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Temporal variation in groundwater quality in the Permian Basin of Texas, a region of increasing unconventional oil and gas development

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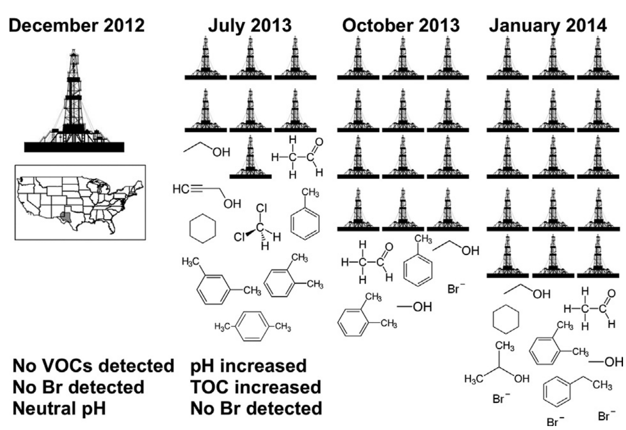
HIGHLIGHTS

- Multiple samples of groundwater quality over time during expanding oil exploration
- Dramatic fluctuations in chemical detections and pH over time
- Bromide concentrations increased with expansion of drilling activity.
- These data provide insight into the life span of possible contamination events.

GRAPHICAL ABSTRACT



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ABSTRACT

The recent expansion of natural gas and oil extraction using unconventional oil and gas development (UD) practices such as horizontal drilling and hydraulic fracturing has raised questions about the potential for environmental impacts. Prior research has focused on evaluations of air and water quality in particular regions without explicitly considering temporal variation; thus, little is known about the potential effects of UD activity on the environment over longer periods of time. Here, we present an assessment of private well water quality in an area of increasing UD activity over a period of 13 months. We analyzed samples from 42 private water wells located in three contiguous counties on the Eastern Shelf of the Permian Basin in Texas. This area has experienced a rise in

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UD activity in the last few years, and we analyzed samples in four separate time points to assess variation in groundwater quality over time as UD activities increased. We monitored general water quality parameters as well as several compounds used in UD activities. We found that some constituents remained stable over time, but others experienced significant variation over the period of study. Notable findings include significant changes in total organic carbon and pH along with ephemeral detections of ethanol, bromide, and dichloromethane after the initial sampling phase. These data provide insight into the potentially transient nature of compounds associated with groundwater contamination in areas experiencing UD activity.

1. Introduction

Previous groundwater studies in the Marcellus Shale formation in the Eastern United States attributed elevated levels of methane (Osborn et al., 2011), stray thermogenic gas (Jackson et al., 2013), brine (Warner et al., 2012), chloride and bromide (Warner et al., 2013) to unconventional oil and gas development (UD) activities, such as horizontal drilling and hydraulic fracturing. Two recent studies of groundwater quality in the Barnett Shale region revealed increased concentrations of arsenic, selenium, strontium (Fontenot et al., 2013), various alcohols, chlorinated species and BTEX (benzene, toluene, ethylbenzene and xylene) compounds in areas closest to UD activities (Hildenbrand et al., 2015). While these studies provide valuable information regarding the potential effects of UD on groundwater quality, the lack of baseline measurements before the onset of UD activities limits the power to draw definitive conclusions about environmental impacts. Furthermore, links between UD activity and the contamination of groundwater quality are currently tenuous due to the lack of full chemical disclosure and the need for oil and gas operators to protect proprietary information and trade secrets. Additionally, the majority of the chemicals used for UD activities are also used in numerous other industrial, agricultural, and residential activities, making contaminant sourcing difficult. Regardless of the source(s) of pollution, there are a number of public health concerns regarding the resilience of groundwater resources to contamination events given that groundwater is often used for drinking water, particularly in rural communities.

Energy production in the Permian Basin (spanning 223,000 km^2 and 52 counties in Texas and New Mexico) historically included conventional oil and gas drilling, but UD activity has increased dramatically since late 2010 with the advent of new techniques to extract oil and gas from formations such as the Cisco, Canyon, Ellenburger, Clear Fork, Strawn, Wolfcamp, and Cline Shale formations. The study area lies within the Great Plains of central Texas, a sub-humid region composed of aluvial terraces, deeply eroded, rugged topography, and a generally calcareous soil type derived from calcareous alluvial sediments of Cretaceous limestone (Shamburger, 1967). All private water wells in this study draw from the Edwards-Trinity Aquifer, which supplies water for irrigation, municipal, industrial, livestock, and private drinking use. The Edwards Trinity aquifer overlies the Santa Rosa Formation, a consolidated and cross-bedded stratum rich in micaceous and carbonaceous material (Shamburger, 1967). The contact between the two layers is unconformable, as is the contact with the underlying Permian strata (see Supporting Information) (Shamburger, 1967). The Edwards-Trinity aquifer consists principally of shallow marine limestone, dolostone, and evaporites with secondary porosity imparted from fractures and solution cavities (upper part) and interbedded fluvial sand, sandstone, and clay (lower part) deposited during the Cretaceous Period (Bush et al., 1994).

The objective of this study was to obtain measurements of groundwater quality from private water wells before, during, and after the widespread implementation of UD activities on the Eastern Shelf of the Permian Basin. We used a broad suite of analytical chemistry methods to measure groundwater composition during four sampling events over a span of 13 months in order to assess groundwater quality in this region over time as well as to document the occurrence and persistence of chemicals thought to be associated with UD activities. Here, we report on the change in groundwater composition during the study period as UD activities increased.

2. Materials and methods

2.1. Sampling

Samples from private water wells located on the Eastern Shelf of the Permian Basin were collected during four separate sampling events as the number of UD wells increased (Fig. 1). The number of sampling sites in this study was subject to private landowner participation in a unique study area that was a) engaged in the early onset of UD activity and b) projected to facilitate additional subsequent activity. The frequency of sampling events and number of water wells sampled during each phase were also subject to well owner availability. Each water well was sampled at least twice, with the exception of two water wells that could be sampled only once due to logistical problems such as plumbing leaks and deteriorated windmills. To assess density of UD activity for each sampling phase, we counted the number of wells in the three contiguous counties making up the study area and determined the number of UD wells within a 5 km radius of each sampling site.

Information regarding the age, depth, flow, and piezometric levels of the water wells was extremely limited; however, the well owners reported that a majority of the wells were over 60 years old and approximately 60 m deep. Conventional shallow oil and gas drilling has also occurred in this region since the 1920s, and past operations could also have impacted groundwater in the study area. However, we used multiple sampling events as UD activity progressed in order to evaluate only variation in water quality from the onset of unconventional oil and gas development.

Each water sample was collected as close to the wellhead as possible, bypassing any filtration or treatment systems. The water wells were purged for a minimum of 30 min until on-site water quality parameter measurements stabilized to ensure samples were representative of groundwater from the Edwards-Trinity Aquifer. Temperature, dissolved oxygen (DO), conductivity (EC), total dissolved solids (TDS), salinity, pH, and oxidation-reduction potential (ORP) were measured on-site with a YSI Professional Plus multi-parametric probe (YSI Incorporated, Ohio, USA). At each site, multiple samples were collected in 200-mL HDPE bottles with no headspace and held for no longer than 48 h at 4 °C 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 purposes. Samples collected for metal ion analysis were preserved with nitric acid to a $pH < 2$. Samples collected for anion analysis were preserved with chloroform and frozen to prevent microbial degradation. Samples collected for the analysis of volatile organic and semi-volatile organic compounds, total organic carbon and total nitrogen, were untreated (Hildenbrand et al., 2015).

2.2. Analysis

Chemical analyses included gas chromatography–mass spectrometry (GC–MS), headspace-gas chromatography (HS-GC), inductively coupled plasma-mass spectrometry and -optical emission spectroscopy (ICP-MS and ICP-OES), ion chromatography, and the determination of total organic carbon analysis, and total nitrogen (TN). Specific organics