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Private groundwater management and risk awareness: A cross-sectional analysis of two age-related subsets in the Republic of Ireland

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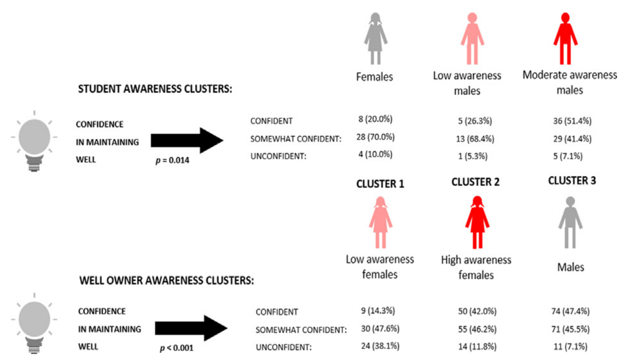
HIGHLIGHTS

- Awareness of private well management factors quantified among 560 Irish well users
- Awareness scores compared between two age-related subsets.
- Median awareness score was 66.7%, with well owners markedly outperforming students.
- Awareness- and gender-based clusters identified in each subset.
- Socio-demographics, perceived self-efficacy and well use recurring determinants of awareness.

GRAPHICAL ABSTRACT



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ABSTRACT

Risk communication represents the optimal instrument for decreasing the incidence of private groundwater contamination and associated waterborne illnesses. However, despite attempts to promote voluntary well maintenance in high groundwater-reliant regions such as the Republic of Ireland, awareness levels of supply status (e.g. structural integrity) have remained low. As investigations of supply awareness are often thematically narrow and homogeneous with respect to sub-population, revised analyses of awareness among both current and future supply owners (i.e. adults of typical well owner and student age) are necessary. Accordingly, the current study utilised a national survey of well users and an age-based comparison of supply awareness. Awareness was measured among 560 Irish private well users using a multi-domain scoring framework and analysed in conjunction with experiential variables including experience of extreme weather events and previous household infections, and perceived self-efficacy in maintaining supply. Respondents displayed a median overall awareness score of 66.7%, with supply owners ($n = 399$) and students ($n = 161$) exhibiting median scores of 75% and 58.3%. Awareness among both combined respondent subsets and well owners was significantly related to gender, well use factors and self-perceived behavioural efficacy while awareness among students was not correlated with any independent variable. Cluster analysis identified three distinct respondent groups characterised by awareness score and gender in both current and future well owner subsets. Male well owners and students displayed higher perceived self-efficacy irrespective of awareness score while female well owners that demonstrated high awareness were significantly more likely to report postgraduate educational ($p < 0.001$). Findings suggest that recent experience of extreme weather events does not significantly influence supply awareness and mirror previously identified knowledge differences between well owners and young adults. Age, gender, supply use and

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perceived self-efficacy emerge as recurring focal points and accordingly merit consideration from groundwater and health communication practitioners for future risk interventions.

1. Introduction

Approximately 16% of the population (750,000 people) in the Republic of Ireland (ROI) is served by private individual household and community-managed groundwater wells (CSO, 2017a). As these supplies are neither regulated nor inventoried nationally, promotion of voluntary well maintenance via risk communication (i.e. the systematic, science-based conveyance of risk to vulnerable populations) is integral to safeguarding public health in groundwater-reliant rural areas (Palenchar, 2010). Conscious knowledge or *awareness* of well status (e.g. structural features, proximity to contamination sources) has been identified as a principal precursor to well management – encompassing supply inspection, water quality testing and treatment (Kreutzwiser et al., 2011; Flanagan et al., 2015; Malecki et al., 2017). However, well management guidelines by local and national government authorities are limited and recent research in the ROI has documented low levels of supply awareness among well users (Hynds et al., 2013). With *E. coli* present in an estimated 30% of Irish household wells in 2017 and exposure to private well water implicated in 44% of notified national cases of verotoxigenic *E. coli* (VTEC) in the same year (HPSC, 2019; EPA, 2020), there is an evident need for improved education of and engagement with Irish private well owners. The urgency for effective interventions is significantly elevated by the increasing occurrence of climate change-related extreme weather events (EWEs) such as flooding and heavy rainfall, which have been demonstrated to facilitate and accelerate microbial contamination of private wells both nationally and internationally (Andrade et al., 2018; O'Dwyer et al., 2016). As more frequent and acute EWEs will necessitate routine, seasonal well maintenance and, in turn, greater awareness of supply management to prevent groundwater contamination, a holistic characterisation of supply awareness and associated determinants is imperative for development of future risk communication initiatives.

While historical shortcomings in enabling improved awareness among private well owners may be attributable to deficiencies in information availability and dissemination (Munene and Hall, 2019; Mooney et al., 2020a), they may also be ascribed to limited acknowledgement of particular experiential and cognitive factors – leading to poorly framed, overly-generalised risk communication materials (Mooney et al., 2020b). Previous literature (encompassing studies from North America, Southeast Asia and the ROI) has variously identified age, gender, education, homeownership, household composition, residential duration and sensorial cues as significant determinants or indicators of well user awareness (Renaud et al., 2011; Hynds et al., 2013; Chappells et al., 2014). However, other aspects of potential relevance to private groundwater end-user awareness such as perceived behavioural competency (or self-efficacy), climate change concern, EWE experience and previous occurrence of a potentially waterborne infection within the household, have been afforded considerably less attention (Fox et al., 2016; Ekstrom et al., 2017). As of now, many drinking water quality guidelines still neglect to include information on climate change adaptation or demonstrate the actual practicality of supply maintenance measures (Khan et al., 2015; Green, 2016). The roles of self-perceived confidence in maintaining supply and recent household illness (i.e. occurrence of gastrointestinal illness) as drivers of awareness are similarly overlooked (Lavallee et al., 2021). Exceptions notwithstanding (Hynds et al., 2013; Lavallee et al., 2021), existing delineations of supply knowledge globally have tended to focus on individual aspects of supply management (e.g. testing history) and often neglect to provide a definitive definition of supply awareness (Mooney et al., 2020a). Aspects of supply awareness conducive to risk prevention and behavioural adoption may encompass knowledge of physical supply characteristics in addition to maintenance history and contamination hazards (Kreutzwiser et al., 2011; Di Pelino et al., 2019).

As more sophisticated media engagement channels and audience categorisation algorithms may be introduced in the future (Hoffman et al., 2019), subsequent generations of well owners may be easier to engage with and thus display greater supply awareness than their antecedents. However, in spite of the impact of modern socio-cultural shifts (ILC Global Alliance, 2012), intergenerational learning (i.e. knowledge and norms imparted from adults) has in certain cases continued to influence environmental risk awareness among younger populations (Williams et al., 2017; Lawson et al., 2019). A comparison of awareness levels among adults of well owner age (current well owners) and student age (emerging well owners) may shed further light on both established and understudied phenomena governing well user awareness and enable prediction of future awareness levels. As today's young adults (i.e. students ≥18 years old) represent the ‘climate change generation’, growing up amid high information saturation and uncertainty regarding climate change-induced EWEs (Wachholz et al., 2014; Ford and King, 2015), future well owners warrant proportionate attention to current well owners in the context of private groundwater supply awareness. To date, there is limited international research comparing supply knowledge levels between these two demographic subsets. Although prior research in the ROI has drawn this distinction (Hynds et al., 2014), the influence of EWE experience and climate change concern on students' and well owners' awareness has yet to be determined.

With the intention of devising a robust delineation of well user awareness and associated determinants, the current study utilises a national survey of private well users in the ROI. A comprehensive awareness scoring framework is introduced encompassing knowledge of physical supply attributes, supply maintenance history and supply contamination. Further to customary socio-demographic and supply use characteristics, the significance of perceived behavioural efficacy, occurrence of household illness, climate change concern and EWE experience are explored as contributory factors to well user awareness. Intergenerational awareness levels are analysed, compared and contrasted using well owner age and young adult age (i.e. student) respondent subsets. Cluster analysis is undertaken to discern latent awareness response trends and audience segments in both subsets, with clusters subsequently analysed to establish key determinants of audience awareness levels. In distinguishing central focal points determining present and future well user knowledge in an era of heightened groundwater contamination and health risk due to climate change, study findings may provide value to both national and international environmental health practitioners, in addition to groundwater professionals such as hydrogeologists and well drillers.

2. Methodology

2.1. Survey parameters

The survey was conducted in the ROI (area = 70,273 km^2), which has a total population of 4.9 million and a relatively large rural population of approximately 1.8 million (CSO, 2017b). The ROI's climate is cool temperate oceanic, with the country thus prone to seasonal surges in precipitation (McCarthy et al., 2015). Accordingly, survey questions relating to well water quality examined pathogenic contaminants (potentially mobilised via EWEs) and contamination sources of anthropogenic origin. Questions pertaining to EWE experience were limited to named events occurring within the last decade to maximise reporting accuracy. The survey layout was informed by the KAP (Knowledge, Attitudes and Practice) model and adopted a structured, standardised format (Warwick, 1983). Survey participants were required to be ≥18 years old (i.e. young adult age) and avail of a private groundwater well as their principal source of domestic potable water.

2.2. Survey design

The survey contained 41 questions across four sections. The first section comprised 11 questions concerning private well use, i.e. supply connection (ownership), construction history and function(s), and respondent demographics. Income and household size categories were informed by existing frameworks (CSO, 2017a; UN Department of Economic and Social Affairs, 2017). The second section comprised 13 questions pertaining to supply knowledge, water quality testing (i.e., chemical and microbial parameters) and human health, with those seeking to discern respondents' supply management awareness and recent household history of gastrointestinal illness retained for the current study. Section 3 contained 9 questions regarding EWEs and climate change, three of which were included herein. For the first question, respondents were requested to disclose household experience of five recent EWEs occurring between 2013 and 2018, including: Storm Deirdre (December 2018 heavy rainfall), summer drought 2018, "Beast from the East" (February–March 2018 snowstorm), Storm Ophelia (October 2017 heavy rainfall) and winter 2013/2014 floods (fluvial flooding). The second question asked respondents citing EWE experience to recall any observed post-event changes in water quality and quantity while the third asked respondents to rate their concern vis-à-vis climate change impacts on groundwater quality. The final section consisted of 7 questions relative to general well maintenance encompassing behavioural barriers, educational preferences and perceived self-efficacy (included herein).

All sections included in the current study employed dichotomous and multiple-choice questions to collect and partition categorical data. Filter questions were utilised to ensure respondents availed of a private groundwater supply and separate well users based on prior experience (i.e. EWE experience); Likert-scale questions were used to establish perceived confidence in undertaking well maintenance and climate change concern.

2.3. Awareness scoring protocol

An awareness scoring protocol adapted from a previous framework by Lavallee et al. (2021) was developed to enable quantitative measurement of well user awareness. A total of 7 domains (tenets of supply awareness) were utilised for scoring, encompassing awareness of well depth, well age, well features (i.e. structural components), water treatment, water quality testing history, relevant pathogens and pathogen sources (Table 1). Well depth categories were derived from Misstear et al. (2006) to enable capture of all well types (e.g. shallow dug wells and deep drilled wells). To quantify overall awareness, dichotomous and trichotomous scoring protocols were used across individual domains. The maximum possible score for overall awareness was 12, with scores standardised between 0 and 100 for statistical analysis. Cronbach's alpha was used to assess internal consistency of responses to scored awareness items.

2.4. Survey completion

The survey was circulated both online and in-person between 17 September and 17 November 2019. The online survey was hosted on the survey-hosting platform *SurveyMonkey* while the physical survey was distributed within four rural agricultural colleges in group format (i.e. classroom setting). Written and electronic survey formats were preferred over phone and postal surveys as both typically yield higher response rates (Dillman et al., 2014). A series of relevant rural interest groups and organisations were consulted via purposive sampling to facilitate online survey distribution, with all informed of study objectives and data handling procedures (exclusion of respondent ID and IP addresses) prior to survey dissemination. Purposive sampling was also utilised to identify agricultural colleges assisting in physical survey dissemination, with all participating institutions providing consent prior to onsite visits. Survey respondents were not offered any incentive (financial or otherwise) to participate.

The majority of physical survey respondents comprised students between the age of 18–24 while online respondents were primarily 25 years old or older (i.e. well owner age). As such, partitioning the survey on the basis of completion mode represented the optimal means of establishing student and well owner subsets.

Table 1
Awareness scoring framework (domains, response categories and scoring protocols).

Awareness domain	Response categories		Scoring protocol	Score[a]
Well age	0–5 years	5–10 years	Aware	1
	10–20 years	20–30 years	Unaware	0
	30–50 years	>50 years		
	Don't know			
Well depth	<10 ft. (3 m)	10–50 ft. (3-15 m)	Aware	1
	50–100 ft. (15-30 m)	100–200 ft. (30-60 m)	Unaware	0
	200–300 ft. (60-90 m)	>300 ft. (90 m)		
	Don't know			
Well features[b,c]	Well cap present	Cemented well casing	Aware of 5–6 features	3
	Damaged well cap	Damaged well casing	Aware of 3–4 features	2
	Pump at base of well	Buried well	Aware of 1–2 features	1
			Aware of 0 features	0
Treatment system present	Yes	No	Aware	1
	Don't know		Unaware	0
Previous water quality test	Yes	No	Aware	1
	Don't know		Unaware	0
Pathogens found in wells[b,d]	*Campylobacter*	*Cryptosporidium*	Aware of 5–6 pathogens	3
	Giardia	*Norovirus*	Aware of 3–4 pathogens	2
	Salmonella	*Verotoxigenic E. coli*	Aware of 1–2 pathogens	1
			Aware of 0 pathogens	0
Pathogen sources[b,d]	Domestic animals	Farmyards	Aware of 3–4 sources	2
	Grazing animals	Septic tanks	Aware of 1–2 sources	1
			Aware of 0 sources	0

[a] Maximum awareness score = 12.
[b] Respondents required to select 'Yes', 'No' or 'Don't know' for each category.
[c] 'Yes' and 'No' answer options classified as 'Aware'.
[d] Only 'Yes' answer option classified as 'Aware'.

2.5. Statistical analysis

Survey data were imported to IBM SPSS Statistics 26 for analysis, with current and future well owner subsets (i.e. well owners and students) analysed separately. Descriptive statistical functions were employed to detect outliers in continuous data (i.e. awareness scores), with the Shapiro-Wilk test used to determine data normality and selection of appropriate statistical approaches. Responses to combined awareness items demonstrated consistency across scales in both integrated and discrete respondent subsets (Appendix A). Mann-Whitney U and Kruskal-Wallis non-parametric tests were used to investigate relationships between awareness and binary/categorical variables, with a significance level of 5% ($p < 0.05$) used by convention.

Two-step cluster analysis was used to identify subsets based on respondent awareness scores and demographic variables, with the intention of identifying discrete audience segments for future risk communication activities. Provisional clusters were developed using two-step clustering and the 'elbow method' to ascertain the optimal cluster number (explained variation as a function of cluster number). The quality of the resulting clusters (i.e. separation distance between classified objects) was assessed using the silhouette measure (silhouette score ≥ 0.7). Upon identification of final clusters, chi-square tests were used to identify significant associations between cluster membership and independent (categorical) variables. Post-hoc tests using adjusted standardised residuals were employed to detect significant differences between variable categories.

Binary logistic regression was employed to identify factors with the greatest predictive power vis-à-vis cluster membership. Explanatory variables used for regression modelling were examined for statistical significance using the Wald statistic. The Hosmer-Lemeshow test was used to evaluate goodness-of-fit between observed and predicted cluster membership (Hosmer et al., 2013).

3. Results

3.1. Respondent characteristics

The survey was undertaken by a total of 765 private well users, with 560 surveys retained for analysis where respondents answered all questions necessary for awareness quantification and subsequent analysis. The online survey was attempted by 572 private well users while the physical survey was attempted by 193 private well users. Subset-specific socio-demographic and supply use characteristics are presented in Table 2. Survey completion bias (noted for respondent education, geographical location and source connection) are outlined in Appendix A.

Table 2
Socio-demographic and supply use characteristics of survey respondents ($n = 560$).

Variable	Total answered[a]	Categories	Frequency (%)		
			All (n = 560)	Well owner age ($n = 399$)	Student age ($n = 161$)
Geographic location (province)	560	Connacht	60 (10.7)	36 (9.0)	24 (14.9)
		Leinster	250 (44.6)	191 (47.9)	59 (36.6)
		Munster	212 (37.9)	138 (34.6)	74 (46.0)
		Ulster	38 (6.8)	34 (8.5)	4 (2.5)
Gender[b]	553	Male	293 (53.0)	180 (45.8)	113 (70.6)
		Female	260 (47.0)	213 (54.2)	47 (29.4)
Age	560	18–24 years	150 (26.8)	20 (5.0)	130 (80.7)
		25–34 years	65 (11.6)	40 (10.0)	25 (15.5)
		35–44 years	111 (19.8)	106 (26.6)	5 (3.1)
		45–54 years	115 (20.5)	114 (28.6)	1 (0.6)
		55–64 years	91 (16.3)	91 (22.8)	–
		>65 years	28 (5.0)	28 (7.0)	–
Household composition[c]	560	Infant (0–5 years)	86 (15.4)	77 (19.3)	9 (5.6)
		Child (6–10 years)	102 (18.2)	91 (22.8)	11 (6.8)
		Adolescent (11–17 years)	197 (35.2)	131 (32.8)	66 (41.0)
		Adult (18–65 years)	535 (95.5)	375 (94.0)	160 (99.4)
		Elderly (>65 years)	103 (18.4)	81 (20.3)	22 (13.7)
Household size	560	Small (1–2 persons)	121 (21.6)	106 (26.6)	15 (9.3)
		Medium (3–4 persons)	229 (40.9)	166 (41.6)	63 (39.1)
		Large (≥5 persons)	210 (37.5)	127 (31.8)	83 (51.6)
Education	536	Primary/secondary school	168 (31.3)	56 (14.8)	112 (71.3)
		University/vocational degree	251 (46.8)	208 (54.9)	43 (27.4)
		Postgraduate (MA/PhD)	117 (21.8)	115 (30.3)	2 (1.3)
Income	440	€0–25,000	32 (7.3)	17 (5.1)	15 (14.3)
		€25,000-50,000	113 (25.7)	75 (22.4)	38 (36.2)
		€50,000-75,000	112 (25.5)	88 (26.3)	24 (22.9)
		€75,000-100,000	92 (20.9)	80 (23.7)	12 (11.4)
		>€100,000	91 (20.7)	75 (22.4)	16 (15.3)
Homeownership	560	Own	542 (96.8)	388 (7.2)	154 (95.7)
		Rent	18 (3.2)	11 (2.8)	7 (4.3)
Residential duration	560	0–10 years	103 (18.4)	92 (23.1)	11 (6.8)
		10–20 years	214 (38.2)	125 (31.3)	89 (55.3)
		>20 years	243 (43.4)	182 (45.6)	61 (37.9)
Well construction history	531	Installed by previous occupants	220 (41.4)	169 (43.4)	51 (35.9)
		Installed during current occupancy	311 (58.6)	220 (56.6)	91 (64.1)
Well connection	560	Individual household	488 (87.1)	348 (87.2)	140 (87.0)
		Group water scheme	72 (12.9)	51 (12.8)	21 (13.0)
Well use[d]	557	Other domestic (e.g. cooking)	505 (90.7)	373 (3.7)	132 (83.0)
		Agriculture	284 (51.0)	157 (39.4)	127 (79.9)
		No other purpose	7 (1.3)	5 (1.3)	2 (1.3)

[a] Chosen answer categories with <10 responses and 'opt out' clauses were excluded from analysis.
[b] Male students over-represented due to agricultural college demographics.
[c] Age groups present in respondent household.
[d] Supplementary to drinking water.

Table 3
Respondent awareness scores across supply management factors.

Scored variable	Awareness score								
	All ($n = 560$)			Well owners ($n = 399$)			Students ($n = 161$)		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
Well age	90.7	100.0	29.0	94.2	100.0	23.3	82.0	100.0	38.5
Well depth	71.1	100.0	45.4	72.9	100.0	44.5	66.5	100.0	47.4
Well features	74.5	100.0	36.0	80.3	100.0	33.1	60.0	66.7	38.7
Well cap present	73.2	100.0	44.3	79.2	100.0	40.6	58.4	100.0	49.4
Cement well casing	61.8	100.0	48.6	67.7	100.0	46.8	47.2	0.0	50.1
Damaged well cap	70.2	100.0	45.8	78.2	100.0	41.3	50.3	100.0	50.2
Damaged well casing	63.9	100.0	48.1	69.7	100.0	46.0	49.7	0.0	50.2
Pump situated at base of well	71.4	100.0	45.2	75.4	100.0	43.1	61.5	100.0	48.8
Buried well	73.4	100.0	44.2	80.5	100.0	39.7	55.9	100.0	49.8
Treatment system present	92.7	100.0	26.1	97.5	100.0	15.7	80.7	100.0	39.6
Previous water quality test	92.9	100.0	25.8	95.2	100.0	21.3	87.0	100.0	33.8
Pathogens found in wells	33.3	33.3	32.8	36.9	33.3	33.2	24.2	0.0	30.0
Campylobacter	19.1	0.0	39.3	20.8	0.0	40.6	14.9	0.0	35.7
Cryptosporidium	43.9	0.0	49.7	51.9	100.0	50.0	24.2	0.0	43.0
Giardia	13.8	0.0	34.5	16.0	0.0	36.7	8.1	0.0	27.3
Norovirus	13.9	0.0	34.7	14.3	0.0	35.0	13.0	0.0	33.8
Salmonella	27.3	0.0	44.6	28.3	0.0	45.1	24.8	0.0	43.3
Verotoxigenic *E. coli*	50.0	50.0	50.0	55.9	100.0	49.7	35.4	0.0	48.0
Pathogen sources	62.1	50.0	39.3	67.2	100.0	39.1	50.3	50.0	36.9
Septic tanks	73.6	100.0	44.1	75.7	100.0	42.9	68.3	100.0	46.7
Farmyards	69.3	100.0	46.2	74.4	100.0	43.7	56.5	100.0	49.7
Grazing animals	47.9	0.0	50.0	54.9	100.0	49.8	30.4	0.0	46.2
Domestic animals	34.5	0.0	47.6	37.8	0.0	48.6	26.1	0.0	44.0
Overall	66.3	66.7	20.7	70.5	75.0	19.4	55.8	58.3	20.4

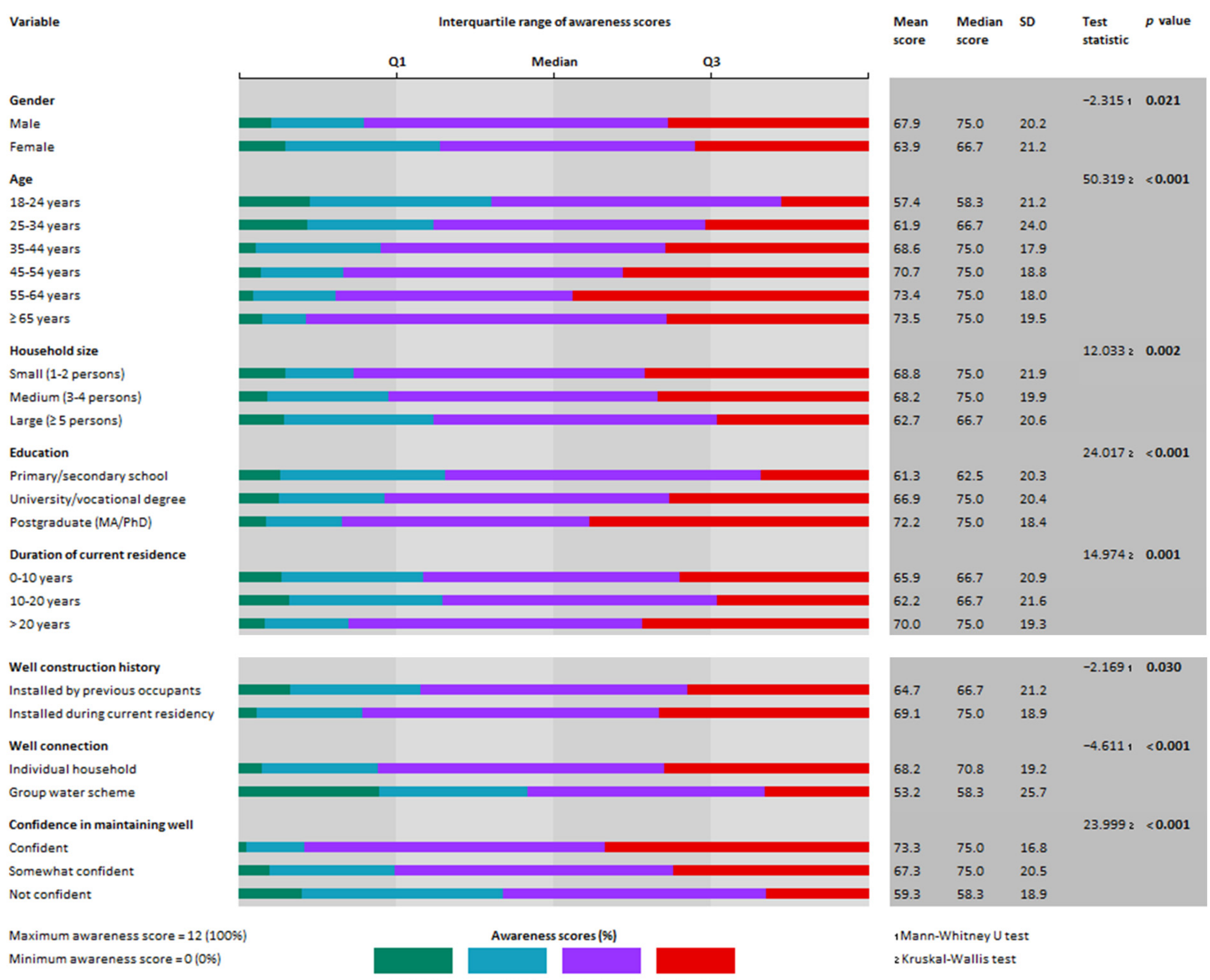

Fig. 1. Significant associations between overall awareness score and socio-demographics, well use characteristics and cognitive factors among all respondents ($n = 560$).

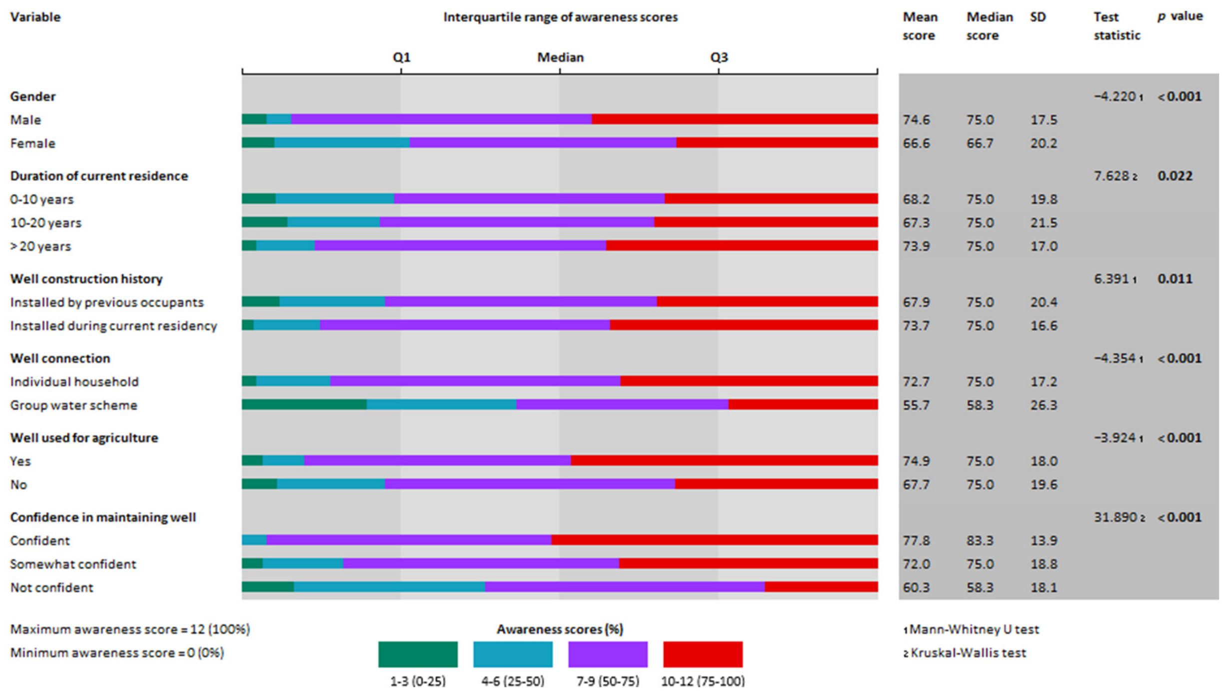

Fig. 2. Significant associations between overall awareness score and socio-demographics, well use characteristics and cognitive factors among well owner age respondents ($n = 399$).

Respondents originated from all 4 provinces in the ROI. A slightly greater proportion of respondents were male (53.0%, $n = 293$) with the most common age range being 18–24 years (26.8%, $n = 150$). Mean household size was 3.9 ($SD = 1.7$), with almost one-third of households (30.7%, $n = 172$) comprising ≥1 member from a 'vulnerable' subpopulation – defined as residents with an elevated risk of contracting a gastrointestinal infection (≤5 or ≥65 years of age). Over two-thirds ($n = 368$) of respondents disclosing prior education reported attainment of a third level degree; 67.0% ($n = 295$) of those disclosing annual household income reported an income range exceeding the average national bracket of €25,000–50,000 (CSO, 2017a).

Permanent property ownership was reported by 96.8% of respondents ($n = 542$), with a large majority also reporting residential duration >10 years (81.6%, $n = 457$). Of those aware of well construction history (i.e. residence relative to supply installation), 58.6% ($n = 311$) stated that their supply was installed during current occupancy. Where providing a function additional to domestic water supply, private wells were most frequently used for agricultural purposes (51.0%, $n = 284$).

Descriptive statistics outlining experiential variables (EWE experience, household health) and cognitive variables (climate change concern, perceived self-efficacy) across age-related subsets are presented in Appendix A (Tables 1-2). Respondents in both subsets were broadly homogeneous in terms of age profile; over 90% ($n = 377$) of respondents in the well owner age subset were >25 years of age and over while 80.7% ($n = 130$) of respondents in the student subset were aged between 18 and 24 years old.

3.2. Respondent awareness

3.2.1. Median awareness scores

Respondents exhibited a median overall awareness score of 66.7% (SD ± 20.7) (Table 3). Median awareness scores exhibited for the categories *physical supply characteristics* (age, depth, structural components), *supply maintenance history* (water quality testing, treatment) and *pathogenic supply contamination* (pathogens, pathogen sources) were 90.0% ($SD = 29.5$), 100.0% ($SD = 20.6$) and 40.0% ($SD = 29.9$), respectively. For individual awareness domains, respondents exhibited highest levels of awareness with respect to water quality testing history (100.0%, $SD \pm 25.8$) and lowest levels of awareness with respect to pathogenic contaminants (33.3%, $SD \pm 32.8$).

Well owners exhibited a higher median overall awareness score than students (75.0%, $SD \pm 19.4$; 58.3%, $SD \pm 20.4$) and higher scores across all individual awareness domains. The greatest differences in individual domain scores between subsets were observed for awareness of well features, well water treatment and pathogen sources. Awareness of pathogens found in wells was the lowest scoring domain by both well owners (33.3%, $SD \pm 33.2$) and students (0.0%, $SD \pm 30.0$).

3.2.2. Overall awareness and respondent characteristics

3.2.2.1. All respondents. Respondent awareness was significantly associated with gender ($p = 0.021$), age ($p < 0.001$) and education ($p < 0.001$). Males registered a higher median score than females while higher age and educational attainment also corresponded with increased awareness (Fig. 1). Awareness also displayed a significant relationship with household size ($p = 0.002$) and residential duration ($p < 0.001$). Respondents residing in small households (1–2 persons) exhibited a median score of 75.0% ($SD \pm 21.9$) compared to a median score of 66.7% ($SD \pm 20.6$) exhibited by respondents residing in large households (≥5 persons); respondents reporting residential duration of 0–10 years in their current property attained a median score of 66.7% ($SD \pm 20.9$) while those whose tenure exceeded 20 years exhibited a median score of 75.0% ($SD \pm 19.3$).

Table 4
Cluster profiles for well owner awareness scores by gender ($n = 393$).

Clusters:	Cluster 1 ($n = 82$)	Cluster 2 ($n = 131$)	Cluster 3 ($n = 180$)
	Low awareness females	High awareness females	Males
Mean awareness score:	45.6	79.7	74.6

Table 5
Cluster profiles for student awareness scores by gender ($n = 160$).

Clusters:	Cluster 1 (n = 47)	Cluster 2 ($n = 29$)	Cluster 3 ($n = 84$)
	Females	Low awareness males	Moderate awareness males
Mean awareness score:	51.8	31.0	66.3

With respect to private well use, awareness demonstrated a significant relationship with well construction history ($p = 0.030$) and well connection ($p < 0.001$). Higher median scores were exhibited by respondents who had their well installed during current occupancy (75.0%, $SD \pm 18.9$) an availed of an individual domestic well (70.8%, $SD \pm 19.2$). Awareness additionally displayed a significant relationship with confidence in maintaining well ($p < 0.001$); respondents expressing confidence in their ability registered a median score of 75.0% ($SD \pm 16.8$) while those who expressed a lack of confidence attained a median score of 58.3% ($SD \pm 18.9$). Neither recent household health history nor EWE experience were significantly related to overall awareness, with observation of post-event changes in water quality/quantity and climate change concern also statistically unrelated.

3.2.2.2. Age-related subsets. Awareness among well owner age respondents demonstrated a significant association with gender ($p < 0.001$) and duration of current residence ($p = 0.022$); males attained a higher median score (75.0%, $SD \pm 17.5$) than females (66.7%, $SD \pm 20.2$) while well owners reporting residential duration of >20 years at their current property exhibited higher awareness than those reporting shorter duration (Fig. 2). Well owner awareness was significantly related to multiple well use characteristics, including supply history ($p = 0.011$), connection ($p < 0.001$) and agricultural use ($p < 0.001$). Well owners reporting well installation during their current residency, ownership of an individual domestic well and agricultural well use registered higher median scores. Well owner awareness was also significantly related to confidence in maintaining well ($p < 0.001$), with well owners citing confidence displaying a median score of 83.3% ($SD \pm 13.9$) compared to 58.3% ($SD \pm 18.1$) among those citing no confidence.

Well owner awareness exhibited no statistically significant association with experiential or concern-based variables. Awareness among student age respondents, meanwhile, was not significantly related to any independent variable employed in this study.

3.3. Awareness-based clustering

3.3.1. Cluster identification and profiling

Final clusters for well owner and student subsets were both based on two variables – gender and overall awareness score. Final clusters were profiled based on respondent gender relative to awareness level, with mean scores between 0–50%, 50–70% and 70–100% referred to as low, moderate and high awareness, respectively. Three discrete clusters with a silhouette score of 0.7 were identified within each subset. Two clusters in the well owner subset exclusively comprised female respondents while two clusters in the student subset exclusively comprised male respondents. Accordingly, clusters 1 and 2 in the well owner subset were labelled 'low awareness females' and 'high awareness females', with clusters 2 and 3 in the student subset labelled 'low awareness males' and 'moderate awareness males' (Tables 4 and 5).

3.3.1.1. Well owner clusters. Well owner cluster membership (Table 6) was significantly associated with respondent age ($p < 0.001$), with post-hoc tests reflecting the particularly high proportion of male respondents aged between 18 and 24 years ($AR = 3.2$) and ≥65 years

Table 6
Significant associations between well owner cluster membership and respondent characteristics ($n = 393$).

Variable	Cluster membership (%)			χ^2	p value
	Cluster 1 (n = 82)	Cluster 2 (n = 131)	Cluster 3 (n = 180)		
Age				25.270	0.005
18–24 years	1 (1.2%)	3 (2.3%)	16 (8.9%)		
25–34 years	10 (12.2%)	12 (9.2%)	17 (9.4%)		
35–44 years	26 (31.7%)	36 (27.5%)	44 (24.4%)		
45–54 years	23 (28.0%)	38 (29.0%)	51 (28.3%)		
55–64 years	20 (24.4%)	37 (28.2%)	31 (17.2%)		
≥65 years	2 (2.4%)	5 (3.8%)	21 (11.7%)		
Household composition					
≥1 elderly person				9.764	0.008
Yes	11 (13.4%)	20 (15.3%)	49 (27.2%)		
No	71 (86.6%)	111 (84.7%)	131 (72.8%)		
Education				19.793	0.001
Primary/secondary school	11 (14.3%)	13 (10.2%)	31 (18.1%)		
University/vocational degree	46 (59.7%)	58 (45.3%)	103 (60.2%)		
Postgraduate (MA/PhD)	20 (26.0%)	57 (44.5%)	37 (21.6%)		
Well connection				13.875	0.001
Individual household	62 (75.6%)	122 (93.1%)	158 (87.8%)		
Group water scheme	20 (24.4%)	9 (6.9%)	22 (12.2%)		
Well used for agriculture				31.973	<0.001
Yes	18 (22.0%)	39 (29.8%)	97 (54.2%)		
No	64 (78.0%)	92 (70.2%)	82 (45.8%)		
Confidence in maintaining well				43.687	<0.001
Confident	9 (14.3%)	50 (42.0%)	74 (47.4%)		
Somewhat confident	30 (47.6%)	55 (46.2%)	71 (45.5%)		
Not confident	24 (38.1%)	14 (11.8%)	11 (7.1%)		
Household illness in last 12 months				17.588	<0.001
Yes	18 (22.5%)	22 (17.1%)	9 (5.2%)		
No	62 (77.5%)	107 (82.9%)	163 (94.8%)		

Table 7
Significant associations between student cluster membership and respondent characteristics ($n = 160$).

Variable	Cluster membership (%)			χ^2	p value
	Cluster 1 (n = 47)	Cluster 2 (n = 29)	Cluster 3 (n = 84)		
Well construction history				6.526	0.038
Installed by previous occupants	19 (47.5%)	17 (68.0%)	54 (71.1%)		
Installed during current occupancy	21 (52.5%)	8 (32.0%)	22 (28.9%)		
Well connection				6.243	0.044
Individual household	36 (76.6%)	26 (89.7%)	77 (91.7%)		
Group water scheme	11 (23.4%)	3 (10.3%)	7 (8.3%)		
Confidence in maintaining well				12.516	0.014
Confident	8 (20.0%)	5 (26.3%)	36 (51.4%)		
Somewhat confident	28 (70.0%)	13 (68.4%)	29 (41.4%)		
Not confident	4 (10.0%)	1 (5.3%)	5 (7.1%)		

($AR = 3.2$) in cluster 3. Cluster membership also demonstrated a significant relationship with presence of elderly residents ($p = 0.008$). Post-hoc tests once again underscored gendered differences, with a notably high proportion of males citing presence of ≥1 elderly person in the household ($AR = 3.1$). Cluster membership additionally exhibited a significant relationship with education ($p < 0.001$), with educational attainment demonstrating an ordered relationship with increased female well owner awareness. While a substantial proportion of high awareness females reported attainment of a postgraduate degree ($AR = 4.3$), a markedly lower proportion of male well owners reported identical educational attainment ($AR = -3.3$).

Cluster membership demonstrated a significant association with well connection ($p = 0.001$) and agricultural well use ($p < 0.001$). The majority of high awareness females availed of an individual household well ($AR = 2.5$) while a significant proportion of low awareness females availed of a private group water scheme ($AR = 3.5$). As a function of respondent sample, agricultural well use was reported by a higher proportion of male well owners ($AR = 5.5$) and a small proportion of high awareness females ($AR = -3.6$) and low awareness females ($AR = -2.7$). Cluster membership varied significantly based on self-perceived confidence in maintaining well ($p < 0.001$). A high proportion of respondents in the low awareness female cluster reported no confidence in their ability to maintain their supply ($AR = 5.9$). Cluster membership was further associated with occurrence of gastrointestinal illness in the household ($p < 0.001$), as evidenced by the high proportion of low awareness females ($AR = 2.9$) and low proportion of males ($AR = -4.0$) citing a recent household episode of gastrointestinal illness.

3.3.1.2. Student clusters. Student cluster membership exhibited a significant relationship with well construction history ($p = 0.038$) and well connection ($p = 0.044$) (Table 7). As a result of sample demographics, a comparatively high proportion of female students reporting having had their private well installed during current occupancy ($AR = 2.5$) while a comparatively low proportion availed of an individual household well ($AR = -2.5$). Student cluster membership was further associated with confidence in maintaining well ($p \leq 0.001$), with a notably high proportion of moderate awareness males ($AR = 2.4$) and low proportion of females ($AR = -2.8$) citing confidence in their ability to maintain their supply.

3.3.2. Awareness cluster modelling

3.3.2.1. Well owner cluster models. In model 1 (low awareness female well owners), self-perceived confidence in maintaining supply ($p < 0.001$) constituted the most significant variable (Table 8). Respondents in cluster 1 were more likely to cited moderate confidence ($OR = 11.593$) or no confidence ($OR = 3.964$) in maintaining their supply. Agricultural well use ($p = 0.004$) and source connection ($p = 0.007$) represented the other significant factors in the model. Low awareness female well owners were 2.970 times more likely to use their well for domestic-only (i.e. non-agricultural) purposes and 3.041 times more likely to be connected to a private group water scheme.

Membership in the high awareness females cluster (Table 9) demonstrated a significant relationship with both educational attainment ($p = 0.001$) and agricultural well use ($p = 0.029$). Respondents with a university/vocational degree and postgraduate qualification were 2.792 and 2.368 times more likely to belong to cluster 2, respectively. Respondents using their well for domestic-only purposes were 1.692 times more likely to belong to this cluster.

A function of respondent demographics, agricultural well use made the most significant contribution to model 3 ($p < 0.001$) as respondents availing of a private well were 3.462 times more likely to belong to the male well owners cluster (Table 10). Cluster membership was also significantly associated with confidence in maintaining well ($p = 0.013$) and reporting of recent household illness ($p = 0.005$). Respondents citing moderate confidence in their ability to maintain their supply ($OR = 3.577$) and no recollection of a recent gastrointestinal illness in the household ($OR = 3.205$) were both significantly more likely to belong to cluster 3.

3.3.2.2. Student cluster models. Well construction history ($p = 0.014$) represented the most significant variable in the female students cluster (Table 11). As a result of sample demographics, female students were 2.721 times more likely to report inheritance of household supply than male students. Reporting of recent household illness ($p = 0.044$) represented the other significant contribution to the model as females

Table 8
Cluster 1 model (low awareness female well owners, $n = 82$).

Variable[a]	B	S.E.	Wald	p value	Odds ratio	95% C.I. for odds ratio	
						Lower	Upper
Confidence in maintaining well (somewhat confident)	2.450	0.462	28.128	<0.001	11.593	4.687	28.672
Confidence in maintaining well (not confident)	1.377	0.364	14.281	<0.001	3.964	1.940	8.096
Well connection (private group water scheme)	1.112	0.410	7.370	0.007	3.041	1.362	6.787
Well used for agriculture (no)	1.089	0.376	8.369	0.004	2.970	1.421	6.210

[a] Reference categories: confidence in maintaining well (confident), well connection (private well), well used for agriculture (yes).

Table 9
Cluster 2 model (high awareness female well owners, $n = 131$).

Variable[a]	B	S.E.	Wald	*p* value	Odds ratio	95% C.I. for odds ratio	
						Lower	Upper
Education (university/vocational degree)	1.027	0.376	7.470	0.006	2.792	1.337	5.830
Education (MA/PhD)	0.862	0.246	12.256	<0.001	2.368	1.462	3.838
Well used for agriculture (no)	0.527	0.241	4.777	0.029	1.693	1.056	2.715

[a] Reference categories: education (primary/secondary school), well used for agriculture (yes).

were almost three times more likely (OR = 2.941) to report a recent household episode of gastrointestinal illness.

While membership of cluster 2 (low awareness male students) was not significantly associated with any predictive variable utilised in this study, membership of cluster 3 (moderate awareness male students) demonstrated a significant relationship with confidence in maintaining supply ($p = 0.005$) (Table 12). High awareness males were 3.915 times more likely to report confidence and 2.769 times more likely to report moderate confidence in their ability to undertake private well maintenance.

4. Discussion

As private domestic groundwater supplies are typically unregulated, the onus to undertake supply maintenance and reduce contamination risk lies with individual well owners. With rising EWEs such as fluvial flooding accelerating global rates of groundwater contamination and waterborne illness, extensive awareness of private well management will be required to reduce risk of supply contamination. To compensate for absence of supply regulation, government authorities in countries with high rural groundwater reliance such as the ROI have attempted to promote such knowledge via top-down risk communication; however, many such countries have yet to attain meaningful levels of supply awareness among relevant groundwater end-users (Hynds et al., 2013; Mooney et al., 2020a). Although several recent studies have attempted to assist risk communication practitioners via updated measurements of supply awareness (Hynds et al., 2013; Lavallee et al., 2021), few have introduced a broad characterisation of awareness or explored important potential predictors such as recent EWE experience and household history of gastrointestinal illness. Comparisons of awareness between well owners and young adults, who represent the first generation to grow up amid heightened global risk of EWEs and thus vital recipients of supply maintenance information going forward, are also scarce. Accordingly, the current study aimed to develop a comprehensive, quantitative measure of well user awareness and associated determinants, with awareness levels compared between well owner and young adult (student) subsets.

In the current study, integrated survey respondent subsets ($n = 560$) exhibited a median overall awareness score of 66.7% – classified as a medium/moderate level of awareness. While attaining high median scores for awareness of physical supply characteristics (90.0%) and supply maintenance history (100.0%), respondents exhibited markedly lower knowledge of pathogenic supply contamination (40.0%). A previous survey of Irish private well users which utilised a similar (though less comprehensive) awareness scoring protocol, documented higher mean scores for awareness of supply structural characteristics and maintenance status (87.8%) and contaminants of concern (72.0%) than those recorded in the present study (Hynds et al., 2013). It may thus be inferred that awareness of private well management characteristics in the ROI has not increased over the past decade – in spite of a nationwide engagement campaign initiated in 2013 to promote household mitigation of supply contamination risk (EPA, 2013). Comparing national findings to those reported in a recent study by Lavallee et al. (2021) in Ontario, Canada, a pattern in awareness levels based on individual aspects of supply management is apparent. Hynds et al. (2013), Lavallee et al. (2021) and the present study notably report near-maximum levels of awareness concerning supply maintenance history, moderate-to-high levels concerning structural components of supply and low-to-moderate levels concerning pathogenic contamination of supply. Knowledge deficits in other, more specific supply knowledge domains (in particular, susceptibility to pathogenic contamination) warrant concerted attention (Mooney et al., 2020a). As knowledge gaps in these domains have been noted in other developed regions and may impede the ability of well owners to accurately assess risk of supply contamination (Murti et al., 2016; Castleden et al., 2015; Ridpath et al., 2016), it is imperative that subsequent studies and well user outreach initiatives address these well user oversights.

The well owner subset exhibited a median awareness score of 75.0% compared to a median score of 58.0% exhibited by 161 agricultural college students (predominantly young adults). As such, there would appear to be little evidence of vertical knowledge transfer from current to prospective well owners (i.e. targeted risk communication to younger groundwater end-users) in the ROI. Prior research undertaken by Hynds et al. (2014) and Straub and Leahy (2014) have also noted appreciable differences in supply awareness between existing well owners (i.e. parents/household heads) and younger well users (i.e. young adults and children). These findings indicate that knowledge differences may be significantly reduced upon first-time residential property acquisition and assumption of household responsibility for private well maintenance. While this, in turn, suggests limited knowledge exchange from parent to young adult, the transferal and impact of social norms, heuristics and experiential phenomena (which may hinder appropriate supply maintenance) cannot be as easily ruled out (Morris et al., 2016). Findings suggest that in order to sufficiently expose prospective well owners to the requisite supply maintenance knowledge, it is likely necessary to develop educational interventions for young adults outside of their domestic environment. Over 20% of educational practitioners (spanning hydrogeology and groundwater policy) interviewed in an international expert elicitation study by Mooney et al. (2020b) recommended increased adoption of groundwater education programmes at

Table 10
Cluster 3 model (male well owners, $n = 180$).

Variable[a]	B	S.E.	Wald	*p* value	Odds ratio	95% C.I. for odds ratio	
						Lower	Upper
Confidence in maintaining well (somewhat confident)	1.274	0.450	8.031	0.005	3.577	1.481	8.635
Confidence in maintaining well (confident)	0.144	0.259	0.308	0.579	1.155	0.695	1.918
Household illness in last 12 months (no)	1.165	0.417	7.791	0.005	3.205	1.415	7.261
Well used for agriculture (yes)	1.242	0.253	24.125	<0.001	3.462	2.109	5.682

[a] Reference categories: confidence in maintaining well (not confident), household illness in last 12 months (yes), well used for agriculture (no).

Table 11
Cluster 1 model (female students, $n = 47$).

Variable[a]	B	S.E.	Wald	*p* value	Odds ratio	95% C.I. for odds ratio	
						Lower	Upper
Household illness in last 12 months (yes)	1.079	0.535	4.066	0.044	2.941	1.031	8.390
Well construction history (installed by previous occupants)	1.001	0.407	6.052	0.014	2.721	1.226	6.039

[a] Reference categories: confidence in maintaining well (not confident), household illness in last 12 months (no), well construction history (installed during current occupancy).

both second and third level institutions in future groundwater risk communication campaigns. In light of the efficacy of recent citizen science initiatives involving young adults in private well water quality testing workshops and potential for child-to-adult intergenerational learning (Thornton and Leahy, 2016; Little et al., 2016), the integration of such programmes into more widespread, large-scale groundwater risk communication interventions merits consideration.

4.1. Awareness and respondent characteristics

Awareness of private well management characteristics among integrated respondent subsets demonstrated a significant association with multiple socio-demographic variables. Associations between awareness, age, education, household size and residential duration underscore the significance of factors related to household tenure and are consistent with previous research in developed regions (Chappells et al., 2014; Flanagan et al., 2016; Lavallee et al., 2021). In the case of respondent age, the greatest differences in awareness score were noted between the 18–24, 25–34 and 35–44 age ranges. As the latter age categories are typically synonymous with assumption of responsibilities synonymous with full adulthood (e.g. parenthood, property ownership), the importance of the transition from well user to dual user/owner is once again apparent. Both well construction history and well connection (ownership) were significantly associated with respondent awareness, denoting the significance of both well tenure and responsibility for supply maintenance. Higher median awareness scores among respondents whose well was installed during current residency were also reported by Hynds et al. (2013) and Lavallee et al. (2021), with the latter study attributing this result to direct engagement with well drilling contractors and decision-making requirements concerning source type and location on the part of the well owner. Familiarity (or lackthereof) with current supply constitutes an important discussion point in the context of rural regions in North America and ROI as an appreciable number of rural residential property transfers (particularly among farmers) are made via family inheritance (Leonard et al., 2017). Residential inheritors who acquire immunity to waterborne disease over time or are unaware of historical well maintenance or contamination issues may falsely perceive a sense of supply security, pointing towards property acquisition as a vital control point for well user engagement (Lavallee et al., 2021). The markedly higher median awareness score by individual (household) well owners represents a novel finding, as few behavioural or knowledge studies to date have sought to differentiate between private group water schemes (i.e. community-managed schemes deriving potable water from a centralised groundwater source) and individual household wells (Brady and Gray, 2010). While source management guidance to well users availing of group schemes is available, as many as forty well users may be precluded from direct supply management responsibility depending on maintenance protocols for individual schemes; in light of this fact and the awareness scores identified in the current study, this sector warrants attention going forward. The association between higher awareness and self-perceived behavioural efficacy in maintaining supply also represents a significant finding, with confidence in maintaining supply potentially representing a causative factor as it also may also encompass ability to find or correctly interpret well maintenance guidance. As a multitude of studies have identified self-perceived behavioural efficacy as a precursor to well maintenance measures such as well water quality testing (Kreutzwiser et al., 2011; Straub and Leahy, 2014), the role of information availability and quality (i.e. legibility and comprehensiveness) in relation to knowledge of and perceived confidence in maintaining supply represents a relevant research agenda.

Awareness levels among the well owner subset were significantly associated with socio-demographics, supply use characteristics and perceived behavioural efficacy. Well owner awareness notably demonstrated a notably significant relationship with agricultural well use, with higher cognisance of well management among agricultural households indicating greater self-perceived responsibility and/or vulnerability concerning contamination risk. As agricultural households represent a significant source and receptor or private groundwater contamination (particularly in light of limited legislation globally restricting agricultural application), this subpopulation represents an important area of focus and highlights the importance of concerted, sector-specific engagement (Mahon et al., 2017; Lall et al., 2020). In contrast to well owners, awareness levels exhibited by young adults demonstrated no association with any independent variable employed in the current study. While this fact may be attributable to sample homogeneity, it may once again reinforce the significance of homeownership and household responsibility towards increasing supply awareness levels among well users. Notably, overall and categorically specific extreme weather event experience and climate change concern did not demonstrate a significant association with respondent awareness among both separate survey subsets. Although recent research in the ROI has demonstrated that previous EWE experience in the form of flooding wields a significant influence on risk perception of supply vulnerability to contamination (McDowell et al., 2020), it would appear that high risk perception of EWE-driven groundwater contamination, does not necessarily correlate with high levels of supply awareness. Despite increased media coverage of EWEs in developed regions such as the United States and Europe (Ford and King, 2015; Berglez and Al-Saqaf, 2020), this finding attests to Khan et al.'s (2015) assertion that water supply management guidelines pertaining to climate change and EWE adaptation are largely absent from formal engagement channels to relevant householders. The absence of association between supply awareness and recent occurrence of gastrointestinal illness (noted by 13.1% of respondents in total) is further indication that supply awareness levels have not increased concurrent to rising risk of contamination and experience of waterborne illness among private well users (EPA, 2020). Previous research has indicated that, contrary to their greater predisposition towards physical illness, older populations are inclined to display passive risk taking (i.e. limited responsive actions) concerning their health (Hanoch et al., 2018), which may indicate why older well owners are less inclined to investigate their supply (in addition to physical capability). However, respondents with young children (15.4% of respondents in total) might be expected to display significantly greater awareness than others, reinforcing Lavallee et al.'s (2021) recommendation that local physicians and healthcare services play a significantly increased, integrated role in communicating supply risk where feasible.

4.2. Cluster analysis

The significantly higher overall awareness score demonstrated by male well owners does not have precedent nationally (Hynds et al., 2013); however, this finding is reflected in Lavallee et al.'s (2021) study

Table 12
Cluster 3 model (moderate awareness male students, $n = 84$).

Variable[a]	B	S.E.	Wald	p value	Odds ratio	95% C.I. for odds ratio	
						Lower	Upper
Confidence in maintaining well (somewhat confident)	1.019	0.710	2.056	0.152	2.769	0.688	11.145
Confidence in maintaining well (confident)	1.365	0.404	11.388	0.001	3.915	1.772	8.650

[a] Reference categories: confidence in maintaining well (not confident).

in Canada and other, less comprehensive studies of well user awareness across North America identified by Munene and Hall (2019). Previous studies analysing the delineation of household labour with respect to gender have established that mechanical and maintenance-oriented tasks requiring technical knowledge are typically executed by male householders, which may explain the higher levels of supply awareness exhibited by male well owners (Altintas, 2009). Conversely, female householders (particularly female household heads) have been found to more frequently display pro-environmental behaviours and knowledge in other environmental health contexts (Strapko et al., 2016). The role of gender and associated cultural norms with respect to groundwater stewardship has yet to be sufficiently investigated in both developed and developing country contexts (Ternes, 2018). However, recent findings by McDowell et al. (2020) in the ROI identified appreciably higher awareness levels among male private well owners with respect to supply maintenance requirements in the event of flooding. While these findings mirror gender-based knowledge differences in the current study, further research exploring gender roles and the potential impact of social and household dynamics with respect to private well management will be necessary to establish legitimate trends and elucidate the relationship between gender and supply awareness.

Cluster analysis and subsequent cluster membership modelling within well owner and young adult subsets revealed both similarities and discrepancies with respect to awareness levels and associated predictors on the basis of gender. Male respondents in both subsets displayed considerably greater confidence in their ability to maintain their supply – irrespective of awareness level. This may indicate a gender-based predilection for maintenance and designation of household tasks, as outlined by Altintas (2009). A significantly greater proportion of female well owners reported recent occurrence of gastrointestinal illness than male well owners, which may further reinforce gender roles among parents – as outlined by Lavallee et al. (2021). In the case where a gastrointestinal illness is identified, female householders may be more inclined to self-educate with respect to well maintenance than male householders, indicating a further gender-specific opportunity for engagement. High awareness female well owners, meanwhile, were significantly more likely to have a postgraduate degree than both low awareness female well owners and male well owners. As such, education and household health may represent central control points governing supply awareness among females and merit attention in future interventions. As higher degrees of household health awareness on the part of female well owners do not necessarily translate into higher degrees of supply awareness, gender socialisation and associated norms may have an inverse effect on private groundwater stewardship. While such research has been frequently outlined and elucidated in developing nations (Figueroa and Kincaid, 2010), it has received relatively little consideration in developed regions. In light of the current study's findings, the theme of gender represents an important potential research agenda in both groundwater-related studies in developed nations.

4.3. Study limitations

The current study was characterised by a number of limitations relating to respondent demographics. The authors wish to note that the survey sample is not representative of the ROI with respect to education and income, as highly educated and high-earning respondents were over-represented. The relatively low number of respondents below the median annual income bracket may be attributable to methods of survey dissemination, which was facilitated by a number of rural interest groups and thus likely to exclude socially disadvantaged and/or unemployed rural private well owners. As a further consequence of data gathering requirements and study timeline, male respondents aged 18–24 were somewhat over-represented in the survey. Survey completion bias was additionally noted based on respondent education, geographical location (province) and supply.

The authors additionally anticipate a degree of recall bias with respect to self-reporting of EWE experience. While respondents were required to select named EWEs occurring between the years 2013–2018 to maximise accuracy of reported experience, they may be cognitively inclined to recall more recent EWEs and concurrently overlook other relevant events.

5. Conclusion

The current study sought to characterise private well management awareness and identify the role of unique experiential and demographic variables in determining well user awareness levels. Awareness levels were compared between well owner and student age well users to establish important generational differences and discern future knowledge trajectories in an era characterised by increased groundwater contamination risk. Current awareness levels among private well owners were not found to deviate significantly from prior national and international findings. Identified knowledge gaps pertaining to supply structural characteristics pathogenic supply contamination have been mirrored in other developed countries such as Canada and North America and thus merit a critical concern in future groundwater risk interventions. The significant difference in awareness score between young adults and well owners also has historical precedent and further indicates that heightened risk of private groundwater contamination and exposure to pathogenic contaminants via EWEs has not translated to sufficient engagement among both young adults and those in middle- and late-stage adulthood. The discrepancy in awareness scores between the two studied subsets (in addition to the significance of residential tenure-related variables such as age, education and household size) indicates supply awareness greatly increases upon homeownership and household responsibility for private well maintenance. While awareness scores observed among adults (i.e. well owners) may be yet to reach levels conducive to sufficient supply maintenance, they are indicative of the significance of full adulthood in necessitating greater cognizance of supply integrity.

Other significant variables within the current study such as self-perceived confidence in maintaining supply and well use characteristics (e.g. agricultural well use) may also be linked with tenure at current property. Cluster analysis highlighted the role of both cognitive and supply-specific variables with respect to awareness level and gender (in addition to household health and education). Accordingly, socio-demographic and experiential variables associated with gender and purchase of residential property relative to private well installation may represent significant nexus points for subsequent interventions seeking to highlight private groundwater contamination risk. While EWE experience was not found to impact awareness among integrated and separate respondent subsets or clusters analysed in the study, more frequent, concerted elucidations of the risks posed by extreme weather in the future may contribute to a gradual rise in supply awareness. As increased media coverage of EWEs has coincided with a gradual rise in risk perception, increased education pertaining to climate change adaptation and consequent maintenance behaviours may precipitate greater awareness of EWE risk mitigation.

CRediT authorship contribution statement

Simon Mooney Methodology, Software, Validation, Data collection, Formal analysis, Writing – original draft; **Jean O'Dwyer**: Conceptualisation, Supervision, Funding acquisition, Writing – review & editing; **Paul Hynds**: Conceptualisation, Supervision, Funding acquisition, Writing – review & editing.

Declaration of competing interest

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

Appendix A

Table 1
Respondent EWE experience and recent history of household illness.

Variable	Total answered	Categories	Frequency (%)		
			All (n = 560)	Well owners (n = 399)	Students (n = 161)
Experienced recent EWE	515	Yes	282 (54.8%)	189 (51.8)	93 (62.0)
		No	233 (45.2%)	176 (48.2)	57 (38.0)
Experienced drought event	515	Yes	168 (32.6%)	102 (27.9)	66 (44.0)
		No	347 (67.4%)	263 (72.1)	84 (56.0)
Experienced flood event	515	Yes	67 (13.0%)	45 (12.3)	22 (14.7)
		No	448 (87.0%)	320 (87.7)	128 (85.3)
Experienced heavy rainfall event	515	Yes	137 (26.6)	99 (27.1)	38 (25.3)
		No	378 (73.4)	266 (72.9)	112 (74.7)
Experienced snowfall event	515	Yes	155 (30.1)	119 (32.6)	36 (24.0)
		No	360 (69.9)	246 (67.4)	114 (76.0)
Observed post-event change(s)[a]	282	Yes	109 (38.7)	58 (30.7)	51 (54.8)
		No	173 (61.3)	131 (69.3)	42 (45.2)
Household illness in last 12 months	535	Yes	70 (13.1)	50 (12.9)	20 (13.5)
		No	465 (86.9)	337 (87.1)	128 (86.5)

[a] Respondents who experienced recent event.

Table 2
Respondent concern about climate change impacts on groundwater quality and self-perceived efficacy in maintaining supply.

Variable	Total answered$_1$	Categories	Frequency (%)		
			All (n = 560)	Well owners (n = 399)	Students (n = 161)
Concern about climate change	515	Concerned	278 (54.0)	203 (55.6)	75 (50.0)
		Neither concerned nor unconcerned	139 (27.0)	92 (25.2)	47 (31.3)
		Unconcerned	98 (19.0)	70 (19.2)	28 (18.7)
Confidence in maintaining well	472	Confident	185 (37.2)	136 (39.7)	49 (38.0)
		Neither confident nor unconfident	227 (45.7)	157 (45.8)	70 (54.3)
		Not confident	60 (12.1)	50 (14.6)	10 (7.8)

Table 3
Cronbach's alpha scores per awareness domain categories among all respondents ($n = 560$).

Scored domain	Variable categories	Component variables	Cronbach's alpha
Awareness	Physical well characteristics	Well age, well depth, well features	0.641
	Well maintenance history	Well water treatment, well water testing	0.412
	Pathogenic well contamination	Pathogens found in wells, pathogen sources	0.862
	All		0.770

Table 4
Cronbach's alpha scores per awareness domain categories among well owners ($n = 399$).

Scored domain	Variable categories	Component variables	Cronbach's alpha
Awareness	Physical well characteristics	Well age, well depth, well status	0.629
	Well maintenance history	Well water treatment, well water testing	0.515
	Pathogenic well contamination	Pathogens found in wells, pathogen sources	0.855
	All		0.741

Table 5
Cronbach's alpha scores per awareness domain categories among young adults (n = 161).

Scored domain	Variable categories	Component variables	Cronbach's alpha
Awareness	Physical well characteristics	Well age, well depth, well status	0.619
	Well maintenance history	Well water treatment, well water testing	0.194
	Pathogenic well contamination	Pathogens found in wells, pathogen sources	0.856
	All		0.761

Table 6
Associations between survey completion and respondent characteristics.

Variable	Survey completion (up to and including Section 3)					p value
	Yes (n = 560)		No (n = 205)		Test statistic[a]	
	Total answered	Frequency (%)	Total answered	Frequency (%)		
Geographic location (province)	560		103		13.717	0.003
Connacht		60 (10.7)		21 (20.4)		
Leinster		250 (44.6)		41 (39.8)		
Munster		212 (37.9)		28 (27.2)		
Ulster		38 (6.8)		13 (12.6)		
Gender	553		81		1.510	0.219
Male		293 (53.0)		37 (45.7)		
Female		260 (47.0)		44 (54.3)		
Age	560		83		1.437	0.920
18–24 years		150 (26.8)		21 (25.3)		
25–34 years		65 (11.6)		7 (8.4)		
35–44 years		111 (19.8)		18 (21.7)		
45–54 years		115 (20.5)		16 (19.3)		
55–64 years		91 (16.3)		16 (19.3)		
>65 years		28 (5.0)		5 (6.0)		
Education	536		78		6.401	0.041
Primary/secondary school		168 (31.3)		29 (37.2)		
University/vocational degree		251 (46.8)		25 (32.1)		
Postgraduate (MA/PhD)		117 (21.8)		24 (30.8)		
Income	440		80		2.505	0.644
€0–25,000		32 (7.3)		9 (11.3)		
€25,000-50,000		113 (25.7)		16 (20.0)		
€50,000-75,000		112 (25.5)		19 (23.8)		
€75,000-100,000		92 (20.9)		18 (22.5)		
>€100,000		91 (20.7)		18 (22.5)		
Homeownership	560		101		0.768	0.381
Own		542 (96.8)		96 (95.0)		
Rent		18 (3.2)		5 (5.0)		
Well connection	560		205		21.159	<0.001
Individual household		488 (87.1)		150 (73.2)		
Group water scheme		72 (12.9)		55 (26.8)		

[a] Chi-square test.

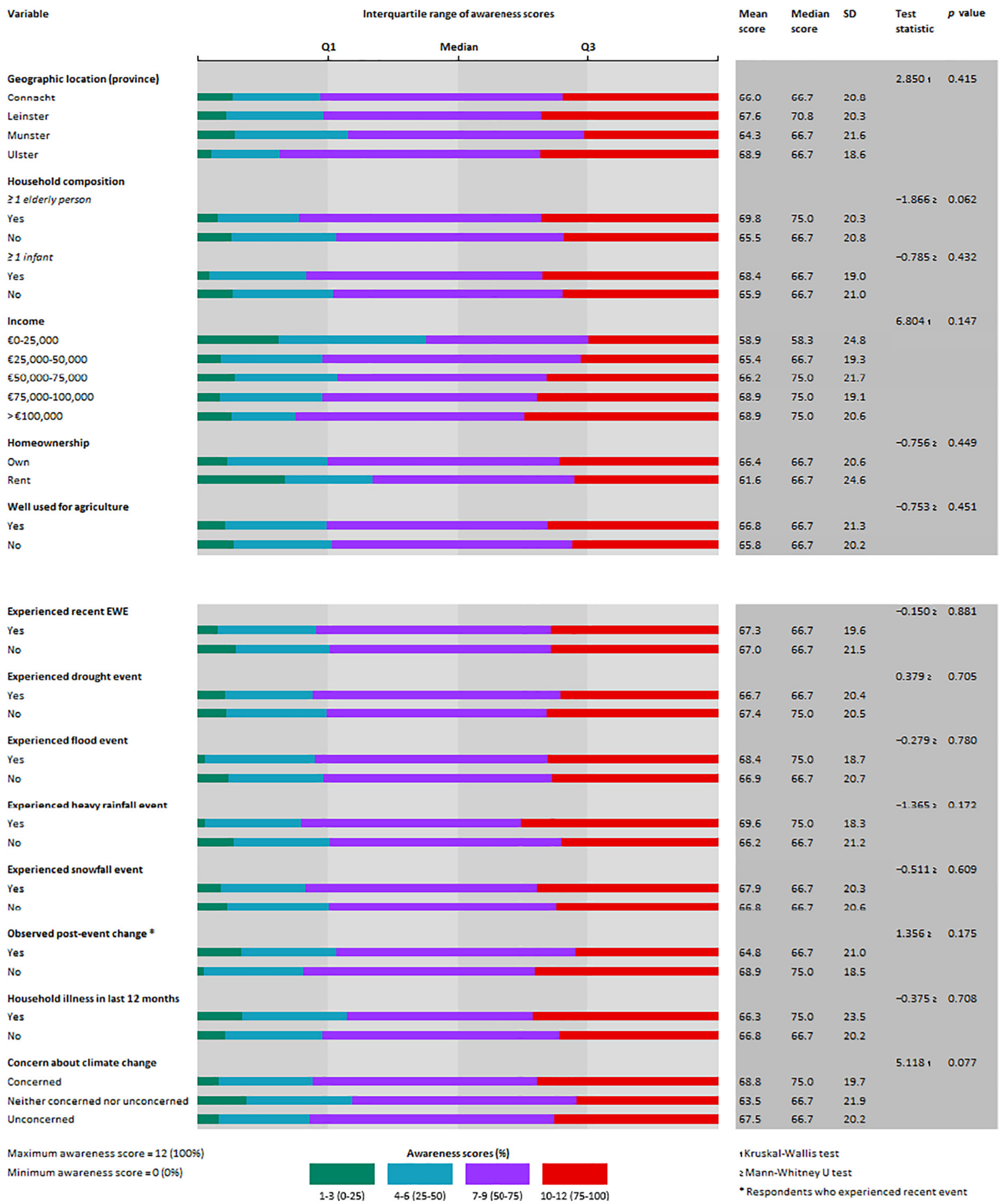

Fig. A1. Non-significant associations between overall awareness score and socio-demographics, well use characteristics and cognitive factors among all respondents (n = 560).

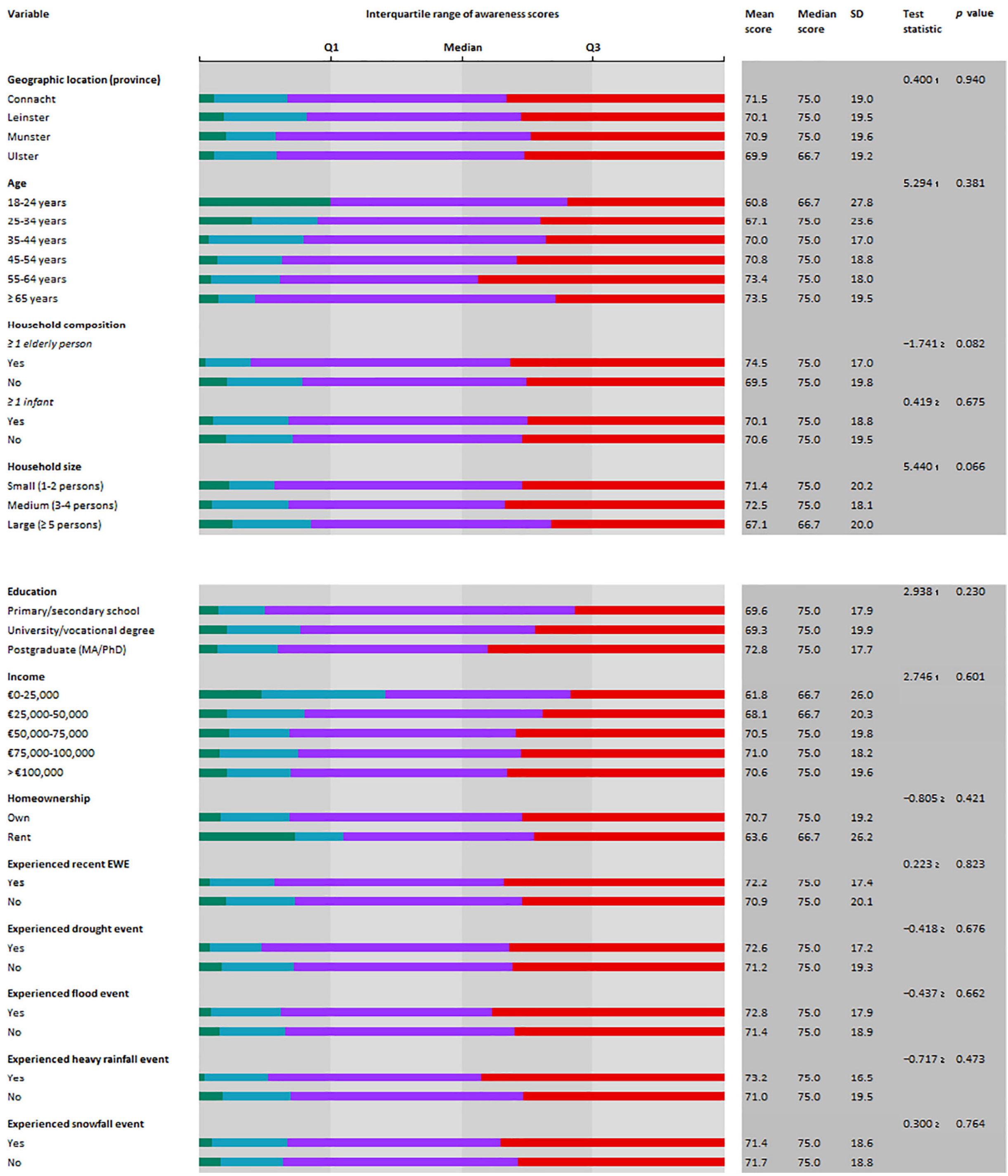

Fig. A2. Non-significant associations between overall awareness score and socio-demographics, well use characteristics and cognitive factors among well owner age respondents (n = 399).

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