Article

Attitudes, Perceptions and Geo-Spatial Analysis of Water Quality and Individual Health Status in a High-Fracking Region

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Abstract: The expansion of unconventional oil and gas development (UD) across the US continues to be at the center of debates regarding safety to health and the environment. This study evaluated the water quality of private water wells in the Eagle Ford Shale within the context of community members perception. Community members (n=75) were surveyed regarding health status and perceptions of drinking water quality. Water samples (n=19) were collected from private wells and tested for a variety of water quality parameters. Of the private wells sampled, 8 had exceedences of MCLs for drinking water standards. Geospatial analysis showed the majority of well owners who did have exceedances self-reported their health status as poor. Surveys showed that the majority of respondents received their water from a municipal source and were significantly more distrustful of their water source than of those on private wells. The data also showed a high number of people self-reporting health problems without a healthcare provider's diagnosis. Attitudes and perceptions of water quality play an important role in the overall perceived health status of community members in high fracking regions, stressing the importance of transparency and communication by the UD industry.

Keywords: unconventional oil and gas development, health survey, anthropogenic impacts, perception.

1. Introduction

The expansion of unconventional oil and gas development (UD) across American shale basins, along with the economic, environmental, and human health implications, has kept the topics of hydraulic fracturing and UD in the center of a contentious debate over its safety. One of the major concerns regarding the various phases of UD involves the contamination of groundwater. In particular, the inherent nature of the UD process requires that it penetrate through aquifers in order to extract hydrocarbons from petroliferous strata, which represents a potential liability. The oil and gas industry exercises a number of precautionary measures to ensure that groundwater quality is not impacted by UD; however, the degradation of protective surface casing and cement have been identified as one of the major points of weakness throughout the lifetime of hydrocarbon production wells [1-3]. As such, it is not surprising that recent environmental investigations have revealed elevated levels of dissolved gases [4-6], heavy [7] and alkaline earth metals [8], and various volatile

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organic compounds (VOCs) [9-12] in groundwater overlying unconventional production zones. It has also been discovered that surface water [13] and soil [14] can be impacted by naturally-occurring radioactive material (NORM) in shale energy basins, a phenomenon that is likely attributed to surface spills and lapses in proper waste management.

Collectively, these findings, and how they are portrayed in the mainstream media, have had a significant influence on the general populace's perception [15, 16]. Personal views expressed through outlets such as Twitter [17] are a notable reflection of mass media's influence. As such, the latest peer-reviewed environmental and human health data pertaining to UD, in conjunction with provocative documentaries on the subject [18], have triggered the mobilization of concerned citizens to become more engaged with respect to the UD activities in their communities. Furthermore, Sangaramoorthy et al. [19] found that UD causes a disruption in local communities, affecting residents' sense of place and social identity through rapid transformations of their surroundings, causing stress within communities [19]. The unwavering energy development in the communities surveyed brought economic benefits, but nonetheless influenced residents' perceptions of UD as mostly negative due to potential environmental and health impacts. Additionally, Choma et al found a correlation between political ideology and knowledge regarding UD as key predictors of attitudes towards UD [20].

There are a number of rural communities and small towns in the Eagle Ford Shale in Texas. This shale hydrocarbon-producing geological formation of significant importance to Texas as it is capable of producing both natural gas and also more oil than other traditional shale plays. It stretches across Texas from the border with Mexico to East Texas, is approximately 50 miles wide and 400 miles long, and runs through 27 mostly rural counties. The Eagle Ford Shale contains a much higher carbonate shale percentage, close to 70%, which makes it more brittle and better for hydraulic fracturing activities, especially in the southern region [21].

This study takes place in Frio, County Texas, which located in the southern portion of the Eagle Ford Shale. This county has a population for approximately 19,820 people with the largest city being Pearsall, which has a population of approximately 9,150. [22]. There are currently 313 oil and gas producing leases, 57 producing operators, and 5,918 drilled wells in Frio County [23]. As of January 2019, there were 584, 836 barrels of oil and 867, 478 MCF of gas produced in the county. This south Texas region saw a fracking boom in 2009 followed by a bust in 2014, in which the communities in surrounding areas were greatly impacted. There has been a slow increase in production over the last year or so, however the region has not fully recovered. No previous water research had been done in this area and the community expressed an interest in learning more about the impacts of UD in their area.

In the work presented here, we assess groundwater quality in relation to quantifiable perceptions of UD and its potential impacts on the environment in the Eagle Ford shale region of southern Texas (Figure 1). Multiple reconnaissance efforts have recently evaluated groundwater quality throughout the Western Gulf Basin, revealing elevated levels of biogenic and thermogenic natural gas [24, 25], BTEX compounds [26], total organic carbon and various organic solvents [27] in private and public water supply wells. However, these data are the first to evaluate the prevalence of organic and inorganic groundwater constituents within the context of community members' perceptions, providing unique insight into the relationship between residents and the UD industry operations.

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2. Materials and Methods

2.1 Water well sampling

The groundwater samples analyzed in this study were collected from 19 private water wells in Frio County Texas within the Eagle Ford Shale region (Figure 1). Sampling sites were selected as a function of well owner participation and availability. We observed a large range in well depth (10-600m), which corresponded with samples being acquired from multiple hydrogeological strata (Gulf Coast, Queen City, Yegua, Mount Selma, and Carrizo aquifers). Well depth information was acquired for 17 of the 19 sampled wells from owner recollection and available documentation.

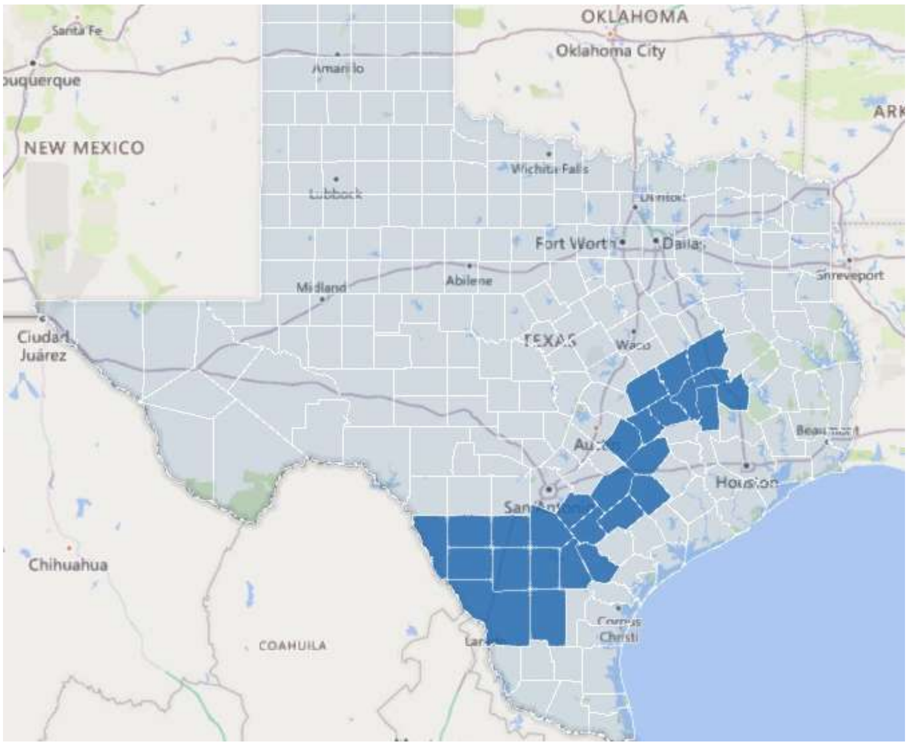

Figure 1. Map of Eagle Ford region in Texas

Water samples were collected as described previously [28]. Briefly, each water sample was collected as close to the water wellhead as possible, prior to any filtration or treatment systems. The water wells were purged until temperature, dissolved oxygen (DO), conductivity, TDS, salinity, pH, and ORP measurements, as determined by a YSI Professional Plus multi-parametric probe (YSI Incorporated, Yellow Springs, Ohio, USA), stabilized to ensure that the samples were representative of groundwater from their respective aquifers following USGS protocols (USGS, 2006). At each site, multiple samples were collected in 125-mL HDPE bottles with no headspace and held for no longer than 48 hours on ice before transport to The University of Texas at Arlington. Field blanks were prepared with deionized water and randomized duplicate samples were used for quality assurance. Samples collected for metal ions analysis were filtered and preserved with concentrated nitric acid to a final concentration of 2% v/v. Samples collected for organic ion analysis were preserved with chromatography grade chloroform to prevent microbial degradation. Samples collected for the analysis of volatile organic and semi-volatile organic compounds, TOC and total nitrogen were untreated [10, 11, 27, 29]. Select samples for dissolved hydrocarbons gases (methane, ethane, and propane) were collected using Isoflask containers as per Molofsky et al. [30]

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2.1 Water quality analysis

Methodology for chemical analyses followed those from our previous studies [10, 31] and included gas chromatography-mass spectrometry (GC-MS), headspace-gas chromatography (HS-GC), inductively coupled plasma - mass spectrometry (ICP-MS), and ion chromatography (IC). Specific organic chemical species were selected from a Congressional Report on hydraulic fracturing fluid ingredients [32], frequently listed components of UD fluids in the national hydraulic fracturing chemical registry (www.fracfocus.org), and from compounds identified in previous studies [10, 33]. These compounds included alcohols, aromatic compounds, aldehydes, amines, and chlorinated species. Whenever possible, we evaluated constituents in relation to their respective Primary or Secondary Maximum Contaminant Limits (MCL) as provided in the United States Environmental Protection Agency's Drinking Water Standards [34]. Information about locations of UD activity in the region was obtained from www.fracfocus.org and the Texas Railroad Commission, the governing body for oil and gas drilling in the state of Texas (www.rrc.state.tx.us).

2.2 Survey and Geospatial Analysis

The study population was a sample of 75 residents in Frio County, Texas, which is within the Eagle Ford Shale region. Eighteen of these residents agreed to have their water wells tested. One resident owned two wells, so there are 19 completed water tests. The residents who received water testing also took the survey and are included in the 75 responses. Data were collected in 2017 through a structured survey administered by interview. The survey included questions about attitudes, perceptions, and knowledge regarding water quality as well as an assessment of individual health status. The Institutional Review Board (IRB) of UTHealth School of Public Health (HSC-SPH-15-0954) approved the study. Participants were recruited by snowball and convenience sampling methods at local establishments, libraries and community-wide events. All survey responses were anonymous and geographic information was visualized as generalized points to prevent identification of participants. Descriptive analysis of the survey was intended to provide insight into the perceptions and attitudes of the participants. Geospatial analysis was performed in Excel and evaluated self-reported health status and well contamination levels. Additional inferential analysis investigated knowledge as a function of demographics. Several other qualitative variables were evaluated for independence. R statistical software was used to analyze the data along with several R packages including "lemon", "psych", "ggplot2", "knitr", and "scales" [35].

3. Results

3.1 Demographics.

The total number of participants in the study was 75 and all were residents living within the Eagle Ford Shale region. Of those 75 participants, 18 agreed to well water testing. Of the respondents, 37% of the participants were male, and the average age was 52. The modal ethnicity was Hispanic (60%), and the most commonly identified race was White (75%). Most participants (28%) had some college, with the second-most (25%) reporting as high school graduates. In terms of income, 29% earned more than $75K annually, while 25% earned less than $25K. Most respondents reported that they were in good, very good, or excellent health (75%). Only 10 individuals reported active or previous work in the oil and gas industry. On average, the number of household members was 2.84.

3.2. Health Status

Participants were asked if they had or had ever been diagnosed with several health conditions. Of the respondents, 39% self-reported asthma and skin disorders, and 40% self-reported cancer. These conditions were not MD-diagnosed at the same rate with only 17% indicating a formal

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diagnosis for asthma, 12% indicating a formal diagnosis for skin disorders, and 8% indicating a formal diagnosis for cancer. Table 1 shows percentages of self-reported and MD-diagnosed conditions.

Table 1. Self-reported and MD-diagnosed conditions of the respondents.

Condition	Self-Reported	MD Diagnosed
Asthma	39%	17%
Skin Disorder	39%	12%
Cancer	40%	8%
Oral Health	39%	9%
Mental Health	29%	8%
Hypertension	27%	43%
Heart Disease	20%	9%
Diabetes	19%	15%
Physical Handicap	16%	8%
Arthritis	13%	31%
Obesity	12%	15%

3.3 Descriptive Statistics: Water Questions

The respondents reported the primary source of drinking water was from a municipal source (59%), while 33% derived their water from private water wells. Most used city water for cooking (56%), while 35% never drank from the tap. Forty percent reported to have filtered their water. Sixty-one percent reported changes in taste, smell, and or appearance of their water in the last year. Many (39%) reported that the water smell changed in the last year. Of those respondents, 7 reported a sewage smell, and 5 reported a sulfur or "rotten egg" smell. Twenty percent reported that the water taste changed, with 6 of those indicating that the water tasted bad or odd. Forty-seven percent noted an unusual appearance during that time with 29 of those indicating that the water was yellow, brown, or rusty. Only 23% of respondents had their water tested; however, the majority did not know or report the results. Fifty-nine percent of respondents had concerns about their water, and 33% indicated they did not believe their water was safe to drink or safe to cook (Appendix A).

3.4 Descriptive Statistics: Well and Well Chemicals

Eighteen respondents agreed to have their well water tested. One respondent owned two wells, so a total of 19 tests were conducted. The average well age was approximately 38 years old, although it was impossible to determine the exact average, as many wells existed for generations. The average well depth was about 600 feet (median 445 feet) with a mean / median temperature of 27 degrees Celsius (80 degrees). On average, the dissolved oxygen was 2.67 mg/L (median 1.94), although the highest concentration was nearly 6 mg/L. Average conductance was 1.05 mS/cm (median 1.1), and the total dissolved solids was high for each well with an average of 684.26 mg/L (median 715). Average salinity was 0.52 mg/L (median 0.54) with an average pH of 7.24 (median 7.22), slightly alkaline. Chloride levels averaged 261.67 mg/L (median 183), above the EPA recommended 250 mg/L, with one well reading 1090 mg/L. The nitrate average across wells was 8.48 mg/L (median <.03, acceptable level =10 mg/L); however, one well exceeded the EPA recommended standard at 148 mg/L. Sulfates averaged 200 mg/L (median = 109, acceptable level=250 mg/L), but six wells exceeded the EPA recommended levels. One well exceeded the strontium allowable maximum contaminant level (MCL), and another well had high levels of methanol, ethanol, and isopropyl alcohol. Table 2 provides the descriptive statistics for the well and parameters measured.

Table 2. Descriptive statistics for the wells sampled and associated parameters measured

	N	Mean	Median	sd	Min	Max
Age	14	38.64	30	28.54	3	80
Depth (ft)	16	597.31	445	510.22	50	1650
Temp (°C)	19	26.86	27.7	3.42	17.3	31.2
DO (mg/L)	19	2.67	1.94	1.76	0.6	6.13
Specific Conductance (mS/cm)	19	1.05	1.1	.20	.72	1.52
TDS (mg/L) 500mg/L	19	684.26	715	131.66	468	988
Salinity (mg/L)	19	0.52	0.54	0.10	0.35	0.77
pH, 6.5-8.5	19	7.24	7.22	0.58	6.02	8.29
ORP (mV)	19	-87.61	-110.4	81.61	-169.2	143.1
TN (mg/L)	19	1.56	0.9	2.52	0.19	11.6
Chloride	19	261.67	183	270.81	11.6	1090
Nitrate	19	8.48	<0.03	33.86	0.03	148
Sulfate	19	199.81	109	221.09	7.56	847

Eight of the 18 (44%) wells had chemical or biological contamination above the EPA drinking water limits, while the remaining 11 (56%) were within standards. Of the 8 wells, two also had biological contamination (see 3.5 for a discussion). A list of the exceedances of drinking water standards for each of the wells is presented in Table 3.

Table 3. List of wells that had exceedances of drinking water standards and the parameters in bold that exceeded US EPA standards.

	Chloride mg/L	Nitrate mg/L	Sulfate mg/L	Strontium mg/L	Methanol	Ethanol	Isopropyl Alcohol
Well 1	**1,090**	**148**	**847**	3.944	0	0	0
Well 2	**447**	0.03	**278**	3.664	0	0	0
Well 3	**404**	0.03	**549**	1.532	0	0	0
Well 4	**581**	1.25	**251**	**4.994**	0	0	0
Well 5	**431**	0.03	198	1.596	0	0	0
Well 6	211	0.03	117	2.780	**150**	**20**	**90**
Well 7	**475**	0.03	**506**	2.273	0	0	0
Well 8	**392**	0.03	**335**	0.345	0	0	0

3.5 Descriptive Statistics: Well Biological Contamination

The EPA goal for maximum coliforms in water is zero, therefore no coliforms should be found in drinking water samples. All 19 samples showed presence of bacteria [28]. However, bacteria from fecal sources (*E. coli C. amalonaticus*) that could present a serious health risk were found in only two

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samples. One of the wells with fecal contamination is located near a septic tank that is most likely contaminating the water well. The other well was surrounded by livestock, which could explain the origin of these coliforms. The other forms of bacteria found in the wells may have been naturally occurring and not necessarily harmful. Detailed description of bacteria found in the wells are previously reported [28].

3.6 Geospatial Analysis

One geospatial question was of specific interest to this study, is self-reported health status associated with water quality? Figure 3 is a combined heat map of the wells exceeding EPA drinking water standards (blue to green to black colors) with a heat map of self-reported health status from 1 to 5 (green to red) with red being indicative of poor health quality. From the map, it appears that the highest intensity clusters of poor health (middle of the figure) are surrounded by contaminated wells.

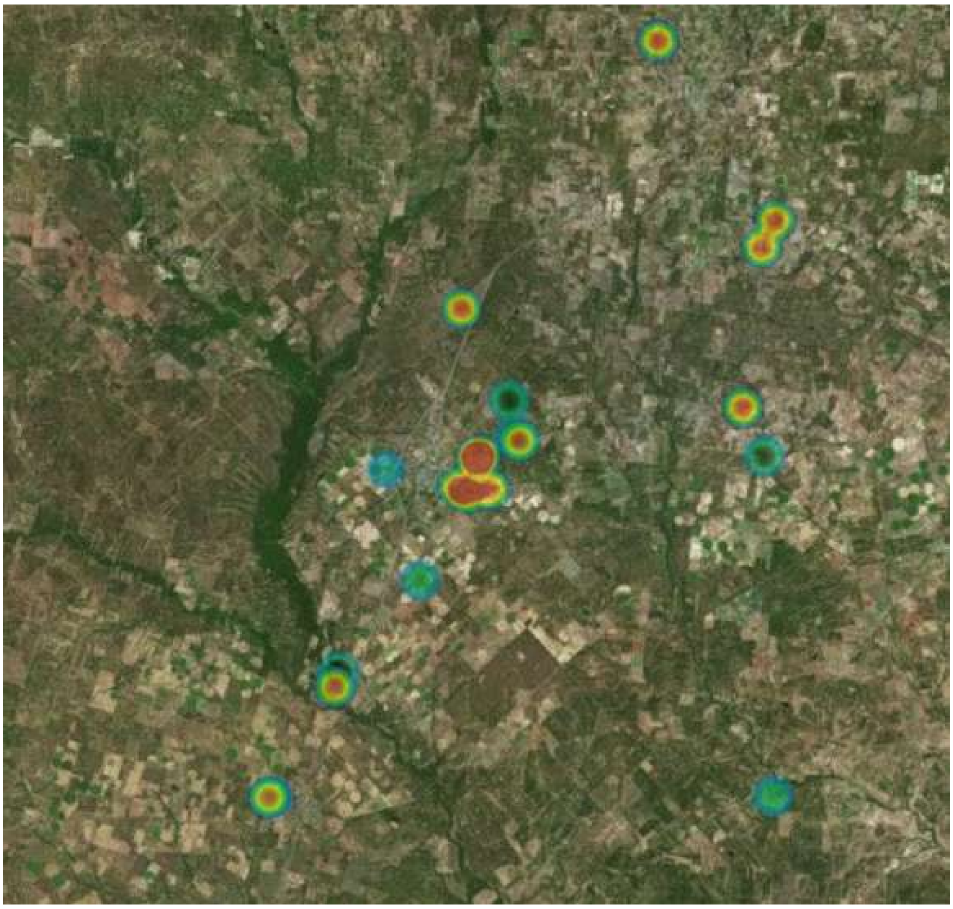

Figure 2. Health status as a function of the number of parameters exceeding EPA standards

3.8. Inferential Statistics

Due to the small sample size and selection bias, inferential analysis was restricted to a few interesting questions. Men were most like to allow well testing (χ^2=4.47, p=.03), and only 1 of 45 Hispanics allowed testing, a statistically significant finding by Fisher's Exact Test (FET p<.01). Hispanics were more likely to report "Fair" health (14 / 45) whereas only 2 others reported the same (2 / 30, FET p=.004). Self-reported health of both genders was not statistically different (p=.927), and gender assessment of water safety for drinking was also not statistically different (p=.307). Using Fisher's Exact Test and simulating the p-value (2000 replicates), health status and income were associated (p=.026); however, education level and assessment of drinking water safety were not related (p=.747). Drinking water safety and health status were also not associated based on FET (p=.9303).

In regards to perceptions and sources of drinking water, an FET suggested that the perceived safety of drinking water was a function of the respondents' drinking water source (p<.001). Interestingly, 12 out of 17 (71%) on city water indicated that they believed their water was not at all safe or only a little bit safe (versus quite a bit and extremely safe) to drink. Only 1 out of 14 individuals (7%) who used a private well for water indicated that the water was not at all safe. Also of interest, 35 out of 44 (80%) of the individuals who reported drinking purchased water indicated that their tap water was not at all safe or only a little bit safe. Table 4 shows those results.

Table 4. Results of the cross-tabulation of safety of water to drink versus source of drinking water

Confidence of home tap water safety to drink	City Water	Private Well	Purchased Water	Totals
Not at all	2	1	22	25
A little bit	10	0	13	23
Quite a bit	3	6	7	16
Extremely	2	7	2	11
Totals	17	14	44	75

4. Discussion

Perceptions about drinking water quality are rather complex. According to deFranca Doria, most people are influenced to believe their water is safe to drink based on organoleptic properties (mostly taste/smell) and risk perceptions. These risks might include perceived contamination of water by chemicals, past health problems and trust of the water supplier or system [36]. The majority of the surveyed participants in this study did not have confidence in the quality of their drinking water with many reporting changes in smell and appearance. Although most reported to be overall in good health, there was a much higher perception of their negative health outcomes than recorded by their healthcare providers. We can speculate that several factors contribute to these perceptions, the most prominent ones are the lack of trust in the UD industry, secret ingredients in the chemicals used, and living near an industrial process that harms some people in the communities where they operate.

The lack of trust by residents is most likely derived from the poor reputation that the UD industry developed in relation to their environmental stewardship, which leads to blaming the industry for negative health and environmental outcomes [37]. Another reason for distrust may be a result of the 2005 Energy Policy Act (i.e., the Halliburton loophole), which allows UD companies to keep their chemicals as a proprietary and undisclosed mix, keeping the public in the dark about which products are being used near their communities [38,39]. This lack of information also creates knowledge gaps for healthcare providers who are unable to test for sensitivities or exposure to harmful chemicals if they do not know what they are looking for, possibly missing a diagnose. This lack of transparency and knowledge can lead to increased fear.

Roughly 17 million Americans live within one mile of an active oil and/or gas well, and are exposed to pollution related to fracking [40,41].There have been reports of residents in heavy UD areas developing health problems caused by industrial activities related to UD [10,11,42-49] heightening the perception and awareness of these outcomes in their community. Mental health disturbances were self-reported at 29% vs. only 8% diagnosed, which could be due to the lack of access or stigma related to seeking mental health care. It is incredibly challenging to test health outcomes that may be a result of exposure because of lifestyle, genetics, access to care, and the lack

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of funding for longitudinal studies, since some of the health issues might only develop after repeated exposure [50].

5. Conclusions

Perceptions and attitudes regarding higher risks of health problems or environmental contaminations in high-fracking regions may be a result in the lack of communication and transparency within the industry with communities. Although this study did not find any substantial concerns with the wells tested, the community still has great concerns regarding water and the impact that local UD activities may have on its quality and subsequently their own health. Improving UD operational activities that prevent public health risks and communicating those improvements to community members is one possible way to improve relationships between UD companies and local residents. Increased monitoring for air and water contaminants coming from UD activities and making that data available could also improve attitudes and perceptions while helping to improve environmental health literacy and risk communications.

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Appendix A

Drinking Water Use and Perception

Main Source of Drinking Water in the Home	**N (%)**
City Water Supply	17 (22.7)
Private Well	14 (18.7)
Grocery Store/Purchased Water	44 (58.7)
Home Have Private Well	
Yes	25 (33.3)
No	50 (66.7)
Main Source of Water for Cooking in the Home	
City Water Supply	42 (56.0)
Private Well	16 (21.3)
Grocery Store/Purchased Water	13 (17.3)
Other	3 (4.0)
Didn't answer	1 (1.3)
Frequency of Drinking Tap Water (Filtered or Unfiltered)	

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Always	19 (25.3)
Often	13 (17.3)
Rarely	17 (22.7)
Never	26 (34.7)
Filter Tap Water Before Drinking It	
Yes	30 (40.0)
No	26 (34.7)
Never	15 (20.0)
Don't know	1 (1.3)
Missing	3 (4.0)
Changes to Water in the Past Year	
Smell	
Yes	29 (38.7)
No	41 (54.7)
Don't Use Tap Water	3 (4.0)
Don't know	2 (2.7)
Taste	
Yes	15 (20.0)
No	40 (53.3)
Don't use tap water	15 (20.0)
Don' t know	4 (5.3)
Appearance	
Yes	35 (46.7)
No	34 (45.3)
Don't use tap water	1 (1.3)
Don't know	3 (4.0)
Tap Water at Home Tested	
Yes	17 (22.7)
No	57 (77.6)
Don't know	1 (1.3)
Concern About the Tap Water	
Yes	44 (58.7)
No	30 (40.0)
Don't know	1 (1.3)
Confidence of Safe Tap Water at Home	
Not at all	25 (33.3)
A little bit	23 (30.7)
Quite a bit	16 (21.3)
Extremely	11 (14.7)
Confidence of Safe Tap Water to Cook with at Home	
Not at all	13 (17.3)
A little bit	18 (24.0)
Quite a bit	25 (33.3)

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Extremely	18 (24.0)
Missing	1 (1.3)

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