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9	New York State Department of Health Study: A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development, December 17, 2014 (excerpts), full report available at: http://www.health.ny.gov/press/reports/docs/high_volume_hydraulic_fracturing.pdf	66-83
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21	Pro Publica: EPA Wants to Look at Full Lifecycle of Fracking in New Study, By Nicholas Kusnetz, February 9, 2011.	142-143
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29	University of Colorado Boulder: CU-Boulder Researchers Confirm Leaks From Front Range Oil and Gas Operations, May 7, 2014.	207-210
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Toward an understanding of the environmental and public health impacts of shale gas development: an analysis of the peer-reviewed scientific literature, 2009-2014

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1. Introduction

Conversations on the environmental and public health impacts of shale gas development enabled by hydraulic fracturing continue to play out in the media, in policy discussions, and among the general public. But what does the science actually say? While research continues to lag behind the rapid scaling of unconventional forms of oil and gas development, there has been a surge of peer-reviewed scientific papers published in recent years (Figure 1). In fact, of all the available literature on the impacts of shale gas development, over 75% has been published since January 1, 2013. What this tells us is that the scientific community is only now beginning to understand the environmental and public health implications. Numerous hazards and risks have been identified, but many data gaps remain. While there is now a far more substantive body of science than there was several years ago, there is still a notable dearth of quantitative epidemiology that assesses associations between risk factors and human health outcomes among populations.

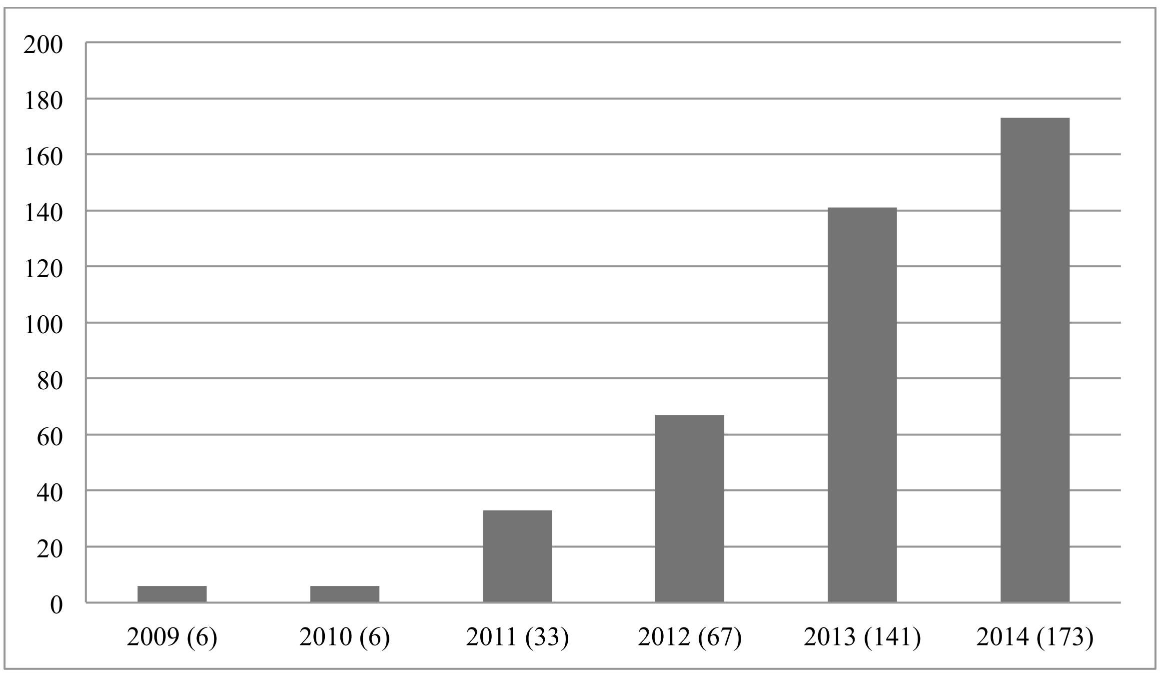

Figure 1. Number of publications that assess the impacts of shale or tight gas development by year, 2009-2014

In this analysis we provide an overview of current scientific knowledge regarding these potential impacts. We include only published peer-reviewed literature available on the subject. Specifically, we analyze studies relevant to near-term and long-term environmental public health among communities in proximity to shale gas development.

As shale gas activities continue to expand, states and countries are in a unique position to learn from experiences and scientific assessment in areas where development is already underway, including parts of Pennsylvania, Texas, and Colorado. While energy policy requires more than empirical data, legislative and regulatory bodies should account for the emerging body of science on the environmental and public health implications of shale gas development. This analysis is an attempt to summarize this emerging body of science from the available peer-reviewed literature.

There are many limitations to our analysis and it provides just a snapshot of the empirical knowledge on the public health hazards, risks, and impacts associated with shale gas development. For a more nuanced discussion please refer to our review article (Shonkoff et al. 2014) published in *Environmental Health Perspectives* (http://ehp.niehs.nih.gov/wp-content/uploads/122/8/ehp.1307866.pdf). Furthermore, as a working paper, this document is preliminary and has not yet been subjected to external peer review. Nonetheless, it provides readers with a general sense of the direction in which the existing body of scientific literature points in terms of identified and potential environmental and public health impacts.

2. Methods

A. Database assemblage and review

This analysis was conducted using the PSE Shale and Tight Gas Study Citation Database (available at: http://psehealthyenergy.org/site/view/1180). This near exhaustive collection of peer-reviewed literature on shale gas development is divided into 12 topics that attempt to organize the papers in a useful and coherent fashion. These topics include air quality, climate, community, ecology, economics, general (comment/review), health, regulation, seismicity, waste/fluids, water quality, and water usage. This study database has been assembled over several years using a number of different search strategies, including the following:

- Systematic searches in scientific databases across multiple disciplines: PubMed (http://www.ncbi.nlm.nih.gov/pubmed/), Web of Science (http://www.webofknowledge.com), and ScienceDirect (http://www.sciencedirect.com)
- Searches in existing collections of scientific literature on shale gas development, such as the Marcellus Shale Initiative Publications Database at Bucknell University (http://www.bucknell.edu/script/environmentalcenter/marcellus), complemented by Google (http://www.google.com) and Google Scholar (http://scholar.google.com)
- Manual searches (hand-searches) of references included in peer-reviewed studies that pertain directly to shale gas development.

For science literature search engines we used a combination of Medical Subject Headings

(MeSH)-based and keyword strategies, which included the following terms as well as relevant combinations thereof:

> shale gas, shale, hydraulic fracturing, fracking, drilling, natural gas, air pollution, methane, water pollution, public health, water contamination, fugitive emissions, air quality, climate, seismicity, waste, fluids, economics, ecology, water usage, regulation, community, epidemiology, Marcellus, Barnett, Denver-Julesberg Basin, unconventional gas development, and environmental pathways.

This database and subsequent analysis excluded technical papers on shale gas development not applicable to determining potential environmental and public health impacts. Examples include papers on optimal drilling strategies, reservoir evaluations, estimation algorithms of absorption capacity, patent analyses, and fracture models designed to inform stimulation techniques. Because this collection is limited to papers subjected to external peer-review in the scientific community, it does not include government reports, environmental impact statements, policy briefs, white papers, law review articles, or other grey literature. Nor does it include studies on coalbed methane, coal seam gas, tar sands or other forms of fossil fuel extraction (offshore drilling, etc.).

We have tried to include all literature that meets our criteria in our collection of the peer-reviewed science; however, it is possible that some papers may have gone undetected. Thus, we refer to the collection as *near* exhaustive. We are sure, however, that the most seminal studies on the environmental public health dimensions of shale gas development in leading scientific journals are accounted for.

The PSE Healthy Energy database has been used and reviewed by academics, experts, and government officials throughout the U.S. and internationally and has been subjected to public and professional scrutiny before and after this analysis. It represents the most comprehensive public collection of peer-reviewed scientific literature on shale and tight gas development in the world and has been accessed by thousands of people. Again, many of the publications in this database through 1 February 2014 are discussed in greater detail in Shonkoff et al. (2014).

B. Scope of analysis

1. Definitions:

There has been great confusion about the environmental dimensions of shale and tight gas development (often termed "fracking") because of the lack of uniform, well-defined terminology and boundaries of analysis. The public and the media use the term fracking as an umbrella term to refer to the entirety of shale gas development, including processes ranging from land clearing to well stimulation, to hydrocarbon development, to waste disposal. On the other hand, the oil and gas industry and many in the scientific community generally use the term as shorthand for one particular type of well stimulation method used to enhance the production of oil and natural gas – hydraulic fracturing.

The PSE Healthy Energy database and this analysis are both concerned with shale gas development in its entirety, enabled by hydraulic fracturing, and not just the method of well stimulation. Environmental and public health analyses that include only the latter should have a limited role in policy discussions. If we are to understand the social, environmental, and public health dimensions of shale gas development we must look beyond just the process of hydraulic fracturing, especially when the scientific literature indicates other aspects of the overall process warrant concern. Thus, this project should be viewed as an analysis of the scientific literature on hydraulic fracturing *and* its associated operations and ancillary infrastructure that comprise the development of shale and tight gas.

2. Inclusion and exclusion criteria:

The temporal focus of this analysis is, first and foremost, on the primary research on shale gas development published between 1 January 2009 and 31 December 2014. The reason for starting this analysis in 2009 is that research on modern, unconventional forms of natural gas development did not appear until around that time. We only include papers that evaluate environmental and public health impacts of shale gas development. As such, not all publications in the PSE Healthy Energy database were used in this analysis. We have excluded the following topics: climate, community, ecology, economics, regulation, seismicity, waste/fluids, and water usage.

We have also not included all papers that fall under the three topics (health, water quality, and air quality) used in this analysis. For instance, with the exception of public health papers, for which there has been very little primary research, we have excluded commentaries and review articles. Further, we have excluded those papers that provide baseline data or address research methods that do not assess impacts. We have also excluded letters to the editors of scientific journals that critique a particular study or the subsequent response of the author(s).

As previously mentioned, we have restricted the studies included in this analysis to those published from 2009 through 2014. There are some studies in the database on conventional forms of oil and natural gas development that are relevant to shale gas, but to maintain greater consistency we have decided to exclude those prior to 2009 from the analysis. For instance, we excluded a study published in *The Lancet* that examined the association between testicular cancer and employment in agriculture and oil and gas development published in 1986 (Sewell et al. 1986). Relatedly, some of the studies included in this analysis may be broader than shale gas development and could potentially include other forms of both conventional and unconventional oil and gas development. This is true for some of the top-down, field based air pollutant emissions studies that gauge leakage rates and emission factors in Western oil and gas fields. Where studies are not specifically related to shale gas development we included them only when the findings were both recent and substantially relevant.

Again, it is important to note that scientists are only beginning to understand the environmental and public health dimensions of these rapidly expanding industrial practices. Our analysis represents a survey of the existing science to date in an attempt to determine the direction in which scientific consensus is headed and to achieve a better understanding of the environmental and public health impacts of this form of energy development.

C. Categorical framework

We have created categories for each topic in an attempt to identify and group studies in ways that are both useful and intuitive. Clearly, there are limitations to this approach and many studies are nuanced or incommensurable in ways that may not be appropriate for this type of analysis. Further, some studies may properly belong in multiple topics. For instance, a few studies that contain data that are relevant to both air quality and public health have been included in both of these topics (Bunch et al. 2014; Colborn et al. 2014; Macey et al. 2014). Nonetheless, in order to glean some kind of emerging scientific consensus on the environmental public health dimensions of shale gas development we strived to create the most simple and accurate approach possible. Please refer to the tables included in the appendix for the citations and categorization of the studies, which are listed alphabetically by author.

Topics	Categories
Health	• Indication of potential public health risks or actual adverse health outcomes • No indication of public health risks or actual adverse health outcomes
Water Quality	• Indication of potential, positive association, or actual incidence of water contamination • Indication of minimal potential, negative association, or rare incidence of water contamination
Air Quality	• Indication of elevated air pollutant emissions and/or atmospheric concentrations • No indication of significantly elevated air pollutant emissions and/or atmospheric concentrations

1. Health

Health outcome studies and epidemiologic investigations continue to be particularly limited and most of the peer-reviewed papers to date are commentaries and reviews. Accordingly, we have also separately analyzed peer-reviewed scientific commentaries and review articles ("all papers") for this topic. Although commentaries should essentially be acknowledged as opinions, they are the opinions of experts formed from the available literature and have also been subjected to peer review.

We have included in this topic papers that consider the question of public health in the context of shale gas development. Of course, research findings in other categories such as air quality and water quality are relevant to public health, but here we only include those studies that *directly* consider the health of individuals and human populations. We only consider research to be original if it measures health outcomes or complaints (i.e., not health research that only attempts to determine public opinion or consider methods for future research agendas).

2. Water Quality

Papers on water quality are more nuanced in that some rely on empirical field measurements, while others explore mechanisms for contamination or use modeled data to determine water quality risks. Further, some of these studies explore only one aspect of shale gas development, such as the well stimulation process enabled by hydraulic fracturing. Thus, these studies do not indicate whether or not shale gas development as a whole is associated with water contamination and are therefore limited in their utility for gauging water quality impacts. Nonetheless, we have included all original research, including modeling studies. We have excluded studies that explore only evaluative methodology or baseline assessments as well papers that simply comment on or review previous studies. Here we are only concerned with actual findings in the field or modeling studies that specifically address the risk or occurrence of water contamination.

3. Air Quality

Air quality is a more complex, subjective measure that beckons comparison to other forms of energy development or industrial processes. Yet a review and analysis of the air quality data is still useful and relevant to health outcomes. Although methane is a precursor to tropospheric ozone we have excluded studies that focus exclusively on methane emissions from this topic. However, studies that address methane *and* non-methane volatile organic compound (VOC) emissions have been included, given the health-damaging dimensions of a number of VOCs (i.e., benzene, toluene, ethylbenzene, xylene, etc.) and the role of VOCs in the production of tropospheric ozone, a strong respiratory irritant. The few studies that have explored the health implications of air pollution emissions and exposure levels are included in both this category and the public health category. The papers in this topic are those that specifically address air emissions and air quality from well stimulation-enabled oil and gas development (i.e., unconventional oil and gas development) at either a local or regional scale. These include local and regional measurements of non-methane volatile organic compounds and tropospheric ozone.

3. Results

Health

Based on our criteria, we included 16 original research studies relevant to questions involving associations between shale gas development and public health outcomes. Of these 16 studies, 14 (87%) identified potential public health risks or actual observed poor public health outcomes and 2 (13%) found no indication of significant public health risks or actual adverse health outcomes (Figure 2). When we included commentaries and review papers in the analysis, 47 of 49 (96%) indicated potential or actual public health hazards or risks (Figure 3). The vast majority of all papers in this topic indicate the need for additional study, particularly large-scale, quantitative epidemiologic research.

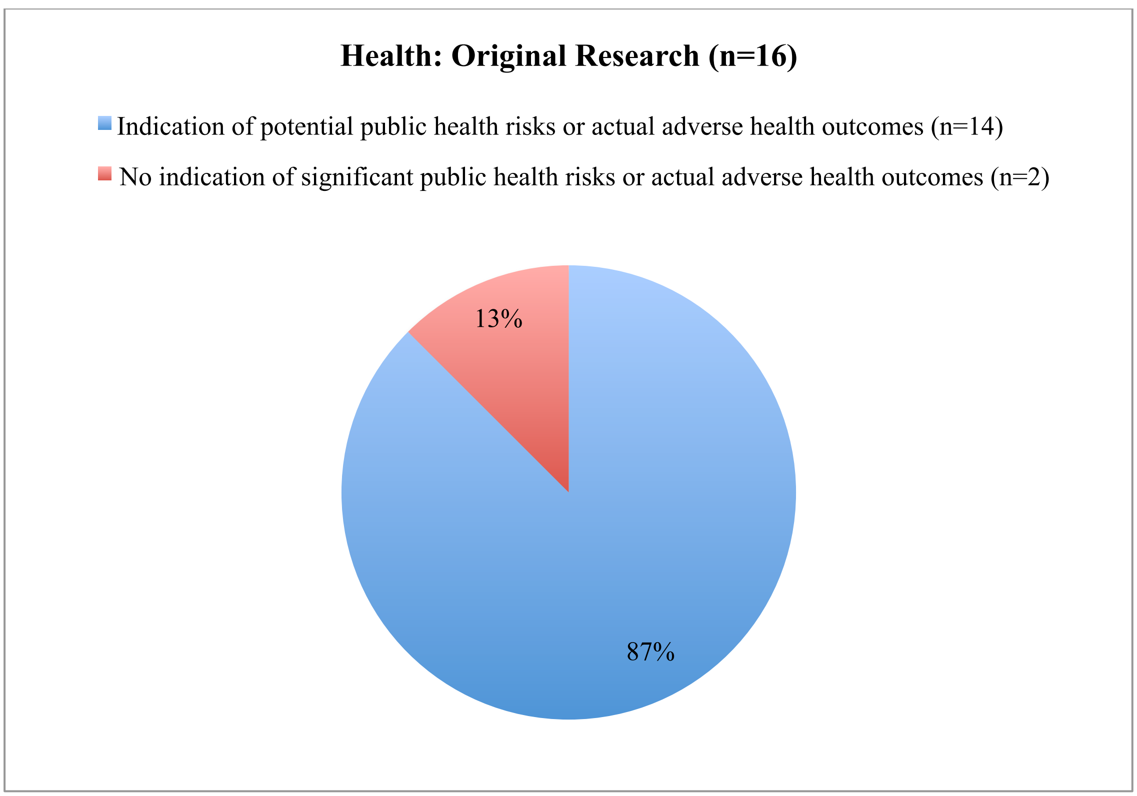

Figure 2. Peer-reviewed publications on the human health dimensions of shale gas development (original research)

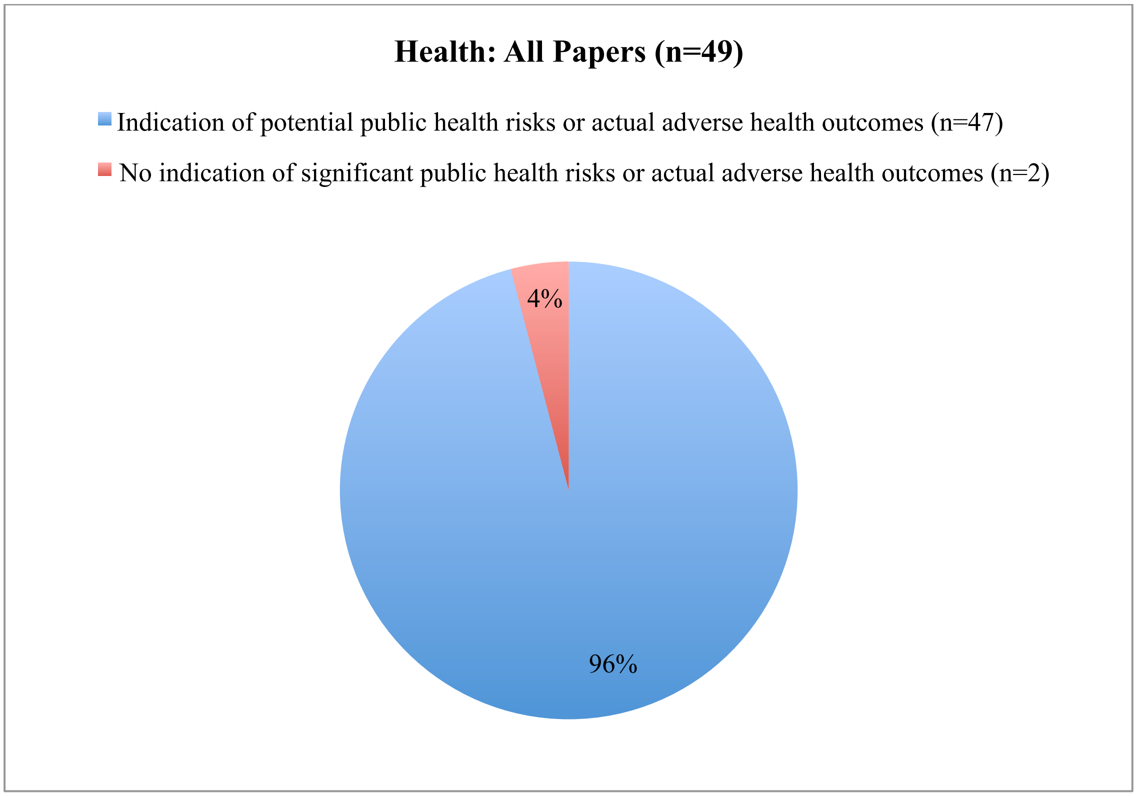

Figure 3. Peer-reviewed publications on the human health dimensions of shale gas development (original research, commentaries, and reviews)

Water Quality

Based on our criteria, we included 30 original research studies relevant to shale gas development and water contamination. Of these 30 studies, 22 (73%) showed indication of potential, positive association, or actual incidence of water contamination associated with shale gas development, while 8 (27%) showed indication of minimal potential, negative association, or rare incidence of water contamination (Figure 4).

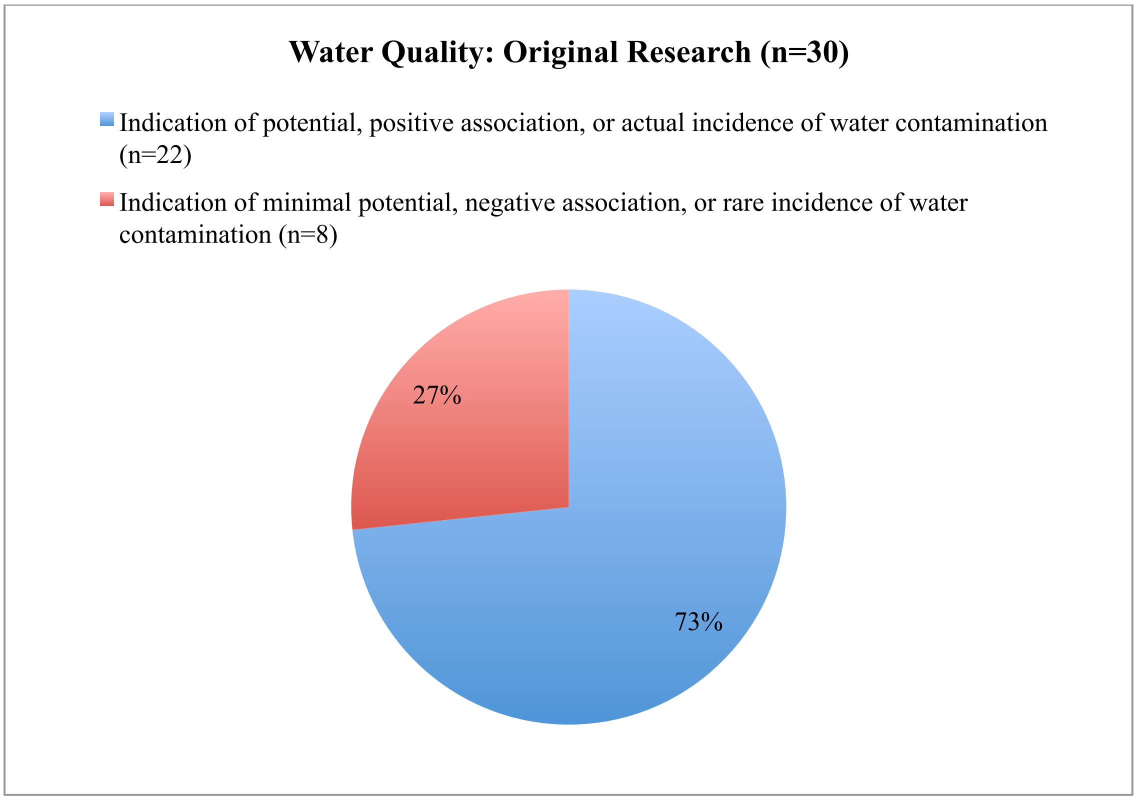

Figure 4. Peer-reviewed publications on shale gas development and water quality contamination (original research)

Air Quality

Based on our criteria, we included 23 original research studies relevant to questions involving associations between shale and tight gas development and air pollutant emissions and atmospheric air pollutant concentrations. Of these 26 studies, 24 (92%) showed indications of elevated air pollutant emissions and/or atmospheric concentrations, while 2 (8%) of the studies showed no indication of significantly elevated air pollutant emissions and/or atmospheric concentrations (Figure 5).

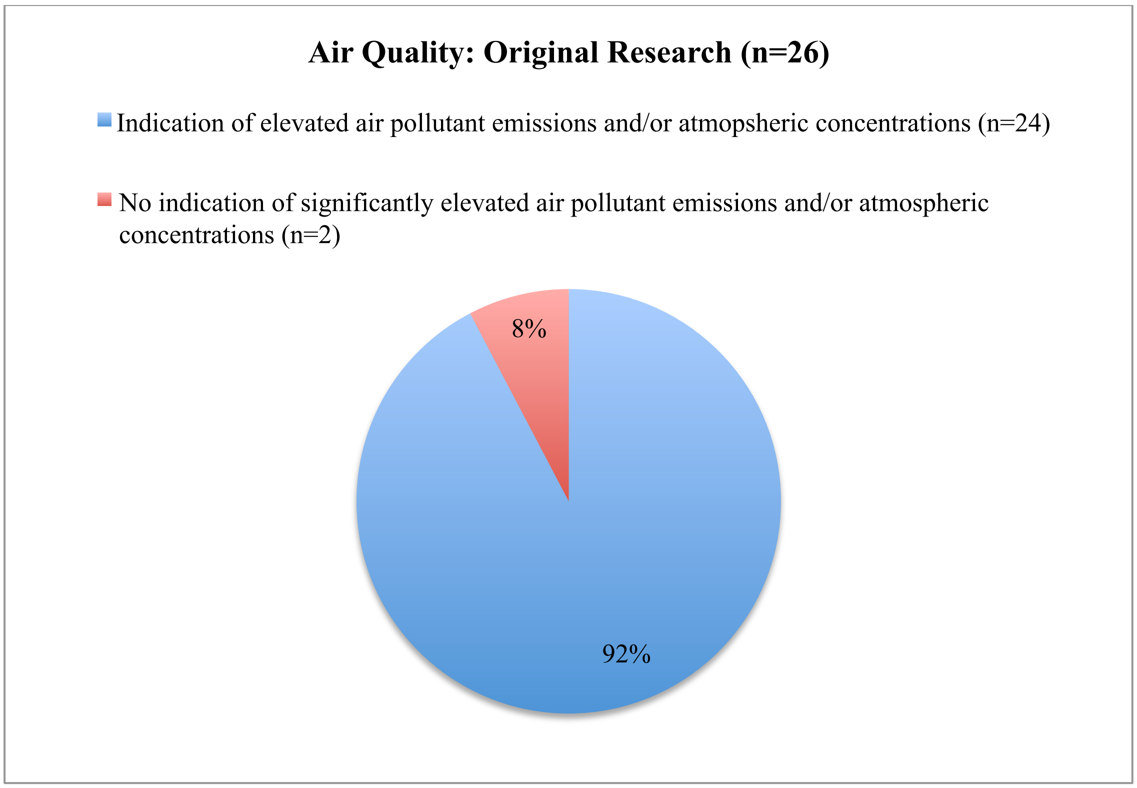

Figure 5. Peer-reviewed publications on shale and tight gas development and air pollutant emissions/air quality degradation (original research)

4. Discussion

In this analysis, we reviewed the direction of findings among papers that assessed the association between shale and tight gas development and air, water, and public health impacts. In each subject area, we found that the majority of studies indicated negative impacts of shale and/or tight gas development on the outcome of interest. Scientific consensus is not yet achievable given comparison limitations due to differences in geological, geographic, engineering, and other attributes, as well as methodological differences between studies. However, these results indicate that shale and tight gas development has known environmental and public health hazards and risks. Regulators, policy makers, and others who are charged with determining how, where, when, and if the development of shale gas should be deployed in their jurisdictional boundaries should take these findings into account.

There are clear limitations to this analysis. It provides just an overview of existing scientific studies based on the world's experience with shale gas development from 1 January 2009 to 31 December 2014. While our database is to our best estimation exhaustive, our literature search may not have captured all relevant scientific literature. Additionally, differences in geography may render some studies less relevant when interpreted across geographic and geological space.

Despite the inherent limitations, our analysis provides a general idea of the weight of the scientific evidence of possible impacts arising from shale gas development. It is important to note that this analysis only concerns itself with current empirical evidence and does not take into account developments that could potentially influence environmental and public health outcomes in positive or negative ways under different regulatory regimes. For instance, technological improvements may mitigate some existing problems, but as development continues, well pad intensities increase, and novel geologies and practices are encountered, impacts may increase.

Finally, all forms of energy production and industrial processing have environmental impacts. This report is only focused on reviewing and presenting the available science on some of the most salient environmental and public health concerns associated with shale gas development. We make no claims about the level of impacts that should be tolerated by society – these are ultimately questions of value.

Appendix

Health: Original Research (n=16)
• *Indication of potential public health risks or actual adverse health outcomes (n=14)*

1. Bamberger M, Oswald RE. 2012. Impacts of Gas Drilling on Human and Animal Health. NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy 22:51–77; doi:10.2190/NS.22.1.e.
2. Colborn T, Kwiatkowski C, Schultz K, Bachran M. 2011. Natural Gas Operations from a Public Health Perspective. Human and Ecological Risk Assessment: An International Journal 17:1039–1056; doi:10.1080/10807039.2011.605662.
3. Colborn T, Schultz K, Herrick L, Kwiatkowski C. 2014. An Exploratory Study of Air Quality near Natural Gas Operations. Human and Ecological Risk Assessment: An International Journal 0:null; doi:10.1080/10807039.2012.749447.
4. Esswein EJ, Breitenstein M, Snawder J, Kiefer M, Sieber WK. 2013. Occupational exposures to respirable crystalline silica during hydraulic fracturing. J Occup Environ Hyg 10:347–356; doi:10.1080/15459624.2013.788352.
5. Esswein EJ, Snawder J, King B, Breitenstein M, Alexander-Scott M, Kiefer M. 2014. Evaluation of Some Potential Chemical Exposure Risks During Flowback Operations in Unconventional Oil and Gas Extraction: Preliminary Results. Journal of Occupational and Environmental Hygiene 11:D174–D184; doi:10.1080/15459624.2014.933960.
6. Ferrar KJ, Kriesky J, Christen CL, Marshall LP, Malone SL, Sharma RK, et al. 2013. Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region. International Journal of Occupational and Environmental Health 19:104–112; doi:10.1179/2049396713Y.0000000024.
7. Kassotis CD, Tillitt DE, Davis JW, Hormann AM, Nagel SC. 2013. Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region. Endocrinology 155:897–907; doi:10.1210/en.2013-1697.
8. Macey GP, Breech R, Chernaik M, Cox C, Larson D, Thomas D, et al. 2014. Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environmental Health 13:82; doi:10.1186/1476-069X-13-82.
9. McKenzie LM, Guo R, Witter RZ, Savitz DA, Newman LS, Adgate JL. 2014. Birth Outcomes and Maternal Residential Proximity to Natural Gas Development in Rural Colorado. Environmental Health Perspectives 122; doi:10.1289/ehp.1306722.
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11. Rabinowitz PM, Slizovskiy IB, Lamers V, Trufan SJ, Holford TR, Dziura JD, et al. 2014. Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania. Environmental Health Perspectives; doi:10.1289/ehp.1307732.
12. Saberi P, Propert KJ, Powers M, Emmett E, Green-McKenzie J. 2014. Field Survey of Health Perception and Complaints of Pennsylvania Residents in the Marcellus Shale Region. Int J Environ Res Public Health 11:6517–6527; doi:10.3390/ijerph110606517.
13. Steinzor N, Subra W, Sumi L. 2013. Investigating Links between Shale Gas Development and Health Impacts Through a Community Survey Project in Pennsylvania. NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy 23:55–83; doi:10.2190/NS.23.1.e.
14. Williams JF, Lundy JB, Chung KK, Chan RK, King BT, Renz EM, et al. 2014. Traumatic Injuries Incidental to Hydraulic Well Fracturing: A Case Series. Journal of Burn Care & Research 1; doi:10.1097/BCR.0000000000000219.

- *No indication of significant public health risks or actual adverse health outcomes (n = 2)*

1. Bunch AG, Perry CS, Abraham L, Wikoff DS, Tachovsky JA, Hixon JG, et al. 2014. Evaluation of impact of shale gas operations in the Barnett Shale region on volatile organic compounds in air and potential human health risks. Science of The Total Environment 468–469:832–842; doi:10.1016/j.scitotenv.2013.08.080.
2. Fryzek J, Pastula S, Jiang X, Garabrant DH. 2013. Childhood cancer incidence in pennsylvania counties in relation to living in counties with hydraulic fracturing sites. J. Occup. Environ. Med. 55:796–801; doi:10.1097/JOM.0b013e318289ee02.

Health: All Papers (n=49)

- *Indication of potential public health risks or actual adverse health outcomes (n=47)*

1. Adgate JL, Goldstein BD, McKenzie LM. 2014. Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development. Environ. Sci. Technol. 48:8307–8320; doi:10.1021/es404621d.
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3. Bamberger M, Oswald RE. 2014. Unconventional oil and gas extraction and animal health. Environ. Sci.: Processes Impacts; doi:10.1039/C4EM00150H.
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12. Finkel M, Hays J, Law A. 2013a. The Shale Gas Boom and the Need for Rational Policy. American Journal of Public Health e1–e3; doi:10.2105/AJPH.2013.301285.
13. Finkel ML, Hays J. 2013. The implications of unconventional drilling for natural gas: a global public health concern. Public Health 127:889–893; doi:10.1016/j.puhe.2013.07.005.
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Water Quality: Original Research (n=30)
• *Indication of potential, positive association, or actual incidence of water contamination (n=22)*

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Air Quality: Original Research (n=26)

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- *No indication of significantly elevated air pollutant emissions and/or atmospheric concentrations (n=2)*

1. Bunch AG, Perry CS, Abraham L, Wikoff DS, Tachovsky JA, Hixon JG, et al. 2014. Evaluation of impact of shale gas operations in the Barnett Shale region on volatile organic compounds in air and potential human health risks. Science of The Total Environment 468–469:832–842; doi:10.1016/j.scitotenv.2013.08.080.
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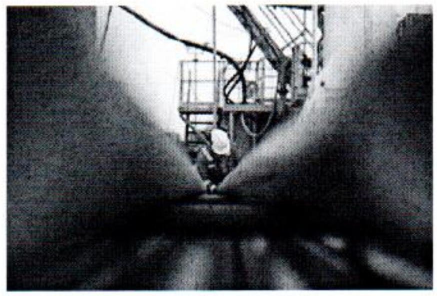
Fracking
Gas Drilling's Environmental Threat

Drilling for Certainty: The Latest in Fracking Health Studies

ProPublica surveys some recent research on potential health implications of hydro fracking.

by Naveena Sadasivam
ProPublica, March 5, 2014, 11:02 a.m.

For years, environmentalists and the gas drilling industry have been in a pitched battle over the possible health implications of hydro fracking. But to a great extent, the debate — as well as the emerging lawsuits and the various proposed regulations in numerous states — has been hampered by a shortage of science.


(Bartek Sadowski/Bloomberg via Getty Images)

In 2011, when ProPublica first reported on the different health problems afflicting people living near gas drilling operations, only a handful of health studies had been published. Three years later, the science is far from settled, but there is a growing body of research to consider.

Below, ProPublica offers a survey of some of that work. The studies included are by no means a comprehensive review of the scientific literature. There are several others that characterize the chemicals in fracking fluids, air emissions and waste discharges. Some present results of community level surveys.

Yet, a long-term systematic study of the adverse effects of gas drilling on communities has yet to be undertaken. Researchers have pointed to the scarcity of funding available for large-scale studies as a major obstacle in tackling the issue.

A review of health-related studies published last month in *Environmental Science & Technology* concluded that the current scientific literature puts forward "both substantial concerns and major uncertainties to address."

Still, for some, waiting for additional science to clarify those uncertainties before adopting more serious safeguards is misguided and dangerous. As a result, a number of researchers and local activists have been pushing for more aggressive oversight immediately.

The industry, by and large, has regarded the studies done to date — a number of which claim to have found higher rates of illness among residents living close to drilling wells — as largely anecdotal and less than convincing.

"The public health sector has been absent from this debate," said Nadia Steinzor, a researcher on the Oil and Gas Accountability Project at the environmental nonprofit, Earthworks.

Departments of health have only become involved in states such as New York and Maryland where regulators responded to the public's insistence on public health and environmental reviews before signing off on fracking operations. The states currently have a moratorium on fracking.

New York State Health Commissioner Nirav Shah is in fact conducting a review of health studies to present to Governor Andrew Cuomo before he makes a decision on whether to allow fracking in the state. It is unclear when the results of the review will be publicly available.

Other states such as Pennsylvania and Texas, however, have been much more supportive

Other states such as Pennsylvania and Texas, however, have been much more supportive of the gas industry. For instance, Texas has been granting permits for fracking in ever increasing numbers while at the same time the Texas Commission on Environmental Quality, the agency that monitors air quality, has had its budget cut substantially.

1. An Exploratory Study of Air Quality near Natural Gas Operations. *Human and Ecological Risk Assessment, 2012.*

The study, performed in Garfield County, Colo., between July 2010 and October 2011, was done by researchers at The Endocrine Disruption Exchange, a non-profit organization that examines the impact of low-level exposure to chemicals on the environment and human health.

In the study, researchers set up a sampling station close to a well and collected air samples every week for 11 months, from when the gas wells were drilled to after it began production. The samples produced evidence of 57 different chemicals, 45 of which they believe have some potential for affecting human health.

In almost 75 percent of all samples collected, researchers discovered methylene chloride, a toxic solvent that the industry had not previously disclosed as present in drilling operations. The researchers noted that the greatest number of chemicals were detected during the initial drilling phase.

While this study did catalogue the different chemicals found in air emissions from gas drilling operations, it did not address exposure levels and their potential effects. The levels found did not exceed current safety standards, but there has been much debate about whether the current standards adequately address potential health threats to women, children and the elderly.

The researchers admitted their work was compromised by their lack of full access to the drilling site. The air samples were collected from a station close to what is known as the well pad, but not the pad itself.

The gas drilling industry has sought to limit the disclosure of information about its operations to researchers. They have refused to publicly disclose the chemicals that are used in fracking, won gag orders in legal cases and restricted the ability of scientists to get close to their work sites. In a highly publicized case last year, a lifelong gag order was imposed on two children who were parties to a legal case that accused one gas company of unsafe fracking operations that caused them to fall sick.

In 2009, the Independent Petroleum Association of America started Energy In Depth, a blog that confronts activists who are fighting to ban fracking and challenges research that in any way depicts fracking as unsafe.

Energy In Depth responded to this Garfield County study and criticized its lack of proper methodology. The blog post also questioned the objectivity of the researchers, asserting that their "minds were already made up."

The industry has also been performing its own array of studies.

Last year, for instance, an industry-funded study on the methane emissions from fracking wells was published in the prestigious journal, *Proceedings of the National Academy of Sciences*. It concluded that only very modest amounts of methane — a known contributor to climate change — was being emitted into the air during fracking operations.

The study came under heavy criticism from Cornell researcher Robert Howarth, who two years prior had published work that claimed methane emissions from shale gas operations were far more significant.

"This study is based only on evaluation of sites and times chosen by industry," he said.

2. Birth Outcomes and Natural Gas Development. *Environmental Health Perspectives, 2014.*

The study examined babies born from 1996 to 2009 in rural Colorado locations — the state has been a center of fracking for more than a decade. It was done by the Colorado School of Public Health and Brown University.

The study asserted that women who lived close to gas wells were more likely to have children born with a variety of defects, from oral clefts to heart issues. For instance, it claimed that babies born to mothers who lived in areas dense with gas wells were 30 percent more likely to have congenital heart defects.

The researchers, however, were unable to include data on maternal health, prenatal care, genetics and a host of other factors that have been shown to increase the risk of birth defects because that information was not publicly available. A common criticism of many scientific studies is that they do not fully analyze the possibility of other contributing factors.

The study has thus come under attack from both the industry and state public health officials. In a statement, Dr. Larry Wolk, the state's Chief Medical Officer, said "people should not rush to judgment" as "many factors known to contribute to birth defects were ignored" in the study.

But Lisa McKenzie, one of the lead authors of the study, said there was value to the work.

"What I think this is telling us is that we need to do more research to tease out what is happening and to see if these early studies hold up when we do more rigorous research," she said.

In Pennsylvania, Elaine Hill, a graduate student at Cornell University, obtained data on gas wells and births between 2003 and 2010. She then compared birth weights of babies born in areas of Pennsylvania where a well had been permitted but never drilled and areas where wells had been drilled. Hill found that the babies born to mothers within 2.5 kilometers (a little over 1.5 miles) of drilled gas sites were 25 percent more likely to have low birth weight compared to those in non-drilled areas. Babies are considered as having low birth weight if they are under 2500 grams (5.5 pounds).

Hill's work is currently under review by a formal scientific journal, a process that could take three or four years.

3. Health Risks and Unconventional Natural Gas Resources. *Science of the Total Environment, 2012.*

Between January 2008 and November 2010, researchers at the Colorado School of Public Health collected air samples in Garfield County, Colo., which has been experiencing intensive drilling operations. Researchers found the presence of a number of hydrocarbons including benzene, trimethylbenzene and xylene, all of which have been shown to pose health dangers at certain levels.

Researchers maintained that those who lived less than half a mile from a gas well had a higher risk of health issues. The study also found a small increase in cancer risk and alleged that exposure to benzene was a major contributor to the risk.

"From the data we had, it looked like the well completion phase was the strongest contributor to these emissions," said Lisa McKenzie, the lead author of the study.

During the completion phase of drilling, a mixture of water, sand and chemicals is forced down the well at high pressure, and is then brought back up. The returning mixture, which contains radioactive materials and some of the natural gas from the geological formation, is supposed to be captured. But at times the mixture comes back up at pressures higher than the system can handle and the excess gas is directly vented into the air.

"I think we ought to be focused on the whole thing from soup to nuts because a lot of the potential hazards aren't around the hydraulic fracturing step itself," said John Adgate, chair of the Department of Environmental and Occupational Health at the Colorado School of Public Health and co-author on the study.

Energy In Depth, the industry blog, responded at length to this study and cited several "bad inputs" which had affected the results of the study. The researchers' assumptions and data were criticized. For instance, the researchers had assumed that Garfield residents would remain in the county until the age of 70 in order to estimate the time period over which they would be exposed to the emissions.

"Unless the 'town' is actually a prison, this is a fundamentally flawed assumption about the length and extent of exposure," Energy In Depth said.

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Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania

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Background: Little is known about the environmental and public health impact of unconventional natural gas extraction activities, including hydraulic fracturing, that occur near residential areas.

Objectives: Our aim was to assess the relationship between household proximity to natural gas wells and reported health symptoms.

Methods: We conducted a hypothesis-generating health symptom survey of 492 persons in 180 randomly selected households with ground-fed wells in an area of active natural gas drilling. Gas well proximity for each household was compared with the prevalence and frequency of reported dermal, respiratory, gastrointestinal, cardiovascular, and neurological symptoms.

Results: The number of reported health symptoms per person was higher among residents living < 1 km (mean ± SD, 3.27 ± 3.72) compared with > 2 km from the nearest gas well (mean ± SD, 1.60 ± 2.14; $p = 0.0002$). In a model that adjusted for age, sex, household education, smoking, awareness of environmental risk, work type, and animals in house, reported skin conditions were more common in households < 1 km compared with > 2 km from the nearest gas well (odds ratio = 4.1; 95% CI: 1.4, 12.3; $p = 0.01$). Upper respiratory symptoms were also more frequently reported in persons living in households < 1 km from gas wells (39%) compared with households 1–2 km or > 2 km from the nearest well (31 and 18%, respectively) ($p = 0.004$). No equivalent correlation was found between well proximity and other reported groups of respiratory, neurological, cardiovascular, or gastrointestinal conditions.

Conclusion: Although these results should be viewed as hypothesis generating, and the population studied was limited to households with a ground-fed water supply, proximity of natural gas wells may be associated with the prevalence of health symptoms including dermal and respiratory conditions in residents living near natural gas extraction activities. Further study of these associations, including the role of specific air and water exposures, is warranted.

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Introduction

Unconventional methods of natural gas extraction, including directional drilling and hydraulic fracturing (also known as "fracking"), have made it possible to reach natural gas reserves in shale deposits thousands of feet underground (Myers 2012). Increased drilling activity in a number of locations in the United States has led to growing concern that natural gas extraction activities could contaminate water supplies and ambient air, resulting in unforeseen adverse public health effects (Goldstein et al. 2012). At the same time, there is little peer-reviewed evidence regarding the public health risks of natural gas drilling activities (Kovats et al. 2014; McDermott-Levy and Kaktins 2012; Mitka 2012), including a lack of systematic surveys of human health effects.

The process of natural gas extraction. Natural gas extraction of shale gas reserves may involve multiple activities occurring over a period of months. These include drilling and casing of deep wells that contain both vertical and horizontal components as well as placement of underground explosives and transport and injection of millions of gallons of water containing sand and a number of chemical additives into the wells at high pressures to extract gas from the shale deposits (hydraulic fracturing) (Jackson RE et al. 2013). Chemicals used in the hydraulic fracturing process can include inorganic acids, polymers, petroleum distillates, anti-scaling compounds, microbicides, and surfactants (Vidic et al. 2013). Although some of these fluids are recovered during the fracking process as "flowback" or "produced" water, a significant amount (as much as 90%) (Vidic et al. 2013) may remain underground. The recovered flowback water—which may contain chemicals added to the fracking fluid as well as naturally occurring chemicals such as salts, arsenic, and barium and naturally occurring radioactive material originating in the geological formations—may be stored in holding ponds or transported offsite for disposal and/or wastewater treatment elsewhere.

Potential water exposures. Although much of the hydraulic fracturing process takes place deep underground, there are a number of potential mechanisms for chemicals used in the fracturing process as well as naturally occurring minerals, petroleum compounds (including volatile organic compounds; VOCs), and other substances of flowback water (Chapman et al. 2012) to enter drinking-water supplies. These include spills during transport of chemicals and flowback water, leaks of a well casing (Kovats et al. 2014), leaks through underground fissures in rock formations, runoff from drilling sites, and disposal of fracking flowback water (Rozell and Reaven 2012). Studies have reported increased levels of methane in drinking water wells located < 1 km from natural gas drilling, suggesting contamination of water wells from hydraulic

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P.M.R. and J.D.D. had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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fracturing activities (Jackson RB et al. 2013; Osborn et al. 2011), although natural movement of methane and brine from shale deposits into aquifers has also been suggested (Warner et al. 2012). If contaminants from hydraulic fracturing activities were able to enter drinking water supplies or surface water bodies, humans could be exposed to such contaminants through drinking, cooking, showering, and swimming.

Potential air exposures. The drilling and completion of natural gas wells, as well as the storage of waste fluids in containment ponds, may release chemicals into the atmosphere through evaporation and off-gassing. In Pennsylvania, flowback fluids are not usually disposed of in deep injection wells; therefore surface ponds containing flowback fluids are relatively common and could be sources of air contamination through evaporation. Flaring of gas wells, operation of diesel equipment and vehicles, and other point sources for air quality contamination around drilling activities may also pose a risk of respiratory exposures to nitrogen oxides, VOCs, and particulate matter. Release of ozone precursors into the environment by natural gas production activities may lead to increases in local ozone levels (Olaguer 2012). Well completion and gas transport may cause leakage of methane and other greenhouse gases into the environment (Allen 2014). Studies in Colorado have reported elevated air levels of VOCs including trimethylbenzenes, xylenes, and aliphatic hydrocarbons related to well drilling activities (McKenzie et al. 2012).

Human health impact. Concerns about the impact of natural gas extraction on the health of nearby communities have included exposures to contaminants in water and air described above as well as noise and social disruption (Witter et al. 2013). A published case series cited the occurrence of respiratory, skin, neurological, and gastrointestinal symptoms in humans living near gas wells (Bamberger and Oswald 2012). A convenience sample survey of 108 individuals in 55 households across 14 counties in Pennsylvania who were concerned about health effects from natural gas facilities found that a number of self-reported symptoms were more common in individuals living near gas facilities, including throat and nasal irritation, eye burning, sinus problems, headaches, skin problems, loss of smell, cough, nosebleeds, and painful joints (Steinzor et al. 2013). Similarly, a convenience sample survey of 53 community members living near Marcellus Shale development found that respondents attributed a number of health impacts and stressors to the development. Stress was the symptom reported most frequently (Ferrar et al. 2013).

Here we report on the analysis of a cross-sectional, random-sample survey of the health of residents who had ground-fed water wells in the vicinity of natural gas extraction wells to determine whether proximity to gas wells was associated with reported respiratory, dermal, neurological, or gastrointestinal symptoms.

Methods

Selection of study area. The Marcellus formation, a principal source of shale-based natural gas in the United States, is a Middle Devonian–age black, low-density, organically rich shale that has been predominantly horizontally drilled for gas extraction in the southwestern portion of Pennsylvania since 2003 [Pennsylvania Spatial Data Access (PASDA) 2013]. In this study we focused on Washington County in southwestern Pennsylvania, an area of active natural gas drilling (Carter et al. 2011). At the time of the administration of the household survey during summer 2012, there were, according to the Pennsylvania Department of Environmental Protection, 624 active natural gas wells in Washington County. Of these natural gas wells, 95% were horizontally drilled (Pennsylvania Department of Environmental Protection 2012). The county has a highly rural classification with nearly 40% of the land devoted to agriculture (U.S. Department of Agriculture 2007). Washington County has a population of approximately 200,000 persons with 94% self-identified as white, 90% having at least a high school diploma, and a 2012 median household income of $53,545 (Center for Rural Pennsylvania 2014). We selected a contiguous set of 38 rural townships within the center of Washington County as our study site in order to avoid urban areas bordering Pittsburgh, which would be unlikely to have ground-fed water wells, and areas near the Pennsylvania border, which might be influenced by gas wells in other states (Figure 1).

Survey instrument. We designed a community environmental health assessment of reported health symptoms and health status based on questions drawn from publicly available surveys. Symptom questions, covering a range of organ systems that had been mentioned in published reports (Bamberger and Oswald 2012; Steinzor et al. 2013), asked respondents whether they or any household members had experienced each condition during the past year (see Supplemental Material, "Questionnaire"). The health assessment also asked a number

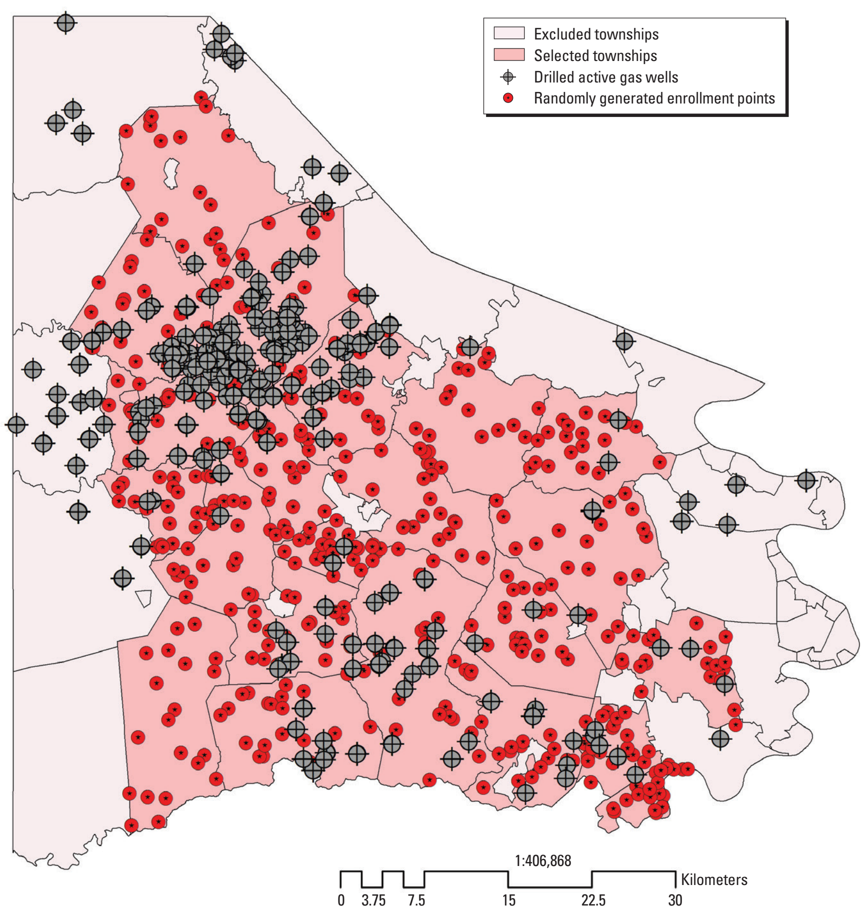

Figure 1. Distribution of drilled active Marcellus Shale natural gas wells (*n* = 624) and randomly generated sampling sites (*n* = 760) for eligible municipalities of Washington County, Pennsylvania.

of general yes/no questions about concerns of environmental hazards in the community, such as whether respondents were satisfied with air quality, water quality, soil quality, environmental noise and odors, and traffic, but did not specifically mention natural gas wells or hydraulic fracturing or other natural gas extraction activities. The survey was pretested with focus groups in the study area in collaboration with a community based group and revised to ensure comprehensibility of questions.

Selection and recruitment of households. Using ArcGIS Desktop 10.0 software (ESRI, Inc., Redlands, CA), we randomly selected 20 geographic points from each of 38 contiguous townships in the study county (Figure 1). We identified an eligible home nearest to each randomly generated sampling point, and visited each home to determine which households were occupied and had ground-fed water wells. We selected households with ground-fed water wells to assess possible health effects related to water contamination. From the original 760 points identified (i.e., 20 points in each of the 38 townships), we excluded 12 duplicate points and 64 points found not to correspond to a house structure (see Supplemental Material, Figure S1). After site visits by the study team who spoke to residents or neighbors, we excluded house locations determined not to have a ground-fed well or spring. Additional points were excluded if the structure was not occupied ($n = 5$) or inaccessible from the road ($n = 4$). During visits to eligible households, a study member invited a responding adult at least 18 years of age to participate in the survey, described as a survey of community environmental health that considered a number of environmental health factors. Three households were excluded when the respondent was unable to answer the questionnaire due to language or health problems. Eligible households were offered a small cash stipend for participation.

The Yale University School of Medicine Human Research Protection Program determined the study to be exempt from Human Subjects review. Respondents provided oral consent but were not asked to sign consent forms; their names were not recorded.

Of the 255 eligible households, respondents refused to complete the survey in 47 households, and we were not able to contact residents in another 26 households. Reasons for refusal included "not interested" ($n = 8$), "no time/too busy" ($n = 3$), "afraid" ($n = 1$), and 35 gave no reason. The rate of refusal varied by distance category, with 12 of 74 (16%) of households < 1 km from a gas well, 10 of 67 (15%) of households 1–2 km from wells, and 25 of 86 (25%) of eligible households > 2 km from a gas well refusing to participate, but the differences were not statistically significant. At the consenting 180 households (71% of eligible households), an adult respondent completed the survey covering the health status of the 492 individuals living in these households.

Administration of survey at residence. Trained study personnel administered the survey in English. The responding adult at the participating household reported on the health status of all persons in the household over the past year. A study team member recorded the global positioning system (GPS) coordinates of the household using a Garmin GPSMAP® 62S Series handheld GPS device (Garmin International, Inc., Olathe, KS). Survey personnel were not aware of the mapping results for gas well proximity to the households being surveyed.

Household proximity to nearest active gas well and age of wells. A map of 624 active natural gas wells in the study area, and their age and type, was created by utilizing gas well permit data publicly available at the PASDA (2013). Ninety five percent of the gas wells had "spud dates" (first date of drilling) between 2008 and 2012, with more than half of spud dates occurring in 2010 and 2011. We used ArcGIS to calculate the distance between each household location (as defined by the GPS reading taken during the site visit) and each natural gas well in the study area. We then classified households according to their distance from the nearest gas well with distance categories of < 1 km, 1–2 km, or > 2 km. We used 1 km as the initial cut point for distance to a nearest gas well because of the reported association of higher methane levels in drinking-water wells located < 1 km from natural gas wells (Osborn et al. 2011), and 2 km as the second cut point because it was close to the mean of the distances between households and nearest gas wells. The mean and median distance between a household and the nearest natural gas well were 2.0 km and 1.4 km, respectively. We classified the age of each gas well as the time interval between spud date and the date that the household survey was conducted during summer, 2012.

Statistical analysis. Demographic variables were analyzed for differences among individuals between distance categories using chi-square, analysis of variance, or generalized linear mixed-model statistics as appropriate. Reported occupation was classified as either blue collar, office sales and service, management/professional, or not working, using classifications of the U.S. Bureau of Labor Statistics (2014).

The prevalence of each outcome and the number of symptoms reported for each household member included in the study were calculated according to the distance of each household (< 1, 1–2, or > 2 km) from the nearest gas well. To test the association between household distance from a well and the overall number of symptoms as well as the presence or absence of each of six groups of health conditions (dermal, upper respiratory, lower respiratory, gastrointestinal, neurological, and cardiovascular), we used SAS 9.3 in a generalized linear mixed model (GLMM) analysis (SAS Institute Inc., Cary, NC). The analysis used maximum likelihood estimation with adaptive quadrature methods (Schabenberger 2007) including a random effect for household to account for the clustering of individuals within a household. The model was adjusted for age of individual (continuous), sex (binary), average adult household education (continuous), smoker present in household (yes/no), awareness of environmental hazard nearby (yes/no), employment type (four categories), and whether animals were present in the home or backyard (yes/no). Given the exploratory nature of this study, no adjustments were made for multiple comparisons and significance was established at the two-sided 0.05 level. Statistical analyses were conducted using SAS 9.3.

Results

Demographics. Individuals living in households < 1 km from gas wells were older (mean, 46.9 ± 21.9) compared with individuals in households > 2 km from a gas well (mean, 40.0 ± 23.5 years, $p = 0.03$) (Table 1). There was a higher proportion of children in the households > 2 km from a gas well compared with those < 1 km from a gas well (27% vs. 14%, $p = 0.008$). Families had lived in their homes an average of 22.8 ± 17.2 years at the time of the interview. Thirty-four percent of individuals had blue-collar jobs and 38% of the subjects were nonworkers (e.g., unemployed, students). Sixty-six percent reported using their ground-fed water (well or natural spring) for drinking water, and 84% reported using it for other activities such as bathing. The age of the nearest gas well was significantly greater for households < 1 km from a gas well (mean, 2.3 ± 1.6) compared with those 1–2 km or > 2 km from a well (1.5 ± 1.3 and 1.1 ± 0.9, respectively, $p < 0.05$). Reported smoking was less common in households near gas wells, whereas reported respondent awareness regarding environmental health risks was higher, although these differences were not statistically significant.

Reported health symptoms. The average number of reported symptoms per person in residents of households < 1 km from a gas well (3.27 ± 3.72) was greater compared with those living > 2 km from gas wells (1.60 ± 2.14, $p = 0.0002$).

Individuals living in households < 1 km from natural gas wells were more likely to report having any of the queried skin conditions over the past year (13%) than residents of households > 2 km from a well (3%; χ^2 = 13.8, p = 0.001) (Table 2). Reported upper respiratory symptoms were also more frequent among households < 1 km (39%) compared with households > 2 km from gas wells (18%; χ^2 = 17.9, p = 0.0001).

In a hierarchical model that adjusted for age, sex, household education level, smokers in household, job type, animals in household, and awareness of environmental risk (Table 3), household proximity to natural gas wells remained associated with number of symptoms reported per person < 1 km (p = 0.002) and 1–2 km (p = 0.05) compared with > 2 km from gas wells, respectively. In similar models, living in a household < 1 km from the nearest gas well remained associated with increased reporting of skin conditions [odds ratio (OR) = 4.13; 95% confidence interval (CI): 1.38, 12.3] and upper respiratory symptoms (OR = 3.10; 95% CI: 1.45, 6.65) compared with households > 2 km from the nearest gas well.

For the other grouped symptom complexes examined, there was not a significant relationship in our adjusted model between the prevalence of symptom reports and proximity to nearest gas well. In the multivariate model, however, environmental risk awareness was significantly associated with report of all groups of symptoms.

Age of the nearest gas well was found to be negatively correlated with distance (r = –0.325; p < 0.0001): Gas wells < 1 km from households tended to be older than the nearest wells in other distance categories. When age of wells was added to the multivariate model, proximity to gas wells remained significantly associated with respiratory symptoms, but the association between proximity and dermal symptoms lost statistical significance.

Discussion

This spatially random health survey of households with ground-fed water supply in a region with a large number of active natural gas wells is to our knowledge the largest study to date of the association of reported symptoms and natural gas drilling activities. We found an increased frequency of reported symptoms over the past year in households in closer proximity to active gas wells compared with households farther from gas wells. This association was also seen for certain categories of symptoms, including skin conditions and upper respiratory symptoms. This association persisted even after adjusting for age, sex, smokers in household, presence of animals in the household, education level, work type, and awareness of environmental risks. Other groups of reported symptoms, including cardiac, neurological, or gastrointestinal symptoms, did not show a similar association with gas well proximity. These results support the need for further investigation of whether natural gas extraction activities are associated with community health impacts.

These findings are consistent with earlier reports of respiratory and dermal conditions in persons living near natural gas wells (Bamberger and Oswald 2012; Steinzor et al. 2013). Strengths of the study included the larger sample size compared with previously published surveys, and the random method of selecting households using geographic information system methodology, which reduces the possibility of selection bias (although only a subset of households, those with ground-fed water supply, were sampled).

A limitation of the study was the reliance on self-report of health symptoms. On one hand, symptoms in other household members may have been underreported by the household respondent; on the other hand, awareness bias in individuals concerned about the presence of an environmental health hazard would be more likely to increase reporting of illness symptoms, leading to recall bias of the results. We did not collect data on whether individuals were receiving financial compensation for gas well drilling on their property, which could have affected their willingness to report symptoms. It is possible that differential refusal to participate could have introduced potential for selection bias; for example, individuals who were receiving compensation for gas drilling on their property might be less willing to participate in the survey. We found instead that the refusal rate, though < 25% overall, was higher among households farther from gas wells, suggesting that such households may have been less interested in participating because they had less awareness of hazards. The study questionnaire did not include questions about natural gas extraction activities, in order to reduce awareness bias. At the same time, it is likely that household residents were aware of gas drilling activities in the vicinity of households; and the fact that reported environmental awareness by respondents was associated with the prevalence of all groups of reported health symptoms suggests a correlation between heightened awareness of health risks and reported health conditions. Nevertheless, the observed association between gas well proximity and reported dermal and upper respiratory symptoms persisted in the multivariate model even after adjusting for environmental awareness. Future studies should attempt to medically confirm particular diagnoses and further assess and control for the effect of awareness on reported health status.

Table 1. Demographics and household characteristics by proximity to the nearest natural gas well.

Characteristic	< 1 km	1–2 km	> 2 km	All
Individuals				
n	150	150	192	492
Sex				
Male	80 (53)	78 (52)	92 (48)	250 (51)
Female	70 (47)	72 (48)	100 (52)	242 (49)
Children	21 (14)*	27 (18)	52 (27)	100 (20)
Education (years)	13.4 ± 2.0	13.5 ± 1.9	13.3 ± 2.0	13.4 ± 1.9
Age (years)	46.9 ± 21.9**	45.5 ± 22.7	40.0 ± 23.5	43.8 ± 23.0
Occupation[a]				
M/P	29 (19)	34 (23)	33 (17)	96 (19)
O/S	17 (11)	11 (7)	14 (7)	42 (9)
BC	60 (40)	51 (34)	56 (29)	167 (34)
NW	44 (29)	54 (36)	89 (46)	187 (38)
Households				
n	62	57	61	180
Smoking[b]	7 (11)	12 (21)	14 (23)	33 (18)
Years in household (*n*)	23.7 ± 16.6	23.5 ± 16.4	21.2 ± 18.6	22.8 ± 17.2
Body mass index (kg/m^2)	27.9 ± 5.1	27.5 ± 5.4	27.9 ± 6.1	27.8 ± 5.5
Use ground-fed water				
Drinking	39 (63)	41 (72)	38 (62)	118 (66)
Other	54 (87)	51 (89)	46 (75)	151 (84)
Water has unnatural appearance	13 (21)	7 (12)	6 (10)	26 (14)
Taste/odor prevents water use	14 (23)	10 (18)	19 (31)	43 (24)
Dissatisfied with odor in environment	7 (11)	1 (2)	1 (2)	9 (5)
Environmental risk awareness[c]	16 (25)	16 (28)	9 (15)	41 (23)
Years since spud date of closest well (years)	2.3 ± 1.6[#]	1.5 ± 1.3	1.1 ± 0.9	1.6 ± 1.4

Values are *n* (%) or mean ± SD.
[a]Participant occupation was categorized into six main industries according to the U.S. Bureau of Labor Statistics (2014), and presented here in four main groups: M/P, management or professional; O/S, office, sales, or service; BC, blue collar (fishing, farming, and forestry; construction, extraction, maintenance, production, transportation, and material moving); NW, nonworker (student, disabled, retired, or unemployed). [b]Household smoking was determined when respondents were asked if they or at least one member of their household smoked cigarettes in the house at the time of the survey. [c]Household respondents were asked if they were aware of any environmental health risks near their residence (yes/no), to approximate potential sources of expectation or awareness bias. *p = 0.008 compared with > 2 km households. **p = 0.03 compared with > 2 km households. [#]p < 0.05 compared with 1–2 km and > 2 km households.

A further study limitation was the fact that our analysis includes multiple comparisons between groups of households, and the consequent possibility that random error could account for some of our findings. We limited such comparisons by grouping individual symptoms into organ system clusters. However, we acknowledge that the multiple comparisons used in the methodology mean that any such particular findings should be viewed as preliminary and hypothesis generating.

Our use of gas well proximity as a measure of exposure was an indirect measure of potential water or airborne exposures. More precise data could come from direct monitoring and modeling of air and water contaminants, and correlating such measured exposures with confirmed health effects should be a focus of future study. Biomonitoring of individuals living near natural gas wells could provide additional information about the role and extent of particular chemical exposures.

There are several potential explanations for the finding of increased skin conditions among inhabitants living near gas wells. One is that natural gas extraction wells could have caused contamination of well water through breaks in the gas well casing or other underground communication between ground water supplies and fracking activities. The geographic area studied has experienced petroleum and coal exploration and extraction activities in the past century, and such activities may increase the risk of chemicals in fracking fluid or flowback water entering ground water and contaminating wells. If such contamination did occur, several types of chemicals in fracking fluid have irritant properties and could potentially cause skin rashes or burning sensation through exposure during showers or baths. There are published reports of associations between the prevalence of eczema and other skin conditions with exposure to drinking water polluted with chemicals including VOCs (Chaumont et al. 2012; Lampi et al. 2000; Yorifuji et al. 2012) as well as changes in water hardness (Chaumont et al. 2012; McNally et al. 1998).

A second possible explanation for the skin symptoms could be exposure to air pollutants including VOCs, particulates, and ozone from upwind sources, such as flaring of gas wells (McKenzie et al. 2012) and exhaust from vehicles and heavy machinery.

A third possibility to explain the clustering of skin and other symptoms would be that they could be related to stress or anxiety that was greater for households living near gas wells. In this study, awareness of environmental risk was independently associated with overall reporting of symptoms as well as reporting of skin problems. However, in multivariate models, proximity to gas wells remained a significant predictor of symptoms even when adjusting for such awareness. These results argue for possible air or water contaminant exposures, in addition to stress, contributing to the observed patterns of increased health symptoms in households near gas wells. A fourth possibility would be the role of allergens or irritant chemicals not related to natural gas drilling activities, such as exposure to agricultural chemicals or household animals. We did not see a correlation between skin conditions and either the presence of an animal in the household or agricultural occupation, making this association less likely. At the same time, it is possible that other confounding could be present but not accounted for in our models.

Table 2. Prevalence of selected health conditions reported by individuals by proximity to the nearest gas well (2011–2012).[a]

Symptoms	< 1 km (*n* = 150)	1–2 km (*n* = 150)	> 2 km (*n* = 192)
Total number of symptoms per individual	3.27 ± 3.72	2.56 ± 3.26	1.60 ± 2.14
Dermal [*n* (%)]	19 (13)	7 (5)	6 (3)
Rashes/skin problems	10 (7)	7 (5)	6 (3)
Dermatitis	6 (4)	5 (3)	2 (1)
Irritation	6 (4)	2 (1)	1 (1)
Burning	8 (5)	4 (3)	1 (1)
Itching	9 (6)	5 (3)	2 (1)
Hair loss	2 (1)	0 (0)	1 (1)
Upper respiratory [*n* (%)]	58 (39)	46 (31)	35 (18)
Allergies/sinus problems	35 (23)	27 (18)	27 (14)
Cough/sore throat	10 (7)	3 (2)	2 (1)
Itchy eyes	19 (13)	22 (15)	10 (5)
Nose bleeds	13 (9)	8 (5)	4 (2)
Stuffy nose	16 (11)	8 (5)	4 (2)
Lower respiratory [*n* (%)]	29 (19)	29 (19)	27 (14)
Asthma/COPD	16 (11)	21 (14)	15 (8)
Chronic bronchitis	8 (5)	2 (1)	2 (1)
Chest wheeze/whistling	6 (4)	9 (6)	7 (4)
Shortness of breath	8 (5)	7 (5)	8 (4)
Chest tightness	4 (3)	6 (4)	5 (3)
Cardiac [*n* (%)]	46 (31)	39 (26)	37 (19)
High blood pressure	38 (25)	33 (22)	29 (15)
Chest pain	8 (5)	5 (3)	6 (3)
Heart palpitations	10 (7)	7 (5)	4 (2)
Ankle swelling	11 (7)	5 (3)	5 (3)
Gastrointestinal [*n* (%)]	15 (10)	13 (9)	11 (6)
Ulcers/stomach problems	11 (7)	7 (5)	8 (4)
Liver problems	4 (3)	0 (0)	1 (0.5)
Nausea/vomiting	1 (1)	3 (2)	1 (0.5)
Abdominal pain	4 (3)	2 (1)	2 (1)
Diarrhea	5 (3)	2 (1)	2 (1)
Bleeding	4 (3)	4 (3)	0 (0)
Neurologic [*n* (%)]	48 (32)	37 (25)	39 (20)
Neurologic problems	1 (0.7)	5 (3)	0 (0)
Severe headache/migraine	24 (16)	14 (9)	18 (9)
Dizziness/balance problems	11 (7)	12 (8)	11 (6)
Depression	4 (3)	3 (2)	2 (1)
Difficulty concentrating/remembering	9 (6)	9 (6)	6 (3)
Difficulty sleeping/insomnia	18 (12)	19 (13)	10 (5)
Anxiety/nervousness	11 (7)	4 (3)	11 (6)
Seizures	2 (1)	2 (1)	1 (0.5)

COPD, chronic obstructive pulmonary disease.
[a]Six categories representing major health conditions of *a priori* interest chosen to ascertain symptom prevalence among individuals living in proximity to the nearest gas well in 2011–2012.

Table 3. Associations of nearest gas well proximity and symptoms.

	< 1 km		1–2 km		
Outcome	OR (95% CI)	*p*-Value	OR (95% CI)	*p*-Value	> 2 km
Dermal	4.13 (1.38, 12.3)	0.011	1.44 (0.42, 4.9)	0.563	Ref
Upper respiratory	3.10 (1.45, 6.65)	0.004	1.76 (0.81, 3.76)	0.148	Ref
Lower respiratory	1.45 (0.67, 3.14)	0.339	1.40 (0.65, 3.03)	0.387	Ref
Cardiac	1.67 (0.85, 3.26)	0.135	1.28 (0.65, 2.52)	0.473	Ref
Gastrointestinal	2.01 (0.49, 8.18)	0.328	1.79 (0.43, 7.41)	0.417	Ref
Neurological	1.53 (0.89, 2.63)	0.123	1.04 (0.59, 1.82)	0.885	Ref

Ref, reference. Results are from hierarchical logistic regression that adjusted for age, household education level, sex, smokers in household, job type, animals in household, and awareness of environmental risk.

Our findings of increased reporting of upper respiratory symptoms among persons living < 1 km from a natural gas well suggests that airborne irritant exposures related to natural gas extraction activities could be playing a role. Such irritant exposures could result from a number of activities related to natural gas drilling, including flaring of gas wells and exhaust from diesel equipment. Because other studies have suggested that airborne exposures could be a significant consequence of natural gas drilling activity, further investigation of the impact of such activities on respiratory health of nearby communities should be investigated. Future studies should collect such data.

Since most of the gas wells in the study area had been drilled in the past 5–6 years, one would not yet expect to see associations with diseases with long latency, such as cancer. Furthermore, if some of the impact of natural gas extraction on ground water happens over a number of years, this initial survey could have failed to detect health consequences of delayed contamination. However, if the finding of skin and respiratory conditions near gas wells indicates significant exposure to either fracking fluids and chemicals or airborne contaminants from natural gas wells, studies looking at such long-term health effects in chronically exposed populations would be indicated.

Conclusions

The results of this study suggest that natural gas drilling activities could be associated with increased reports of dermal and upper respiratory symptoms in nearby communities; these results support the need for further research into health effects of natural gas extraction activities. Such research could include longitudinal assessment of the health of individuals living in proximity to natural gas drilling activities, medical confirmation of health conditions, and more precise assessment of contaminant exposures.

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