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ORIGINAL PAPER

Ethical Implications of the Impact of Fracking on Brain Health

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Abstract Environmental ethicists and experts in human health have raised concerns about the effects of hydraulic fracking to access natural oil and gas resources found deep in shale rock formations on surrounding ecosystems and communities. In this study, we analyzed the prevalence of discourse on brain and mental health, and ethics, in the peer-reviewed and grey literature in the five-year period between 2016 and 2022. A total of 84 articles met inclusion criteria for analysis. Seventy-six percent (76%) mentioned impacts on brain (e.g., neural tube defects, neurological symptoms), and mental health (e.g., negative psychological effects, stress, depression) briefly; 11 reports dedicated substantive discourse to either or both together. References to safety (77%) dominated the ethics context. Discussion of environmental injustices as fracking sites disproportionately affect vulnerable communities appeared in 38% of the papers. We examine the findings through the lens of environmental neuroethics that brings human-made changes to the environment, brain and mental health, and ethics together into three interwoven lines of inquiry.

Keywords Brain · Mental health · Hydraulic fracturing · Environmental neuroethics

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Introduction

Human ingenuity proves to be an indispensable resource time after time, and a case in point is the response to the growing demand for natural gas that brought about major technological advances in hydraulic fracturing (fracking) and horizontal drilling [1] that enabled access to natural gas and oil deep in shale formations. This technology, also termed unconventional oil and natural gas development (UOGD), provided hope and promise to many. In the United States (US), for example, UOGD created employment opportunities for hundreds of thousands of people [2] was a pathway to massive energy production and expansions [3, 4] and helped to reduce carbon emissions by substituting natural gas for coal [5].

The early twenty-first century saw a fracking boom known by many as the shale gale [6]. Over 2.5 million wells were drilled worldwide, 40% of which were in the US alone [6]. At the time, UOGD was seen as a valuable contributor to economies [7] as it decreased the need for foreign oil through domestic energy independence [8]. It was viewed as beneficial for the local economy in rural, impoverished areas [9, 10], and

would enhance services like the local police and medical facilities [9]. It was promoted as an intermediate between burning dirty fossil fuels like coal and oil to using renewable energy [4, 11], with some countries suggesting it as a necessary step for the transition to renewables [11, 12]. The production and use of UOGD has not diminished; between 2005 and 2022, the US doubled its natural gas production and millions of people continue to be employed by the industry [13]. Over 17 million US residents live within one mile of an active well [14].

Human ingenuity also has consequences, however, and those related to fracking have not gone unnoticed by environmental ethicists and other experts in environmental and human health [14–22] The fracking fluid, of which millions of gallons are injected into each well to fracture the rock, is comprised of water, sand, and chemicals [23]. This wastewater, termed produced water by the industry [24], returns to the surface with numerous new components, including heavy metals (i.e., lead or arsenic [24]), formaldehyde [25], radioactive materials [26] and organic compounds (e.g., benzene [24], methane [27] or toluene [28]). The produced water is either reused or injected back into disposal wells [24]. It can be held in the wells for months or years, and eventually may be sent to water treatment facilities where it is processed and released back into the local water cycle. In British Columbia, Canada, for example, there is no process for treating this water to return in back into the water cycle: it is brought by truck or pipeline to holding ponds (plastic-lined pits) or C-rings [24]. Concerns are associated with contamination of drinking water and air quality from spills during transport, and pipeline or pond leaks [24, 29–32]. Risk of contaminated water and air greatly affects the health and well-being of both workers and nearby residents, as these compounds can have carcinogenic effects [25], disrupt endocrine function, [33] and are neurotoxic [34].

The documented impact of fracking on brain health comes from concern about neurotoxins present in the fracking fluid or released as a byproduct during the process [34]. Some of the neurotoxins that are byproducts of the fracking process are heavy metals, such as manganese [34–36], exposure to which can cause clinical symptoms similar to Parkinson's disease [37]. There are also reports of increased incidences of neural tube defects in communities nearby wells [38, 39]. Even at very small concentrations, exposure to neurotoxins can have long-term consequences, particularly during neurodevelopment when the brain is most vulnerable to insult [40]. For example, the wastewater produced from an UOGD site in North Texas contained levels of arsenic above safety guidelines [41]. Arsenic has detrimental effects on neurodevelopment, including impaired neural tube formation [42] neuron growth, and can have negative effects on cognition when exposure occurs early in life [34].

Recent attention has also been brought to the impacts of fracking on mental health and socio-psychological well-being [43]. Reports suggest that people who are exposed to fracking experience increased anxiety and depression about lifestyle, health, and safety due to the changes in the physical landscape that surrounds them, and potential exposure to neurotoxic and carcinogenic compounds [44]. Individuals living nearby UOGD sites also report disordered sleep [45], internalizing disorders [46], health issues from noise pollution [47] and overall community distress [48].

Diverse populations with different cultural perspectives bring unique experiences to environmental change [49] as, for many, relationships with the lands around them are framed by traditional ecological knowledge (TEK) [50]. TEK encompasses set of unique systemic attributes: it refers to a long-lasting, culturally distinctive, and habitat-specific collection of knowledge that has specifically enabled Indigenous peoples to live in their lands for thousands of years while maintaining ecological welfare [51]. For individuals connected to the natural world [52] it is a perceptual realm and does not necessarily separate ecosystem health from human health impacts. In Canada, UOGD has brought forward some of the challenges faced by the government in terms of fulfilling its commitment to honouring, respecting, and maintaining relationships with Indigenous communities. Experts in the field are calling for alternate approaches that uphold Indigenous peoples' values, respect their ways of life, and minimize the risks of water and land contamination [53].

As a further historical concern, minority group neighbourhoods, predominantly comprising people of colour and those from high poverty areas, are disproportionately affected by hazardous waste facilities, landfills, and other sources of environmental pollution such as fracking [54–56]. Marginalized communities often reside in neighbourhoods

in proximity to industrial sites, highways, or waste disposal sites. They may lack the political power and resources to resist the location of fracking operations in their neighbourhoods [57] and may not have access to ombudspersons as intermediaries, community liaisons with time and expertise, or the same standards of legal protection as other groups [58]. In New Brunswick, Canada for example, a fracking project was initiated on traditional territories of Indigenous peoples without proper consultation [59]. First Nations communities in the northeastern region of British Columbia face greater environmental and health risks from fracking than their counterparts in Alberta or the USA because the fracking process requires the most water for extraction. These communities are additionally burdened by associated infrastructure that impacts their quality and way of life, such as hunting and fishing [60].

In consideration of these issues, we sought to conduct a contemporary analysis of ethics discourse and inquiry in the published fracking literature as it pertains to brain and mental health.

Methods

Search Strategy

We mined Google Scholar from for the five-year period (2016–2022) immediately following and using the same search criteria described in Cabrera et al. [22]. We applied the primary search terms {unconventional natural gas (±) development}, {shale gas (±) development}, {fracking} and {hydraulic fracturing} were combined with either {brain}, {neuro}, {neurological} and {mental} or {ethics}, {safety}, {environmental racism} and secondary search terms {culture}, {first nations}, {health}, {ethic} to examine the prevalence of discussion surrounding fracking, brain and mental health, and ethics. All papers were published in English in the peer-reviewed or gray literature (e.g., transcripts from briefings). Dissertations, conference papers, and abstracts were excluded. Studies based on animal models were also excluded.

Coding

Ethics terms, and brain and mental health terms, were coded separately and managed in NVivo (QSR 12). Codebooks were developed for each topic of interest and key words were used to identify a priori and emergent themes.

Data Analysis

All coded content was examined using conventional content analysis [61]. Brain and mental health terms were further analyzed with respect to the depth of information discussed on the topic using the codes of ***mentioned*** (i.e., term used in a list), ***brief*** (i.e., term cited with some definition in at least one sentence), and ***substantive*** (term discussed in detail with more than a single sentence). Coding of content was completed by the authors with help from a trained Research Assistant. We applied a rich coding strategy allowing for multiple codes to be assigned to a single paper. The authors finalized the database and codes by consensus.

Results

General Characteristics of the Data Set

A total of 93 articles were captured in the search. Eighty-four (84) returns met inclusion criteria for content analysis. Final codes identifying themes and discussion of brain and mental health and ethics in hydraulic fracking are shown in Table 1. Articles appeared in a range of journals from different disciplines: environmental studies (n = 23), environment and health (n = 14), human health (n = 14), economics (n = 9), bioethics (n = 5), energy and mining (n = 5), others (e.g., policy, engineering, law (n = 1 or 2 each).

Publications by year gradually decreased, with the most published in 2017 (n = 21) and least in 2022 (n = 4) for the time period of interest (Fig. 1).re>

Corresponding authors originated mainly from the United States (n = 55), with others from Canada (n = 12), the UK (n = 8), Australia (n = 3), China, Spain, South Africa, Mexico, Argentina, and Germany (n = 1 each).

Table 1 Codes identifying themes and discussion of brain and mental health and ethics in hydraulic fracking

Theme	Key Words
Brain	{neuro}, {brain}, {nerve}, {nervous system}
Mental Health	{depression}, {anxiety}, {mental health}, {well-being}
Safety	{safety}, {harm}, {vulnerable}
Environmental Racism	{rural}, {race}, {inequality}, {equity marginalization}
Ethics	{safety}, {trust}, {vulnerability}, {justice}, {disempowerment}, {human rights}, {ethic}

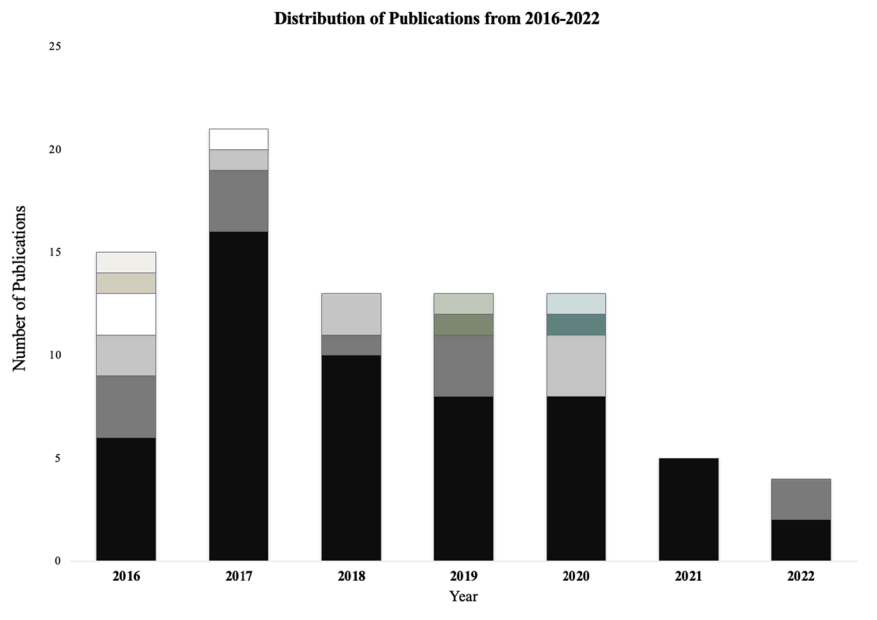

Fig. 1 Distribution of the articles according to country and year

Discourse Pertaining to Brain and Mental Health

Of 84 papers included in the database, 64 (76%) mentioned brain and mental health or referred to the terms briefly. Three papers had substantive discussion of the impacts on brain [32, 62, 63] and six on mental health [44, 45, 48, 64–66]; and two went into substantial discussion of both brain and mental health [34, 67]

The majority of the papers mentioning brain health would do so without any depth per se. For instance, they would state that there are increased hospitalizations for neurologic conditions in communities nearby wells but not elaborate. Others made broad statements about how fracking can negatively impact the central nervous system. Of the 46 (~55%) papers that addressed brain health, two provided a detailed discussion on the effects of fracking chemicals on the brain [32, 34]. These both discussed in detail the chemicals associated with the fracking process and the known impacts they have on the nervous system. Webb et al. [34] was the first paper to address fracking fluids and their downstream neurological effects with special respect to the developing brain.

The impact on mental wellness of workers or those living in communities in proximity to wells was dominant in the dataset, with related discourse or references in 39 (46%) of the reports. Major findings include that individuals living in proximity to extraction sites experience negative mental health outcomes [46–48, 68–72] and that some of these effects may be a result of noise [71], light pollution [73], uncertainties surrounding health risks associated with mining [74], or psychosocial stress [43, 48]. Aryee et al. [48] found that the stress was not only associated with the developments but because of interacting with fracking

officials and decision-makers. Additionally, Soyer et al. [43] discovered an "us vs. them" mentality in community interactions between those who support and oppose fracking causes stress. Two articles paid specific attention to the mental health of pregnant women [64, 66] and one devoted attention to adolescent internalizing disorders [46]. Others focused on depression [45], sleep quality [45, 73], and quality of life [75]. Lai et al. [76] found that perceptions had an impact on the effects of UOGD development in communities; individuals who had positive perceptions of UOGD were more likely to experience benefits whereas those who held negative perceptions towards UOGD experienced adverse impacts on their wellbeing [75].

Seventy-five papers discussed ethics; 65 discussed safety, a first principle for any industry whether for the environment, science or medicine. Safety was frequently discussed with specific attention to water or air contamination [77]. These papers spoke to government policies that consider chemicals in contaminated water to be safe until proven to be harmful, when possibly decades are needed to appreciate their full effects [78], and a lack of safety standards for workers [34]. Other ethics concepts such as loss of trust, vulnerability, and disempowerment appeared in 4 papers. Thirty-two papers (38%) discussed themes surrounding environmental racism and injustice experienced by communities as a result of UOGD; 27 overlapped with papers discussing safety.

Discussion

We examined a total of 84 papers published between 2016–2022 that focus on the impact of hydraulic fracking on mental health and brain health, as well as the related ethics discourse. Safety was a ubiquitous theme. While 46 papers mentioned impacts on brain health, few devoted in-depth discussions to those impacts. Concerns about the effects of fracking on the mental health of nearby communities were apparent, with some specific attentions to pregnant women and young or adolescents. The reduction in publications per year may be mirroring the degree of news coverage on the topic. The opposition to fracking arose and peaked in the US between 2012–2014 and has since diminished [79], consistent with advocacy peaks news coverage of topics of interest [79].

Primary and Collateral Harms

Where discourse was substantive, the intersection of adverse effects on mental health as they relate to the disproportionate placement of fracking sites near vulnerable or rural and remote communities is notable. This is consistent with Griffiths [80], among others [19], who argue that fracking is an environmental justice issue. We observed that wellbeing of pregnant women living nearby wells received some specific attention in the dataset. McHenry [15, 17] outlines the gendered impacts of fracking, and argues for a feminist approach, given the unique vulnerabilities than women experience through UOGD. Additional concerns in this context of environmental injustice arise with respect to the discrepancy in the rate of progress between hydraulic fracking site development and the much slower development of a comprehensive plan to protect and promote the water rights of Indigenous communities [81]. The issue of foreign corporations benefitting more than host communities where the wells are drilled also supports this observation [82].

There was a lack of detailed discussion about the effects of fracking on the brain, despite that over half of the papers in the dataset refer to brain health in some manner, (i.e., neurological deficits, nerve damage). This may be due to the nature of the research problem: it is difficult to study direct effects of the environment on human neurological health. The handful of papers that delve into the effects of fracking on the brain highlight concerns with neurotoxins that may be present in contaminated water or air. Individuals aware of the potential or documented long-term consequences of exposure to these chemicals on the brain are very concerned. A compendium was published in 2023, outlining all the health impacts related to fracking [14]. These experts state that there is ample evidence to be concerned, and many are calling to use the precautionary principle and call for a ban on fracking [14]. The rate of development of UOGD is much faster than the rate at which we can study neurodegenerative and neurodevelopmental disorders, which may not be prevalent for decades [71]. Individuals in communities adjacent to UOGD are at a greater risk of experiencing negative health effects from hydraulic fracking.

The domains of UOGD encompass many different disciplines, including economics, the environment, politics, social sciences, law, climate change, and

human health, among many others. Due to its multidisciplinary, and consequently semi-political character, UOGD communicates with a variety of viewpoints, some of which may be inadvertently but ultimately biased. The portrayal of fracking in the media changes tone considerably depending on the region [82–84]. Lachapelle et al. [84] found that individualist and egalitarian cultural biases strongly predict a person's attitude towards hydraulic fracturing. Further, depending on the region, media outlets may leave environmental and health risks unaddressed while focusing solely on economic benefits when discussing fracking [83, 85]. A unique problem is occurring in that these sources collectively suggest impairments in scientific communication with respect to fracking. The lack of collaboration between those at the forefront of advancing UOGD and those concerned with human and environmental health impacts compounds this communication problem [19, 86, 87]. Instead of working together to midigate risks to nearby communities, they are keeping each other at distance [88]. The region-specific issues with fracking call for better collaboration between the community, researchers, developers [19, 86, 87] and meaningful collaboration with Indigenous communities [89]. This would fill critical knowledge gaps and attempt to give a more complete, nonbiased approach for the public to absorb [86]. These issues emphasize the importance of proper scientific research in shaping environmental policy [88].

We recognize the limitations of this study, including the possibility that papers were missed either through the constraints of the search strategy or inclusion criteria that yielded the resulting database. Even with simple qualitative content analysis used to identify the presence of content with little interpretation needed, we also accept our positionality as researchers within a major Canadian university and the inherent biases that we bring to the analytic strategy. It is difficult to know the true source of the decrease in publications per year in the dataset. Finally, if neurotoxins are present in farming regions nearby or prior to the development of fracking wells, it is difficult to determine if UOGD is the only source of chemicals.

Conclusion

In 2011, Kern called fracking "*the latest threat to human rights*" [90]. In 2017, Webb et al. argued that neurodevelopmental toxicity from harmful environmental exposures is a "*global silent pandemic*" [34]. These assertions provide the foundation for considering human-made environmental change, as it exists from UOGD at least, through a lens that places brain and mental health jointly with ethics in focus.

In 2016, Cabrera et al. [22] offered an environmental neuroethics framework for such an exceptional consideration. The present data fit directly into the first four of the five components of the framework – relationality, health, academic and public discourse, and cross-cultural learning and understandings. The components capture the importance of the relationships and inherent value of natural and built space. Health is at the center of the analysis. Full transparency is a key feature of trust in public discourse and trustworthiness with the public, whether it is communicated through the academic or gray literature, or conveyed by news media that shape public opinion. Cross-cultural considerations take into account both the potential for personal and population prosperity through the creation of jobs and economic benefit, alongside racially-motivated injustices that may bring harm to already socially and medically marginalized populations. The fifth component – activism and social policy – may be beneficially updated to more directly capture advocacy than policy per se *at this time*. This last component, in its call to action, speaks to the interdisciplinary, intersectoral work that remains to be done to achieve any form of balance in the risk-gain UOGD ecosystem for human autonomy and wellness.

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Data Availability Data are available by request to the corresponding author.

Declarations

Conflict of interest The authors have no conflicts of interest to disclose.

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