

## Consumer water quality evaluation of private and public drinking water sources

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### ABSTRACT

Private water wells have no requirements to be tested or monitored to ensure safe drinking water quality, and yet those receiving their primary drinking water from private supplies are more frequently confident that their tap drinking water is safe. Using data from surveys administered in 2008 and 2014, this study assesses public attitudes and perceptions regarding drinking water. This study examines the results of a random sample survey of Texans to evaluate citizen awareness and attitudes on water issues. Most respondents reported that they believe their drinking water is of high quality, with 81.4% responding that they believe their tap water is safe to drink. An even larger number, 92.1%, of those receiving their water from private sources believe their tap water is safe. Conversely, only 57.0% of respondents who consume bottled water as their primary source of drinking water believe their tap water is safe to drink. Additionally, more than 65% of Texans receiving their primary drinking water from private supplies (usually their private water well) have never had their water supply tested. A large majority (81.3%) of those primarily receiving their drinking water from private supplies believed groundwater in their area to be of good or excellent quality.

**Key words** | attitudes, drinking water, perception, private water wells, survey

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### INTRODUCTION

Through the regulatory framework established by the US Safe Drinking Water Act (SDWA) in 1974, citizens are assured safe drinking water from public drinking water suppliers. In Texas and throughout the United States, private water wells are not regulated under the Safe Drinking Water Act or any other rule, and are not required to be tested to ensure that drinking water meets water quality standards for public water supplies. Management and protection of private water wells are under the control of the landowner, and therefore, depend primarily on education rather than regulation.

Public attitudes and perceptions of water quality can vary based on where one lives. [Hu & Morton \(2011\)](#) reported that those residing in rural areas perceive their water to be of

better quality than do those living in urban areas. Typically, people living in more rural areas receive their water from a rural public water supply system or a private well. Overall, cases of drinking water disease outbreaks have decreased for public water supply systems since the 1980s, while there has been an increase in the annual proportion of outbreaks reported for private systems ([Craun \*et al.\* 2010](#)).

Texas A&M AgriLife Extension Service in conjunction with a national needs assessment project initiated through the Pacific Northwest Regional Water Program has facilitated two random sample surveys of Texans to evaluate citizen awareness, attitudes, and willingness to act on water issues ([Mahler \*et al.\* 2013](#)). The first survey was conducted in 2008. The original survey was re-issued to

another random sample of Texans in 2014 as a follow-up to the 2008 survey.

This study examines differences in the perception of water quality based on an individual's primary drinking water source. The questions of interest are: Where do you primarily get your drinking water? Possible responses to this question included: Public supply – municipal, Public supply – rural water district, Private supply, and Purchase bottled water. Private supply was assumed to be water from a private water well and not from a river, pond, or lake. Past research indicates that individuals who buy bottled water are more likely to believe their drinking water is unsafe, and also likely to regularly buy bottled water when they have a view that local groundwater is of low quality (Hu *et al.* 2011). However, factors potentially influencing perception have not been evaluated with the focus on respondents who primarily receive their drinking water from private supplies.

This evaluation of Texans' perceptions of water quality will aim to answer questions such as: Do public drinking water customers trust the quality of their water supply more than private well owners trust the quality of the water they drink? Are private well owners satisfied with their drinking water, and do they believe it is safe to drink? Is a difference in perception of local groundwater quality reflected by the respondent's primary drinking water source? Furthermore, this study will examine whether there is a relationship between choice of primary drinking water source and perceptions of types of potential pollutants in drinking water that could affect health.

## MATERIALS AND METHODS

A state-wide survey was developed to assess Texans' perceptions and attitudes about water resources within the state. The questionnaire is one of the survey components comprising the National Integrated Water Quality Program Needs Assessment Survey project initiated in 2002 and is based on the 2002 template developed by water quality coordinators in the Pacific Northwest region with input from other participating Land Grant Institution (LGI) water quality coordinators for the Southern, Mid-Atlantic, Northwest, Northeast, and Caribbean Island Regional Water Programs (Mahler 2010). The survey was sent to 1,275 randomly selected Texas residents in

August, 2008 following methods described in Boellstorff *et al.* (2010); 419 surveys (33%) were completed and returned. Minor modifications were made to the template survey to adapt it to Texas' water management agencies and organizations, and to modernize particular questions before the survey was re-issued in 2014. The survey questionnaire included 59 questions addressing water resource, water quality, and other environmental issues. The study population consisted of the adult residents of Texas.

In April of 2014, the questionnaire was sent via direct mail survey to 1,800 randomly selected residences in Texas following the tailored survey design method (Dillman 2000). As in 2008, individuals were mailed a paper copy of the survey instrument, a cover letter, and a self-addressed, stamped envelope. Twenty days later, individuals were sent a reminder postcard. Twenty days after the reminder postcard was sent, another survey instrument, cover letter, and self-addressed, stamped envelope were mailed. Twenty days later, a final reminder postcard was mailed to participants. Individuals returning the evaluation or indicating that they did not want to participate in the study were removed from the mailing list so that they were not re-contacted. Taking into account the number of (1) surveys 'returned to sender for incorrect address', (2) recipients requesting to not participate, and (3) recipient death, the effective number of mailed questionnaires in 2014 was 1,655 and the return rate for the completed survey questionnaires was 29%. Survey responses were coded and entered into a database. Missing data were excluded from analyses.

This study focused on Texans' perception of the quality of their drinking water with an emphasis on private well owners and how they compare to respondents receiving their water from public supplies or purchasing bottled water. This study examined public perceptions of drinking water and groundwater quality, and possible actions citizens may have adopted to safeguard their drinking water. Furthermore, the study analyzed factors influencing the likelihood of well owners having their water wells tested. Because 2008 and 2014 responses were not significantly different for the questions examined for this article, the data for both years were combined for this study. Responses to the following questions were analyzed.

*Where do you primarily get your drinking water?* (Mark only one answer) Answer choices included: Private supply,

Public supply – municipal, Public supply – rural water district, Purchase bottled water, and I don't know.

*Do you feel that your home tap drinking water is safe to drink? (Yes or No)*

*Do you have your home drinking water tested? (Yes or No)*

*In your opinion, what is the quality of groundwater (sources of well water) in your area? Answer choices were Good or excellent; Good, and improving; Good, but deteriorating; Fair; Poor, but improving; Poor; and No opinion/don't know.*

*Do you know of or suspect that any of the following pollutants affect either surface or groundwater quality in your area? A list of 12 pollutants was provided with answer choices including: Know it is NOT a problem; Suspect it is NOT a problem; Don't Know; Suspect it IS a problem; and Know it IS a problem.*

*Please check all of the boxes that apply to your home drinking water system. Answer options included: I have a water treatment system (softener, etc.); I have a water filter; I purchase 5 gallon containers of drinking water; I often use bottled water for drinking purposes; I never buy bottled water; I am satisfied with my drinking water (piped in house); and My drinking water is separate from my water supply system.*

The Statistical Package for Social Sciences (SPSS) Version 23 was used for data analyses. Descriptive summary statistics were calculated for socio-demographic variables. Chi-square analyses as well as descriptive statistics were used to evaluate differences among respondents and residence locations potentially affecting treatment of home drinking water systems, acquiring water tests, and the perceived quality of groundwater and surface water. Analyses of variance (ANOVA) were conducted to determine any differences among residence location and suspected pollutants affecting respondent drinking water supplies. All tests of statistical significance were conducted using an a priori alpha of 0.05. The null hypothesis is that the response frequencies are the same for the various answer options.

## RESULTS

The 2014 survey achieved a response rate of 29.4% (491 out of 1,671 surveys) with 327 respondents coming from

the first mailing, and 164 from the second. Socio-demographic characteristics regarding residence for 2008 and 2014 were not significantly different other than for gender; with 2014 more closely reflecting the actual demographics of the state: 48.7% male and 51.3% female ( $p < 0.0001$ ). Because 2008 and 2014 responses were not significantly different for the questions examined for this article, the data for both years were combined for this study. Also, as only five respondents, or 0.6%, indicated that they did not know from where they primarily received their drinking water, for the question 'Where do you primarily get your drinking water?' the response of 'I don't know' was excluded from the analysis. (Answer choices had included: Private supply, Public supply – municipal, Public supply – rural water district, Purchase bottled water, and I don't know.) As shown in Table 1, 51.0% of survey respondents lived in communities of more than 100,000. In addition, 73.1% of survey respondents lived inside city limits. A total of 71.4% of respondents resided in communities of 25,000 or more people, while 17.0% of respondents lived in or associated with small communities of 7,000 people or fewer. A large majority, more than 90%, of respondents had lived in Texas for more than ten years or for all their lives. Respondents were somewhat better educated and older than the general Texas population (US Census Bureau 2013, 2015). Seven percent of all respondents had less than a high school education, 14.4% were high school graduates, 29.6% had some college or vocational training, 29.7% were college graduates, and 21.9% had advanced degrees.

Respondents were asked where they primarily get their drinking water, and 57.1% indicated they received their water from public supplies – municipal. Unexpectedly, the next highest percentage was bottled water, with almost a quarter (23.5%) of Texans indicating they receive their primary drinking water from bottled water. Almost 8% of the respondents indicated they received their primary drinking water from private supplies (private wells).

### Tap water safety

Respondents were asked, 'Do you feel that your home tap drinking water is safe to drink?' Overall, 81.4% responded that they felt their tap water was safe. As shown in

**Table 1** | Demographics of respondents

Category	% (n)
Primary drinking water source <sup>a</sup>	
Private supply	7.6 (64)
Public supply – municipal	57.1 (480)
Public supply – rural water district	11.8 (99)
Purchase bottled water	23.5 (198)
Gender	
Male	56.6 (447)
Female	43.4 (343)
Years lived in Texas	
All my life	47.3 (377)
More than 10 years	43.0 (343)
5 to 9 years	5.8 (46)
Less than 5 years	3.9 (31)
Size of residence community	
>100,000	51.0 (428)
25,000 to 100,000	20.4 (171)
7,000 to 25,000	11.7 (98)
3,500 to 7,000	7.1 (60)
<3,500	9.9 (83)
Education	
Less than or some high school	4.4 (38)
High school graduate	14.4 (125)
Some college	29.6 (258)
College graduate	29.7 (259)
Advanced college degree	21.9 (191)
Age	
18–24	0.9 (7)
25–34	5.6 (45)
35–49	22.3 (178)
50–64	34.3 (274)
65 years old or older	36.9 (295)
Residence location	
Inside city limits	73.1 (639)
Outside city limits, not farming	22.7 (198)
Outside city limits, farming	4.2 (37)

<sup>a</sup>Responses of 'I don't know' were excluded from the analyses.

**Table 2**, 92.1% of respondents who primarily get their drinking water from private supplies felt their drinking water was safe. Conversely, only 57.0% ( $p < 0.0001$ ) of respondents purchasing bottled water for their primary drinking water

**Table 2** | Comparisons of beliefs on safety of drinking water by source

Variable	Do you feel your home tap drinking water is safe to drink?	
	Yes	No
Primary drinking water source***	Percentage of respondents	
Private supply	92.1	7.9
Public supply – municipal	88.8	11.2
Public supply – rural water district	85.6	14.4
Purchase bottled water	57.0	43.0
Gender*		
Male	84.1	15.9
Female	78.4	21.6
Residence location		
Inside city limits	82.3	17.7
Outside city limits, farming	79.2	20.8
Outside city limits, engaged in farming	83.8	16.2
Education		
Less than high school	76.3	23.7
High school graduate	82.5	17.5
Some college or vocational	80.4	19.6
College graduate	83.1	16.9
Advanced degree	81.2	18.8
Age**		
18–34	84.3	15.7
35–49	77.1	22.9
50–64	76.3	23.7
65 and older	88.2	11.8

\*Significant at the 0.05 level.

\*\*Significant at the 0.001 level.

\*\*\*Significant at the 0.0001 level.

felt their tap drinking water was safe. Responses from those receiving their drinking water from public suppliers were very similar and indicated that respondents believed their water to be safe. Confidence in water from municipal suppliers was 88.8% and for water from rural water districts was 85.6%.

Males (84.1%) were more likely to feel that their drinking water was safe than were females (78.4%,  $p < 0.05$ ). Also, respondents 65 and older were more likely to feel their water was safe (88.2%) compared to those 35–49 (77.1%) and 50–64 (76.4%) years of age, and surprisingly,

similar to those 18–34 years old (84.3%). Community size or location of residence did not affect whether respondents felt that their water was safe to drink.

### Home drinking water systems

Respondents were asked to check all that apply to their home drinking water systems from the following choices: I have a water treatment system (softener, etc.), I have a water filter, I purchase 5 gallon containers of drinking water, I often use bottled water for drinking purposes, I never buy bottled water, I am satisfied with my drinking water (piped in house), and my drinking water is separate from my water supply system. As expected, responses regarding home drinking water treatment for those purchasing bottled water as their primary water source were significantly different for all response options except for having a water treatment system (softener, etc.). Those receiving their water from private supplies were also more likely to have a water treatment system for their home drinking water than those receiving their water from public supplies – municipal ( $p < 0.0001$ ), public supplies – rural water district ( $p < 0.01$ ), or purchasing bottled water ( $p < 0.0001$ ).

Interestingly, those receiving their primary source of drinking water through private supplies did not differ from those receiving water from any other sources (public – municipal, public – rural water district, or bottled water) regarding whether a water filter was installed on their home drinking water system. The same analysis was performed regarding residence location. Responses from those living inside city limits, those living outside city limits and farming, and those living outside city limits and not farming were significantly different for ‘I never buy bottled water’ and ‘I am satisfied with my drinking water (piped in house).’ Those living outside city limits and engaged in farming were significantly ( $p < 0.05$ ) more satisfied with their drinking water than respondents living inside city limits. Furthermore, respondents living outside city limits and farming were more likely to never buy bottled water than those living within city limits and those living outside city limits and not farming ( $p < 0.01$ ). Responses regarding the five other options for this question (I have a water treatment system (softener, etc.), I have a water filter, I purchase 5

gallon containers of drinking water, I often use bottled water for drinking purposes, and my drinking water is separate from my water supply system) were not significantly different for residence location or community size.

### Testing home drinking water

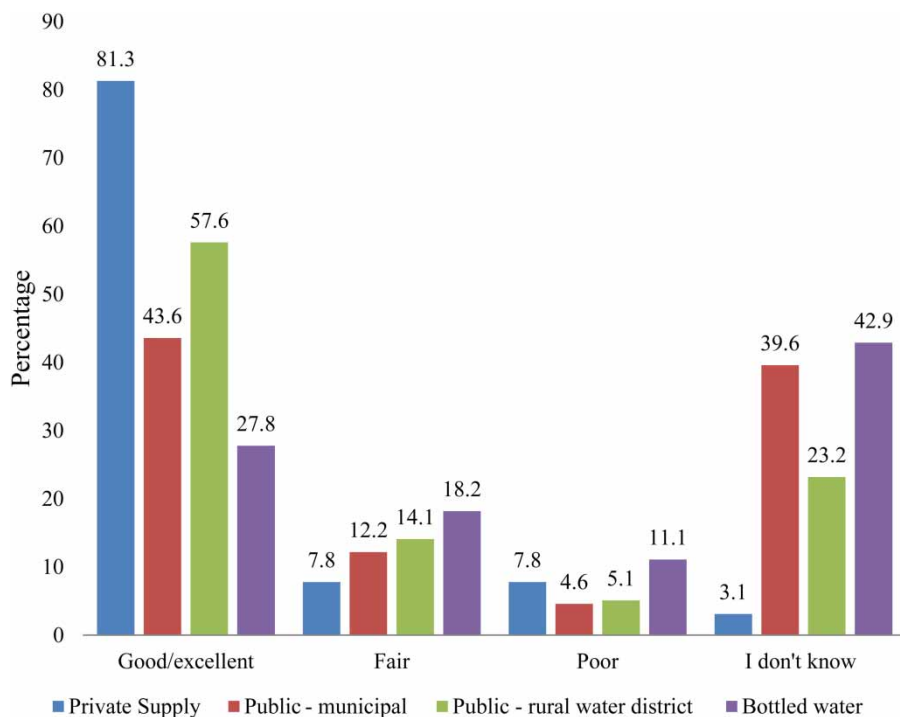
Respondents were asked if they tested their home drinking water. Those receiving their water primarily from private supplies were significantly more likely than those obtaining their primary drinking water from other sources to test their home drinking water ( $p < 0.0001$ ). As shown in Table 3, about a third of those primarily receiving their drinking water from private supplies responded that their water had been tested.

### Perceptions of water quality

Respondents were asked to evaluate both their local surface and groundwater quality. For this analysis, the seven possible responses (Good or excellent; Good, and improving; Good, but deteriorating; Fair; Poor, but improving; Poor; and No opinion/don't know) were grouped into four categories, 1 = Good/excellent, 2 = Fair (also includes Good, but deteriorating), 3 = Poor, and 4 = No opinion/I don't know. As shown in Figure 1, 81.3% of residents who get their drinking water from private supplies (typically groundwater wells) view the groundwater in their area as good or excellent, and only 7.8% perceive groundwater quality to be poor. Respondents getting their drinking water from public – municipal supplies were more likely than those with drinking water from private supplies (42.9% vs 3.1%) to not know or have no opinion of the quality of the groundwater ( $p < 0.0001$ ). Bottled water consumers had the lowest

Table 3 | Do you have your home drinking water tested?

Drinking water source	Test your drinking water	
	Yes	No
Private supply	34.4%	65.6%
Public supply – municipal	10.7%	89.3%
Public supply – rural water district	14.3%	85.7%
Purchase bottled water	10.7%	89.3%



**Figure 1** | Quality of groundwater in your area.

rating for good or excellent (27.8%). About the same percentages of respondents receiving drinking water from the various sources had the opinion that their groundwater quality was poor. Future studies in focused areas might fruitfully examine the degree of alignment of consumer perception of groundwater quality and actual groundwater quality measurements. There was no difference in perception of surface water quality among those receiving their primary drinking water from the various drinking water sources.

### Perceptions of sources of pollutants

Respondents were given a list of 12 pollutants and asked if they knew of or suspected that the pollutants affected the quality of the surface or groundwater in their area. For this analysis, responses (1 = Know it is NOT a problem, 2 = Suspect it is NOT a problem, 3 = Don't know, 4 = Suspect it IS a problem, 5 = Know it IS a problem) were recoded into the following three categories: (1 = Is NOT a problem, 2 = Don't know, 3 = IS a problem). Analysis of variance was used to determine any differences in perception of possible pollutants related to respondents' primary drinking water

sources. Perceptions of possible pollutants reported by those receiving their primary drinking water from private supplies, public supplies – municipal, public supplies – rural water district, and those purchasing bottled water significantly differed for six potential pollutants (Table 4).

Overall, those receiving their primary drinking water from bottled water were more frequently likely to suspect/know a pollutant was a problem. The next most frequent group to believe surface water or groundwater in their area was affected by the same pollutants (in some cases) were respondents who receive their primary drinking water from public supplies – municipal sources. The highest rated concerns for those who get their primary drinking water from bottled water were Fertilizer/Nitrates (2.36), Fertilizer/Phosphates (2.35), and Pesticides (2.33). These three highest rated concerns for those drinking bottled water as their primary source are frequently associated with agriculture, but are also commonly used to manage lawns and gardens within city limits.

Those who received their drinking water from public supplies – municipal were similarly concerned about Fertilizer/Nitrates (2.32), Fertilizer/Phosphates (2.33), and

**Table 4** | Do you know of or suspect that any of the following pollutants affect either surface or groundwater quality in your area?

Pollutant	Primary drinking water source	N	Mean	S.D.	F-value	Bonferroni post hoc <sup>a</sup> (Cohen's d) <sup>b</sup>
Pathogens (bacteria, viruses, germs)	Private supply	32	1.94	0.72	3.069	Bottled water (0.50)
	Public supply – municipal	254	2.06	0.66		
	Public supply – rural water district	43	1.86	0.68		
	Bottled water	103	2.19	0.64		
Fertilizer/Nitrates	Private supply	33	2.09	0.80	2.269	No significant differences
	Public supply – municipal	256	2.32	0.66		
	Public supply – rural water district	43	2.14	0.74		
	Bottled water	105	2.36	0.61		
Fertilizer/Phosphates	Private supply	33	2.06	0.79	2.8532	No significant differences
	Public supply – municipal	254	2.33	0.66		
	Public supply – rural water district	44	2.11	0.72		
	Bottled water	103	2.35	0.61		
Heavy metals (lead, arsenic, mercury)	Private supply	32	1.84	0.63	1.253	No significant differences
	Public supply – municipal	256	2.03	0.68		
	Public supply – rural water district	45	1.96	0.67		
	Bottled water	105	2.09	0.64		
Minerals (iron, manganese, calcium)	Private supply	33	2.09	0.72	0.401	No significant differences
	Public supply – municipal	255	2.12	0.67		
	Public supply – rural water district	44	2.14	0.70		
	Bottled water	105	2.20	0.66		
Pesticides	Private supply	33	2.09	0.77	4.100	Public supply – municipal (0.48); Bottled water (0.50)
	Public supply – municipal	252	2.33	0.67		
	Public supply – rural water district	45	2.00	0.74		
	Bottled water	105	2.33	0.61		
Salinity (water too salty)	Private supply	33	1.42	0.50	3.873	Bottled water (0.70)
	Public supply – municipal	255	1.71	0.70		
	Public supply – rural water district	45	1.69	0.73		
	Bottled water	104	1.88	0.69		
Pharmaceuticals (antibiotics, personal care products)	Private supply	33	1.73	0.67	4.223	Public supply – municipal (0.50); Bottled water (0.56)
	Public supply – municipal	254	2.08	0.69		
	Public supply – rural water district	45	1.84	0.64		
	Bottled water	105	2.10	0.65		
Petroleum products	Private supply	33	1.76	0.71	4.530	Bottled water (0.64)
	Public supply – municipal	256	2.05	0.69		
	Public supply – rural water district	45	1.87	0.66		
	Bottled water	106	2.19	0.66		

(continued)

Table 4 | continued

Pollutant	Primary drinking water source	N	Mean	S.D.	F-value	Bonferroni post hoc <sup>a</sup> (Cohen's d) <sup>b</sup>
Algae	Private supply	33	1.82	0.77	4.893	Bottled water (0.72)
	Public supply – municipal	255	2.13	0.70		
	Public supply – rural water district	45	1.91	0.67		
	Bottled water	105	2.11	0.64		
Product and waste water from mining	Private supply	33	1.39	0.61	0.779	No significant differences
	Public supply – municipal	252	1.69	0.61		
	Public supply – rural water district	46	1.61	0.68		
	Bottled water	105	1.85	0.65		
Septic systems	Private supply	33	1.73	0.80		
	Public supply – municipal	255	1.86	0.67		
	Public supply – rural water district	45	1.93	0.75		
	Bottled water	105	1.91	0.64		

<sup>a</sup>As in Hu & Morton (2011), the categories shown below are the ones that show significant differences (at 0.05 level) from the group being considered.

<sup>b</sup>Cohen's d shows effect size for the difference between two means. In general, the value is calculated by dividing the difference between the two means with the standard deviation (or pooled standard deviation). Usually a Cohen's d of 0.20 means small effect, 0.50 is moderate effect, and 0.80 is large effect. Practically, a Cohen's d falling between 0.25 and 0.50 is considered significant (Cohen 1988; Hu & Morton 2011).

Pesticides (2.33). There was no difference in perceptions of pollutants potentially affecting surface and groundwater for those receiving their drinking water from private supplies or public supplies – rural water districts. Pathogens (bacteria, viruses, germs) were generally viewed as a low threat to water quality; however, those receiving their drinking water primarily from public supplies – rural water districts believed that pathogens were significantly less of a problem for surface or groundwater quality in their area than those who used bottled water. Both those who get their primary drinking water from public supplies – municipal or bottled water were more likely to be concerned with pharmaceuticals (antibiotics, personal care products) affecting local surface or groundwater than those receiving their drinking water from private supplies. Those who received their drinking water from bottled water (2.19) were more concerned with petroleum products affecting the water quality in their area than those receiving their drinking water from private supplies (1.76).

The greatest differences in perceptions of pollutants affecting water quality are between those who obtain their drinking water from private supplies and those drinking bottled water and their perception of potential pollution by product and waste water from mining (Cohen's d = 0.72) and salinity (Cohen's d = 0.70).

## DISCUSSION AND CONCLUSION

Using data from surveys administered in 2008 and 2014, this manuscript assesses public attitudes and perceptions regarding drinking water. Most respondents reported that they believe their drinking water is of high quality, with 81.4% responding that they believe their tap water is safe to drink. An even larger number, 92.1%, of those receiving their water from private sources believe their tap water is safe. Conversely, only 57.0% of respondents who consume bottled water as their primary source of drinking water believe their tap water is safe to drink. Both municipal and rural water district public water systems are regulated, maintained, and under rigorous monitoring and testing requirements. Private water wells have no requirements to be tested or monitored to ensure safe drinking water quality, and yet those receiving their primary drinking water from private supplies are more frequently confident that their tap drinking water is safe.

Kreutzwiser *et al.* (2011) found that complacency was a significant barrier for well owners testing their water, and that experiencing problems was what motivated well owners to test. As expected, fewer of those receiving their drinking water primarily from bottled water believe



their tap water is safe. Furthermore, research has shown that perceived risk of unsafe drinking water is what drives consumers to buy bottled water as their primary drinking water source (Anadu & Harding 2000; Hu *et al.* 2011). However, studies have shown that the common belief that bottled water is safer than tap water may not be accurate (Lalumandier & Ayers 2000; Raj 2005). Overall, almost a quarter of the respondents (23.5%) indicated that bottled water is their primary drinking water source. Results indicated that females (78.4%) were less likely to feel their drinking water was safe than were males (84.1%), and those 65 years and older were the age group most likely to respond that their water was safe (88.2%). Perhaps experience of drinking water from private supplies for many years with no noticeable health issues results in the older group perceiving their water to be safer than it may be, as Craun *et al.* (2010) reported that drinking water disease outbreaks have increased for private water sources.

Those receiving their primary drinking water from private supplies are consuming the least regulated water and yet are the most certain that their water is safe to drink. Several factors that may influence this perception are those indicating their primary source of drinking water was private supply were much more likely to have a water treatment system for their home than those receiving their primary drinking water from public supplies – municipal ( $p < 0.0001$ ) and public supplies – rural water district ( $p < 0.01$ ) sources. Having a water treatment system could give private well owners a false sense of security. For example, water softeners are a common treatment system for private water well users, but do not address the bacteriological issues that can occur for up to one-third of private well owners (DeSimone & Hamilton 2009) and also do not address other potential contaminants that may be of concern. Private water supplies should be tested regularly, at least annually, for fecal coliform or *Escherichia coli*. According to the results of the present survey, more than 65% of Texans receiving their primary drinking water from private supplies (usually their private water well) have never had their water supply tested. This figure is substantially lower than other studies where 65% (Hexemer *et al.* 2008) and 75% (Kreutzwiser *et al.* 2011) of private well owners responded that they tested their water annually.

As expected, those receiving their primary drinking water from private supplies tested their water significantly more (34.4%,  $p < 0.0001$ ) than those receiving their primary drinking water from public sources. Respondents who received their primary drinking water from public water supplies may not have personally initiated testing the tap water in their home, but because regular testing is required for public water systems, their water was being regularly tested by the supplier.

As shown in Figure 1, few respondents (4.6% to 11.1%) perceived groundwater quality to be poor in their area. A large majority (81.3%) of those primarily receiving their drinking water from private supplies believed groundwater in their area to be of good or excellent quality and only 3.1% did not know or did not have an opinion regarding local groundwater quality. These findings are in agreement with Benham *et al.* (2016), who reported the most common reason for no action taken by private well owners to protect their water supply was due to perceptions of no problems with their water system. In contrast, those receiving their primary source of drinking water from public supplies – municipal (43.6%) and public supplies – rural water districts (57.6%) believed area groundwater to be of good or excellent quality, and almost 40% of those receiving their primary drinking water from public supplies – municipal sources had no opinion or did not know the quality of groundwater in the area. As also suggested by Boellstorff *et al.* (2013) for the southern region of the United States, the results of the present survey indicate a significant need for expanded water resource education and outreach programs for the Texas urban sector, including information regarding groundwater quality and local drinking water sources. As Gholson (2017a) reports that the water resource topic of greatest interest to Texans living within city limits was ‘Protecting Public Drinking Water Supplies’, this type of water resource educational programming should be well received by urban audiences. In addition, although the 2014 Texas Integrated Report developed by the TCEQ (Texas Commission on Environmental Quality 2014) confirms that the most frequent parameter resulting in impairment of Texas waterbodies is bacteria (pathogens), only 26.3% of respondents believed or suspected that pathogens were a pollutant of concern and 73.7% indicated they don’t know, or know suspected pathogens are not a

problem. As many watershed protection plans and total maximum daily load efforts in Texas aim to address bacteria loads and impairments at least partially through public engagement and the adoption of appropriate best management practices, it is important for the public to be informed about the impact of pathogens on water quality.

Further analysis of perceptions of pollutants potentially affecting drinking water quality indicated that those who get their primary drinking supply from bottled water or from public supplies – municipal were more likely to believe that pollution had occurred than those who get their drinking water from private or public supplies – rural water districts. These results were similar to those reported by [Hu & Morton \(2011\)](#) and [Borisova \*et al.\* \(2013\)](#) comparing perceptions of water quality expressed by urban and rural residents. In particular, those living in urban areas were more likely than those living outside city limits to believe that agriculturally related potential pollutants such as Pesticides, Fertilizer/Nitrates, and Fertilizer/Phosphates could be negatively affecting water quality. It is unclear if city dwellers believe the sources of these pollutants are agricultural, or whether they also attribute them to pesticide and fertilizer uses within urban areas. To address residential uses, outreach programs targeting audiences concerned with lawn and turf management, as well as proper irrigation of lawns, should reduce excess run-off and pollutant transport to water supplies. [Gholson \(2017a\)](#) reported that water management for home and garden landscaping is of interest to almost 60% of those living within city limits.

Although elevated *E. coli* concentrations are the most common reason for streams to be considered impaired in Texas ([Texas Commission on Environmental Quality 2014](#)), generally, Texans did not perceive ‘pathogens (bacteria, viruses, germs)’ to affect water quality in their area. In addition, industrial activities such as mining and oil and gas operations that are associated with petroleum production and waste water from mining usually occurring in more rural areas, did not affect the level of concern for respondents who receive their drinking water from public supplies – rural water districts or private supplies. Although concerns regarding unconventional oil and gas operations impacting groundwater supplies have been reported in the popular press, pollutants associated with these activities

did not appear to be of concern to rural residents typically in these production areas.

[Gholson \(2017b\)](#) also reported that for well owners, typically those living outside city limits and engaged in farming, the water resource topic of greatest interest was private well protection. Because private well owners believe they have knowledge regarding the quality of their drinking water supply (groundwater) and feel more in control of the management of their water supply, they will frequently participate in outreach programs that encourage well testing and proper well maintenance, if made available ([Texas Water Resource Institute 2014](#)). As [Hu \*et al.\* \(2011\)](#) suggest, as well owners are more involved in the management of their water supply, they have greater trust in the quality and safety of the water, even though [Craun \*et al.\* \(2010\)](#) report that drinking water disease outbreaks associated with private wells are increasing as outbreaks associated with public systems decrease.

Regional and state-wide surveys are important tools for evaluating public perceptions and attitudes regarding water resources. Such evaluations identify knowledge gaps, topics of interest, and target audiences. For example, [Morris \*et al.\* \(2016\)](#) emphasized the importance of understanding the barriers private well owners may have to implementing best management practices so that effective outreach programs may be developed. In the future, further study of the characteristics of those receiving their primary drinking water from private supplies that focuses on perceptions, barriers, and factors influencing the likelihood of well owners testing their water and properly managing their private water well system would yield insights beneficial for developing appropriate programs encouraging water testing.

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