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Examining influential drivers of private well users' perceptions in Ontario: A cross-sectional population study

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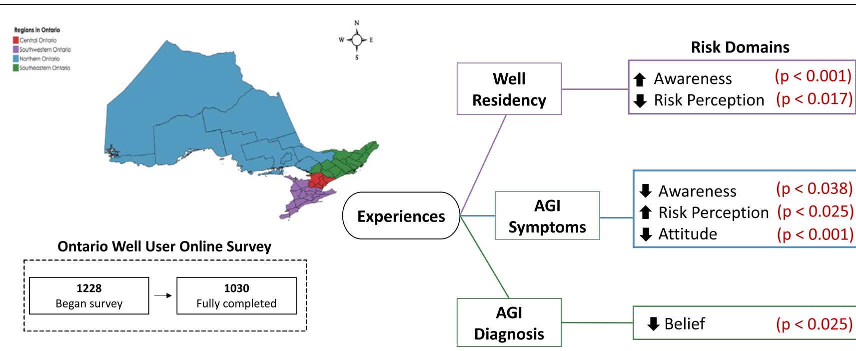
HIGHLIGHTS

- Over one thousand private well users surveyed.
- Novel domain (awareness, attitude, risk perception, belief) scoring protocol developed.
- Significant gender differences found with respect to risk perceptions.
- Residence at time of well construction significantly associated with awareness and perceptions of risk.
- Previous gastrointestinal symptoms significantly associated with perceptions of risk and attitudes.

GRAPHICAL ABSTRACT



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ABSTRACT

Private well users are responsible for managing and maintaining the quality of their drinking water source. Previous studies in Canada have reported low testing rates among well users, a cornerstone of well stewardship behaviours that can prevent the consumption of contaminated groundwater. To improve well stewardship, it is important to understand the interactions between, and the impacts of, various factors that may influence behaviours. Accordingly, the objective of the current study was to investigate the impact of socio-demographics, property characteristics, and experiences with well construction and acute gastrointestinal illness (AGI) (i.e., previous experiences) on levels of awareness, attitudes, risk perceptions, and beliefs (i.e., risk domains) among private well users in Ontario. A link to a province-wide online survey was circulated between May and August 2018 and novel "risk domain" scoring protocols were developed to classify and summarize response data. The survey was undertaken by 1228 respondents, of which 1030 completed the survey in full. Results indicate a low level of waterborne pathogen awareness, with 50.8% of respondents unaware of any groundwater associated pathogens. Respondents' geographic location, gender, and well type were significantly associated with well users' attitudes and perceptions of risk regarding their personal well water supply and the quality and quantity of local groundwater sources. Higher levels of awareness and lower risk perception scores (i.e., lower perceptions of risk) were associated with residential presence during well construction ($p < 0.001$ and $p = 0.017$, respectively). Previous case(s) of AGI within the respondent's household were significantly associated with negative attitudes towards

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their well water ($p < 0.001$) and higher risk perception scores ($p = 0.025$) with respect to the quantity of local groundwater sources. Results may be used to identify critical experiential control points (e.g., during well construction or after a physician confirmed AGI diagnosis) and develop improved risk management and communication strategies aimed at private well users.

1. Introduction

Over 4 million Canadian residents are currently served by a private groundwater supply (i.e., wells serving a single household) (Statistics Canada, 2017; Murphy et al., 2016). Rural households in Ontario depend almost entirely on groundwater from private wells, with an estimated 500,000 domestic wells serving approximately 1.5 million individuals in the province (Bollman, 2016; Statistics Canada, 2015). Although private wells represent a vital domestic resource, numerous factors (e.g., lack of appropriate maintenance, location relative to hazards, hydrogeological setting, high impact weather events) may result in these supplies being susceptible to contamination from myriad sources, including agricultural run-off, landfill leachates, and wastewater (septic) effluents (Carbó et al., 2009; Zacheus and Miettinen, 2011; Hynds et al., 2014). Groundwater contamination by enteric pathogens represents a significant risk to human health due to the potential for subsequent acute infection (Charrois, 2010). A recent study by Murphy et al. (2016) estimates that approximately 80,000 cases of acute gastrointestinal infection (AGI) are attributable to microbial contamination of untreated private domestic wells per year in Canada.

Private wells are not required to meet regulatory standards under the *Ontario Safe Drinking Water Act (2002)* and are not addressed in the *Ontario Clean Water Act (2006)*, unlike municipal drinking water systems. Private well construction is regulated under the *Ontario Water Resources Act (1990)*; however, well users are responsible for the condition and maintenance of their private drinking water source. As such, appropriate levels of awareness, risk perception, and the capacity to undertake private well stewardship (also referred to as "protective actions" or "healthy behaviours") are required. Water treatment, well maintenance, and regular water quality testing are considered the three primary protective actions to prevent consumption of contaminated groundwater (Hynds et al., 2013; Di Pelino et al., 2019). Low testing rates previously reported among well users in Canada highlight a lack of well stewardship behaviour, likely due to gaps in knowledge (e.g., the importance of testing) (Jones et al., 2006; Roche et al., 2013; Maier et al., 2014).

Given the potential risk of waterborne infection associated with private well water supplies and the lack of associated regulation, it is critical to understand and address well user awareness, attitudes, perceptions, experiences, geography, socio-demographics, and their potential contribution to contamination and waterborne infection (Sivapalan et al., 2012; Di Pelino et al., 2019). Both awareness and perceptions of water quality have been shown to influence the implementation of protective actions (de França Doria, 2010; Kreutzwiser et al., 2011; Munene and Hall, 2019). Private well users are often faced with a series of decisions, such as where or when to get their water tested, what parameters to test for, and what methods of treatment to employ. Additionally, well users with a low perception of contamination risk often fail to undertake necessary protective actions, thus increasing their risk of waterborne infection (Chappells et al., 2015; Malecki et al., 2017). Results from a study in Canada found that well users were more inclined to routinely test their water if they have experienced adverse health effects potentially linked to well water, such as gastrointestinal illness (Kreutzwiser et al., 2011). Further, a study in the Republic of Ireland found that respondents living on the property during well design or construction ("well residency") exhibited a higher source awareness (i.e., the level of awareness regarding their personal groundwater source) than residents who inherited the well with the property (Hynds et al., 2013). The association between well residency and awareness has yet to be explored in the Canadian context. Although relationships between testing behaviours and awareness, perception, and experience have been found, significantly less work has focused on understanding the associations of previous experiences (e.g., health, well residency), socio-demographics, and property characteristics on well users' cognitive understanding of risk.

In order to establish effective strategies for supporting private well users, it is important to understand the associations of potential confounders (i.e., socio-demographic, property characteristics) and drivers (i.e., experiences) on the cognitive precursors (i.e., risk domains) to protective actions. Accordingly, this study sought to investigate the impact of socio-demographics, property characteristics, and previous experiences on levels of awareness, attitudes, risk perceptions, and beliefs among private well users in Ontario, with respect to their private well, local and regional groundwater sources, and possible adverse health impacts. The current study is part of a larger overall project that will investigate drivers associated with protective actions among private well users. Findings may be employed by public health practitioners in developing improved risk management and communication strategies aimed at private well users. More specifically, results may identify critical experiential (i.e., temporal) control points which may be leveraged to enhance risk management and communication (e.g., during well construction or after the occurrence of waterborne infection within the household).

2. Materials and methods

2.1. Questionnaire development

A closed-ended questionnaire comprised of nine sections and 38 questions was designed to collect data from a sample of Ontario private well users (Appendix A). No existing model for questionnaire development was deemed appropriate for the current study. Ten questions were related to the respondent's socio-demographics, property characteristics and personal groundwater supply. Fifteen questions were used to quantify respondent risk domains (awareness, attitudes, perceptions, and beliefs) regarding their private well, protective actions, local and regional groundwater quality and quantity, health and environmental risks. The remaining thirteen questions referred to previous experiences, (household) groundwater consumption patterns, and communication preferences. The questionnaire included dichotomous and nominal questions, and (Likert) scaled and ranking (ordinal) questions. The questionnaire and overarching surveying approach were granted ethical approval by Public Health Ontario (2017-035.01) and Queen's University General Research Ethics Board, Ontario (6022907).

2.2. Survey distribution

The survey was initiated and distributed online and hosted on Acuity4 Survey (Voxco), an online survey software program. This method was chosen to maximize spatial and demographic representation within the target population (Rhodes et al., 2003; Jones, 2017). Numerous organizations with a user-base likely to include private well users (i.e., health units, conservation authorities, cottage associations (including seasonal and year-round residents)) were asked to promote the online survey to potential participants in various regions across Ontario. The sharable link directing potential participants to the online survey was promoted on websites and through social media outlets, newsletters, and email distribution lists. The survey included an information section that captured consent and constrained participation to self-identified private well users over 18 years of age currently residing in Ontario.

2.3. Survey completion

The survey link was available for four months (May to August 2018). Using standard sample size calculations (Moore and McCabe, 2006), and an estimated percentage of households served by private wells in Ontario (10%) (Statistics Canada, 2011), a sample size of 385 respondents (each representing one private well-reliant household) was necessary to achieve a $\pm$ 5% margin of error (95% level of confidence). Survey completion took an average of 16 min per respondent, less than the 20-minute maximum recommended by Cape (2010) to ensure response quality and minimise bias or development of response patterns. No incentive was offered to respondents.

2.4. Domain development & scoring

Well user "risk domains" were developed and defined as cognitive factors potentially affecting personal behaviours and consequent environmental or human health risks. Four risk domains and associated scoring protocols were developed to classify and summarize response data and develop composite scores for analyses (Appendix B, Tables B.1–B.4). Based upon previous research (Jones et al., 2006; Imgrund et al., 2011; Kreutzwiser et al., 2011; Hynds et al., 2013; Chappells et al., 2015; Flanagan et al., 2015; Malecki et al., 2017), the four identified domains were awareness, attitudes, risk perceptions, and beliefs. Risk perceptions were separated into four distinct sub-domains (source risk perception, regional risk perception, local (quantity) risk perception, local (quality) risk perception). Similarly, beliefs were separated into three distinct sub-domains, namely; spiritual belief, external responsibility belief, and personal responsibility belief. Domain scores were calculated as the sum of responses (raw score) and standardized based on respondent's calculated scores divided by the maximum possible scores, resulting in normalized (latent) domain scores [Range: 0–1] for all individual respondents. Brief descriptions of risk domains, experiences, respondent demographics and property characteristics, and associated scoring protocols are presented below.

2.4.1. Awareness

Awareness is defined as the state or condition of being aware and having knowledge and consciousness of a topic (Chalmers, 1996). In the context of well stewardship, this domain was defined as the level of awareness relating to private wells, protective actions, and potential pathogen sources associated with groundwater contamination. Eight survey questions, one of which had four sub-questions, were used to score awareness (Appendix B, Table B.1). Eight questions (including sub-questions) employed dichotomous scoring (0/1), and three used ordinal (ranked) scoring (0–2), resulting in a maximum possible awareness score of 14.

2.4.2. Attitude

Attitude is defined as a mindset or tendency to act in a particular way due to an individual's temperament (Pickens, 2005). In the context of private well water supplies, well user attitudes measure complacency and satisfaction towards the quality of their drinking water sources, with a positive attitude indicating a "trusting" or "satisfied" mindset towards their personal source. One survey question comprised four sub-questions used to score attitudes towards private well water supplies, all of which employed ordinal scoring (0–2) (Appendix B, Table B.2). The maximum possible attitude score was 8.

2.4.3. Risk perception

Risk perception is an important determinant of health and risk related decisions, such as adopting health protective behaviours, and is defined as "an individual's perceived susceptibility to a threat" (Ferrer and Klein, 2015). In the context of the current study, risk perception was used to measure respondents' perceived susceptibility to a threat related to regional/local groundwater sources and their private well. Four survey questions were used to develop four distinct sub-domains (i.e., sub-domains were not used collectively in analyses) under the "risk perception" domain and a scoring protocol was developed (Appendix B, Table B.3). Respondents with "high risk perception scores" are defined as individuals who perceive their risk or susceptibility to a threat as high, and vice versa. One question comprising nine response items related to respondents' personal source (i.e., private well) was used to score "source risk perception", with one question comprising ten response items related to Ontario's groundwater resource being used to score "regional risk perception"; both employed ordinal scoring (0–2). In relation to risk perceptions and the quantity and quality of local groundwater supplies (i.e., the aquifer with which respondents' well is associated in their area/community), one survey question employed ordinal scoring (1—10) to assess "local (quantity) risk perceptions", and one question employed categorical variables to assess "local (quality) risk perceptions" (i.e., no assigned score). Maximum risk perception scores were: source risk perception (18), regional risk perception (20), and local (quantity) risk perception (10).

2.4.4. Belief

Despite the prevalence and availability of scientific knowledge, water-related beliefs are influenced by traditional and local knowledge, lived experiences, religious belief systems, culture and importance or availability of water (Summers, 2010). The current study investigated well users' beliefs relating to spirituality and groundwater governance both within their community and personal property. Two survey questions were used to develop three distinct sub-domains under the "belief" domain and a scoring protocol was developed (Appendix B, Table B.4). One survey question, comprising six sub-questions, was used to score spiritual beliefs about water. The second question was used to score beliefs associated with groundwater governance (i.e., "who do you believe should be responsible for protecting groundwater where you live?"). The groundwater governance survey question was split into two sub-domains, "external responsibility belief" and "personal responsibility belief". All belief questions employed ordinal scoring (0–2), with maximum belief scores as follows: spiritual belief (12), external responsibility belief (10), personal responsibility belief (4).

2.4.5. Experiences

Previous experiences among well users relating to their private wells and health were collected to investigate their associations on the risk domains. Three survey questions were used to dichotomously classify three distinct experiences. Questions were associated with well "residency" (residing on the property during well construction), previous AGI symptoms in the past 12 months, and previous AGI diagnoses (confirmed by a physician) in the past 12 months. Experiences were categorised as binary (potential) predictor variables (Y/N).

2.4.6. Socio-demographics and property characteristics

Respondents' socio-demographic status and property characteristics were collected to investigate their associations on the risk domains (i.e. potential confounders). The geographic location of private well users was collected to investigate their associations on risk domains (i.e., potential confounder). One survey question was used to develop this variable, with respondents asked to indicate the first three characters of their residential postal code. Based upon the indicated postal code characters, four regions in Ontario were categorically classified (i.e., Northern Ontario, Southeastern Ontario, Southwestern Ontario, Central Ontario) (Appendix B, Fig. B.1). Four categorical survey questions were used to characterise respondent socio-demographic status, including gender, age, education, and income. Similarly, five categorical survey questions were used to characterise respondent households, including the residence and property served by their well, well water use (i.e., drinking, domestic use, agriculture and irrigation), household drinking water source type (e.g., drilled well) and wastewater management.

2.5. Statistical analysis

Exploratory factor analysis (EFA) with varimax (orthogonal) rotation was conducted on the original 15 survey questions used to quantify the four risk domains and associated sub-domains, and to identify the number of factors these loaded within. The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity were used to assess data suitability for EFA. Several criteria were followed to identify factors, including; (1) retaining factors with loadings greater than 0.3 by convention (Costello and Osborne, 2005), (2) using a scree test with Kaiser's eigen-value >1, and (3) variances accounted for by extracted factors (Gorsuch, 1988). The internal consistency of each risk domain was tested using Cronbach's alpha (α). The level of consistency for each domain was classified as low ($\alpha < 0.6$), moderate (i.e., acceptable) ($0.6 > \alpha < 0.7$), or high ($\alpha \geq 0.7$) (Kline, 2000). Results of EFA and internal consistency analysis for developed domains (and associated scoring) are presented in supplementary materials (Tables S.1 & S.2).

Standard R × C contingency chi-square tests of independence were used to determine the presence of associations between categorical (dichotomous and nominal) variable pairs. Odds ratios (OR) were calculated to examine the level of association between dichotomous pairs (df = 1). Continuous variables were tested for normality using quantile-quantile (Q-Q) plots, with independent sample *t*-tests and one-way ANOVA used to examine associations between parametric continuous and categorical variables. Mann–Whitney U and Kruskal-Wallis H tests were employed to explore associations between non-parametric continuous data and categorical variables. The significance level was set at 5% ($p < 0.05$), by convention, with IBM SPSS Statistics 25 employed for all analyses.

3. Results

3.1. Respondent characteristics

The survey was undertaken by a total of 1228 private well users, of which 1030 completed the survey in full (± 2.16% CI, 95% Level of Confidence). It should be noted that sample sizes vary by survey question due to the exclusion of response items irrelevant to the current analyses or respondent choice to leave a question blank. As shown (Table 1), a majority of respondents (60.8%) resided in Southeastern Ontario, and a slight majority (54.6%) of respondents were female. Most respondents fell within the age ranges 55 to 64 (27.2%) and 65+ (26.8%). Overall, 64.7% of respondents had attended university, with nearly 40% of respondents self-reporting an annual household income of ≥$125,000.

A large majority (96.7%) of respondents owned the property served by their well, with 82.8% residing at a permanent residence as opposed to a seasonal property (e.g., summer cottage). Approximately three quarters (74.8%) of respondents used a drilled well (i.e. borehole), while 77.3% reported using their private well water exclusively for domestic purposes (e.g., drinking, bathing, and cooking).

3.2. Risk domains

EFA indicated that the Kaiser-Meyer-Olkin (KMO = 0.794) and Bartlett's test of sphericity were significant ($X^2 = 16{,}069.304$, df = 1035, $p < 0.001$). Principal component analysis revealed that 15 items could be grouped into four subscales (i.e., risk domains) that accounted for 64.14% of the total variance (Supplementary Materials, Table S.1). Three of four developed risk domains, namely; awareness, risk perception, and belief exhibited high levels of external consistency ($\alpha = 0.826$, $\alpha = 0.908$, $\alpha = 0.754$, respectively), with an acceptable level of consistency found within the attitude domain ($\alpha = 0.624$) (Supplementary Materials, Table S.2).

Table 1
Socio-demographic and property characteristics among surveyed private well users in Ontario. Varying sample size due to the exclusion of response items or lack of response to the question.

Variable	Response items[a]	N	Frequency (%)
Geographic location	Southeastern Ontario	1129	686 (60.8)
	Northern Ontario		205 (18.2)
	Southwestern Ontario		154 (11.4)
	Central Ontario		84 (7.4)
Respondent gender	Female	1161	634 (54.6)
	Male		527 (45.4)
Respondent age	18–24	1167	6 (0.5)
	25–34		118 (10.1)
	35–44		197 (16.9)
	45–54		216 (18.5)
	55–64		317 (27.2)
	65+		313 (26.8)
Respondent education	High school	1155	94 (8.1)
	College[b]		314 (27.2)
	University[c]		747 (64.7)
Annual household income	$0–$38,999	904	48 (5.3)
	$39,000–$61,999		109 (12.1)
	$62,000–$87,999		162 (17.9)
	$88,000–$124,999		226 (25)
	$125,000+		359 (39.7)
Household drinking water source type	Drilled well	1171	876 (74.8)
	Dug well		150 (12.8)
	Bottled water		120 (10.2)
	Well, unknown type		25 (2.1)
Property ownership	Yes	1228	1188 (96.7)
	No		40 (3.3)
Property type	Permanent	1228	1017 (82.8)
	Seasonal (e.g., cottage)		211 (17.2)
Well water use[d]	Domestic	1207	933 (77.3)
	Agriculture and irrigation		9 (0.7)
	Domestic, agriculture and irrigation		265 (22)
Wastewater management	Septic system	1219	1178 (96.6)
	Municipal sewage		21 (1.7)
	Other		20 (1.6)

[a] Excluded “Prefer not to answer” response items.
[b] Colleges are defined as an institution that offers certificate programs, diplomas, apprenticeships and degrees (MCU, 2019).
[c] Universities are defined as an institution that offers undergraduate and graduate degrees and other professional programs (MCU, 2019).
[d] Excluded “Industrial or commercial purposes” and “Other” response items due to low sample size.

3.2.1. Awareness

Respondents exhibited a median awareness score of 0.71. As shown (Table 2), almost all (98.8%) exhibited an awareness of the presence (or absence) of domestic water treatment, of whom 41.8% ($n = 490$) stated that no treatment process of any kind was currently employed. Similarly, 98.3% of respondents exhibited an awareness (Yes/No) of previous bacterial testing, with 11.4% stating that laboratory testing had never been previously undertaken.

As shown (Table 2), 38.6% and 10.6% were aware of 1 to 3 and 4 to 6 waterborne pathogens, respectively, with 50.8% unaware of any listed pathogens; highest levels of awareness were associated with *Escherichia coli* O157 (*E. coli* O157) (46.1%), *Giardia* (25.1%), and *Cryptosporidium* (19.1%).

Table 2
Levels of awareness exhibited by surveyed private well users in Ontario and total sample size of each completed question. Varying sample size due to the exclusion of response items or lack of response to the question.

Variable		N	Frequency (%)
1. Well age	Aware	1228	1076 (87.6)
2. Well depth	Aware	1228	962 (78.3)
3. Treatment use	Aware	1185	1171 (98.8)
4. Previous testing practices	Aware	1183	1163 (98.3)
5. Private well water (4 sub-questions)[a]:			
i. Contamination in my well could affect my neighbors water quality	Aware	1141	811 (71.1)
ii. Manure spreading on or near my property could contaminate my well water	Aware	1141	969 (84.9)
iii. Groundwater travels through underground rivers before reaching my well*	Aware	1141	86 (7.5)
iv. I could call a water company to fill up my well if it has gone dry*	Aware	1141	594 (52.1)
6. Well condition[b]	Aware of 0 features	1211	42 (3.5)
	Aware of 1–2 features		83 (6.9)
	Aware of 3–4 features		1086 (89.7)
7. Pathogens associated with well water contamination	Aware of 0 pathogens	1141	580 (50.8)
	Aware of 1–3 pathogens		440 (38.6)
	Aware of 4–6 pathogens		121 (10.6)
8. Potential contamination sources	Aware of 0 sources		(19.7)
	Aware of 1–2 sources		221 (19.4)
	Aware of 3–4 sources	1141	695 (60.9)

[a] Response options: Strongly Agree/Somewhat Agree (i.e., Aware); Neither Agree nor Disagree, Somewhat Disagree/Strongly Disagree (i.e., Unaware). Scoring was reversed for statements with asterisks.
[b] Response options: "Yes" or "No" (i.e., Awareness of 1–4 details), "I do not know" (i.e., Awareness of 0 details).

3.2.2. Attitudes

Respondents exhibited a median attitude score of 0.88. Over three quarters of respondents (78.9%) (strongly or somewhat) agreed with the statement: "I enjoy the taste of my well water", while 17.6% and 20.7% (strongly or somewhat) agreed with the statements: "I prefer to drink municipal (city) source water" and "I worry I might become ill from drinking my well water", respectively (Fig. 1).

3.2.3. Risk perception

Overall, 98.6%, 98.4% and 94.6% of survey participants considered water quantity, water quality, and location of septic system, respectively, as very or somewhat important when constructing a well (i.e., source risk perception) (Fig. 2a). Respondents exhibited a median source risk perception score of 0.94. Likewise, 94.4%, 90.7% and 90.5% reported being very or somewhat concerned about human contamination, pesticide usage and water quality, respectively, in relation to regional groundwater supplies (i.e., regional risk perception) (Fig. 2b). Respondents exhibited a median regional risk perception score of 1.0. In terms of local groundwater supplies (i.e., groundwater quality and quantity in their community), 84.7% rated the quality as "Excellent, no concerns", "Good, and improving", or "Consistently good" (Fig. 2c). Most respondents (59.2%) indicated that it is "Likely" there will be enough groundwater in their community in 10 years' time (Fig. 2d). Respondents exhibited a median local quantity risk perception score of 0.3.

3.2.4. Beliefs

Overall, 89.8%, 57.5%, and 71.6% of respondents (strongly or somewhat) agreed with the following statements: Water "Is a human right", "Has its own rights", and "Is culturally significant" (Fig. 3a). Respondents exhibited a median spiritual belief score of 0.5. When asked "Who do you believe should be responsible for protecting groundwater where you live?", 75.8% to 88.4% agreed to each statement related to external responsibility (Fig. 3b). Similarly, 94.9% and 84.6% agreed that they (i.e., surveyed individual) and their community are responsible for groundwater protection where they live, respectively (Fig. 3c). Respondents exhibited a median external responsibility belief score of 1.0. Similarly, a median personal responsibility belief score of 1.0 was found.

3.3. Respondent characteristics and risk domains

Awareness domain scores were significantly lower among respondents without post-secondary level education ($p < 0.001$) (Fig. 4a). Respondents acquiring their household drinking water supply from a drilled well ($n = 821$) exhibited higher awareness domain scores compared to respondents that use bottled water ($n = 110$) ($p = 0.005$).

Significantly higher attitude domain scores (i.e., more positive attitude) with respect to private well water supplies were exhibited by respondents residing in Southeastern Ontario ($n = 622$) and Northern Ontario ($n = 182$) when compared to respondents residing in Central Ontario ($n = 77$) ($p = 0.014$) (Fig. 4b). Drilled well (borehole) users exhibited a significantly higher attitude domain score than those using a dug well ($p = 0.001$) or bottled water ($p < 0.001$).

As shown (Table 3), three of four calculated risk perception domains were significantly associated with gender. More specifically, significantly higher median levels of source, regional, and local (quantity)

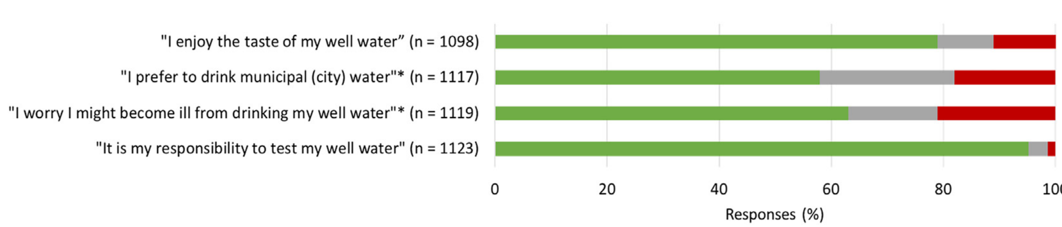

Fig. 1. Responses to Likert-scale statements provided by surveyed private well users in Ontario and included for "attitude" domain scoring. Responses to each statement are classified as Strongly Agree/Somewhat Agree, representing a "positive" attitude towards private well water supplies (GREEN); Neither Agree or Disagree, representing a "neutral" attitude towards private well water supplies (GREY); Strongly Disagree/Somewhat Disagree, representing a "negative" attitude towards private well water supplies (RED). Scoring was reversed for statements (asterisks) that demonstrate a negative attitude. Varying sample size due to the exclusion of response items and/or incomplete surveys.

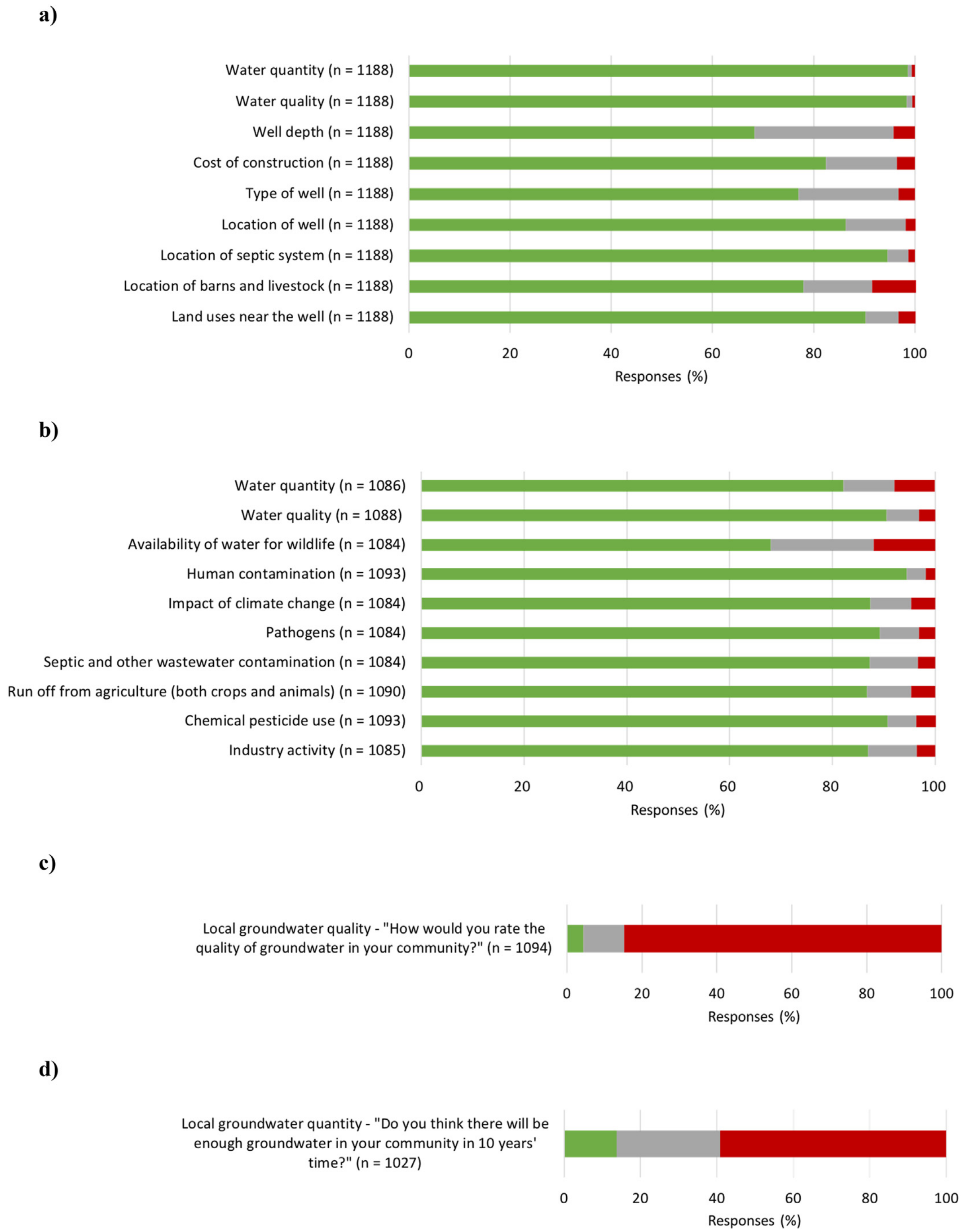

Fig. 2. Responses to Likert-scale statements and sliding scale question by surveyed private well users in Ontario and included for "risk perception" domain scoring. Responses to each statement are classified as Very Important/Somewhat Important, representing a "high" perception of risk (GREEN); Neither Important or Unimportant, representing a "neutral" perception of risk (GREY); Very Unimportant/Somewhat Unimportant, representing a "low" perception of risk (RED). (a) Responses to statements relating to factors perceived as important during well construction (i.e., source risk perception). (b) Responses to statements related to factors of concern regarding regional groundwater supplies (i.e., regional risk perception). (c) Responses to statements related to the quality of local groundwater supplies (i.e., local (quality) risk perception). Responses are classified as "Consistently poor" and "Poor and declining", representing a "high" perception of risk (GREEN); "Good, but declining" and "Poor, but improving", representing a "neutral" perception of risk (GREY); "Excellent, no concerns", "Good, and improving", and "Consistently good", representing a "low" perception of risk (RED). (d) Responses to a slider-scale question related to the quantity of local groundwater supplies (i.e., local (quantity) risk perception). Responses are classified as Unlikely (7–10), representing a "high" perception of risk (GREEN); Neutral (4–6), representing a "neutral" perception of risk (GREY); Likely (1–3), representing a "low" perception of risk (RED). Varying sample size due to the exclusion of response items or lack of response to the question.

risk perception scores were exhibited by female respondents ($p = 0.007$, $p = 0.017$, $p < 0.001$, respectively). Respondents with a drilled well exhibited significantly lower local (quantity) risk perception scores ($p < 0.001$). Similarly, a significant difference was found between household drinking water source type and local (quality) risk perceptions. Of those respondents that use a drilled well, dug well and bottled water, 87.9% ($n = 663$), 79.4% ($n = 100$), and 67% ($n = 65$), respectively, rated the quality of their local groundwater supplies as "Excellent, no concerns", "Good, and improving", or "Consistently good", representing a "low" perception of risk.

Spiritual beliefs regarding water were significantly higher among respondents residing in Northern Ontario ($p = 0.002$) and

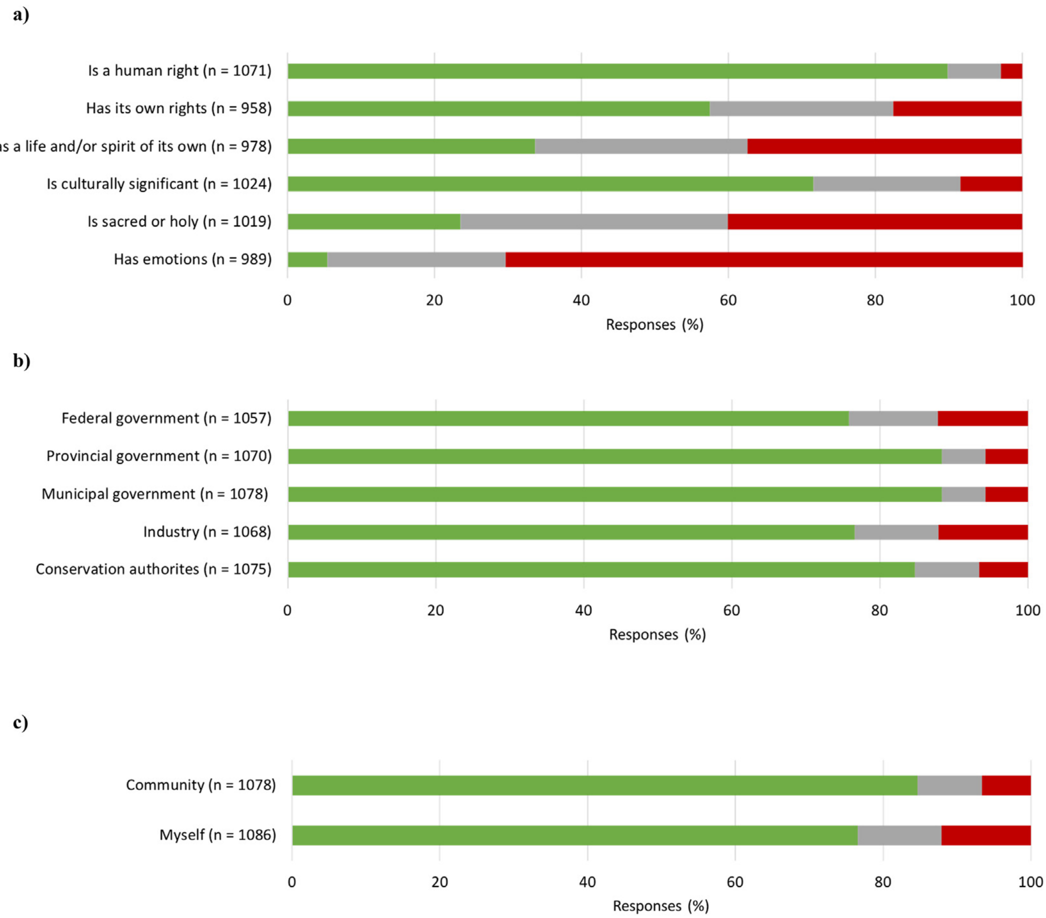

Fig. 3. Responses to Likert-scale statements provided by surveyed private well users in Ontario and included for "belief" domain scoring. Responses to each statement are classified as Strongly Agree/Somewhat Agree (GREEN); Neither Agree or Disagree (GREY); Strongly Disagree/Somewhat Disagree (RED). (a) Responses to statements were related to spiritual beliefs about water. (b) Responses represent beliefs regarding the responsibility of groundwater protection in their community (i.e., external responsibility). (c) Responses represent beliefs regarding the responsibility of groundwater protection in their community (i.e., personal responsibility). Varying sample size due to the exclusion of response items or lack of response to the question.

female respondents ($p = 0.001$) (Table 4). Similarly, higher belief scores regarding external responsibility (e.g., government, conservation authorities, industries) ($p < 0.001$) and personal responsibility (i.e., the well user, local community) for local groundwater protection ($p = 0.034$) were found among female respondents (Table 4).

3.4. Previous respondent experiences and characteristics

Overall, 34.6% ($n = 425$) of respondents resided on the property during well construction. Significant differences were found between household drinking water source type and well residency ($p < 0.001$); of those respondents that resided on the property during well design or construction or design, 37.6% ($n = 329$), 32.7% ($n = 49$), and 25% ($n = 30$) used a drilled well, dug well, and bottled water, respectively, as their primary consumption source (Table 5).

Overall, 14.7% ($n = 171$) of respondents reported the occurrence of AGI symptoms within their household in the 12-month period prior to survey completion. As shown (Table 5), a significant relationship between gender and AGI symptoms within the household ($p = 0.023$); 16.6% ($n = 101$) and 11.8% ($n = 59$) of female and male respondents, respectively, reported AGI symptoms within their household. Additionally, higher levels of AGI symptom reporting were reported by 25–34 and 35–44 year olds, with a decreasing trend concurring with increasing age ($p < 0.001$). Similarly, significantly higher levels of AGI symptoms within the household were found among respondents that concurrently used their well water for domestic, agriculture and irrigation purposes ($p = 0.004$).

Of those respondents who reported previous AGI symptoms within the household, 14.6% ($n = 25$) reported a (physician) confirmed AGI diagnosis. A relationship was found between property ownership and AGI diagnosis ($p = 0.011$) (Table 5); respondents that owned the property served by their well were approximately 6 times less likely to report AGI diagnosis within the household in the past 12 months than "renters" (OR = 0.171 95% CI 0.048–0.614).

3.5. Previous respondent experiences and risk domains

As shown (Figs. 5a & 6c), respondents residing on the property during well construction exhibited significantly higher levels of awareness ($p < 0.001$) and lower local (quantity) risk perception scores ($p = 0.017$) compared to those that inherited the well with the property. Respondents that reported previous AGI symptoms within the household in the past 12 months exhibited significantly lower awareness domain scores ($p = 0.038$) (Fig. 5a) and significantly lower attitudinal domain score ($p < 0.001$) (Fig. 5b) compared to those that did not experience AGI symptoms. Additionally, respondents that reported AGI symptoms within the household exhibited significantly higher local (quantity) risk perception scores ($p = 0.025$) (Fig. 6c). Respondents that reported

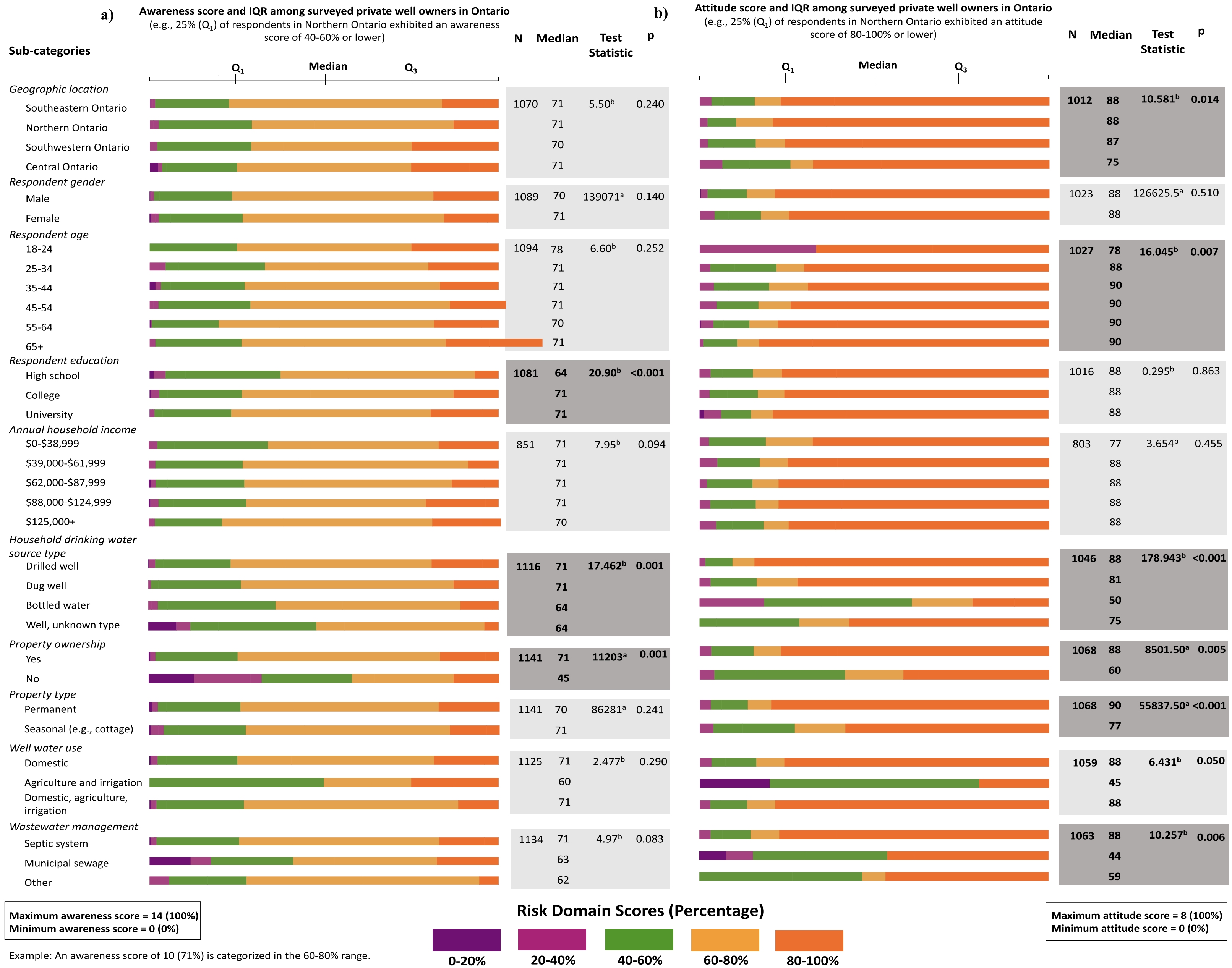

Fig. 4. Stacked plots of (a) awareness domain scores and (b) attitude domain scores delineated by geographic location, demographic and household characteristic variables. Vertical scales are used to measure central tendency and summarize descriptive results for the calculated risk domain scores. Each scale includes the median (50th percentile), Q_1 (25th percentile) and Q_3 (75th percentile). IQR = Interquartile range = $Q_3 - Q_1$. Data in grey boxes to right of plots include; total sample size, bivariate test statistic (i.e., [a]Mann Whitney *U* test, [b]Kruskal-Wallis test) and *p*-value for each variable, and the median score (%) of each group within respective characteristic variables. Dark grey boxes and bold text used to indicate statistically significant results i.e., $p < 0.05$.

Table 3
Bivariate analyses of respondent socio-demographic and property characteristics and calculated risk perception scoring among surveyed private well users in Ontario ($p < 0.05$).

Variables	Source risk perception Maximum score: 18			Regional risk perception Maximum score: 20			Local (quality) risk perception (No assigned score)			Local (quantity) risk perception Maximum score: 10		
	N	Test statistic	p	N	Test statistic	p	N	Test statistic	p	N	Test statistic	p
Geographic location	1103	6.709[b]	0.082	986	12.526[b]	**0.006**	969	8.963[c]	0.176	1025	12.642[b]	**0.005**
Respondent gender	1127	143,165.50[a]	**0.007**	1003	114,093.00[a]	**0.017**	988	2.841[c]	0.242	1046	99,952.500[a]	**<0.001**
Respondent age	1134	23.881[b]	**<0.001**	1010	12.618[b]	**0.027**	991	11.598[c]	0.313	1050	7.173[b]	0.208
Respondent education	1123	1.561[b]	0.458	999	11.244[b]	**0.004**	983	1.818[c]	0.769	1040	1.558[b]	0.459
Annual household income	878	5.514[b]	0.239	792	2.792[b]	0.593	783	11.331[c]	0.184	820	11.874[b]	**0.018**
Household drinking water source type	1158	5.944[b]	0.203	1028	5.942[b]	0.204	999	41.038[c]	**<0.001**	1074	29.512[b]	**<0.001**
Property ownership	1184	17,910.00[a]	0.381	1045	10,903.500[a]	0.095	1027	1.951[c]	0.377	1094	12,065.500[a]	**0.041**
Property type	1184	78,539.500[a]	**<0.001**	1045	76,141.500[a]	0.922	1027	0.862[c]	0.650	1094	71,006.500[a]	**0.001**
Well water use	1166	2.716[b]	0.257	1034	1.314[b]	0.518	1018	7.704[c]	0.082	1079	100,456.00[b]	0.379
Wastewater management	1177	1.934[b]	0.380	1042	2.658[b]	0.265	1026	1.799[c]	0.687	1089	0.730[b]	0.694

Bold used to indicate statistically significant results i.e., $p < 0.05$.
[a] Mann Whitney *U* test.
[b] Kruskal-Wallis test.
[c] Chi-square test.

Table 4
Bivariate analyses of respondent socio-demographic, property characteristics and calculated belief scoring among surveyed private well users in Ontario ($p < 0.05$).

Variables	Spiritual belief Maximum score: 12			External responsibility belief Maximum score: 10			Personal responsibility belief Maximum score: 4		
	N	Test statistic	p	N	Test statistic	p	N	Test statistic	p
Geographic location	808	4.899[e]	**0.002**	982	4.581[b]	0.205	1025	4.955[b]	0.175
Respondent gender	828	−3.294[d]	**0.001**	997	106,400.0[a]	**<0.001**	1044	127792[b]	**0.034**
Respondent age	834	1.001[e]	0.416	1002	5.497[b]	0.358	1048	2.342[b]	0.800
Respondent education	824	0.946[e]	0.389	993	1.245[b]	0.537	1038	1.654[b]	0.437
Annual household income	667	1.548[e]	0.187	787	2.718[b]	0.606	821	3.614[c]	0.461
Household drinking water source type	846	1.613[e]	0.185	1022	1.983[b]	0.739	1067	3.038[c]	0.552
Property ownership	860	−1.593[d]	0.111	1039	11,296.50[a]	0.291	1086	10,225.0[a]	**0.003**
Property type	860	−1.478[d]	0.140	1039	73,774.0[a]	0.567	1086	82,100.0[b]	0.949
Well water use	849	2.978[e]	0.051	1028	93,210.0[b]	0.633	1075	7.741[b]	**0.021**
Wastewater management	856	2.696[e]	0.068	1036	1.177[b]	0.555	1083	6.042[b]	0.049

Bold used to indicate statistically significant results i.e., $p < 0.05$.
[a] Mann Whitney U test.
[b] Kruskal-Wallis test.
[c] Chi-square test.
[d] Independent samples *t*-test.
[e] One-way ANOVA.

AGI diagnosis exhibited significantly lower spiritual belief domain scores ($p = 0.025$) (Fig. 7a).

4. Discussion

Private well users are responsible for maintaining, testing, and upgrading their private water systems. Understanding the interactions between, and impacts of, various factors that may influence protective actions is necessary to improve environmental quality and public health. The current study sought to investigate the impact of previous experiences, socio-demographic status, and property characteristics on risk domains among private well users in Ontario. Specifically, a questionnaire was developed and completed by 1030 private well users. Four novel risk domains and a scoring protocol (Section 2.4)

Table 5
Results of chi-square tests of independence between respondent socio-demographic, property characteristics and reported previous experiences among surveyed private well users in Ontario ($p < 0.05$).

Variables	Well residency			AGI symptoms			AGI diagnosis		
	N	X^2	p	N	X^2	p	N	X^2	p
Geographic location	1129	9.752[a]	**0.021**	1082	9.188[a]	**0.027**	156	11.418[b]	**0.006**
Respondent gender	1161	5.32[a]	**0.021**	1106	5.132[a]	**0.023**	160	1.888[a]	0.234
Respondent age	1161	91.622[a]	**<0.001**	1112	67.147[a]	**<0.001**	161	7.088[b]	0.208
Respondent education	1155	0.499[a]	0.779	1101	0.275[a]	0.871	161	0.873[a]	0.700
Annual household income	904	4.563[a]	0.335	864	4.261[a]	0.372	134	0.853[b]	0.980
Household drinking water source type	1171	21.645[a]	**<0.001**	1115	5.756[a]	0.124	160	5.202[b]	0.130
Property ownership	1228	8.931[a]	**0.003**	1162	9.380[a]	**0.002**	171	8.955[a]	**0.011**
Property type	1228	25.852[a]	**<0.001**	1162	19.463[a]	**<0.001**	171	2.665[a]	0.128
Water use	1207	3.949[a]	0.139	1145	11.076[a]	**0.004**	168	7.697[a]	**0.008**
Wastewater management	1219	7.487[a]	**0.024**	1155	5.719[a]	0.057	169	5.821[b]	0.060

Bold used to indicate statistically significant results i.e., $p < 0.05$.
Note. Fishers exact test employed, provided at least one cell had <5 respondents.
[a] Chi-square test.
[b] Fishers exact test.

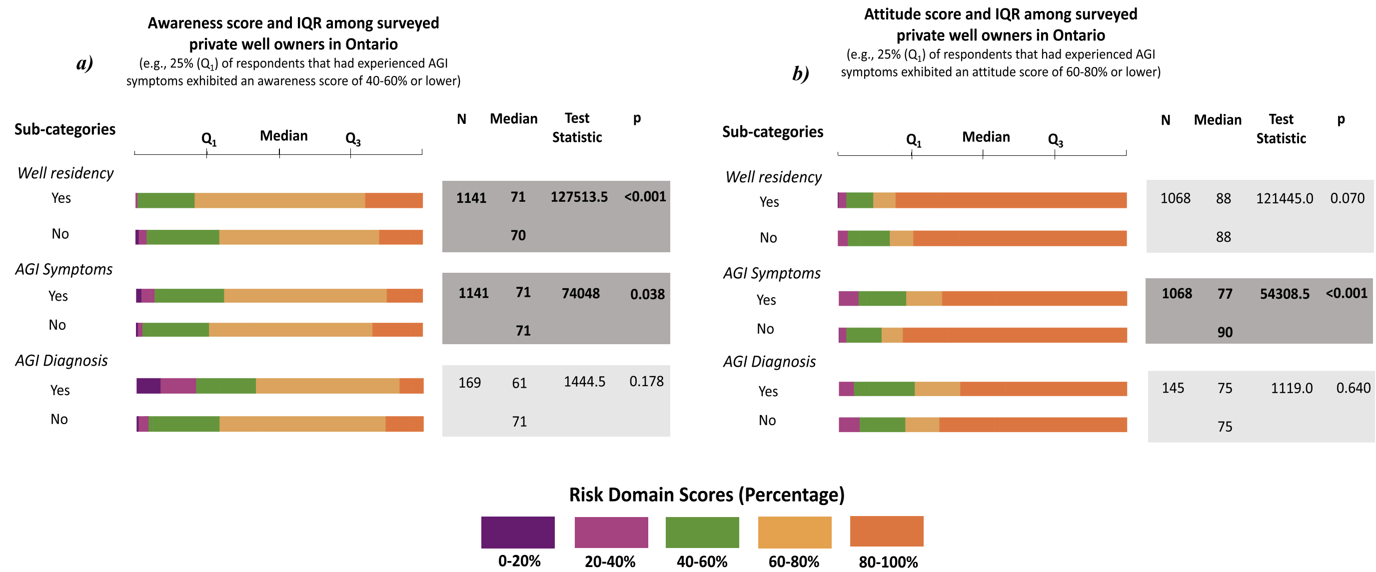

Fig. 5. Stacked plots of (a) awareness domain scores and (b) attitude domain scores delineated by experience variables. The vertical scales are used to measure central tendency and summarize descriptive results for the calculated risk domain scores. Each scale includes the median (50th percentile), Q_1 (25th percentile) and Q_3 (75th percentile). IQR = Interquartile range = $Q_3 - Q_1$. Data in grey boxes beside plots include; total sample size, bivariate test statistic (i.e., Mann Whitney U test) and p-value for each variable, and the median score (%) of each group within respective experience variables. Dark grey boxes and bold text used to indicate statistically significant results i.e., p < 0.05.

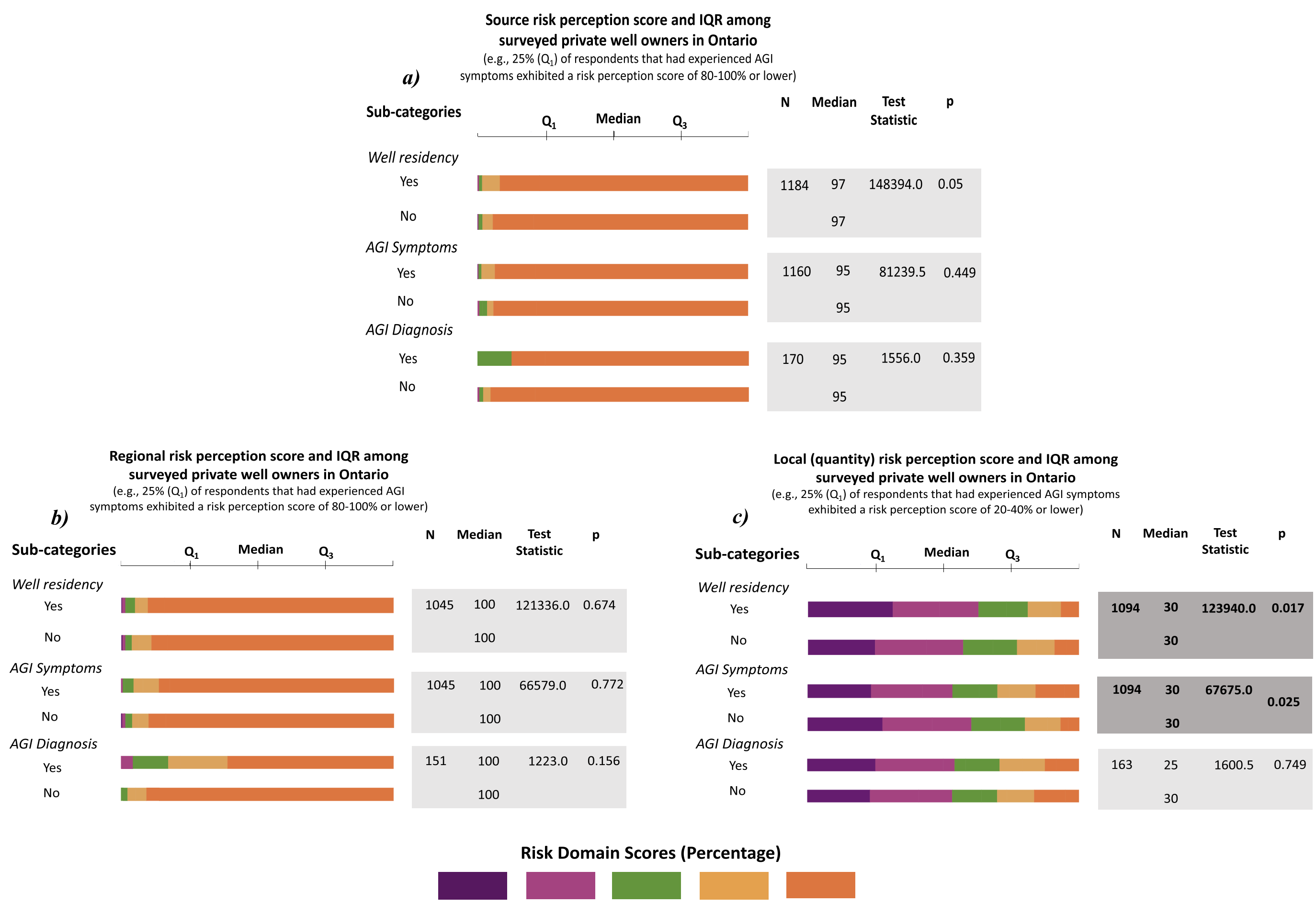

Fig. 6. Stacked plots of risk perception domain scores separated by sub-domains ((a) source risk perception, (b) regional risk perception, (c) local (quantity) risk perception) delineated by experience variables. The vertical scales are used to measure central tendency and summarize descriptive results for the calculated risk domain scores. Each scale includes the median (50th percentile), Q_1 (25th percentile) and Q_3 (75th percentile). IQR = Interquartile range = $Q_3 - Q_1$. Data in grey boxes beside plots include; total sample size, bivariate test statistic (i.e., Mann Whitney *U* test) and p-value for each variable, and the median score (%) of each group within respective experience variables. Dark grey boxes and bold text used to indicate statistically significant results i.e., $p < 0.05$.

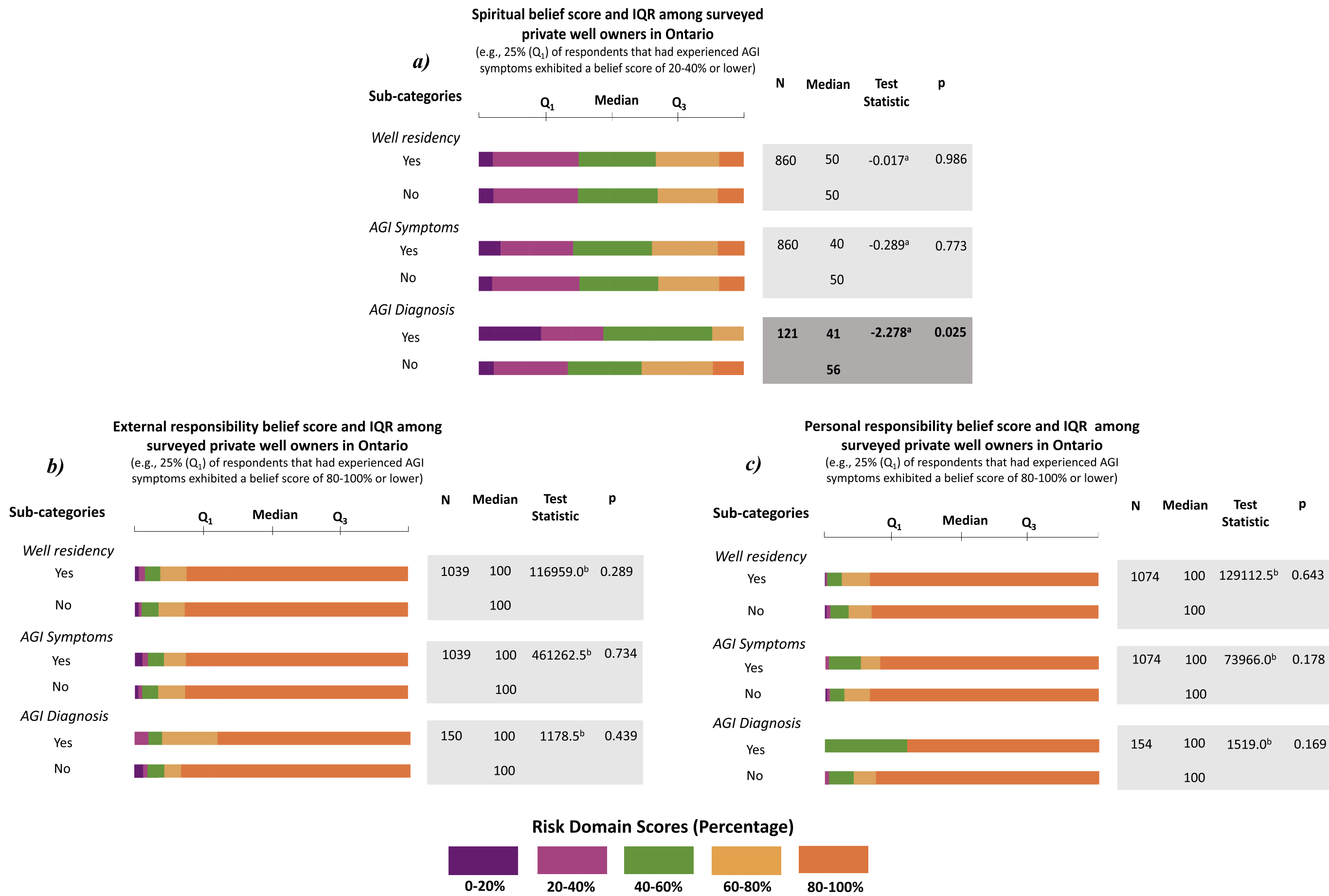

Fig. 7. Stacked plots of belief domain scores separated by sub-domains ((a) spiritual belief, (b) external responsibility belief, (c) personal responsibility belief) based on developed scoring methodology delineated by experience variables. The vertical scales are used to measure central tendency and summarize descriptive results for the calculated risk domain scores. Each scale includes the median (50th percentile), Q_1 (25th percentile) and Q_3 (75th percentile). IQR = Interquartile range = $Q_3 - Q_1$. Data in grey boxes beside plots include; total sample size, bivariate test statistic (i.e., [a]One-way ANOVA, [b]Mann Whitney U test) and p-value for each variable, and the median score (%) of each group within respective experience variables. Dark grey boxes and bold text used to indicate statistically significant results i.e., $p < 0.05$.

assigned to each domain were developed. To date, no work has designed latent "risk domains" and associated composite scores to quantify and compare well users across Ontario, and further afield. Results from EFA and Cronbach's alpha tests (Section 3.2) indicate that the developed risk domains display high inter-item correlation and may represent a transferable framework for future research.

4.1. Risk domains and geographic location

Geographic location was shown to be associated with well users' risk domain scores. Specifically, significant associations were found when comparing geographic location to both attitude (Fig. 4b) and risk perception (Table 3). Respondents residing in Central Ontario exhibited significantly lower attitude domain scores (i.e., increasingly negative attitude) and higher regional and local (quantity) risk perception scores than respondents in Southeastern Ontario and Northern Ontario. Studies have shown that contamination events may be particularly pronounced in areas where increasingly intensive agricultural activities may combine with peri-urban sprawl and population growth to threaten the quality of private drinking water supplies (Elshafei et al., 2014; Valle Junior et al., 2014). Urbanization and population growth are expected to increase significantly in the northern region of the Greater Toronto Area, placing pressures on historically rural regions in Central Ontario (Boume et al., 2003; Vaz and Arsanjani, 2015). For example, the populations of Central, Southeastern, and Southwestern Ontario are projected to grow by 35%, 29%, and 25% by 2046, respectively, whereas the population of Northern Ontario is projected to grow by just 2.3% (Ontario Ministry of Finance, 2019). Thus, lower attitudinal scores and higher perceptions of risk may be associated with the rapidly evolving peri-urban landscapes, population growth, and lack of greenspace surrounding and encroaching on rural areas in Central Ontario and may also occur in Southeastern and Southwestern Ontario.

4.2. Risk domains and respondent characteristics

Although respondents' awareness was generally high (Median: 0.71), findings indicate a low level of awareness related to waterborne pathogens among the current sample. Approximately 50.8% of respondents were unaware of any listed groundwater associated pathogens (i.e., *E. coli* O157, *Giardia*, *Cryptosporidium*, *Campylobacter* and norovirus) (Table 2), thus representing a possible public health concern due to the unregulated nature of these supplies and the consequent responsibilities for their owners (Charrois, 2010; Thomas et al., 2017). Populations dependent on private water supplies are characterized by an increased risk of gastrointestinal illness versus those using municipal water systems which are monitored and regulated (Uhlmann et al., 2009; Murphy et al., 2016). Quantitative microbial risk assessment models have estimated that approximately 80,000 AGI cases per year in Canada are attributable to the consumption of water containing *Giardia*, *Cryptosporidium*, *Campylobacter*, *E. coli* O157 and norovirus from untreated private drinking water wells (Murphy et al., 2016). Although these infections are typically considered non-life threatening in healthy adults, vulnerable populations, including infants, young children, the elderly, pregnant women and the immuno-compromised are considered to be at a greater risk of serious illness and mortality (Gerba et al., 1996). These findings suggest that future risk communication and educational strategies designed to increase awareness among well users must consider the current status of awareness in relation to potential waterborne pathogens to address significant knowledge gaps.

Results suggest a marked gender gap with respect to risk perception and belief domains. For example, significantly higher median levels of source, regional and local (quantity) risk perception scores were exhibited by female respondents (Table 3). Similarly, significantly higher belief scores related to spirituality, external responsibility (e.g., government, conservation authorities, industry) and personal responsibility (i.e., the well user, local community) for local groundwater protection were found among female respondents (Table 4). Findings are consistent with the literature concerning gender and risk perception, with several studies related to environmental health risks noting that females generally perceive higher risks and express more concern than males (Finucane et al., 2000; Morioka, 2014; McDowell et al., 2020). Biological and social hypotheses have been put forward to explain these differences in perceptions of risk among gender. For example, women have been characterized as more concerned about the environment, human health, and safety because they are socialized into caregiver roles producing a "motherhood mentality" (Blocker and Eckberg, 1997; Strapko et al., 2016). Additionally, previous studies have suggested that gender roles may be reinforced by parenthood (Gustafsod, 1998; Laferriere et al., 2016). According to Blocker and Eckberg (1989), mothers may perceive higher environmental or health risks than women without children (i.e., the "mother effect"), while fathers are more concerned with economic than environmental or health consequences (i.e., the "father effect"). The aforementioned hypothesis may also explain the gender difference with respect to reported AGI symptoms within the household in the past year (Table 5); a higher proportion of female respondents reported AGI symptoms in the household compared to male respondents. An understanding of gendered risk perception is critical for developing effective risk communication strategies in the context of private well water supplies. Findings support the need for gender-focused communication and educational strategies (e.g., male or female interest groups, various media outlets), perhaps starting in younger populations with or without young children living in the household.

Respondents with dug wells exhibited significantly lower attitude domain scores (i.e., more negative attitude) (Fig. 4b) and higher local (quantity and quality) perceptions of risk (Table 3), than drilled well users. This reinforces a previous finding by Kreutzwiser et al. (2011), who reported that users of dug wells were more likely to have inspected their wells within the last year than users of drilled wells. Although no significant associations in awareness were found between drilled versus dug well users, findings suggest a potential level of awareness related to the risk of well water contamination depending on well type (i.e., drilled versus dug). For example, dug wells are typically more susceptible to pathogen ingress as water is acquired from relatively shallow groundwater reserves with greater likelihood of contamination from the surface (e.g., livestock waste) (Hynds et al., 2012). Future research should seek to quantify this potential association to represent key factors influencing well users' attitudes and perceptions of risk. Given the significant differences between private well type and respondents' attitude and risk perception scores, it is considered important that future guidance and regulation address household drinking water source types independently.

4.3. Risk domains and experiences

Findings indicate that experiential predictors are significantly associated with well users' risk domains. More specifically, well users that resided on the property during well design or construction exhibited higher levels of awareness (Fig. 5a) and lower local (quantity) risk perception scores (Fig. 6c) than residents who inherited the well with the property. Similarly, previous research in the Republic of Ireland found that experience influences knowledge acquisition among private well users. A study by Hynds et al. (2013) found that respondents living on the property during well design or construction exhibited a higher source awareness, than residents who inherited the well with the property. Likewise, Summers (2010) investigated well users' previous experiences with well contractors during the well design or construction process in Alberta, Canada. Respondents that hired a well contractor were asked if appropriate construction methods were discussed, along with important characteristics to consider during the well design or construction process. Approximately 75% of respondents agreed that their well contractor explained the importance of proper construction methods, while 66% took the time to discuss the importance of well location and possible sources of contamination. Findings from the current study suggest that the experience of "well residency" may be a key driver to increased levels of awareness and consequently attitude or perception, as these well users are more likely to have direct contact with the well contractor or be directly involved in the process of well location or construction. Thus, household inheritance or purchase represents a potential critical control point, whereby future educational strategies may be focused towards well users that inherited the well with the property.

Similar to well residency, results indicate that previous AGI symptoms and well users' risk domains are significantly associated (Figs. 5 & 6). For example, gastrointestinal illness within the household in the past 12 months was significantly associated with lower awareness and attitudinal domain scores (Fig. 5a,b) in relation to private well water supplies and higher local (quantity) risk perception scores (Fig. 6c). Previous Canadian well user surveys suggest that well users may perceive their risk for infection to be higher or develop negative attitudes in relation to their personal well water supplies when they or a household member have experienced an illness in the past (Jones et al., 2006; McLeod et al., 2015; Imgrund et al., 2011). Negative attitudes and higher perceptions of risk towards household drinking water wells have been found to influence the decision to switch to an alternative water supply (e.g. bottled water) (Jones et al., 2006; Roche et al., 2013). Given the burden of disease resulting from water-borne illness among well users and consequent negative attitudes towards private well water supplies, it is recommended that physicians and other healthcare providers (particularly those in rural areas) enquire about water supplies and potential sources of contamination when taking a patient's medical history (Charrois, 2010). Further, physicians and healthcare professionals should receive appropriate training to emphasize the potential risks to private well users and the importance of proactive measures to ensure that private water systems are safe for all household members and others who may visit the household and use the water supply. Further examination into the aforementioned hypotheses is beyond the scope of the current study. Future work will be conducted to determine the directionality of associations between AGI and awareness, while considering additional variables (e.g., protective actions) that may mediate relationships.

4.4. Study limitations

The main study limitation was associated with obtaining a representative sample of the general population. Specifically, respondents who attended high school as their highest education level (8.1%) were under-represented. In 2016, 24.5% of the Ontario population aged 25 to 64 had a high school diploma or equivalency certificate as the highest educational qualification (Statistics Canada, 2016), although this has not been disaggregated by urban and rural populations. Additionally, respondents with an annual household income of <39,000 (5.3%) are somewhat under-represented, as the average household income in rural areas is around $40,000 (Rural Ontario Institute, 2018; Statistics Canada, 2016). Greater participation by more educated and higher income individuals results in a sample that may not fully represent private well users in the province (Moazzami, 2015). This is a common limitation for online data collection, as it is difficult to reach socioeconomically or educationally disadvantaged individuals who may lack the skills to use or may not have adequate access to a computer or internet connection (Galea and Tracy, 2007; Suarez-Balcazar et al., 2009). Designing effective outreach and communication strategies involves developing a comprehensive understanding of the target audience (Fox et al., 2016). Therefore, it is suggested that future studies focus on less educated and lower income population subsets in order to better design successful outreach programs. Caution is additionally advised regarding awareness associated with potential pathogens and well condition. Overconfidence in the condition of their well may have been construed as awareness, and there may be systematic bias against those without education related to the specific names of pathogens listed (i.e., those that are unable to name pathogens but are conscious of potential risks associated with microbial contamination). Finally, it is important to acknowledge that there may be some self-selection bias in the sampling data, due to internet use and the absence of an incentive. Although results should be interpreted with caution, the authors consider that findings are largely generalizable, as this was a large statistically representative sample size garnered from the entire province of Ontario (Section 3.1).

5. Conclusion

This study adds to current understanding of the relationships between demography, property characteristics on levels of awareness, attitudes, risk perceptions, and beliefs among private well users. Although findings indicate that awareness levels among well users are relatively high, knowledge gaps exist; a low level of awareness related to waterborne pathogens should be considered when designing appropriate educational strategies, as contamination by enteric pathogens represents a significant risk to the safety of private drinking water users. Results indicate that well users' attitudes and perceptions of risk are significantly associated with geographic location, gender, and private well type. With respect to geographic location, further investigation is needed to identify the presence of casual factors underlying this association, to provide strong evidence-based support in terms of where to focus future public health initiatives. Additionally, it is suggested that gender and household drinking water source type be analyzed separately during further investigations and for future guidance strategies, such as targeted risk communication.

Findings suggest that previous experiences are significant predictors of well users' risk domains. Analyses of experiential factors may be used to identify critical control points and potential intervention targets. With respect to well residency, users that resided on the property during well design or construction exhibited differing awareness and risk perception patterns compared with those who inherited the well with the property. Therefore, it is recommended that future guidance and regulation address these two groups separately. For example, future educational programs can target well users at the point of inheritance (purchase) and implement policies and regulations associated with knowledge transfer among well contractors and users during the well construction process. Additionally, previous illness within the household was found to be associated with negative attitudes, lower levels of awareness, and higher perceptions of risk in relation to private well water supplies. Hence, involving physicians and other health care providers in educational and guidance strategies at the time of infection is recommended as an effective method for decreasing the adverse human health risks associated with private well water. Future work will further develop network-based models to illustrate the cause-effect relationships between risk domains, past experiences, and behaviour, thus enabling public health agencies to design evidence-based interventions and communication strategies for private well users.

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CRediT authorship contribution statement

Sarah Lavallee: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing. **Paul D. Hynds:** Conceptualization, Methodology, Investigation, Supervision, Writing - review & editing. **R. Stephen Brown:** Conceptualization, Methodology, Funding acquisition, Supervision, Writing - review & editing. **Corinne Schuster-Wallace:** Conceptualization, Writing - review & editing. **Sarah Dickson-Anderson:** Conceptualization. **Stephanie Di Pelino:** Methodology. **Rylan Egan:** Writing - review & editing. **Anna Majury:** Conceptualization, Methodology, Investigation, Visualization, Project administration, Funding acquisition, Supervision, 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.

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