most participants’ ability to implement behavioural changes consistent with ongoing well stewardship. Such barriers align with prior findings of Jones et al. [64]. Nevertheless, it has been recognised in previous Irish flood studies that reliance on communications strategies derived from an information deficit model may fail to account for many situational factors and social, cultural, and psychological attributes that influence how people respond locally [65]. At variance with the optimism reported by most participants about their well water quality in this study, lab results indicated that five (16%) of those that presented well water samples subsequently tested positive for *E. coli.* This highlights a degree of disconnect between the real susceptibility of participants’ private wells to contamination and their perception of exposure to contamination sources, with many expressing strong optimism about their own well water quality, and limited contamination exposure compared with neighbours.

Previous research concerning the ‘correctness’ of perceived risk extent from fluvial flooding found significant deviations with objective measures [66]. Therefore, the optimism and misperception noted here is less surprising, as it would seem that few participants truly understand the intersect between flooding and private groundwater, combined with the difference between visible flooding and groundwater flooding with long-term saturation.

However, widespread reference to a waterborne outbreak of cryptosporidiosis in Galway city (this high-profile outbreak saw 242 laboratory-confirmed cases with a boil water notice in situ for 158 days impacting 120,000 city residents and workers, at a total societal cost of €19 million; the largest such outbreak in Ireland since outbreak surveillance began [67]), dating back to 2007, did highlight a strong degree of awareness of the potential threat arising from water contamination events. It also pointed to enduring trust concerns regarding public water supplies that may also act as a barrier to change to alternative public supplies if they were available. The illusion of 'control' referred to by Hooks et al. [34] may also represent a barrier to change. For example, some participants when referring to potential exposure to contamination reported that their 'control' over the use of the surrounding land, over their domestic wastewater treatment system ('septic tank'), or indeed their well location within the terrain, provided protection to their well water relative to others. Given that risk perception is influenced by a combination of perceived severity of, and susceptibility to, a threat [43,68], without fully appreciating these factors, combined with a dependence on sensory mechanisms, the likelihood of focus group participants carrying out risk prevention behaviours is reduced. Indeed, amongst the few participants that had experienced flooding, just one pursued protective action. As noted previously, there is evidence of cognitive dissonance (whereby individuals hold conflicting attitudes, beliefs, or behaviours) found in views expressed and reported behaviours by many focus group participants.

It is useful to reflect upon the findings here on a comparative basis. On the one hand the results reached in this study highlight at least a latent awareness of the risk of contamination of water used for consumption and associated health implications. On the other hand, the real context in the field regarding participants' well locations in terms of terrain topography, exposure to floods, lack of water treatment, and the presence of other sources of contamination, points to a degree of misperception amongst participants whose assessments of risk exposure were frequently overly optimistic. For example, none of the participants whose well water subsequently tested positive for *E. coli.* anticipated that it would. Even where there is conscious acceptance of potential contamination, the evidence suggests a lack of follow through in terms of protective actions amongst many participants.

A question arises as to how to engage or target such 'hypocrite' behaviours. One potential method is the 'hypocrisy paradigm' that seeks to induce feelings of hypocrisy and associated negative emotions [69]. Dickerson et al. [70] and Taylor et al. [71], for example, highlights the potential to exploit cognitive dissonance to encourage water conservation by making people feel hypocritical where their underlying beliefs are inconsistent with their behaviours. Nevertheless, we found that most participants acknowledged that they did not proactively think about the connection between their health and their well, or conciously think about the connection between flooding and their supply. A public policy response is required that considers that effects may lag by 2–3 months depending on the time of year and hydrogeological setting, and that is more multidiciplinary and embraces 'policy coherence' [72]. Therefore more spatial and temporal targetting of communications is required to effectively promote protective actions, with message framing also important [73]. Likely contributing to the low levels of protective action, a lack of knowledge on how or where to test water was also identified. Participants expressed a preference towards water testing services provided by people without a "vested interest" in the test result, such as scientists (as opposed to the public authorities that they may work for), and many participants reported attending the focus groups to avail of the free water test. However, the degree to which people actively sought information on testing services prior to attending the focus groups is unclear. It seems likely that, prior to receiving the prompt provided by this study, participants were content in their beliefs that the chance of potential contamination of their wells was relatively small and that they knew their wells best. This, however, does suggest that people would be more likely to test their well water periodically if it was a free and accessible service. Some consideration could be given to a service that meets those criteria as delivered in Alberta and Ontario, Canada [52].

4.2. Implications & Future Research

This was a small-scale study involving 35 participants recruited from four case study areas. Whilst reliability was pursued by undertaking a number of focus groups until a high degree of consensus across focus groups was achieved, and consistent and validated coding was applied, significance of association was not tested, as the methodology does not offer statistical validity. Nevertheless, qualitative studies provide opportunities to improve understanding of socio-cognitive factors, as they can provide more contextually sensitive and relevant information [74], and case study approaches provide detail, richness, and completeness, as compared with statistical studies that offer breadth [75]. In this case, qualitative research using focus groups provides deeper insights into well owners perceptions and preparedness. Indeed, the 'richer' qualitative data found here complements previous survey data that involved larger numbers of respondents, but provided more limited opportunities for probing and related contextual data.

Despite its limited scale, this study provides some tentative indicators regarding future socio-hydrogeological interventions that could assist individuals and communities in taking an active role in protecting their water supply and, in turn, their own health. Findings pointed to various factors undermining protective actions amongst participants viewed through the lens of HBM. Given the low levels of perceived exposure amongst participants', we suggest that future interventions should seek, firstly, to promote preparedness at the individual level, secondly, be more targeted in communication both spatially and temporally by focusing on the most vulnerable locations to effectively communicate when wells may be at risk, thirdly, through targeted message framing, communicate what actions should be undertaken following flooding, and finally, to consider making access to well water testing accessible and low cost or preferably free to householders. These interventions would assist in shifting people beyond simple awareness of the importance of regular well water testing to being more likely to carry out this action as a desirable social norm. To further support such interventions, findings from this study could be integrated with results from other quantitative studies in the Irish context to develop guidance for policy makers, local authorities, health authorities, and non-experts. Future research would also benefit from employing quantitative methods to further identify the specific HBM elements that might best explain protective behaviours following flooding near private wells.

4.3. Limitations

Just eight (23%) of the participants who attended the focus group sessions in the current study reported prior flooding experience. As a result, the findings of the current study largely reflect participants' beliefs on how they would react following a flooding event, which may differ from how they would actually react in those circumstances. Secondly, whilst good practice techniques in recruitment were followed, three planned focus group sessions did not proceed due to an inadequate number of participants. This may be an indication of the challenge of engaging people in qualitative research where the benefit of participation might appear low if you do not consider yourself to be at risk. This aligns to the third limitation; a number of the participants who participated indicated that the offer of a free well water assessment was part of the motivation to participate. Hence, there is a degree of selection bias among participants and so the composition and output of a small-scale qualitative study will not necessarily be representative of the views and experiences within the overall population of private well users; however, the study does provide good representation of various hydro-geological contexts nationally. A further limitation is associated with the application of the HBM itself. The HBM does not define the relationships between the constructs and has been found to have limited predictive capability of actual behaviour [31]. On the other hand, as noted by Orji et al. [57], it is this lack of definition that provides flexibility and adaptability in applying the HBM to other health-related behaviours, as it was applied in this study. Finally, whilst we can be confident of having reliably identified a consensus across groups (data saturation), we do not provide any assessment of the relative strength of opinion across focus group, as the group dynamic within each focus group was context specific.

5. Conclusions

The rising frequency and severity of extreme weather events such as flooding may represent a significant trigger for contamination of private water supplies, directly increasing the risk of waterborne infections. The HBM provides a useful lens for exploring environmental behaviours with human health implications. In the current study, participants were aware of the potential severity of well contamination following flooding; however, most did not consider themselves to be at risk and had not given much consideration to flooding or its implications for their water supply or health. Moreover, their capacity to engage in appropriate actions following flooding was reduced by a range of factors. However, more spatially and temporally targeted risk communications regarding appropriate protective actions to mitigate risks would increase socio-hydrogeological awareness. In addition, the provision of free well-water testing would assist individuals and communities in taking an active role in protecting their water supply and health.

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Appendix A

Table A1. Short Questionnaire.

1	What is your gender: ☐ Male	 ☐ Female			
2	How old are you? ☐ 18–24	 ☐ 25–34	 ☐ 35–49	 ☐ 50–65	 ☐ 65+
3	How long have you lived in your current home? ☐ 0–1 years	 ☐ 2–5 years	 ☐ 6–10 years		 ☐ Over 10 years
4	Do you own it or rent your current home? ☐ Own	 ☐ Rent	 ☐ Other		
5	Please provide your eircode so we can identify your well's hydrogeological information: ________________				
6	How many people that currently live in your household (including yourself) fall under each of the following age groups? Leaving blank space equals 0 (zero) persons in that age group Less than 1 year old: ___ 1–5 years old: ___ 6–10 years old: ___		 11–17 years old: ___ 18–65 years old: ___ Over 65 years old: ___		
7	Which of the following is a source of drinking water in your household? ☐ Private household well		 ☐ Private group (ground)water scheme		

Table A1. *Cont.*

8	What type of well do you have?		
	☐ Hand-dug	☐ Borehole	☐ Don't know
9	How deep is your well?		
	☐ Under 15 ft (Under 5 m)	☐ 31 to 65 ft (11 to 20 m)	☐ Over 100 ft (Over 30 m)
	☐ 15 to 30 ft (5 to 10 m)	☐ 66 to 100 ft (21 to 30 m)	☐ Don't know
10	Do you apply any of the following to your well water before consuming it? Mark as many options as are applicable		
	☐ Chlorination	☐ UV treatment	☐ I boil my water before drinking
	☐ Jug Filters	☐ Water softener	☐ None of the ones mentioned
	☐ Cartridge filters	☐ Reverse osmosis	☐ Don't know
11	Do you drink the water from your well?		
	☐ Yes	☐ No	
12	Have you ever had your well water tested for contamination by a laboratory (before today)?		
	☐ Yes—and didn't find contamination	☐ No	
	☐ Yes—and found contamination	☐ Don't know	
13	Has flooding (as shown in the pictures below) ever occurred within 100 m of your well? 		
	☐ Yes—every year	☐ No—but it has happened to people I know	
	☐ Yes—a few of times in the past	☐ No—and it has not happened to anyone I know	
	☐ Yes—once before	☐ Don't know	

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