Applied Geography 60 (2015) 165–174

Contents lists available at ScienceDirect

Applied Geography

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

Spatial distribution of unconventional gas wells and human populations in the Marcellus Shale in the United States: Vulnerability analysis

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ARTICLE INFO

Article history:
Available online 17 April 2015

Keywords:
Hydraulic fracturing
Environmental justice
Vulnerability
LISA

ABSTRACT

Modern forms of drilling and extraction have recently led to a boom in oil and gas production in the U.S. and stimulated a controversy around its economic benefits and environmental and human health impacts. Using an environmental justice paradigm this study applies Geographic Information Systems (GIS) and spatial analysis to determine whether certain vulnerable human populations are unequally exposed to pollution from unconventional gas wells in Pennsylvania, West Virginia, and Ohio. Several GIS-based approaches were used to identify exposed areas, and a t-test was used to find statistically significant differences between rural populations living close to wells and rural populations living farther away. Sociodemographic indicators include age (children and the elderly), poverty level, education level, and race at the census tract level. Local Indicators of Spatial Autocorrelation (LISA) technique was applied to find spatial clusters where both high well density and high proportions of vulnerable populations occur. The results demonstrate that the environmental injustice occurs in areas with unconventional wells in Pennsylvania with respect to the poor population. There are also localized clusters of vulnerable populations in exposed areas in all three states: Pennsylvania (for poverty and elderly population), West Virginia (for poverty, elderly population, and education level) and Ohio (for children).

Introduction

Background

Worldwide, oil and natural gas are principle sources of energy. Advances in drilling and extraction technology, a supportive domestic energy policy, and economic developments have recently stimulated an increase in oil and gas production in the United States. Hydraulic fracturing, introduced in the late 1940s, is one of these advanced technologies (Kolb, 2013). It is a process of drilling and injecting fluids (water mixed with sand and other components) into the ground at a high pressure in order to fracture rocks to release oil or natural gas trapped inside (Mooney, 2011). Hydraulic fracturing technology enables the extraction of oil and natural gas from “unconventional reservoirs” such as shale rock and is currently used in 17 states in areas with shale deposits, often referred to as “plays”. The most well-known are the Barnett, Marcellus, Utica and Bakken (Kolb, 2013). Another recent technology called directional or horizontal drilling turns a downward drill bit 90° and enables it to continue drilling within a shale layer. Combinations of these two technologies with other technologies (multi-well pads and cluster drilling) have led to a boom in natural gas production in the United States. Natural gas production has been steadily increasing in the country since 2005; in 2013, the US generated 20.6% of the world's gas, making it the top natural gas producer (BP, 2014).

Water is the key ingredient in the fracturing fluid, but there are other ingredients that have very specific purposes in the process. For example, hydrochloric acid is used to initiate cracks in shale, glutaraldehyde and ammonium bisulfite to reduce or inhibit corrosion, polyacrilamide to minimize friction between water and pipe, silica to hold fractures open and allow gas to escape, and isopropanol to increase viscosity of the fluid (Kolb, 2013). The complete chemical makeup of the hydraulic fracturing fluid has long been legally understood as a trade secret by the companies, but some chemicals were recently disclosed due to increasing pressure from federal and state regulations and the public (Waxman, Markey, & Degette, 2011).

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http://dx.doi.org/10.1016/j.apgeog.2015.03.011
0143-6228/

While proponents of this new technology argue that it brings new employment opportunities and stimulates local economic activity, its numerous opponents are voicing strong concerns about ground and surface water contamination, risks to air quality from the liquid waste lagoons, and serious health effects (CCFE, 2010; CEH, 2013). The controversy between the economic effects and the environmental and health impacts of hydraulic fracturing has generated a constant stream of research publications and reports from public health organizations and advocacy groups (Nolon & Polidoro, 2012).

Several studies have explored the potential impacts of hydraulic fracturing on public health (Colborn, Kwiatkowski, Schultz, & Bachran, 2011; Ferrar et al., 2013; Howarth, Ingraffea, & Engelder, 2011; Finkel & Hays, 2013; Goldstein, Kriesky, & Pavliakova, 2012; McKenzie et al., 2014; Witter et al., 2013) and concluded that there is evidence of potential health risks resulting from harmful levels of pollutants in air and water. Air pollution resulting from drilling, processing, gas leaks, and diesel emissions from transportation includes nitrogen oxides, particulate matter (Litovitz, Curtright, Abramzon, Burger, & Samaras, 2013), and ozone (Kemball-Cook et al., 2010; Olaguer, 2012).

One of the main sources of pollution is water that returns to the surface. It may be contaminated with radiation that naturally occurs in the rock (Radium-226 and radon) and salts of barium, which can then enter streams and rivers (Warner, Christie, Jackson, & Vengosh, 2013). Three studies also found systematic evidence for methane contamination of drinking water associated with shale-gas extraction (Darrah, Vengosh, Jackson, Warner, & Poreda, 2014; Jackson et al., 2013; Osborn, Vengosh, Warner, & Jackson, 2011). Hydraulic fracturing process and injection of used water back into the ground, can also lead to increased seismic activity in areas that have never had earthquakes (Kolb, 2013).

Clearing of land for well pads and construction of access roads lead to heavy traffic and noise pollution and substantially changes traditional life styles of residents in rural areas (EA, 2013; Kolb, 2013). Noise pollution can lead to hypertension, sleep disturbance, and cardiovascular disease (Babisch, Beule, Schust, Kersten, & Ising, 2005; Van Kempen et al., 2002). These communities also experience an influx of temporary workers, which often leads to social disruption, increase in crime, and a change in social norms and behaviors (CEH, 2013). A recent study documented self-reported health impacts and mental and physical health stressors perceived to result from natural gas development (Ferrar et al., 2013). Stress was the most commonly reported health effect, with sources of stress listed as “denied or provided false information”, “corruption”, “concerns/complaints ignored” and “being taken advantage of”; the lack of transparency between the hydraulic fracturing industry and the local communities is one of the root causes of stress (Ferrar et al., 2013).

Theoretical framework

While multiple studies analyzed potential health effects of hydraulic fracturing, few investigated socio-demographic characteristics of population disproportionately exposed to its effects. Our study attempts to add to this body of literature and analyzes this issue using an environmental justice framework. “Environmental justice” is defined by U.S. EPA as “the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations, and policies” (http://www.epa.gov/environmentaljustice/basics/index.html) and refers to the fair distribution of environmental benefits and burdens. It argues for equal access to a clean environment and equal protection from possible environmental harm, irrespective of race, income, class, or any other differentiating feature of socioeconomic status (Cutter, 1995). In 1987, the Unites Church of Christ published a report analyzing the relationship between waste site locations and race in the Unites States (Commission for Racial Justice, 1987). This report, along with U.S. Government Accounting Office report (GAO, 1983), helped mobilize the environmental justice movement and shaped a new research framework within geography, sociology, and other disciplines. Environmental justice research focuses on examining a hazardous facility in relationship to demographic characteristics such as percent poor or percent minority, and many studies have found evidence of significant positive correlation between race, educational attainment or poverty and emissions from hazardous facilities (Boone, Fragkias, Buckley, & Grove, 2014; Osiecki, Kim, Chukwudozie, & Calhoun, 2013; Sicotte & Swanson, 2007). U.S. Environmental Protection Agency recently attempted to conduct an environmental justice screening in the context of studying the potential impacts of hydraulic fracturing on drinking water resources, but found that data available at the time of the study was insufficient (EPA, 2012).

For more than a decade, Geographic Information Systems (GIS) and associated spatial analytical techniques have been used to examine environmental injustice issues (Fisher, Kelly, & Romm, 2006; Maantay, 2007; Mennis, 2002). Spatial coincidence and proximity analysis are two commonly used methods to determine exposure potential in environmental justice research (Chakraborty & Maantay, 2011; Maantay, 2007). The spatial coincidence method simply treats populations within a certain geographic unit containing a polluting facility as potentially exposed to environmental burdens, while the proximity analysis assumes populations living within a certain specified distance of the polluting facility are impacted, and those outside the buffer are not impacted. The proximity analysis method more adequately captures the potential for exposure than the spatial coincidence method (Chakraborty & Maantay, 2011), and many GIS-based environmental justice studies use it to determine the exposure potential (Maranville, Ting, & Zhang, 2009; Miranda, Keating, & Edwards, 2008).

Our study aims to contribute to the environmental justice literature and determine whether certain vulnerable groups are unequally exposed to pollution from unconventional gas wells. Traditionally, environmental justice studies analyze unequal exposure based on race, poverty and educational attainment of the population. One recent study concluded that more epidemiological studies are needed on vulnerable populations that live, work and play in shale gas development areas (Shonkoff, Hays, & Finkel, 2014). The study included children and the elderly, along with pregnant women and those with compromised immune systems. Children are more susceptible to health effect of pollution because they take in 20–50% more air than adults (Kleinman, 2000), have faster metabolic rates and immature and developing body systems (Lauver, 2012). Elderly people are more susceptible to air pollution due to ageing (Bentayeb et al., 2012) and because air pollution can aggravate existing health conditions (EPA, 2009).

Our study objective is to use GIS and spatial statistics to analyze relationships between the proximity and the density of unconventional gas wells and the characteristics of potentially affected populations at the Census tract level in the Marcellus Shale area. More specifically, our research question is: are unconventioanl gas wells disproportionately located in the communities with higher proportions of vulnerable populations.

Study area

The Marcellus Shale is a rock formation that underlies the Southern Tier and Finger Lakes regions of New York, northern and western Pennsylvania, eastern Ohio, and most of West Virginia. It