Wastewater Disposal Wells, Fracking, and Environmental Injustice in Southern Texas

Jill E. Johnston, PhD, Emily Werder, MSPH, and Daniel Sebastian, BS

Objectives. To investigate race and poverty in areas where oil and gas wastewater disposal wells, which are used to permanently inject wastewater from hydraulic fracturing (fracking) operations, are permitted.

Methods. With location data of oil and gas disposal wells permitted between 2007 and 2014 in the Eagle Ford area, a region of intensive fracking in southern Texas, we analyzed the racial composition of residents living less than 5 kilometers from a disposal well and those farther away, adjusting for rurality and poverty, using a Poisson regression.

Results. The proportion of people of color living less than 5 kilometers from a disposal well was 1.3 times higher than was the proportion of non-Hispanic Whites. Adjusting for rurality, disposal wells were 2.04 times (95% confidence interval = 2.02, 2.06) as common in areas with 80% people of color or more than in majority White areas. Disposal wells are also disproportionately sited in high-poverty areas.

Conclusions. Wastewater disposal wells in southern Texas are disproportionately permitted in areas with higher proportions of people of color and residents living in poverty, a pattern known as "environmental injustice." (*Am J Public Health.* 2016;106:550–556. doi:10.2105/AJPH.2015.303000)

Waste disposal is an enduring public health problem. Throughout history, waste disposal has often resulted in environmental pollution and, consequently, harm to human health.[1] Waste disposal sites are often unequally distributed and located away from the individuals who receive most of the benefits associated with activities that generate the waste.[2–4] Nationwide, a disproportionate number of waste disposal facilities are sited in communities of color, a pattern known as "environmental injustice."[5,6] Rural areas, whose residents often face political marginalization, have often been burdened with waste from urban and industrial sources.[7,8] Waste facilities, and their unequal distribution, can adversely affect the health of communities in which they are sited.[9]

Over the past decade, the United States has experienced a dramatic increase in unconventional oil and gas (UOG) development. This technique combines horizontal drilling with the pressurized high-volume injection of fluids to fracture the underground shale and release the oil or gas trapped within, a process known as hydraulic fracturing or "fracking." Approximately 100 000 UOG wells have been drilled throughout the United States as of 2012.[10] Each hydraulically fractured well requires an estimated 11 to 19 million liters of water for drilling.[11] In these wells, sand and a complex mixture of chemical additives, many associated with known adverse health risks (e.g., endocrine disruption and cancer), are injected along with the water.[12] For every well, an average of 5.2 million liters of fracking fluid returns to the surface as wastewater.[13,14] The management of this wastewater presents a significant public health problem.[12]

UOG wastewater contains chemical additives used in the drilling process, along with salts, heavy metals, radioactive material, and hydrocarbons from the subsurface.[15–18] The vast majority of this wastewater is disposed of via pumping into underground disposal wells.[19] Wastewater from oil and gas operations is not considered a hazardous material under federal law and is therefore allowed to be disposed of in class II injection wells. These wells are subject to fewer safety requirements than are hazardous waste (class I) wells and are structurally similar to production wells. UOG wastewater is typically pumped directly back into the subsurface, without any treatment or containers for waste. The term "disposal well" refers to all permitted underground wells for injecting oil and gas wastewater.

Wastewater injected into disposal wells may, in some circumstances, migrate to the surface or into freshwater aquifers.[20–23] Toxins can migrate to groundwater through leaks, cracks, or nearby abandoned wells, and multiple cases of groundwater contamination associated with wastewater disposal wells have been identified.[24] For example, in southeastern Texas, groundwater near oil and gas disposal wells was found to have higher concentrations of chloride and bromide than was groundwater farther away.[25] In addition, there is growing evidence regarding the seismic hazards associated with the practice of disposing of fracking wastewater into injection wells.[10,26,27] In northern Texas, the epicenters of small earthquakes were found to be related to disposal well proximity.[28–30]

The environmental justice dimensions of UOG development and the fate of its waste products have yet to be characterized. One recent study of the Marcellus shale in

ABOUT THE AUTHORS

Jill E. Johnston is with the Division of Environmental Health, Keck School of Medicine, University of Southern California, Los Angeles. Emily Werder is with the Department of Epidemiology, Gillings School of Global Public Health, University of North Carolina at Chapel Hill. Daniel Sebastian is with the Curriculum on the Environmental and Ecology, University of North Carolina at Chapel Hill.

Correspondence should be sent to Jill E. Johnston, Division of Environmental Health, Keck School of Medicine, 2001 N. Soto St, University of Southern California, Los Angeles, CA 90032 (e-mail: jillj@usc.edu). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints" link.

This article was accepted November 19, 2015.

doi: 10.2105/AJPH.2015.303000

Pennsylvania found that UOG operations were concentrated in areas with higher poverty rates but did not find a difference with respect to race.[31]

The Eagle Ford shale formation covers 26 counties in the southern and eastern stretches of Texas (Figure 1). Eagle Ford ranked first for the volume of oil produced and fourth for gas production in the United States in 2013.[32] More than 1000 new disposal wells have been permitted in this region since 2007, the start of the shale boom. Unlike in Pennsylvania and other major regions of UOG drilling, a large proportion of people of color live in the rural counties overlying the formation.[33]

In 2013, the community-based organizations Centro por la Justicia and Southwest Workers' Union, along with local residents, organized a series of meetings to discuss the social, environmental, and human health dimensions of the extraction, production, and ultimate disposal of oil, natural gas, and its byproducts in the Eagle Ford area. One concern raised at these meetings was the siting of new disposal wells for wastewater with respect to race and ethnicity and their potential impact on local drinking water supplies. The local organizations invited us to partner with them to investigate the racial, ethnic, and economic composition of communities receiving UOG waste in the region.

METHODS

We defined UOG wells as horizontal wells that were permitted for oil extraction, gas extraction, or both and disposal wells as any permitted for injection or disposal of oil or gas wastewater regulated by the Texas Railroad Commission (TRRC). We extracted information on and the location of all horizontal oil, gas, and injection wells permitted

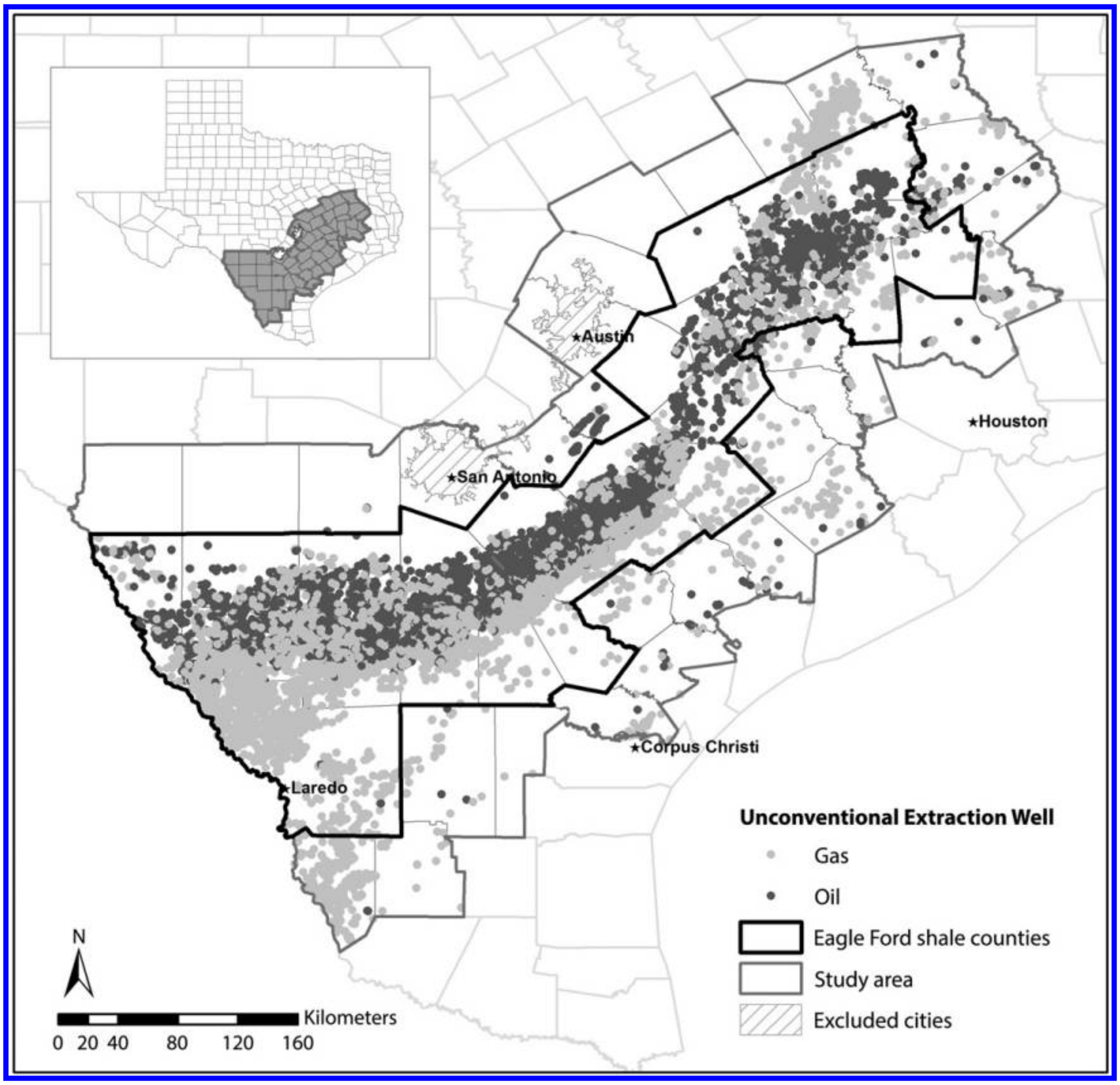


FIGURE 1—Area and Location of Permits for Unconventional Oil and Gas Extraction Wells: Eagle Ford Shale Region, TX, 2007–2014

by the TRRC from 2007 to 2014 from DrillingInfo,[34] an oil and gas permit, completion, and production mapping database. The study area comprised the 26 counties defined as part of the Eagle Ford Shale formation by the TRRC[35] plus all adjacent counties (n = 31; Figure 1).

The database we generated included the following well-specific information: American Petroleum Institute identification number, permit type (oil, gas, disposal, or injection), relevant well dates (permit, spud, completion, and production initiation), drill direction (horizontal vs vertical), and geocoded well location. Because of variability in reporting between counties, we relied on data from both the permitting and production databases. We used permit, spud, and completion dates to determine when a well was permitted. We used drill direction and permit type to identify UOG and injection wells. We mapped wells and generated proximity measures using ArcGIS desktop version 10.1 (Environmental Systems Resource Institute, Redlands, CA).

We conducted our primary analyses of disproportionate permitting of disposal wells using proportion of people of color categories because an individual's vulnerability to the presence of polluting facilities nearby is modified by the race and ethnicity of other people in their community.[36] On the basis of US Census 2010 data, we defined the following racial/ethnic categories: non-Hispanic White (non-Hispanics who identified as White and no other race), people of color (all people not categorized as non-Hispanic White), Hispanic of any race, non-Hispanic Black, and non-Hispanic Native American. We used block race/ethnicity–specific population counts. To examine socioeconomic characteristics, we also extracted race/ethnicity and poverty information at the census block group level from the American Community Survey 2009–2013.[37] There are 147 568 blocks in the study area and 1814 block groups. Populated census blocks in the study area cover an average of 0.4 square kilometer, which contain 1 to 250 people (median = 17), whereas census block groups range from 9 to 5700 residents (median = 1400) over 9 square kilometers.

Because of legal restrictions, waste disposal wells are not located inside densely populated urban areas. We therefore excluded the residents of the 2 major cities in the region: San Antonio and Austin. Furthermore, we calculated the population density of each census block or block group, defined as the number of people per square kilometer. Population density is a measure of rurality, which is strongly associated with land value and availability of land for waste disposal. Land ownership patterns differ in Texas by race and ethnicity. There are more than 116 000 square kilometers of agricultural and ranchland in the study area (~80% of the total land area). Of this land area, only 11.9% has a principal owner who identifies as either Black or Hispanic.[38]

We considered residents of census blocks to be near a disposal well if a well was permitted within the block or within a 5-kilometer radius of the census block centroid. We dichotomized census blocks according to the presence or absence of a permitted disposal well. We used a weighted Poisson regression to quantify relationships between race/ethnicity and permitting 1 or more disposal wells within 5 kilometers of a census block since 2007. We used 2010 census block populations as weights. In density-adjusted models we included variables for the cubic natural logarithm of population density. The cubic polynomial term maximized model fit, as is consistent with previous research.[36]

We categorized race/ethnicity as the proportion of people of color residing in each census block, using 20% increments. We conducted a sensitivity analysis of our exposure definition (< 5 km from a disposal well) to less than 3 kilometers and less than 10 kilometers. We conducted a parallel analysis for UOG extraction wells. We replicated these methods at the block group level to analyze the association with poverty and with race adjusted for poverty. We defined high-poverty block groups as exceeding the mean percentage of residents living in poverty for the study region (> 18.6%). We completed statistical analyses using Stata IC version 14 (StataCorp LP, College Station, TX).

Community members cited the contamination of private groundwater wells near drilling and disposal operations as a potential exposure route. Groundwater is the primary source of fresh water for residents in southern Texas. There is little public information about the potential impact of UOG wastewater on groundwater in the region. There is, however, detailed data on the location of domestic groundwater wells in the study region in the Texas Submitted Driller's Reports Database, which was compiled by the Texas Water Development Board. The database includes required reporting of new well construction and well repairs since 2001 from registered water well drillers. We identified all wells in the database designated for use as domestic water wells in the study area to approximate locations of private drinking water wells in the region.

RESULTS

As of December 2014, approximately 35 000 permitted class II injection wells regulated by the TRRC existed across the state of Texas. We identified 1152 disposal wells permitted for oil and gas waste between 2007 and 2014 in the study area. Disposal wells were permitted in 48 of the 57 counties, with an average of 144 new wells permitted each year (Figure A, available as a supplement to the online version of this article at http://www.ajph.org).

We further identified 23 435 permits for UOG wells in the Eagle Ford region from 2007 to 2014. Both oil and gas are extracted from the region via fracking techniques, with the western part dominated by oil extraction (n = 11 548), whereas the eastern section is primarily natural gas (n = 11 887; Figure 1). More than two thirds of all drilling permits in the region were for unconventional wells.

In 2010, approximately 2.8 million people lived in the 57 counties in and around the Eagle Ford shale region, not including residents of San Antonio and Austin. Of these, 50.1% were people of color and 49.9% were non-Hispanic White. Among the people of color, 77.0% were Hispanic/Latino, 18.0% Black, and 1.0% Native American. An estimated 385 000 people (13.7% of study area) lived within 5 kilometers of a waste disposal well, whereas 790 000 lived near a UOG extraction well (Table 1). The proportion of people of color living near an injection well was 1.30 times higher than was the proportion of non-Hispanic Whites living near an injection well.

TABLE 1—Racial Composition of Census Blocks in the Study Area Within 5 Km of an Oil and Gas Disposal or Where Unconventional Extraction Wells Are Permitted: Eagle Ford Shale Region, TX, 2007–2014

Race/Ethnicity	Population	Disposal Well[a] <5 Km, No. (%)	Unconventional Well[b] <5 Km, No. (%)
White	1 406 086	167 258 (11.9)	418 850 (29.8)
All people of color	1 412 181	217 624 (15.4)	372 516 (26.4)
Hispanic, any race	1 086 979	181 397 (16.7)	281 075 (25.9)
Non-Hispanic Black	253 188	30 202 (11.9)	70 727 (27.9)
Non-Hispanic Native American	14 032	2 058 (14.7)	3 483 (24.8)
Total	2 818 267	384 882 (13.7)	791 366 (28.1)

[a]Disposal wells receive oil and gas wastewater to inject underground.
[b]Unconventional wells extract oil and gas using hydraulic fracturing ("fracking") and horizontal drilling.

We further categorized each census block on the basis of the percentage of people of color living in that block (Figure A). Overall, the proportion of residents living near a well was positively associated with the proportion of people of color. In census blocks composed of less than 40.0% people of color, 10.0% of residents had a disposal well sited within 5 kilometers; in areas with 40.0% to less than 60.0% people of color, 12.4% of residents had disposal wells nearby; and in areas with 60.0% to less than 80.0% people of color, it was 15.5%. In areas with 80.0% or more people of color, the percentage of residents living near a disposal well rose to 18.4%. These ratios were elevated for all areas with 60.0% or more people of color relative to the less than 20.0% people of color area with or without adjustment for rurality. When accounting for rurality, in areas with 80.0% or more people of color, more than 2.04 times (95% confidence interval [CI] = 2.02, 2.06) as many people had disposal wells permitted nearby than had people in areas with less than 20.0% people of color (Figure 2; Table A, available as a supplement to the online version of this article at http://www.ajph.org).

The racial disparities were similar at the block group level, even after adjusting for poverty. In high-poverty block groups, more than 1.29 times (95% CI = 1.28, 1.30) as many people had a disposal well permitted in their block group or within 5 kilometers of its centroid than did people in low-poverty areas after adjusting for rurality (Table B available as a supplement to the online version of this article at http://www.ajph.org). Adjusting for both poverty and rurality, we still found that as the proportion of people of color in the census block group increased, so did the presence of disposal wells (Figure 3; Table C, available as a supplement to the online version of this article at http://www.ajph.org).

By contrast, the racial disparities related to the location of UOG extraction wells were small but inverse: 29.8% of non-Hispanic Whites residents (418 850) lived within 5 kilometers of an extraction well compared with 26.4% of people of color (372 516). Non-Hispanic Whites, however, own more than 85.0% of the land atop the Eagle Ford geological shale formation.[38]

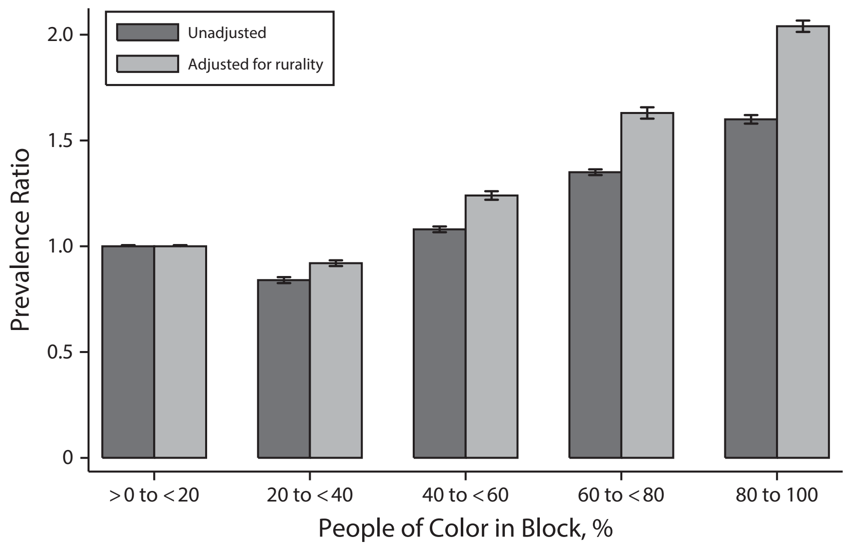
There were 32 817 domestic water wells in the study area according to the Submitted Driller's Reports Database as of 2014. Of these wells, 16.0% were within 5 kilometers of a waste disposal well and 1.3% were within 1 kilometer. On average, each disposal well was less than 5 kilometers from 4.5 domestic groundwater wells in the region.

The pattern of racial disparities held with changing distances of exposure classification. Using a definition of 3 kilometers, we observed a similar pattern of increasing exposure to disposal wells as the proportion of people of color increased (Table D, available as a supplement to the online version of this article at http://www.ajph.org). In fact, with a narrower definition of exposure, we saw that disparities were more pronounced for the blocks of 80% or more people of color with an adjusted prevalence ratio of 2.32 (95% CI = 2.30, 2.36) than for the 5-kilometer radius. By contrast, this relationship attenuated as we increased the radius of exposure to 10 kilometers (Table E, available as a supplement to the online version of this article at http://www.ajph.org). Nonetheless, the blocks with the highest burden were those with the highest proportion of people of color.

DISCUSSION

Disposal of wastewater from UOG operations is an important public health concern. As an emerging area of research, there are limited data on the human health and quality of life consequences to local residents near underground oil and gas waste disposal wells. We examined the location of the 1152 underground injection wells permitted by the TRRC since 2007 near the Eagle Ford shale in relation to the race and ethnicity of the people living in proximity to the disposal sites. Our findings mirror a national trend that was notably identified more than 2 decades ago in studies confirming that toxic waste sites were sited disproportionately near people of color.[39] Additionally, we found that disposal wells are more likely to be permitted in communities with higher levels of poverty, although patterns of racial disparities persist after accounting for poverty. Our analysis suggests that this pattern of environmental injustice extends to the Eagle Ford shale region with respect to oil and gas wastewater disposal. We offer further evidence of racial disparities in rural areas.

Few studies have examined UOG development in this region or the consequences of underground injection of massive quantities of wastewater. Permitted disposal wells can be actively used for decades, receiving millions of gallons of toxic wastes, whereas the active life of an extraction well is typically a few years.[40] The Energy Policy Act of 2005 specifically excludes the underground injection of oil and gas fluids from the Safe Water Drinking Act, which authorizes the Environmental Protection Agency to regulate chemicals in drinking water to protect public health.[41] Current regulations allow the oil and gas industry to inject and indefinitely store hazardous materials underground and near drinking water supplies.[42] A geochemical analysis of wastewater from the Eagle Ford shale region found levels of chromium, mercury, and arsenic exceeding the maximum contaminant levels set by the Environmental Protection Agency.[43] The contamination of groundwater aquifers overlying shale formations would be

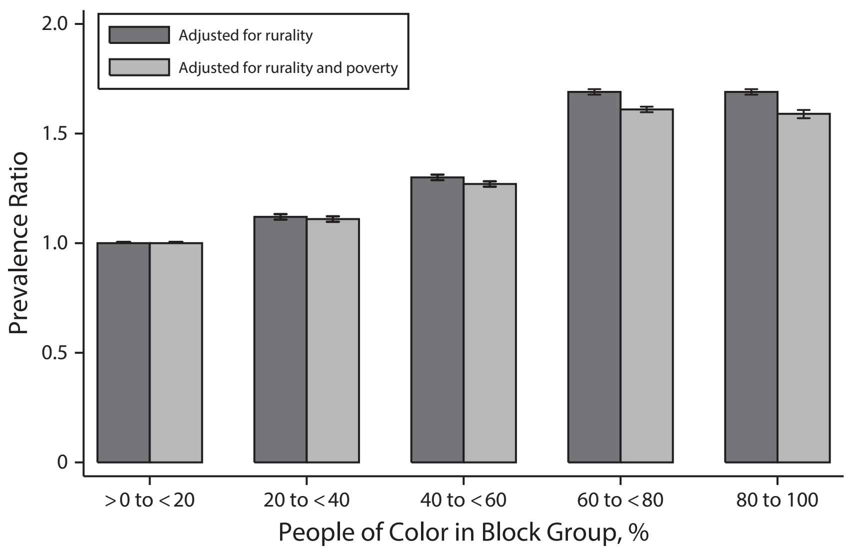


Note. The adjustment uses a cubic polynomial of the natural logarithm of population density. Error bars depict 95% confidence intervals.

FIGURE 2—Prevalence Ratios Comparing the Percentage of People Living Near an Oil and Gas Disposal Well in Census Block Groups With ≥ 20% People of Color vs Those With < 20% People of Color, Unadjusted and Adjusted for Rurality: Eagle Ford Shale Region, TX, 2007–2014

particularly problematic in southern Texas because these aquifers provide drinking water to the region, including to many rural residents with unregulated private wells.

According to an analysis of Environmental Protection Agency records, 70% of disposal wells across Texas had at least 1 violation between 2008 and 2010. More than 4000 of these had test failures for significant leaks.[44] Faulty construction or failure in well integrity, such as cracks and cement deterioration, has been linked to groundwater contamination in shale formations.[45] Such events can result in gases or liquids leaking outside the cement well; gases or liquids can then migrate up into shallower aquifers. In addition to potential effects on ground and surface water quality and local seismicity, trucks are needed to transport the wastewater to the well site. Increased traffic is associated with adverse effects on local air quality, increased noise, more frequent accidents, and accelerated deterioration of local roads.



Note. Dichotomized into high and low poverty on the basis of the mean census block group level. Error bars depict 95% confidence intervals.

FIGURE 3—Prevalence Ratios Comparing the Percentage of People Living Near a Disposal Well in Census Block Groups With ≥ 20% People of Color vs Those With < 20% People of Color, Adjusted for Rurality and Rurality With Poverty: Eagle Ford Shale Region, TX, 2007–2014

As UOG drilling proliferates, it is important to evaluate UOG waste disposal siting practices and their potential environmental, public health, and equity implications. Our results demonstrate differences in race in the communities where UOG extraction is occurring compared with race in communities hosting the oil and gas waste disposal sites. Locations of UOG extraction wells are largely dictated by subsurface geology. Accordingly, we would not expect social or political forces to strongly drive which communities are prone to UOG extraction operations. Moreover, non-Hispanic Whites own the vast majority of land above the shale formation. These landowners may receive economic benefits from UOG drilling operations, and they potentially avoid environmental ills when wastewater is transported to other communities for disposal.

Permitting for disposal wells is virtually ubiquitous across Texas, suggesting few siting restrictions, unlike other states.[13,25] We did not address siting decisions or specific factors for individual disposal well facilities, nor did we examine the permit application procedures. The particular reasoning behind any single well's location may be particular to local history, land suitability, transportation feasibility, economic factors, and land and mineral ownership. We do suggest that the discrepancies in locations of new wastewater disposal wells may be driven by and contribute to differences in political capital between people of color and White communities and between high- and low-wealth areas.

Marginalized communities are often targeted because of the perceived lack of political power and limited resources with which to challenge a permit.[36,46] In this case, owning land is one indicator of power—and people of color own only a fraction of land compared with White residents. Public involvement and access to information about permit applications and site locations, even by local officials, is limited, as is the opportunity for the public to influence the decision-making process. As the UOG industry grows in southern Texas, so will the waste from the production processes. Although landowners may receive some incentives for allowing disposal wells, the public health threats are many.

Studies have found significant associations between residential proximity to environmental hazards or waste facilities and adverse health outcomes, including poor pregnancy outcomes, childhood cancer, and renal disease.[47] More research is needed to understand potential pathways of exposure to toxic wastewater disposal through underground injection and the potential consequences of such exposure. Case reports of animals, which can be indicative of human impacts, have identified infertility, stillbirths, and death in cattle exposed to fracking wastewater.[48]

Communities of color often have limited influence on land use decisions that bring waste, pollution, and unsustainable development. Preferentially permitting waste disposal facilities near communities of color has been documented across the United States.[3,49] This disproportionate burden can result in increased exposure to harmful pollutants and degradation in environmental quality. Exposure to these harmful conditions results in harmful health outcomes, increased stress, and a reduction in quality of life and neighborhood sustainability.[50] In addition, there is evidence of racial disparities in the frequency of governmental inspections of hazardous waste facilities.[51] Less enforcement may lead to an increased risk of environmental contamination, ultimately exacerbating health disparities, in these communities.

Newly permitted injection wells for oil and gas wastewater in the Eagle Ford region are disproportionately located near communities of color and in high-poverty regions. Wastewater from UOG development contains substances harmful to human health. This wastewater has the potential to contaminate groundwater and increase local seismic activity. These discriminatory impacts could be reduced by decreasing the quantity of wastewater produced, using fewer toxic substances, mandating the use of improved technologies to prevent releases of pollutants, and increasing the distance between injection wells and private water wells. The meaningful involvement of community members in decisions regarding wastewater management may strengthen environmental health protections. AJPH

CONTRIBUTORS

J. E. Johnston developed the framework for the project, drafted the article, and conducted the analysis. E. Werder assisted in data extraction, analysis, and preparing the findings. D. Sebastian assisted in data analysis and developing the figures. All of the authors revised the article.

ACKNOWLEDGMENTS

This project was supported in part by the National Institute of Environmental Health Sciences (grants T32ES007018, P30ES007048).

We recognize the invaluable support from Chavel Lopez, Diana Lopez, Centro por la Justicia, and the Southwest Workers' Union.

HUMAN PARTICIPANT PROTECTION

No protocol approval was necessary because no human participants were involved in this study.

REFERENCES

1. Hamer G. Solid waste treatment and disposal: effects on public health and environmental safety. *Biotechnol Adv*. 2003;22(1–2):71–79.

2. Griffith J, Duncan RC, Riggan WB, Pellom AC. Cancer mortality in US counties with hazardous waste sites and ground water pollution. *Arch Environ Health*. 1989;44(2):69–74.

3. Norton JM, Wing S, Lipscomb HJ, Kaufman JS, Marshall SW, Cravey AJ. Race, wealth, and solid waste facilities in North Carolina. *Environ Health Perspect*. 2007;115(9):1344–1350.

4. Lowman A, McDonald MA, Wing S, Muhammad N. Land application of treated sewage sludge: community health and environmental justice. *Environ Health Perspect*. 2013;121(5):537–542.

5. Bullard RD, Mohai P, Saha R, Wright B. Toxic wastes and race at twenty: why race still matters after all of these years. *Envtl L*. 2008;38(2):371–411.

6. Bryant BI, Mohai P. *Race and the Incidence of Environmental Hazards*. Boulder, CO: Westview Press; 1992.

7. Jones CC. Environmental justice in rural context: land-application of biosolids in central Virginia. *Environ Justice*. 2011;4(1):220–233.

8. Bullard RD. *Dumping in Dixie: Race, Class, and Environmental Quality*. 3rd ed. Boulder, CO: Westview Press; 2000.

9. Martuzzi M, Mitis F, Forastiere F. Inequalities, inequities, environmental justice in waste management and health. *Eur J Public Health*. 2010;20(1):21–26.

10. Ellsworth WL. Injection-induced earthquakes. *Science*. 2013;341(6142):1225942.

11. *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*. Washington, DC: US Environmental Protection Agency; 2015.

12. Colborn T, Kwiatkowski C, Schultz K, Bachran M. Natural gas operations from a public health perspective. *Hum Ecol Risk Assess*. 2011;17(5):1039–1056.

13. Lutz BD, Lewis AN, Doyle MW. Generation, transport, and disposal of wastewater associated with Marcellus Shale gas development. *Water Resour Res*. 2013;49(2):647–656.

14. Ferrar KJ, Michanowicz DR, Christen CL, Mulcahy N, Malone SL, Sharma RK. Assessment of effluent contaminants from three facilities discharging Marcellus Shale wastewater to surface waters in Pennsylvania. *Environ Sci Technol*. 2013;47(7):3472–3481.

15. Brown VJ. Radionuclides in fracking wastewater: managing a toxic blend. *Environ Health Perspect*. 2014;122(2):A50–A55.

16. Haluszczak LO, Rose AW, Kump LR. Geochemical evaluation of flowback brine from Marcellus gas wells in Pennsylvania, USA. *Appl Geochem*. 2013;28:55–61.

17. Barbot E, Vidic NS, Gregory KB, Vidic RD. Spatial and temporal correlation of water quality parameters of produced waters from devonian-age shale following hydraulic fracturing. *Environ Sci Technol*. 2013;47(6):2562–2569.

18. Thacker JB, Carlton DD, Hildenbrand ZL, Kadjo AF, Schug KA. Chemical analysis of wastewater from unconventional drilling operations. *Water*. 2015;7(4):1568–1579.

19. Veil JA, Clark CE; Argonne National Lab; US Office of Fossil Energy. *Produced Water Volumes and Management Practices in the United States*. Oakridge, TN: US Department of Energy Office of Scientific and Technical Information; 2009.

20. Myers T. Potential contaminant pathways from hydraulically fractured shale to aquifers. *Ground Water*. 2012;50(6):872–882.

21. Jackson RE, Gorody AW, Mayer B, Roy JW, Ryan MC, Van Stempvoort DR. Groundwater protection and unconventional gas extraction: the critical need for field-based hydrogeological research. *Ground Water*. 2013;51(4):488–510.

22. Vengosh A, Jackson RB, Warner N, Darrah TH, Kondash A. A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. *Environ Sci Technol*. 2014;48(15):8334–8348.

23. Yuan Z, Gardoni P, Schubert J, Teodoriu C. Cement failure probability analysis in water injection well. *J Petrol Sci Eng*. 2013;107:45–49.

24. *Safeguards Are Not Preventing Contamination from Injected Oil and Gas Wastes*. Washington, DC: US Government Accountability Office; 1989.

25. Hudak PF, Wachal DJ. Effects of brine injection wells, dry holes, and plugged oil/gas wells on chloride, bromide, and barium concentrations in the Gulf Coast Aquifer, southeast Texas, USA. *Environ Int*. 2001;26(7–8):497–503.

26. Horton S. Disposal of hydrofracking waste fluid by injection into subsurface aquifers triggers earthquake swarm in central Arkansas with potential for damaging earthquake. *Seismol Res Lett*. 2012;83(2):250–260.

27. Holland A, Gibson AR. Analysis of the Jones, Oklahoma, earthquake swarm. *Seismol Res Lett*. 2011;82:279.

28. Frohlich C. Two-year survey comparing earthquake activity and injection-well locations in the Barnett Shale, Texas. *Proc Natl Acad Sci U S A*. 2012;109(35):13934–13938.

29. McGarr A, Bekins B, Burkardt N, et al. Coping with earthquakes induced by fluid injection. *Science*. 2015;347(6224):830–831.

30. Petersen MD, Mueller CS, Moschetti MP, et al. *Incorporating Induced Seismicity in the 2014 United States National Seismic Hazard Model: Results of the 2014 Workshop and Sensitivity Studies*. Reston, VA: US Geological Survey; 2015.

31. Ogneva-Himmelberger Y, Huang L. Spatial distribution of unconventional gas wells and human populations in the Marcellus Shale in the United States: vulnerability analysis. *Appl Geogr*. 2015;60:165–174.

32. Scanlon BR, Reedy RC, Nicot J-P. Comparison of water use for hydraulic fracturing for unconventional oil and gas versus conventional oil. *Environ Sci Technol*. 2014; 48(20):12386–12393.

33. US Census Bureau. 2010 Census data. 2014. Available at: http://www.census.gov/2010census/data. Accessed November 23, 2014.

34. DrillingInfo. Drilling info. 2014. Available at: http://www.drillinginfo.com. Accessed April 23, 2015.

35. Railroad Commission of Texas. Eagle Ford shale information. 2015. Available at: http://www.rrc.state.tx.us/oil-gas/major-oil-gas-formations/eagle-ford-shale/#counties. Accessed January 17, 2015.

36. Wing S, Cole D, Grant G. Environmental injustice in North Carolina's hog industry. *Environ Health Perspect*. 2000;108(3):225–231.

37. US Census Bureau. American Community Survey 2009–2013. 2014. Available at: https://www.census.gov/programs-surveys/acs. Accessed September 2, 2015.

38. US Department of Agriculture. Race, ethnicity and gender profiles. Available at: http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Race,_Ethnicity_and_Gender_Profiles. Accessed May 10, 2015.

39. *Toxic Wastes and Race in the United States: A National Report on the Racial and Socio-Economic Characteristics of Communities With Hazardous Waste Sites*. New York, NY: United Church of Christ Commission for Racial Justice; 1987.

40. Hughes JD. Energy: a reality check on the shale revolution. *Nature*. 2013;494(7437):307–308.

41. Rahm D. Regulating hydraulic fracturing in shale gas plays: the case of Texas. *Energy Policy*. 2011;39(5): 2974–2981.

42. Finkel M, Hays J, Law A. The shale gas boom and the need for rational policy. *Am J Public Health*. 2013;103(7): 1161–1163.

43. Maguire-Boyle SJ, Barron AR. Organic compounds in produced waters from shale gas wells. *Environ Sci Process Impacts*. 2014;16(10):2237–2248.

44. Lustgarten A, Schmidt KK. Injection wells: the hidden risks of pumping waste underground. 2012. Available at: http://projects.propublica.org/graphics/underground-injection-wells. Accessed April 15, 2015.

45. Davies RJ, Almond S, Ward RS, et al. Oil and gas wells and their integrity: implications for shale and unconventional resource exploitation. *Mar Petrol Geol*. 2014; 56:239–254.

46. Morello-Frosch RA. Discrimination and the political economy of environmental inequality. *Environ Plann C Gov Policy*. 2002;20(4):477–496.

47. Brender JD, Maantay JA, Chakraborty J. Residential proximity to environmental hazards and adverse health outcomes. *Am J Public Health*. 2011;101(suppl 1): S37–S52.

48. Bamberger M, Oswald RE. Impacts of gas drilling on human and animal health. *New Solut*. 2012;22(1):51–77.

49. Ebert ES, Wilson N, Wacksman M, Loper JR, Schell JD, Fowler A. Utilization survey of a rural creek fishery in central Alabama. *Risk Anal*. 2012;32(3):416–432.

50. Gee GC, Payne-Sturges DC. Environmental health disparities: a framework integrating psychosocial and environmental concepts. *Environ Health Perspect*. 2004;112 (17):1645–1653.

51. Spina F. Environmental justice and patterns of state inspections. *Soc Sci Quart*. 2015;96(2):417–429.

This article has been cited by:

1. Pierce Greenberg. 2018. Coal Waste, Socioeconomic Change, and Environmental Inequality in Appalachia: Implications for a Just Transition in Coal Country. *Society & Natural Resources* **22**, 1-17. [Crossref]
2. Emily Clough. 2018. Environmental justice and fracking: A review. *Current Opinion in Environmental Science & Health* **3**, 14-18. [Crossref]
3. Genevieve S. Silva, Joshua L. Warren, Nicole C. Deziel. 2018. Spatial Modeling to Identify Sociodemographic Predictors of Hydraulic Fracturing Wastewater Injection Wells in Ohio Census Block Groups. *Environmental Health Perspectives* **126**:06. . [Crossref]
4. Kameshwari Pothukuchi, Melissa Arrowsmith, Natalie Lyon. 2018. Hydraulic Fracturing. *Journal of Planning Literature* **33**:2, 155-170. [Crossref]
5. Nicole C. Deziel, Zoe Humeau, Elise G. Elliott, Joshua L. Warren, Linda M. Niccolai. 2018. Shale gas activity and increased rates of sexually transmitted infections in Ohio, 2000–2016. *PLOS ONE* **13**:3, e0194203. [Crossref]
6. Raoul S. Liévanos, Pierce Greenberg, Ryan Wishart. 2018. In the shadow of production: Coal waste accumulation and environmental inequality formation in Eastern Kentucky. *Social Science Research* **71**, 37-55. [Crossref]
7. Hong Yao, Bo Liu, Zhen You, Li Zhao. 2018. Risk perception of aquatic pollution originated from chemical industry clusters in the coastal area of Jiangsu province, China. *Environmental Science and Pollution Research* **25**:6, 5711-5721. [Crossref]
8. Anne E. Sanders, Gary D. Slade. 2018. Blood Lead Levels and Dental Caries in U.S. Children Who Do Not Drink Tap Water. *American Journal of Preventive Medicine* **54**:2, 157-163. [Crossref]
9. Élyse Caron-Beaudoin, Naomi Valter, Jonathan Chevrier, Pierre Ayotte, Katherine Frohlich, Marc-André Verner. 2018. Gestational exposure to volatile organic compounds (VOCs) in Northeastern British Columbia, Canada: A pilot study. *Environment International* **110**, 131-138. [Crossref]
10. Samuel J. Maguire-Boyle, Joseph E. Huseman, Thomas J. Ainscough, Darren L. Oatley-Radcliffe, Abdullah A. Alabdulkarem, Sattam Fahad Al-Mojil, Andrew R. Barron. 2017. Superhydrophilic Functionalization of Microfiltration Ceramic Membranes Enables Separation of Hydrocarbons from Frac and Produced Water. *Scientific Reports* **7**:1. . [Crossref]
11. Trey Murphy, Christian Brannstrom, Matthew Fry. 2017. Ownership and Spatial Distribution of Eagle Ford Mineral Wealth in Live Oak County, Texas. *The Professional Geographer* **69**:4, 616-628. [Crossref]
12. Pierce Greenberg. 2017. Disproportionality and Resource-Based Environmental Inequality: An Analysis of Neighborhood Proximity to Coal Impoundments in Appalachia. *Rural Sociology* **82**:1, 149-178. [Crossref]
13. Lisa M. McKenzie, William B. Allshouse, Troy Burke, Benjamin D. Blair, John L. Adgate. 2016. Population Size, Growth, and Environmental Justice Near Oil and Gas Wells in Colorado. *Environmental Science & Technology* **50**:21, 11471-11480. [Crossref]
14. Mary Finley-Brook, Erica Holloman. 2016. Empowering Energy Justice. *International Journal of Environmental Research and Public Health* **13**:9, 926. [Crossref]