

1 Article

2 Attitudes, Perceptions and Geo-Spatial Analysis of 3 Water Quality and Individual Health Status in a 4 High-Fracking Region

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14 **Abstract:** The expansion of unconventional oil and gas development (UD) across the US continues
15 to be at the center of debates regarding safety to health and the environment. This study evaluated
16 the water quality of private water wells in the Eagle Ford Shale within the context of community
17 members' perceptions. Community members (n=75) were surveyed regarding health status and
18 perceptions of drinking water quality. Water samples from respondent volunteers (n=19) were
19 collected from private wells and tested for a variety of water quality parameters. Of the private wells
20 sampled, 8 had exceedances of MCLs for drinking water standards. Geospatial descriptive analysis
21 illustrates the distributions of the well exceedance as well as the well owners' overall health status.
22 Surveys showed that the majority of respondents received their water from a municipal source and
23 were significantly more distrustful of their water source than of those on private wells. In many
24 cases, there are statistically significant differences between self-reported, provider undiagnosed
25 conditions and self-reported, provider diagnosed conditions. Attitudes and perceptions of water
26 quality may play an important role in the overall perceived health status of community members in
27 high fracking regions.

28 **Keywords:** unconventional oil and gas development; health survey; anthropogenic impacts;
29 perception
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31 1. Introduction

32 The expansion of unconventional oil and gas development (UD) across American shale basins,
33 along with the economic, environmental, and human health implications, has kept the topics of
34 hydraulic fracturing and UD in the center of a contentious debate over its safety. One of the major
35 concerns regarding the various phases of UD involves the contamination of groundwater. In
36 particular, the inherent nature of the UD process requires that it penetrate through aquifers in order
37 to extract hydrocarbons from petroliferous strata, which represents a potential liability. The oil and
38 gas industry exercises a number of precautionary measures to ensure that groundwater quality is not
39 impacted by UD; however, the degradation of protective surface casing and cement have been
40 identified as one of the major points of weakness throughout the lifetime of hydrocarbon production
41 wells [1-3]. As such, it is not surprising that recent environmental investigations have revealed
42 elevated levels of dissolved gases [4-6], heavy [7] and alkaline earth metals [8], and various volatile
43 organic compounds (VOCs) [9-12] in groundwater overlying unconventional production zones. It

44 has also been discovered that surface water [13] and soil [14] can be impacted by naturally-occurring
45 radioactive material (NORM) in shale energy basins, a phenomenon that is likely attributed to surface
46 spills and lapses in proper waste management.

47 Collectively, these findings, and how they are portrayed in the mainstream media, have had a
48 significant influence on the general populace's perception [15, 16]. Personal views expressed through
49 outlets such as Twitter [17] are a notable reflection of mass media's influence. As such, the latest peer-
50 reviewed environmental and human health data pertaining to UD, in conjunction with provocative
51 documentaries on the subject [18], have triggered the mobilization of concerned citizens to become
52 more engaged with respect to the UD activities in their communities. Furthermore, Sangaramoorthy
53 et al. [19] found that UD causes a disruption in local communities, affecting residents' sense of place
54 and social identity through rapid transformations of their surroundings, causing stress within
55 communities [19]. The unwavering energy development in the communities surveyed brought
56 economic benefits, but nonetheless influenced residents' perceptions of UD as mostly negative due
57 to potential environmental and health impacts. Additionally, Choma et al found a correlation
58 between political ideology and knowledge regarding UD as key predictors of attitudes towards UD
59 [20].

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

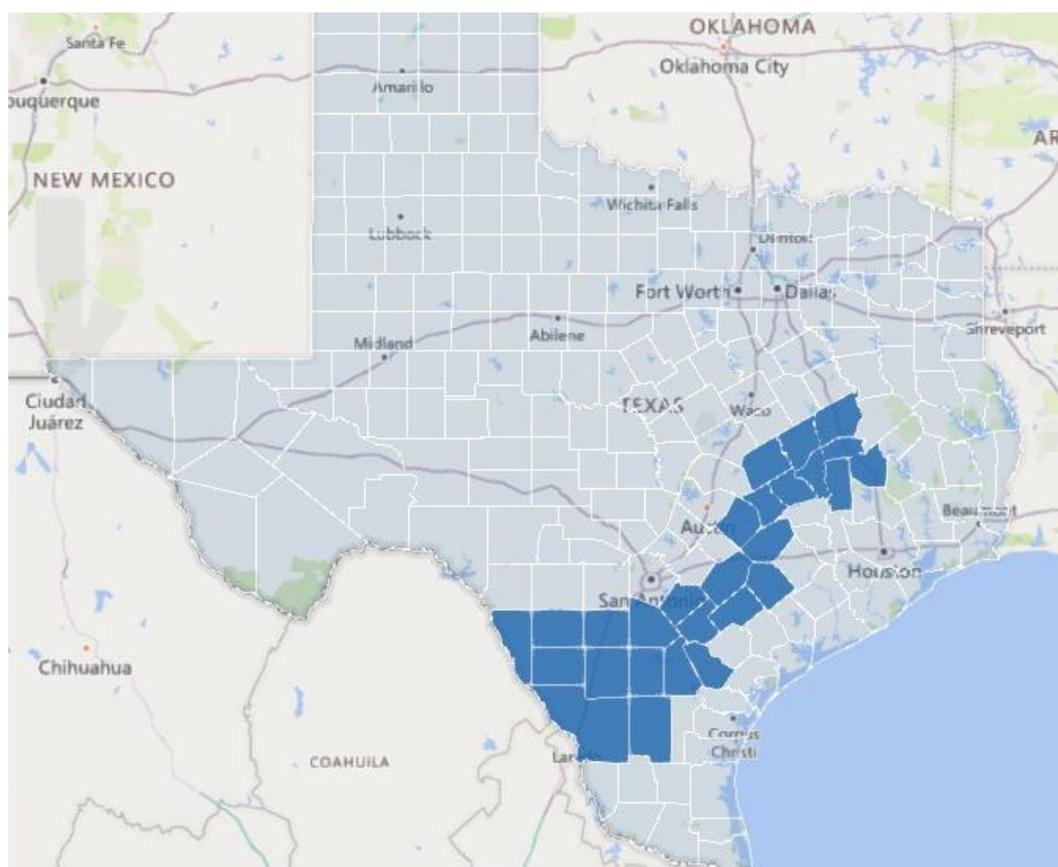
67 This study takes place in Frio, County Texas, which is located in the southern portion of the
68 Eagle Ford Shale. This county has a population for approximately 19,820 people with the largest city
69 being Pearsall, which has a population of approximately 9,150. [22]. There are currently 313 oil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

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

85 **2. Materials and Methods**

86 *2.1. Water Well Sampling*

87 The groundwater samples analyzed in this study were collected from 19 private water wells in
88 Frio County Texas within the Eagle Ford Shale region (Figure 1). Sampling sites were selected as a
89 function of well owner participation and availability. We observed a large range in well depth (10-
90 600m), which corresponded with samples being acquired from multiple hydrogeological strata (Gulf
91 Coast, Queen City, Yegua, Mount Selma, and Carrizo aquifers). Well depth information was acquired
92 for 17 of the 19 sampled wells from owner recollection and available documentation.



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Figure 1. Map of Eagle Ford region in Texas (all counties in blue, Eagle Ford counties in dark blue).

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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

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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

120 Protection Agency's Drinking Water Standards [34]. Information about locations of UD activity in the
121 region was obtained from www.fracfocus.org and the Texas Railroad Commission, the governing
122 body for oil and gas drilling in the state of Texas (www.rrc.state.tx.us).

123 2.2. Survey and Geospatial Analysis

124 The study population was a sample of 75 residents in Frio County, Texas, which is within the
125 Eagle Ford Shale region. Eighteen of these residents agreed to have their water wells tested. One
126 resident owned two wells, so there are 19 completed water tests. The residents who received water
127 testing also took the survey and are included in the 75 responses. Data were collected in 2017 through
128 a structured survey administered by interview. The survey included questions about attitudes,
129 perceptions, and knowledge regarding water quality as well as an assessment of individual health
130 status. The Institutional Review Board (IRB) of UTHealth School of Public Health (HSC-SPH-15-
131 0954) approved the study. Participants were recruited by snowball and convenience sampling
132 methods at local establishments, libraries and community-wide events. All survey responses were
133 anonymous and geographic information was visualized as generalized points to prevent
134 identification of participants. Descriptive analysis of the survey was intended to provide insight into
135 the perceptions and attitudes of the participants. Geospatial analysis was performed in Excel and
136 evaluated self-reported health status and well contamination levels. Additional inferential analysis
137 investigated knowledge as a function of demographics. Several other qualitative variables were
138 evaluated for independence. R statistical software was used to analyze the data along with several
139 R packages including "lemon", "psych", "ggplot2", "knitr", and "scales" [35].

140 3. Results

141 3.1. Demographics.

142 The total number of participants in the study was 75 and all were residents living within the
143 Eagle Ford Shale region. Of those 75 participants, 18 agreed to well water testing. Of the respondents,
144 37% of the participants were male, and the average age was 52. The modal ethnicity was Hispanic
145 (60%), and the most commonly identified race was White (75%). Most participants (28%) had some
146 college, with the second-most (25%) reporting as high school graduates. In terms of income, 29%
147 earned more than \$75K annually, while 25% earned less than \$25K. Most respondents reported that
148 they were in good, very good, or excellent health (75%). Only 10 individuals reported active or
149 previous work in the oil and gas industry. On average, the number of household members was 2.84.

150 The Census Bureau estimates the male population of Frio county at 49.3%, the median age as
151 31.7, and the Hispanic population at nearly 80%, somewhat different from the sample statistics [22].
152 There is little reason to expect that the voluntary sample in the high-fracking region would represent
153 the entire county population due to sub-geographic area selection and survey opt-out prevalent in
154 various groups.

155 3.2. Health Status

156 Participants were asked if they had or had ever been diagnosed with several health conditions.
157 Of the respondents, 39% self-reported asthma and skin disorders, and 40% self-reported cancer.
158 These conditions were not provider-diagnosed (based on the respondents' reporting) at the same rate
159 with only 17% indicating a formal diagnosis for asthma, 12% indicating a formal diagnosis for skin
160 disorders, and 8% indicating a formal diagnosis for cancer. Table 1 shows percentages of self-
161 reported and MD-diagnosed conditions.

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163 **Table 1.** Self-reported, provider undiagnosed and self-reported, provider-diagnosed conditions of
164 the respondents are shown.

| Condition | Self-Reported, Provider Undiagnosed Conditions | Self-Reported, Provider Diagnosed Conditions | National Prevalence |
|-------------------|--|--|---------------------|
| Asthma | 39% | 17% | 8% [36] |
| Skin Disorder | 39% | 12% | 27% [37] |
| Cancer | 40% | 8% | 38% [38] |
| Oral Health | 39% | 9% | 47% [39] |
| Hypertension | 27% | 43% | 29% [40] |
| Heart Disease | 20% | 9% | 11.5% [41] |
| Diabetes | 19% | 15% | 9.4% [42] |
| Physical Handicap | 16% | 8% | 12.6% [43] |
| Obesity | 12% | 15% | 39.8% [44] |

165 3.3. Qualitative Perceptions

166 Respondents of the survey provided qualitative perceptions of the taste, smell, look and
167 concerns about the water. Many comments were associated with these criteria; however, 10 out of
168 75 respondents provided specific concerns that are likely associated with fracking. Table 2 shows
169 those comments.

170 **Table 2.** Qualitative responses likely associated with fracking activities without spelling corrections

171 Respondent Comments Linked to Fracking

- 172 • sewage/butane smell-gas smell
- 173 • after oil explosion/smell odd
- 174 • improved smell/sulfur smell decreased. (*Fracking*) Well blew out 5 miles away in the past year (SW
175 Pearsall)
- 176 • oil in water/rust
- 177 • oil in water/sweres exploded and changed water
- 178 • city has problems with pipes, sewer pipes, afraid they leak. Also, fracking, heard waste going into
179 river. Maybe that's causing cancer
- 180 • what am I drinking...metals?
- 181 • drilling chemicals
- 182 • pollutants-lead and H2S
- 183 • snce fracking started, some of that stuff getting into my water. Earthquakes, casing breaks. Just don't
184 know. "we can live without oil, but we can't live without drinking water"

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188 3.3. Descriptive Statistics: Water Questions

189 The respondents reported the primary source of drinking water was from a municipal source
190 (59%), while 33% derived their water from private water wells. Most used city water for cooking
191 (56%), while 35% never drank from the tap. Forty percent reported to have filtered their water. Sixty-
192 one percent reported changes in taste, smell, and or appearance of their water in the last year. Many
193 (39%) reported that the water smell changed in the last year. Of those respondents, 7 reported a
194 sewage smell, and 5 reported a sulfur or "rotten egg" smell. Twenty percent reported that the water
195 taste changed, with 6 of those indicating that the water tasted bad or odd. Forty-seven percent noted
196 an unusual appearance during that time with 29 of those indicating that the water was yellow, brown,

197 or rusty. Only 23% of respondents had their water tested; however, the majority did not know or
 198 report the results. Fifty-nine percent of respondents had concerns about their water, and 33%
 199 indicated they did not believe their water was safe to drink or safe to cook (Appendix A).

200 3.4. Descriptive Statistics: Well and Well Chemicals

201 Eighteen respondents agreed to have their well water tested. One respondent owned two wells,
 202 so a total of 19 tests were conducted. The average well age was approximately 38 years old
 203 (median=30), although it was impossible to determine the exact average, as many wells existed for
 204 generations. The average well depth was about 600 feet (median 445 feet) with a mean / median
 205 temperature of 27 degrees Celsius (80 degrees Fahrenheit). On average, the dissolved oxygen was
 206 2.67 mg/L (median 1.94), although the highest concentration was nearly 6 mg/L. Average
 207 conductance was 1.05 mS/cm (median 1.1), and the total dissolved solids was high for each well with
 208 an average of 684.26 mg/L (median 715). Average salinity was 0.52 mg/L (median 0.54) with an
 209 average pH of 7.24 (median 7.22), slightly alkaline. Chloride levels averaged 261.67 mg/L (median
 210 183), above the EPA recommended 250 mg/L, with one well reading 1090 mg/L. The nitrate average
 211 across wells was 8.48 mg/L (median <.03, acceptable level =10 mg/L); however, one well exceeded the
 212 EPA recommended standard at 148 mg/L. Sulfates averaged 200 mg/L (median = 109, acceptable
 213 level=250 mg/L), but six wells exceeded the EPA recommended levels. One well exceeded the
 214 strontium allowable maximum contaminant level (MCL), and another well had high levels of
 215 methanol, ethanol, and isopropyl alcohol. Table 3 provides the descriptive statistics for the well and
 216 parameters measured.

217 **Table 3.** 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 | .03 | 33.86 | 0.03 | 148 |
| Sulfate | 19 | 199.81 | 109 | 221.09 | 7.56 | 847 |

218 A study from Fontenot et al. [45] evaluated 100 wells in the vicinity of natural gas extraction sites
 219 in the Barnett shale formation of Texas. Table 4 provides descriptive statistics from this study for
 220 identical variables to support comparison. The samples appear to be similar.

221 **Table 4.** Descriptive statistics for the wells sampled and associated parameters measured.

| | N | Mean | Median | sd | Min | Max |
|-------------------------------------|----------|-------------|---------------|-----------|------------|------------|
| Depth (ft) | 100 | 336.58 | 300.00 | 240.00 | 29 | 1400 |
| Temp (°C) | 100 | 23.71 | 23.11 | 2.58 | 20.03 | 33.63 |
| DO (mg/L) | 100 | 3.99 | 2.98 | 3.98 | .00 | 34 |
| Specific Conductance (mS/cm) | 100 | 0.88 | .74 | .48 | .303 | 2.97 |
| TDS (mg/L) 500mg/L | 100 | 578.45 | 500.00 | 32.03 | 200.00 | 1900.00 |
| Salinity (mg/L) | 100 | .44 | .37 | .26 | .15 | 1.55 |
| pH, 6.5-8.5 | 100 | 7.91 | 7.69 | 0.90 | 5.47 | 9.33 |

222 Another study of well water quality in northwest Texas by Hudak [46] provides the basis for
 223 comparison of chlorides, nitrates, and sulfates. Table 5 provides those findings. In this study,
 224 chlorides were lower, and sulfates were higher than in the current sample.

225 **Table 5.** Descriptive statistics for the wells sampled and associated parameters measured.

| | N | Median | Min | Max |
|-------------------|-----|--------|------|-------|
| Depth (ft) | 597 | 280 | 30 | 900 |
| Chloride | 590 | 38.45 | 2.24 | 2400 |
| Nitrate | 19 | 11.2 | <.02 | 566.7 |
| Sulfate | 19 | 109 | 7.56 | 847 |

226 Eight of the 18 (44%) wells had chemical or biological contamination above the EPA drinking
 227 water limits, while the remaining 11 (56%) were within standards. Of the 8 wells, two also had
 228 biological contamination (see 3.5 for a discussion). A list of the exceedances of drinking water
 229 standards for each of the wells is presented in Table 6.

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232 **Table 6.** List of wells that had exceedances of drinking water standards and the parameters in bold that
 233 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 |

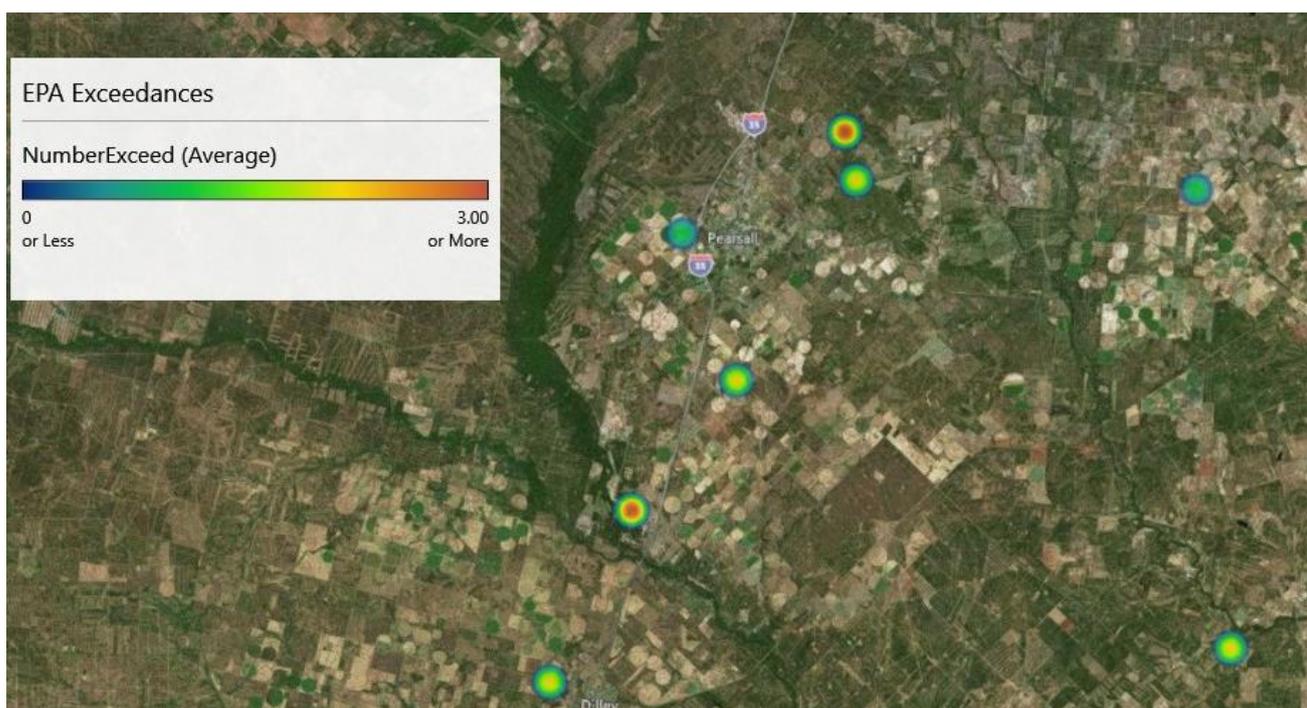
234 3.5 Descriptive Statistics: Well Biological Contamination

235 The EPA goal for maximum coliforms in water is zero, therefore no coliforms should be found
 236 in drinking water samples. All 19 samples showed presence of bacteria [28]. However, bacteria from
 237 fecal sources (*E. coli C. amalonaticus*) that could present a serious health risk were found in only two
 238 samples. One of the wells with fecal contamination is located near a septic tank that is most likely
 239 contaminating the water well. The other well was surrounded by livestock, which could explain the
 240 origin of these coliforms. The other forms of bacteria found in the wells may have been naturally
 241 occurring and not necessarily harmful. Detailed description of bacteria found in the wells are
 242 previously reported [28].

243 3.6. Geospatial Analysis

244 Figure 2 is heat map of the wells exceeding EPA drinking water Figure 3 is a heat map of health
 245 status. The intent of these maps is to provide insights into the geographic distributions of both
 246 variables.

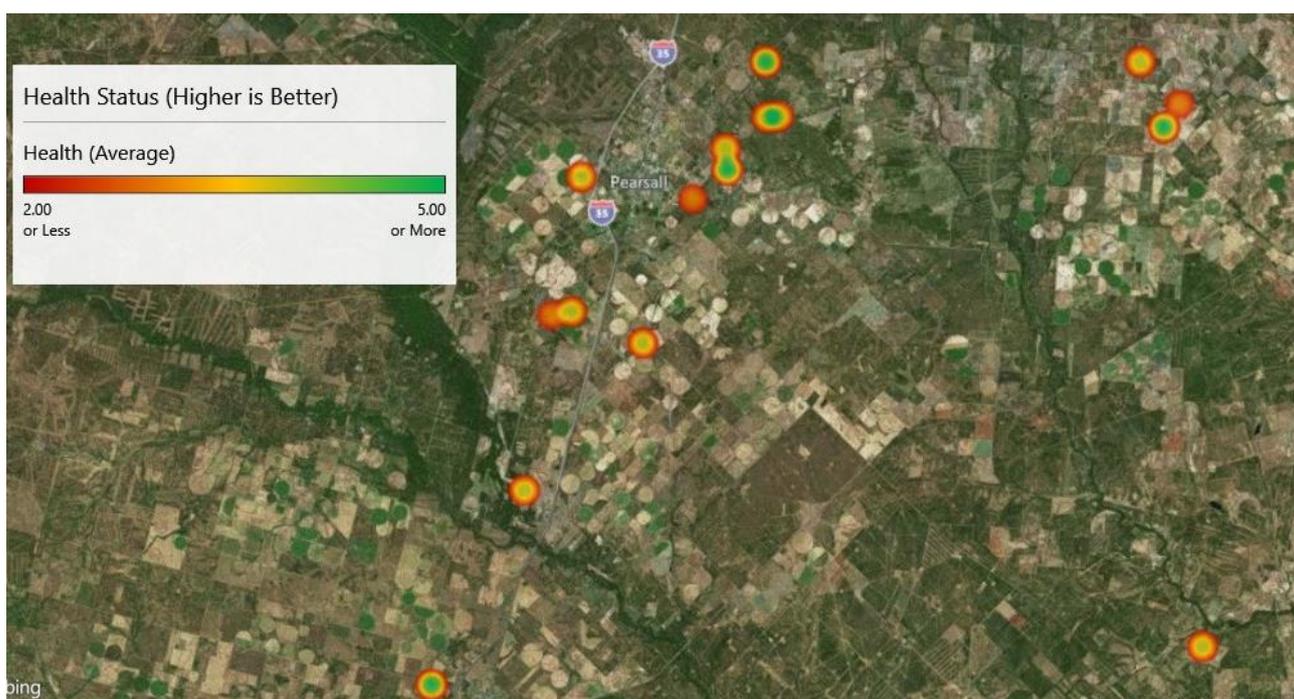
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Figure 2. EPA Exceedances Heat Map



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Figure 3. Health Status Heat Map

252 3.8. Inferential Statistics

253 Due to the small sample size and selection bias, inferential analysis was restricted to a few
 254 interesting questions. Men were most likely to allow well testing ($\chi^2=4.47$, $p=.03$), and only 1 of 45
 255 Hispanics allowed testing, a statistically significant finding by Fisher's Exact Test (FET $p<.01$).
 256 Hispanics were more likely to report "Fair" health (14 / 45) whereas only 2 others reported the same
 257 (2 / 30, FET $p=.004$). Self-reported health of both genders was not statistically different ($p=.927$), and
 258 gender assessment of water safety for drinking was also not statistically different ($p=.307$). Using
 259 Fisher's Exact Test (FET) and simulating the p-value (2000 replicates), health status and income were

260 associated ($p=.026$); however, education level and assessment of drinking water safety were not
 261 related ($p=.747$). Drinking water safety and health status were also not associated based on FET
 262 ($p=.9303$).

263 Well tests were linked to the respondents. Of the 11 respondents without exceedances, 3
 264 reported water concerns (27%) whereas 3 of 7 with exceedances reported water concerns (43%).
 265 Possibly due to the small sample size, tests of the odds ratio ($OR=2.0$) were not statistically significant
 266 ($p=.63$).

267 The correlation between the number of exceedances and health status was positive, $r= 0.36$.
 268 Although not statistically significant at the $\alpha=.05$ level ($p=.12$), the sample size is necessarily limited
 269 to those permitting a well test (voluntary).

270 Point-biserial correlational analysis of the haversine distance between respondents and well
 271 exceedances revealed four statistically significant relationships {Well 11, Well 12, Well 13, Well 14}
 272 with correlations of {.47, .53, .50, .48} and p-values of {0.04, 0.02, 0.03, 0.04}, respectively. These
 273 correlations suggest that as distance from these wells increase, there is a higher likelihood of
 274 exceedances. Well 16 was significant at the $\alpha = .10$ level with a p-value of .06 and a correlation of
 275 $-.44$, indicating that some evidence exists that proximity to this well increases the probability of
 276 exceedances.

277
 278 With respect to perceptions and sources of drinking water, an FET suggested that the perceived
 279 safety of drinking water was a function of the respondents' drinking water source ($p<.001$).
 280 Interestingly, 12 out of 17 (71%) on city water indicated that they believed their water was not at all
 281 safe or only a little bit safe (versus quite a bit and extremely safe) to drink. Only 1 out of 14 individuals
 282 (7%) who used a private well for water indicated that the water was not at all safe. Also, 35 out of 44
 283 (80%) of the individuals who reported drinking purchased water indicated that their tap water was
 284 not at all safe or only a little bit safe. Table 4 shows those results.
 285

286 Tests of proportional differences between self-reported conditions and provider-reported
 287 conditions revealed statistical significance in most cases (Table 7). Interestingly, 22% of
 288 respondents self-reported presence of cancer without a provider's diagnosis.
 289

290 **Table 7.** Self-reported, provider undiagnosed and self-reported, provider-diagnosed conditions of
 291 the respondents are shown. Asterisks indicate statistically significant differences at the $\alpha=.05$ level.

| Condition | Self-Reported, Provider Undiagnosed Conditions | Self-Reported, Provider Diagnosed Conditions | Difference in Proportions |
|-------------------|--|--|---------------------------|
| Asthma | 39% | 17% | 22%* |
| Skin Disorder | 39% | 12% | 27%* |
| Cancer | 40% | 8% | 32%* |
| Oral Health | 39% | 9% | 30%* |
| Hypertension | 27% | 43% | -16%* |
| Heart Disease | 20% | 9% | 11%* |
| Diabetes | 19% | 15% | 4% |
| Physical Handicap | 16% | 8% | 8%* |
| Obesity | 12% | 15% | -3% |

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293

294 **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 |

295 When combining the bottom two categories and top two categories for “confident of home tap
 296 water safety to drink,” an FET test actually demonstrated that those relying on municipal water or
 297 purchased water assessed that it was less safe to drink than those relying on private wells for
 298 drinking ($p < .001$, Odds Ratio, OR=44.32, 95% CI={5.8, 2003.5}) and cooking ($p < .003$, OR=13.20, 95%
 299 CI={1.8, 589.9}). A reason behind this interesting finding may be that all but one well owner use
 300 filtration systems, whereas only 7 of 17 filtered the municipal water. (The single well owner who did
 301 not filter used purchased water and avoided drinking the well water.)

302 **4. Discussion**

303 Perceptions about drinking water quality are rather complex. According to deFranca Doria, most
 304 people are influenced to believe their water is safe to drink based on organoleptic properties (mostly
 305 taste/smell) and risk perceptions. These risks might include perceived contamination of water by
 306 chemicals, past health problems and trust of the water supplier or system [47]. The majority of the
 307 surveyed participants in this study did not have confidence in the quality of their drinking water
 308 with many reporting changes in smell and appearance. Although most reported to be overall in good
 309 health, there was a much higher perception of their negative health outcomes than recorded by their
 310 healthcare providers. We can speculate that several factors contribute to these perceptions, the most
 311 prominent ones are the lack of trust in the UD industry, secret ingredients in the chemicals used, and
 312 living near an industrial process that harms some people in the communities where they operate.

313 Interestingly, many respondents in the study indicated the presence of disease without a
 314 provider’s diagnosis. In the case of cancer, 22% of the respondents stated the presence of this disease
 315 without provider diagnosis. It is possible that this result is associated with skin cancers, which are
 316 quite prevalent in South Texas [48].

317 While this study provides data regarding water quality, it cannot link these findings directly to
 318 fracking activities. Perceptions of water quality, however, may be influenced by fracking activities.
 319 As an example, one respondent stated the following: “city has problems with pipes, sewer pipes,
 320 afraid they leak. Also, fracking, heard waste going into river. Maybe that's causing cancer.” Another
 321 respondent stated the following: “since fracking started, some of that stuff getting into my water.
 322 Earthquakes, casing breaks. Just don't know. we can live without oil, but we can't live without
 323 drinking water.” These statements likely reflect the influence of fracking on these two respondents’
 324 perspectives.

325 Another limitation of this study is that the sample size is small. While the survey provides
 326 sufficient data for inferential analysis, the small number of wells sampled limits the power of this
 327 study. Further, the voluntary nature of the study may result in biased responses that do not reflect
 328 the entirety of the population. No other studies are available for evaluating the effects of this
 329 potential bias.

330 The lack of trust by residents is most likely derived from the poor reputation that the UD
 331 industry developed in relation to their environmental stewardship, which leads to blaming the
 332 industry for negative health and environmental outcomes [49]. Another reason for distrust may be a
 333 result of the 2005 Energy Policy Act (i.e., the Halliburton loophole), which allows UD companies to
 334 keep their chemicals as a proprietary and undisclosed mix, keeping the public in the dark about
 335 which products are being used near their communities [50,51]. This lack of information also creates

336 knowledge gaps for healthcare providers who are unable to test for sensitivities or exposure to
 337 harmful chemicals if they do not know what they are looking for, possibly missing a diagnose. This
 338 lack of transparency and knowledge can lead to increased fear.

339 Roughly 17 million Americans live within one mile of an active oil and/or gas well, and are
 340 exposed to pollution related to fracking [52,53]. There have been reports of residents in heavy UD
 341 areas developing health problems caused by industrial activities related to UD [10,11,54-61]
 342 heightening the perception and awareness of these outcomes in their community. Mental health
 343 disturbances were self-reported at 29% vs. only 8% diagnosed, which could be due to the lack of
 344 access or stigma related to seeking mental health care. It is incredibly challenging to test health
 345 outcomes that may be a result of exposure because of lifestyle, genetics, access to care, and the lack
 346 of funding for longitudinal studies, since some of the health issues might only develop after repeated
 347 exposure [62]

348 5. Conclusions

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

359 **Acknowledgements:** This research was partially supported by donations from concerned mineral
 360 rights owners to the Collaborative Laboratories for Environmental Analysis and Remediation at the
 361 University of Texas at Arlington. These efforts were supported by charitable donations by the Earth
 362 Day Texas organization. The project described was also supported by the National Center for
 363 Advancing Translational Sciences, National Institutes of Health, through the Institute for Integration
 364 of Medicine & Science/Clinical and Translational Science Award (IIMS/CTSA) UL1 TR001120. The
 365 content is solely the responsibility of the authors and does not necessarily represent the official views
 366 of the NIH. The authors would also like to thank the community members of the Translational
 367 Advisory Board in Frio County, faculty mentors at UTHealth and the South Texas AHEC for their
 368 support.

369 Appendix A

370 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) | |
| 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) |
| Extremely | 18 (24.0) |
| Missing | 1 (1.3) |

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