Preconceptional, gestational, and lactational exposure to an unconventional oil and gas chemical mixture alters energy expenditure in adult female mice


ABSTRACT

Previous studies conducted in our laboratory have found altered adult health outcomes in animals with prenatal exposure to environmentally relevant levels of unconventional oil and gas (UOG) chemicals with endocrine-disrupting activity. This study aimed to examine potential metabolic health outcomes following a preconception, prenatal and postnatal exposure to a mixture of 23 UOG chemicals. Prior to mating and from gestation day 1 to postnatal day 21, C57BL/6J mice were developmentally exposed to a laboratory-created mixture of 23 UOG chemicals in maternal drinking water. Body composition, spontaneous activity, energy expenditure, and glucose tolerance were evaluated in 7-month-old female offspring. Neither body weight nor body composition differed in 7-month female mice. However, females exposed to 1.5 and 150 µg/kg/day UOG mix had lower total and resting energy expenditure within the dark cycle. In the light cycle, the 1500 µg/kg/day group had lower total energy expenditure and the 1.5 µg/kg/day group had lower resting energy expenditure. Females exposed to the 150 µg/kg/day group had lower spontaneous activity in the dark cycle, and females exposed to the 1500 µg/kg/day group had lower activity in the light cycle. This study reports for the first time that developmental exposure to a mixture of 23 UOG chemicals alters energy expenditure and spontaneous activity in adult female mice.

FUNDING: Funding was received from NIH R21ES026395 (SN), R01ES021394-04S1 (SN and VB), and from the department of Obstetrics, Gynecology and Women's Health, University of Missouri (SN and VB), VA-Merit Grant I01BX003271-01 (RR), and NIH DK086940 (JT), VA Merit Award I01BX002567-01 (JT), and United States Environmental Protection Agency Science To Achieve Results Fellowship Assistance Agreement FP-91747101 (CK). We wish to thank members of the Nagel lab for helping with animal husbandry, particularly Sierra Baxter, Brittany Parmenter, Leighton McCabe, Anne Maas, Katelyn Cinnamon, and Kara Klemp.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal; experimental

EXPOSURE ROUTES: oral

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: 2-(2-methoxyethoxy)ethanol; 2-ethylhexanol; acrylamide; benzene; BTEX; BPA; bronopol; cumene; diethanolamine; ethoxylated nonylphenol; ethoxylated octylphenol; ethylbenzene; ethylene glycol; ethylene glycol monobutyl ether (2-BE); naphthalene; n,n-dimethylformamide; phenol; propylene glycol; styrene; toluene; trimethylbenzenes; triethylene glycol; xylenes

HEALTH EFFECTS: Endocrine system; Mental Health and Behavior; Metabolic; Pregnancy and Reproduction

Surface water and groundwater analysis using aryl hydrocarbon and endocrine receptor biological assays and liquid chromatography-high resolution mass spectrometry in Susquehanna County, PA


ABSTRACT

The contamination of surface water and ground water by human activities, such as fossil fuel extraction and agriculture, can be difficult to assess due to incomplete knowledge of the chemicals and chemistry involved. This is particularly true for the potential contamination of drinking water by nearby extraction of oil and/or gas from wells completed by hydraulic fracturing. A case that has attracted considerable attention is unconventional natural gas extraction in Susquehanna County, Pennsylvania, particularly around Dimock, Pennsylvania. We analyzed surface water and groundwater samples collected throughout Susquehanna County with complementary biological assays and high-resolution mass spectrometry. We found that Ah receptor activity was associated with proximity to impaired gas wells. We also identified certain chemicals, including disclosed hydraulic fracturing fluid additives, in samples that were either in close proximity to impaired gas wells or that exhibited a biological effect. In addition to correlations with drilling activity, the biological assays and high-resolution mass spectrometry detected substances that arose from other anthropogenic sources. Our complementary approach provides a more comprehensive picture of water quality by considering both biological effects and a broad screening for chemical contaminants.

FUNDING: This study was supported by grants from the Claneil Foundation to R. E. O. and the Atkinson Center for a Sustainable Future to R. E. O. and D. E. H., NIH R21ES026395 (S. C. N.) and the University of Missouri (S. C. N. and R. F. K.). The authors would like to thank Drs Adam Law, Gregory A. Weiland, and John Dennis for helpful discussions. There are no conflicts to declare.
Shedding light on the effects of hydraulic fracturing flowback and produced water on phototactic behavior in Daphnia magna

ABSTRACT

The effluent produced during hydraulic fracturing (i.e. flowback and produced water; FPW), is a complex hyper-saline solution that is known to negatively impact the survival and the fitness of the water flea Daphnia magna, but to date effects on behavior are unstudied. In the current study, the effects of FPW on phototactic behavior of D. magna were examined. Exposure of naïve animals to FPW resulted in a dose-dependent increase in the speed of appearance of daphnids in the illuminated zone of the test apparatus (i.e. a faster positive phototaxis response). A similar dose-dependent response was observed in a test solution where the salt content of FPW was recreated in the absence of other components, suggesting that the effect was largely driven by salinity. The effect of FPW was significant when the raw FPW sample was diluted to 20% of its initial strength, while the effect of salt-matched solution was significant at a 10% dilution. A distinct effect was observed following FPW pre-exposure. After a 24 h pre-exposure to 1.5% FPW, Daphnia displayed a significantly inhibited positive phototaxis response when examined in control water, relative to control animals that were not pre-exposed to FPW. This effect was not observed in salinity pre-exposed animals, however these daphnids displayed a significantly reduced phototactic response when tested in saline waters, indicating a loss of the positive phototaxis seen in naïve organisms. These data indicate that FPW can induce perturbations in the behavior of aquatic invertebrates, an effect that may influence processes such as feeding and predation rates.

FUNDING: The project was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) grant CRDPJ 469308-14. The authors would like to thank Encana Corporation for their support to G.G.G. C.N.G. is supported by a Campus Alberta Innovates Program Research Chair. T.A.B. is supported by an NSERC post-doctoral fellowship. We also thank Katherine Snihur and Dr. Daniel Alessi for their technical assistance. The authors of this present study declare no conflicts of interest.

HEALTH EFFECTS: Endocrine system
The osmotic effect of hyper-saline hydraulic fracturing fluid on rainbow trout, Oncorhynchus mykiss


ABSTRACT

Flowback and produced water (FPW) is a complex, often brackish, solution formed during the process of hydraulic fracturing. Despite recent findings on the short-term toxicity of FPW on aquatic biota, longer-term impacts of FPW on fish have not yet been investigated and the mechanisms of chronic effects remain unknown. The aim of the present study was to observe the effect of a diluted FPW on ionoregulatory endpoints in the rainbow trout Oncorhynchus mykiss, following a 28-d sub-chronic exposure. A salinity-matched control solution (SW), recreating the salt content of the FPW, was used to differentiate the specific effect of the salts from the effects of the other FPW components (i.e. organics and metals). Overall, fish ionoregulation was not impacted by the chronic exposure. An accumulation of strontium (Sr) and bromide (Br) occurred in the plasma of the FPW-exposed fish only, however no change of plasma ions (Na, K, Cl, Ca, Mg) was observed in SW- or FPW-exposed fish. Similarly, exposures did not alter branchial activity of the osmoregulatory enzymes sodium/potassium ATPase and proton ATPase. Finally, FPW exposure resulted in modifications of gill morphology over time, with fish exposed to the fluid displaying shorter lamellae and increased interlamellar-cell mass. However, these effects were not distinct from morphological changes that also occurred in the gills of control groups.

FUNDING: This project was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development Grant CRDPJ 469308-14 to DSA and GGG with Encana Corporation providing additional support with sample collection and delivery. Dr. Chris N. Glover is supported by a Campus Alberta Innovates Program Research Chair. Dr. Tamzin Blewett is supported by an NSERC post-doctoral fellowship. The authors would like to thank the staff of the University of Alberta Aquatic Facility for their assistance in housing the rainbow trout, as well as Alyssa Weinrauch and Arlene Oatway for their assistance and technical help with the histological analysis. The authors of this present study declare no conflicts of interest.


ABSTRACT

Objectives: To examine relationships between short-term and long-term exposures to unconventional natural gas development, commonly known as fracking, and county hospitalization rates for a variety of broad disease categories. Study design: This is an ecological study based on county-level data for Pennsylvania, United States, 2003–2014. Methods: We estimated multivariate regressions with county and year fixed effects, using two 12-year panels: all 67 Pennsylvania counties and 54 counties that are not large metropolitan. Results: After correcting for multiple comparisons, we found a positive association of cumulative well density (per km2) with genitourinary hospitalization rates. When large metropolitan counties were excluded, this relationship persisted, and positive associations of skin-related hospitalization rates with cumulative well count and well density were observed. The association with genitourinary hospitalization rates is driven by females in 20–64 years group, particularly for kidney infections, calculus of ureter, and urinary tract infection. Contemporaneous wells drilled were not significantly associated with hospitalizations after adjustment for multiple comparisons. Conclusions: Our study shows that long-term exposure to unconventional gas development may have an impact on prevalence of hospitalizations for certain diseases in the affected populations and identifies areas of future research on unconventional gas development and health.
Increased energy demands and innovations in upstream oil and natural gas (ONG) extraction technologies have enabled the United States to become one of the world’s leading producers of petroleum and natural gas hydrocarbons. The US Environmental Protection Agency (EPA) lists 187 hazardous air pollutants (HAPs) that are known or suspected to cause cancer or other serious health effects. Several of these HAPs have been measured at elevated concentrations around ONG sites, but most have not been studied in the context of upstream development. In this review, we analyzed recent global peer-reviewed articles that investigated HAPs near ONG operations to (a) identify HAPs associated with upstream ONG development, (b) identify their specific sources in upstream processes, and (c) examine the potential for adverse health outcomes from HAPs emitted during these phases of hydrocarbon development.
ABSTRACT

Unconventional natural gas development (UNGD), which includes the processes of horizontal drilling and hydraulic fracturing to extract natural gas from unconventional reservoirs such as shale, has dramatically expanded since 2000. In parallel, concern over environmental and community impacts has increased along with the threats they pose for health. Shale gas reservoirs are present on all continents, but only a small proportion of global reserves has been extracted through 2016. Natural gas production from UNGD is highest in the United States in Pennsylvania, Texas, Louisiana, Oklahoma, and Arkansas. But unconventional production is also in practice elsewhere, including in eighteen other U.S. states, Canada, and China. Given the rapid development of the industry coupled with its likelihood of further growth and public concern about potential cumulative and long-term environmental and health impacts, it is important to review what is currently known about these topics. The environmental impacts from UNGD include chemical, physical, and psychosocial hazards as well as more general community impacts. Chemical hazards commonly include detection of chemical odors; volatile organic compounds (including BTEX chemicals [benzene, toluene, ethylbenzene, and xylene], and several that have been implicated in endocrine disruption) in air, soil, and surface and groundwater; particulate matter, ozone, and oxides of nitrogen (NOx) in air; and inorganic compounds, including heavy metals, in soil and water, particularly near wastewater disposal sites. Physical hazards include noise, light, vibration, and ionizing radiation (including technologically enhanced naturally occurring radioactive materials [TENORMs] in air and water), which can affect health directly or through stress pathways. Psychosocial hazards can also operate through stress pathways and include exposure to increases in traffic accidents, heavy truck traffic, transient workforces, rapid industrialization of previously rural areas, increased crime rates, and changes in employment opportunities as well as land and home values. In addition, the deep-well injection of wastewater from UNGD has been associated with increased seismic activity. These environmental and community impacts have generated considerable concern about potential health effects and corresponding political debate over whether UNGD should be promoted, regulated, or banned. For several years after the expansion of the industry, there were no well-designed, population-based studies that objectively measured UNGD activity or associated exposures in relation to health outcomes. This delay is inherent after the introduction of new industries, but hundreds of thousands of wells were drilled before any health studies were completed. By 2017, there were a number of important, peer-reviewed studies published in the scientific literature that raised concern about potential ongoing health impacts. These studies have reported associations between proximity to UNGD and pregnancy and birth outcomes; migraine headache, chronic rhinosinusitis, severe fatigue, and other symptoms; asthma exacerbations; and psychological and stress-related concerns. Beyond its direct health impacts, UNGD may be substantially contributing to climate change (due to fugitive emissions of methane, a powerful greenhouse gas), which has further health impacts. Certain health outcomes, such as cancer and neurodegenerative diseases, cannot yet be studied because insufficient time has passed in most regions since the expansion of UNGD to allow for latency considerations. With the potential for tens of thousands of additional wells across large geographic areas, these early health studies should give pause about whether and how UNGD should proceed. Citing health concerns, several U.S. states and nations in Europe have already decided to not allow UNGD.

FUNDING: Not addressed

PUBLICATION TYPE: book chapter

EVIDENCE STREAMS: human: non-occupational; human: population health

EXTERNAL EXPOSURES: air; spills/leaks; surface water; wastewater; well density/drilling activity

STATES/COUNTRIES: CO; OH; PA; TX

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Acute Toxicity/Poisoning; Blood, Heart, and Circulation; Brain and Nerves; Cancers; Digestive System; Endocrine system; Eyes, Ears, Nose, and Throat; Kidneys and Urinary System; Lungs and Breathing; Mental Health and Behavior; Metabolic; Pregnancy and Reproduction; Sexual Health Issues; Skin, Hair, and Nails
compared to children with no wells (2nd tertile PPR: 1.34, 95% CI: 0.93, 1.93; 3rd tertile PPR: 1.20, 95% CI: 0.82, 1.75). We observed no association with CCHD or oral clefts overall. Specific CCHDs of common truncus, transposition of the great arteries, pulmonary valve atresia and stenosis, tricuspid valve atresia and stenosis, interrupted aortic arch, and total anomalous pulmonary venous connection were increased among those living in areas with natural gas activity compared to those living in areas without activity, though not statistically significant. Discussion: Our results were similar to previous studies for NTDs and specific CCHDs. Future directions include evaluating the association between specific phases of the drilling process and congenital anomalies to better refine the relevant exposure period.

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PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: well density/drilling activity

STATES/COUNTRIES: OK

GAS/OIL: conventional; natural gas; unconventional

HEALTH EFFECTS: Pregnancy and Reproduction; Brain and Nerves; Blood, Heart, and Circulation

Impact of upstream oil extraction and environmental public health: A review of the evidence


ABSTRACT

Upstream oil extraction, which includes exploration and operation to bring crude oil to the surface, frequently occurs near human populations. There are approximately 40,000 oil fields globally and 6 million people that live or work nearby. Oil extraction can impact local soil, water, and air, which in turn can influence community health. As oil resources are increasingly being extracted near human populations, we highlight the current scope of scientific knowledge regarding potential community health impacts with the aim to help identify scientific gaps and inform policy discussions surrounding oil drilling operations. In this review, we assess the wide range of both direct and indirect impacts that oil drilling operations can have on human health, with specific emphasis on understanding the body of scientific literature to assess potential environmental and health risks to residents living near active onshore oil extraction sites. From an initial literature search capturing 2236 studies, we identified 22 human studies, including 5 occupational studies, 5 animal studies, 6 experimental studies and 31 oil drilling-related exposure studies relevant to the scope of this review. The current evidence suggests potential health impacts due to exposure to upstream oil extraction, such as cancer, liver damage, immunodeficiency, and neurological symptoms. Adverse impacts to soil, air, and water quality in oil drilling regions were also identified. Improved characterization of exposures by community health studies and further study of the chemical mixtures associated with oil extraction will be critical to determining the full range of health risks to communities living near oil extraction.

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PUBLICATION TYPE: review

EVIDENCE STREAMS: human: population health; human: occupational; human: non-occupational; animal: wildlife; animal: pets; animal: livestock; animal: experimental

EXTERNAL EXPOSURES: wastewater; surface water; soil; drinking water; air

STATES/COUNTRIES: United States; Tunisia; Trinidad and Tobago; Russia; Peru; Oman; Nigeria; Kuwait; Kazakhstan; Italy; Iraq; Iran; India; Ecuador; Colombia; China; Bolivia; Australia

GAS/OIL: conventional; oil; unconventional

HEALTH EFFECTS: Skin, Hair, and Nails; Pregnancy and Reproduction; Mental Health and Behavior; Lungs and Breathing; Kidneys and Urinary System; Immune System; Eyes, Ears, Nose, and Throat; Endocrine system; Digestive System; Cancers; Brain and Nerves; Bones, Joints, and Muscles; Blood, Heart, and Circulation
The impact of several hydraulic fracking chemicals on Nile tilapia and evaluation of the protective effects of Spirulina platensis


ABSTRACT

Hydraulic fracturing (fracking) chemicals are used to maximize the extraction of hard-to-reach underground energy resources. Large amounts of fracking fluid could escape to the surrounding environments, including underground and surface water resources, during the chemical mixing stage of the hydraulic fracturing water cycle due to equipment failure or human error. However, the impact of pollution resulting from operational discharges is difficult to assess in aquatic ecosystems. In this study, pathological investigations, chromosomal aberrations, DNA damage, and biochemical and hematological parameters were used to evaluate the effects of such chemicals on Nile tilapia. Chromosomal aberrations are considered very sensitive genetic markers of exposure to genotoxic chemicals and are used as indicators of DNA damage. The appearance of different types of chromosomal aberrations (gaps and breaks) due to chemical exposure was significantly reduced by treatment with spirulina. Various deleterious findings in Nile tilapia, in the current study, could attributed to the presence of fracking chemicals in the aquatic environment. However, the presence of spirulina in the diet reduced the hazards of such chemicals. In addition, cytogenetic studies in the current work revealed the importance of spirulina in ameliorating the genotoxic effects of a mixture of some chemicals used in fracking.

FUNDING: The authors would like to express their gratitude to Prof. R. Tolba, director of the Department for Laboratory Animal Science, and Dr. J. Steitz and Dr. P. K. Srinivasan at the Department for Laboratory Animal Science, University Hospital, RWTH Aachen, Germany, for their continuous encouragement, valuable advice, and help in the production of this article. Funding and conflict of interest not addressed.

Does fracking drive you to drink? Unconventional oil and gas production and alcohol consumption in U.S. counties.


ABSTRACT

Unconventional drilling technologies like hydraulic fracturing and directional drilling have markedly increased oil and gas production in the United States while also bringing production in proximity with many communities. Foundational research in rural sociology predicts the rise of local “boontown” problems like excessive alcohol consumption as a result of sudden energy booms. In this paper, we use data from U.S. counties to understand the relationship between energy production and alcohol consumption. Results suggest that oil and gas production has very modest effects on binge drinking and heavy drinking, and that these effects may vary by gender and across U.S. states.

FUNDING: not addressed
HEALTH EFFECTS: Mental Health and Behavior

Developmental exposure to chemicals associated with unconventional oil and gas extraction alters immune homeostasis and viral immunity of the amphibian Xenopus


ABSTRACT

Although aquatic vertebrates and humans are increasingly exposed to water pollutants associated with unconventional oil and gas extraction (UOG), the long-term effects of these pollutants on immunity remains unclear. We have established the amphibian Xenopus laevis and the ranavirus Frog Virus 3 (FV3) as a reliable and sensitive model for evaluating the effects of waterborne pollutants. X. laevis tadpoles were exposed to a mixture of equimass amount of UOG chemicals with endocrine disrupting activity (0.1 and 1.0 μg/L) for 3 weeks, and then long-term effects on immune function at steady state and following viral (FV3) infection was assessed after metamorphosis. Notably, developmental exposure to the mixture of UOG chemicals at the tadpole stage affected metamorphic development and fitness by significantly decreasing body mass after metamorphosis completion. Furthermore, developmental exposure to UOGs resulted in perturbation of immune homeostasis in adult frogs, as indicated by significantly decreased number of splenic innate leukocytes, B and T lymphocytes; and a weakened antiviral immune response leading to increased viral load during infection by the ranavirus FV3. These findings suggest that mixture of UOG-associated waterborne endocrine disruptors at low but environmentally–relevant levels have the potential to induce long-lasting alterations of immune function and antiviral immunity in aquatic vertebrates and ultimately human populations.

FUNDING: We thank Tina Martin for animal husbandry. This work was supported by the National Institute of Allergy and Infectious Diseases at the National Institutes of Health (grant number: R24-AI-059830), the National Science Foundation (grant number: IOS-1754274) and a Pilot Project Grant from the Rochester Environmental Health Sciences Center (P30-ES01247). C. M. is supported by the Toxicology Program (T32-ES07026).

PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: experimental

EXPOSURE ROUTES: dermal

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: 2-(2-methoxyethoxy)ethanol; 2-ethylhexanol; 2-methyl-4-isothiazolin-3-one; acrylamide; benzene; BTEX; bronopol; cumene; diethanolamine; ethoxylated nonylphenol; ethoxylated octylphenol; ethylbenzene; ethylene glycol; ethylene glycol monobutyl ether (2-BE); naphthalene; n,n-dimethylformamide; phenol; propylene glycol; sodium tetraborate decahydrate; styrene; toluene; trimethylbenzenes; triethylene glycol; xylenes

HEALTH EFFECTS: Immune System; Mortality; Pregnancy and Reproduction

Greenness index evaluation of fracking chemicals using SDS (Safety Data Sheet) information


ABSTRACT

The fracking industry faces various challenges although technologies have been advanced in the hydraulic fracturing and horizontal drilling. Treatment for the water used after the fracking process is one of the key issues preventing hydraulic fracturing from being widely implemented. Especially the chemicals that are used for various purposes during fracturing remain in the water that flows back to the surface. Reports have been seen that the problematic chemicals used in the fracking process cause HSE (Health, Safety and Environment) issues. Before any chemical used in the fracking is eliminated or replaced with alternatives, its greenness should be evaluated. A tool called Greenness Index was used in this study to evaluate several typical chemicals used in the current fracking process. SDS (Safety Data Sheet) information was used by Greenness Index to assess the chemicals. It was found that with similar amount of SDS information available, citric acid is relatively greener than ammonium persulfate. SDS information of guar gum is less than that of citric acid and ammonium persulfate, but the evaluation for guar gum still indicates that it is a green chemical based on the limited data from its SDS. When more information with respect to how they behave during the fracking process is available, Greenness Index can provide more comprehensive evaluations.

FUNDING: Not addressed.

PUBLICATION TYPE: original research
A critical review of risks, characteristics, and treatment strategies for potentially toxic elements in wastewater from shale gas extraction


ABSTRACT

Shale gas extraction via horizontal drilling and hydraulic fracturing (HF) has enhanced gas production world-wide, which has altered global energy markets and reduced the prices of natural gas and oil. Water management has become the most challenging issue of HF, as it demands vast amounts of freshwater and generates high volumes of complex liquid wastes contaminated by diverse potentially toxic elements at variable rates. This critical review focuses on characterizing HF wastewater and establishing strategies to mitigate environmental impacts. High prioritization was given to the constituents with mean concentrations over 10 times greater than the maximum contamination level (MCL) guidelines for drinking water. A number of potentially harmful organic compounds in HF wastewaters were identified via the risk quotient approach to predict the associated toxicity for freshwater organisms in recipient surface waters. Currently, two options for HF wastewater treatment are preferred, i.e., disposal by deep well injection or on-site re-use as a fracturing fluid. Supplementary treatment will be enforced by increasingly rigorous regulations. Partial treatment and reuse remain the preferred method for managing HF wastewater where feasible. Otherwise, advanced technologies such as membrane separation/distillation, forward osmosis, mechanical vapor compression, electrocoagulation, advanced oxidation, and adsorption-biological treatment will be required to satisfy the sustainable requirements for reuse or surface discharge.

FUNDING: The authors appreciate the financial support from the Hong Kong Research Grants Council (E-PolyU503/17 and PolyU 15222115) for this study. Conflict of interest not addressed.

EXTERIOR EXPOSURES: wastewater

GEOLOGIC FORMATIONS: Bakken Shale; Barnett Shale; Duvernay Formation; Eagle Ford Shale; Marcellus Shale

STATES/COUNTRIES: ND; PA; TX; Canada

CHEMICALS: benzene; benzo(a)pyrene; BTEX; ethylbenzene; heptachlor; naphthalene; PAHs; phenanthrene; styrene; toluene; vinyl chloride; xylenes; chloroform; dibromochloromethane; dioxins; endocrines; heptachlor epoxide; hexachlorobenzene; hexachlorocyclopentadiene; methoxychlor; pentachlorophenol; toxaphene; hexahydro-1,3,5-trimethyl-1,3,5-triazine-2-thione; 2-methylphenanthrene; 1,1,1-trichloroethane; 1,1,2-trichloroethylene; 1,2-dichloroethane; 1,2-dichloropropane; 1,2,4-trichlorobenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; carbon disulfide; carbon tetrachloride; aluminum; arsenic; ammonia; antimony; beryllium; boron; bromide; cadmium; calcium; chloride; chromium; cobalt; copper; cyanide; fluoride; iron; lead; lithium; manganese; magnesium; mercury; molybdenum; nickel; nitrate; nitrite; phosphorus; potassium; rubidium; selenium; silicon; silver; sodium; strontium; sulfate; thallium; vanadium; zinc

HEALTH EFFECTS: Acute Toxicity/Poisoning; Blood, Heart, and Circulation; Bones, Joints, and Muscles; Brain and Nerves; Cancers; Digestive System; Endocrine system; Eyes, Ears, Nose, and Throat; Genotoxicity; Immune System; Kidneys and Urinary System; Lungs and Breathing; Metabolic; Pregnancy and Reproduction; Skin, Hair, and Nails

A systematic assessment of carcinogenicity of chemicals in hydraulic-fracturing fluids and flowback water

ABSTRACT

Service registry numbers for chemicals were used for data linkage. Among 1173 chemicals, 1039 were identified only in HF fluids, 97 only in wastewater, and 37 in both. Compared with IARC, we found information of 104 chemicals and 48 of them may have potentially carcinogenic risk to human, among which 14 are definitely carcinogenic, 7 probably carcinogenic and 27 possibly carcinogenic. Using the CPDB data, it suggests that 66 chemicals are potentially carcinogenic based on rats and mouse models.

FUNDING: The authors declare they have no actual or potential competing financial interests.

PUBLICATION TYPE: review

EVIDENCE STREAMS: human: non-occupational; animal: experimental

EXTERNAL EXPOSURES: wastewater

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: 1,3-butadiene; acrylamide; benzene; benzo(a)pyrene; diethanolamine; ethylbenzene; ethylene glycol monobutyl ether (2-BE); formaldehyde; naphthalene; n,n-dimethylformamide; PAHs; particulate matter; silica; styrene; ethanol; ethylene oxide; beryllium; cadmium; Lindane; radium; arsenic; chromium; acrylamide; epichlorohydrin; hydrazine; dibenz(a,h)anthracene; tetrachloroethylene; dichloromethane; 1,2-propanol; sodium; sodium nitrate; n-dichloroethylene; pentachlorophenol; acetaldehyde; acrylamide; acrylonitrile; chloroform; cobalt; heptachlor; nickel; safrole; 1,4-dioxane; lead; crotonaldehyde; 1,3-dichloropropene; 1-tert-butoxy-2-propanol; 2-butanone oxime; 2-ethyl-1-hexanol; 4-methoxyphenol; acetaldehyde; acrylamide; amaranth; benzyl chloride; coumarin; dapsone; diethylene glycol; d-limonene

HEALTH EFFECTS: Cancers

Assessing residential exposure risk from spills of flowback water from Marcellus Shale hydraulic fracturing activity


ABSTRACT

Identifying sources of concern and risk from shale gas development, particularly from the hydraulic fracturing process, is an important step in better understanding sources of uncertainty within the industry. In this study, a risk assessment of residential exposure pathways to contaminated drinking water is carried out. In this model, it is assumed that a drinking water source is contaminated by a spill of flowback water; probability distributions of spill size and constituent concentrations are fit to historical datasets and Monte Carlo simulation was used to calculate a distribution of risk values for two scenarios: (1) use of a contaminated reservoir for residential drinking water supply and (2) swimming in a contaminated pond. The swimming scenario did not produce risks of concern from a single exposure of 1 h duration, but 11 such 1-h exposures did produce risks of 10−6 due to radionuclide exposure. The drinking water scenario over a 30-year exposure duration produced cancer risk values exceeding 10−6 for arsenic, benzene, benzo(a)pyrene, heptachlor, heptachlor epoxide, pentachlorophenol, and vinyl chloride. However, this extended exposure duration is probably not realistic for exposure by a spill event. Radionuclides produced risks in the residential drinking water scenario of 10−6 in just 8 h, a much more realistic timeline for continual exposure due to a spill event. In general, for contaminants for which inhalation exposure was applicable, this pathway produced the highest risks with exposure from ingestion posing the next greatest risk to human health followed by dermal absorption (or body emersion for radionuclides). Considering non-carcinogenic effects, only barium and thallium exceed target limits, where the ingestion pathway seems to be of greater concern than dermal exposure. Exposure to radionuclides in flowback water, particularly through the inhalation route, poses a greater threat to human health than other contaminants examined in this assessment and should be the focus of risk assessment and risk mitigation efforts.

FUNDING: Funding not addressed. The authors declare no conflict of interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation

EXPOSURE ROUTES: dermal; inhalation; oral

EXTERNAL EXPOSURES: wastewater; spills/leaks; drinking water

GEOLOGIC FORMATIONS: Marcellus Shale

GAS/OIL: natural gas; unconventional
Potential impacts of emissions associated with unconventional hydrocarbon extraction on UK air quality and human health


ABSTRACT

Here, we report the first results of model sensitivity simulations to assess the potential impacts of emissions related to future activities linked to unconventional hydrocarbon extraction (fracking) in the UK on air pollution and human health. These simulations were performed with the Met Office Air Quality in the Unified Model, a new air quality-forecasting model, and included a wide range of extra emissions of volatile organic compounds (VOCs) and nitrogen oxides (NOx) to reflect emissions from the full life cycle of fracking-related activities and simulate the impacts of these compounds on levels of nitrogen dioxide (NO2) and ozone (O3). These model simulations highlight that increases in NOx and VOC emissions associated with unconventional hydrocarbon extraction could lead to large local increases in the monthly means of daily 1-h maximum NO2 of up to + 30 ppb and decreases in the maximum daily 8-h mean O3 up to − 6 ppb in the summertime. Broadly speaking, our simulations indicate increases in both of these compounds across the UK air shed throughout the year. Changes in the 1-h maximum of NO2 and 8-h mean of O3 are particularly important for their human health impacts. These respective changes in NO2 and O3 would contribute to approximately 110 (range 50–530) extra premature-deaths a year across the UK based on the use of recently reported concentration response functions for changes in annual average NO2 and O3 exposure. As such, we conclude that the release of emissions of VOCs and NOx be highly controlled to prevent deleterious health impacts.

FUNDING: We acknowledge the NERC and NCAS for contributing to the funding of the development of the UKCA model which underpins AQUM. ATA also acknowledges NERC grant NE/M00273X/1 for the funding. Conflict of interest not addressed.

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: air

STATES/COUNTRIES: United Kingdom

GAS/OIL: natural gas; unconventional

CHEMICALS: formaldehyde, ozone, toluene, xylenes, VOCs, nitrogen oxides; ethane; propane; butane; ethene; propene; acetaldehyde; acetone; methanol; isoprene

HEALTH EFFECTS: mortality

In vitro nuclear receptor inhibition and cytotoxicity of hydraulic fracturing chemicals and their binary mixtures


ABSTRACT

The widespread use of hydraulic fracturing (HF) in oil and gas extraction operations has led to concern over environmental risks posed by chemicals used in HF fluids. Here we employed a suite of stable luciferase reporter gene assays to investigate the potential for selected HF chemicals or geogenics to activate or antagonise nuclear receptor signalling. We screened three biocides (bronopol [BP], glutaraldehyde [GA], and tetraakis(hydroxymethyl)phosphonium sulfate [THPS]), a surfactant (2-butoxyethanol), a friction reducer (polyacrylamide), and a coal seam geogenic (o-cresol) for their potential to act as agonists or antagonists of the
FUNDING: We thank Debra Gonzago for technical assistance. We are grateful to Simon Apte for critical review of the manuscript and contextual advice. The study was funded by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia.

FUNDING: Funding and conflict of interest not addressed. We thank seminar participants at the RAND DC Health Unit Seminar, FDA Economics Brown Bag, University of Hawaii, the 2016 Population Association of American Annual Meetings, and the 2016 ASHEcon Biannual Meetings for useful comments. We also thank three anonymous referees for their review and invaluable comments that helped improve a previous version of this manuscript. This article reflects the views of the authors and should not be construed to represent FDAs or The Lewin Group's views or policies. No official support or endorsement by the FDA or The Lewin Group is intended or should be inferred.

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ABSTRACT

In the past decade, the technological developments in the oil and natural gas extraction industry made the extraction of shale gas economically feasible and prompted local economic booms across the US. Anecdotal evidence suggests that areas with unconventional gas development experience a disproportionate increase in the young male population who are more likely to be involved in risk-taking behavior. Moreover, the sudden income gains or demographic shifts might increase the demand for various goods and services, including entertainment and illegal activities provided by the adult entertainment industry. We investigate the relationship between unconventional gas development and a variety of risk-taking outcomes such as sexually transmitted infections, and prostitution-related arrests. Our identification strategy exploits the variation in shale gas or unconventional well drilling across time and counties in conjuncture with a number of datasets that allow us to investigate the potential mechanisms. Our findings indicate that Pennsylvania counties with fracking activities have higher rates of gonorrhea and chlamydia infections (7.8% and 2.6%, respectively), as well as higher prostitution related arrests (19.7%). We posit that changes in the labor market and associated impacts to income or composition of workers may play a role in the estimated effects, but we do not find evidence in support of these hypotheses.

FUNDING: Funding and conflict of interest not addressed. We thank seminar participants at the RAND DC Health Unit Seminar, FDA Economics Brown Bag, University of Hawaii, the 2016 Population Association of American Annual Meetings, and the 2016 ASHEcon Biannual Meetings for useful comments. We also thank three anonymous referees for their review and invaluable comments that helped improve a previous version of this manuscript. This article reflects the views of the authors and should not be construed to represent FDAs or The Lewin Group's views or policies. No official support or endorsement by the FDA or The Lewin Group is intended or should be inferred.

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Physical immobility as a sensitive indicator of hydraulic fracturing fluid toxicity towards Daphnia magna


ABSTRACT

The process of extracting hydrocarbon resources by hydraulic fracturing is an increasingly utilised technique worldwide, resulting in an effluent called flowback and produced water (FPW). This effluent is a complex mixture of salts, metals and organic compounds, and has been shown to be highly toxic to aquatic biota, an effect attributed mainly to its salt and organic components. However, in the current study we show that the water flea, Daphnia magna, is physically impaired by, and rendered immobile at the surface of, test waters containing FPW. This effect occurs at concentrations significantly lower than the reported median lethal concentration for the same test FPW, and suggests that physical immobility is a more sensitive ecological indicator of adverse environmental effects associated with FPW exposure. We showed that this effect could be mediated by the dual action of waterborne surfactants, which decrease surface tension, and floating hydrocarbons, which adhere to daphnids that break through the water surface and prevent resubmergence. While mortality does not occur in physically impaired daphnids within the prescribed 48 h, animals are unable to return to the water column, and thus cannot feed. Stranding at the water surface will also impaire the capacity of the animals to shed the carapace, thus impeding reproduction. These results suggest that assessment of acute toxicity of FPW may need to be determined differently from traditional effluent toxicity assessments.

FUNDING: This project was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) grant CRDPJ 4693308-14 and support from the Encana Corporation to D.S.A and G.G.G. The authors thank Erik Folkerts for his assistance on the project. TAB is supported by an NSERC postdoctoral fellowship. CNG is supported by a Campus Alberta Innovates Program Research Chair.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: experimental

EXPOSURE ROUTES: dermal

EXTERNAL EXPOSURES: wastewater

GEOLOGIC FORMATIONS: Duvernay Formation

STATES/COUNTRIES: Alberta, Canada

GAS/OIL: natural gas; unconventional

CHEMICALS: surfactants

HEALTH EFFECTS: mortality; Brain and Nerves

Exploring the endocrine activity of air pollutants associated with unconventional oil and gas extraction


ABSTRACT

In the last decade unconventional oil and gas (UOG) extraction has rapidly proliferated throughout the United States (US) and the world. This occurred largely because of the development of directional drilling and hydraulic fracturing which allows access to fossil fuels from geologic formations that were previously not cost effective to pursue. This process is known to use greater than 1,000 chemicals such as solvents, surfactants, detergents, and biocides. In addition, a complex mixture of chemicals, including heavy metals, naturally-occurring radioactive chemicals, and organic compounds are released from the formations and can enter air and water. Compounds associated with UOG activity have been linked to adverse reproductive and developmental outcomes in humans and laboratory animal models, which is possibly due to the presence of endocrine active chemicals.

FUNDING: Funding provided by Arkansas Community Foundation, Winslow Foundation, Cornell Douglas Foundation, Wallace Foundation, New-Land Foundation, and Tides Foundation. The authors declare that they have no competing interests.
Developmental exposure to a mixture of 23 chemicals associated with unconventional oil and gas operations alters the immune system of mice


ABSTRACT

Chemicals used in unconventional oil and gas (UOG) operations have the potential to cause adverse biological effects, but this has not been thoroughly evaluated. A notable knowledge gap is their impact on development and function of the immune system. Herein, we report an investigation of whether developmental exposure to a mixture of chemicals associated with UOG operations affects the development and function of the immune system. We used a previously characterized mixture of 23 chemicals associated with UOG, and which was demonstrated to affect reproductive and developmental endpoints in mice. C57Bl/6 mice were maintained throughout pregnancy and during lactation on water containing two concentrations of this 23-chemical mixture, and the immune system of male and female adult offspring was assessed. We comprehensively examined the cellularity of primary and secondary immune organs, and used three different disease models to probe potential immune effects: house dust mite-induced allergic airway disease, influenza A virus infection, and experimental autoimmune encephalomyelitis (EAE). In all three disease models, developmental exposure altered frequencies of certain T cell sub-populations in female, but not male, offspring. Additionally, in the EAE model disease onset occurred earlier and was more severe in females. Our findings indicate that developmental exposure to this mixture had persistent immunological effects that differed by sex, and exacerbated responses in an experimental model of autoimmune encephalitis. These observations suggest that developmental exposure to complex mixtures of water contaminants, such as those derived from UOG operations, could contribute to immune dysregulation and disease later in life.

FUNDING: This work was supported by a University of Rochester Provost’s Office Research Award, the National Institutes of Health [R01ES023260, R01ES004862, T32ES07026, P30ES01247, and R24AI-059830], and the Morris Foundation [D14ZO-084].
Association between Oklahoma earthquakes and anxiety-related Google search episodes


ABSTRACT

Background: Oklahoma has experienced a rise in seismicity since 2010, with many earthquakes induced by wastewater injection. While large single earthquakes have documented mental health repercussions, health implications of these new, frequent earthquakes remain unknown. We aimed to examine associations between Oklahoma earthquakes and statewide anxiety measured by Google queries. Methods: The U.S. Geologic Survey’s Advanced National Seismic System Comprehensive Catalog supplied earthquake dates and magnitudes. We used the Google Health application programming interface to compile the proportion of weekly Oklahoma-based health-related search episodes for anxiety. A quasi-experimental time-series analysis from January 2010 to May 2017 evaluated monthly counts of earthquakes ≥ magnitude 4 (a level felt by most people) in relation to anxiety, controlling for US-wide anxiety search episodes and Oklahoma-specific health-related queries. Results: Oklahoma experienced an average of two (SD = 2) earthquakes ≥ magnitude 4 per month during the study period. For each additional earthquake ≥ magnitude 4, the proportion of Google search episodes for anxiety increased by 1.3% (95% confidence interval = 0.1%, 2.4%); 60% of this increase persisted for the following month. In months with 2 or more ≥ magnitude 4 earthquakes, the proportion of Google search episodes focused on anxiety increased by 5.8% (95% confidence interval = 2.3%, 9.3%). In a sub-analysis, Google search episodes for anxiety peaked about 3 weeks after ≥ magnitude 4 quakes. Conclusions: These findings suggest that the recent increase in Oklahoma earthquakes has elicited a psychological response that may have implications for public health and regulatory policy.

FUNDING: We thank G. Stocking and A. Mitchell at Pew Charitable Trusts for help in accessing and downloading the Google search data and for valuable comments on the manuscript, as well as Google’s data experts for providing access to and assistance in understanding the structure of the data. The authors declare that they have no conflicts of interest with regard to the content of this report.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: population health

STATES/COUNTRIES: OK

GAS/OIL: natural gas; oil; unconventional

HEALTH EFFECTS: Mental Health and Behavior

Associations of unconventional natural gas development with depression symptoms and disordered sleep in Pennsylvania


ABSTRACT

Environmental and community factors may influence the development or course of depression and sleep problems. We evaluated the association of unconventional natural gas development (UNGD) with depression symptoms and disordered sleep diagnoses using the Patient Health Questionnaire-8 and electronic health record data among Geisinger adult primary care patients in Pennsylvania. Participants received a retrospective metric for UNGD at their residence (very low, low, medium, and high) that incorporated dates and durations of well development, distance from patient homes to wells, and well characteristics. Analyses included 4,762 participants with no (62%), mild (23%), moderate (10%), and moderately severe or severe (5%) depression symptoms in 2014–2015 and 3,868 disordered sleep diagnoses between 2009–2015. We observed associations between living closer to more and bigger wells and depression symptoms, but not disordered sleep diagnoses in models weighted to account for sampling design and participation. High UNGD (vs. very low) was associated with depression symptoms in an adjusted negative binomial model (exponentiated coefficient = 1.18, 95% confidence interval [CI]: 1.04–1.34). High and low UNGD (vs. none) were associated with depression symptoms (vs. none) in an adjusted multinomial logistic model. Our findings suggest that UNGD may be associated with adverse mental health in Pennsylvania.

FUNDING: This research was funded by National Institutes of Health U19 AI106683 (PI Robert Schleimer), R21 ES023675 (PI Brian Schwartz), K99 ES027023 (Joan Casey), and the Degenstein Foundation. Drs Casey, Wilcox, Hirsch and Pollak declare they have no actual or potential competing financial interests. Dr. Schwartz is a Fellow of the Post Carbon Institute (PCI), serving as an informal advisor on climate, energy, and health issues. He receives no payment for this role. His research is entirely independent of PCI, and is not motivated, reviewed, or funded by PCI.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXTERNAL EXPOSURES: well density/drilling activity; survey/questionnaire/interview
The CSG arena: A critical review of unconventional gas developments and best-practice health impact assessment in Queensland, Australia


ABSTRACT

This paper compares a government-commissioned health study of coal seam gas (CSG) developments in Queensland with international best-practice health impact assessment (HIA) methodologies. A literature review was conducted of (HIA) methods and health studies of CSG development areas in Queensland. Forty-eight interviews were conducted in the Darling Downs CSG region in Queensland. One Queensland Health report was identified but failed to meet HIA international best practice because 7 of 9 key steps were omitted. Interview participants reported poor consultation by government and industry within affected communities. Lack of and poor quality health data was found to exacerbate community tensions. We recommend application of HIAs, epidemiological studies, consultation with communities and consideration of social risks of poor quality health studies.

FUNDING: Funding not addressed. No potential conflict of interest was reported by the authors.

PUBLICATION TYPE: review

EVIDENCE STREAMS: human: non-occupational

STATES/COUNTRIES: Queensland, Australia

GAS/OIL: coalbed methane; unconventional

HEALTH EFFECTS: Eyes, Ears, Nose, and Throat; Brain and Nerves; acute toxicity/poisoning; Skin, Hair, and Nails

Toxicological and chemical studies of wastewater from hydraulic fracture and conventional shale gas wells


ABSTRACT

New technology has enabled recovery of inaccessible natural gas shale deposits, however, the potential impacts to human health from the migration of brines into drinking water or surface spills are unknown. To provide information that can inform these potential impacts, chemical characterization and in vitro toxicologic testing were conducted using pre- and post-injection waters from conventional and unconventional oil and gas wells. Wastewater concentrations may be diluted or reduced by fate and transport processes when released into the environment by unknown amounts, and lab studies only imply potential effects. In acute cytotoxicity and wound healing assays, there was dose-dependent toxicity in human and rat cells with growth promotion at low concentrations. Lethality was measured in time studies up to 10 days post-injection. Produced water samples from both well types were equally toxic to human cells and were corrosive at high concentrations. Measurement of protein and gene expression identified metabolic pathways responding to both well types as NQO1 oxidative stress-responsive enzyme and tight junction protein genes. A KCl sample of matched ionic strength showed a different toxicity profile than produced waters, indicating that salts alone were not the cause of toxicity. Organic chemicals and branched alkanes were present in hydraulic fracture wells and mainly branched alkanes were present in conventional wells. One organic substance was still present after 240 days. The known properties of these chemicals include potential toxicity to multiple human organs, sensitization, irritation, developmental effects and tumor promotion, depending upon the concentrations and synergistic effects of chemicals during exposure.
Shale gas activity and increased rates of sexually transmitted infections in Ohio, 2000–2016


ABSTRACT

Background: The growing shale gas (“fracking”) industry depends on a mobile workforce, whose influx could have social impacts on host communities. Sexually transmitted infections (STIs) can increase through sexual mixing patterns associated with labor migration. No prior studies have quantified the relationship between shale gas activity and rates of three reportable STIs: chlamydia, gonorrhea, and syphilis. Methods: We conducted a longitudinal, ecologic study from 2000–2016 in Ohio, situated in a prolific shale gas region in the United States (US). Data on reported cases of chlamydia, gonorrhea, and syphilis by county and year were obtained from the Ohio Department of Health. All 88 counties were classified as none, low, and high shale gas activity in each year, using data from the Ohio Department of Natural Resources. Annual rate ratios (RR) and 95% confidence intervals (95% CIs) were calculated from mixed-effects Poisson regression models evaluating the relationship between shale gas activity and reported annual STI rates while adjusting for secular trends and potential confounders obtained from the US Census. Results: Compared to counties with no shale gas activity, counties with high activity had 21% (RR = 1.21; 95%CI = 1.08–1.36) increased rates of chlamydia and 19% (RR = 1.27; 95%CI 0.98–1.44) increased rates of gonorrhea, respectively. No association was observed for syphilis. Conclusion: This first report of a link between shale gas activity and increased rates of both chlamydia and gonorrhea may inform local policies and community health efforts.

FUNDING: Funding: Joshua Warren was supported by CTSA Grant Number UL1 TR001863 and KL2 TR001862 from the National Center for Advancing Translational Science (NCATS). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. Competing interests: The authors have declared that no competing interests exist.
A community-based evaluation of proximity to unconventional oil and gas wells, drinking water contaminants, and health symptoms in Ohio


ABSTRACT

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

FUNDING: This work was partially funded by Yale Institute of Biospheric Studies and the Jan A. J. Stolwijk Fellowship, which had no role in the research. We are grateful to the study participants for their contributions. We would like to thank the Plata lab members for their technical support, in particular Brian Drollette. We declare no competing financial interests.

Assessing human health PM2.5 and ozone impacts from U.S. oil and natural gas sector emissions in 2025


ABSTRACT

Incomplete information regarding emissions from oil and natural gas production has historically made it challenging to characterize the air quality or air pollution-related health impacts for this sector in the United States. Using an emissions inventory for the oil and natural gas sector that reflects information regarding the level and distribution of PM2.5 and ozone precursor emissions, we simulate annual mean PM2.5 and summer season
average daily 8 h maximum ozone concentrations with the Comprehensive Air-Quality Model with extensions (CAMx). We quantify the incidence and economic value of PM2.5 and ozone health related effects using the environmental Benefits Mapping and Analysis Program (BenMAP). We find that ambient concentrations of PM2.5 and ozone, and associated health impacts, are highest in a handful of states including Colorado, Pennsylvania, Texas and West Virginia. On a per-ton basis, the benefits of reducing PM2.5 precursor emissions from this sector vary by pollutant species, and range from between $6,300 and $320,000, while the value of reducing ozone precursors ranges from $500 to $8,200 in the year 2025 (2015$).

FUNDING: Funding not addressed. The authors declare no competing financial interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: air

STATES/COUNTRIES: TX; PA; OK; OH; IL

GAS/OIL: conventional; natural gas; oil; unconventional

CHEMICALS: ozone; particulate matter; VOCs; sulfur dioxide, nitrogen oxides; ammonia; carbon monoxide

HEALTH EFFECTS: mortality; Lungs and Breathing; Blood, Heart, and Circulation

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ABSTRACT

As unconventional natural gas development (UNGD) activities such as “fracking” have proliferated across the U.S., research has begun to examine their impacts on human life. Much scholarship has centered on possible health and environmental impacts. However, a range of plausible psychosocial impacts has begun to emerge. Utilizing grounded theory methods and data from qualitative interviews with residents of two counties in Appalachian Eastern Ohio (Guernsey and Noble), we examined the quality of life (QoL) impacts on residents, who live and work amid UNGD. QoL impacts were reported in five core categories, specifically psychological stress, social stress, environment, physical health, and traffic. Psychological stress was a particularly salient theme, as residents living near UNGD found themselves anxious about the uncertainties of fracking; frustrated by interactions with oil and gas industry officials; stressed about noise or light pollution; and, in some instances, facing the possibility of moving from the region.

FUNDING: This work was supported by the National Institutes of Health (NIH/NIEHS P30ES006096).

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXTERNAL EXPOSURES: well density/drilling activity; survey/questionnaire/interview

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: OH

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Mental Health and Behavior
Demographic response of Louisiana Waterthrush, a stream obligate songbird of conservation concern, to shale gas development


ABSTRACT

Shale gas development continues to outpace the implementation of best management practices for wildlife affected by development. We examined demographic responses of the Louisiana Waterthrush (Parkesia motacilla) to shale gas development during 2009–2011 and 2013–2015 in a predominantly forested landscape in West Virginia, USA. Forest cover across the study area decreased from 95% in 2008 to 91% in 2015, while the area affected by shale gas development increased from 0.4% to 3.9%. We quantified nest survival and productivity, a source–sink threshold, riparian habitat quality, territory density, and territory length by monitoring 58.1 km of forested headwater streams (n = 14 streams). Across years, we saw annual variability in nest survival, with a general declining trend over time. Of 11 a priori models tested to explain nest survival (n = 280 nests), 4 models that included temporal, habitat, and shale gas covariates were supported, and 2 of these models accounted for most of the variation in daily nest survival rate. After accounting for temporal effects (rainfall, nest age, and time within season), shale gas development had negative effects on nest survival. Population-level nest productivity declined and individual productivity was lower in areas disturbed by shale gas development than in undisturbed areas, and a source sink threshold suggested that disturbed areas were more at risk of being sink habitat. Riparian habitat quality scores, as measured by a U.S. Environmental Protection Agency index and a waterthrush-specific habitat suitability index, differed by year and were negatively related to the amount of each territory disturbed by shale gas development. Territorial density was not related to the amount of shale gas disturbance, but decreased over time as territory lengths increased. Overall, our results suggest a decline in waterthrush site quality as shale gas development increases, despite relatively small site-wide forest loss.

FUNDING: Our research was funded by the West Virginia Division of Natural Resources, U.S. Department of Energy National Energy Technology Laboratory, West Virginia University, and National Aviary. None of our funders had any influence on the content of the submitted or published manuscript and only the U.S. Geological Survey (USGS) required approval of the final manuscript prior to publication as required by their Fundamental Sciences Practices protocols (https://pubs.usgs.gov/circ/1367/). West Virginia Division of Natural Resources (WVDNR) provided access to the study area and Wheeling Jesuit University provided access to field housing. We thank many field assistants and graduate students who collected data during our 6-yr study. In particular we thank J. Mizel, D. Becker, and K. Aldinger for assistance with data collection and analysis approaches. We are grateful to L. Fanwell, S. Latta, A. Welsh, M. Strager, and S. Welsh for helpful comments that improved the manuscript. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: wildlife

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: WV

GAS/OIL: unconventional; natural gas

HEALTH EFFECTS: mortality

Demographic characteristics of an avian predator, Louisiana Waterthrush (Parkesia motacilla), in response to its aquatic prey in a Central Appalachian USA watershed impacted by shale gas development


ABSTRACT

We related Louisiana Waterthrush (Parkesia motacilla) demographic response and nest survival to benthic macroinvertebrate aquatic prey and to shale gas development parameters using models that accounted for both spatial and non-spatial sources of variability in a Central Appalachian USA watershed. In 2013, aquatic prey density and pollution intolerant genera (i.e., pollution tolerance value <4) decreased statistically with increased waterthrush territory length but not in 2014 when territory densities were lower. In general, most demographic responses to aquatic prey were variable and negatively related to aquatic prey in 2013 but positively related in 2014. Competing aquatic prey covariate models to explain nest survival were not statistically significant but differed annually and in general reversed from negative to positive influence on daily survival rate. Potential hydraulic fracturing runoff decreased nest survival both years and was statistically significant in 2014. While potential hydraulic fracturing

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runoff in 2013 may have increased Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness, in 2014 shale gas territory disturbance decreased EPT richness. In 2014, intolerant genera decreased at the territory and nest level with increased shale gas disturbance suggesting the potential for localized negative effects on waterthrush. Loss of food resources does not seem directly or solely responsible for demographic declines where waterthrush likely were able to meet their foraging needs. However collective evidence suggests there may be a shale gas disturbance threshold at which waterthrush respond negatively to aquatic prey community changes. Density-dependent regulation of their ability to adapt to environmental change through acquisition of additional resources may also alter demographic response.

**FUNDING:** Our research was funded by the West Virginia Division of Natural Resources (WVDNR) to PBW, West Virginia University (WVU) to MWF, National Aviary to PBW, and Appalachian Stewardship Foundation (ASF) to MWF. None of our funders had any influence on the content of the submitted or published manuscript and only the U.S. Geological Survey (USGS) required approval of the final manuscript prior to publication as required by their Fundamental Sciences Practices protocols (https://pubs.usgs.gov/circ/1367/). The authors have declared that no competing interests exist.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** animal: wildlife

**EXTERNAL EXPOSURES:** well density/drilling activity; surface water

**GEOLOGIC FORMATIONS:** Marcellus Shale

**STATES/COUNTRIES:** WV

**GAS/OIL:** conventional; natural gas; unconventional

**HEALTH EFFECTS:** Pregnancy and Reproduction; Mortality

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**Developmental toxicity of the organic fraction from hydraulic fracturing flowback and produced waters to early life stages of zebrafish (Danio rerio)**


**ABSTRACT**

Hydraulic fracturing (HF) has emerged as a major recovery method of unconventional oil and gas reservoirs and concerns have been raised regarding the environmental impact of releases of Flowback and Produced Water (FPW) to aquatic ecosystems. To investigate potential effects of HF-FPW on fish embryo development, HF-FPW samples were collected from two different wells and the organic fractions were isolated from both aqueous and particle phases to eliminate the confounding effects of high salinity. Each organic extract was characterized by non-target analysis with HPLC-Orbitrap-MS, with targeted analysis for polycyclic aromatic hydrocarbons provided as markers of petroleum-affected water. The organic profiles differed between samples, including PAHs and alkyl PAHs, and major substances identified by non-target analysis included polyethylene glycols, alkyl ethoxylates, octylphenol ethoxylates and other high molecular weight (C49-79) ethylene oxide polymeric material. Zebrafish embryos were exposed to various concentrations of FPW organic extracts to investigate acute (7-day) and developmental toxicity in early life stages. The acute toxicity (LD50) of the extracted FPW fractions ranged from 2.8× to 26× the original organic content. Each extracted FPW fraction significantly increased spinal malformation, pericardial edema, and delayed hatch in exposed embryos and altered the expression of a suite of target genes related to biotransformation, oxidative stress and endocrine-mediation in developing zebrafish embryos. These results provide novel information on the variation of organic profiles and developmental toxicity among different sources and fractions of HF-FPWs.

**FUNDING:** The project was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) grant CRDPJ 469308-14, with support from the Encana Corporation, to Danial S. Alessi, Jonathan W. Martin, and Greg 458 G. Goss. As per our research agreement, oversight by from Encana is limited to a maximum 60 days review period prior to publication only. Encana provides samples and sample collection data but does not provide input into either research directions or interpretation of results generated. We would like to thank Science Animal Support Services for assistance in animal care. The authors declare no competing financial interest.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** animal: experimental

**EXPOSURE ROUTES:** dermal; oral

**EXTERNAL EXPOSURES:** wastewater

**GEOLOGIC FORMATIONS:** Duvernay Formation

**STATES/COUNTRIES:** Alberta, Canada
In vitro assessment of endocrine disrupting potential of organic fractions extracted from hydraulic fracturing flowback and produced water (HF-FPW)


ABSTRACT

Potential effects of horizontal drilling combined with high-volume hydraulic fracturing (HF) have drawn significant public concern, especially on the handling, treatment, and disposal of HF flowback and produced water (HF-FPW). Previous studies indicated HF-FPW could significantly disrupt biotransformation and expressions of genes related to the endocrine system. This study focused on effects of organic extracts of HF-FPW on receptor binding activity using several transactivation assays. Six HF-FPW samples were collected from 2 wells (Well A and Well B, 3 time points at each well). These were separated by filtration into aqueous (W) and particulate (S) phases, and organics were extracted from all 12 subsamples. Of all the tested fractions, sample B1-S had the greatest Σ13PAH (11,000 ng/L) and B3-S has the greatest Σ4alkyl-PAHs (16,000 ng/L). Nuclear receptor binding activity of all the extracts on aryl hydrocarbon receptor (AhR), estrogen receptor (ER), and androgen receptor (AR) were screened using H4IIE-luc, MVLN-luc, and MDA-kb2 cells, respectively. FPWs from various HF wells exhibited distinct nuclear receptor binding effects. The strongest AhR agonist activity was detected in B3-S, with 450 ± 20 μg BaP/L equivalency at 5 × exposure. The greatest ER agonist activity was detected in A1-W, with 5.3 ± 0.9 nM E2 equivalency at 10× exposures. There is a decreasing trend in ER agonist activity from A1 to A3 in both aqueous and particulate fractions from Well A, while there is an increasing trend in ER agonist activity from B1 to B3 in aqueous fractions from Well B. This study provides novel information on the sources of endocrine disruptive potentials in various HF-FPW considering both temporal and spatial variability. Results suggest that reclamation or remediation and risk assessment of HF-FPW spills likely requires multiple strategies including understanding the properties of each spill with respect to fractured geological formation and physiochemical properties of the injected fluid.

FUNDING: The project was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) grant CRDPJ 469308-14, with support from the Encana Corporation, to Dr. Daniel S. Alessi, Dr. Jonathan W. Martin, and Dr. Greg G. Goss. Encana provides samples and sample collection data but does not provide input into either research directions or interpretation of results generated. Dr. Giesy was supported by the Canada Research Chair program, the 2012 “High Level Foreign Experts” (#GDT20143200016) program, funded by the State Administration of Foreign Experts Affairs, the P.R. China to Nanjing University and the Einstein Professor Program of the Chinese Academy of Sciences and a Distinguished Visiting Professorship in the School of Biological Sciences of the University of Hong Kong.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: in vitro

EXPOSURE ROUTES: in vitro

EXTERNAL EXPOSURES: wastewater

GEOLOGIC FORMATIONS: Duvernay Formation

STATES/COUNTRIES: Alberta, Canada

GAS/OIL: natural gas; unconventional

CHEMICALS: PAHs

HEALTH EFFECTS: Endocrine system

Shale gas development and infant health: Evidence from Pennsylvania

ABSTRACT

This research exploits the introduction of shale gas wells in Pennsylvania in response to growing controversy around the drilling method of hydraulic fracturing. Using detailed location data on maternal addresses and GIS coordinates of gas wells, this study examines singleton births to mothers residing close to a shale gas well from 2003 to 2010 in Pennsylvania. The introduction of drilling increased low birth weight and decreased term birth weight on average among mothers living within 2.5 km of a well compared to mothers living within 2.5 km of a permitted well. Adverse effects were also detected using measures such as small for gestational age and APGAR scores, while no effects on gestation periods were found. In the intensive margin, an additional well is associated with a 7 percent increase in low birth weight, a 5 g reduction in term birth weight and a 3 percent increase in premature birth. These results are robust to other measures of infant health, many changes in specification and falsification tests. These findings suggest that shale gas development poses significant risks to human health.

FUNDING: I am grateful to the Cornell Population Center for their generous financial support. These data were supplied by the Bureau of Health Statistics & Research, Pennsylvania Department of Health, Harrisburg, Pennsylvania. Conflict of interest not addressed.

PUBLIC TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Pregnancy and Reproduction

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ABSTRACT

Hydraulic fracturing flowback and produced water (FPW) samples were analyzed for toxicity and microbiome characterization over 220 days for a horizontally drilled well in the Denver-Julesberg (DJ) Basin in Colorado. Cytotoxicity, mutagenicity, and estrogenicity of FPW were measured via the BioLuminescence Inhibition Assay (BLIA), Ames II mutagenicity assay (AMES), and Yeast Estrogen Screen (YES). Raw FPW stimulated bacteria in BLIA, but were cytotoxic to yeast in YES. Filtered FPW stimulated cell growth in both BLIA and YES. Concentrating 25× by solid phase extraction (SPE) revealed significant toxicity throughout well production by BLIA, toxicity during the first 55 days of flowback by YES, and mutagenicity by AMES. The selective pressures of fracturing conditions (including toxicity) affected bacterial and archaeal communities, which were characterized by 16S rRNA gene V4V5 region sequencing. Conditions selected for thermophilic, anaerobic, halophilic bacteria and methanogenic archaea from the groundwater used for fracturing fluid, and from the native shale community. Trends in toxicity echoed the microbial community, which indicated distinct stages of early flowback water, a transition stage, and produced water. Biota in another sampled DJ Basin horizontal well resembled similarly aged samples from this well. However, microbial signatures were unique compared to samples from DJ Basin vertical wells, and wells from other basins. These data can inform treatability, reuse, and management decisions specific to the DJ Basin to minimize adverse environmental health and well production outcomes.

FUNDING: This project was partly funded by Grant No. CBET-1240584 by the National Science Foundation as part of the AirWaterGas Sustainability Research Network (http://airwatergas.org/). The Environmental Defense Fund also supported this research. The authors declare that they have no competing interests.

PUBLIC TYPE: original research

EVIDENCE STREAMS: in vitro

EXPOSURE ROUTES: in vitro
Prioritization of reproductive toxicants in unconventional oil and gas operations using a multi-country regulatory data-driven hazard assessment


ABSTRACT

Background: Recent trends have witnessed the global growth of unconventional oil and gas (UOG) production. Epidemiologic studies have suggested associations between proximity to UOG operations with increased adverse birth outcomes and cancer, though specific potential etiologic agents have not yet been identified. To perform effective risk assessment of chemicals used in UOG production, the first step of hazard identification followed by prioritization specifically for reproductive toxicity, carcinogenicity and mutagenicity is crucial in an evidence-based risk assessment approach. To date, there is no single hazard classification list based on the United Nations Globally Harmonized System (GHS), with countries applying the GHS standards to generate their own chemical hazard classification lists. A current challenge for chemical prioritization, particularly for a multi-national industry, is inconsistent hazard classification which may result in misjudgment of the potential public health risks. We present a novel approach for hazard identification followed by prioritization of reproductive toxicants found in UOG operations using publicly available regulatory databases. Methods: GHS classification for reproductive toxicity of 157 UOG-related chemicals identified as potential reproductive or developmental toxicants in a previous publication was assessed using eleven governmental regulatory agency databases. If there was discordance in classifications across agencies, the most stringent classification was assigned. Chemicals in the category of known or presumed human reproductive toxicants were further evaluated for carcinogenicity and germ cell mutagenicity based on government classifications. A scoring system was utilized to assign numerical values for reproductive health, cancer and germ cell mutation hazard endpoints. Using a Cytoscape analysis, both qualitative and quantitative results were presented visually to readily identify high priority UOG chemicals. Results: We observed substantial inconsistencies in classification among the 11 databases. By adopting the most stringent classification within and across countries, 43 chemicals were classified as known or presumed human reproductive toxicants (GHS Category 1), while 31 chemicals were classified as suspected human reproductive toxicants (GHS Category 2). The 43 reproductive toxicants were further subjected to analysis for carcinogenic and mutagenic properties. Calculated hazard scores and Cytoscape visualization yielded several high priority chemicals including potassium dichromate, cadmium, benzene and ethylene oxide. Conclusions: Our findings reveal diverging GHS classification outcomes for UOG chemicals across regulatory agencies. Adoption of the most stringent classification with application of hazard scores provides a useful approach to prioritize reproductive toxicants in UOG and other industries for exposure assessments and selection of safer alternatives.

FUNDING: SHI-H would like to thank the Bureau of Educational and Cultural Affairs (ECA) of the US Department of State and the Malaysian American Commission on Educational Exchange (MACEE) for the Fulbright Visiting Scholar Program at Yale School of Public Health. The authors thank Mr Khairul Anuar Ismail and Ms Nurul Ain Alias for their technical support. Nicole Deziel was supported in part by the U.S. Environmental Protection Agency Grant# 83924901.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: ethanol; 2-ethoxyethanol; 2-methoxyethanol; ethylene oxide; formamide; n-methyl-2-pyrrolidone; n-n-dimethylformamide; nickel sulfate; potassium dichromate; benzene; di(2-ethylhexyl) phthalate; lead; toluene; benzo(a)pyrene; cadmium; carbon disulfide; dibutyl phthalate; lithium; mercury; thallium; acetaldehyde; acrylamide; bisphenol A (BPA); borax; boric acid; boron sodium oxide; chlorine dioxide; copper sulfate; diethylene glycol momomethyl ether; iron sulfate; potassium iodide; sodium iodide; sodium perborate; styrene; ethylbenzene; methanol; phenol; xylenes; acrylonitrile; chloromethane; diekdrin; lindane; manganese

HEALTH EFFECTS: Pregnancy and Reproduction; genotoxicity; cancers

Endocrine-disrupting activities and organic contaminants associated with oil and gas operations in Wyoming groundwater

ABSTRACT

Unconventional oil and natural gas (UOG) operations couple horizontal drilling with hydraulic fracturing to access previously inaccessible fossil fuel deposits. Hydraulic fracturing, a common form of stimulation, involves the high-pressure injection of water, chemicals, and sand to fracture the target layer and release trapped natural gas and/or oil. Spills and/or discharges of wastewater have been shown to impact surface, ground, and drinking water. The goals of this study were to characterize the endocrine activities and measure select organic contaminants in groundwater from conventional oil and gas (COG) and UOG production regions of Wyoming. Groundwater samples were collected from each region, solid-phase extracted, and assessed for endocrine activities (estrogen, androgen, progesterone, glucocorticoid, and thyroid receptor agonism and antagonism), using reporter gene assays in human endometrial cells. Water samples from UOG and conventional oil areas exhibited higher ER antagonist activities than water samples from conventional gas areas. Samples from UOG areas tended to exhibit progesterone receptor antagonism more often, suggesting there may be a UOG-related impact on these endocrine activities. We also report UOG-specific contaminants in Pavillion groundwater extracts, and these same chemicals at high concentrations in a local UOG wastewater sample. A unique suite of contaminants was observed in groundwater from a permitted drinking water well at a COG well pad and not at any UOG sites; high levels of endocrine activities (most notably, maximal estrogenic activity) were noted there, suggesting putative impacts on endocrine bioactivities by COG. As such, we report two levels of evidence for groundwater contamination by both UOG and COG operations in Wyoming.

FUNDING: Funding: Project supported by funds provided by Coming Clean, Inc. (Brattleboro, Vermont), as well as STAR Fellowship Assistance Agreement No. FP-91747101 awarded by the US EPA (CDK). The views and conclusions in this article represent the views of the authors but not necessarily the views of the EPA. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. Conflict of interest: The authors declare that they have no conflict of interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: in vitro

EXPOSURE ROUTES: in vitro

EXTERNAL EXPOSURES: drinking water

STATES/COUNTRIES: WY

GAS/OIL: conventional; natural gas; oil; unconventional

CHEMICALS: 2-ethylhexanol; benzene; cumene, ethylbenzene; methylcyclohexane; naphthalene; styrene; toluene; xylenes; diethylbenzenes; 1-methylnaphthalene; 2-methylnaphthalene; m/p-ethyltoluene; 1,3,5-trimethylbenzene; 1,2,4-trimethylbenzene; 1,2,3-trimethylbenzene; 1,2,4,5-tetramethylbenzene; 2-heptanone; 4-heptanone; butyl cyclohexane; d-limonene; ethyl cyclohexane; ethylhexanol-1; methylcyclohexane; n-decane; n-dodecane; n-nonane; n-undecane; octane; pentadecane; propylbenzene; tetradecane; tridecane; VOCS; n-heptane

HEALTH EFFECTS: Endocrine system

Unconventional oil and gas chemicals and wastewater-impacted water samples promote adipogenesis via PPARy-dependent and independent mechanisms in 3T3-L1 cells


ABSTRACT

Unconventional oil and natural gas (UOG) operations have contributed to a surge in domestic oil and natural gas production in the United States, combining horizontal drilling with hydraulic fracturing to unlock previously inaccessible fossil fuel deposits. >1000 organic chemicals are used in the production process, and wastewater is produced following injection and for the life of the producing well. This wastewater is typically disposed of via injecting into disposal wells for long-term storage, treatment and discharge from wastewater treatment plants, and/or storage in open evaporation pits; however, wastewater spill rates are reported at 2–20% of active well sites across regions, increasing concerns about the environmental impacts of these wastewaters. This study assessed adipogenic activity (both triglyceride accumulation and pre-adipocyte proliferation) for a mixture of 23 commonly used UOG chemicals and a small subset of UOG wastewater-impacted surface water extracts from Colorado and West Virginia, using 3T3-L1 cells and a peroxisome proliferator activated receptor gamma (PPARy) reporter assay. We report potent and efficacious adipogenic activity induced by both a laboratory-created UOG chemical mixture and UOG-impacted water samples at concentrations below environmental levels. We further report activation of PPARy at similar concentrations for some samples, suggesting a causative molecular pathway for the observed effects, but not for other adipogenic samples, implicating PPARy-dependent and independent effects from UOG associated chemicals. Taken together, these results suggest that UOG wastewater has the potential to impact metabolic health at environmentally relevant concentrations.
Chronic anthropogenic noise disrupts glucocorticoid signaling and has multiple effects on fitness in an avian community


ABSTRACT

Anthropogenic noise is a pervasive pollutant that decreases environmental quality by disrupting a suite of behaviors vital to perception and communication. However, even within populations of noise-sensitive species, individuals still select breeding sites located within areas exposed to high noise levels, with largely unknown physiological and fitness consequences. We use a study system in the natural gas fields of northern New Mexico to test the prediction that exposure to noise causes glucocorticoid-signaling dysfunction and decreases fitness in a community of secondary cavity-nesting birds. In accordance with these predictions, and across all species, we find strong support for noise exposure decreasing baseline corticosterone in adults and nestlings and, conversely, increasing acute stressor-induced corticosterone in nestlings. We also document fitness consequences with increased noise in the form of reduced hatching success in the western bluebird (Sialia mexicana), the species most likely to nest in noisiest environments. Nestlings of all three species exhibited accelerated growth of both feathers and body size at intermediate noise amplitudes compared with lower or higher amplitudes. Our results are consistent with recent experimental laboratory studies and show that noise functions as a chronic, inescapable stressor. Anthropogenic noise likely impairs environmental risk perception by species relying on acoustic cues and ultimately leads to impacts on fitness. Our work, when taken together with recent efforts to document noise across the landscape, implies potential widespread, noise-induced chronic stress coupled with reduced fitness for many species reliant on acoustic cues.

FUNDING: The authors declare no conflict of interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: wildlife

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: San Juan Basin

STATES/COUNTRIES: NM

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Endocrine system
Exposure assessment using secondary data sources in unconventional natural gas development and health studies


ABSTRACT

Studies of unconventional natural gas development (UNGD) and health have ranked participants along a gradient of geographic information system (GIS)-based activity that incorporated distance between participants’ home addresses and unconventional natural gas wells. However, studies have used different activity metrics, making results comparisons across studies difficult. Existing studies have only incorporated wells, without accounting for other components of development (e.g., compressors, impoundments, flaring events), for which it is often difficult to obtain reliable data, but may have relevance to health. Our aims were to: (1) describe, in space and time, UNGD-related compressors, impoundments, and flaring events, (2) evaluate whether and how to incorporate these into UNGD activity assessment, (3) evaluate associations of these different approaches with mild asthma exacerbations. We identified 361 compressor stations, 1,218 impoundments, and 216 locations with flaring events. A principal component analysis identified a single component that was approximately an equal mix of the metrics for compressors, impoundments, and four phases of well development (pad preparation, drilling, stimulation, and production). However, temporal coverage for impoundments and flaring data was sparse. Ultimately, we evaluated three UNGD activity metrics, including two based on existing studies and a novel metric that included well pad development, drilling, stimulation, production and compressor engine aspects of UNGD. The three metrics had varying magnitudes of association with mild asthma exacerbations, although the highest category of each metric (vs. the lowest) was associated with the outcome.

FUNDING: This study was funded by the National Institute of Environmental 497 Health Sciences grant ES023675-01 (PI: B S Schwartz), training grant ES07141 (S G Rasmussen), grant K99ES027023 (J A Casey), the Degenstein Foundation, and the National Science Foundation Integrative Graduate Education and Research Traineeship (S G Rasmussen). No funders had input into the study design, conduct, data collection or analysis, or manuscript preparation. Dr. Schwartz is a Fellow of the Post Carbon Institute (PCI), serving as an informal advisor on climate, energy, and health issues. He receives no payment for this role. His research is entirely independent of PCI, and is not motivated, reviewed, or funded by PCI.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Lungs and Breathing

Air Pollution and human health hazards: a compilation of air toxins acknowledged by the gas industry in Queensland’s Darling Downs


ABSTRACT

The paper offers an attempt to determine whether emissions from the unconventional gas industry are associated with hospitalisations in the Darling Downs, Queensland, Australia. Hospitalisation data were obtained from the Darling Downs Hospital and Health Services (DDHHS) and Coal Seam Gas (CSG) emissions data from the National Pollutants Inventory (NPI). Hospital admissions for circulatory and respiratory conditions, controlled for population, increased significantly from 2007 to 2014 (p < 0.001). Acute circulatory admissions increased 133% (2198-5141) and acute respiratory admissions increased 142% (1257-3051). CSG emissions increased substantially over the same period: nitrogen oxides (489% to 10,048 tonnes), carbon monoxide (800% to 6800 tonnes), PM10 (6000% to 1926 tonnes), volatile organic compounds (337% to 670 tonnes) and formaldehyde (12 kg to over 160 tonnes). Increased cardiopulmonary hospitalisations are coincident with the rise in pollutants known to cause such symptoms. Apparently, controls to limit exposure are ineffective. The burden of air pollution from the gas industry on the wellbeing of the Darling Downs population is a significant public health concern.
Ambient non-methane hydrocarbon levels along Colorado’s northern Front Range: Acute and chronic health risks


ABSTRACT

Oil and gas (O&G) facilities emit air pollutants that are potentially a major health risk for nearby populations. We characterized prenatal through adult health risks for acute (1-hour) and chronic (30-year) residential inhalation exposure scenarios to non-methane hydrocarbons (NMHCs) for these populations. We used ambient air sample results to estimate and compare risks for four residential scenarios. We found that air pollutant concentrations increased with proximity to an O&G facility, as did health risks. Acute hazard indices for neurological (18), hematological (15), and developmental (15) health effects indicate that populations living within 152 meters of an O&G facility could experience these health effects from inhalation exposures to benzene and alkanes. Lifetime excess cancer risks exceeded 1 in a million for all scenarios. The cancer risk estimate of 8.3 per 10,000 for populations living within 152 meters of an O&G facility exceeded the United States Environmental Protection Agency’s 1 in 10,000 upper threshold. These findings indicate that state and federal regulatory policies may not be protective of health for populations residing near O&G facilities. Health risk assessment results can be used for informing policies and studies aimed at reducing and understanding health effects associated with air pollutants emitted from O&G facilities.

FUNDING: The risk analysis was conducted as part of the AirWaterGas Sustainability Research Network funded by the National Science Foundation under Grant No. CBET-1240584. Funding for the collection of the 1-minute samples was supplied by the Colorado Department of Public Health and Environment, with additional resources from the NASA DISCOVER-AQ project. We would like to thank Gabrielle Pétron Anne Thompson, Simone Meinardi, Jason Schroeder, Daniel Bon, Amy Townsend-Small, and Bianca Baier for their assistance with ground sampling. Funding for the collection of the continuous air measurements was supplied by the NASA DISCOVER-AQ project. Funding for the collection of the 72-96 hour samples was supplied by Boulder County Public Health.

PUBLIC TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: well density/drilling activity; air

GEOLOGIC FORMATIONS: Denver-Julesberg Basin/Niobrara Shale

STATES/COUNTRIES: CO

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: benzene, BTEX, ethylbenzene, toluene, xylenes, VOCs, alkanes
**HEALTH EFFECTS:** Pregnancy and Reproduction; Lungs and Breathing; cancers; Brain and Nerves; Blood, Heart, and Circulation; acute toxicity/poisoning

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**Relationships between indicators of cardiovascular disease and intensity of oil and natural gas activity in Northeastern Colorado**


**ABSTRACT**

**Background:** Oil and natural gas (O&G) extraction emits pollutants that are associated with cardiovascular disease, the leading cause of mortality in the United States. **Objective:** We evaluated associations between intensity of O&G activity and cardiovascular disease indicators. **Methods** Between October 2015 and May 2016, we conducted a cross-sectional study of 97 adults living in Northeastern Colorado. For each participant, we collected 1–3 measurements of augmentation index, systolic and diastolic blood pressure (SBP and DBP), and plasma concentrations of interleukin (IL)−1β, IL-6, IL-8 and tumor necrosis factor alpha (TNF-α). We modelled the intensity of O&G activity by weighting O&G well counts within 16km of a participant’s home by intensity and distance. We used linear models accounting for repeated measures within person to evaluate associations. Results Adjusted mean augmentation index differed by 6.0% (95% CI: 0.6, 11.4%) and 5.1% (95%CI: −0.1, 10.4%) between high and medium, respectively, and low exposure tertiles. The greatest mean IL-1β, and α-TNF plasma concentrations were observed for participants in the highest exposure tertile. IL-6 and IL-8 results were consistent with a null result. For participants not taking prescription medications, the adjusted mean SBP differed by 6 and 1mm Hg (95% CIs: 0.1, 13mm Hg and −6, 8mm Hg) between the high and medium, respectively, and low exposure tertiles. DBP results were similar. For participants taking prescription medications, SBP and DBP results were consistent with a null result. Conclusions: Despite limitations, our results support associations between O&G activity and augmentation index, SBP, DBP, IL-1β, and TNF-α. Our study was not able to elucidate possible mechanisms or environmental stressors, such as air pollution and noise.

**FUNDING:** The authors declare they have no actual or potential competing financial interests. This work was funded by support from the National Institutes for Environmental Health Sciences (NIEHS) (R21-ES025140-01). It was also supported by data and resources from the AirWaterGas Sustainability Research Network funded by the National Science Foundation (NSF) under Grant No. CBET-1240584. Any opinions, findings conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of NIEHS, the National Institutes of Health, or the NSF.

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**Exposures and health risks from volatile organic compounds in communities located near oil and gas exploration and production activities in Colorado (U.S.A.)**


**ABSTRACT**

**The study objective was to use a preliminary risk based framework to evaluate the sufficiency of existing air data to answer an important public health question in Colorado: Do volatile organic compounds (VOCs) emitted into the air from oil and gas (OG) operations result in exposures to Coloradoans living at or greater than current state setback distances (500 feet) from OG operations at levels that may be harmful to their health?** We identified 56 VOCs emitted from OG operations in Colorado and compiled 47 existing air monitoring datasets that measured these VOCs in 34 locations across OG regions. From these data, we estimated acute and chronic exposures and compared these exposures to health guideline levels using maximum and mean air concentrations. Acute and chronic non-cancer hazard quotients were below one for all individual VOCs. **Hazard**
indices combining exposures for all VOCs were slightly above one. Lifetime excess cancer risk estimates for benzene were between $1.0 \times 10^{-5}$ to $3.6 \times 10^{-5}$ and ethylbenzene was $7.3 \times 10^{-6}$. This evaluation identified a small subset of VOCs, including benzene and n-nonane, which should be prioritized for additional exposure characterization in site-specific studies that collect comprehensive time-series measurements of community scale exposures to better assess community exposures.

FUNDING: This study was funded by general funds from the State of Colorado. The authors declare no conflict of interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: air

GEOLOGIC FORMATIONS: Denver-Julesberg Basin/Niobrara Shale; Piceance Basin

STATES/COUNTRIES: CO

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: benzene; cyclohexane; ethylbenzene; isopropylbenzene; methylcyclohexane; nonane; styrene; toluene; trimethylbenzenes; xylenes; VOCs; ethylcyclohexane; 3-dimethylcyclohexane isomers; propylene; ethane; propane; 1,2,3-trimethylbenzene; 1,2,4-trimethylbenzene; 1-butene; 1-pentene; 2,2,4-trimethylpentane; 2,3,4-trimethylpentane; 2,3-dimethylpentane; 2,4-dimethylpentane; 2-methylheptane; 2-methylpentane; 3-methylheptane; 3-methylpentane; butene; cyclohexane; cyclopentane; dimethylcyclohexanes; ethylcyclohexane; isobutane; isopentane; isoprene; dimethylbenzenes; methanol; methylcyclopentane; butane; decane; heptane; hexane; nonane; octane; pentane; propylbenzene; undecane; ethyltoluenes; pentene

HEALTH EFFECTS: cancer

The health implications of unconventional natural gas development in Pennsylvania


ABSTRACT

We investigate the health impacts of unconventional natural gas development of Marcellus shale in Pennsylvania between 2001 and 2013 by merging well permit data from the Pennsylvania Department of Environmental Protection with a database of all inpatient hospital admissions. After comparing changes in hospitalization rates over time for air pollution-sensitive diseases in counties with unconventional gas wells to changes in hospitalization rates in nonwell counties, we find a significant association between shale gas development and hospitalizations for pneumonia among the elderly, which is consistent with higher levels of air pollution resulting from unconventional natural gas development. We note that the lack of any detectable impact of shale gas development on younger populations may be due to unobserved factors contemporaneous with drilling, such as migration.

FUNDING: Funding not addressed. The authors have no conflict of interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: population health

EXTERNAL EXPOSURES: well density/drilling activity; air

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

CHEMICALS: benzene; BTEX; ethylbenzene; formaldehyde; hexane; particulate matter; toluene; xylenes; VOCs; NOx; 2,2,4-trimethylpentane; SOx
**Noise concerns of residents living in close proximity to hydraulic fracturing sites in Southwest Pennsylvania**


**ABSTRACT**

Objective: Noise associated with nontraditional gas industry (NTGI) sites (e.g., hydraulic fracturing well pads, compressor stations, processing plants) may create disturbances and anxiety in rural populations. This study evaluated levels of concern among residents of Southwestern Pennsylvania residing near NTGI sites. Design: Noise measurements were collected inside and outside residences, and surveys were administered to residents. Results: Daytime instantaneous sound levels ranged between 45.0 and 61.0 dBA. Dosimeter studies recorded day–night levels (Ldn) of 53.5–69.4 dBA outside and 37.5–50.1 dBA inside, exceeding United States Environmental Protection Agency guidelines. Respondents indicated the NTGI noise disturbed their sleep, and the majority of respondents (96%) reported being worried about their overall health as a result of the noise. Conclusions: Health care professionals serving rural areas impacted by hydraulic fracturing (fracking) should be aware of potential noise stressors on the populations they serve.

**FUNDING:** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Authors had no disclosures. We would like to thank Emily Romberger, Katlyn Plotzer, and Mina Matuizek for their data collection and entry.

**EVIDENCE STREAMS:** human: non-occupational

**EXTERNAL EXPOSURES:** well density/drilling activity

**GEOLOGIC FORMATIONS:** Marcellus Shale

**STATES/COUNTRIES:** PA

**GAS/OIL:** natural gas; unconventional

**HEALTH EFFECTS:** Mental Health and Behavior

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**Water contaminants associated with unconventional oil and gas extraction cause immunotoxicity to amphibian tadpoles**


**ABSTRACT**

Chemicals associated with unconventional oil and gas (UOG) operations have been shown to contaminate surface and ground water with a variety of endocrine disrupting compounds (EDCs) inducing multiple developmental alteration in mice. However, little is known about the impacts of UOG-associated contaminants on amphibian health and resistance to an emerging ranavirus infectious disease caused by viruses in the genus Ranavirus, especially at the vulnerable tadpole stage. Here we used tadpoles of the amphibian Xenopus laevis and the ranavirus Frog virus 3 (FV3) as a model relevant to aquatic environment conservation research for investigating the immunotoxic effects of exposure to a mixture of 23 UOG-associated chemicals with EDC activity. Xenopus tadpoles were exposed to an equimass mixture of 23 UOG-associated chemicals (range from 0.1 to 10 µg/l) for 3 weeks prior to infection with FV3. Our data show that exposure to the UOG chemical mixture is toxic for tadpoles at ecological doses of 5 to 10 µg/l. Lower doses significantly altered homeostatic expression of myeloid lineage genes and compromised tadpole responses to FV3 through expression of TNF-α, IL-1β, and Type I IFN genes, correlating with an increase in viral load. Exposure to a subset of 6 UOG chemicals was still sufficient to perturb the antiviral gene expression response. These findings suggest that UOG-associated water pollutants at low but environmentally relevant doses have the potential to induce acute alterations of immune function and antiviral immunity.

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Maryland is not for shale: Scientific and public anxieties of predicting health impacts of fracking


ABSTRACT

In 2011, Maryland established the Marcellus Shale Safe Drilling Initiative to determine whether and how gas production in the state could be accomplished without causing unacceptable risks to public health, safety, natural resources, and the environment. This initiative required a statewide health impact assessment of unconventional natural gas development and production via hydraulic fracturing (i.e., fracking). Increasing number of studies have shown that fracking has significant potential to impact health and non-health outcomes. However, because of its rapid development, there is a lack of substantive research related to the public health effects of fracking. I discuss my firsthand experiences as a medical anthropologist and public health researcher on a multi-disciplinary research team tasked with conducting Maryland’s first health impact assessment to determine the potential public health impacts associated with fracking. I focus on how fracking, as a relatively new economically viable source of energy and an emergent focus of study, brings about public and scientific anxieties, and how these anxieties shape subsequent environmental and health policy decision making processes. I reflect on the potential role of social scientists in matters of scientific knowledge production and resulting policy decisions and the broader implications of such engagement for public social science.

FUNDING: Not addressed

Prenatal exposure to unconventional oil and gas operation chemical mixtures altered mammary gland development in adult female mice


ABSTRACT
Unconventional oil and gas operations (UOG), which combine hydraulic fracturing (fracking) and directional drilling, involve the use of hundreds of chemicals including many with endocrine disrupting properties. Two previous studies examined mice exposed during early development to a 23-chemical mixture of UOG compounds (UOG-MIX) commonly used or produced in the process. Both male and female offspring exposed prenatally to one or more doses of UOG-MIX displayed alterations to endocrine organ function and serum hormone concentrations. We hypothesized that prenatal UOG-MIX exposures would similarly disrupt development of the mouse mammary gland. Female C57Bl/6 mice were exposed to approximately 3, 30, 300 or 3000 μg/kg/day UOG-MIX from gestational day 11 to birth. Although no effects were observed on the mammary glands of these females prior to puberty, in early adulthood, females exposed to 300 or 3000 μg/kg/day UOG-MIX developed more dense mammary epithelial ducts; females exposed to 3 μg/kg/day UOG-MIX had an altered ratio of apoptosis to proliferation in the mammary epithelium. Furthermore, adult females from all UOG-MIX-treated groups developed intraductal hyperplasia that resembled terminal end buds, i.e., highly proliferative structures typically seen at puberty. These results suggest that the mammary gland is sensitive to mixtures of chemicals used in unconventional oil and gas production, at exposure levels that are environmentally relevant. The impact of these findings on the long-term health of the mammary gland, including its lactational capacity and its risk of cancer, should be evaluated in future studies.

FUNDING: The authors thank other members of the Vandenberg and Nagel labs for feedback on this study. This work was supported by the National Institute of Environmental Health Sciences of the National Institutes of Health [Award Number K22-ES025811 (LNV), R21-ES026395 (SCN) and R01-ES021394-04S1 (SCN)]. The content of this manuscript is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. LNV has received travel reimbursement from Universities, Governments, NGOs and Industry, to speak about endocrine-disrupting chemicals. SAS, CDK, and SCN have nothing to disclose.

A review of the public health impacts of unconventional natural gas development


ABSTRACT

The public health impact of hydraulic fracturing remains a high profile and controversial issue. While there has been a recent surge of published papers, it remains an under-researched area despite being possibly the most substantive change in energy production since the advent of the fossil fuel economy. We review the evidence of effects in five public health domains with a particular focus on the UK: exposure, health, socio-economic, climate change and seismicity. While the latter would seem not to be of significance for the UK, we conclude that serious gaps in our understanding of the other potential impacts persist together with some concerning signals in the literature and legitimate uncertainties derived from first principles. There is a fundamental requirement for high-quality epidemiological research incorporating real exposure measures, improved understanding of methane leakage throughout the process, and a rigorous analysis of the UK social and economic impacts. In the absence of such intelligence, we consider it prudent to incentivise further research and delay any proposed developments in the UK. Recognising the political realities of the planning and permitting process, we make a series of recommendations to protect public health in the event of hydraulic fracturing being approved in the UK.

FUNDING: not addressed
Community-based health and exposure study around urban oil developments in South Los Angeles


ABSTRACT

Oilfield-adjacent communities often report symptoms such as headaches and/or asthma. Yet, little data exists on health experiences and exposures in urban environments with oil and gas development. In partnership with Promotoras de Salud (community health workers), we gathered household surveys nearby two oil production sites in Los Angeles. We tested the capacity of low-cost sensors for localized exposure estimates. Bilingual surveys of 205 randomly sampled residences were collected within two 1500 ft. buffer areas (West Adams and University Park) surrounding oil development sites. We used a one-sample proportion test, comparing overall rates from the California Health Interview Survey (CHIS) of Service Planning Area 6 (SPA6) and Los Angeles County for variables of interest such as asthma. Field calibrated low-cost sensors recorded methane emissions. Physician diagnosed asthma rates were reported to be higher within both buffers than in SPA6 or LA County. Asthma prevalence in West Adams but not University Park was significantly higher than in Los Angeles County. Respondents with diagnosed asthma reported rates of emergency room visits in the previous 12 months similar to SPA6. 45% of respondents were unaware of oil development; 63% of residents would not know how to contact local regulatory authorities. Residents often seek information about their health and site-related activities. Low-cost sensors may be useful in highlighting differences between sites or recording larger emission events and can provide localized data alongside resident-reported symptoms. Regulatory officials should help clarify information to the community on methods for reporting health symptoms. Our community-based participatory research (CBPR) partnership supports efforts to answer community questions as residents seek a safety buffer between sensitive land uses and active oil development.

FUNDING: This research was supported by the 11th Hour Project, a program of the Schmidt Family Foundation. Additional support for air quality monitoring was provided through the NSF-SRN AirWaterGas Project (CBET: 1240584) and the MetaSense Project (NSF grant CNS-1446912). We thank students Sofia Polo, Edgar Galicia, Daniela Borquez, and Alison Salazar and Promotoras de Salud in Action, a program of Esperanza Community Housing for their dedication and ongoing work in the community. The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of the funders.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: air

GEOLOGIC FORMATIONS: Los Angeles Basin

STATES/COUNTRIES: CA

GAS/OIL: oil; unconventional

CHEMICALS: methane

HEALTH EFFECTS: Pregnancy and Reproduction; Lungs and Breathing

Environmental and human health impacts of spreading oil and gas wastewater on roads


ABSTRACT

Thirteen states in the United States allow the spreading of O&G wastewaters on roads for deicing or dust suppression. In this study, the potential environmental and human health impacts of this practice are evaluated. Analyses of O&G wastewaters spread on roads in the northeastern, U.S. show that these wastewaters have salt, radioactivity, and organic contaminant concentrations often many times above drinking water standards. Bioassays also indicated that these wastewaters contain organic micropollutants that affected signaling pathways consistent with xenobiotic metabolism and caused toxicity to aquatic organisms like Daphnia magna. The potential toxicity of these wastewaters is a concern as lab experiments demonstrated that nearly all of the metals from these wastewaters leach from roads after rain events, likely reaching ground and surface water. Release of a known carcinogen (e.g., radium) from roads treated with O&G wastewaters has been largely ignored. In Pennsylvania from 2008 to 2014, spreading O&G wastewater on roads released over 4 times more radium to the environment (320 millicuries) than O&G wastewater treatment facilities and 200 times more radium than spill events. Currently, state-by-state regulations do not require radium analyses prior to treating roads with O&G wastewaters. Methods for reducing the potential impacts of spreading O&G wastewaters on roads are discussed.
Examination of child and adolescent hospital admission rates in Queensland, Australia, 1995–2011: A comparison of coal seam gas, coal mining, and rural areas


ABSTRACT

At present, coal seam gas (CSG) is the most common form of unconventional natural gas development occurring in Australia. Few studies have been conducted to explore the potential health impacts of CSG development on children and adolescents. This analysis presents age-specific hospitalisation rates for a child and adolescent cohort in three study areas in Queensland. Methods Three geographic areas were selected: a CSG area, a coal mining area, and a rural area with no mining activity. Changes in area-specific hospital admissions were investigated over the period 1995–2011 in a series of negative binomial regression analyses for 19 International Classification of Diseases (ICD) chapters, adjusting for sociodemographic factors. Results The strongest associations were found for respiratory diseases in 0–4 year olds (7% increase [95% CI 4%, 11%] and 6% increase [95% CI 1%, 18%] in the CSG area relative to the coal mining and rural areas, respectively) and 10–14 year olds (9% increase [95% CI 1%, 18%] and 11% increase [95% CI 1%, 21%] in the CSG area compared to the coal mining and rural areas, respectively). The largest effect size was for blood/immune diseases in 5–9 year olds in the CSG area (467% increase [95% CI 139%, 1244%]) compared to the rural area with no mining activity. Conclusions for Practice Higher rates of hospitalisation existed in the CSG area for certain ICD chapters and paediatric age groups, suggesting potential age-specific health impacts. This study provides insights on associations that should be explored further in terms of child and adolescent health.

FUNDING: This work was supported by the University of Queensland, as well as the University of Queensland’s Minerals Industry Safety and Health Centre and Centre for Water in the Minerals Industry. Aspects of this work not reported on here have been supported by the University of Queensland’s Centre for Coal Seam Gas. The university and the centres had no role in the preparation of this manuscript or in the decision to publish. The scientific interpretation was not subject to any funders’ control. The authors declare that they have no conflict of interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human; population health

EXTERNAL EXPOSURES: well density/drilling activity

STATES/COUNTRIES: Queensland, Australia

GAS/OIL: coalbed methane; unconventional

HEALTH EFFECTS: Skin, Hair, and Nails; Pregnancy and Reproduction; Mental Health and Behavior; Lungs and Breathing; Kidneys and Urinary System; Immune System; Eyes, Ears, Nose, and Throat; endocrine system; Digestive System; cancers; Brain and Nerves; Bones, Joints, and Muscles; Blood, Heart, and Circulation
Drilling and production activity related to unconventional gas development and severity of preterm birth


ABSTRACT

BACKGROUND: Studies of unconventional gas development (UGD) and preterm birth (PTB) have not presented risk estimates by well development phase or trimester. OBJECTIVE: We examined phase and trimester-specific associations between UGD activity and PTB. METHODS: We conducted a case–control study of women with singleton births in the Barnett Shale area, Texas, from 30 November 2010 to 29 November 2012. We individually age- and race/ethnicity-matched five controls to each PTB case (n=13,328) and truncated controls’ time at risk according to the matched case’s gestational age. We created phase-specific UGD-activity metrics: a) inverse squared distance–weighted (IDW) count of wells in the drilling phase ≤0.5 mi (804.7 meters) of the residence and b) IDW sum of natural gas produced ≤0.5 mi of the residence. We also constructed trimester- and gestation-specific metrics. Metrics were categorized as follows: zero wells (reference), first, second, third tertiles of UGD activity. Analyses were repeated by PTB severity: extreme, very, and moderate (>28, 28 to<32, and 32 to<37 completed weeks). Data were analyzed using conditional logistic regression. RESULTS: We found increased odds of PTB in the third tertile of the UGD drilling (odds ratio (OR)=1.20 [95% confidence interval (CI): 1.06, 1.37]) and UGD-production [OR=1.15 (1.05, 1.26)] metrics. Among women in the third tertile of UGD-production, associations were strongest in trimesters one [OR=1.18 (1.02, 1.37)] and two [OR=1.14 (0.99, 1.31)]. The greatest risk was observed for extremely PTB [third tertile ORs: UGD drilling, 2.00 (1.23, 3.24); UGD production, 1.53 (1.03–2.27)]. CONCLUSIONS: We found evidence of differences in phase- and trimester-specific associations of UGD and PTB and indication of particular risk associated with extremely preterm birth. Future studies should focus on quantifying specific chemical and nonchemical stressors associated with UGD.

FUNDING: This study was funded by the National Institute of Environmental Health Sciences/National Institutes of Health (NIEHS/NIH) grant no. 1R03ES023954-01. AKM was supported by an Occupational Epidemiology Traineeship funded by grant no. T42OH008421 from the National Institute for Occupational Safety and Health' Centers for Disease Control and Prevention (NIOSH/CDC) to the Southwest Center for Occupational and Environmental Health, a NIOSH-funded Education and Research Center.

EXTERNAL EXPOSURES: well density/drilling activity

GEOPHYSICAL FORMATIONS: Barnett Shale

STATES/COUNTRIES: TX

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Pregnancy and Reproduction

Unconventional natural gas development and pediatric asthma hospitalizations in Pennsylvania


ABSTRACT

Background: Pediatric asthma is a common chronic condition that can be exacerbated by environmental exposures, and unconventional natural gas development (UNGD) has been associated with decreased community air quality. This study aims to quantify the association between UNGD and pediatric asthma hospitalizations. Methods: We compare pediatric asthma hospitalizations among zip codes with and without exposure to UNGD between 2003 and 2014 using a difference-in-differences panel analysis. Our UNGD exposure metrics include cumulative and contemporaneous drilling as well as reported air emissions by site. Results: We observed consistently elevated odds of hospitalizations in the top tertile of pediatric patients exposed to unconventional drilling compared with their unexposed peers. During the same quarter a well was drilled, we find a 25% increase (95% CI: 1.07, 1.47) in the odds of being hospitalized for asthma. Ever-establishment of an UNGD well within a zip code was associated with a 1.19 (95% CI: 1.04, 1.36) increased odds of a pediatric asthma hospitalization. Our results further demonstrate that increasing specific air emissions from UNGD sites are associated with increased risks of pediatric asthma hospitalizations (e.g. 2,2,4-trimethylpentane, formaldehyde, x-hexane). These results hold across multiple age groups and sensitivity analyses. Conclusions: Community-level UNGD exposure metrics were associated with increased odds of pediatric asthma-related hospitalization among young children and adolescents. This study provides evidence that additional regulations may be necessary to protect children's respiratory health from UNGD activities.

FUNDING: Ms. Willis and Dr. Hill 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. This study was funded by NIH grant DP5OD021338 (Dr. Hill). The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.
High-volume hydraulic fracturing and human health outcomes: A Scoping Review


ABSTRACT

Objective: Examine extent of peer-reviewed literature exploring human health effects of hydraulic fracturing (HVHF). Methods: A scoping review methodology was used to examine peer-reviewed studies published from 2000 through 2017 that empirically examine direct health impacts of hydraulic fracturing. Results: Through September 2017, only 18 studies were found published in peer-reviewed journals that met our requirements for inclusion in the review. Most of these studies resulted in mixed findings of health outcomes. Conclusions: The paucity of studies reflects the difficulty in drawing direct connections between HVHF and human health outcomes. Many health outcomes may take years to emerge, exposure often occurs in lightly populated rural areas with older, poorer, and sicker residents, and diagnosis is difficult without physician knowledge of prior exposure. Primary care providers should record thorough histories to help guide future treatment.

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Toxicity of acidization fluids used in California oil exploration

ABSTRACT

There has been considerable public interest regarding the toxicity of chemicals used in hydraulic fracturing, but little is known about its sister technique, acidizing. Little to no research has been done on what the chemicals of acidization are and what impact they could have on humans and the environment. This paper discusses the differences between three acidizing techniques (acid maintenance, matrix acidization, and acid fracturing) and quantifies the amounts of the chemicals used for each. Washington State's Quick Chemical Assessment Tool is used to identify F-graded toxins, which are known carcinogens, mutagens, reproductive toxins, developmental toxins, endocrine disruptors, or high acute toxicity chemicals. The analysis of the present data shows that there have been over 600 instances of acidizing in urbanized Southern and Central California from April 2013 to August 2015. Although most of the chemicals of acidizing are similar to hydraulic fracturing, those used most frequently are different. There are close to 200 specific chemicals used in acidization, with at least 28 of them being F-graded hazardous chemicals. Some are used frequently in the range of 100–1000 kg per treatment, such as hydrofluoric acid, xylene, diethylene glycol, and ethyl benzene. Close to 90 more chemicals are identified using non-specific names as trade secrets or reported with no quantity. Unlike hydraulic fracturing the chemical concentrations in acidizing are high, ranging from 6% to 18%, and the waste returns can be highly acidic, in the range of pH 0–3. With this paper it is hoped that acidization becomes part of the larger discussion on concerns with oil exploration and be evaluated by appropriate authorities.

FUNDING: We thank the National Water Research Institute and The Schmidt Family Foundation for supporting this research. A special thanks to Jennifer Taylor and Zhongtian Li for their help with this project. No potential conflict of interest was reported by the authors.

EVIDENCE STREAMS: original research

EXTERNAL EXPOSURES: surface water

STATES/COUNTRIES: CA

GAS/OIL: oil; unconventional

CHEMICALS: acrylamide; cumene; diethanolamine; ethylbenzene; ethylene glycol; formaldehyde; naphthalene; toluene; xylenes; methanol; hydrofluoric acid; polyethyleneglycolnonylphenyl ether; poly(oxy-1,2-ethanediyl); a(nonylphenyl)-w-hydroxy; diethylene glycol; ethylene oxide; silica; nitroliacetic acid; ethanol; light aromatic naphtha; cristobalite; naphthalenes; paraffinic petroleum distillate; methyl isobutyl ketone; oxyalkylated alkylphenols; boric acid; cyclotetrasiloxane; 2,2,4,4,6,6,8,8-octamethyl acrylonitrile

HEALTH EFFECTS: Pregnancy and Reproduction; genotoxicity; endocrine system; cancers; Brain and Nerves; acute toxicity/poisoning

The sub-lethal and reproductive effects of acute and chronic exposure to flowback and produced water from hydraulic fracturing on the water flea Daphnia magna


ABSTRACT

Hydraulic fracturing is an industrial process allowing for the extraction of gas or oil. To fracture the rocks, a proprietary mix of chemicals is injected under high pressure, which later returns to the surface as flowback and produced water (FPW). FPW is a complex chemical mixture consisting of trace metals, organic compounds, and often, high levels of salts. FPW toxicity to the model freshwater crustacean, Daphnia magna, was characterized utilizing acute (48 h median lethal concentrations, LC50) and chronic (21 d) exposures. A decrease in reproduction was observed, with a mean value of 18.5 neonates produced per replicate over a 21-d chronic exposure to 0.04% FPW, significantly decreased from the average of 64 neonates produced in controls. The time to first brood was delayed in the highest FPW (0.04%) treatment. Neonates exhibited an LC50 of 0.19% of full-strength FPW, making them more sensitive than adults, which displayed an LC50 value of 0.75%. Quantitative PCR highlighted significant changes in expression of genes encoding xenobiotic metabolism (cyp4) and molting (cut). This study is the first to characterize chronic FPW toxicity and will help development of environmental monitoring and risk assessment of FPW spills.

FUNDING: The project was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) grant CRDPJ 469308-14 and support from the Encana Corporation to D.S.A., G.G.G and J.W.M. We would like to thank both Arthur Qi and Dr. Chris Glover for their assistance and technical help with the Daphnia colony.

PUBLICATION TYPE: original research

EXPOSURE ROUTES: dermal

EXTERNAL EXPOSURES: wastewater
The effect of hydraulic flowback and produced water on gill morphology, oxidative stress and antioxidant response in rainbow trout (Oncorhynchus mykiss)


ABSTRACT

Hydraulic fracturing fluid are complex mixtures containing high concentrations of salts (up to 330,000 ppm), organic, and metal contaminants. However, little data exist on the potential mechanisms of toxicity of these flowback and produced wastewaters (FPW) on aquatic biota. Juvenile rainbow trout were exposed to either control, FPW (2.5 or 7.5%), FPW that had been treated with activated charcoal (AC), or a custom salt-matched control (SW, replicating only the salt content of FPW) for 48 hours. Gill histology revealed decreases in interlamellar cell mass (ILCM) and mean lamellar length in all treatments (FPW, AC and SW) compared to control, indicative of hyperosmotic stress. Liver CYP1A1 activity was significantly elevated by 7.5-fold in the FPW 7.5% treatment only, indicative of Phase I metabolism. Superoxide dismutase activity significantly decreased in the gills to all treatments with the lowest activity occurring in the 7.5% FPW group. Catalase activity increased in liver with the highest values noted in fish exposed to 7.5% FPW. No changes were observed with respect to glutathione-S-transferase, while increased lipid peroxidation was only observed in both FPW treatments (2.5, 7.5%). These data suggest a characteristic signature of FPW impact which may help in risk assessment and biomonitoring of FPW spills.

FUNDING: The project was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) grant CRDPJ 469308-14 and support from the Encana Corporation to Daniel Alessi, Greg G. Goss and John Martin. We would like to thank Henry He and Arthur Qi for their technical assistance on this project.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: experimental

EXPOSURE ROUTES: dermal; oral

EXTERNAL EXPOSURES: wastewater

GEOLOGIC FORMATIONS: Duvernay Formation

STATES/COUNTRIES: Alberta, Canada

GAS/OIL: natural gas; unconventional

CHEMICALS: PAHs; sodium; chloride; zinc; metals; fluorene; dimethylphenanthrene

HEALTH EFFECTS: Lungs and Breathing; Digestive System

There's a world going on underground — Infant mortality and fracking in Pennsylvania


ABSTRACT
Background: There has been a rapid global development of the horizontal drilling and hydraulic fracturing process termed fracking. This involves the dispersion of “produced water” which contains naturally occurring radioactive material (NORM) which may contaminate surface water and pose a health risk. Objectives: To investigate association between early (0-28 days) infant mortality by county in Pennsylvania and fracking. Methods: We compared early infant mortality for 2007-2010 after fracking developed with a control period 2003-2006, contrasting a group of the 10 most heavily fracked counties with the rest of Pennsylvania. Results: Whilst early infant deaths decreased by 2.4% in the State over the period, in the 82,558 births in the 10 fracked counties there was a significant increase in mortality (238 vs 193; RR = 1.29; 95% CI 1.05, 1.55; p = 0.011). For the five north east fracked counties Bradford, Susquehanna, Lycoming, Wyoming and Tioga the combined early infant mortality increased from 34 deaths to 60 (RR 1.66; 1.05, 2.51; p = 0.014), whereas in the south western 5 counties Washington, Westmoreland, Fayette, Butler and Greene the increase was modest, 157 to 178 (RR 1.18; 0.95, 1.46; p = 0.13). Increased risk was associated with exposure to groundwater, expressed as the county ratio of water wells divided by the number of births. Conclusions: Fracking appears to be associated with early infant mortality in populations living in counties where the process is carried out. There is some evidence that the effect is associated with private water well density and/or environmental law violations.

Modeling potential occupational inhalation exposures and associated risks of toxic organics from chemical storage tanks used in hydraulic fracturing using AERMOD


ABSTRACT

Various toxic chemicals used in hydraulic fracturing fluids may influence the inherent health risks associated with these operations. This study investigated the possible occupational inhalation exposures and potential risks related to the volatile organic compounds (VOCs) from chemical storage tanks and flowback pits used in hydraulic fracturing. Potential risks were evaluated based on radial distances between 5 m and 180 m from the wells for 23 contaminants with known inhalation reference concentration (RfC) or inhalation unit risks (IUR). Results show that chemicals used in 12.4% of the wells posed a potential acute non-cancer risks for exposure and 0.11% of the wells with may provide chronic non-cancer risks for exposure. Chemicals used in 7.5% of the wells were associated with potential acute cancer risks for exposure. Those chemicals used in 5.8% of the wells were associated with chronic cancer risks for exposure with IUR greater than 10−6, suggesting formaldehyde was the dominant contributor to both types of risks for exposure in hydraulic fracturing. This study also found that due to other existing on-site emission sources of VOCs and the geographically compounded air concentrations from other surrounding wells, chemical emissions data from storage tanks and flowback pits used in this study were lower than reported concentrations from field measurements where higher occupational inhalation risks for exposure may be expected.

FUNDING: We would like to thank Dr. Joshua S. Fu and Dr. Qiang He from the Department of Civil and Environmental Engineering and Dr. Paul D. Terry from the Department of Medicine at the University of Tennessee - Knoxville, Knoxville, TN for providing their valuable suggestions for this manuscript. This research did not receive any specific grant or funding from any agency in the public, commercial, or not-for-profit sectors.
Comparative human toxicity impact of electricity produced from shale gas and coal

ABSTRACT
The human toxicity impact (HTI) of electricity produced from shale gas is lower than the HTI of electricity produced from coal, with 90% confidence using a Monte Carlo Analysis. Two different impact assessment methods estimate the HTI of shale gas electricity to be 1–2 orders of magnitude less than the HTI of coal electricity (0.016–0.024 DALY/GWh versus 0.69–1.7 DALY/GWh). Further, an implausible shale gas scenario where all fracturing fluid and untreated produced water is discharged directly to surface water throughout the lifetime of a well also has a lower HTI than coal electricity. Particulate matter dominates the HTI for both systems, representing a much larger contribution to the overall toxicity burden than VOCs or any aquatic emission. Aquatic emissions can become larger contributors to the HTI when waste products are inadequately disposed or there are significant infrastructure or equipment failures. Large uncertainty and lack of exposure data prevent a full risk assessment; however, the results of this analysis provide a comparison of relative toxicity, which can be used to identify target areas for improvement and assess potential trade-offs with other environmental impacts.

FUNDING: This material is based in part upon work supported by the University of Michigan Water Center and M-Cubed program and the National Science Foundation under grant number 1214416. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the University of Michigan or the National Science Foundation.

PUBLICATION TYPE: original research
EVIDENCE STREAMS: modeling/QSAR/risk calculation
EXTERNAL EXPOSURES: wastewater; surface water; spills/leaks; air
GEOLOGIC FORMATIONS: Marcellus Shale
STATES/COUNTRIES: PA
GAS/OIL: unconventional; natural gas
CHEMICALS: particulate matter, VOCs, NOx

Hydraulic fracturing and infant health: New evidence from Pennsylvania

ABSTRACT
The development of hydraulic fracturing (“fracking”) is considered the biggest change to the global energy production system in the last half-century. However, several communities have banned fracking because of unresolved concerns about the impact of this process on human health. To evaluate the potential health impacts of fracking, we analyzed records of more than 1.1 million births in Pennsylvania from 2004 to 2013, comparing infants born to mothers living at different distances from active fracking sites and those born both before and after fracking was initiated at each site. We adjusted for fixed maternal determinants of infant health by comparing siblings who were and were not exposed to fracking sites in utero. We found evidence for negative health effects of in utero exposure to fracking sites within 3 km of a mother’s residence, with the largest health impacts seen for in utero exposure within 1 km of fracking sites. Negative health impacts include a greater incidence of low–birth weight babies as well as significant declines in average birth weight and in several
other measures of infant health. There is little evidence for health effects at distances beyond 3 km, suggesting that health impacts of fracking are highly local. Informal estimates suggest that about 29,000 of the nearly 4 million annual U.S. births occur within 1 km of an active fracking site and that these births therefore may be at higher risk of poor birth outcomes.

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**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** human: non-occupational

**EXPOSURE ROUTES:** inhalation

**EXTERNAL EXPOSURES:** well density/drilling activity

**GEOLOGIC FORMATIONS:** Marcellus Shale

**STATES/COUNTRIES:** PA

**GAS/OIL:** natural gas; unconventional

**HEALTH EFFECTS:** Pregnancy and Reproduction

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**Unconventional oil and gas development and risk of childhood leukemia: Assessing the evidence**


**ABSTRACT**

The widespread distribution of unconventional oil and gas (UO&G) wells and other facilities in the United States potentially exposes millions of people to air and water pollutants, including known or suspected carcinogens. Childhood leukemia is a particular concern because of the disease severity, vulnerable population, and short disease latency. A comprehensive review of carcinogens and leukemogens associated with UO&G development is not available and could inform future exposure monitoring studies and human health assessments. The objective of this analysis was to assess the evidence of carcinogenicity of water contaminants and air pollutants related to UO&G development. We obtained a list of 1177 chemicals in hydraulic fracturing fluids and wastewater from the U.S. Environmental Protection Agency and constructed a list of 143 UO&G-related air pollutants through a review of scientific papers published through 2015 using PubMed and ProQuest databases. We assessed carcinogenicity and evidence of increased risk for leukemia/lymphoma of these chemicals using International Agency for Research on Cancer (IARC) monographs. The majority of compounds (> 80%) were not evaluated by IARC and therefore could not be reviewed. Of the 111 potential water contaminants and 29 potential air pollutants evaluated by IARC (119 unique compounds), 49 water and 20 air pollutants were known, probable, or possible human carcinogens (55 unique compounds). A total of 17 water and 11 air pollutants (20 unique compounds) had evidence of increased risk for leukemia/lymphoma, including benzene, 1,3-butadiene, cadmium, diesel exhaust, and several polycyclic aromatic hydrocarbons. Though information on the carcinogenicity of compounds associated with UO&G development was limited, our assessment identified 20 known or suspected carcinogens that could be measured in future studies to advance exposure and risk assessments of cancer-causing agents. Our findings support the need for investigation into the relationship between UO&G development and risk of cancer in general and childhood leukemia in particular.

**FUNDING:** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** human: non-occupational

**EXPOSURE ROUTES:** dermal; inhalation; oral

**EXTERNAL EXPOSURES:** wastewater; surface water; spills/leaks; drinking water; air

**GAS/OIL:** natural gas; oil; unconventional
A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity


**ABSTRACT**

Hydraulic-fracturing fluids and wastewater from unconventional oil and natural gas development contain hundreds of substances with the potential to contaminate drinking water. Challenges to conducting well-designed human exposure and health studies include limited information about likely etiologic agents. We systematically evaluated 1021 chemicals identified in hydraulic-fracturing fluids (n=925), wastewater (n=132), or both (n=36) for potential reproductive and developmental toxicity to triage those with potential for human health impact. We searched the REPROTOX database using Chemical Abstract Service registry numbers for chemicals with available data and evaluated the evidence for adverse reproductive and developmental effects. Next, we determined which chemicals linked to reproductive or developmental toxicity had water quality standards or guidelines. Toxicity information was lacking for 781 (76%) chemicals. Of the remaining 240 substances, evidence suggested reproductive toxicity for 103 (43%), developmental toxicity for 95 (40%), and both for 41 (17%).

Of these 157 chemicals, 67 had or were proposed for a federal water quality standard or guideline. Toxicity information was lacking for 781 (76%) chemicals. Of the remaining 240 substances, evidence suggested reproductive toxicity for 103 (43%), developmental toxicity for 95 (40%), and both for 41 (17%). Of these 157 chemicals, 67 had or were proposed for a federal water quality standard or guideline. Our systematic screening approach identified a list of 67 hydraulic fracturing-related candidate analytes based on known or suspected toxicity. Incorporation of data on potency, physicochemical properties, and environmental concentrations could further prioritize these substances for future drinking water exposure assessments or reproductive and developmental health studies.

**FUNDING:** The authors declare no conflict of interest.

**PUBLICATION TYPE:** review

**EVIDENCE STREAMS:** human: non-occupational; animal: experimental

**EXPOSURE ROUTES:** oral

**EXTERNAL EXPOSURES:** wastewater

**GAS/OIL:** natural gas; oil; unconventional

**CHEMICALS:** VOCs

**HEALTH EFFECTS:** Pregnancy and Reproduction

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The Human Health Implications of Oil and Natural Gas Development


**ABSTRACT**

Shale energy extraction activities in residential areas have the potential to adversely affect human health. The oil and gas sector is the largest industrial source of volatile organic compounds, which are dangerous because they include hazardous air pollutants, such as the carcinogen benzene; and because they are precursors to ozone, which is also hazardous to health. Leaks from a small number of high-emitting sources account for a large percentage of these emissions. Furthermore, recent studies from several shale basins suggest that benzene emissions from oil and natural gas activities are significantly greater than accounted for in state inventories. Benzene may reach dangerous levels within legal residential distances in very close proximity to individual facilities, and sometimes at the regional level as well. Recent studies of ozone indicate that oil and natural gas activities are responsible for a significant percentage of regional ozone levels in densely drilled shale basins, with potential health impacts on millions of people. A study of well blowouts revealed that the average evacuation radius due to a major blowout is 0.8 miles and displaces 49 families. Additionally, six epidemiologic public health studies demonstrated that people who live in close proximity to multiple oil and gas wells in densely developed shale basins have experienced an increased incidence of childhood leukemia, asthma attacks, congenital heart defects, low birth weight, and preterm birth compared to people who live with no production wells nearby. Collectively, these data indicate that dense shale development, as currently practiced, may pose a risk to human health.
Pulmonary toxicity following acute coexposures to diesel particulate matter and alpha-quartz crystalline silica in the Sprague-Dawley rat


ABSTRACT

The effects of acute pulmonary coexposures to silica and diesel particulate matter (DPM), which may occur in various mining operations, were investigated in vivo. Rats were exposed by intratracheal instillation (IT) to silica (50 or 233 mg), DPM (7.89 or 50 mg) or silica and DPM combined in phosphate-buffered saline (PBS) or to PBS alone (control). At one day, one week, one month, two months and three months postexposure bronchoalveolar lavage and histopathology were performed to assess lung injury, inflammation and immune response. While higher doses of silica caused inflammation and injury at all time points, DPM exposure alone did not. DPM (50 mg) combined with silica (233 mg) increased inflammation at one week and one-month postexposure and caused an increase in the incidence of fibrosis at one month compared with exposure to silica alone. To assess susceptibility to lung infection following coexposure, rats were exposed by IT to 233 mg silica, 50 mg DPM, a combination of the two or PBS control one week before intratracheal inoculation with 5 × 10⁵ Listeria monocytogenes. At 1, 3, 5, 7 and 14 days following infection, pulmonary immune response and bacterial clearance from the lung were evaluated. Coexposure to DPM and silica did not alter bacterial clearance from the lung compared to control. Although DPM and silica coexposure did not alter pulmonary susceptibility to infection in this model, the study showed that noninflammatory doses of DPM had the capacity to increase silica-induced lung injury, inflammation and onset/incidence of fibrosis.

FUNDING: This work was supported by National Institute for Occupational Safety and Health. No potential conflict of interest was reported by the authors. Disclaimer: The findings and conclusions in this article are those of the author(s) and do not necessarily represent the view of the National Institute for Occupational Safety and Health.
Cardio-respirometry disruption in zebrafish (Danio rerio) embryos exposed to hydraulic fracturing flowback and produced water


ABSTRACT

Hydraulic fracturing to extract oil and natural gas reserves is an increasing practice in many international energy sectors. Hydraulic fracturing flowback and produced water (FPW) is a hyper saline wastewater returned to the surface from a fractured well containing chemical species present in the initial fracturing fluid, geogenic contaminants, and potentially newly synthesized chemicals formed in the fracturing well environment. However, information on FPW toxicological mechanisms of action remain largely un-known. Both cardio-toxic and respirometric responses were explored in zebrafish (Danio rerio) embryos after either an acute sediment-free (FPW-SF) or raw/sediment containing (FPW-S) fraction exposure of 24 and 48 h at 2.5% and 5% dilutions. A 48 h exposure to either FPW fraction in 24e72 h post fertilization zebrafish embryos significantly increased occurrences of pericardial edema, yolk-sac edema, and tail/ spine curvature. In contrast, larval heart rates significantly decreased after FPW fraction exposures. FPW-S, but not FPW-SF, at 2.5% doses significantly reduced embryonic respiration/metabolic rates (MO2), while for 5% FPW, both fractions reduced MO2. Expression of select cardiac genes were also significantly altered in each FPW exposure group, implicating a cardiovascular system compromise as the potential cause for reduced embryonic MO2. Collectively, these results support our hypothesis that organics are major contributors to cardiac and respiratory responses to FPW exposure in zebrafish embryos. Our study is the first to investigate cardiac and respiratory sub-lethal effects of FPW exposure, demonstrating that FPW effects extend beyond initial osmotic stressors and verifies the use of respirometry as a potential marker for FPW exposure.

FUNDING: This research was funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development Grant CRDPJ 460308e14 and support from Encana Services Company Ltd. to Drs. Dan Alessi, Greg Goss and Jon Martin. We would like to extend our gratitude to the Science Animal Support Services (SASS), as well as the University of Alberta zebrafish aquatics facility staff for their assistance with animal care and maintenance. Additionally, we would like to acknowledge Troy Locke at the Molecular Biology Services Unit (MBSU) for his assistance with this study. The authors declare no conflicts of interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: experimental

EXPOSURE ROUTES: dermal; oral

EXTERNAL EXPOSURES: wastewater

GEOLOGIC FORMATIONS: Duvernay Formation

STATES/COUNTRIES: Alberta, Canada

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Pregnancy and Reproduction; Metabolic; Lungs and Breathing; Blood, Heart, and Circulation

Alterations to juvenile zebrafish (danio rerio) swim performance after acute embryonic exposure to sub-lethal exposures of hydraulic fracturing flowback and produced water


ABSTRACT

Hydraulic fracturing flowback and produced water (FPW) is a wastewater produced during fracturing activities in an operating well which is hyper saline and chemically heterogeneous in nature, containing both anthropogenic and petrogenic chemicals. Determination of FPW associated toxicity to embryonic fish is limited, while investigation into how embryonic exposures may affect later life stages is not yet studied. Juvenile zebrafish embryos (24hrs post fertilization) were acutely exposed to 2.5% and 5% FPW fractions for either 24 or 48hrs and returned to freshwater. After either 24 or 48h exposures, embryos were examined for expression of 3 hypoxia related genes. Erythropoietin (epoa) but not hypoxia inducible factor (hif1aa) nor hemoglobin −ß chain (hbbe1.1) was up-regulated after either 24 or 48h FPW exposure. Surviving embryos were placed in freshwater and grown to a juvenile stage (60days post fertilization). Previously exposed zebrafish were analyzed for both swim performance (Ucrit and Umax) and aerobic capacity. Fish exposed to both sediment containing (FPW-S) or sediment free (FPW-SF) FPW displayed significantly reduced aerobic scope and Ucrit/Umax values compared to control conditions. Our results collectively suggest that organics present in our FPW sample may be responsible for sub-lethal fitness and metabolic responses. We provide evidence supporting the theory that the cardio-respiratory system is impacted by FPW exposure. This is the first known research associating embryonic FPW exposures to sub-lethal performance related responses in later life fish stages.
Chapter Six: Public Health Concerns and Unconventional Oil and Gas Development


ABSTRACT

Increases in unconventional oil and gas development (UD) near urban centers and communities has brought with it public health risks from the operations and stressors put on the surrounding environment. Direct health impacts from exposures to chemicals in the air or water may put workers and residents living near UD activities at risk for certain diseases. There are also indirect health impacts that may result from stressors such as noise pollution, truck traffic, odors, and boomtown effects. All of these factors need to be taken into consideration when assessing the public health implications of UD activities. Researchers are calling for more comprehensive studies to better understand risks associated with UD. Unfortunately, very limited resources have been allocated toward this field of research, therefore making it difficult to understand human health exposures and the possible magnitude of the long-term health burdens associated with UD. Engaging the industry with public health professionals and community leaders can help to improve monitoring of environmental health concerns, generate open dialogues to reduce anxiety, and guide best practices and policies to protect public health.

FUNDING: not addressed

PUBLICATION TYPE: book chapter

EVIDENCE STREAMS: human: occupational; human: non-occupational

EXTERNAL EXPOSURES: wastewater; spills/leaks; drinking water; air

GEOLOGIC FORMATIONS: Utica Shale; Marcellus Shale; Eagle Ford Shale; Denver-Julesberg Basin/Niobrara Shale; Barnett Shale

STATES/COUNTRIES: TX; PA; NY; CO

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: benzene; BTEX; ethylbenzene; ethylene glycol; ethylene glycol monobutyl ether (2-BE); hydrogen sulfide; methane; ozone; particulate matter; silica; toluene; xylenes; VOCs; NOx

HEALTH EFFECTS: Skin, Hair, and Nails; Pregnancy and Reproduction; Lungs and Breathing; Kidneys and Urinary System; Immune System; Eyes, Ears, Nose, and Throat; Digestive System; cancers; Brain and Nerves; Blood, Heart, and Circulation
A Historical Perspective of Unconventional Oil and Gas Extraction and Public Health


ABSTRACT

Technological advances in directional well drilling and hydraulic fracturing have enabled extraction of oil and gas from once unobtainable geological formations. These unconventional oil and gas extraction (UOGE) techniques have positioned the United States as the fastest-growing oil and gas producer in the world. The onset of UOGE as a viable subsurface energy abstraction technology has also led to the rise of public concern about its potential health impacts on workers and communities, both in the United States and other countries where the technology is being developed. Herein we review in the national and global impact of UOGE from a historical perspective of occupational and public health. Also discussed are the sociological interactions between scientific knowledge, social media, and citizen action groups, which have brought wider attention to the potential public health implications of UOGE.

FUNDING: not addressed

PUBLICATION TYPE: book chapter

EVIDENCE STREAMS: human: population health; human: non-occupational

EXTERNAL EXPOSURES: wastewater; drinking water; air

GEOLOGIC FORMATIONS: Utica Shale; Permian Basin; Marcellus Shale; Haynesville Shale; Eagle Ford Shale; Denver-Julesberg Basin/Niobrara Shale; Bakken Shale

STATES/COUNTRIES: WY; WV; UT; TX; PA; OH; ND; MT; LA; CO; CA; AR

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: benzene; ethylbenzene; NORM; toluene; trimethylbenzenes; xylenes; barium; strontium

HEALTH EFFECTS: Skin, Hair, and Nails; Pregnancy and Reproduction; Mental Health and Behavior; Lungs and Breathing; Eyes, Ears, Nose, and Throat; Endocrine system; Digestive System; Cancers; Brain and Nerves; Blood, Heart, and Circulation

Public health implications of environmental noise associated with unconventional oil and gas development


ABSTRACT

Modern oil and gas development frequently occurs in close proximity to human populations and increased levels of ambient noise have been documented throughout some phases of development. Numerous studies have evaluated air and water quality degradation and human exposure pathways, but few have evaluated potential health risks and impacts from environmental noise exposure. We reviewed the scientific literature on environmental noise exposure to determine the potential concerns, if any, that noise from oil and gas development activities present to public health. Data on noise levels associated with oil and gas development are limited, but measurements can be evaluated amidst the large body of epidemiology assessing the non-auditory effects of environmental noise exposure and established public health guidelines for community noise. There are a large number of noise dependent and subjective factors that make the determination of a dose response relationship between noise and health outcomes difficult. However, the literature indicates that oil and gas activities produce noise at levels that may increase the risk of adverse health outcomes, including annoyance, sleep disturbance, and cardiovascular disease. More studies that investigate the relationships between noise exposure and human health risks from unconventional oil and gas development are warranted. Finally, policies and mitigation techniques that limit human exposure to noise from oil and gas operations should be considered to reduce health risks.

FUNDING: JH and SBCS are employees of PSE Healthy Energy, a scientific research institute that supports the adoption of evidence-based energy policies. PSE received initial funding for parts of this research and manuscript from the California Council on Science and Technology (CCST). MM is supported by Environmentally Friendly Drilling, a consortium that is jointly funded by government and industry groups. He was previously employed by the U.S. Department of Labor as an expert witness in a case involving drilling. He is also supported by grants from the U.S. Department of Energy and has served as a consultant to the state of West Virginia on drilling issues. We are grateful for comments and suggestions provided by Adam Law, MD of Weill Cornell Medicine and Daisy Pistey-Lyhne, MS of PSE Healthy Energy. The figure was created by Yoonseo Cha. PSE Healthy Energy received initial resources for parts of this research and manuscript from the California Council on Science and Technology (CCST). The California Natural Resources Agency commissioned CCST to conduct an independent scientific assessment of well stimulation in California, pursuant to Senate Bill 4.
Effects on biotransformation, oxidative stress, and endocrine disruption in rainbow trout (Oncorhynchus mykiss) exposed to hydraulic fracturing flowback and produced water

He Y; Folkerts EJ; Zhang Y; Martin JW; Alessi DS; Goss GG. 2017. Effects on biotransformation; oxidative stress; and endocrine disruption in rainbow trout (Oncorhynchus mykiss) exposed to hydraulic fracturing flowback and produced water. Environ Sci Technol 51(2):940-947, doi: 10.1021/acs.est.6b04695.

ABSTRACT

The effects of hydraulic fracturing (HF) flowback and produced water (HF-FPW), a complex saline mixture of injected HF fluids and deep formation water that return to the surface, was examined in rainbow trout (Oncorhynchus mykiss). Exposure to HF-FPW resulted in significant induction of ethoxyresorufin-O-deethylase (EROD) activity in both liver and gill tissues. Increased lipid peroxidation via oxidative stress was also detected by thiobarbituric acid reactive substances (TBARS) assay. The mRNA expressions of a battery of genes related to biotransformation, oxidative stress, and endocrine disruption were also measured using quantitative real-time polymerase chain reaction (Q-RT-PCR). The increased expression of cyp1a (2.49 ± 0.28-fold), udpgt (2.01 ± 0.31-fold), sod (1.67 ± 0.09-fold), and gpx (1.58 ± 0.10-fold) in raw sample exposure group (7.5%) indicated elevated metabolic enzyme activity, likely through the aryl hydrocarbon receptor pathway, and generation of reactive oxygen species. In addition, the elevated vtg and era2 expression demonstrated endocrine disrupting potential exerted by HF-FPW in rainbow trout. The overall results suggested HF-FPW could cause significant adverse effects on fish, and the organic contents might play the major role in its toxicity. Future studies are needed to help fully determine the toxic mechanism(s) of HF-FPW on freshwater fish, and aid in establishing monitoring, treatment, and remediation protocols for HF-FPW.

FUNDING: Research Council of Canada (NSERC) Collaborative Research and Development (CRD) Grant CRDPJ 469308-14 and support from Encana Services Company Ltd. to D.S.A., G.G.G., and J.W.M.

Chemical and toxicological characterizations of hydraulic fracturing flowback and produced water

ABSTRACT

Hydraulic fracturing (HF) has emerged as a major method of unconventional oil and gas recovery. The toxicity of hydraulic fracturing flowback and produced water (HF-FPW) has not been previously reported and is complicated by the combined complexity of organic and inorganic constituents in HF fluids and deep formation water. In this study, we characterized the solids, salts, and organic signatures in an HF-FPW sample from the Duvernay Formation, Alberta, Canada. Untargeted HPLC-Orbitrap revealed numerous unknown dissolved polar organics. Among the most prominent peaks, a substituted tri-phenyl phosphate was identified which is likely an oxidation product of a common polymer antioxidant. Acute toxicity of zebrafish embryo was attributable to high salinity and organic contaminants in HF-FPW with LC50 values ranging from 0.6% to 3.9%, depending on the HF-FPW fractions and embryo developmental stages. Induction of ethoxyresorufin-O-deethylase (EROD) activity was detected, due in part to polycyclic aromatic hydrocarbons (PAHs), and suspended solids might have a synergistic effect on EROD induction. This study demonstrates that toxicological profiling of real HF-FPW sample presents great challenges for assessing the potential risks and impacts posed by HF-FPW spills.

FUNDING: The work was supported by Natural Sciences and Engineering Research Council of Canada (NSERC) Collaborative Research and Development (CRD) grant [CRDPJ 469308-14] and support from the Encana Corporation to D.S.A., G.G.G and J.W.M. The authors declare no competing financial interest.

EVIDENCE STREAMS: animal: experimental
EXPOSURE ROUTES: dermal; oral
EXTERNAL EXPOSURES: wastewater
GEOLOGIC FORMATIONS: Duvernay Formation
STATES/COUNTRIES: Alberta, Canada

CHEMICALS: naphthalene; PAHs; phenanthrene; acenaphthene; acenaphthenone; anthracene; fluoranthene; pyrene; benzo(a)anthracene; chrysene; benzo(b)fluoranthene; benzo(k+j)fluoranthene; benzo(a)pyrene; indeno(1,2,3-cd)pyrene; benzo(g,h,i)perylene; dibenz(a,h)anthracene; dibenzothiophene; retene; 1-methylanthracene; 1-methylfluorene; 1-methylphenanthrene; 3,6-dimethylphenanthrene; 1-methylpyrene; Benzo(a)pyrene; Silica; nitrogen; chloride; bromide; sulfate; sodium; calcium; potassium; polyethylene glycol surfactants (PEG-EOn); tris(2,4-di-tert-butylphenyl) phosphate; triphenyl phosphate

HEALTH EFFECTS: Mortality; Metabolic; Endocrine system; Acute Toxicity/Poisoning

FUNDING: The authors declare that they have no conflicts of interest.

PUBLICATION TYPE: original research

EXTERNAL EXPOSURES: wastewater
GEOLOGIC FORMATIONS: Marcellus Shale

ABSTRACT

Psychosocial impact of fracking: A review of the literature on the mental health consequences of hydraulic fracturing


ABSTRACT

The process of natural gas extraction known as hydraulic fracturing, or fracking, is a controversial energy acquisition technique often viewed with disdain by the public, due to its potential for environmental harm. However, the mental health and psychological well-being of fracking communities, including potential benefits and detriments, are often overlooked. We reviewed the literature on the association between fracking and psychological functioning, finding that although persons living in fracking communities may experience some minimal, initial benefits such as land lease income or infrastructure development, they may also experience worry, anxiety, and depression about lifestyle, health, safety, and financial security, as well as exposure to neurotoxins and changes to the physical landscape. Indeed, entire communities can experience collective trauma as a result of the “boom/bust” cycle that often occurs when industries impinge on community life. Impacted communities are often already vulnerable, including poor, rural, or indigenous persons, who may continue to experience the deleterious effects of fracking for generations. An influx of workers to fracking communities often stokes fears about outsiders and crime, yet, it must be recognized that this population of mobile workers is also vulnerable, often ostracized, and without social support. Practitioners, researchers, and policy makers alike should continue to investigate the potential psychological ramifications of fracking, so that effective and targeted intervention strategies can be developed, disseminated, and implemented to improve mental health in fracking communities.

FUNDING: The authors declare that they have no conflicts of interest.

PUBLICATION TYPE: review

EVIDENCE STREAMS: human: population health
GEOLOGIC FORMATIONS: Marcellus Shale
Fracking and public health: Evidence from gonorrhea incidence in the Marcellus Shale region


ABSTRACT

The United States (US) began to experience a boom in natural gas production in the 2000s due to the advent of hydraulic fracturing (fracking) and horizontal drilling technology. While the natural gas boom affected many people through lower energy prices, the strongest effects were concentrated in smaller communities where the fracking occurred. We analyze one potential cost to communities where fracking takes place: an increase of sexually transmitted diseases. We use a quasi-natural experiment within the Marcellus shale region plus panel data estimation techniques to quantify the impact of fracking activity on local gonorrhea incidences. We found fracking activity to be associated with an increase in gonorrhea. Our findings may be useful to public health officials. To make informed decisions about resource extraction, policy makers as well as regulators and communities need to be informed of all the benefits as well as the costs.

FUNDING: not addressed

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: population health

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: WV; PA; OH; NY

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Sexual Health Issues

Coping with change in rural landscapes: The psychological stress of rural residents experiencing unconventional gas developments


ABSTRACT

Rural landscapes in many parts of the world are experiencing increasing pressure from competing uses. One particular use, unconventional natural gas extraction, has received considerable attention over the past decade owing to its rapid growth and associated impacts on rural landscapes. This study examined how a sample of Australian rural residents experienced the processes of psychological stress induced by a coal seam gas project that created perceived undesirable changes to resources they valued. Its effect on residents' psychological well-being slowly unfolded over several years. We deconstructed the stress processes by investigating primary appraisal, secondary appraisal, and subsequent emotional and coping responses guided by the cognitive theory of stress and coping. Primary appraisal measured how the impacts of change on personal and communal resources were assessed while secondary appraisal gauged the options available to individuals to cope. Our results show that when primary appraisal alerts individuals of resource loss, negative emotions are more likely experienced. Such an appraisal directly drives engagement in eight coping strategies classified into four categories: problem-focused, support-based, emotion-focused, and maladaptive coping. It also motivates coping indirectly except for one strategy of emotion-focused coping mediated by negative emotions. While secondary appraisal also directly contributes to four coping strategies that each pertains to one of the four coping categories, it has no effect on negative emotions and four remaining coping strategies that are emotion-focused and maladaptive. These findings shed light on our understanding of the psychological
Identification and comparative mammalian cell cytotoxicity of new iodo-phenolic disinfection byproducts in chloraminated oil and gas wastewaters


ABSTRACT

Hydraulic fracturing wastewaters discharged to surface water have led to elevated bromide and iodide levels, as well as enhanced formation of brominated trihalomethanes, haloacetic acids, haloacetonitriles, and iodo-trihalomethanes at downstream drinking water treatment plants, in chlorinated effluent from wastewater treatment plants, and in controlled laboratory studies. This enhanced formation of brominated and iodinated disinfection byproducts (DBPs) raises concerns regarding human health, because they are much more toxic than chlorinated DBPs. This study represents the first nontarget, comprehensive analysis of iodinated DBPs formed in chloraminated produced waters associated with hydraulic fracturing of shale and conventional gas formations. Fifty-six iodo-phenolics were identified, comprising three homologous series of mono-, di-, and tri-iodinated phenols, along with two new classes of DBPs: iodomethylphenols and iododimethylphenols. Four iodo-phenolics (2-iodophenol, 4-iodophenol, 2,4,6-triiodophenol, and 4-iodo-2-methylphenol) were investigated for mammalian cell cytotoxicity. All were cytotoxic, especially 2,4,6-triiodophenol, which was more cytotoxic than all trihalomethanes and most haloacetic acids. In addition, geogenic organic compounds present in the oil and gas produced waters, including methylphenol and dimethylphenol, were found to be potential precursors to these iodo-DBPs.

FUNDING: The authors declare no competing financial interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: in vitro

EXPOSURE ROUTES: in vitro

EXTERNAL EXPOSURES: wastewater

GEOLOGIC FORMATIONS: Barnett Shale

STATES/COUNTRIES: TX

GAS/OIL: unconventional; natural gas

CHEMICALS: iodophenol; diiodophenol; triiodophenol; iodomethylphenol; diiodomethylphenol; triiodomethylphenol; iododimethylphenol; diiododimethylphenol; triiododimethylphenol; bromide; iodide; methylphenols; dimethylphenols

HEALTH EFFECTS: acute toxicity/poisoning
Exploring the determinants of health and wellbeing in communities living in proximity to coal seam gas developments in regional Queensland


ABSTRACT

Background: There is some concern that coal seam gas mining may affect health and wellbeing through changes in social determinants such as living and working conditions, local economy and the environment. The onward impact of these conditions on health and wellbeing is often not monitored to the same degree as direct environmental health impacts in the mining context, but merits attention. This study reports on the findings from a recurrent theme that emerged from analysis of the qualitative component of a comprehensive Health Needs Assessment (HNA) conducted in regional Queensland, that health and wellbeing of communities was reportedly affected by nearby coal seam gas (CSG) development beyond direct environmental impacts. Methods: Qualitative analysis was initially completed using the Framework Method to explore key themes from 11 focus group discussions, 19 in-depth interviews, and 45 key informant interviews with health and wellbeing service providers and community members. A key theme emerged from the analysis that forms the basis of this paper. This study is part of a larger comprehensive HNA involving qualitative and quantitative data collection to explore the health and wellbeing needs of three communities living in proximity to CSG development in regional Queensland, Australia. Results: Communities faced social, economic and environmental impacts from the rapid growth of CSG development, which were perceived to have direct and indirect effects on individual lifestyle factors such as alcohol and drug abuse, family relationships, social capital and mental health; and community-level factors including social connectedness, civic engagement and trust. Conclusions: Outer regional communities discussed the effects of mining activity on the fabric of their town and community, whereas the inner regional community that had a longer history of industrial activity discussed the impacts on families and individual health and wellbeing. The findings from this study may inform future health service planning in regions affected by CSG in the development/construction phase and provide the mining sector in regional areas with evidence from which to develop social responsibility programs that encompass health, social, economic and environmental assessments that more accurately reflect the needs of the affected communities.

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PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: population health

EXTERNAL EXPOSURES: well density/drilling activity

STATES/COUNTRIES: Queensland, Australia

GAS/OIL: coalbed methane

HEALTH EFFECTS: Mental Health and Behavior

Energy boom and gloom? Local effects of oil and natural gas drilling on subjective well-being


ABSTRACT

Prior to the precipitous drop in oil prices in 2014, the U.S. had experienced a substantial increase in oil and natural gas extraction due to technological advancements including horizontal drilling and hydraulic fracturing. This increased energy development likely created both benefits and costs, but the net effects for local residents are not well understood. This paper examines the effects of conventional and horizontal oil and natural gas drilling in Texas on subjective assessments of life-satisfaction and bad mental health days for nearby residents. Horizontal drilling has statistically significant deleterious effects on well-being, but the effects are driven by the Dallas-Fort Worth (DFW) metropolitan area, an area with both very high levels of horizontal drilling and a large urban population.

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PUBLICATION TYPE: original research

EVIDENCE STREAMS: original research
Quality of life and unconventional oil and gas development: Towards a comprehensive impact model for host communities


ABSTRACT

New technologies like hydraulic fracturing and directional drilling have ushered in a boom of domestic oil and gas production in the United States. Oil and gas drilling often occurs in close proximity to where people live and work, creating the potential for significant quality of life impacts. In this review, we integrate across diverse literatures to develop a holistic account of how oil and gas development might impact quality of life in host communities. Our review suggests that the potential effect of oil and gas development is complex, as it can provide economic growth for beleaguered rural areas but also degrade human health, environmental quality and have other deleterious impacts. We conclude by suggesting directions for future research.

FUNDING: not addressed

PUBLICATION TYPE: review

EVIDENCE STREAMS: human: population health; human: non-occupational

GAS/OIL: natural gas; oil; unconventional

HEALTH EFFECTS: Mental Health and Behavior

Does increased traffic flow around unconventional resource development activities represent the major respiratory hazard to neighboring communities?: Knowns and unknowns


ABSTRACT

The objective of this review is to demonstrate that the focus on air emissions causing respiratory effects and associated with gas development may be misplaced by attributing those exposures mainly to well pad activities. Recent findings: The most recent publications on the health effects of hydraulic fracturing operations seem to parallel findings from studies of diesel particulate exposure near roadways and the health effects associated with those exposures. It seems at least possible that some, if not all, of the respiratory effects associated with unconventional resource development may be traffic-related. Road traffic generated by hydraulic fracturing operations is one possible source of environmental impact whose significance has, until now, been largely neglected in the available literature with 4000 to 6000 vehicles visiting the well pad. Summary: Exposures from well pads diminish rapidly with distances of only a few kilometers but there is evidence showing disease risk multiple kilometers from well pads. This leaves open the possibility that the several thousand vehicle trips per well pad create traffic emissions over wide areas away from the pad. This alternative source of exposure has not previously been well studied but is being more seriously considered.

FUNDING: Thanks are due to Ms. Maya Nye and Alexandria Dzomba for their assistance in preparation of the Figure and Tables used herein. This work was funded by US Department of Energy National Energy Technology Laboratory, Award No.: DE-FE0024297. There are no conflicts of interest.

PUBLICATION TYPE: review
Childhood hematologic cancer and residential proximity to oil and gas development


ABSTRACT

Background: Oil and gas development emits known hematological carcinogens, such as benzene, and increasingly occurs in residential areas. We explored whether residential proximity to oil and gas development was associated with risk for hematologic cancers using a registry-based case-control study design. Methods: Participants were 0–24 years old, living in rural Colorado, and diagnosed with cancer between 2001–2013. For each child in our study, we calculated inverse distance weighted (IDW) oil and gas well counts within a 16.1-kilometer radius of residence at cancer diagnosis for each year in a 10 year latency period to estimate density of oil and gas development. Logistic regression, adjusted for age, race, gender, income, and elevation was used to estimate associations across IDW well count tertiles for 87 acute lymphocytic leukemia (ALL) cases and 50 non-Hodgkin lymphoma (NHL) cases, compared to 528 controls with non-hematologic cancers. Findings: Overall, ALL cases 0–24 years old were more likely to live in the highest IDW well count tertiles compared to controls, but findings differed substantially by age. For ages 5–24, ALL cases were 4.3 times as likely to live in the highest tertile, compared to controls (95% CI: 1.1 to 16), with a monotonic increase in risk across tertiles (trend p-value = 0.035). Further adjustment for year of diagnosis increased the association. No association was found between ALL for children aged 0–4 years or NHL and IDW well counts. While our study benefited from the ability to select cases and controls from the same population, use of cancer-controls, the limited number of ALL and NHL cases, and aggregation of ages into five year ranges, may have biased our associations toward the null. In addition, absence of information on O&G well activities, meteorology, and topography likely reduced temporal and spatial specificity in IDW well counts. Conclusion: Because oil and gas development has potential to expose a large population to known hematologic carcinogens, further study is clearly needed to substantiate both our positive and negative findings. Future studies should incorporate information on oil and gas development activities and production levels, as well as levels of specific pollutants of interest (e.g. benzene) near homes, schools, and day care centers, provide age-specific residential histories, compare cases to controls without cancer, and address other potential confounders, and environmental stressors.

FUNDING: This work was supported by the University of Colorado Cancer Center. The authors have declared that no competing interests exist.

EVIDENCE STREAMS: human: non-occupational
EXTERNAL EXPOSURES: well density/drilling activity
STATES/COUNTRIES: CO
GAS/OIL: natural gas; oil; unconventional
CHEMICALS: benzene
HEALTH EFFECTS: Immune System; cancers; Blood, Heart, and Circulation
Organic geochemistry and toxicology of a stream impacted by unconventional oil and gas wastewater disposal operations


ABSTRACT

The large volume of wastewater produced during unconventional oil and gas (UOG) extraction is a significant challenge for the energy industry and of environmental concern, as the risks due to leaks, spills, and migration of these fluids into natural waters are unknown. UOG wastewater is often hypersaline, and contains myriad organic and inorganic substances added for production purposes and derived from the source rock or formation water. In this study, we examined the organic composition and toxicology of water and sediments in a stream adjacent to an underground injection disposal facility that handles UOG wastewaters. We sampled water and streambed sediments from an unnamed tributary of Wolf Creek upstream from the disposal facility, near the injection well, and downstream. Two sites downstream from the disposal facility contained organic compounds in both water and sediments that were consistent with a source from UOG wastewater. These compounds included: 2-(2-butoxyethoxy)-ethanol, tris(1-chloro-2-propyl)phosphate, a, a-dimethyl-benzenemethanol, 3-ethyl-4-methyl-1H-pyrrole-2,5-dione, and tetrahydro-thiophene-1,1-dioxide in water, diesel fuel hydrocarbons (e.g. pentacosane, Z-14-nonacosane), and halogenated hydrocarbons (e.g., 1-iodo-octadecane, octatriacontyl trifluoroacetate, dotriacontyl pentafluoropropionate) in sediments. Concentrations of UOG-derived organic compounds at these sites were generally low, typically 4 to <1 mg/L in the water, and <70 mg/g (dry wt.) in the sediment. In addition, water and sediment at a site immediately downstream from the facility contained many chromatographically unresolved and unidentified hydrocarbons. In contrast, sites upstream from the facility or in nearby watersheds not influenced by the disposal well facility contained primarily natural (biologically produced) organic substances from the local environment. Toxicological assays of human cell line exposures to water and sediment showed minimal effects. Results indicate that UOG wastewater has entered the stream and that UOG-derived organic substances are present. The contamination level, however, is low and appears to be restricted to sites immediately downstream from the disposal facility at this time.

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PUBLICATION TYPE: original research

EVIDENCE STREAMS: in vitro

EXPOSURE ROUTES: in vitro

EXTERNAL EXPOSURES: surface water; wastewater

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: WV

GAS/OIL: coalbed methane; natural gas; oil; unconventional

CHEMICALS: ethylene glycol; hexane; methane; NORM; PAHs; pentane; glutaraldehyde; 2-butoxyethanol; 2,2-dibromo-3-nitrilopropionamide; dibromooacetoneitrile; ethane; propane; butane; 2-(2-butoxyethoxy)ethanol; tris(1-chloro-2-propyl)phosphate; 3-ethyl-4-methyl-1H-pyrrole-2,5-dione; tetrahydro-thiophene-1,1-dioxide; pentacosane; z-14-nonacosane; diesel; 1-iodo-octadecane; octatriacontyl trifluoroacetate; dotriacontyl pentafluoropropionate; a,a-dimethyl-benzenemethanol

HEALTH EFFECTS: acute toxicity/poisoning

Overview of silica-related clusters in the United States: Will fracking operations become the next cluster?


ABSTRACT

Silicosis is the oldest know occupational pulmonary disease. It is a progressive disease and any level of exposure to respirable crystalline silica particles or dust has the potential to develop into silicosis. Silicosis is caused by silica particles or dust entering the lungs and damaging healthy lung tissue. The damage restricts the ability to breathe. Exposure to silica increases a worker’s risk of developing cancer or tuberculosis. This special report will provide background history of silicosis in the U.S., including the number of workers affected and their common industries. Over the years, these industries have impeded government oversight, resulting in silicosis exposure clusters. The risk of acquiring silicosis is diminished when industry implements safety measures with oversight by governmental agencies. Reputable authorities believe that the current innovative drilling techniques such as fracking will generate future cases of silicosis in the U.S. if safety measures to protect workers are ignored.
Bounding analysis of drinking water health risks from a spill of hydraulic fracturing flowback water


ABSTRACT

A bounding risk assessment is presented that evaluates possible human health risk from a hypothetical scenario involving a 10,000-gallon release of flowback water from horizontal fracturing of Marcellus Shale. The water is assumed to be spilled on the ground, infiltrates into groundwater that is a source of drinking water, and an adult and child located downgradient drink the groundwater. Key uncertainties in estimating risk are given explicit quantitative treatment using Monte Carlo analysis. Chemicals that contribute significantly to estimated health risks are identified, as are key uncertainties and variables to which risk estimates are sensitive. The results show that hypothetical exposure via drinking water impacted by chemicals in Marcellus Shale flowback water, assumed to be spilled onto the ground surface, results in predicted bounds between 10−10 and 10−6 (for both adult and child receptors) for excess lifetime cancer risk. Cumulative hazard indices (HICUMULATIVE) resulting from these hypothetical exposures have predicted bounds (5th to 95th percentile) between 0.02 and 35 for assumed adult receptors and 0.1 and 146 for assumed child receptors. Predicted health risks are dominated by noncancer endpoints related to ingestion of barium and lithium in impacted groundwater. Hazard indices above unity are largely related to exposure to lithium. Salinity taste thresholds are likely to be exceeded before drinking water exposures result in adverse health effects. The findings provide focus for policy discussions concerning flowback water risk management. They also indicate ways to improve the ability to estimate health risks from drinking water impacted by a flowback water spill (i.e., reducing uncertainty).

FUNDING: Support for this study was provided by Hull & Associates, Inc. (Hull). Hull is an associate member of the Marcellus Shale Coalition (MSC). The MSC had no input or influence over the design, execution, or content of this study. The authors gratefully acknowledge the Risk Analysis reviewers for recommendations that improved this article. We also thank Rick Nelson at ToxStrategies for his assistance in preparing the final article.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation

EXPOSURE ROUTES: oral

EXTERNAL EXPOSURES: wastewater; spills/leaks; soil; drinking water

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

CHEMICALS: barium, benzene, BTEX, ethylbenzene, ethylene glycol, ethylene glycol monobutyl ether (2-BE), propylene glycol, xylenes, bromide; fluoride; nitrate; aluminum; antimony; arsenic; boron; cadmium; cobalt; copper; iron; lithium; manganese; molybdenum; nickel; selenium; strontium; thallium; zinc; hexavalent chromium; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; benz(a)pyrene; bis(2-ethylhexyl)phthalate; dibenz(a,h)anthracene; hexachlorobenzene; pyridine; beta-BHC; gamma-BHC; butyl alcohol; methanol; hydro-treated light petroleum distillates; ethoxylated alcohols; 2,2-dibromo-3-nitropropanamide; ammonium peroxysulfate; glutaraldehyde; propagaryl alcohol

HEALTH EFFECTS: Cancers
Mule deer and energy development—Long-term trends of habituation and abundance


ABSTRACT

As the extent and intensity of energy development in North America increases, so do disturbances to wildlife and the habitats they rely upon. Impacts to mule deer are of particular concern because some of the largest gas fields in the USA overlap critical winter ranges. Short-term studies of 2–3 years have shown that mule deer and other ungulates avoid energy infrastructure; however, there remains a common perception that ungulates habituate to energy development, and thus, the potential for a demographic effect is low. We used telemetry data from 187 individual deer across a 17-year period, including 2 years predevelopment and 15 years during development, to determine whether mule deer habituated to natural gas development and if their response to disturbance varied with winter severity. Concurrently, we measured abundance of mule deer to indirectly link behavior with demography. Mule deer consistently avoided energy infrastructure through the 15-year period of development and used habitats that were an average of 913 m further from well pads compared with predevelopment patterns of habitat use. Even during the last 3 years of study, when most wells were in production and reclamation efforts underway, mule deer remained >1 km away from well pads. The magnitude of avoidance behavior, however, was mediated by winter severity, where aversion to well pads decreased as winter severity increased. Mule deer abundance declined by 36% during the development period, despite aggressive onsite mitigation efforts (e.g. directional drilling and liquid gathering systems) and a 45% reduction in deer harvest. Our results indicate behavioral effects of energy development on mule deer are long term and may affect population abundance by displacing animals and thereby functionally reducing the amount of available habitat.

FUNDING: Funding for this work was provided by Bureau of Land Management, Mule Deer Foundation, Pinedale Anticline Project Office, Questar Exploration and Production, Rocky Mountain Elk Foundation, University of Wyoming, Wyoming Game and Fish Department. We thank the Wyoming Migration Initiative and University of Oregon Cartography Lab for assistance with infographics. Comments from three anonymous reviewers helped improve the manuscript.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: wildlife

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Green River Basin

STATES/COUNTRIES: WY

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Mental Health and Behavior

A review of the human health impacts of unconventional natural gas development


ABSTRACT

This review summarizes the recent epidemiologic literature examining health outcomes in communities living close to unconventional natural gas development (UNGD) and identifies areas requiring further study. Recent Findings: To date, these studies have been primarily retrospective in design and used self-report of health symptoms or electronic health databases to obtain outcome information. Proximity to UNGD is often used as a surrogate for exposure. There is preliminary evidence linking respiratory outcomes, including asthma exacerbations, and birth outcomes, such as reduced fetal growth and preterm birth, to UNGD, however, results differ across study populations and regions. Summary: Although small, the current body of literature suggests that living near UNGD may have negative health consequences for surrounding communities, but additional work using more granular estimates of exposure or personalized monitoring is urgently needed.

FUNDING: Shaina L. Stacy declares no potential conflict of interest.

PUBLICATION TYPE: review

EVIDENCE STREAMS: human: non-occupational

EXPOSURE ROUTES: dermal; inhalation; oral
EXTERNAL EXPOSURES: well density/drilling activity; spills/leaks; drinking water; air

GAS/OIL: natural gas; unconventional

CHEMICALS: benzene; ethylbenzene; particulate matter; xylenes; VOCs; nitrous oxides; metals; radionuclides; bromine

HEALTH EFFECTS: Skin, Hair, and Nails; Mental Health and Behavior; Lungs and Breathing; cancers; Brain and Nerves; Blood, Heart, and Circulation

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Comparison of chemical-use between hydraulic fracturing, acidizing, and routine oil and gas development


ABSTRACT

The potential hazards and risks associated with well-stimulation in unconventional oil and gas development (hydraulic fracturing, acid fracturing, and matrix acidizing) have been investigated and evaluated and federal and state regulations requiring chemical disclosure for well-stimulation have been implemented as part of an overall risk management strategy for unconventional oil and gas development. Similar evaluations for chemicals used in other routine oil and gas development activities, such as maintenance acidizing, gravel packing, and well drilling, have not been previously conducted, in part due to a lack of reliable information concerning on-field chemical-use. In this study, we compare chemical-use between routine activities and the more closely regulated well-stimulation activities using data collected by the South Coast Air Quality Monitoring District (SCAQMD), which mandates the reporting of both unconventional and routine on-field chemical-use for parts of Southern California. Analysis of this data shows that there is significant overlap in chemical-use between so-called unconventional activities and routine activities conducted for well maintenance, well-completion, or rework. A comparison within the SCAQMD shows a significant overlap between both types and amounts of chemicals used for well-stimulation treatments included under State mandatory-disclosure regulations and routine treatments that are not included under State regulations. A comparison between SCAQMD chemical-use for routine treatments and state-wide chemical-use for hydraulic fracturing also showed close similarity in chemical-use between activities covered under chemical disclosure requirements (e.g. hydraulic fracturing) and many other oil and gas field activities. The results of this study indicate regulations and risk assessments focused exclusively on chemicals used in well-stimulation activities may underestimate potential hazard or risk from overall oil field chemical-use.

FUNDING: This material is based upon work supported by the Department of Energy under Award Number DE-IA0000018. This study was supported in part by grants from The Broad Reach Fund and Laboratory Directed Research and Development (LDRD) funding from Berkeley Lab, provided by the Director, Office of Science, of the U.S. Department of Energy under Contract No. DEAC02-05CH1123. The authors have declared that no competing interests exist.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation; animal: experimental

EXPOSURE ROUTES: oral; inhalation

GEOLOGIC FORMATIONS: Monterey Formation

STATES/COUNTRIES: CA

GAS/OIL: unconventional; oil; natural gas

CHEMICALS: 2-methyl-3(2H)-isothiazolone; 5-chloro-2-methyl-3(2H)-isothiazolone; α-(nonylphenyl)-w-hydroxy-; acrylamide; alcohols; aluminum; aluminum chloride; benzene; benzoisothiazolinone; canola oil; cocomidopropyl betaine; cyclohexasiloxane; cyclopentasiloxane; DBNPA (2,2-dibromo-3-nitrilopropionamide); dodecylbenzene sulfonic acid; ethanesulfonia acid; ethoxylated hexanol; ethylbenzeze; ethylene glycol monobutyl ether; ethylene oxide; ethoxylated hexanol; fatty acids; ferric chloride; formaldehyde; glutaraldehyde; glycolic acid; glyoxal; heavy aromatic hydrocarbons; hydrochloric acid; hydrodistilled oil; hydrodistilled light petroleum distillate; isopropylbenzene; isothiazolone; lecithins; light aromatic hydrocarbons; lithiv; lithium hypochlorite; naphtha; naphthalene; petroleum; petroleum distillates; poly(oxy-1,2-ethylenyl)); polysiloxanes; propargyl alcohol; quinoline; silicon; sodium; sodium hypochlorite; solvent naphtha; sulfuric acid; tall oil; tetrasodium ethylenediaminetetraacetate; thioglycolic acid; toluene; trimethylbenzenes; xylenes; zinc; zinc sulfate

HEALTH EFFECTS: mortality; acute toxicity/poisoning
Identifying chemicals of concern in hydraulic fracturing fluids used for oil production


ABSTRACT

Chemical additives used for hydraulic fracturing and matrix acidizing of oil reservoirs were reviewed and priority chemicals of concern needing further environmental risk assessment, treatment demonstration, or evaluation of occupational hazards were identified. We evaluated chemical additives used for well stimulation in California, the third largest oil producing state in the USA, by the mass and frequency of use, as well as toxicity. The most frequently used chemical additives in oil development were gelling agents, cross-linkers, breakers, clay control agents, iron and scale control agents, corrosion inhibitors, biocides, and various impurities and product stabilizers used as part of commercial mixtures. Hydrochloric and hydrofluoric acids, used for matrix acidizing and other purposes, were reported infrequently. A large number and mass of solvents and surface active agents were used, including quarternary ammonia compounds (QACs) and nonionic surfactants. Acute toxicity was evaluated and many chemicals with low hazard to mammals were identified as potentially hazardous to aquatic environments. Based on an analysis of quantities used, toxicity, and lack of adequate hazard evaluation, QACs, biocides, and corrosion inhibitors were identified as priority chemicals of concern that deserve further investigation.

FUNDING: This work was supported by the California Natural Resources Agency and the U.S. Bureau of Land Management, under Work for Others Agreements with the U.S. Department of Energy at LBNL, under contract number DE-AC02-05CH11231. We appreciate the cooperation and leadership of Jane Long and Laura Feinstein of the California Council on Science and Technology (CCST) in the execution of the SB4 Scientific Study.

PUBLICATION TYPE: review

EVIDENCE STREAMS: animal: experimental

EXPOSURE ROUTES: oral

GEOLOGIC FORMATIONS: Monterey Formation

STATES/COUNTRIES: CA

GAS/OIL: unconventional; oil

HEALTH EFFECTS: mortality; acute toxicity/poisoning

Neurodevelopmental and neurological effects of chemicals associated with unconventional oil and natural gas operations and their potential effects on infants and children


ABSTRACT

Heavy metals (arsenic and manganese), particulate matter (PM), benzene, toluene, ethylbenzene, xylene (BTEX), polycyclic aromatic hydrocarbons (PAHs) and endocrine disrupting chemicals (EDCs) have been linked to significant neurodevelopmental health problems in infants, children and young adults. These substances are widely used in, or become byproducts of unconventional oil and natural gas (UOG) development and operations. Every stage of the UOG lifecycle, from well construction to extraction, operations, transportation and distribution can lead to air and water contamination. Residents near UOG operations can suffer from increased exposure to elevated concentrations of air and water pollutants. Here we focus on five air and water pollutants that have been associated with potentially permanent learning and neuropsychological deficits, neurodevelopmental disorders and neurological birth defects. Given the profound sensitivity of the developing brain and central nervous system, it is reasonable to conclude that young children who experience frequent exposure to these pollutants are at particularly high risk for chronic neurological diseases. More research is needed to understand the extent of these concerns in the context of UOG, but since UOG development has expanded rapidly in recent years, the need for public health prevention techniques, well-designed studies and stronger state and national regulatory standards is becoming increasingly apparent.

FUNDING: Research funding: The authors have no relevant financial relationships. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent is not applicable. Ethical approval: The conducted research is not related to either human or animal use.

PUBLICATION TYPE: review

EVIDENCE STREAMS: human: occupational; human: non-occupational; animal: experimental
EXPOSURE ROUTES: inhalation; oral

EXTERNAL EXPOSURES: well density/drilling activity; wastewater; surface water; drinking water; air

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: benzene, BTEX; benzo(a)pyrene, ethylbenzene, naphthalene, PAHs, particulate matter, phenanthrene, toluene, xylenes, arsenic; manganese

HEALTH EFFECTS: Pregnancy and Reproduction; Endocrine system; Brain and Nerves

Health symptoms in residents living near shale gas activity: a retrospective record review from the Environmental Health Project


ABSTRACT

Increasing evidence demonstrates an association between health symptoms and exposure to unconventional natural gas development (UNGD). The purpose of this study is to describe the health of adults in communities with intense UNGD who presented for evaluation of symptoms. Records of 135 structured health assessments conducted between February 2012 and October 2015 were reviewed retrospectively. Publicly available data were used to determine proximity to gas wells. Analysis was restricted to records of adults who lived within 1 km of a well in Pennsylvania and denied employment in the gas industry (n=51). Symptoms in each record were reviewed by a physician. Symptoms that could be explained by pre-existing or concurrent conditions or social history and those that began or worsened prior to exposure were excluded. Exposure was calculated using date of well drilling within 1 km. The number of symptoms/participant ranged from 0 - 19 (mean=6.2; SD=5.1). Symptoms most commonly reported were: sleep disruption, headache, throat irritation, stress or anxiety, cough, shortness of breath, sinus problems, fatigue, nausea, and wheezing. These results are consistent with findings of prior studies using self-report without physician review. In comparison, our results are strengthened by the collection of health data by a health care provider, critical review of symptoms for possible alternative causes, and confirmation of timing of exposure to unconventional natural gas well relative to symptom onset or exacerbation. Our findings confirm earlier studies and add to the growing body of evidence of the association between symptoms and exposure to UNGD.

FUNDING: This work was supported by Heinz Endowments, Pittsburgh, PA. Heinz Endowments had no role in study design; collection, analysis and interpretation of data; writing of the report; or the decision to submit the article for publication. The authors declare no conflict of interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Skin, Hair, and Nails; Metabolic; Mental Health and Behavior; Lungs and Breathing; Eyes, Ears, Nose, and Throat; Digestive System; Brain and Nerves; Bones, Joints, and Muscles; Blood, Heart, and Circulation

Is increasing coal seam gas well development activity associated with increasing hospitalisation rates in Queensland, Australia? An exploratory analysis 1995–2011


ABSTRACT
The majority of Australia's coal seam gas (CSG) reserves are in Queensland, where the industry has expanded rapidly in recent years. Despite concerns, health data have not been examined alongside CSG development. This study examined hospitalisation rates as a function of CSG development activity in Queensland, during the period 1995–2011. Admissions data were examined with CSG well numbers, which served as a proxy for CSG development activity. Time series models were used to assess changes in hospitalisation rates for periods of "low", "medium", "high", and "intense" activity compared to a period of "very low" activity, adjusting for covariates. "All-cause" hospitalisation rates increased monotonically with increasing gas well development activity in females (324.0 to 390.3 per 1000 persons) and males (294.2 to 335.4 per 1000 persons). Hospitalisation rates for "Blood/immune" conditions generally increased for both sexes. Female and male hospitalisation rates for "Circulatory" conditions decreased with increasing CSG activity. Hospitalisation rates were generally low for reproductive and birth outcomes; no clear associations were observed. This study showed some outcomes were associated with increasing CSG development activity. However, as a condition of data access, the population and outcomes were aggregated to a broad geographic study area rather than using higher geographic resolution data. Higher resolution data, as well as other data sources, should be explored.

Further research should be conducted with an expanded time period to determine if these trends continue as the industry grows.

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Publication Type: original research

Evidence Streams: Human: population health

States/Countries: Queensland, Australia

Gas/Oil: Coalbed methane

Health Effects: Pregnancy and Reproduction; Lungs and Breathing; Immune System; Blood, Heart, and Circulation

Maternal residential proximity to unconventional gas development and perinatal outcomes among a diverse urban population in Texas


ABSTRACT

Objective: To assess associations between unconventional natural gas development (UGD) and perinatal outcomes. Methods: We conducted a retrospective birth cohort study among 158,894 women with a birth or fetal death from November 30, 2010-November 29, 2012 in the Barnett Shale, in North Texas. We constructed three UGD-activity metrics by calculating the inverse distance-weighted sum of active wells within three separate geographic buffers surrounding the maternal residence: ≤½, 2, or 10-miles. We excluded women if the nearest well to her residence was >20 miles. Metrics were categorized by tertiles among women with ≥1 well within the respective buffer; women with zero wells ≤10 miles (the largest buffer) served as a common referent group. We used logistic or linear regression with generalized estimating equations to assess associations between UGD-activity and preterm birth, small-for-gestational age (SGA), fetal death, or birthweight. Adjusted models of fetal death and birthweight included: maternal age, race/ethnicity, education, pre-pregnancy body mass index, parity, smoking, adequacy of prenatal care, previous poor pregnancy outcome, and infant sex. Preterm birth models included all of the above except parity. SGA models included all of the above except previous poor pregnancy outcome. Results: We found increased adjusted odds of preterm birth associated with UGD-activity in the highest tertiles of the ½- (odds ratio (OR) = 1.14; 95% confidence interval 1.03, 1.25), 2- (1.14; 1.07, 1.22), and 10-mile (1.15; 1.08, 1.22) metrics. Increased adjusted odds of fetal death were found in the second tertile of the 2-mile metric (1.56; 1.16, 2.11) and the highest tertile of the 10-mile metric (1.34; 1.04–1.72). We found little indication of an association with SGA or term birthweight. Conclusions: Our results are suggestive of an association between maternal residential proximity to UGD-activity and preterm birth and fetal death. Quantifying chemical and non-chemical stressors among residents near UGD should be prioritized.

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Publication Type: original research

Evidence Streams: Human: non-occupational

Exposure Routes: dermal; inhalation; oral
Potential health implications related to fracking


ABSTRACT

Within the last decade, however, fracking and horizontal well drilling have provided access to deeper less-porous rock strata (often called source rock), containing even larger volumes of fossil fuel. By injecting large volumes of water into shale (along with acid, surfactant, and sand), the petroleum industry is able to generate sufficient pressures within this previously inaccessible source rock to liberate unconventional fuel reserves at unprecedented rates. Because the process of fracking these shales has increased the relative role of the continental United States in the worldwide production of oil and natural gas, it is increasingly important to understand the potential implications of this technology on the health of individuals and the US population.

FUNDING: Dr. Wilke reports funding through the National Institutes of Health (NIH) (1U01HG007253). Both authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest and none were reported.

PUBLICATION TYPE: commentary

EVIDENCE STREAMS: human: occupational; human: non-occupational

EXPOSURE ROUTES: oral

EXTERNAL EXPOSURES: wastewater; drinking water; air

GEOLOGIC FORMATIONS: Marcellus Shale; Eagle Ford Shale; Barnett Shale; Bakken Shale

STATES/COUNTRIES: WY; WV; VA; TX; SD; PA; OH; NY; ND; MT; MD; KY

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: ozone, particulate matter, silica, methanol; manganese; mercurymethyl mercury; iron; radium; xylenes; toluene; BTEX; benzene; barium

HEALTH EFFECTS: Lungs and Breathing; Kidneys and Urinary System; Brain and Nerves

A decision analysis framework for estimating the potential hazards for drinking water resources of chemicals used in hydraulic fracturing fluids


ABSTRACT
Systematic review of the association between oil and natural gas extraction processes and human reproduction


ABSTRACT

This systematic review identified 45 original published research articles related to oil and gas extraction activities and human reproductive endpoints. Reproductive outcomes were categorized as [1] birth outcomes associated with maternal exposure, [2] semen quality, fertility, and birth outcomes associated with adult paternal exposure, [3] reproductive cancers, and [4] disruption of human sex steroid hormone receptors. The results indicate there is moderate evidence for an increased risk of preterm birth, miscarriage, birth defects, decreased semen quality, and prostate cancer. The quality of the evidence is low and/or inadequate for stillbirth, sex ratio, and birth outcomes associated with paternal exposure, and testicular cancer, female reproductive tract cancers, and breast cancer, and the evidence is inconsistent for an increased risk of low birth weight, therefore, no conclusions can be drawn for these health effects. There is ample evidence for disruption of the estrogen, androgen, and progesterone receptors by oil and gas chemicals, which provides a mechanistic rationale for how exposure to oil and gas activities may increase the health risks we have outlined. The results from this systematic review suggest there is a negative impact on human reproduction from exposure to oil and gas activities. Many of the 45 studies reviewed identified potential human health effects. Most of these studies focused on conventional oil and gas operations on human health. The impact of unconventional oil and gas activities may be greater than that of conventional activity, given that unconventional activities employ many of the same approaches and use dozens of known endocrine-disrupting chemicals in hydraulic fracturing.

FUNDING: The authors thank Rebecca Graves for sharing her knowledge of systematic reviews and database searching. Drs. Kris Thayer, Kembra Howedeshell and Kather ine Pelch from Office of Hazard Assessment and the National Toxicology Program, for sharing their expertise, and Sierra Baxter and Katelyn Cinnamon for retrieving articles. V.D.B. has nothing to disclose. C.-X.M. has nothing to disclose. C.-D.K. has nothing to disclose. R.K. has nothing to disclose. S.C.N. has nothing to disclose. J.C.-G. has nothing to disclose.

PUBLICATION TYPE: systematic review

EVIDENCE STREAMS: in vitro; human: occupational; human: non-occupational
Hazard ranking methodology for assessing health impacts of unconventional natural gas development and production: the Maryland Case Study


ABSTRACT

The recent growth of unconventional natural gas development and production (UNGDP) has outpaced research on the potential health impacts associated with the process. The Maryland Marcellus Shale Public Health Study was conducted to inform the Maryland Marcellus Shale Safe Drilling Initiative Advisory Commission, State legislators and the Governor about potential public health impacts associated with UNGDP so they could make an informed decision that considers the health and well-being of Marylanders. In this paper, we describe an impact assessment and hazard ranking methodology we used to assess the potential public health impacts for eight hazards associated with the UNGDP process. The hazard ranking included seven metrics: 1) presence of vulnerable populations (e.g. children under the age of 5, individuals over the age of 65, surface owners), 2) duration of exposure, 3) frequency of exposure, 4) likelihood of health effects, 5) magnitude/severity of health effects, 6) geographic extent, and 7) effectiveness of setbacks. Overall public health concern was determined by a color-coded ranking system (low, moderately high, and high) that was generated based on the overall sum of the scores for each hazard. We provide three illustrative examples of applying our methodology for air quality and health care infrastructure which were ranked as high concern and for water quality which was ranked moderately high concern. The hazard ranking was a valuable tool that allowed us to systematically evaluate each of the hazards and provide recommendations to minimize the hazards.

FUNDING: The work presented in this manuscript was supported by the Maryland Department of Health and Mental Hygiene (DHMH: M00B4400326). The authors have declared that no competing interests exist.

Hydraulic fracturing for natural gas: Impact on health and environment


ABSTRACT

Shale deposits exist in many parts of the world and contain relatively large amounts of natural gas and oil. Recent technological developments in the process of horizontal hydraulic fracturing (hydrofracturing or fracking) have suddenly made it economically feasible to extract natural gas from shale. While natural gas is a much cleaner burning fuel than coal, there are a number of significant threats to human health from the extraction process as currently practiced. There are immediate threats to health resulting from air pollution from volatile organic compounds, which contain carcinogens such as benzene and ethyl-benzene, and which have adverse neurologic and respiratory effects. Hydrogen sulfide, a component of natural gas, is a potent neuro- and respiratory toxin. In addition, levels of formaldehyde are elevated around fracking sites due to truck traffic and conversion of methane to formaldehyde by sunlight. There are major concerns about water contamination because the chemicals used can get into both ground and surface water. Much of the produced water (up to 40% of what is injected) comes back out of the gas well with significant radioactive activity because radium in subsurface rock is relatively water soluble. There are significant long-term threats beyond cancer, including exacerbation...
of climate change due to the release of methane into the atmosphere, and increased earthquake activity due to disruption of subsurface tectonic plates. While fracking for natural gas has significant economic benefits, and while natural gas is theoretically a better fossil fuel as compared to coal and oil, current fracking practices pose significant adverse health effects to workers and near-by residents. The health of the public should not be compromised simply for the economic benefits to the industry.

**FUNDING:** Not addressed

**PUBLICATION TYPE:** review

**EXTERNAL EXPOSURES:** wastewater; surface water; spills/leaks; drinking water; air

**GEOLOGIC FORMATIONS:** Marcellus Shale

**STATES/COUNTRIES:** WY; PA; AR

**GAS/OIL:** natural gas; unconventional

**CHEMICALS:** 1,3-butadiene; benzene; ethylbenzene; formaldehyde; hexane; hydrogen sulfide; NORM; PAHs; sulfur dioxide; xylenes; VOCs; radium; radon

**HEALTH EFFECTS:** Skin, Hair, and Nails; Pregnancy and Reproduction; Lungs and Breathing; Eyes, Ears, Nose, and Throat; Digestive System; Cancers; Brain and Nerves; Blood, Heart, and Circulation

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Unconventional natural gas development and birth outcomes in Pennsylvania, USA


**ABSTRACT**

Background: Unconventional natural gas development has expanded rapidly. In Pennsylvania, the number of producing wells increased from 0 in 2005 to 3,689 in 2013. Few publications have focused on unconventional natural gas development and birth outcomes. Methods: We performed a retrospective cohort study using electronic health record data on 9,384 mothers linked to 10,946 neonates in the Geisinger Health System from January 2009 to January 2013. We estimated cumulative exposure to unconventional natural gas development activity with an inverse-distance squared model that incorporated distance to the mother's home, dates and durations of well pad development, drilling, and hydraulic fracturing, and production volume during the pregnancy. We used multilevel linear and logistic regression models to examine associations between activity index quartile and term birth weight, preterm birth, low 5-minute Apgar score and small size for gestational age birth, while controlling for potential confounding variables. Results: In adjusted models, there was an association between unconventional natural gas development activity and preterm birth that increased across quartiles, with a fourth quartile odds ratio of 1.4 (95% confidence interval = 1.0, 1.9). There were no associations of activity with Apgar score, small for gestational age birth, or term birth weight (after adjustment for year). In a posthoc analysis, there was an association with physician-recorded high-risk pregnancy identified from the problem list (fourth vs. first quartile, 1.3 [95% confidence interval = 1.1, 1.7]). Conclusion: Prenatal residential exposure to unconventional natural gas development activity was associated with two pregnancy outcomes, adding to evidence that unconventional natural gas development may impact health.

**FUNDING:** This study was funded by the National Institute of Environmental Health Sciences Grant ES023675-01 (PI: B. Schwartz) and Training Grant ES07141 (S. Rasmussen). Additional support was provided by the Degenstein Foundation for compilation of well data, the Robert Wood Johnson Foundation Health & Society Scholars program (J. Casey), and the National Science Foundation Integrative Graduate Education and Research Traineeship (S. Rasmussen). The authors report no conflicts of interest.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** human: non-occupational

**EXPOSURE ROUTES:** inhalation

**EXTERNAL EXPOSURES:** well density/drilling activity

**GEOLOGIC FORMATIONS:** Marcellus Shale

**STATES/COUNTRIES:** PA

**GAS/OIL:** natural gas; unconventional
Environmental signatures and effects of an oil and gas wastewater spill in the Williston Basin, North Dakota


ABSTRACT

Wastewaters from oil and gas development pose largely unknown risks to environmental resources. In January 2015, 11.4 M L (million liters) of wastewater (300 g/L TDS) from oil production in the Williston Basin was reported to have leaked from a pipeline, spilling into Blacktail Creek, North Dakota. Geochemical and biological samples were collected in February and June 2015 to identify geochemical signatures of spilled wastewaters as well as biological responses along a 44-km river reach. February water samples had elevated chloride (1030 mg/L) and bromide (7.8 mg/L) downstream from the spill, compared to upstream levels (11 mg/L and < 0.4 mg/L, respectively). Lithium (0.25 mg/L), boron (1.75 mg/L) and strontium (7.1 mg/L) were present downstream at 5–10 times upstream concentrations. Light hydrocarbon measurements indicated a persistent thermogenic source of methane in the stream. Semi-volatile hydrocarbons indicative of oil were not detected in filtered samples but low levels, including tetramethylbenzenes and di-methylnaphthalenes, were detected in unfiltered water samples downstream from the spill. Labile sediment-bound barium and strontium concentrations (June 2015) were higher downstream from the Spill Site. Radium activities in sediment downstream from the Spill Site were up to 15 times the upstream activities and, combined with Sr isotope ratios, suggest contributions from the pipeline fluid and support the conclusion that elevated concentrations in Blacktail Creek water are from the leaking pipeline. Results from June 2015 demonstrate the persistence of wastewater effects in Blacktail Creek several months after remediation efforts started. Aquatic health effects were observed in June 2015, fish bioassays showed only 2.5% survival at 7.1 km downstream from the spill compared to 89% at the upstream reference site. Additional potential biological impacts were indicated by estrogenic inhibition in downstream waters. Our findings demonstrate that environmental signatures from wastewater spills are persistent and create the potential for long-term environmental health effects.

FUNDING: This project was supported by the USGS Toxic Substances Hydrology Program, USGS Energy Resources Program, and the USGS Fisheries Program. The authors are grateful to Joanna Thamke and two anonymous reviewers for their helpful comments. The authors would like to thank Matthew Olson, Bill Damschen, and Robert Lundgren for assistance in the field, Katherine Akstin, Kalla Flegel, Meagan Mnich, Michael Doughten, and Tracey Spencer for laboratory assistance, and John Swiecichowski for assistance with tables. We would like to thank John M. Besser and Chris D. Ivey for conducting invertebrate sediment bioassays and statistical interpretations of the data. Sincere thanks to Jenn Cornelius Green and Chris Kassotis for their work to process water samples and test for EDC activity. In addition, we would like to thank the local landowners who allowed access to field sites. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Assessing dermal exposure risk to workers from flowback water during shale gas hydraulic fracturing activity

ABSTRACT

Hydraulic fracturing is a well stimulation technique used in the production of natural gas from shale. While hydraulic fracturing has been in use for decades as a method for oil and gas recovery, recent advances in horizontal drilling techniques and fracturing fluid production have made previously unattainable natural gas reservoirs accessible and economically recoverable. Flowback water produced from the hydraulic fracturing process can pose environmental and human health risks. The objective of this study is to assess cancer risk following dermal exposure to flowback water among workers at hydraulic fracturing sites. Median, 2.5th percentile, and 97.5th percentile concentrations for high priority constituents in flowback water were collected from a previous study and used to estimate cancer risk from dermal exposure to carcinogenic agents in water compared to a target lifetime cancer risk value of 10^-6. Hazard quotients, which compare exposure dose to dose at which no adverse effects are expected, were also calculated for non-carcinogenic components of flowback water and compared to an acceptable value of 1. The cancer risk estimate for median concentrations did not exceed the target lifetime cancer risk of 10^-6 except for benzo(a)pyrene where the cancer risk of full hand exposure to flowback water for 3 h (one event per week for 4 years) falls within this range (2.9 × 10^-6 – 1.4 × 10^-5), which exceeds the target risk level even at the 2.5 percentile value. The upper limit of cancer risk form exposure to heptachlor also exceeds 10^-6 in this model. Hazard quotient for barium in the same model exceeds 1 (1.7) and results in a total hazard index of 2.

FUNDING: Not addressed

Shale gas development and cancer incidence in southwest Pennsylvania


ABSTRACT

Objective: To what extent does unconventional gas development lead to an increase in cancer incidence in heavily drilled Southwest Pennsylvania? Study design: Ecological study. Methods: Data for urinary bladder, thyroid and leukaemia were abstracted from the Pennsylvania Cancer Registry (PCR). Cancer incidence among counties with high, moderate and minimal number of producing wells is compared before drilling activity and thereafter. Observed vs expected cases, standardized incidence ratio and 95% confidence intervals are presented. Data are presented by county, diagnosis and sex for the years 2000-2004, 2004-2008 and 2008-2012. The percent difference between the observed cases from 2000 to 2004 and 2008-2012 was calculated. Results: The observed number of urinary bladder cases was higher than expected in both sexes in counties with shale gas activity. In counties with the fewest number of producing wells, the increase was essentially non-existent. The number of observed cases of thyroid cancer increased substantially among both sexes over the time period in all counties regardless of the number of wells drilled. The pattern for leukaemia was mixed among males and females and among the counties regardless of the extent of shale gas development activities. Conclusion: Potential risk factors other than shale gas development must be taken into account to explain the higher than expected cancer cases in counties with and without shale gas wells before and during unconventional shale gas activity.

FUNDING: The authors thank Maritza Montalvo for preparing the Tables, and Eliza Czolowski for preparing the well location map for Washington County. They also thank Jake Hays for his insightful suggestions and recommendations. The authors thank Sejal Shah and Anastasia Vinar for compiling the data. No grant funding was sought for this study and because the data are abstracted from the Pennsylvania's Department of Health Division of Health Informatics public database, no IRB approval was deemed not necessary. No ethical approval sought. Competing interests: None declared.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: population health

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale
Environmental and health impacts of ‘fracking’: Why epidemiological studies are necessary


ABSTRACT

FUNDING: Competing interests: None declared. Provenance and peer review: Commissioned, internally peer reviewed.

Fracked ecology: Response of aquatic trophic structure and mercury biomagnification dynamics in the Marcellus Shale Formation


ABSTRACT

Unconventional natural gas development and hydraulic fracturing practices (fracking) are increasing worldwide due to global energy demands. Research has only recently begun to assess fracking impacts to surrounding environments, and very little research is aimed at determining effects on aquatic biodiversity and contaminant biomagnification. Twenty-seven remotely-located streams in Pennsylvania’s Marcellus Shale basin were sampled during June and July of 2012 and 2013. At each stream, stream physiochemical properties, trophic biodiversity, and structure and mercury levels were assessed. We used δ15N, δ13C, and methyl mercury to determine whether changes in methyl mercury biomagnification were related to the fracking occurring within the streams’ watersheds. While we observed no difference in rates of biomagnification related to within-watershed fracturing activities, we did observe elevated methyl mercury concentrations that were influenced by decreased stream pH, elevated dissolved stream water Hg values, decreased macroinvertebrate Index for Biotic Integrity scores, and lower Ephemeroptera, Plecoptera, and Trichoptera macroinvertebrate richness at stream sites where fracking had occurred within their watershed. We documented the loss of scrapers from streams with the highest well densities, and no fish or no fish diversity at streams with documented frackwater fluid spills. Our results suggest fracking has the potential to alter aquatic biodiversity and methyl mercury concentrations at the base of food webs.

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PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: wildlife

EXTERNAL EXPOSURES: surface water; well density/drilling activity
Adequacy of current state setbacks for directional high-volume hydraulic fracturing in the Marcellus, Barnett, and Niobrara Shale plays


ABSTRACT

Background: There is an increasing awareness of the multiple potential pathways leading to human health risks from hydraulic fracturing. Setback distances are a legislative method to mitigate potential risks. Objectives: We attempted to determine whether legal setback distances between well-pad sites and the public are adequate in three shale plays. Methods: We reviewed geography, current statutes and regulations, evacuations, thermal modeling, air pollution studies, and vapor cloud modeling within the Marcellus, Barnett, and Niobrara Shale Plays. Discussion: The evidence suggests that presently utilized setbacks may leave the public vulnerable to explosions, radiant heat, toxic gas clouds, and air pollution from hydraulic fracturing activities. Conclusions: Our results suggest that setbacks may not be sufficient to reduce potential threats to human health in areas where hydraulic fracturing occurs. It is more likely that a combination of reasonable setbacks with controls for other sources of pollution associated with the process will be required.

FUNDING: We are most grateful for the comments and suggestions provided by J. Hays (PSE Healthy Energy). M.H. is a radiation oncology consultant for Guidepoint Global, a consulting company that connects clients with experts in various fields of industry and medicine. M.M. is supported by Environmentally Friendly Drilling, a consortium of government and industry groups. He is also supported by grants from the U.S. Department of Energy. He was previously employed by the U.S. Department of Labor as an expert witness in a case involving drilling. He has also served as a consultant to the state of West Virginia on drilling issues. A.C.E. owns stock in Exxon, Chevron, and British Petroleum. She previously received travel expenses for a lecture given in Mansfield, Texas, on the health and environmental impacts of fracking. B.A. is currently retired. He serves on the board of directors of Western Colorado Congress, a nonprofit alliance for community empowerment to protect and enhance quality of life in western Colorado. The other author (E.F.B) declares she has no actual or potential competing financial interests.

PUBLICATION TYPE: review

EVIDENCE STREAMS: human; population health

EXTERNAL EXPOSURES: air

GEOLOGIC FORMATIONS: Barnett Shale; Denver-Julesberg Basin/Niobrara Shale; Marcellus Shale

STATES/COUNTRIES: CO; PA; TX

GAS/OIL: natural gas; unconventional

Health concerns associated with unconventional gas mining in rural Australia


ABSTRACT

Context: Many governments globally are investigating the benefits and risks associated with unconventional gas mining for shale, tight and coal seam gas (coalbed methane) to determine whether the industry should proceed in their jurisdiction. Most locations likely to be developed are in rural areas, with potential impact on farmers and small communities. Despite significant health concerns, public health knowledge and growing
The body of science evaluating the potential impacts of unconventional natural gas development (UNGD) has grown significantly in recent years, although many data gaps remain. Still, a broad empirical understanding of the impacts is beginning to emerge amidst a swell of research. The present categorical assessment provides an overview of the peer-reviewed scientific literature from 2009-2015 as it relates to the potential impacts of UNGD on public health, water quality, and air quality. We have categorized all available original research during this time period in an attempt to understand the weight and direction of the scientific literature. Our results indicate that at least 685 papers have been published in peer-reviewed scientific journals that are relevant to assessing the impacts of UNGD. 84% of public health studies contain findings that indicate public health hazards, elevated risks, or adverse health outcomes, 69% of water quality studies contain findings that indicate potential, positive association, or actual incidence of water contamination, and 87% of air quality studies indicate that at least 685 papers have been published in peer-reviewed scientific journals that are relevant to assessing the impacts of UNGD. 84% of public health studies contain findings that indicate public health hazards, elevated risks, or adverse health outcomes, 69% of water quality studies contain findings that indicate potential, positive association, or actual incidence of water contamination, and 87% of air quality studies contain findings that indicate elevated air pollutant emissions and/or atmospheric concentrations. This paper demonstrates that the weight of the findings in the scientific literature indicates hazards and elevated risks to human health as well as possible adverse health outcomes associated with UNGD. There are limitations to this type of assessment and it is only intended to provide a snapshot of the scientific knowledge based on the available literature. However, this work can be used to identify themes that lie in or across studies, to prioritize future research, and to provide an empirical foundation for policy decisions.

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PUBLICATION TYPE: review

EVIDENCE STREAMS: human: non-occupational; animal: pets; animal: livestock; animal: experimental

EXTERNAL EXPOSURES: wastewater; drinking water; air
Characterizing hydraulic fracturing fluid greenness: application of a hazard-based index approach


ABSTRACT

Growth of the unconventional gas industry is predicted to continue to be an important component of the global energy landscape. The rapid expansion of shale and tight gas development has raised many environmental and human health concerns, particularly in regards to ground and surface water contamination. The unconventional gas industry has begun to transition toward the use of hydraulic fracturing chemicals that pose minimal environmental and human health hazards in order to mitigate the risks associated with possible chemical containment failure. Integrated chemical hazard evaluation has been facilitated by an adapted index-based approach to combine noncommensurate multiparameter chemical hazard data into a single score value. Comparative analysis of existing chemical hazard index scoring systems as well as the formulation of a novel hydraulic fracturing fluid greenness assessment system revealed several important considerations for index development and application. Index scores calculated using the investigated index systems highlighted the need for informed, optimized hazard class selection as input for score determination, the maintenance of hazard category intensity during parameter transformation, as well as representative hazard class and chemical component mathematical weightings, and robust aggregation techniques for final score calculation. Continued research should work to model the combined hazard posed by individual chemicals while considering the effect of dilution as well as incorporate additional index metrics beyond hazard intensity. Fully disclosed index systems, applied with complete knowledge of their strengths and weaknesses, provide useful monitoring and communication tools to promote environmental-best practices in the unconventional gas industry.

FUNDING: The authors gratefully acknowledge the funding provided by British Columbia Oil and Gas Commission (BC OGC) to conduct the study. The authors also appreciate the time and technical support provided by BC OGC personnel.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation

Cytotoxic actions of 2,2-dibromo-3-nitrilopropionamide, a biocide in hydraulic fracturing fluids, on rat thymocytes


ABSTRACT

2,2-Dibromo-3-nitrilopropionamide (DBNPA) is a major biocide in hydraulic fracturing fluids. Most biocides in fracturing fluids are considered to have low acute toxicity to mammals, but little information is available in the literature regarding the toxic actions of DBNPA on mammalian cells. This information is important to suggest the DBNPA toxicity on wild mammals. In this study, the effects of DBNPA on rat thymocytes were studied using flow cytometric techniques in order to further characterize the cytotoxicity of DBNPA for its safe use. DBNPA at 3-7.5 μM produced a steep concentration-dependent increase in cell lethality. At 5 μM, DBNPA significantly depolarized the membranes with a disturbance of the asymmetrical distribution of membrane phospholipids. The lethal effect of DBNPA was completely abolished under cold conditions, and was augmented in the presence of ethanol. It is suggested that the lethal action of DBNPA is linked to changes in membrane fluidity. Because the concentration-dependent change of DBNPA-induced lethal action was very steep under in vitro conditions, the adverse actions of DBNPA on wild mammals are concerning, even though such reports have not yet surfaced.

FUNDING: This study for graduate students was supported via ordinary expenditures from the Graduate School of Integrated Arts and Sciences, Tokushima University (Tokushima, Japan) and the Grant-in-Aid for Scientific Research (C26340039) from the Japanese Society for the Promotion of Sciences (Tokyo, Japan). All authors affirm that there are no conflicts of interest to declare.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: in vitro
Endocrine-disrupting chemicals in oil and natural gas operations: potential environmental contamination and recommendations to assess complex environmental mixtures


ABSTRACT

Background: Hydraulic fracturing technologies, developed over the last 65 years, have only recently been combined with horizontal drilling to unlock oil and gas reserves previously deemed inaccessible. While these technologies have dramatically increased domestic oil and natural gas production, they have also raised concerns for the potential contamination of local water supplies with the approximately 1,000 chemicals used throughout the process, including many known or suspected endocrine-disrupting chemicals. Objectives: We discuss the need for an endocrine component to health assessments for drilling-dense regions in the context of hormonal and anti-hormonal activities for chemicals used. Methods: We discuss the literature on 1) surface and ground water contamination by oil and gas extraction operations, and 2) potential human exposure, particularly in context of the total hormonal and anti-hormonal activities present in surface and ground water from natural and anthropogenic sources, with initial analytical results and critical knowledge gaps discussed. Discussion: In light of the potential for environmental release of oil and gas chemicals that can disrupt hormone receptor systems, we recommend methods for assessing complex hormonally active environmental mixtures. Conclusions: We describe a need for an endocrine-centric component for overall health assessments and provide supporting information that using this may help explain reported adverse health trends as well as help develop recommendations for environmental impact assessments and monitoring programs.

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PUBLICATION TYPE: commentary

EVIDENCE STREAMS: modeling/QSAR/risk calculation; in vitro; human: occupational; human: non-occupational; animal: pets; animal: livestock; animal: experimental

EXPOSURE ROUTES: dermal; in vitro; inhalation; ocular; oral

EXTERNAL EXPOSURES: surface water; spills/leaks; drinking water; air

STATES/COUNTRIES: WY; PA; CO

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: benzene; BTEX; ethylbenzene; naphthalene; NORM; PAHs; toluene; xylenes; VOCs; alkenes; alkanes; aldehydes; polyethylene glycols; ethoxylated surfactants

HEALTH EFFECTS: Pregnancy and Reproduction; endocrine system; cancers

Endocrine disrupting activities of surface water associated with a West Virginia oil and gas industry wastewater disposal site


ABSTRACT
Currently, 95% of end disposal of hydraulic fracturing wastewater from unconventional oil and gas operations in the US occurs via injection wells. Key data gaps exist in understanding the potential impact of underground injection on surface water quality and environmental health. The goal of this study was to assess endocrine disrupting activity in surface water at a West Virginia injection well disposal site. Water samples were collected from a background site in the area and upstream, on, and downstream of the disposal facility. Samples were solid-phase extracted, and extracts assessed for agonist and antagonist hormonal activities for five hormone receptors in mammalian and yeast reporter gene assays. Compared to reference water extracts upstream and distal to the disposal well, samples collected adjacent and downstream exhibited considerably higher antagonist activity for the estrogen, androgen, progesterone, glucocorticoid and thyroid hormone receptors. In contrast, low levels of agonist activity were measured in upstream/distal sites, and were inhibited or absent at downstream sites with significant antagonism. Concurrent analyses by partner laboratories (published separately) describe the analytical and geochemical profiling of the water, elevated conductivity as well as high sodium, chloride, strontium, and barium concentrations indicate impacts due to handling of unconventional oil and gas wastewater. Notably, antagonist activities in downstream samples were at equivalent authentic standard concentrations known to disrupt reproduction and/or development in aquatic animals. Given the widespread use of injection wells for end-disposal of hydraulic fracturing wastewater, these data raise concerns for human and animal health nearby.

**FUNDING:** Project supported by the USGS Toxic Substances Hydrology Program, the University of Missouri, Mizzou Advantage Grant, and STAR Fellowship Assistance Agreement no. FP-91747101 awarded by the US EPA (CDK). The authors declare no competing financial interests.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** in vitro

**EXPOSURE ROUTES:** in vitro

**EXTERNAL EXPOSURES:** wastewater; surface water

**GEOLOGIC FORMATIONS:** Marcellus Shale

**STATES/COUNTRIES:** WV

**GAS/OIL:** natural gas; oil; unconventional

**HEALTH EFFECTS:** Endocrine system

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**Adverse reproductive and developmental health outcomes following prenatal exposure to a hydraulic fracturing chemical mixture in female C57Bl/6 mice**


**ABSTRACT**

Unconventional oil and gas operations using hydraulic fracturing can contaminate surface and groundwater with endocrine-disrupting chemicals. We have previously shown that 23 of 24 commonly used hydraulic fracturing chemicals can activate or inhibit the estrogen, androgen, glucocorticoid, progesterone, and/or thyroid receptors in a human endometrial cancer cell reporter gene assay and that mixtures can behave synergistically, additively, or antagonistically on these receptors. In the current study, pregnant female C57Bl/6 dams were exposed to a mixture of 23 commonly used unconventional oil and gas chemicals at approximately 3, 30, 300, and 3000 μg/kg.d, flutamide at 50 mg/kg.d, or a 0.2% ethanol control vehicle via their drinking water from gestational day 11 through birth. This prenatal exposure to oil and gas operation chemicals suppressed pituitary hormone concentrations across experimental groups (prolactin, LH, FSH, and others), increased body weights, altered uterine and ovary weights, increased heart weights and collagen deposition, disrupted folliculogenesis, and other adverse health effects. This work suggests potential adverse developmental and reproductive health outcomes in humans and animals exposed to these oil and gas operation chemicals, with adverse outcomes observed even in the lowest dose group tested, equivalent to concentrations reported in drinking water sources. These endpoints suggest potential impacts on fertility, as previously observed in the male siblings, which require careful assessment in future studies.

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**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** animal: experimental

**EXPOSURE ROUTES:** oral

**EXTERNAL EXPOSURES:** drinking water
Impacts of hydraulic fracturing development on macroinvertebrate biodiversity and gill morphology of net-spinning caddisfly (Hydropsychidae, Diplectrona) in northwestern Pennsylvania, USA


ABSTRACT

Hydraulic fracturing (fracking) poses significant threats to freshwater resources and stream ecosystems. Little research exists to quantify the ecological impact and in Pennsylvania alone over 10,000 wells have been permitted. This study aimed to determine if hydraulic fracturing is having any impacts on stream ecosystem health by measuring stream pH and temperature, macroinvertebrate index of biological integrity (IBI), and the gill morphology of individuals in the Hydropsychidae Diplectrona taxa. Six streams in northwestern Pennsylvania were selected as study sites (three with fracking occurring in their watershed and three without fracking). IBI scores were significantly higher at non-fracked sites and were also correlated with stream pH. Macroinvertebrate gill width did not vary between fracked and non-fracked sites but was correlated with percent hydric soils, suggesting that hydric soils may be a good long-term indicator of stream dissolved oxygen. While our results did not indicate differences in Hydropsychidae Diplectrona gill widths between fracked and non-fracked sites, we did observe that fracked sites had more acidic stream water and lower IBI scores. These results indicate the need for further study to assess the potential impacts of hydraulic fracturing on stream ecosystems.

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PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: wildlife

EXTERNAL EXPOSURES: surface water; well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Lungs and Breathing

Time series evaluation of birth defects in areas with and without unconventional natural gas development


ABSTRACT

Few studies have evaluated the association of unconventional natural gas development (UNGD) on birth defects and most of them neglect birth defects secular trend prior to UNGD and did not fully take into account maternal characteristics. We used 2003-2012 Pennsylvania birth registry data to assess the association between UNGD and birth defects using segmented regression analysis of interrupted time series method controlling for maternal characteristics and pre-drilling secular trend. Among areas with UNGD, birth defects prevalence rate was 6.3/1,000 live births before UNGD and 5.0/1,000 live births after UNGD, a 20.6% drop with P<0.01,
while birth defects prevalence rate in zip code areas without UNGD was 4.7/1,000 live births. After controlling for maternal characteristics and secular trend, the adjusted odds ratio (aOR) for annual post-UNGD birth defects trend did not change (aOR=1.00, P=0.29) and post-UNGD birth defects level decreased but was not statistically significant (aOR =0.97, P=0.12). The aOR for unconventional well number per square kilometer was 0.93, P=0.10. We conclude UNGD was not associated with birth defects prevalence rate trend and level changes. Further studies are needed to address why birth defects prevalence rate in UNGD areas were consistently 22% higher than in non-UNGD areas.

FUNDING: Authors declare they have no competing interests.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: genotoxicity; Digestive System; Brain and Nerves; Blood, Heart, and Circulation; Pregnancy and Reproduction

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Health concerns of northeastern Pennsylvania residents living in an unconventional oil and gas development county


ABSTRACT

Objectives: This study was conducted to describe the health concerns of residents of an unconventional oil and natural gas development (UOGD) community and identify methods to best disseminate health information to the residents. Design and Sample: A qualitative descriptive study of 27 residents of Wyoming County, Pennsylvania, was conducted. Results: Residents described their health concerns in terms of their changing community as a result of UOGD, their feelings of stress and powerlessness related to these changes, and the limited response of their local policymakers and protective agencies. There were indications of misinformation related to routine environmental health and UOGD environmental risks. Web-based educational programs with downloadable printed materials to bridge the knowledge gaps of residents and health professionals are recommended. Conclusions: Recommendations include public health nurses providing education to communities and other health professionals regarding environmental health risks, working with communities to advocate for health-protective regulations, and adopting a community-based participatory approach to meet the needs of community members.

FUNDING: Not addressed

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: population health

EXPOSURE ROUTES: dermal; in vitro; inhalation; ocular; oral

EXTERNAL EXPOSURES: survey/questionnaire/interview

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; oil; unconventional

HEALTH EFFECTS: Mental Health and Behavior; Lungs and Breathing

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Emissions of polycyclic aromatic hydrocarbons from natural gas extraction into air


ABSTRACT

Natural gas extraction, often referred to as “fracking”, has increased rapidly in the United States in recent years. To address potential health impacts, passive air samplers were deployed in a rural community heavily affected by the natural gas boom. Samplers were analyzed for 62 polycyclic aromatic hydrocarbons (PAHs). Results were grouped based on distance from each sampler to the nearest active well. Levels of benzo[a]pyrene, phenanthrene, and carcinogenic potency of PAH mixtures were highest when samplers were closest to active wells. PAH levels closest to natural gas activity were comparable to levels previously reported in rural areas in winter. Sourcing ratios indicated that PAHs were predominantly petrogenic, suggesting that PAH levels were influenced by direct releases from the earth. Quantitative human health risk assessment estimated the excess lifetime cancer risks associated with exposure to the measured PAHs. At sites closest to active wells, the risk estimated for maximum residential exposure was 0.04 in a million, which is below the U.S. Environmental Protection Agency’s acceptable risk level. Overall, risk estimates decreased 30% when comparing results from samplers closest to active wells to those farthest from them. This work suggests that natural gas extraction is contributing PAHs to the air, at levels that would not be expected to increase cancer risk.

FUNDING: This work was funded by grants from the National Institute of Environmental Health Sciences to Oregon State University (P30-ES000210) and the University of Cincinnati (P30-ES06096). We thank Glenn Wilson, Ricky Scott, Jorge Padilla, Gary Points, and Melissa McCartney of the OSU FSES Program for help with analysis. Thank you to Dr. Diana Rohlman of the OSU Environmental Health Sciences Center Outreach and Engagement Core (COEC), Sarah Elam of the University of Cincinnati (UC) Environmental Health Sciences Center COEC, Jody Alden of UC, and Paul Feezel of Carroll Concerned Citizens, all for assistance with volunteer recruitment and communication. Thank you to Pierce Kuhnell of UC for mapping sample sites. Finally, thank you to the volunteer participants in Ohio for making this study possible. The authors declare no competing financial interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation; human: population health; human: occupational

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: well density/drilling activity; air

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: OH

GAS/OIL: unconventional; natural gas

CHEMICALS: benzo(a)pyrene; naphthalene; PAHs; phenanthrene; benzo[c]fluorene; fluoranthene; benzo[b]fluoranthene; benzo[a]anthracene; chrysene; benzo[a]pyrene; cyclopenta[c]pyrene; indeno[1,2,3- c; d]pyrene; benzo[b]fluoranthene; benzo[g,h,i]perylene; anthracene; pyrene; 2-methylnaphthalene; 1-methylnaphthalene; acenaphthene

HEALTH EFFECTS: cancer

Occupational health surveillance: Pulmonary function test in proppant exposures


ABSTRACT

Workers involved in hydraulic fracturing processes are exposed to various types of chemicals and dusts in their workplaces, such as proppants, which hold open the fissures created in the fracturing process. Recently, ceramic proppants have been developed that may be less hazardous to workers than traditional proppants. Pulmonary function testing of workers producing ceramic proppant was used to assess the potential inhalation hazards of ceramic proppant. 100 male workers from a producer of ceramic proppant were evaluated with pulmonary function test data collected and evaluated using The American Thoracic Society (ATS) acceptability criteria. A comparison group was selected from the Third National Health and Nutrition Examination Survey (NHANES III) spirometry laboratory subset. No pulmonary function deficits were found in the worker group in comparison to the NHANES III population. Mean FEV1 and FVC values in workers were 3.8 and 4.8 liters respectively, and were greater as compared to the NHANES III population of similar demographics. An FEV1/FVC ratio of less than 0.8, when compared to the NHANES III group, produced an odds ratio of 0.44 in worker group, indicating less risk of preclinical pulmonary dysfunction. Overall, exposure to ceramic proppant was not found to produce an adverse impact on pulmonary function in workers engaged in the manufacture of ceramic proppant.
Association between unconventional natural gas development in the Marcellus Shale and asthma exacerbations


ABSTRACT
Importance: Asthma is common and can be exacerbated by air pollution and stress. Unconventional natural gas development (UNGD) has community and environmental impacts. In Pennsylvania, UNGD began in 2005, and by 2012, 6253 wells had been drilled. There are no prior studies of UNGD and objective respiratory outcomes. Objective: To evaluate associations between UNGD and asthma exacerbations. Design: A nested case-control study comparing patients with asthma with and without exacerbations from 2005 through 2012 treated at the Geisinger Clinic, which provides primary care services to over 400 000 patients in Pennsylvania. Patients with asthma aged 5 to 90 years (n = 35 508) were identified in electronic health records, those with exacerbations were frequency matched on age, sex, and year of event to those without. Exposures: On the day before each patient’s index date (cases, date of event or medication order, controls, contact date), we estimated activity metrics for 4 UNGD phases (pad preparation, drilling, stimulation [hydraulic fracturing, or “fracking”], and production) using distance from the patient’s home to the well, well characteristics, and the dates and durations of phases. Main Outcomes and Measures: We identified and defined asthma exacerbations as mild (new oral corticosteroid medication order), moderate (emergency department encounter), or severe (hospitalization). Results We identified 20 749 mild, 1870 moderate, and 4782 severe asthma exacerbations, and frequency matched these to 18 693, 9350, and 14 104 control index dates, respectively. In 3-level adjusted models, there was an association between the highest group of the activity metric for each UNGD phase compared with the lowest group for 11 of 12 UNGD-outcome pairs: odds ratios (ORs) ranged from 1.5 (95% CI, 1.2-1.7) for the association of the pad metric with severe exacerbations to 4.4 (95% CI, 3.8-5.2) for the association of the production metric with mild exacerbations. Six of the 12 UNGD-outcome associations had increasing ORs across quartiles. Our findings were robust to increasing levels of covariate control and in sensitivity analyses that included evaluation of some possible sources of unmeasured confounding. Conclusions and Relevance: Residential UNGD activity metrics were statistically associated with increased risk of mild, moderate, and severe asthma exacerbations. Whether these associations are causal awaits further investigation, including more detailed exposure assessment.

FUNDING: Funding/Support: This study was funded by National Institute of Environmental Health Sciences grant ES023675-01 (Dr Schwartz) and training grant ES07141 (Ms Rasmussen). Additional support was provided by the Degenstein Foundation for compilation of well data, the RobertWood Johnson Foundation Health & Society Scholars program (Dr. Casey), and the National Science Foundation Integrative Graduate Education and Research Traineeship (Ms Rasmussen). Conflict of Interest Disclosures: Dr Schwartz is a Fellow of the Post Carbon Institute (PCI), serving as an informal advisor on climate, energy, and health issues. He receives no payment for this role. His research is entirely independent of PCI and is not motivated, reviewed, or funded by PCI. No other disclosures are reported.
Place-based perceptions of the impacts of fracking along the Marcellus Shale


ABSTRACT

We examined community perspectives and experiences with fracking in Doddridge County, West Virginia, USA as part of a larger assessment to investigate the potential health impacts associated with fracking in neighboring Maryland, USA. In November 2013, we held two focus groups with community residents who had been impacted by fracking operations and conducted field observations in the impacted areas. Employing grounded theory, we conducted qualitative analysis to explore emergent themes related to direct and indirect health impacts of fracking. Three components of experience were identified, including (a) meanings of place and identity, (b) transforming relationships, and (c) perceptions of environmental and health impacts. Our findings indicate that fracking contributes to a disruption in residents’ sense of place and social identity, generating widespread social stress. Although community residents acknowledged the potential for economic growth brought about by fracking, rapid transformations in meanings of place and social identity influenced residents’ perceptions of environmental and health impacts. Our findings suggest that in order to have a more complete understanding of the health impacts of fracking, future work must consider the complex linkages between social disruption, environmental impacts, and health outcomes through critical engagements with communities undergoing energy development.

FUNDING: Conflict of interest not addressed. We would like to express our deepest gratitude and appreciation for the communities in West Virginia and Western Maryland and to the individuals who participated in this research and shared their stories, experiences, and expectations with our team. We thank Laura Delmarre, Rianna Murray, and Diane Pitcock for assistance with research and data collection. We also thank three anonymous reviewers for their constructive feedback, which led to considerable improvements in this paper. The work presented in this manuscript was supported by the Maryland Department of Health and Mental Hygiene (DHMH:M00B4400326). The findings and conclusions of this manuscript do not necessarily represent the official views or policies of DHMH.

A review on risk assessment techniques for hydraulic fracturing water and produced water management implemented in onshore unconventional oil and gas production


ABSTRACT

The objective of this paper is to review different risk assessment techniques applicable to onshore unconventional oil and gas production to determine the risks to water quantity and quality associated with hydraulic fracturing and produced water management. Water resources could be at risk without proper management of water, chemicals, and produced water. Previous risk assessments in the oil and gas industry were performed from an engineering perspective leaving aside important social factors. Different risk assessment methods and techniques are reviewed and summarized to select the most appropriate one to perform a holistic and integrated analysis of risks at every stage of the water life cycle. Constraints to performing risk assessment are identified including gaps in databases, which require more advanced techniques such as modeling. Discussions on each risk associated with water and produced water management, mitigation strategies, and future research direction are presented. Further research on risks in onshore unconventional oil and gas will benefit not only the U.S. but also other countries with shale oil and gas resources.

FUNDING: The authors would like to acknowledge the North Dakota Water Resource Research Institute, Fargo, North Dakota, USA for partial funding to support the first author (Luisa Torres) for her stipend.

ABSTRACT

Background: Unconventional natural gas development (UNGD) produces environmental contaminants and psychosocial stressors. Despite these concerns, few studies have evaluated the health effects of UNGD. Objectives: We investigated associations between UNGD activity and symptoms in a cross-sectional study in Pennsylvania. Methods: We mailed a self-administered questionnaire to 23,700 adult patients of the Geisinger Clinic. Using standardized and validated questionnaire items, we identified respondents with chronic rhinosinusitis (CRS), migraine headache, and fatigue symptoms. We created a summary UNGD activity metric that incorporated well phase, location, total depth, daily gas production and inverse distance-squared to patient residences. We used logistic regression, weighted for sampling and response rates, to assess associations between quartiles of UNGD activity and outcomes, both alone and in combination. Results: The response rate was 33%. Of 7,785 study participants, 1,850 (24%) had current CRS symptoms, 1,765 (23%) had migraine headache, and 1,930 (25%) had higher levels of fatigue. Among individuals who met criteria for two or more outcomes, adjusted odds ratios for the highest quartile of UNGD activity compared to the lowest were [OR (95% CI)] 1.49 (0.78, 2.85) for CRS plus migraine, 1.88 (1.08, 3.25) for CRS plus fatigue, 1.95 (1.18, 3.21) for migraine plus fatigue, and 1.84 (1.08, 3.14) for all three outcomes together. Significant associations were also present in some models of single outcomes. Conclusions: This study provides evidence that UNGD is associated with nasal and sinus, migraine headache, and fatigue symptoms in a general population representative sample.

FUNDING: Dr. Schwartz is a Fellow of the Post Carbon Institute (PCI), serving as an informal advisor on climate, energy, and health issues. He receives no payment for this role. His research is entirely independent of PCI, and is not motivated, reviewed, or funded by PCI. The other authors declare they have no actual or potential competing financial interests.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Metabolic; Lungs and Breathing; Eyes, Ears, Nose, and Throat

Associations between unconventional natural gas development and nasal and sinus, migraine headache, and fatigue symptoms in Pennsylvania


ABSTRACT

Background: Unconventional natural gas development (UNGD) produces environmental contaminants and psychosocial stressors. Despite these concerns, few studies have evaluated the health effects of UNGD. Objectives: We investigated associations between UNGD activity and symptoms in a cross-sectional study in Pennsylvania. Methods: We mailed a self-administered questionnaire to 23,700 adult patients of the Geisinger Clinic. Using standardized and validated questionnaire items, we identified respondents with chronic rhinosinusitis (CRS), migraine headache, and fatigue symptoms. We created a summary UNGD activity metric that incorporated well phase, location, total depth, daily gas production and inverse distance-squared to patient residences. We used logistic regression, weighted for sampling and response rates, to assess associations between quartiles of UNGD activity and outcomes, both alone and in combination. Results: The response rate was 33%. Of 7,785 study participants, 1,850 (24%) had current CRS symptoms, 1,765 (23%) had migraine headache, and 1,930 (25%) had higher levels of fatigue. Among individuals who met criteria for two or more outcomes, adjusted odds ratios for the highest quartile of UNGD activity compared to the lowest were [OR (95% CI)] 1.49 (0.78, 2.85) for CRS plus migraine, 1.88 (1.08, 3.25) for CRS plus fatigue, 1.95 (1.18, 3.21) for migraine plus fatigue, and 1.84 (1.08, 3.14) for all three outcomes together. Significant associations were also present in some models of single outcomes. Conclusions: This study provides evidence that UNGD is associated with nasal and sinus, migraine headache, and fatigue symptoms in a general population representative sample.

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PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Metabolic; Lungs and Breathing; Eyes, Ears, Nose, and Throat
Potential hazards of air pollutant emissions from unconventional oil and gas operations on the respiratory health of children and infants


ABSTRACT

Research on air pollutant emissions associated with unconventional oil and gas (UOG) development has grown significantly in recent years. Empirical investigations have focused on the identification and measurement of oil and gas air pollutants [e.g. volatile organic compounds (VOCs), particulate matter (PM), methane] and the influence of UOG on local and regional ambient air quality (e.g. tropospheric ozone). While more studies to better characterize spatial and temporal trends in exposure among children and newborns near UOG sites are needed, existing research suggests that exposure to air pollutants emitted during lifecycle operations can potentially lead to adverse respiratory outcomes in this population. Children are known to be at a greater risk from exposure to air pollutants, which can impair lung function and neurodevelopment, or exacerbate existing conditions, such as asthma, because the respiratory system is particularly vulnerable during development in-utero, the postnatal period, and early childhood. In this article, we review the literature relevant to respiratory risks of UOG on infants and children. Existing epidemiology studies document the impact of air pollutant exposure on children in other contexts and suggest impacts near UOG. Research is sparse on long-term health risks associated with frequent acute exposures – especially in children – hence our interpretation of these findings may be conservative. Many data gaps remain, but existing data support precautionary measures to protect the health of infants and children.

PUBLICATION TYPE: review

EVIDENCE STREAMS: human: population health

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: air

STATES/COUNTRIES: WY; UT; TX

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: benzene; formaldehyde; ozone; particulate matter; silica

HEALTH EFFECTS: Lungs and Breathing

All-age hospitalization rates in coal seam gas areas in Queensland, Australia, 1995–2011


ABSTRACT

Unconventional natural gas development (UNGD) is expanding globally, with Australia expanding development in the form of coal seam gas (CSG). Residents and other interest groups have voiced concerns about the potential environmental and health impacts related to CSG. This paper compares objective health outcomes from three study areas in Queensland, Australia to examine potential environmentally-related health impacts.

FUNDING: The authors declare that they have no competing interests. Dr Cameron was supported by a Public Health Fellowship (ID 428254) from the NHMRC. This work was supported by the University of Queensland, as well as the University of Queensland’s Minerals Industry Safety and Health Centre (MISHC) and Centre for Water in the Minerals Industry (CWIMI)

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: population health

EXTERNAL EXPOSURES: well density/drilling activity

STATES/COUNTRIES: Queensland, Australia
Louisiana Waterthrush and benthic macroinvertebrate response to shale gas development


ABSTRACT

Because shale gas development is occurring over large landscapes and consequently is affecting many headwater streams, an understanding of its effects on headwater-stream faunal communities is needed. We examined effects of shale gas development (well pads and associated infrastructure) on Louisiana waterthrush Parkesia motacilla and benthic macroinvertebrate communities in 12 West Virginia headwater streams in 2011. Streams were classed as impacted (n = 6) or unimpacted (n = 6) by shale gas development. We quantified waterthrush demography (nest success, clutch size, number of fledglings, territory density), a waterthrush Habitat Suitability Index, a Rapid Bioassessment Protocol habitat index, and benthic macroinvertebrate metrics including a genus-level stream-quality index for each stream. We compared each benthic metric between impacted and unimpacted streams with a Student's t-test that incorporated adjustments for normalizing data. Impacted streams had lower genus-level stream-quality index scores; lower overall and Ephemeroptera, Plecoptera, and Trichoptera richness; fewer intolerant taxa, more tolerant taxa, and greater density of 0–3-mm individuals (P ≤ 0.10). We then used Pearson correlation to relate waterthrush metrics to benthic metrics across the 12 streams. Territory density (no. of territories/km of stream) was greater on streams with higher genus-level stream-quality index scores; greater density of all taxa and Ephemeroptera, Plecoptera, and Trichoptera taxa; and greater biomass. Clutch size was greater on streams with higher genus-level stream-quality index scores. Nest survival analyses (n = 43 nests) completed with Program MARK suggested minimal influence of benthic metrics compared with nest stage and Habitat Suitability Index score. Although our study spanned only one season, our results suggest that shale gas development affected waterthrush and benthic communities in the headwater streams we studied. Thus, these ecological effects of shale gas development warrant closer examination.

FUNDING: West Virginia Division of Natural Resources provided access to the study area and Wheeling Jesuit University provided access to field housing. We thank Debbie Archer, Darin Blood, and Jim Sheehan for field assistance. Kyle Aldinger, Jeremy Mizel, and Jim Sheehan assisted with data summaries and analyses. We thank Greg Pond and Kelly Krock (USEPA, Region III) for processing and identifying benthic macroinvertebrates and Greg Pond for summaries and assistance with analyses of the benthic data. Kyle Aldinger, Greg Pond, Jim Sheehan, Brian Trevelline, the Associate Editor, and three anonymous reviewers provided helpful comments on this manuscript. Banding was conducted under U.S. Geological Survey banding permit no. 23412. This study was completed under the auspices of West Virginia University IACUC protocol 04-0302, 07-0303.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: wildlife

EXTERNAL EXPOSURES: surface water; well density/drilling activity

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: WV

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Mortality; Pregnancy and Reproduction

Inspiring collaboration: The legacy of Theo Colborn’s transdisciplinary research on fracking


ABSTRACT

This article describes Dr Theo Colborn’s legacy of inspiring complementary and synergistic environmental health research and advocacy. Colborn, a founder of endocrine disruption research, also stimulated study of hydraulic fracturing (fracking). In 2014, the United States led the world in oil and gas production, with fifteen million Americans living within one mile of an oil or gas well. Colborn pioneered efforts to understand and control the impacts of this sea change in energy production. In 2005, her research organization The Endocrine Disruption Exchange (TEDX) developed a database of chemicals used in natural gas extraction and their health
Funding: The authors declare no competing financial interest. We thank Allen Davis, John Whalen, John Vandenberg, and Steve Dutton for their comments on previous drafts of this manuscript. This work was supported in part by an appointment to the Research Participation Program at the EPA National Center for Environmental Assessment, administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and EPA. The views expressed in this manuscript are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Publication Type: original research

Evidence Streams: modeling/QSAR/risk calculation

Exposure Routes: oral

External Exposures: drinking water

Estimating the potential toxicity of chemicals associated with hydraulic fracturing operations using quantitative structure–activity relationship modeling


Abstract

The United States Environmental Protection Agency (EPA) identified 1173 chemicals associated with hydraulic fracturing fluids, flowback, or produced water, of which 1026 (87%) lack chronic oral toxicity values for human health assessments. To facilitate the ranking and prioritization of chemicals that lack toxicity values, it may be useful to employ toxicity estimates from quantitative structure–activity relationship (QSAR) models. Here we describe an approach for applying the results of a QSAR model from the TOPKAT program suite, which provides estimates of the rat chronic oral lowest-observed-adverse-effect level (LOAEL). Of the 1173 chemicals, TOPKAT was able to generate LOAEL estimates for 515 (44%). To address the uncertainty associated with these estimates, we assigned qualitative confidence scores (high, medium, or low) to each TOPKAT LOAEL estimate, and found 481 to be high-confidence. For 48 chemicals that had both a high-confidence TOPKAT LOAEL estimate and a chronic oral reference dose from EPA's Integrated Risk Information System (IRIS) database, Spearman rank correlation identified 68% agreement between the two values (permutation p-value = 1 x 10−11). These results provide support for the use of TOPKAT LOAEL estimates in identifying and prioritizing potentially hazardous chemicals. High-confidence TOPKAT LOAEL estimates were available for 389 of 1026 hydraulic fracturing-related chemicals that lack chronic oral RfVs and OSFs from EPA-identified sources, including a subset of chemicals that are frequently used in hydraulic fracturing fluids.
Overview of chronic oral toxicity values for chemicals present in hydraulic fracturing fluids, flowback, and produced waters


ABSTRACT

Concerns have been raised about potential public health effects that may arise if hydraulic fracturing-related chemicals were to impact drinking water resources. This study presents an overview of the chronic oral toxicity values specifically, chronic oral reference values (RfVs) for noncancer effects, and oral slope factors (OSFs) for cancer that are available for a list of 1173 chemicals that the United States (U.S.) Environmental Protection Agency (EPA) identified as being associated with hydraulic fracturing, including 1076 chemicals used in hydraulic fracturing fluids and 134 chemicals detected in flowback or produced waters from hydraulically fractured wells. The EPA compiled RfVs and OSFs using six governmental and intergovernmental data sources. Ninety (8%) of the 1076 chemicals reported in hydraulic fracturing fluids and 83 (62%) of the 134 chemicals reported in flowback/produced water had a chronic oral RfV or OSF available from one or more of the six sources. Furthermore, of the 36 chemicals reported in hydraulic fracturing fluids in at least 10% of wells nationwide (identified from EPA's analysis of the FracFocus Chemical Disclosure Registry 1.0), 8 chemicals (22%) had an available chronic oral RfV. The lack of chronic oral RfVs and OSFs for the majority of these chemicals highlights the significant knowledge gap that exists to assess the potential human health hazards associated with hydraulic fracturing.

FUNDING: The views expressed in this manuscript are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. The authors declare no competing financial interest. We acknowledge Samir Sahasrabudhe and Emma McConnell for their assistance in gathering toxicity values in support of this project. We would also like to thank John Vandenberg, Debra Watch, Elizabeth Oesterling Owens, and Jeff Gift for their comments on previous drafts of this manuscript. This work was supported in part by an appointment to the Research Participation Program at the EPA National Center for Environmental Assessment, administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the EPA.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation; human: non-occupational

EXPOSURE ROUTES: oral

EXTERNAL EXPOSURES: drinking water

GAS/OIL: unconventional

CHEMICALS: 1,3-butadiene; acrylamide; benzene; benzo(a)pyrene; benzyl chloride; BTEX; ethylene glycol; ethylene glycol monobutyl ether (2-BE); heptachlor; naphthalene; trimethylbenzenes

HEALTH EFFECTS: Pregnancy and Reproduction; Metabolic; Kidneys and Urinary System; Digestive System; cancers; Brain and Nerves; Bones, Joints, and Muscles

Long-term impacts of unconventional drilling operations on human and animal health


ABSTRACT

Public health concerns related to the expansion of unconventional oil and gas drilling have sparked intense debate. In 2012, we published case reports of animals and humans affected by nearby drilling operations. Because of the potential for long-term effects of even low doses of environmental toxicants and the cumulative impact of exposures of multiple chemicals by multiple routes of exposure, a longitudinal study of these cases is necessary. Twenty-one cases from five states were followed longitudinally, the follow-up period averaged 25 months. In addition to humans, cases involved food animals, companion animals and wildlife. More than half of all exposures were related to drilling and hydraulic fracturing operations, these decreased slightly over time. More than a third of all exposures were associated with wastewater, processing and production operations, these exposures increased slightly over time. Health impacts decreased for families and animals moving from intensively drilled areas or remaining in areas where drilling activity decreased. In cases of families remaining...
in the same area and for which drilling activity either remained the same or increased, no change in health impacts was observed. Over the course of the study, the distribution of symptoms was unchanged for humans and companion animals, but in food animals, reproductive problems decreased and both respiratory and growth problems increased. This longitudinal case study illustrates the importance of obtaining detailed epidemiological data on the long-term health effects of multiple chemical exposures and multiple routes of exposure that are characteristic of the environmental impacts of unconventional drilling operations.

**FUNDING:** Not addressed

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** human: non-occupational; animal: wildlife; animal: pets; animal: livestock

**EXTERNAL EXPOSURES:** wastewater; survey/questionnaire/interview; surface water; spills/leaks; soil; drinking water; air

**GEOLOGIC FORMATIONS:** Piceance Basin; Marcellus Shale; Fayetteville Shale; Bakken Shale

**STATES/COUNTRIES:** PA; NY; ND; CO; AR

**GAS/OIL:** natural gas; oil; unconventional

**HEALTH EFFECTS:** Skin, Hair, and Nails; Pregnancy and Reproduction; Mortality; Metabolic; Lungs and Breathing; Immune System; Endocrine system; Digestive System; Brain and Nerves; Bones, Joints, and Muscles; Blood, Heart, and Circulation

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**Human exposure to unconventional natural gas development: A public health demonstration of periodic high exposure to chemical mixtures in ambient air**


**ABSTRACT**

Directional drilling and hydraulic fracturing of shale gas and oil bring industrial activity into close proximity to residences, schools, daycare centers and places where people spend their time. Multiple gas production sources can be sited near residences. Health care providers evaluating patient health need to know the chemicals present, the emissions from different sites and the intensity and frequency of the exposures. This research describes a hypothetical case study designed to provide a basic model that demonstrates the direct effect of weather on exposure patterns of particulate matter smaller than 2.5 microns (PM2.5) and volatile organic chemicals (VOCs). Because emissions from unconventional natural gas development (UNGD) sites are variable, a short term exposure profile is proposed that determines 6-hour assessments of emissions estimates, a time scale needed to assist physicians in the evaluation of individual exposures. The hypothetical case is based on observed conditions in shale gas development in Washington County, Pennsylvania, and on estimated emissions from facilities during gas development and production. An air exposure screening model was applied to determine the ambient concentration of VOCs and PM2.5 at different 6-hour periods of the day and night. Hourly wind speed, wind direction and cloud cover data from Pittsburgh International Airport were used to calculate the expected exposures. Fourteen months of daily observations were modeled. Higher than yearly average source terms were used to predict health impacts at periods when emissions are high. The frequency and intensity of exposures to PM2.5 and VOCs at a residence surrounded by three UNGD facilities was determined. The findings show that peak PM2.5 and VOC exposures occurred 83 times over the course of 14 months of well development. Among the stages of well development, the drilling, flaring and finishing, and gas production stages produced higher intensity exposures than the hydraulic fracturing stage. Over one year, compressor station emissions created 118 peak exposure levels and a gas processing plant produced 99 peak exposures over one year. The screening model identified the periods during the day and the specific weather conditions when the highest potential exposures would occur. The periodicity of occurrence of extreme exposures is similar to the episodic nature of the health complaints reported in Washington County and in the literature. This study demonstrates the need to determine the aggregate quantitative impact on health when multiple facilities are placed near residences, schools, daycare centers and other locations where people are present. It shows that understanding the influence of air stability and wind direction is essential to exposure assessment at the residential level. The model can be applied to other emissions and similar sites. Profiles such as this will assist health providers in understanding the frequency and intensity of the human exposures when diagnosing and treating patients living near unconventional natural gas development.

**FUNDING:** This research was supported by the Heinz Foundation and the Colcom Foundation.

**PUBLICATION TYPE:** review

**EXPOSURE ROUTES:** inhalation

**EXTERNAL EXPOSURES:** well density/drilling activity; air

**GEOLOGIC FORMATIONS:** Marcellus Shale

**STATES/COUNTRIES:** PA
**Does methane pose significant health and public safety hazards?—A review**


**ABSTRACT**

It has been suggested by some that methane contamination of water wells is the main negative consequence of the development of natural gas resources. Concurrently, speculation in academic white papers and in the press that methane may be toxic has resulted in public concern. In northern Pennsylvania, methane being released from groundwater and entering homes (so-called stray gas) has become a focus of this concern. This phenomenon was widespread decades before shale gas development was initiated. This paper reviews the available literature on the safety and health hazards associated with natural gas. It concludes that the risks to homeowners are highest from flash fires occurring in methane-oxygen gas clouds at relatively low methane concentrations collecting in poorly ventilated, confined areas of houses such as basements. Such risks can be mitigated effectively and in most cases at minimal cost. Methane can result in death from hypoxia (lack of oxygen) but only at methane levels in the air of more than 60%, which are unlikely to develop except under exceptional circumstances. There is no evidence that low to moderate levels of exposure to methane in air have any toxic effect on humans, and evidence for such effects at very high levels (already fatal because of hypoxia) is equivocal. It seems likely that methane at concentrations at least as high as 2.5% may well have positive health benefits for some diseases.

**FUNDING:** This paper was supported by funds from a grant from the Cynthia and George Mitchell Foundation with additional funding from a RIPSEA Grant to JP Nicot.

**PUBLICATION TYPE:** review

**EXPOSURE ROUTES:** inhalation

**EXTERNAL EXPOSURES:** drinking water; air

**GEOLOGIC FORMATIONS:** Marcellus Shale

**STATES/COUNTRIES:** WV; PA

**GAS/OIL:** natural gas

**CHEMICALS:** methane

**HEALTH EFFECTS:** Pregnancy and Reproduction; Lungs and Breathing; Digestive System; Brain and Nerves; acute toxicity/poisoning; mortality

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The Barnett Shale: From problem formulation to risk management


**ABSTRACT**

There is a nationwide trend to develop shale formations due to advances in horizontal drilling and hydraulic fracturing technology. The Barnett Shale in north Texas is one of the largest onshore natural gas fields in the US, and has experienced exponential growth since the 1990's. This immense amount of well development and gas production has occurred near heavily populated, urban areas, leading to increased public concern regarding the impacts of these activities on human health and welfare. The Texas Commission on Environmental Quality (TCEQ) is charged with regulating sources of air emissions from natural gas operations (NGOs) and is in a unique position to evaluate any associated risks. The goal of this manuscript is to describe the problem formulation process used by the TCEQ to characterize risks associated with air emissions from NGOs, and the
subsequent risk management strategies implemented. Details on how potential sources of risk to human health were identified and quantified are provided. Initial assessments identified volatile organic compounds (VOCs) as chemicals of concern. Over 4.7 million data points for VOCs were used in this assessment on both a short-term and long-term basis. Only three short-term samples measured VOCs above short-term health-based air monitoring comparison values (AMCVs). Several short-term samples measured VOCs above odor-based AMCVs. Long-term VOC levels were below long-term health-based AMCVs. We describe efforts to engage stakeholders early in the risk assessment process and outreach programs used. Finally, details on new rules and regulations that are being used to more efficiently manage risks are provided. Given the resources and experience TCEQ possesses to evaluate environmental impacts that may be caused by shale gas development and production, it is our hope that this manuscript may serve as a resource to others to identify and manage risks associated with oil and gas activities in their area.

**FUNDING:** We are grateful for the contributions by the following individuals: Raj B. Nadkarni, GISP, Anne Inman, PE, Alyssa Taylor, Anne Marie Callery, the incredibly talented and dedicated staff of the TCEQ Monitoring Division and Region 4 office staff, and the various entities responsible for the funding and placement of new VOC monitors in the Barnett Shale area.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** modeling/QSAR/risk calculation

**EXPOSURE ROUTES:** inhalation

**EXTERNAL EXPOSURES:** air

**GEOLOGIC FORMATIONS:** Barnett Shale

**STATES/COUNTRIES:** TX

**GAS/OIL:** natural gas; unconventional

**CHEMICALS:** benzene; VOCs; NOx

**HEALTH EFFECTS:** Cancers

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**Unconventional gas and oil drilling is associated with increased hospital utilization rates**


**ABSTRACT**

Over the past ten years, unconventional gas and oil drilling (UGOD) has markedly expanded in the United States. Despite substantial increases in well drilling, the health consequences of UGOD toxicant exposure remain unclear. This study examines an association between wells and healthcare use by zip code from 2007 to 2011 in Pennsylvania. Inpatient discharge databases from the Pennsylvania Healthcare Cost Containment Council were correlated with active wells by zip code in three counties in Pennsylvania. For overall inpatient prevalence rates and 25 specific medical categories, the association of inpatient prevalence rates with number of wells per zip code and, separately, with wells per km2 (separated into quantiles and defined as well density) were estimated using fixed-effects Poisson models. To account for multiple comparisons, a Bonferroni correction with associations of p<0.00096 was considered statistically significant. Cardiology inpatient prevalence rates were significantly associated with number of wells per zip code (p<0.00096) and wells per km2 (p<0.00096) while neurology inpatient prevalence rates were significantly associated with wells per km2 (p<0.00096). Furthermore, evidence also supported an association between well density and inpatient prevalence rates for the medical categories of dermatology, neurology, oncology, and urology. These data suggest that UGOD wells, which dramatically increased in the past decade, were associated with increased inpatient prevalence rates within specific medical categories in Pennsylvania. Further studies are necessary to address healthcare costs of UGOD and determine whether specific toxicants or combinations are associated with organ-specific responses.

**FUNDING:** This work was funded by grants from the National Institute of Environmental Health Sciences (www.niehs.nih.gov): P30-ES013508 (GLG MH PS NF TMP JR KJP RAP) and P30-ES009089 (GLG MN SC BY MS MH PS NF TMP JR KJP RAP). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** human: population health

**EXTERNAL EXPOSURES:** well density/drilling activity

**GEOLOGIC FORMATIONS:** Marcellus Shale
Endocrine-disrupting activity of hydraulic fracturing chemicals and adverse health outcomes after prenatal exposure in male mice


ABSTRACT

Oil and natural gas operations have been shown to contaminate surface and ground water with endocrine-disrupting chemicals. In the current study, we fill several gaps in our understanding of the potential environmental impacts related to this process. We measured the endocrine-disrupting activities of 24 chemicals used and/or produced by oil and gas operations for five nuclear receptors using a reporter gene assay in human endometrial cancer cells. We also quantified the concentration of 16 of these chemicals in oil and gas wastewater samples. Finally, we assessed reproductive and developmental outcomes in male C57BL/6J mice after the prenatal exposure to a mixture of these chemicals. We found that 23 commonly used oil and natural gas operation chemicals can activate or inhibit the estrogen, androgen, glucocorticoid, progesterone, and/or thyroid receptors, and mixtures of these chemicals can behave synergistically, additively, or antagonistically in vitro. Prenatal exposure to a mixture of 23 oil and gas operation chemicals at 3, 30, and 300 μg/kg · d caused decreased sperm counts and increased testes, body, heart, and thymus weights and increased serum T in male mice, suggesting multiple organ system impacts. Our results suggest possible adverse developmental and reproductive health outcomes in humans and animals exposed to potential environmentally relevant levels of oil and gas operation chemicals.

FUNDING: This work was supported by grants from the Passport Foundation Science Innovation Fund (to S.C.N.), the University of Missouri Research Council, a crowd funding campaign on Experiment.com, and STAR Fellowship Assistance Agreement FP-91747101 awarded by the US Environmental Protection Agency (to C.D.K.). The authors have nothing to disclose.

Air contaminants associated with potential respiratory effects from unconventional resource development activities


ABSTRACT
Unconventional natural gas development uses horizontal drilling in conjunction with hydraulic fracturing to gain access to natural gas deposits which may be tightly held in shale deposits and unavailable to conventional vertical drilling operations. The intensive work required to extract this source of energy results in higher than usual numbers of vehicles involved; potential release of emissions from those vehicles in congested zones surrounding the drill site; and release of other contaminants from materials drawn back out of the borehole after fracturing of the shale. Typical contaminants would be diesel exhaust particulate and gases; volatile organic compounds and other hydrocarbons both from diesels and the drilling process; crystalline silica, used as part of the hydraulic fracturing process in kiloton quantities; and methane escaping from the borehole and piping. A rise in respiratory disease with proximity to the process has been reported in nearby communities and both silica and diesel exposures at the worksite are recognized respiratory hazards. Because of the relatively short time this process has been used to the extent it is currently being used, it is not possible to draw detailed conclusions about the respiratory hazards that may be posed. However, based on the traffic volume associated with each drill site and the number of drill sites in any locale; it is possible at least to compare the effects to that of large traffic volume highways which are known to produce some respiratory effects in surrounding areas.

**FUNDING:** Not addressed

**PUBLICATION TYPE:** review

**EVIDENCE STREAMS:** human; occupational

**EXPOSURE ROUTES:** inhalation

**EXTERNAL EXPOSURES:** air

**GEOLOGIC FORMATIONS:** Marcellus Shale; Barnett Shale

**STATES/COUNTRIES:** WV; TX

**GAS/OIL:** natural gas; unconventional

**CHEMICALS:** benzene; BTEX; cumene; cyclohexane; ethylbenzene; formaldehyde; hexane; hydrogen sulfide; methane; naphthalene; ozone; PAHs; particulate matter; phenanthrene; silica; styrene; sulfur dioxide; toluene; trimethylbenzenes; xylenes; VOCs; diesel exhaust; acetaldehyde; benzaldehyde; benz(a)anthracene; benz(a)pyrene; benz(b)fluoranthene; chrysene; crotonaldehyde; dibenz(a, h)anthracene; ethanol; indeno(1,2,3-cd)pyrene; isoprene; methacrolein; methyl chloride; n-decane; n-octane; propylene; 1,1-dichlorobenzene; 2-hexanone; 2-propanol; 4-methyl-2-pentanone; ammonia; NOx; ionizing radiation

**HEALTH EFFECTS:** Lungs and Breathing

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**High volume hydraulic fracturing operations: Potential impacts on surface water and human health**


**ABSTRACT**

High volume, hydraulic fracturing (HVHF) processes, used to extract natural gas and oil from underground shale deposits, pose many potential hazards to the environment and human health. HVHF can negatively affect the environment by contaminating soil, water, and air matrices with potential pollutants. Due to the relatively novel nature of the process, hazards to surface waters and human health are not well known. The purpose of this article is to link the impacts of HVHF operations on surface water integrity, with human health consequences. Surface water contamination risks include: increased structural failure rates of unconventional wells, issues with wastewater treatment, and accidental discharge of contaminated fluids. Human health risks associated with exposure to surface water contaminated with HVHF chemicals include increased cancer risk and turbidity of water, leading to increased pathogen survival time. Future research should focus on modeling contamination spread throughout the environment, and minimizing occupational exposure to harmful chemicals.

**FUNDING:** No potential conflict of interest was reported by the authors.

**PUBLICATION TYPE:** review

**EXTERNAL EXPOSURES:** well density/drilling activity; wastewater; surface water; spills/leaks; drinking water; air

**GEOLOGIC FORMATIONS:** Raton Basin; Piceance Basin; Marcellus Shale; Haynesville Shale; Eagle Ford Shale; Barnett Shale; Bakken Shale

**STATES/COUNTRIES:** Canada; WY; WV; VA; UT; TX; TN; PA; OK; OH; NM; ND; MS; MN; LA; KS; CO; AR

**GAS/OIL:** natural gas; oil; unconventional

**CHEMICALS:** benzene; ethylbenzene; dibromochloronitromethane; methane; n,n-dimethylformamide; NORM; silica; toluene; xylenes; bromide; bromate; chloride; sulfate; BTEX
HEALTH EFFECTS: cancers; acute toxicity/poisoning

Modelling the health risks of exposure to respirable crystalline silica from hydraulic fracturing operations in the USA shale plays


ABSTRACT

Respirable crystalline silica (RCS) is a known human carcinogen and a contaminant of potential concern. Proppants are used during the process of well stimulation (hydraulic fracturing) as additives in the fluid cocktail and sand is often used as a proppant which contains high percentage of silica determined by the quartz content. Empirical occupational exposure risk models were employed in this study to assess the potential health consequences from chronic RCS exposures based on RCS data from NIOSH and risk assessment formulas. Evaluating the lifetime (LT) excess cancer risk (LCR) potential, based on a risk target of 105, the job titles that are likely to experience any substantial potential effect of cancer induction are the sand mover (LCR = 16.1 × 105) and transfer belt (LCR = 19.2 × 105) operators. The sand truck driver and data Van operators are among the job functions with a cumulative disease burden of 7.2% that are unlikely to be affected by < 2% carcinogenic disease burden. The chemical truck, sand mover and transfer belt (T-belt) operators may potentially be at risk of other occupational nonmalignant respiratory diseases with hazard quotient (HQ) of 0.65, 1.79, and 2.13 respectively. It is recommended that continuous occupational health monitoring of potentially exposed workers should be included as part of the project plan and the engineering risk controls that have been put in place should be ranked to highlight the effectiveness of any risk reduction/prevention methodology employed.

FUNDING: Not addressed

PUBLIC TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation; human: occupational

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: air

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: Silica

HEALTH EFFECTS: Lungs and Breathing; cancers

Popular epidemiology and "fracking": Citizens' concerns regarding the economic, environmental, health and social impacts of unconventional natural gas drilling operations


ABSTRACT

Pennsylvania sits atop the Marcellus Shale, a reservoir of natural gas that was untapped until the 2004 introduction of unconventional natural gas drilling operations (UNGDO) in the state. Colloquially known as fracking, UNGDO is a controversial process that employs large volumes of water to fracture the shale and capture gas; it has become a multi-billion dollar industry in Pennsylvania. We analyzed letters to the editor of the most widely circulated local newspaper in Pennsylvania (Bradford County) in order to characterize residents' concerns and their involvement in popular epidemiology—the process by which citizens investigate risks associated with a perceived environmental threat. We reviewed 215 letters to the editor that referenced natural gas operations and were published by The Daily Review between January 1, 2008 and June 8, 2013. We used NVivo 10 to code and analyze letters and identify major themes. NVivo is qualitative data analysis software (http://www.qsrinternational.com/products_nvivo.aspx) that allows researchers to code and analyze "unstructured" data, including text files of any type (e.g., interview transcripts, news articles, letters, archival materials) as well as photographs and videos. NVivo can be used to classify, sort, query, comment on, and share data across a research group. Letters demonstrated citizen engagement in beginning and intermediate stages of lay epidemiology, as well as discord and stress regarding four main issues: socio-economic impacts, perceived threats to water, population growth and implications, and changes to the rural landscape. Residents called for stronger scientific evidence and a balance of economic development and health and environmental protections. Citizens' distress regarding UNGDO appeared to be exacerbated by a dearth of information to guide economic growth and health, environmental, and social concerns. This analysis proposes locally informed questions to guide future surveillance and research.
Proximity to natural gas wells and reported health status: Results of a household survey in Washington County, Pennsylvania


ABSTRACT

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: 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 to 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 3.27 ± 3.72) compared with >2 km from the nearest gas well (mean 1.60 ± 2.14, p=0.02). In a model that adjusted for age, gender, 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 (OR= 4.1, 95%CI: 1.4, 12.3, p=0.01). Upper respiratory symptoms were also more frequently reported in persons living in households less than 1 km from gas wells (39%) compared to 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: While 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.

FUNDING: This study was supported by grants from The Heinz Endowments, as well as the 11th Hour Project, a program of the Schmidt Family Foundation, and the Claneil Foundation. Additional support was received from the Jan Stolwijk Fellowship fund and by the Yale University Clinical and Translational Science Award grant UL1 RR024139 from the National Center for Research Resources and the National Center for Advancing Translational Science, components of the National Institutes of Health (NIH), and the NIH Roadmap for Medical Research. None of the funders participated in the study design, data collection, or analysis of study results. 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. The contents are solely the responsibility of the authors and do not necessarily represent the official views of NIH. The authors declare they have no actual or potential competing financial interests.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXPOSURE ROUTES: inhalation; oral

EXTERNAL EXPOSURES: well density/drilling activity; survey/questionnaire/interview

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Skin, Hair, and Nails; Mental Health and Behavior; Lungs and Breathing; Digestive System; Brain and Nerves; Blood, Heart, and Circulation
The risk of hydraulic fracturing on public health in the UK and the UK’s fracking legislation


ABSTRACT

Background: Hydraulic fracturing to extract natural gas from shale rock is a new, rapidly expanding industry in the United States (US). However, there is concern that these operations could be having large negative impacts such as groundwater contamination, increased air pollution and seismic events. The United Kingdom (UK) is looking at the potential for emulating the success of ‘shale gas’ in the US. Differences in population density and geological conditions mean that the public health impacts recorded in the US cannot be directly extrapolated to the UK. There is limited academic literature available but findings suggest that the UK government is not fully recognising the inherent risks of hydraulic fracturing exposed by this literature. Government reports suggest a reliance on engineering solutions and better practice to overcome problems found in the US when evidence suggests that there are inherent risks and impacts that cannot be eliminated. Results: This study applies US results to approximate the impact of one exposure pathway, inhalation of hydrocarbons by the public from operational air emissions over the 30 year lifetime of a well and finds that 7.2 extra cancer cases from exposure to air contamination would be expected in the UK if all test sites, approved test sites and test sites awaiting approval as of January 2015 went on to extract gas. Conclusions: In conclusion, limited assessment of the public health implications of hydraulic fracturing operations is available but the UK government appears to not be applying the precautionary principle to potentially significant legislation.

FUNDING: I would like to thank Nicola Carslaw and Roman Ashauer for comments on earlier versions of this manuscript. The author declares that she has no competing interests.

REPORTED HEALTH CONDITIONS IN ANIMALS RESIDING NEAR NATURAL GAS WELLS IN SOUTHWESTERN PENNSYLVANIA


ABSTRACT

Natural gas extraction activities, including the use of horizontal drilling and hydraulic fracturing, may pose potential health risks to both human and animal populations in close proximity to sites of extraction activity. Because animals may have increased exposure to contaminated water and air as well as increased susceptibility to contaminant exposures compared to nearby humans, animal disease events in communities living near natural gas extraction may provide “sentinel” information useful for human health risk assessment. Community health evaluations as well as health impact assessments (HIAs) of natural gas exploration should therefore consider the inclusion of animal health metrics in their assessment process. We report on a community environmental health survey conducted in an area of active natural gas drilling, which included the collection of health data on 2452 companion and backyard animals residing in 157 randomly-selected households of Washington County, Pennsylvania (USA). There were a total of 127 reported health conditions, most commonly among dogs. When reports from all animals were considered, there were no significant associations between reported health condition and household proximity to natural gas wells. When dogs were analyzed separately, we found an elevated risk of ‘any’ reported health condition in households less than 1km from the nearest gas well (OR D 3.2, 95% CI 1.07–9.7), with dermal conditions being the most common of canine disorders. While these results should be considered hypothesis generating and preliminary, they suggest value in ongoing assessments of pet dogs as well as other animals to better elucidate the health impacts of natural gas extraction on nearby communities.

FUNDING: This study was supported by grants from The Heinz Endowments, as well as The 11th Hour Project, a program of the Schmidt Family Foundation and the Claneil Foundation. None of these funders took part in the planning or conduct of the study including data analysis. Additional support was received from the Yale University School of Public Health Jan A.J. Stolwijk Fellowship fund. Conflict of interest was not addressed.
Perinatal outcomes and unconventional natural gas operations in southwest Pennsylvania


ABSTRACT

Unconventional gas drilling (UGD) has enabled extraordinarily rapid growth in the extraction of natural gas. Despite frequently expressed public concern, human health studies have not kept pace. We investigated the association of proximity to UGD in the Marcellus Shale formation and perinatal outcomes in a retrospective cohort study of 15,451 live births in Southwest Pennsylvania from 2007–2010. Mothers were categorized into exposure quartiles based on inverse distance weighted (IDW) well count, least exposed mothers (first quartile) had an IDW well count less than 0.87 wells per mile, while the most exposed (fourth quartile) had 6.00 wells or greater per mile. Multivariate linear (birth weight) or logistical (small for gestational age (SGA) and prematurity) regression analyses, accounting for differences in maternal and child risk factors, were performed. There was no significant association of proximity and density of UGD with prematurity. Comparison of the most to least exposed, however, revealed lower birth weight (3323 ± 558 vs 3344 ± 544 g) and a higher incidence of SGA (6.5 vs 4.8%, respectively, odds ratio: 1.34, 95% confidence interval: 1.10–1.63). While the clinical significance of the differences in birth weight among the exposure groups is unclear, the present findings further emphasize the need for larger studies, in regio-specific fashion, with more precise characterization of exposure over an extended period of time to evaluate the potential public health significance of UGD.

FUNDING: This study was supported by the Heinz Endowments (website: http://www.heinz.org/) (BRP). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. Competing Interests: The authors have declared that no competing interests exist.

**ABSTRACT**

The basic biologies and ecologies of most freshwater fishes throughout the world are poorly understood. But such knowledge may be critical for conservation decisions. The redfin darter (Etheostoma whipplei), a poorly understood fish species, is an excellent model for highlighting this situation. Much of the limited range of this species is experiencing nontraditional natural gas extraction activities including hydraulic fracturing, which may be a significant source of silt input for streams. We investigated aspects of the ecology and metrics of reproductive success of redfin darters in central Arkansas. We examined habitat occupation through quantitative surveys of fish assemblages and habitat variables, and reproductive life history through field and laboratory surveys in Cypress Creek, Arkansas. We also examined the proportion of young fishes in populations relative to intensity of natural gas extraction activity. Ordination analysis found habitat gradients relating primarily to stream size. Redfin darters had the highest relative abundance in samples in small, high gradient streams. Redfin darters reproduce in the spring, peaking with the rainy season, using larger substrate than their close relatives. Reproductive success appears to be negatively related to natural gas extraction intensity. Redfin darters reproduce at both a time and in a habitat which may be especially susceptible to siltation from natural gas extraction activities, which may be reflected in fewer young fishes in populations. Our research highlights the importance of life history data in understanding responses to novel disturbances in freshwater fishes.

**FUNDING:** This work was funded by grants provided by the Arkansas Game and Fish Commission, United States Fish and Wildlife, and the University of Central Arkansas. We owe a great debt of gratitude to our collaborating agencies, the University of Arkansas, and The Nature Conservancy. S. Entrekin, M. Evans-White, B. Austin, N. Jensen, and J. Kelso were instrumental collaborators in the natural gas portion of this project. We wish to thank J. Larson, R. Walker, C. Johnson, and J. Christian for their dedicated time in the field and lab, and we extend our thanks to the many undergraduates and graduate students at the University of Central Arkansas who donated time in the field. Without their help, this project would not have reached its full potential. All sampling protocols were approved by an Institutional Animal Care and Use Committee (IACUC 09–007). Conflict of interest not addressed.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** animal: wildlife

**EXPOSURE ROUTES:** dermal; oral

**EXTERNAL EXPOSURES:** surface water; well density/drilling activity

**GEOLOGIC FORMATIONS:** Fayetteville Shale

**STATES/COUNTRIES:** AR

**GAS/OIL:** natural gas; unconventional

**HEALTH EFFECTS:** Pregnancy and Reproduction

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**Impact of Marcellus Shale natural gas development in southwest Pennsylvania on volatile organic compound emissions and regional air quality**


**ABSTRACT**

The Marcellus Shale is the largest natural gas deposit in the U.S. and rapid development of this resource has raised concerns about regional air pollution. A field campaign was conducted in the southwestern Pennsylvania region of the Marcellus Shale to investigate the impact of unconventional natural gas (UNG) production operations on regional air quality. Whole air samples were collected throughout an 8050 km2 grid surrounding Pittsburgh and analyzed for methane, carbon dioxide, and C1–C10 volatile organic compounds (VOCs). Elevated mixing ratios of methane and C2–C8 alkanes were observed in areas with the highest density of UNG wells. Source apportionment was used to identify characteristic emission ratios for UNG sources, and results indicated that UNG emissions were responsible for the majority of mixing ratios of C2–C8 alkanes, but accounted for a small proportion of alkene and aromatic compounds. The VOC emissions from UNG operations accounted for 17 ± 19% of the regional kinetic hydroxyl radical reactivity of nonbiogenic VOCs suggesting that natural gas emissions may affect compliance with federal ozone standards. A first approximation of methane emissions from the study area of 10.0 ± 5.2 kg s−1 provides a baseline for determining the efficacy of regulatory emission control efforts.

**FUNDING:** Funding for this work was provided by the Clean Air Task Force. We thank Dan Riemer for the loan of instrumentation and Appalachian State University environmental science and chemistry students for sample collection.

**PUBLICATION TYPE:** original research
Avoidance of unconventional oil wells and roads exacerbates habitat loss for grassland birds in the North American great plains


ABSTRACT

Oil development in the Bakken shale region has increased rapidly as a result of new technologies and strong demand for fossil fuel. This region also supports a particularly high density and diversity of grassland bird species, which are declining across North America. We examined grassland bird response to unconventional oil extraction sites (i.e. developed with hydraulic fracturing and horizontal drilling techniques) and associated roads in North Dakota. Our goal was to quantify the amount of habitat that was indirectly degraded by oil development, as evidenced by patterns of avoidance by birds. Grassland birds avoided areas within 150 m of roads (95% CI: 87–214 m), 267 m of single-bore well pads (95% CI: 157–378 m), and 150 m of multi-bore well pads (95% CI: 67–233 m). Individual species demonstrated variable tolerance of well pads. Clay-colored sparrows (Spizella pallida) were tolerant of oil-related infrastructure, whereas Sprague’s pipit (Anthus spragueii) avoided areas within 350 m (95% CI: 215–485 m) of single-bore well pads. Given these density patterns around oil wells, the potential footprint of any individual oil well, and oil development across the region, is greatly multiplied for sensitive species. Efforts to reduce new road construction, concentrate wells along developed corridors, combine numerous wells on multi-bore pads rather than build many single-bore wells, and to place well pads near existing roads will serve to minimize loss of suitable habitat for birds. Quantifying environmental degradation caused by oil development is a critical step in understanding how to better mitigate harm to wildlife populations.

FUNDING: We thank the Plains and Prairie Pothole Landscape Conservation Cooperative for funding. We thank T. Arnold and 3 anonymous reviewers for helpful comments on this manuscript. We are grateful for logistical support provided by staffs at Lake Ilo and Lostwood National Wildlife Refuges and the Crosby Wetland Management District. We also thank numerous individuals at the US Forest Service Dakota Prairie National Grasslands and North Dakota Game and Fish Department for assistance. We specifically thank M. Ditmer, T. Gallion, S. Goebel, K. Luttschwager, M. Rabenberg, K. Richardson, L. Richardson, C. Sutheimer, A. Wiker, and E. Wiley for their assistance. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. government.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: animal: wildlife

EXTERNAL EXPOSURES: well density/drilling activity

GEOLOGIC FORMATIONS: Bakken Shale

STATES/COUNTRIES: ND

GAS/OIL: oil; unconventional

HEALTH EFFECTS: Mental Health and Behavior
Assessment of the acute and chronic hazards of hydraulic fracturing fluids

ABSTRACT
There is growing concern about how hydraulic fracturing affects public health because this activity involves handling large volumes of fluids that contain toxic and carcinogenic constituents, which are injected under high pressure through wells into the subsurface to release oil and gas from tight shale formations. The constituents of hydraulic fracturing fluids (HFFs) present occupational health risks because workers may be directly exposed to them, and general public health risks because of potential air and water contamination. Hazard identification, which focuses on the types of toxicity that substances may cause, is an important step in the complex health risk assessment of hydraulic fracturing. This article presents a practical and adaptable tool for the hazard identification of HFF constituents, and its use in the analysis of HFF constituents reported to be used in 2,850 wells in North Dakota between December 2009 and November 2013. Of the 569 reported constituents, 347 could be identified by a Chemical Abstract Service Registration Number (CASRN) and matching constituent name. The remainder could not be identified either because of trade secret labeling (210) or because of an invalid CASRN (12). Eleven public databases were searched for health hazard information on thirteen health hazard endpoints for 168 identifiable constituents that had at least 25 reports of use. Health hazard counts were generated for chronic and acute endpoints, including those associated with oral, inhalation, ocular, and dermal exposure. Eleven of the constituents listed in the top 30 by total health hazard count were also listed in the top 30 by reports of use. This includes naphthalene, which along with benzyl chloride, has the highest health hazard count. The top 25 constituents reportedly used in North Dakota largely overlap with those reported for Texas and Pennsylvania, despite different geologic formations, target resources (oil vs. gas), and disclosure requirements. Altogether, this database provides a public health tool to help inform stakeholders about potential health hazards, and to aid in the reformulation of less hazardous HFFs.

FUNDING: This research was supported by a grant from the University of Minnesota Futures Grant program, funded by the University of Minnesota Office of the Vice President of Research.

EVIDENCE STREAMS: modeling/QSAR/risk calculation; human: population health; human: occupational

EXPOSURE ROUTES: dermal; inhalation; ocular; oral

GEOLOGIC FORMATIONS: Marcellus Shale; Barnett Shale; Bakken Shale

STATES/COUNTRIES: TX; PA; ND

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: 2-ethylhexanol; acrylamide; benzyl chloride; ethylene glycol; ethylene glycol monobutyl ether (2-BE); formaldehyde; naphthalene; silica; trimethylbenzenes; potassium hydroxide; guar gum; methanol; solvent naphtha; petroleum distillates; sodium hydroxide; sodium chloride; ammonium peroxysulfate; ethanol; Poly(oxy-1,2-ethanediyl); alpha-(4-nonylphenyl)-omega-hydroxy-; branched; isopropyl alcohol; potassium metaborate; sodium chloride; potassium formate; glutaraldehyde; sodium perborate tetrahydrate; mullite; Sorbitan; mono-9- octadecenoate; (Z)-; ammonium chloride; potassium carbonate; polyethylene glycol; acetic acid; alcohols; C12-16 ethoxylated; Propylene glycol

HEALTH EFFECTS: Skin, Hair, and Nails; Pregnancy and Reproduction; Lungs and Breathing; Eyes, Ears, Nose, and Throat; cancers; Brain and Nerves; acute toxicity/poisoning

Environmental health impacts of unconventional natural gas development: A review of the current strength of evidence

ABSTRACT
Rapid global expansion of unconventional natural gas development (UNGD) raises environmental health concerns. Many studies present information on these concerns, yet the strength of epidemiological evidence remains tenuous. This paper is a review of the strength of evidence in scientific reporting of environmental hazards from UNGD activities associated with adverse human health outcomes. Studies were drawn from peer-reviewed and grey literature following a systematic search. Five databases were searched for studies published from January 1995 through March 2014 using key search terms relevant to environmental health. Studies were screened, ranked and then reviewed according to the strength of the evidence presented on adverse environmental health outcomes associated with UNGD. The initial searches yielded 1000 studies, but this was reduced to 109 relevant studies after the ranking process. Only seven studies were considered highly relevant based on strength of evidence. Articles spanned several relevant topics, but most focussed on impacts on typical environmental media, such as water and air, with much of the health impacts inferred rather than evidenced. Additionally, the majority of studies focussed on short-term, rather than long-term, health impacts, which is expected considering the timeframe of UNGD, therefore, very few studies examined health outcomes with longer latencies such as cancer or developmental outcomes. Current scientific evidence for UNGD that
demonstrates associations between adverse health outcomes directly with environmental health hazards resulting from UNGD activities generally lacks methodological rigour. Importantly, however, there is also no evidence to rule out such health impacts. While the current evidence in the scientific research reporting leaves questions unanswered about the actual environmental health impacts, public health concerns remain intense. This is a clear gap in the scientific knowledge that requires urgent attention.

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**PUBLICATION TYPE:** review

**EVIDENCE STREAMS:** modeling/QSAR/risk calculation; human: population health; human: occupational; human: non-occupational; animal: wildlife; animal: pets; animal: livestock

**EXPOSURE ROUTES:** dermal; inhalation; oral

**INTERNAL EXPOSURES:** urine; blood

**EXTERNAL EXPOSURES:** survey/questionnaire/interview; surface water; spills/leaks; soil; drinking water; air

**GEOLOGIC FORMATIONS:** Powder River Basin; Marcellus Shale; Barnett Shale

**STATES/COUNTRIES:** United Kingdom; Australia; TX; PA; KY; CO

**GAS/OIL:** coalbed methane; natural gas; unconventional

**CHEMICALS:** barium; benzene; ethylene glycol; hydrogen sulfide; methane; ozone; PAHs; sulfur dioxide; toluene; VOCs; silica; radioactive material; acetic acid; ammonia; 2-BE; isopropanol; methanol; sodium nitrate; arsenic; selenium; strontium; carbon monoxide; nitrogen oxides

**HEALTH EFFECTS:** Skin, Hair, and Nails; Pregnancy and Reproduction; Mortality; Metabolic; Mental Health and Behavior; Lungs and Breathing; Kidneys and Urinary System; Eyes, Ears, Nose, and Throat; Endocrine system; Digestive System; Cancers; Brain and Nerves; Blood, Heart, and Circulation; Acute Toxicity/Poisoning

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**Malignant human cell transformation of Marcellus Shale gas drilling flow back water**


**ABSTRACT**

The rapid development of high-volume horizontal hydraulic fracturing for mining natural gas from shale has posed potential impacts on human health and biodiversity. The produced flow back waters after hydraulic stimulation are known to carry high levels of saline and total dissolved solids. To understand the toxicity and potential carcinogenic effects of these wastewaters, flow back waters from five Marcellus hydraulic fracturing oil and gas wells were analyzed. The physicochemical nature of these samples was analyzed by inductively coupled plasma mass spectrometry and scanning electron microscopy/energy dispersive X-ray spectroscopy. A cytotoxicity study using colony formation as the endpoint was carried out to define the LC50 values of test samples using human bronchial epithelial cells (BEAS-2B). The BEAS-2B cell transformation assay was employed to assess the carcinogenic potential of the samples. Barium and strontium were among the most abundant metals in these samples and the same metals were found to be elevated in BEAS-2B cells after long-term treatment. BEAS-2B cells treated for 6 weeks with flow back waters produced colony formation in soft agar that was concentration dependent. In addition, flow back water-transformed BEAS-2B cells show better migration capability when compared to control cells. This study provides information needed to assess the potential health impact of post-hydraulic fracturing flow back waters from Marcellus Shale natural gas mining.

**FUNDING:** Included "Transparency Document" which indicated no conflicts of interest. We thank Dr. Carl S Kirby from Bucknell University and Dr. Judith T Zelikoff from New York University for generously providing flow back water, laboratory colleagues and EHSCC inter-Center Work Group for their valuable discussions and suggestions. This work was supported by a supplement to NIEHS Center grant #ES 000260 awarded to Costa and by grant R01ES023174, R01ES022935 and the Fundamental Research Funds for the Central Universities #3092013011020 awarded to Wu.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** in vitro

**EXPOSURE ROUTES:** in vitro

**GEOLOGIC FORMATIONS:** Marcellus Shale
Fate of radium in Marcellus Shale flowback water impoundments and assessment of associated health risks


ABSTRACT

Natural gas extraction from Marcellus Shale generates large quantities of flowback water that contain high levels of salinity, heavy metals, and naturally occurring radioactive material (NORM). This water is typically stored in centralized storage impoundments or tanks prior to reuse, treatment or disposal. The fate of Ra-226, which is the dominant NORM component in flowback water, in three centralized storage impoundments in southwestern Pennsylvania was investigated during a 2.5-year period. Field sampling revealed that Ra-226 concentration in these storage facilities depends on the management strategy but is generally increasing during the reuse of flowback water for hydraulic fracturing. In addition, Ra-226 is enriched in the bottom solids (e.g., impoundment sludge), where it increased from less than 10 pCi/g for fresh sludge to several hundred pCi/g for aged sludge. A combination of sequential extraction procedure (SEP) and chemical composition analysis of impoundment sludge revealed that Barite is the main carrier of Ra-226 in the sludge. Toxicity characteristic leaching procedure (TCLP) (EPA Method 1311) was used to assess the leaching behavior of Ra-226 in the impoundment sludge and its implications for waste management strategies for this low-level radioactive solid waste. Radiation exposure for on-site workers calculated using the RESRAD model showed that the radiation dose equivalent for the baseline conditions was well below the NRC limit for the general public.

FUNDING: The authors declare no competing financial interest. As part of the National Energy Technology Laboratory’s Regional University Alliance (NETL-RUA), a collaborative initiative of the NETL, this study was performed under Task Release No. TR 131, Project Activity No. 4.605.920.009.812. We thank Dr. Kelvin Gregory and Dr. Arvind Murali Mohan for the assistance with sampling and Dr. Daniel Bain and David Pompeani for radionuclide measurement.

Potential public health hazards, exposures and health effects from unconventional natural gas development


ABSTRACT
The rapid increase in unconventional natural gas (UNG) development in the United States during the past decade has brought wells and related infrastructure closer to population centers. This review evaluates risks to public health from chemical and nonchemical stressors associated with UNG, describes likely exposure pathways and potential health effects, and identifies major uncertainties to address with future research. The most important occupational stressors include mortality, exposure to hazardous materials and increased risk of industrial accidents. For communities near development and production sites the major stressors are air pollutants, ground and surface water contamination, truck traffic and noise pollution, accidents and malfunctions, and psychosocial stress associated with community change. Despite broad public concern, no comprehensive population-based studies of the public health effects of UNG operations exist. Major uncertainties are the unknown frequency and duration of human exposure, future extent of development, potential emission control and mitigation strategies, and a paucity of baseline data to enable substantive before and after comparisons for affected populations and environmental media. Overall, the current literature suggests that research needs to address these uncertainties before we can reasonably quantify the likelihood of occurrence or magnitude of adverse health effects associated with UNG production in workers and communities.

**FUNDING:** Drs. Adgate and McKenzie were supported, in part, by funds from the National Science Foundation (NSF CBET-1240584), Research Partnership to Secure Energy for America/Department of Energy (EFDTIP2-TIP213), and the Colorado School of Public Health. We thank Nathan De Jong for his support in developing the manuscript.

**PUBLIC TYPE:** review

**EVIDENCE STREAMS:** modeling/QSAR/risk calculation; human: population health; human: occupational

**EXTERNAL EXPOSURES:** wastewater; surface water; spills/leaks; soil; drinking water; air

**GAS/OIL:** natural gas; unconventional

**CHEMICALS:** ozone; trimethylbenzenes; xylenes; methane; VOCs; silica; hydrogen sulfide

**HEALTH EFFECTS:** mortality; Mental Health and Behavior; Lungs and Breathing; Brain and Nerves; Bones, Joints, and Muscles; Blood, Heart, and Circulation; Skin, Hair, and Nails; Pregnancy and Reproduction

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**Unconventional oil and gas extraction and animal health**


**ABSTRACT**

The extraction of hydrocarbons from shale formations using horizontal drilling with high volume hydraulic fracturing (unconventional shale gas and tight oil extraction), while derived from methods that have been used for decades, is a relatively new innovation that was introduced first in the United States and has more recently spread worldwide. Although this has led to the availability of new sources of fossil fuels for domestic consumption and export, important issues have been raised concerning the safety of the process relative to public health, animal health, and our food supply. Because of the multiple toxicants used and generated, and because of the complexity of the drilling, hydraulic fracturing, and completion processes including associated infrastructure such as pipelines, compressor stations and processing plants, impacts on the health of humans and animals are difficult to assess definitively. We discuss here findings concerning the safety of unconventional oil and gas extraction from the perspectives of public health, veterinary medicine, and food safety.

**FUNDING:** Not addressed

**PUBLIC TYPE:** commentary

**EVIDENCE STREAMS:** animal: livestock

**EXTERNAL EXPOSURES:** well density/drilling activity; air

**GAS/OIL:** natural gas; oil; unconventional

**CHEMICALS:** benzene; sulfur dioxide; toluene; VOCs

**HEALTH EFFECTS:** Pregnancy and Reproduction; mortality; Metabolic; Lungs and Breathing; Immune System; endocrine system; Bones, Joints, and Muscles; Blood, Heart, and Circulation

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**Assessing worker exposure to inhaled volatile organic compounds from Marcellus Shale flowback pits**
Natural gas drilling sites employing hydraulic fracturing present a potential source of inhalation exposure to volatile organic compounds (VOCs) via the use of flowback pits. These open-air pits are used as a means of storing flowback water, a waste product of hydraulic fracturing, and represent an understudied source of VOC exposure for workers. The objective of this study was to assess this worker exposure and the resulting health risks for 12 VOCs present in flowback water stored in such an open reservoir on a drilling site. Flowback pit VOC mean, 2.5 percentile, and 97.5 percentile concentrations were used to model aqueous phase concentrations, and the effect of volatilization was applied to estimate the flux to the gas phase. A mass-balance approach was used to estimate gas phase concentrations that were, in turn, used to estimate worker exposure. A literature review was performed to determine VOC health effects, exposure limits, and worker protection methods. Neither model demonstrated an increased risk of adverse effects due to subchronic exposure at the 2.5 percentile and mean concentration values for the 12 VOCs as indicated by hazard quotients, hazard indices, or excess lifetime cancer risks, however, 97.5 percentile hazard indices approached 1 in one model and did demonstrate unacceptable risks in the evaluation of limitations. Either model may apply to worker health assessment depending upon industry practice, however, differing weather conditions, industry practice, and the small number of VOCs evaluated necessitate further research regarding worker risks and health effects.

FUNDING: The authors have no conflict of interest to declare. Mark Weir contributed to initial discussions on this topic and identified volatilization from flowback storage reservoirs as an issue of concern. Dr. Esther Chernak provided valuable advice, support, and writing assistance.

ABSTRACT

Case study descriptions of acute onset of respiratory, neurologic, dermal, vascular, abdominal, and gastrointestinal sequelae near natural gas facilities contrast with a subset of emissions research, which suggests that there is limited risk posed by unconventional natural gas development (UNGD). An inspection of the pathophysiological effects of acute toxic actions reveals that current environmental monitoring protocols are incompatible with the goal of protecting the health of those living and working near UNGD activities. The intensity, frequency, and duration of exposures to toxic materials in air and water determine the health risks to individuals within a population. Currently, human health risks near UNGD sites are derived from average population risks without adequate attention to the processes of toxicity to the body. The objective of this paper is to illustrate that current methods of collecting emissions data, as well as the analyses of these data, are not sufficient for accurately assessing risks to individuals or protecting the health of those near UNGD sites. Focusing on air pollution impacts, we examined data from public sources and from the published literature. We compared the methods commonly used to evaluate health safety near UNGD sites with the information that would be reasonably needed to determine plausible outcomes of actual exposures. Such outcomes must be based on the pathophysiological effects of the agents present and the susceptibility of residents near these sites. Our study has several findings. First, current protocols used for assessing compliance with ambient air standards do not adequately determine the intensity, frequency or durations of the actual human exposures to the mixtures of toxic materials released regularly at UNGD sites. Second, the typically used periodic 24-h average measures can underestimate actual exposures by an order of magnitude. Third, reference standards are set in a form that inaccurately determines health risk because they do not fully consider the potential synergistic combinations of toxic air emissions. Finally, air dispersion modeling shows that local weather conditions are strong determinates of individual exposures. Appropriate estimation of safety requires nested protocols that measure real time exposures. New protocols are needed to provide 1) continuous measures of a surrogate compound to show periods of extreme exposure; 2) a continuous screening model based on local weather conditions to warn of periodic high exposures, and 3) comprehensive detection of chemical mixtures using canisters or other devices that capture the major components of the mixtures.
Evaluation of impact of shale gas operations in the Barnett Shale region on volatile organic compounds in air and potential human health risks


ABSTRACT
Shale gas exploration and production (E&P) has experienced substantial growth across the U.S. over the last decade. The Barnett Shale, in north-central Texas, contains one of the largest, most active onshore gas fields in North America, stretching across 5000 square miles and having an estimated 15,870 producing wells as of 2011. Given that these operations may occur in relatively close proximity to populated/urban areas, concerns have been expressed about potential impacts on human health. In response to these concerns, the Texas Commission on Environmental Quality established an extensive air monitoring network in the region. This network provides a unique data set for evaluating the potential impact of shale gas E&P activities on human health. As such, the objective of this study was to evaluate community-wide exposures to volatile organic compounds (VOCs) in the Barnett Shale region. In this current study, more than 4.6 million data points (representing data from seven monitors at six locations, up to 105 VOCs/monitor, and periods of record dating back to 2000) were evaluated. Measured air concentrations were compared to federal and state health-based air comparison values (HBACVs) to assess potential acute and chronic health effects. None of the measured VOC concentrations exceeded applicable acute HBACVs. Only one chemical (1,2-dibromoethane) exceeded its applicable chronic HBACV, but it is not known to be associated with shale gas production activities. Annual average concentrations were also evaluated in deterministic and probabilistic risk assessments and all risks/hazards were below levels of concern. The analyses demonstrate that, for the extensive number of VOCs measured, shale gas production activities have not resulted in community-wide exposures to those VOCs at levels that would pose a health concern. With the high density of active wells in this region, these findings may be useful for understanding potential health risks in other shale play regions.

FUNDING: This work was supported by the Barnett Shale Energy Education Council (BSEEC). BSEEC had no role in the data collection and analysis, decision to publish, or preparation of the manuscript. BSEEC was given the opportunity to review the manuscript draft at the time of external peer review. The purpose of such review was to allow input on the clarity of the science presented but not on interpretation of the findings. The researchers’ scientific conclusions and professional judgments were not subject to the funders’ control.

PUBLICATION TYPE: original research
EVIDENCE STREAMS: modeling/QSAR/risk calculation
EXPOSURE ROUTES: inhalation
EXTERNAL EXPOSURES: air
GEOLOGIC FORMATIONS: Barnett Shale
STATES/COUNTRIES: TX
An exploratory study of air quality near natural gas operations


ABSTRACT

This exploratory study was designed to assess air quality in a rural western Colorado area where residences and gas wells co-exist. Sampling was conducted before, during, and after drilling and hydraulic fracturing of a new natural gas well pad. Weekly air sampling for 1 year revealed that the number of non-methane hydrocarbons (NMHCs) and their concentrations were highest during the initial drilling phase and did not increase during hydraulic fracturing in this closed-loop system. Methylene chloride, a toxic solvent not reported in products used in drilling or hydraulic fracturing, was detected 73% of the time, several times in high concentrations. A literature search of the health effects of the NMHCs revealed that many had multiple health effects, including 30 that affect the endocrine system, which is susceptible to chemical impacts at very low concentrations, far less than government safety standards. Selected polycyclic aromatic hydrocarbons (PAHs) were at concentrations greater than those at which prenatally exposed children in urban studies had lower developmental and IQ scores. The human and environmental health impacts of the NMHCs, which are ozone precursors, should be examined further given that the natural gas industry is now operating in close proximity to human residences and public lands.

FUNDING: Funding for this study was provided by The Winslow Foundation, Cornell Douglas Foundation, New-Land Foundation, Arkansas Community Trust, and an individual donor. The authors declare no competing financial interests.

EXPOSURE ROUTES: inhalation

EXTERNAL EXPOSURES: air

GEOLOGIC FORMATIONS: Piceance Basin

STATES/COUNTRIES: CO

GAS/OIL: natural gas; unconventional

CHEMICALS: benzene; cyclohexane; formaldehyde; hexane; methane; naphthalene; PAHs; toluene; VOCs; non-methane hydrocarbons; methylene chloride; Carbonyls; heptane; acetone; ethane; propane; acetaldehyde; crotonaldehyde

HEALTH EFFECTS: Skin, Hair, and Nails; Pregnancy and Reproduction; Lungs and Breathing; Kidneys and Urinary System; Immune System; genotoxicity; Eyes, Ears, Nose, and Throat; endocrine system; Digestive System; cancers; Brain and Nerves; Blood, Heart, and Circulation

The role of toxicological science in meeting the challenges and opportunities of hydraulic fracturing


ABSTRACT

We briefly describe how toxicology can inform the discussion and debate of the merits of hydraulic fracturing by providing information on the potential toxicity of the chemical and physical agents associated with this process, individually and in combination. We consider upstream activities related to bringing chemical and physical agents to the site, on-site activities including drilling of wells and containment of agents injected into or...
produced from the well, and downstream activities including the flow/removal of hydrocarbon products and of produced water from the site. A broad variety of chemical and physical agents are involved. As the industry expands this has raised concern about the potential for toxicological effects on ecosystems, workers, and the general public. Response to these concerns requires a concerted and collaborative toxicological assessment. This assessment should take into account the different geology in areas newly subjected to hydraulic fracturing as well as evolving industrial practices that can alter the chemical and physical agents of toxicological interest. The potential for ecosystem or human exposure to mixtures of these agents presents a particular toxicological and public health challenge. These data are essential for developing a reliable assessment of the potential risks to the environment and to human health of the rapidly increasing use of hydraulic fracturing and deep underground drilling techniques for tightly bound shale gas and other fossil fuels. Input from toxicologists will be most effective when employed early in the process, before there are unwanted consequences to the environment and human health, or economic losses due to the need to abandon or rework costly initiatives.

**FUNDING:** Funding: National Institute of Environmental Health Sciences (NIEHS) P30-ES013508 (T.M.P., in part). We gratefully acknowledge the excellent assistance of Martha Lindauer and Jade Coley. Conflict of interest: B.D.G. has served as a public health expert for the City of Morgantown, W.V. on the judicial issue of whether hydraulic fracturing could be prohibited.

**PUBLIC TYPE:** review

**EVIDENCE STREAMS:** human: population health; human: occupational; animal: wildlife

**EXTERNAL EXPOSURES:** well density/drilling activity; surface water; spills/leaks; drinking water; air

**GEOLOGIC FORMATIONS:** Marcellus Shale; Haynesville Shale; Barnett Shale

**STATES/COUNTRIES:** Canada; WY; TX; PA; LA; AR

**GAS/OIL:** natural gas; unconventional

**CHEMICALS:** benzene; BTEX; ethylbenzene; hydrogen sulfide; methane; NORM; ozone; PAHs; particulate matter; silica; toluene; xylenes; VOCs; dibromochloropropane; NOx

**HEALTH EFFECTS:** mortality; Lungs and Breathing; cancers; Brain and Nerves; Blood, Heart, and Circulation

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**Estrogen and androgen receptor activities of hydraulic fracturing chemicals and surface and ground water in a drilling-dense region**


**ABSTRACT**

The rapid rise in natural gas extraction using hydraulic fracturing increases the potential for contamination of surface and ground water from chemicals used throughout the process. Hundreds of products containing more than 750 chemicals and components are potentially used throughout the extraction process, including more than 100 known or suspected endocrine-disrupting chemicals. We hypothesized that a selected subset of chemicals used in natural gas drilling operations and also surface and ground water samples collected in a drilling-dense region of Garfield County, Colorado, would exhibit estrogen and androgen receptor activities. Water samples were collected, solid-phase extracted, and measured for estrogen and androgen receptor activities using reporter gene assays in human cell lines. Of the 39 unique water samples, 89%, 41%, 12%, and 46% exhibited estrogenic, antiestrogenic, androgenic, and antiandrogenic activities, respectively. Testing of a subset of natural gas drilling chemicals revealed novel antiestrogenic, novel antiandrogenic, and limited estrogenic activities. The Colorado River, the drainage basin for this region, exhibited moderate levels of estrogenic, antiestrogenic, and antiandrogenic activities, suggesting that higher localized activity at sites with known natural gas-related spills surrounding the river might be contributing to the multiple receptor activities observed in this water source. The majority of water samples collected from sites in a drilling-dense region of Colorado exhibited more estrogenic, antiestrogenic, or antiandrogenic activities than reference sites with limited nearby drilling operations. Our data suggest that natural gas drilling operations may result in elevated endocrine-disrupting chemical activity in surface and ground water.

**FUNDING:** This work was supported by grants from the Passport Foundation Science Innovation Fund, the University of Missouri, and STAR Fellowship Assistance Agreement (FP-91747101-1 awarded by the U.S. Environmental Protection Agency to C.D.K.). The authors have nothing to disclose.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** in vitro

**EXPOSURE ROUTES:** in vitro

**EXTERNAL EXPOSURES:** wastewater; surface water; spills/leaks; drinking water
Unconventional natural gas development and public health: Toward a community-informed research agenda


ABSTRACT

Unconventional natural gas development (UNGD) using high-volume horizontal hydraulic fracturing (“fracking”) has vastly increased the potential for domestic natural gas production in recent years. However, the rapid expansion of UNGD has also raised concerns about its potential impacts on public health. Academics and government agencies are developing research programs to explore these concerns. Community involvement in activities such as planning, conducting, and communicating research is widely recognized as having an important role in promoting environmental health. Historically, however, communities most often engage in research after environmental health concerns have emerged. This community information needs assessment took a prospective approach to integrating community leaders’ knowledge, perceptions, and concerns into the research agenda prior to initiation of local UNGD. We interviewed community leaders about their views on environmental health information needs in three states (New York, North Carolina, and Ohio) prior to widespread UNGD. Interviewees emphasized the cumulative, long-term, and indirect determinants of health, as opposed to specific disease outcomes. Responses focused not only on information needs, but also on communication and transparency with respect to research processes and funding. Interviewees also prioritized investigation of policy approaches to effectively protect human health over the long term. Although universities were most often cited as a credible source of information, interviewees emphasized the need for multiple strategies for disseminating information. By including community leaders’ concerns, insights, and questions from the outset, the research agenda on UNGD is more likely to effectively inform decision making that ultimately protects public health.

FUNDING: not addressed

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human; population health

EXTERNAL EXPOSURES: survey/questionnaire/interview

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: OH; NY

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Mental Health and Behavior

Health and fracking: Should the medical profession be concerned?


ABSTRACT
The use of natural gas that is obtained from high-volume hydraulic fracturing (fracking) may reduce carbon emissions relative to the use of coal and have substantial economic benefits for South Africa. However, concerns have been raised regarding the health and environmental impacts. The drilling and fracking processes use hundreds of chemicals as well as silica sand. Additional elements are either released from or formed in the shale during drilling. These substances can enter the environment in various ways: through failures in the well casing, via alternative underground pathways, as wastewater, spills and leaks on the wellpad, through transportation accidents, and as air pollution. Although many of these chemicals and elements have known adverse health effects, there is little evidence available on the health impacts of fracking. These health concerns have not yet been fully addressed in policy making, and the authors recommend that the voice of health professionals should be part of the public debate on fracking and that a full health impact assessment be required before companies are given the go-ahead to drill.

**Unconventional natural gas development: Economic salvation or looming public health disaster?**


**ABSTRACT**

**PUBLICATION TYPE**: commentary

**EVIDENCE STREAMS**: human: occupational; human: non-occupational; animal: wildlife; animal: pets; animal: livestock

**EXTERNAL EXPOSURES**: survey/questionnaire/interview; drinking water; air

**STATES/COUNTRIES**: Queensland, Australia

**GAS/OIL**: coalbed methane; natural gas; unconventional

**CHEMICALS**: benzene; VOCs; hydrocarbons; propylene; acrolein

**HEALTH EFFECTS**: Pregnancy and Reproduction; mortality; Lungs and Breathing; Kidneys and Urinary System; Immune System; genotoxicity; Eyes, Ears, Nose, and Throat; endocrine system; Digestive System; cancers; Brain and Nerves; Blood, Heart, and Circulation; Skin, Hair, and Nails

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**Birth outcomes and maternal residential proximity to natural gas development in rural Colorado**


**ABSTRACT**

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Background: Birth defects are a leading cause of neonatal mortality. Natural gas development (NGD) emits several potential teratogens, and U.S. production of natural gas is expanding. Objectives: We examined associations between maternal residential proximity to NGD and birth outcomes in a retrospective cohort study of 124,842 births between 1996 and 2009 in rural Colorado. Methods: We calculated inverse distance weighted natural gas well counts within a 10-mile radius of maternal residence to estimate maternal exposure to NGD. Logistic regression, adjusted for maternal and infant covariates, was used to estimate associations with exposure tertiles for congenital heart defects (CHDs), neural tube defects (NTDs), oral clefts, preterm birth, and term low birth weight. The association with term birth weight was investigated using multiple linear regression. Results: Prevalence of CHDs increased with exposure tertile, with an odds ratio (OR) of 1.3 for the highest tertile (95% CI: 1.2, 1.5), NTD prevalence was associated with the highest tertile of exposure (OR = 2.0, 95% CI: 1.0, 3.9, based on 59 cases), compared with the absence of any gas wells within a 10-mile radius. Exposure was negatively associated with preterm birth and positively associated with fetal growth, although the magnitude of association was small. No association was found between exposure and oral clefts. Conclusions: In this large cohort, we observed an association between density and proximity of natural gas wells within a 10-mile radius of maternal residence and prevalence of CHDs and possibly NTDs. Greater specificity in exposure estimates is needed to further explore these associations.

FUNDING: This study was supported by the Department of Environmental and Occupational Health at the Colorado School of Public Health. The Colorado Department of Public Health and Environment’s (CDPHE) Health Statistics and Colorado Responds to Children with Special Needs provided outcome data for this study. The authors declare they have no actual or potential competing financial interests.

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In vitro cytotoxicity assessment of a hydraulic fracturing fluid


ABSTRACT

Hydraulic fracturing fluids are chemical mixtures used to enhance oil and gas extraction. There are concerns that fracturing fluids are hazardous and that their release into the environment – by direct injection to coal and shale formations or as residue in produced water – may have effects on ecosystems, water quality and public health. This study aimed to characterise the acute cytotoxicity of a hydraulic fracturing fluid using a human gastrointestinal cell line and, using this data, contribute to the understanding of potential human health risks posed by coal seam gas (CSG) extraction in Queensland, Australia. Previous published research on the health effects of hydraulic fracturing fluids has been limited to desktop studies of individual chemicals. As such, this study is one of the first attempts to characterise the toxicity of a hydraulic fracturing mixture using laboratory methods. The fracturing fluid was determined to be cytotoxic, with half maximal inhibitory concentrations (IC50) values across mixture variations ranging between 25 and 51 mM. When used by industry, these fracturing fluids would be at concentrations of over 200 mM before injection into the coal seam. A 5-fold dilution would be sufficient to reduce the toxicity of the fluids to below the detection limit of the assay. It is unlikely that human exposure would occur at these high ('before use') concentrations and likely that the fluids would be diluted during use. Thus, it can be inferred that the level of acute risk to human health associated with the use of these fracturing fluids is low. However, a thorough exposure assessment and additional chronic and targeted toxicity assessments are required to conclusively determine human health risks.

FUNDING: MP was supported by a Water Quality Research Australia scholarship and the project was funded by the Griffith University School of Environment Honours program.

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In vitro cytotoxicity assessment of a hydraulic fracturing fluid
Environmental health research recommendations from the Inter-Environmental Health Sciences Core Center Working Group on unconventional natural gas drilling operations


ABSTRACT

BACKGROUND: Unconventional natural gas drilling operations (UNGDO) (which include hydraulic fracturing and horizontal drilling) supply an energy source that is potentially cleaner than liquid or solid fossil fuels and may provide a route to energy independence. However, significant concerns have arisen due to the lack of research on the public health impact of UNGDO. OBJECTIVES: Environmental Health Sciences Core Centers (EHSCCs), funded by the National Institute of Environmental Health Sciences (NIEHS), formed a working group to review the literature on the potential public health impact of UNGDO and to make recommendations for needed research. DISCUSSION: The Inter-EHSCC Working Group concluded that a potential for water and air pollution exists that might endanger public health, and that the social fabric of communities could be impacted by the rapid emergence of drilling operations. The working group recommends research to inform how potential risks could be mitigated. CONCLUSIONS: Research on exposure and health outcomes related to UNGDO is urgently needed, and community engagement is essential in the design of such studies.

FUNDING: The Inter-Environmental Health Sciences Core Center (EHSCC) Working Group is supported by grants from the NIEHS, National Institutes of Health (NIH), as follows: P30-ES013508 (T.M.P. and M.H.), P30-ES038319 (P.N.B.), P30-ES010126 (K.G.), P30-ES000089 (B.Y.), P30-ES000002 (Harvard University), P30-ES00210 (Oregon State University), P30-ES000260 (New York University), P30-ES005022 (Rutgers University), P30-ES006096 (University of Cincinnati), P30-ES006050 (University of Iowa), P30-ES001247 (University of Rochester), P30-ES007048 (University of Southern California), P30-ES006676 (University of Texas Medical Branch), P30-ES007033 (University of Washington), and P30-ES004184 (University of Wisconsin-Milwaukee). The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of the NIEHS or the NIH. T.M.P. has given expert testimony in methyl-tertbutyl-ether products liability litigation. The other authors declare they have no actual or potential competing financial interests.

PUBLICATION TYPE: commentary

EVIDENCE STREAMS: human; population health

EXTERNAL EXPOSURES: wastewater; surface water; spills/leaks; drinking water; air

GAS/OIL: unconventional; natural gas

CHEMICALS: benzene; methane; NORM; ozone; particulate matter; silica; xylenes; VOCs; ethane; propane; barium; strontium; bromides; chlorides; NOx


ABSTRACT

Objective: Short-term exposure to ground-level ozone has been linked to respiratory and other health effects, previous studies typically have focused on summer ground-level ozone in urban areas. During 2008–2011, Sublette County, Wyoming (population: ~10,000 persons), experienced periods of elevated ground-level ozone concentrations during the winter. This study sought to evaluate the association of daily ground-level ozone concentrations and health clinic visits for respiratory disease in this rural county. Methods: Clinic visits for respiratory disease were ascertained from electronic billing records of the two clinics in Sublette County for January 1, 2008–December 31, 2011. A time-stratified case-crossover design, adjusted for temperature and humidity, was used to investigate associations between ground-level ozone concentrations measured at one station and clinic visits for a respiratory health concern by using an unconstrained distributed lag of 0–3 days and single-day lags of 0 day, 1 day, 2 days, and 3 days. Results: The data set included 12,742 case-days and 43,285 selected control-days. The mean ground-level ozone observed was 47±8 ppb. The unconstrained distributed lag of 0–3 days was consistent with a null association (adjusted odds ratio [aOR]: 1.001, 95% confidence interval [CI]: 0.990–1.012), results for lags 0, 2, and 3 days were consistent with the null. However, the results for lag 1 were indicative of a positive association, for every 10-ppb increase in the 8-h maximum ground-level ozone, a 3.0% increase in respiratory clinic visits the following day was observed (aOR: 1.031, 95% CI: 0.994–1.069). Season modified the adverse respiratory effects: ground-level ozone was significantly associated with respiratory clinic visits during the winter months. The patterns of results from all sensitivity analyses were consistent with the a priori model. Conclusions: The results demonstrate an association of increasing ground-level ozone with an increase in clinic visits for adverse respiratory-related effects in the following day (lag day 1) in Sublette County, the magnitude was strongest during the winter months, this association during the winter months in a rural location warrants further investigation.
Hydraulic fracturing and the risk of silicosis


ABSTRACT

"Fracking," the common name for hydraulic fracturing is widely used to extract oil and gas, particularly from deep shale formations. A single well requires the use of millions of gallons of water and tons of sand. Air sampling results show that the majority of silica levels at hydraulic fracturing sites were above the Occupational Safety and Health Administration allowable standard and 84% were above Occupational Safety and Health Administration's new proposed standard. These exposure levels put workers, particularly sand mover operators and T-belt operators who had the highest levels, at risk of silicosis and the other silica-related conditions of lung cancer, end-stage renal disease, chronic obstructive pulmonary disease, tuberculosis, and connective tissue disease. Because of the fracking industry's demand for silica, sand mining has markedly increased, which has also increased the number of workers at risk of developing silicosis and other silica-related conditions in the mining industry. This paper reviews the parts of the country where health care providers should be most concerned about possible patients in their practice who are at risk from this newly recognized source of silica exposure and the appropriate medical testing to perform. However, given the long latency, 20 or more years, of most silica-related health conditions and the fact that fracking did not become widely used until the 2000s, it may be years before health care providers see clinical-related disease in their practices.

FUNDING: Partially funded by National Institute for Occupational Safety and Health (Agreement #U60 OH008466). The author declares that there are no conflicts of interest.

ABSTRACT

Background: The United States has experienced a boom in natural gas production due to recent technological innovations that have enabled this resource to be produced from shale formations. Objectives: We reviewed the body of evidence related to exposure pathways in order to evaluate the potential environmental public health impacts of shale gas development. We highlight what is currently known and identify data gaps and research limitations by addressing matters of toxicity, exposure pathways, air quality, and water quality. Discussion: There is evidence of potential environmental public health risks associated with shale gas development. Several studies suggest that shale gas development contributes to ambient air concentrations of pollutants known to be associated with increased risk of morbidity and mortality. Similarly, an increasing body of studies suggest that water contamination risks exist through a variety of environmental pathways, most notably during wastewater transport and disposal, and via poor zonal isolation of gases and fluids due to structural integrity impairment of cement in gas wells. Conclusion: Despite a growing body of evidence, data gaps persist. Most important, there is a need for more epidemiological studies to assess associations between risk factors, such as air and water pollution, and health outcomes among populations living in close proximity to shale gas operations.

FUNDING: We are grateful for comments and suggestions provided by A. Law (Weill Cornell Medical College) and R. Morello-Frosch (University of California, Berkeley). S.B.C.S. and J.H. are employees of Physicians Scientists and Engineers for Healthy Energy (PSE), a nonprofit organization funded by private donations whose mission is to bring scientific transparency to discussions on energy sources and energy production. PSE received no funding for the preparation of this manuscript. M.L.F. declares she has no actual or potential competing financial interests.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human; non-occupational

EXTERNAL EXPOSURES: well density/drilling activity; survey/questionnaire/interview

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Skin, Hair, and Nails; Mental Health and Behavior; Lungs and Breathing; Kidneys and Urinary System; Eyes, Ears, Nose, and Throat; Digestive System; Brain and Nerves; Bones, Joints, and Muscles; Blood, Heart, and Circulation

Environmental public health dimensions of shale and tight gas development


ABSTRACT

Pennsylvania Marcellus Shale region residents have reported medical symptoms they believe are related to nearby Unconventional Natural Gas Development (UNGD). Associations between medical symptoms and UNGD have been minimally explored. The objective of this descriptive study is to explore whether shale region Pennsylvania residents perceive UNGD as a health concern and whether they attribute health symptoms to UNGD exposures. A questionnaire was administered to adult volunteers with medical complaints in a primary-care medical office in a county where UNGD was present. Participants were asked whether they were concerned about health effects from UNGD, and whether they attributed current symptoms to UNGD or to some other environmental exposure. There were 72 respondents, 22% perceived UNGD as a health concern and 13% attributed medical symptoms to UNGD exposures. Overall, 42% attributed one or more of their medical symptoms to environmental causes, of which UNGD was the most frequent. A medical record review conducted on six participants who attributed their medical symptoms to UNGD revealed that only one of these records documented both the symptoms in question and the attribution to UNGD. The results of this pilot study suggest that there is substantial concern about adverse health effects of UNGD among Pennsylvania Marcellus Shale residents, and that these concerns may not be adequately represented in medical records. Further efforts to determine the relationship between UNGD and health are recommended in order to address community concerns.

FUNDING: Pouné Saberi takes primary responsibility of the manuscript. She conceived of and designed the study while a resident at the Occupational and Environmental Residency Program at Hospital of University of Pennsylvania. She obtained a pilot grant from the Center of Excellence in Environmental Toxicology, assisted with analysis and interpretation of the data, and wrote the manuscript. Kathleen Joy Propert contributed to study design, data analysis, data interpretation, and manuscript editing. Martha Powers assisted in data collection and editing the manuscript. Edward Emmett assisted with writing the grant study design, data interpretation and writing the manuscript. Judith Green-McKenzie served as faculty advisor, participated in study conception and design, grant writing and submission, data interpretation, and manuscript preparation and editing. The authors declare no conflict of interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXTERNAL EXPOSURES: well density/drilling activity; survey/questionnaire/interview

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Skin, Hair, and Nails; Mental Health and Behavior; Lungs and Breathing; Kidneys and Urinary System; Eyes, Ears, Nose, and Throat; Digestive System; Brain and Nerves; Bones, Joints, and Muscles; Blood, Heart, and Circulation

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FUNDING: Pouné Saberi takes primary responsibility of the manuscript. She conceived of and designed the study while a resident at the Occupational and Environmental Residency Program at Hospital of University of Pennsylvania. She obtained a pilot grant from the Center of Excellence in Environmental Toxicology, assisted with analysis and interpretation of the data, and wrote the manuscript. Kathleen Joy Propert contributed to study design, data analysis, data interpretation, and manuscript editing. Martha Powers assisted in data collection and editing the manuscript. Edward Emmett assisted with writing the grant study design, data interpretation and writing the manuscript. Judith Green-McKenzie served as faculty advisor, participated in study conception and design, grant writing and submission, data interpretation, and manuscript preparation and editing. The authors declare no conflict of interest.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXTERNAL EXPOSURES: well density/drilling activity; survey/questionnaire/interview

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Skin, Hair, and Nails; Mental Health and Behavior; Lungs and Breathing; Kidneys and Urinary System; Eyes, Ears, Nose, and Throat; Digestive System; Brain and Nerves; Bones, Joints, and Muscles; Blood, Heart, and Circulation
Physical, chemical, and biological characteristics of compounds used in hydraulic fracturing


ABSTRACT

Hydraulic fracturing (HF), a method to enhance oil and gas production, has become increasingly common throughout the U.S. As such, it is important to characterize the chemicals found in HF fluids to evaluate potential environmental fate, including fate in treatment systems, and human health impacts. Eighty-one common HF chemical additives were identified and categorized according to their functions. Physical and chemical characteristics of these additives were determined using publicly available chemical information databases. Fifty-five of the compounds are organic and twenty-seven of these are considered readily or inherently biodegradable. Seventeen chemicals have high theoretical chemical oxygen demand and are used in concentrations that present potential treatment challenges. Most of the HF chemicals evaluated are non-toxic or of low toxicity and only three are classified as Category 2 oral toxins according to standards in the Globally Harmonized System of Classification and Labeling of Chemicals, however, toxicity information was not located for thirty of the HF chemicals evaluated. Volatilization is not expected to be a significant exposure pathway for most HF chemicals. Gaps in toxicity and other chemical properties suggest deficiencies in the current state of knowledge, highlighting the need for further assessment to understand potential issues associated with HF chemicals in the environment.

FUNDING: The work was completed by the Ecological Engineering Research Program with funding from the University of the Pacific, School of Engineering and Computer Science. Part of this work was conducted at Lawrence Berkeley National Laboratory under its U.S. Department of Energy contract DE-AC02-05CH11231.

EVIDENCE STREAMS: animal: experimental

EXPOSURE ROUTES: inhalation; oral

GAS/OIL: natural gas; oil; unconventional
Developmental and reproductive effects of chemicals associated with unconventional oil and natural gas operations


ABSTRACT

Unconventional oil and gas (UOG) operations have the potential to increase air and water pollution in communities located near UOG operations. Every stage of UOG operation from well construction to extraction, operations, transportation, and distribution can lead to air and water contamination. Hundreds of chemicals are associated with the process of unconventional oil and natural gas production. In this work, we review the scientific literature providing evidence that adult and early life exposure to chemicals associated with UOG operations can result in adverse reproductive health and developmental effects in humans. Volatile organic compounds (VOCs) [including benzene, toluene, ethyl benzene, and xylene (BTEX) and formaldehyde] and heavy metals (including arsenic, cadmium and lead) are just a few of the known contributors to reduced air and water quality that pose a threat to human developmental and reproductive health. The developing fetus is particularly sensitive to environmental factors, which include air and water pollution. Research shows that there are critical windows of vulnerability during prenatal and early postnatal development, during which chemical exposures can cause potentially permanent damage to the growing embryo and fetus. Many of the air and water pollutants found near UOG operation sites are recognized as being developmental and reproductive toxicants, therefore there is a compelling need to increase our knowledge of the potential health consequences for adults, infants, and children from these chemicals through rapid and thorough health research investigation.

FUNDING: The authors have no relevant financial relationships and no conflicts of interest.

PUBLICATION TYPE: review

EXPOSURE ROUTES: dermal; inhalation; oral

EXTERNAL EXPOSURES: well density/drilling activity; wastewater; surface water; spills/leaks; drinking water; air

GAS/OIL: natural gas; oil; unconventional

CHEMICALS: acrylamide; barium; benzene; BTEX; ethylbenzene; formaldehyde; hexane; hydrogen sulfide; methane; NORM; ozone; particulate matter; toluene; xylenes; VOCs; radium; nitrogen oxides; hydrocarbons; acetaldehyde

HEALTH EFFECTS: Pregnancy and Reproduction; endocrine system

Occupational exposures in the oil and gas extraction industry: State of the science and research recommendations


ABSTRACT

The oil and gas extraction industry is rapidly growing due to horizontal drilling and high volume hydraulic fracturing (HVHF). This growth has provided new jobs and economic stimulus. The industry occupational fatality rate is 2.5 times higher than the construction industry and 7 times higher than general industry, however injury rates are lower than the construction industry, suggesting injuries are not being reported. Some workers are exposed to crystalline silica at hazardous levels, above occupational health standards. Other hazards (particulate, benzene, noise, radiation) exist. In this article, we review occupational fatality and injury rate data, discuss research looking at root causes of fatal injuries and hazardous exposures, review interventions aimed at improving occupational health and safety, and discuss information gaps and areas of needed research. We also describe Wyoming efforts to improve occupational safety in this industry, as a case example.

FUNDING: Contract grant sponsor: NIOSH Mountain and Plains Education and Research Center (partial support). Disclosure Statement: The authors report no conflicts of interests.

PUBLICATION TYPE: review

EVIDENCE STREAMS: human: occupational
Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region


ABSTRACT

Concerns for health and social impacts have arisen as a result of Marcellus Shale unconventional natural gas development. Our goal was to document the self-reported health impacts and mental and physical health stressors perceived to result from Marcellus Shale development. Methods: Two sets of interviews were conducted with a convenience sample of community members living proximal to Marcellus Shale development, session 1 March-September 2010 (n = 33) and session 2 January-April 2012 (n = 20). Symptoms of health impacts and sources of psychological stress were coded. Symptom and stressor counts were quantified for each interview. The counts for each participant were compared longitudinally. Results: Participants attributed 59 unique health impacts and 13 stressors to Marcellus Shale development. Stress was the most frequently-reported symptom. Over time, perceived health impacts increased (P = 0.042), while stressors remained constant (P = 0.855). Discussion: Exposure-based epidemiological studies are needed to address identified health impacts and those that may develop as unconventional natural gas extraction continues. Many of the stressors can be addressed immediately.

FUNDING: Funding provided by the Environmental and Occupational Health Department of the University of Pittsburgh Graduate School of Public Health.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: human: non-occupational

EXTERNAL EXPOSURES: survey/questionnaire/interview

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Pregnancy and Reproduction; Metabolic; Mental Health and Behavior; Lungs and Breathing; Kidneys and Urinary System; Immune System; Eyes, Ears, Nose, and Throat; endocrine system; Digestive System; Brain and Nerves; Bones, Joints, and Muscles; Blood, Heart, and Circulation; Skin, Hair, and Nails

The implications of unconventional drilling for natural gas: a global public health concern


ABSTRACT
Unconventional drilling for natural gas by means of high volume horizontal hydraulic fracturing (fracking) is an important global public health issue. Given that no sound epidemiologic study has been done to assess the extent of exposure-related adverse health effects among populations living in areas where natural gas extraction is going on, it is imperative that research be conducted to quantify the potential risks to the environment and to human health not just in the short-term, but over a longer time period since many diseases (i.e., cancers) appear years after exposure. It should not be concluded that an absence of data implies that no harm is being done.

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**PUBLIC TYPE:** review

**EVIDENCE STREAMS:** human: population health; animal: livestock

**GAS/OIL:** natural gas; unconventional

**HEALTH EFFECTS:** Pregnancy and Reproduction; Mental Health and Behavior; Lungs and Breathing; Eyes, Ears, Nose, and Throat; Brain and Nerves; Blood, Heart, and Circulation

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**Childhood cancer incidence in Pennsylvania counties in relation to living in counties with hydraulic fracturing sites**


**ABSTRACT**

Objective: Evaluate whether childhood cancer incidence is associated with counties with hydraulic fracturing (HF). Methods: We compared cancer incidence in children in Pennsylvania counties before and after HF drilling began, using standardized incidence ratios (SIRs) and 95% confidence intervals (CIs). Results: The total number of cancers observed was close to expected both before drilling began (SIR = 0.94, 95% CI, 0.90 to 0.99) and after drilling (SIR = 1.02, 95% CI, 1.02 to 1.07) for counties with oil and natural gas wells. Analyses for childhood leukemia were also unremarkable (SIR for leukemia before drilling = 0.97 [95% CI, 0.88 to 1.06], SIR for leukemia after drilling = 1.01 [95% CI, 0.92 to 1.11]). A slightly elevated SIR was found for central nervous system tumors after drilling (SIR = 1.13, 95% CI, 1.02 to 1.25). This was because of a slight excess in those counties with the fewest number of wells. Conclusions: This study offers comfort concerning health effects of HF on childhood cancers.

**FUNDING:** This research was supported by a grant from America’s Natural Gas Alliance. The authors declare no conflict of interest.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** human: population health

**EXTERNAL EXPOSURES:** well density/drilling activity

**GEOLOGIC FORMATIONS:** Marcellus Shale

**STATES/COUNTRIES:** PA

**GAS/OIL:** coalbed methane; conventional; natural gas; oil; unconventional

**HEALTH EFFECTS:** cancers; Brain and Nerves; Blood, Heart, and Circulation

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**Hydraulic fracturing: A toxicological threat for groundwater and drinking-water?**


**ABSTRACT**
This paper deals with the possible impact of hydraulic fracturing (fracking), employed in the exploitation of unconventional shale gas and tight gas reservoirs, on groundwater, which is the most important source of drinking-water in Germany and many other European countries. This assessment, which is part of an interdisciplinary study by a panel of neutral experts on the risks and environmental impact of hydraulic fracturing, is based mainly on data obtained from three ExxonMobil drilling sites in northern Germany. First, the basic technical aspects of fracking and its relevant water fluxes are explained. The type, purpose and fate of the constituents of the fracking fluids are discussed. The chemicals used in the fracking fluids are assessed with regard to their hazardous properties according to the Regulation (EC) No. 1272/2008 of the European Parliament and of the Council on the classification, labelling and packaging of substances and mixtures (CLP regulation) and the German “Water Hazard Classes”. Contamination of groundwater by ingredients of fracking fluids may occur from underground or may result from above-ground accidents associated with the transport; storage and handling of hazardous substances used as additives in fracking fluids. The degree of groundwater contamination cannot be predicted in a general way. Therefore, different dilutions of the fracking fluid in groundwater are considered. It is shown that the concentrations of most ingredients resulting from a 1:10,000 up to 1:100,000 dilution of the fracking fluid in groundwater are below the limit values of the European Drinking Water Quality; and other health-based guide values for drinking-water. Regarding the salinity of fracking fluids; a dilution of 1:1,000 is sufficient to reach concentrations which are acceptable for drinking-water. From the human-toxicological point of view, the constituents of flowback water are more problematic with respect to drinking-water produced from groundwater than those of the fracking fluids. The few reliable data which have become available, as well as hydrogeological considerations, point in the direction of considerable salt concentrations and toxic constituents, e.g., Hg, As, Pb, Zn, Cd, BTEX, PAHs, or even radioactive elements. The identification and assessment of reaction products and metabolites, which are produced as a result of the fracking operation and the metabolic activity of microorganisms, are important topics for further research. The recommendations include the need for a better understanding of the environmental impact of fracking operations, especially with regard to the development of sustainable rules for planning; permission, performance and management of fracking, and for the monitoring of groundwater quality around fracked drilling sites.

FUNDING: The authors thank Alejandra Linis Parra and Joërg Mießner for help with the data and the manuscript. Fiona Crowther’s help with language polishing is gratefully acknowledged.

PUBLICATION TYPE: review

EVIDENCE STREAMS: modeling/QSAR/risk calculation

EXTERNAL EXPOSURES: wastewater; drinking water

GAS/OIL: natural gas; unconventional

CHEMICALS: ethylene glycol monobutyl ether (2-BE); carbon dioxide; 5-chloro-2-methyl-2H-isothiazol-3-one; 2-methyl-2H-isothiazol-3-one; magnesium chloride; magnesium nitrate; tetramethylammonium chloride; potassium chlorite; hydroxylated light petroleum distillates; polyethylene glycol-octylphenyl ether; CMHPG polymer; triethanolamine; sodium tetraborate; zirconium dichloride oxide; inorganic salts; citric acid; sodium thiosulphate pentahydrate; tetraethylpentamine; sodium bromate; diammonium peroxodisulphate; isopropyl alcohol; methanol; ethoxy-alkyl alcohols; amphoteric alkyl amines; glycol ether; acetic acid; sodium hydroxide; sodium hydrogen carbonate; ethylene-di-xylene; dimethanol; choline chloride; polyethylene glycol monoxyl ether; 2-(2-butoxy-ethoxy)-ethanol; benzene; BTEX; ethylbenzene; naphthalene; PAHs; phenanthrene; styrene; toluene; xylene; cumol; acenaphthylene; acenaphthene; fluorene; anthracene; fluorantracene; pyrene; benz(a)anthracene; chrysene; benzo(b)fluoranthene; benzo(k)fluoranthene; benzo(a)pyrene; dibenzo(a,h)anthracene; benzog/hpyrene; 2-butoxyethanol; methanol; propan-2-ol

HEALTH EFFECTS: Skin, Hair, and Nails; Pregnancy and Reproduction; Mortality; Lungs and Breathing; Eyes, Ears, Nose, and Throat; Brain and Nerves; Acute Toxicity/Poisoning

Migrating mule deer: Effects of anthropogenically altered landscapes


ABSTRACT

Background: Migration is an adaptive strategy that enables animals to enhance resource availability and reduce risk of predation at a broad geographic scale. Ungulate migrations generally occur along traditional routes, many of which have been disrupted by anthropogenic disturbances. Spring migration in ungulates is of particular importance for conservation planning, because it is closely coupled with timing of parturition. The degree to which oil and gas development affects migratory patterns, and whether ungulate migration is sufficiently plastic to compensate for such changes, warrants additional study to better understand this critical conservation issue. Methodology/Principal Findings: We studied timing and synchrony of departure from winter range and arrival to summer range of female mule deer (Odocoileus hemionus) in northwestern Colorado, USA, which has one of the largest natural-gas reserves currently under development in North America. We hypothesized that in addition to local weather, plant phenology, and individual life-history characteristics, patterns of spring migration would be modified by disturbances associated with natural-gas extraction. We captured 205 adult female mule deer, equipped them with GPS collars, and observed patterns of spring migration during 2008–2010. Conclusions/Significance: Timing of spring migration was related to winter weather (particularly snow depth) and access to emerging vegetation, which varied among years, but was highly synchronous across study areas within years. Additionally, timing of migration was influenced by the collective effects of anthropogenic disturbance, rate of travel, distance traveled, and body condition of adult females. Rates of travel were more rapid over shorter migration distances in areas of high natural-gas development resulting in the delayed departure, but early arrival for females migrating in areas with high development compared with less-developed areas. Such shifts in behavior could have consequences for timing of arrival on birthing areas, especially where mule deer migrate over longer distances or for greater durations.

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Fracking, the environment, and health


ABSTRACT

FUNDING: The authors have disclosed no potential conflicts of interest, financial or otherwise.

Histopathological analysis of fish from Acorn Fork Creek, Kentucky, exposed to hydraulic fracturing fluid releases


ABSTRACT

Fracking fluids were released into Acorn Fork, KY, a designated Outstanding State Resource Water, and habitat for the threatened Chrosomus cumberlandensis (Blackside Dace). As a result, stream pH dropped to 5.6 and stream conductivity increased to 35,000 µS/cm, and aquatic invertebrates and fish were killed or distressed. The objective of this study was to describe post-fracking water quality in Acorn Fork and evaluate if the changes in water quality could have extirpated Blackside Dace populations. Semotilus atromaculatus (Creek Chub) and Lepomis cyanellus (Green Sunfish) were collected from Acorn Fork a month after fracking in lieu of...
Tissues were histologically analyzed for indicators of stress and percent of fish with lesions. Fish exposed to affected Acorn Fork waters showed general signs of stress and had a higher incidence of gill lesions than unexposed reference fish. Gill lesions observed were consistent with exposure to low pH and toxic concentrations of heavy metals. Gill uptake of aluminum and iron was demonstrated at sites with correspondingly high concentrations of these metals. The abrupt and persistent changes in post-fracking water quality resulted in toxic conditions that could have been deleterious to Blackside Dace health and survival.

**FUNDING:** The authors are grateful to Bob Snow, Mindi Lawson, Michael Floyd, and Mike Armstrong (US Fish and Wildlife Service) for their many long days of field support, also to John Brumley (Kentucky Division of Water) and John Williams (Kentucky Department of Fish and Wildlife Resource), and their crew, with post-release field assessments. Special thanks to Ryder Velasco for his assistance during the in situ treatment, and in particular to Valerie Hudson (former Deputy Commissioner of the Energy and Environment Cabinet), whose support, coordination, vision, and spirit helped maintain steady progress. The authors thank Mandy Annis and Vanessa Velez for preparation of fish samples for histopathology, Susan Finger assisted with initial study design, supplies, and advice. Julia Towns-Campell provided invaluable library support. Dr. Jeffrey Wolf (Experimental Pathology Laboratories) reviewed some of the histology slides. Marcia Nelson, CERC Outreach Coordinator, assisted with graphics and publication. Finally, we are grateful for the determination of the Reverend Ova Grubb, a life-long resident of Acorn Form, who called agencies and experts until he could resolve the environmental damage occurring to the aquatic ecosystem near his residence. This work was partially supported with funding from US Fish and Wildlife Service, under contract agreement No. 401818NS02.

**PUBLICATION TYPE:** original research

**EVIDENCE STREAMS:** animal: wildlife

**EXPOSURE ROUTES:** dermal; oral

**EXTERNAL EXPOSURES:** surface water; spills/leaks

**GEOLOGIC FORMATIONS:** Appalachian Basin

**STATES/COUNTRIES:** KY

**GAS/OIL:** conventional; natural gas; unconventional

**CHEMICALS:** chlorine; aluminum; cadmium; chromium; copper; iron; magnesium; manganese; nickel; lead; sulfate; strontium; zinc

**HEALTH EFFECTS:** Pregnancy and Reproduction; Mental Health and Behavior; Lungs and Breathing; Kidneys and Urinary System; Immune System; Digestive System; acute toxicity/poisoning
Proposal for applying a component-based mixture approach for ecotoxicological assessment of fracturing fluids


ABSTRACT

Hydraulic fracturing is increasingly being used to produce gas from unconventional resource sites for energy supply. Therefore, concerns about risks of this technology related to human health and the environment have to be addressed. Among the major issues is the potential contamination of surrounding water systems by chemical additives used in fracturing fluids. In this study, the ecotoxicological hazards of fracturing fluids, both, their individual components (chemicals) as well as their mixtures (product) were assessed using a component-based mixture approach. For five exemplary fracturing fluids, 40–90 wt% of the contained substances could unambiguously be defined in their chemical identity. The concentrations used in the applied fluid mixture were considered as (maximum) exposure concentrations. For components with mass fractions between 10 and 74 wt%, the effect concentrations for acute and chronic toxicity of fish, daphnia and algae were retrieved from experimental databases and through predictive modeling. The hazard indices calculated from the ratio of exposure to effect concentration were >1 for all fracturing fluids, using different scenarios. This indicated a hazard from the undiluted fracturing fluids. The assessment framework presented in this study allows for dealing with data gaps and uncertainties in a tiered fashion and in particular accommodates for combined effects resulting from chemical mixtures. It might be employed for ecotoxicological risk assessment of products containing chemical mixtures and optimization of their environmental performance.

FUNDING: We would like to thank Beate Escher from the ENTOX Centre of the University of Queensland, Australia, for scientific support with application of toxicity modeling and for helpful comments on the manuscript. Special thanks also to Julia Ortmann and Patrick Renner for a data quality check. Further, we would like to thank the members of the information and dialogue process for excellent support and discussions and ExxonMobil Production Deutschland GmbH for initial data and financing of the Process/Dialogue platform.

PUBLICATION TYPE: original research

EVIDENCE STREAMS: modeling/QSAR/risk calculation; animal: wildlife

GAS/OIL: unconventional; natural gas

CHEMICALS: Ethylene glycol monobutyl ether (2-BE); potassium chloride; sodium thiosulphate pentahydrate; polysaccharide; tetraethylenepentamine; aliphatic acid; sodium bromate; triethanolamine; sodium hydrogencarbonate; hexanol; ammonium peroxydisulphate; 2,2-dibromo-2-cyanoacetamide; dibromoacetonitrile

HEALTH EFFECTS: mortality

Navigating medical issues in shale territory


ABSTRACT

The introduction of natural gas drilling with high-volume hydraulic fracturing to Pennsylvania and neighboring states since 2004 has been accompanied by numerous reports of varied symptoms and illnesses by those living near these operations. Pollutants with established toxic effects in humans may be introduced into the environment at various points during gas extraction and processing. Some community residents, as well as employees of the natural gas industry, believe that their health has deteriorated as a result of these operations and have sought medical care from local practitioners, who may have limited access to immediate toxicological consultations. This article reviews taking an environmental exposure history in the context of natural gas activities, underscoring the importance of thorough and guided history-taking in the discovery of environmental exposure clusters. It also highlights the critical need for funding, research, and peer-reviewed studies to help generate the body of evidence that is needed by practitioners.
Investigating links between shale gas development and health impacts through a community survey project in Pennsylvania


ABSTRACT

Across the United States, the race for new energy sources is picking up speed and reaching more places, with natural gas in the lead. While the toxic and polluting qualities of substances used and produced in shale gas development and the general health effects of exposure are well established, scientific evidence of causal links has been limited, creating an urgent need to understand health impacts. Self-reported survey research documenting the symptoms experienced by people living in proximity to gas facilities, coupled with environmental testing, can elucidate plausible links that warrant both response and further investigation. This method, recently applied to the gas development areas of Pennsylvania, indicates the need for a range of policy and research efforts to safeguard public health.

FUNDING: This project would not have been possible without the caring, concern, and openness of project participants, who shared their time and personal experiences and trusted us to write about them. Much gratitude is also owed to the community members and organizational partners who provided the contacts and guidance that made it possible to engage project participants. Many thanks to the Colcom Foundation for its generous support of this project and commitment to protecting the environment and public health. Any potential conflicts of interest may be elucidated from the provided author biographies.

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

HEALTH EFFECTS: Skin, Hair, and Nails; Lungs and Breathing; Eyes, Ears, Nose, and Throat; Digestive System

The use of health impact assessment for a community undergoing natural gas development
ABSTRACT

The development of natural gas wells is rapidly increasing, yet little is known about associated exposures and potential public health consequences. We used health impact assessment (HIA) to provide decision-makers with information to promote public health at a time of rapid decision making for natural gas development. We have reported that natural gas development may expose local residents to air and water contamination, industrial noise and traffic, and community changes. We have provided more than 90 recommendations for preventing or decreasing health impacts associated with these exposures. We also have reflected on the lessons learned from conducting an HIA in a politically charged environment. Finally, we have demonstrated that despite the challenges, HIA can successfully enhance public health policymaking.

FUNDING: The Battlement Mesa health impact assessment was funded by a contract from the Garfield County Board of County Commissioners. Technical assistance was funded by the Health Impact Project, a collaboration of the Robert Wood Johnson Foundation and the Pew Charitable Trusts. In kind support was also provided by the Colorado School of Public Health.

EVIDENCE STREAMS: modeling/QSAR/risk calculation; human: population health
EXPOSURE ROUTES: dermal; inhalation; oral
EXTERNAL EXPOSURES: survey/questionnaire/interview; drinking water; air
GEOLOGIC FORMATIONS: Piceance Basin
STATES/COUNTRIES: CO
GAS/OIL: natural gas; unconventional
CHEMICALS: methane; PAHs; particulate matter; trimethylbenzenes; xylenes; VOCs
HEALTH EFFECTS: Sexual Health Issues; Pregnancy and Reproduction; mortality; Lungs and Breathing; Eyes, Ears, Nose, and Throat; cancers; Brain and Nerves; Blood, Heart, and Circulation; Metabolic

Impacts of gas drilling on human and animal health


ABSTRACT

Environmental concerns surrounding drilling for gas are intense due to expansion of shale gas drilling operations. Controversy surrounding the impact of drilling on air and water quality has pitted industry and leaseholders against individuals and groups concerned with environmental protection and public health. Because animals often are exposed continually to air, soil, and groundwater and have more frequent reproductive cycles, animals can be used as sentinels to monitor impacts to human health. This study involved interviews with animal owners who live near gas drilling operations. The findings illustrate which aspects of the drilling process may lead to health problems and suggest modifications that would lessen but not eliminate impacts. Complete evidence regarding health impacts of gas drilling cannot be obtained due to incomplete testing and disclosure of chemicals, and nondisclosure agreements. Without rigorous scientific studies, the gas drilling boom sweeping the world will remain an uncontrolled health experiment on an enormous scale.

FUNDING: Conflict of interest and funding not addressed. We would like to thank Sandra Podulka (Cornell University) and Dr. Sandra Steingraber (Ithaca College) for comments on an early draft of the manuscript.

PUBLICATION TYPE: original research
EVIDENCE STREAMS: human: non-occupational; animal: wildlife; animal: pets; animal: livestock
EXTERNAL EXPOSURES: well density/drilling activity; wastewater; survey/questionnaire/interview; surface water; spills/leaks; soil; drinking water; air
GEOLOGIC FORMATIONS: Piceance Basin; Marcellus Shale; Fayetteville Shale; Barnett Shale
STATES/COUNTRIES: TX; PA; OH; NY; LA; CO
Environmental health advocacy: An overview of natural gas drilling in northeast Pennsylvania and implications for pediatric nursing


ABSTRACT

This article presents an overview of the Marcellus Shale gas well drilling project in northeast Pennsylvania and serves as a model for how nurses can evaluate such problems in their own communities. Resources to help nurses become involved in the environmental health advocacy process are made available.

FUNDING: not addressed

PUBLICATION TYPE: review

EVIDENCE STREAMS: human: population health

EXTERNAL EXPOSURES: surface water; drinking water

GEOLOGIC FORMATIONS: Marcellus Shale

STATES/COUNTRIES: PA

GAS/OIL: natural gas; unconventional

CHEMICALS: benzene; ethylene glycol; naphthalene; toluene; glutaraldehyde; hydrochloric acid; boric acid; isopropyl alcohol; 2,2-dibromo-3-nitrilopropionamide; strontium; arsenic

HEALTH EFFECTS: Skin, Hair, and Nails; Lungs and Breathing; Kidneys and Urinary System; Immune System; Genotoxicity; Eyes, Ears, Nose, and Throat; Digestive System; Cancers; Brain and Nerves

Human health risk assessment of air emissions from development of unconventional natural gas resources


ABSTRACT

BACKGROUND: Technological advances (e.g. directional drilling, hydraulic fracturing), have led to increases in unconventional natural gas development (NGD), raising questions about health impacts. OBJECTIVES: We estimated health risks for exposures to air emissions from a NGD project in Garfield County, Colorado with the objective of supporting risk prevention recommendations in a health impact assessment (HIA). METHODS: We used EPA guidance to estimate chronic and subchronic non-cancer hazard indices and cancer risks from exposure to hydrocarbons for two populations: (1) residents living >½ mile from wells and (2) residents living ≤ ½ mile from wells. RESULTS: Residents living ≤ ½ mile from wells are at greater risk for health effects from NGD than are residents living >½ mile from wells. Subchronic exposures to air pollutants during well completion activities present the greatest potential for health effects. The subchronic non-cancer hazard index (HI) of 5 for residents ≤ ½ mile from wells was driven primarily by exposure to trimethylbenzenes, xylenes, and aliphatic hydrocarbons. Chronic HIs were 1 and 0.4 for residents ≤ ½ mile from wells and >½ mile from wells, respectively. Cumulative cancer risks were 10 in a million and 6 in a million for residents living ≤ ½ mile and >½ mile from wells, respectively, with benzene as the major contributor to the risk. CONCLUSIONS: Risk assessment can be used in HIAs to direct health risk prevention strategies. Risk management approaches should focus on reducing exposures to emissions during well completions. These preliminary results indicate that health effects resulting from air emissions during unconventional NGD warrant further study. Prospective studies should focus on health effects associated with air pollution.

FUNDING: This study was supported by the Garfield County Board of County Commissioners and the Colorado School of Public Health. The authors declare they have no competing financial interests.
Natural gas operations from a public health perspective


ABSTRACT

The technology to recover natural gas depends on undisclosed types and amounts of toxic chemicals. A list of 944 products containing 632 chemicals used during natural gas operations was compiled. Literature searches were conducted to determine potential health effects of the 353 chemicals identified by Chemical Abstract Service (CAS) numbers. More than 75% of the chemicals could affect the skin, eyes, and other sensory organs, and the respiratory and gastrointestinal systems. Approximately 40–50% could affect the brain/nervous system, immune and cardiovascular systems, and the kidneys, 37% could affect the endocrine system, and 25% could cause cancer and mutations. These results indicate that many chemicals used during the fracturing and drilling stages of gas operations may have long-term health effects that are not immediately expressed. In addition, an example was provided of waste evaporation pit residuals that contained numerous chemicals on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Emergency Planning and Community Right-to-Know Act (EPCRA) lists of hazardous substances. The discussion highlights the difficulty of developing effective water quality monitoring programs. To protect public health we recommend full disclosure of the contents of all products, extensive air and water monitoring, coordinated environmental/human health studies, and regulation of fracturing under the U.S. Safe Drinking Water Act.

FUNDING: We thank The New York Community Trust, the Winslow Foundation, and the US Environmental Protection Agency (Grant no. EQ-97838701) for their support. This data collection and analysis were partially funded through a USEPA grant. The authors have no conflicts of interest.
Abstract

Efforts to identify alternative sources of energy have focused on extracting natural gas from vast shale deposits. The Marcellus Shale, located in western New York, Pennsylvania, and Ohio, is estimated to contain enough natural gas to supply the United States for the next 45 years. New drilling technology—horizontal drilling and high-volume hydraulic fracturing of shale (fracking)—has made gas extraction much more economically feasible. However, this technique poses a threat to the environment and to the public’s health. There is evidence that many of the chemicals used in fracking can damage the lungs, liver, kidneys, blood, and brain. We discuss the controversial technique of fracking and raise the issue of how to balance the need for energy with the protection of the public’s health.

Funding: Funding and conflict of interest not addressed. We are grateful for comments and suggestions made by A. R. Ingraffea, PhD, Dwight C. Baum Professor of Engineering at Cornell University, and Robert W. Howarth, PhD, David R. Atkinson Professor of Ecology and Environmental Biology at Cornell University.

Publication Type: commentary

Evidence Streams: human; population health

External Exposures: wastewater; surface water; spills/leaks; soil; air

Geologic Formations: Marcellus Shale

States/Countries: PA; NY

Gas/Oil: natural gas; unconventional

Health effects: Pregnancy and Reproduction; Lungs and Breathing; Eyes, Ears, Nose, and Throat; endocrine system; Digestive System; cancers; Brain and Nerves; Skin, Hair, and Nails