Environmental Research 167 (2018) 550–557

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

A community-based evaluation of proximity to unconventional oil and gas wells, drinking water contaminants, and health symptoms in Ohio

Elise G. Elliott[a], Xiaomei Ma[a], Brian P. Leaderer[a], Lisa A. McKay[a], Courtney J. Pedersen[a], Chang Wang[a], Christopher J. Gerber[a], Thomas J. Wright[b], Andrew J. Sumner[b], Mairead Brennan[b], Genevieve S. Silva[a], Joshua L. Warren[a], Desiree L. Plata[b], Nicole C. Deziel[a,*]

[a] Yale School of Public Health, Yale University, 60 College Street, New Haven, CT 06510, USA
[b] Yale School of Engineering and Applied Science, Yale University, 17 Hillhouse Avenue, New Haven, CT 06510 USA

ARTICLE INFO

Keywords:
Environmental exposure
Human health
Hydraulic fracturing
Unconventional oil and gas
Water contaminants

ABSTRACT

Over 4 million Americans live within 1.6 km of an unconventional oil and gas (UO&G) well, potentially placing them in the path of toxic releases. We evaluated relationships between residential proximity to UO&G wells and (1) water contamination and (2) health symptoms in an exploratory study. We analyzed drinking water samples from 66 Ohio households for 13 UO&G-related volatile organic compounds (VOCs) (e.g., benzene, disinfection byproducts [DBPs]), gasoline-range organics (GRO), and diesel-range organics. We interviewed participants about health symptoms and calculated metrics capturing proximity to UO&G wells. Based on multivariable logistic regression, odds of detection of bromoform and dibromochloromethane in surface water decreased significantly as distance to nearest UO&G well increased (odds ratios [OR]: 0.28–0.29 per km). Similarly, distance to nearest well was significantly negatively correlated with concentrations of GRO and toluene in ground water ($r_{Spearman}$: −0.40 to −0.44) and with concentrations of bromoform and dibromochloromethane in surface water ($r_{Spearman}$: −0.48 to −0.50). In our study population, those with higher inverse-distance-squared-weighted UO&G well counts within 5 km around the home were more likely to report experiencing general health symptoms (e.g. stress, fatigue) (OR: 1.52, 95%CI: 1.02–2.26). This exploratory study, though limited by small sample size and self-reported health symptoms, suggests that those in closer proximity to multiple UO&G wells may be more likely to experience environmental health impacts. Further, presence of brominated DBPs (linked to UO&G wastewater) raises the question of whether UO&G activities are impacting drinking water sources in the region. The findings from this study support expanded studies to advance knowledge of the potential for water quality and human health impacts; such studies could include a greater number of sampling sites, more detailed chemical analyses to examine source attribution, and objective health assessments.

1. Introduction

Unconventional oil and gas (UO&G) development, the extraction of oil and gas from low-permeability rock formations using directional drilling and hydraulic fracturing, has rapidly expanded in the United States with an estimated 25,000–35,000 UO&G wells drilled and hydraulically fractured from 2011 to 2014 (U.S. Environmental Protection Agency, 2015). Consequently, more than 4 million people live within 1.6 km (one mile) of an UO&G well (Czolowski et al., 2017) and more than 9 million people have drinking water sources within 1.6 km of an UO&G well (U.S. Environmental Protection Agency, 2015), potentially placing them in the path of hazardous agents. Data are critically needed to better understand potential water quality and health impacts in communities near UO&G development.

Pathways of groundwater and surface water contamination from UO&G activities include leaks from deteriorating or improperly constructed UO&G wells, surface spills, and improper wastewater storage and disposal (U.S. Environmental Protection Agency, 2015). Chemicals used in or produced by hydraulic fracturing include biocides (Kahrilas et al., 2015), endocrine disruptors (Kassotis et al., 2014), reproductive/developmental toxicants (Elliott et al., 2017a), and carcinogenic compounds (Elliott et al., 2017b). Several studies have detected more than a dozen health-relevant compounds in ground and surface water near UO&G extraction sites (Drollette et al., 2015; Fontenot et al., 2013; Hildenbrand et al., 2015; Llewellyn et al., 2015; McMahon et al., 2017). However, they represent only a small fraction of the hazardous

* Correspondence to: Yale School of Public Health, 60 College Street, New Haven, CT 06510, USA.
E-mail address: nicole.deziel@yale.edu (N.C. Deziel).

https://doi.org/10.1016/j.envres.2018.08.022
Received 9 April 2018; Received in revised form 23 July 2018; Accepted 15 August 2018
Available online 17 August 2018
0013-9351/

chemicals known to exist in hydraulic fracturing fluids and UO&G wastewaters. Additionally, existing studies have primarily been conducted in Pennsylvania, Texas, Colorado, and West Virginia, while Ohio remains under-studied, and the types and concentrations of contaminants may vary geographically. Though studies have examined the chemical constituents of drinking water samples, they often use distance to nearest well as a surrogate for proximity to UO&G activity, but do not consider the presence of multiple UO&G wells surrounding a drinking water source. Further, they generally do not have individual-level demographic or health information to complement the water monitoring data.

Epidemiologic studies of UO&G development have observed associations with increased risk of perinatal outcomes (Casey et al., 2016; Currie et al., 2017; McKenzie et al., 2014; Stacy et al., 2015; Whitworth et al., 2017), self-reported dermal and respiratory irritation (Rabinowitz et al., 2015), asthma symptom exacerbations (Rasmussen et al., 2016), respiratory, migraine, and fatigue symptoms (Tustin et al., 2016), childhood leukemia (McKenzie et al., 2017), and increased hospitalization rates (Jemielita et al., 2015). These studies have relied on proximity-based metrics and models to assess potential exposure rather than on environmental or biological measurements. These models do capture proximity and density of multiple UO&G wells around the home, and often include other well attributes, such as production volume and well depth, as surrogates of UO&G activity (Allshouse et al., 2017; Rasmussen et al., 2016). Measurements in large epidemiologic investigations of UO&G development are not yet practical due to the lack of knowledge of specific etiologic agents and the varying sampling methods, analysis procedures, and costs required to examine the wide-ranging potential contaminants. However, there is a need to measure environmental contaminants to inform exposure and environmental health studies on UO&G development.

Our primary objective was to explore whether there were associations between residential proximity to UO&G wells and detection and concentrations of health-relevant drinking water contaminants in a community-based setting in Ohio. As a secondary objective, we evaluated whether there were relationships between residential UO&G proximity and prevalent health symptoms to complement the exposure assessment and obtain a preliminary indication of health status and concerns in the community.

2. Materials and methods

2.1. Study population

We recruited 66 residents of Belmont County, Ohio, the county with the highest number of permitted shale wells in Ohio (Fig. 1) (Ohio Department of Natural Resources, 2018), as part of the Ohio Water and Air Quality Study, a multi-media exposure and health study. Participants were recruited using mailed informational flyers, local newspaper and television news stories, and social media. Eligible participants were required to be: ≥ 21 years old, a head of household, and English-speaking. We enrolled participants living at varying distances to UO&G wells (Fig. 2), and preferentially enrolled participants with groundwater (private well or spring) as their primary drinking water source, as compared to surface water (municipal reservoirs or creek water). We prioritized groundwater sources because our proximity metrics would be most relevant for evaluating potential impacts, as these sources are co-located with the home, where drinking water samples were collected. We included homes serviced by surface water also because surface water may be vulnerable to UO&G activity either at the source or via the distribution system. Home visits were completed during June-August 2016. All participants provided informed consent prior to study activities. Protocols were approved by the Yale Institutional Review Board.

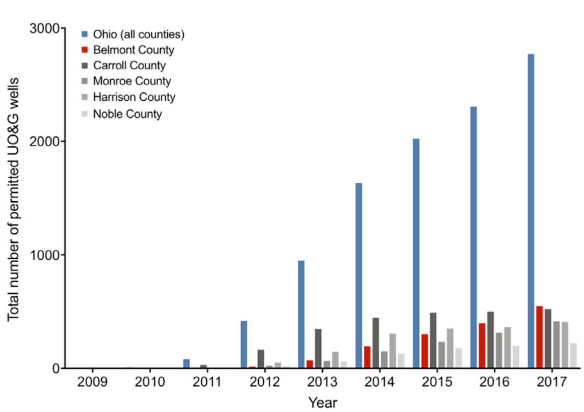

Fig. 1. Unconventional oil and gas (UO&G) well permits in Ohio over time. Total number of permitted UO&G wells in Belmont County (N [%]), by year: 2009: 2 (67%), 2010: 4 (44%), 2011: 5 (6%), 2012: 15 (4%), 2013: 70 (7%), 2014: 195 (12%), 2015: 302 (15%), 2016: 398 (17%), 2017: 548 (20%).

2.2. Interviewer-administered questionnaire

Trained interviewers queried participants about demographics and housing and drinking water source characteristics. Using a questionnaire adapted from a previous community health study (Rabinowitz et al., 2015), interviewers also asked participants about prevalent health symptoms to assess potential health concerns in the community. We considered health outcomes that could be related to environmental exposures and with relatively short latencies: respiratory (e.g., allergies, wheezing), dermal (e.g., skin rash ≥ 3 days, burning skin), neurologic (e.g., severe headaches, dizziness), gastro-intestinal (e.g., stomach ulcers, nausea), and general (e.g., stress, fatigue).

2.3. Residential proximity to UO&G Wells

ArcGIS 10.1 (ESRI, Redlands, CA) was used to geocode residential street addresses and calculate residential proximity to UO&G wells. We obtained data on latitude, longitude, and permit date of all “active” shale wells (in the drilling, drilled, or production phase at the time of the home visit) in Belmont County from the Ohio Department of Natural Resources (Ohio Department of Natural Resources, 2018). We constructed three proximity metrics based on the different types of metrics used in the geochemical and epidemiologic literature. We calculated distance to nearest active UO&G well (km), consistent with the geochemical literature identifying increased methane, metals, gasoline range organic compounds (GRO), and diesel range organic compounds (DRO) concentrations in drinking water samples 1–2 km from the nearest UO&G well (Drollette et al., 2015; Fontenot et al., 2013; Jackson et al., 2013; Osborn et al., 2011). We also calculated an inverse-distance weighted (IDW, Eq. (1)) well count and inverse-distance-squared weighted (ID^{2}W, Eq. (2)) well count for all wells within 5 km of a residence, similar to some of the epidemiologic literature (McKenzie et al., 2014; Stacy et al., 2015).

$$IDW\ well\ count = \sum_{i=1}^{n} \frac{1}{d_i} \tag{1}$$

$$ID^2W\ well\ count = \sum_{i=1}^{n} \frac{1}{d_i^2} \tag{2}$$

where distance (d) in km between the wellhead (i) to the maternal residence, and n is the number of UO&G wells within 5 km around the residence; giving more weight to wells closer to the residence and less weight to wells further from the residence. For use in sensitivity analyses, we calculated metrics specific to the drilling/drilled or production phases and explored all inverse-distance weighted metrics with alternative buffer sizes of 1 km and 2 km.