Title: Oil and Gas Development in Proximity to Colorado Schools: A Quantitative Analysis of Risk Distribution

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ABSTRACT

Unequal exposure to industrial activity (and the associated environmental harms) is a well-studied phenomenon within the environmental inequality literature, yet little has been written about children and oil and gas development. In this paper, I aim to determine whether certain school-level characteristics make a school more likely to be located near oil and gas wells. I focus on Colorado public schools, and utilize a combination of spatial and statistical methods. I begin by mapping all Colorado public schools and all oil and gas wells within the state and constructing buffers around each school (at 2,500 and 5,000 feet). I then utilize logistic regression to determine which school-level characteristics increase the likelihood of having at least one well in each of the buffer zones. Percentage of Hispanic and Latino students and a history of poor academic performance increased the likelihood of a school being situated near oil and gas drilling, while a higher percentage of students eligible for free and reduced lunch (a proxy for socioeconomic status) decreased this likelihood. This research has implications for Colorado setback policies.

Key Words: Environmental inequality, children, energy, oil and gas, Colorado, schools

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INTRODUCTION

Colorado is a state rich in oil and gas (O&G) deposits, containing 10 of the United States' 100 largest natural gas fields, and three of the country's 100 largest oil fields (Weiner 2014). The state has been producing oil and gas since 1881, but recent decades have seen a drastic increase in production rates. In fact, since the early 2000s, Colorado's natural gas production has more than doubled, and the state's crude oil production has increased roughly six-fold (U.S. EIA 2017). These increases are largely due to advances in unconventional drilling technologies. These unconventional extraction techniques (a combination directional drilling and high-volume hydraulic fracturing, commonly referred to as "fracking") have allowed for the development of previously inaccessible oil and natural gas reserves, which may lie underneath communities with little to no history of O&G development.

As the industry grows, so too do concerns related to the effects that O&G development may have on the environment and human health/safety. The possibility for air, water, and noise pollution, as well as the potential for natural gas explosions, is the subject of a growing body of literature, spanning the social and natural sciences (Brasier et al. 2011; Field, Soltis, and Murphy 2014; Food and Water Watch: A Pennsylvania Case Study 2012; Gullion 2015; Malin, Ryder, and Hall 2018). The distribution of these potential risks, however, remains largely understudied, and even less is known about the distribution of risk among potentially vulnerable populations (Thomas et al. 2013).

The present research aims to fill this gap by focusing on schoolchildren, a subset of the population that experiences a unique set of mental, physical, and educational risks related to natural and technological hazards (Peek 2008). In this paper, I aim to measure school-level inequalities in the potential for exposure to O&G activity related to the drilling and maintenance of wells. Thus, this study is guided by the following overarching research question: Are certain schools more likely to be situated near an oil or gas well, and if so, are there certain school-level characteristics (e.g. percentage of ethnic minority students, poor academic performance) that increase this likelihood? To answer this question, this study utilizes a combination of spatial modelling using ArcGIS and logistic regression. I situate my findings within the environmental inequality literature. Unequal exposure to industrial activity (and the associated environmental harms) is a well-studied phenomenon within this body of literature, yet little has been written about children and O&G development. Thus, what the present research aims to achieve is a preliminary investigation of school proximity to oil and gas wells, which I argue is a first step toward understanding inequality in school-level exposure to well-related O&G risk.

BACKGROUND

In Colorado, proximity to O&G development is the subject of ongoing and often intense debate.[1] This paper offers one of the first analyses of O&G development in relation to a core social institution (schools) and a vulnerable subset of the population (children). There are over 100,000 oil and gas wells in the state, over 40,000 of which are in the active, drilling, or producing stages of development, and 6,000 of which are permitted and will be drilled in the near future (Table 1) (COGCC 2018.). As Table 1 demonstrates, many of the existing wells are abandoned, dry and abandoned, or plugged and abandoned, but this does not mean they no

[1] Concerned citizens successfully petitioned to get setback distances on the ballot via Proposition 112 in the 2018 state elections. If it had passed, this measure would have required a minimum distance of 2,500 feet from occupied buildings and other areas deemed vulnerable (Ballotpedia n.d.). Despite scientific evidence in support of increased setbacks (see Wong n.d. for a review of the scientific literature), Proposition 112 was voted down by a vote of 56.1% to 43.9% (Denver Post 2018) due perhaps in part to fears of economic consequences (see Vital for Colorado 2018 for a summary of the arguments against Prop. 112).

longer pose a risk to the surrounding area. According to the American Geosciences Institute, wells that are no longer active may still contribute to air, water, and soil contamination due to faulty or degrading materials, or to prior contamination that was never remediated (Allison and Mandler 2018).

Given the state's resource-rich geology, it is no surprise that the oil and gas industry is an important part of Colorado's economy. According to the American Petroleum Institute (API), O&G development supports over 232,900 jobs in Colorado, and contributes $31.38 billion to the state's economy (PwC 2017). Some of these economic benefits are passed along to the state's schools; Colorado O&G development contributes an estimated average of $699 million per year to K-12 and higher education (Vital for Colorado 2019).

Table 1: Wells in Colorado by Status

Facility Status	*Frequency*	*Percentage*	*Cumulative*
Abandoned	6	0.01	0.01
Active	319	0.27	0.28
Abandoned Location	17,077	14.57	14.84
Closed	1	0	14.84
Dry and Abandoned	20,777	17.72	32.57
Drilling	1,696	1.45	34.01
Domestic Well	45	0.04	34.05
Injecting	706	0.6	34.65
Plugged and Abandoned	19,236	16.41	51.06
Producing	38,881	33.17	84.23
Shut In	10,345	8.82	93.05
Temporarily Abandoned	1,569	1.34	94.39
Waiting on Completion	132	0.11	94.5
Permitted Location	6,443	5.5	100
Total	117,233	100	

Nonetheless, not all Coloradoans wholeheartedly support the increasing O&G development, particularly when the development is occurring in close proximity to schools, homes, and public spaces (see: Turkewitz and Krauss 2018). Residents of Colorado, as with other states, are expressing growing concerns over a wide range of potential O&G impacts, including air, water, and noise pollution, as well as the potential for fires and/or explosions (Gullion 2015; Malin et al. 2018). These concerns do not appear to be entirely unfounded. In the years between 2006 and 2015, O&G facilities reported a total of 116 fires and explosions (Blair et al. 2017), and in 2017 a school football stadium in Greeley, Colorado was evacuated after a nearby well experienced a valve failure (Miller 2017). Additionally, in 2017, two people were killed in a home explosion in Firestone, Colorado, caused by an untapped gas line from a nearby well (Kovaleski 2017). In response to these concerns, some cities have attempted to impose moratoria on O&G drilling. However, the Colorado Supreme Court deemed such measures unconstitutional in 2016 (City of Fort Collins v. Colo. Oil and Gas Assn. 2016).

An example of the controversy surrounding drilling can be seen in the city of Broomfield, Colorado. In 2017, Extraction Oil and Gas, Inc. proposed large-scale development of the Denver-Julesburg Basin, the rich oil and gas reserve underlying much of Broomfield. The original plan proposed 140 horizontal wells ("octopus wells") across four well pads within the city. Of particular concern, one pad was to be developed within 1,000 feet of the Anthem Ranch neighborhood and its elementary school (Extraction Oil and Gas, Inc. 2017). After nearly a year of back-and-forth deliberation between the Broomfield Oil and Gas Development Committee and Extraction, the plan was revised to include 84 wells across six pads, with a minimum setback (distance from a given building or location) distance of 1,000 feet from nearby homes (Extraction Oil and Gas, Inc. 2018). The city had initially imposed a moratorium on drilling, and the reversal of this policy by the Supreme Court generated public outcry (Fox 31 Denver 2016), and numerous City Council meetings were held to discuss the proposed drilling. These meetings were both highly attended and highly contentious, with public comment sessions lasting late into the night (Hood 2017). Local youth and teens became involved, and in March of 2017, under pressure from both students and parents, Prospect Ridge Academy (a high school in the Anthem Ranch community) turned down a generous, and much-needed, donation from Extraction (Bunch 2017).

In the Broomfield case, schools featured prominently in the debate, as they have in others throughout the state, with residents voicing concerns for the health and safety of Colorado schoolchildren (see: Hood 2018). As of 2017, there were over 900,000 elementary, middle, and high school students enrolled in Colorado public schools (Colorado Department of Education 2018). With this in mind, in 2018 the Colorado Oil and Gas Conservation Committee (COGCC) implemented a rule mandating a distance of 1,000 feet between new O&G wells and schools/childcare centers. However, exceptions may be made if (a) school administrators agree to allow drilling within 1,000ft, or (b) the O&G company requests a hearing with COGCC (COGCC 2018). This may put certain schools, particularly underfunded schools, at greater risk of nearby O&G drilling, as O&G companies have been known to make sizable donations to Colorado schools (e.g. Rios 2017).

It is important to recognize that the 1,000-foot setback policy is not supported by scientific evidence. Despite a growing body of literature on the environmental and human health and safety risks associated with O&G development (for example: Adgate, Goldstein, and McKenzie 2014; Hays, McCawley, and Shonkoff 2017), little is known about the spatial boundaries of such risks. Moreover, a study by Lewis et al. (2018) convened a panel of 18 experts (including health care providers, public health practitioners, environmental advocates, and researchers/scientists) in an attempt to reach a consensus on appropriate setback distances. While panelists failed to reach any such consensus, they did all agree that setback distances less than one quarter mile should not be recommended, and that setbacks should be *increased for schools and other vulnerable sites* (though they did not reach a consensus on by how much setbacks should be increased).

While setbacks are not the focus of this paper, this debate emphasizes the importance of understanding school-level vulnerability to O&G development and recognizing that schools are socially contested spaces where these environmental battles are being fought. Given that children are particularly vulnerable to environmental harms, and the growing body of evidence to suggest that O&G development poses such harms to the surrounding community, an important set of questions arise. First, if O&G drilling presents a risk to schoolchildren, do all schoolchildren experience that risk equally? Second, if inequalities exist, are they more prominent as distance between a school and well decreases? These questions are important sociologically in that they may illuminate broader processes of social stratification. Furthermore, the answers to such questions may also have significant policy implications for lawmakers attempting to institute setback distances.

It should also be noted that much of the pushback against drilling in proximity to public schools seems to originate from more affluent suburban communities, as is true of the Broomfield case referenced above (for an in-depth discussion of O&G development in largely white, affluent neighborhoods, see Gullion, 2015). The population of Broomfield is predominantly white, with a median income of $81,898 (Data USA 2016). There is noticeably less public contestation of O&G drilling from poorer and more rural neighborhoods, suggesting that perhaps this has not been framed as an environmental or social justice issue in these neighborhoods.

There is currently very little social science research on the siting of oil and gas (O&G) wells (for a notable exception, see: O'Rourke and Connolly 2003). It is largely assumed that the siting of these facilities is geologically-determined (e.g. Gullion 2015), and this is obviously true to some extent, in that certain geologies produce oil and gas while others do not. However, given the vast size of geologic formations and the advances in directional/horizontal drilling technology, there may be some flexibility in the siting of O&G wells. In fact, supporters cite this as one of the main advantages of directional drilling. As DrillingInfo.com (a pro-industry website) describes this as, "[p]ossibly the greatest benefit of all is the ability to locate well sites away from residential areas and sensitive ecosystems. Oil companies today can access oil and gas by drilling a well that is miles away from a specific property or site" (Goode 2014:1). Overall, the research on O&G well siting remains scarce, with little-to-no exploration of non-geological factors that may impact siting decisions. This leaves the field ripe for sociological investigation.

Likewise, disparities in children's potential for exposure to O&G drilling remains understudied, despite a growing body of scholarly work that highlights the potential health and environmental impacts associated with O&G development, particularly unconventional drilling (Adgate et al. 2014; Bamberger and Oswald 2012; Czolowski Eliza D. et al. 2017). There is already a voluminous literature that suggests that certain population groups are more vulnerable to environmental hazards than others (Brulle and Pellow 2006; Evans and Kantrowitz 2002; Finucane et al. 2000). Therefore, this study aims to determine a) whether or not some schools are more likely to be exposed to O&G drilling activities, and b) what school-level characteristics, if any, increase the likelihood that a school will be subjected to nearby drilling.

LITERATURE REVIEW

Place-Based Environmental Inequality and Spatial Modelling

Disparities in exposure to environmental harms are well-documented within the environmental inequality literature (Brulle and Pellow 2006; Evans and Kantrowitz 2002; Finucane et al. 2000). The evidence repeatedly shows a strong relationship between poverty and proximity to environmental hazards (Derezinski, Lacy, and Stretesky 2003; Mohai and Bryant 1992; Morello-Frosch, Pastor, and Sadd 2001). Similarly, a number of studies demonstrate that polluting facilities tend to favor locations in minority communities (Downey 1998; Mohai and Bryant 1992; Morello-Frosch et al. 2001; Pulido 2000), though some controversy exists over the relationship between race and proximity to harm (Frickel et al. 2010; Oakes, Anderton, and Anderson 1996). However, as Downey (2006a) points out, this lack of evidence may be the result of methodological shortcomings, rather than the absence of the phenomenon altogether. Popular methods for assessing inequalities in environmental risk rely on what Mohai and Saha (2006) refer to as “unit-hazard coincidence,” utilizing census tracts (Anderton et al. 1994; Davidson and Anderton 2000) or zip codes (United Church of Christ 1987) as the unit of measure. This method of measurement fails to take into account the potential for unequal exposure within the unit of measure (Downey 2006a). In other words, the polluting facility may not be equidistant from all individuals living within the zip code or census tract, thus harms are not evenly distributed throughout the unit of measure.

For this reason, some researchers have turned to distance-based approaches to studying disparities in the potential for exposure (Bullard et al. 2007; Chakraborty, Maantay, and Brender 2011; Downey 2006b, 2006a; Legot, London, and Shandra 2010; Mohai and Saha 2006). Two approaches dominate the literature: “distance-decay modeling”, which involves weighting observations inversely by distance from the polluter, and the creation of “buffers”, which focus on neighborhoods within circular buffer zones surrounding a polluting facility (Chakraborty et al. 2011; Downey 2006a; Mohai and Saha 2006). While distance-decay modeling is often a complicated procedure, buffer generation is made relatively simple through the use of GIS software (Chakraborty et al. 2011). By comparing the sociodemographic characteristics of populations inhabiting the buffer zones with those outside of the buffer, researchers are able to examine disproportionate potential for exposure to environmental and industrial hazards (see: Chakraborty et al. 2011; Downey 2006a; Legot, London, and Shandra 2010; Mohai and Saha 2006).

Oil and Gas Development

A growing body of research emphasizes the human health and environmental impacts of extractive industries (Huseman and Short 2012; Kimerling 1994; O’Rourke and Connolly 2003; Szasz 1994). Studies conducted prior to the large-scale implementation of unconventional directional drilling tend to focus more on the siting of refineries, pipelines, and gas stations (e.g. O’Rourke and Connolly 2003), rather than of the wells themselves. Existing studies that do focus on well placement tend to focus primarily on the health and environmental impacts of unconventional drilling (for example: Adgate et al. 2014; Colborn et al. 2011; Hays et al. 2017), particularly in already-impoverished and environmentally-degraded regions of Appalachia (Bell 2009; Bell and York 2010).

The literature provides substantial evidence to suggest that drilling and well-development activities may be associated with social, environmental, and human-health risks. Much of this work bears a striking similarity to that of the anti-toxics movement, focusing on pollution sources and potential exposure pathways (Adgate et al. 2014; Guynup 2013). This approach is not unjustified, given the vast quantities of toxic chemicals (Konschnik and Dayalu 2016; Pennsylvania Department of Environmental Protection 2010) used in the development of unconventional oil and gas deposits, and their subsequent potential for air and water contamination. In particular, health research related to unconventional oil and gas extraction tends to investigate two potential exposure pathways. First, researchers have found evidence of increased air pollution (Colborn et al. 2011; Guynup 2013; Howarth, Santoro, and Ingraffea 2011). An analysis by McKenzie et al. (2012) found that reported sub-chronic health effects (headache, throat and eye irritation) were consistent with known health effects of hydrocarbons that could potentially be released into the air during well drilling activities. Reported respiratory and nervous system effects were also shown to be consistent with potential air emissions. Second, there is evidence of groundwater contamination through faulty infrastructure, chemical spills, flowback, and run-off (Chameides 2013; Gross et al. 2013; Rozell and Reaven 2011). Furthermore, both conventional and unconventional wells release detectable levels of pollution, specifically particulate matter, nitrogen oxides, ozone, volatile organic carbons (VOCs), carbon monoxide, and in some locations, hydrogen sulfide (Czolowski et al). While these studies provide valuable insights into the risks associated with O&G development, there remains a dearth of research on the distribution of these risks among vulnerable populations.

Environmental Disparities Among Schoolchildren

School children are an important study population, given that children are particularly vulnerable to environmental harms. According to the Pediatric Environmental Health Specialty Unit, a subcommittee of the American Pediatric Society, "[c]hildren are more vulnerable to environmental hazards…They eat, drink and breathe more than adults on a pound for pound basis" (PEHSU 2011). Exposure to airborne toxins during childhood can cause long-lasting respiratory problems, such as asthma (Pastor, Jr., Sadd, and Morello-Frosch 2002; Pastor, Sadd, and Morello-Frosch 2004) which may lead to missed school days (Bener et al. 1994; Fowler, Davenport, and Garg 1992; Pastor et al. 2004)). Absences from school, due to respiratory illness, also diminish academic performance (Lucier et al. 2011; Pastor, Jr. et al. 2002; Pastor et al. 2004). Although the bulk of the literature focuses on respiratory illness, there is also evidence to suggest that exposure to pollution negatively impacts children's development and neurological functioning (Crain 2000; Landrigan and Garg 2002; Wright et al. 2006) and that proximity to polluting facilities may lead higher rates of autism (DeSoto 2009).

In addition to these physical vulnerabilities, children also lack control over the environments in which they live and go to school (Landrigan, Rauh, and Galvez 2010). The place where one lives, and therefore attends school, is the product of ascriptive forces (e.g. racial and socioeconomic inequalities) (Legot et al. 2010). Yet the physical and spatial inequalities that shape children's proximity and exposure to environmental harms remain a largely understudied dimension of environmental inequality (Legot et al. 2010).

Epidemiological evidence of the relationship between O&G development and the wellbeing of children is limited at best, as many chemicals go untested for potential impacts to childhood development (Landrigan and Garg 2002). Even if all chemicals were tested (which would undoubtedly prove a costly and time-consuming endeavor), researchers would still lack knowledge of chemical interactions (Wright et al. 2006), thus making it nearly impossible to infer causal pathways (Gullion 2015). Thus, as Gullion (2015) argues, a shift away from reliance on epidemiological studies is necessary in understanding environmental health inequalities, particularly those related to O&G development.

One way in which researchers can circumvent these barriers is through the use of alternative measures of environmental inequality. Spatial analyses of potential exposure may provide such a measure, as several notable studies have demonstrated. Pastor et al. (2004), for example, conducted a spatial analysis of schools and industrial polluting facilities, they found that not only were poor and minority students in the Los Angeles Unified School District exposed to a disproportionate amount of air pollution, and these students also performed relatively poorly on standardized tests. Similar studies by Lucier et al. (2011), Mohai et al. (2012)., and Pastor, Morello-Frosch & Sadd (2006) uncovered similar findings for children in Louisiana, Michigan, and California, respectively. More recently, Grineski and Collins (2018) conducted a national-level study of U.S. public schools, and found that schools enrolling a higher percentage of minority students faced disproportionate exposure to environmental neurotoxicants, which previous research suggests may negatively impact cognitive function (Brockmeyer and D'Angiulli 2016; Calderón-Garcidueñas et al. 2016).

Existing research does not tell us whether or not the potential risks associated with oil and gas drilling are distributed evenly, particularly among vulnerable populations, which is of special relevance to the present study. Thus, I situate my research within the existing literatures on place-based environmental disparities, and the potential for school-level exposure to environmental harms, in an attempt to contribute to the broader literature on environmental inequality. I frame this research as a study of the potential for exposure, via proximity to industrial activity, rather than as a study of exposure, because at this time no exposure data for schools and well activity in Colorado exists.

METHODS

Data

Data for this research were obtained from two main sources: the Colorado Oil and Gas Conservation Commission (COGCC), and the Colorado Department of Education (CDE). The COGCC requires industry operators to submit a permit application for the drilling and completion of a well, as well as to submit reports upon completion of permitted operations. All of the data contained in these reports are stored in the Colorado Oil and Gas Information System (COGIS) database. Certain publicly-available subsets of the data (for example, well location or complaints data) are aggregated into individual files for download via the COGCC website. One such dataset contains spatial data on all oil and gas wells drilled in Colorado (dating back to pre-1900). A second dataset contains similar information for all directional wells (any well that is drilled horizontally, as opposed to the more conventional vertical drilling) in Colorado.

Similarly, the Colorado Department of Education maintains a database of public school physical addresses. To capture the spatial relationship between wells and schools, I overlay the COGCC shapefiles with the physical addresses of Colorado schools using ArcGIS, and utilize a buffer method similar to that described by Downey (2006). The creation of buffers around each school location, at 2,500 feet and 5,000 feet, then allows me to connect each school (and all of its corresponding attributes) to individual wells within that buffer distance. The map is shown in Figures 1 and 2. This approach differs slightly from the buffer zone approach described above, in that I center my buffers around the schools themselves, rather than the polluting facilities (in this case, the wells). I opt to construct my maps in this way because the schools are the focus of this research, and because the wells are so numerous that to create buffers around each one would render the map indecipherable. Combining the COGCC and CDE datasets in ArcGIS yields a binary dependent variable, coded "1" if a school has at least one well within the buffer zone, and "0" if there is no well within the buffer zone.

Figure 1: Map of O&G Wells and Colorado Schools

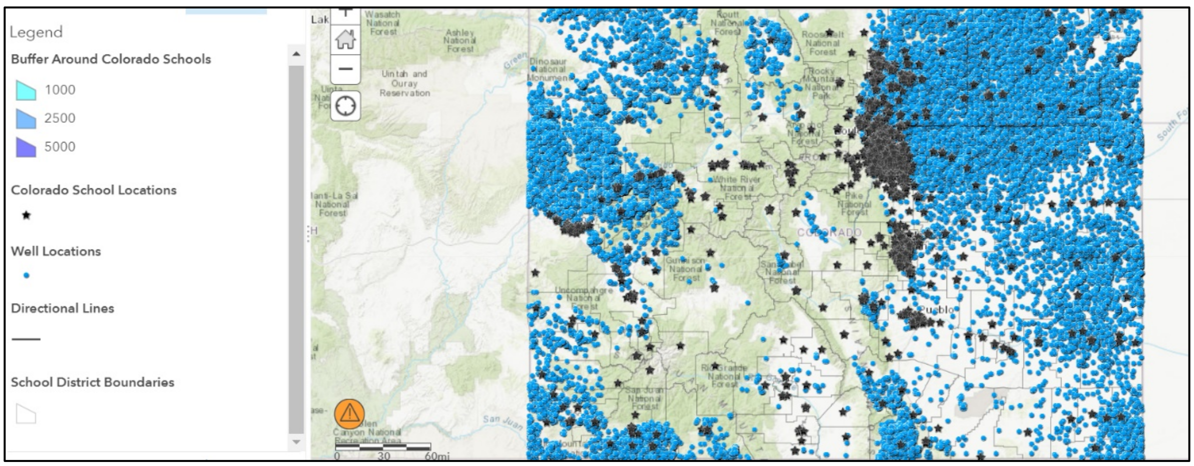
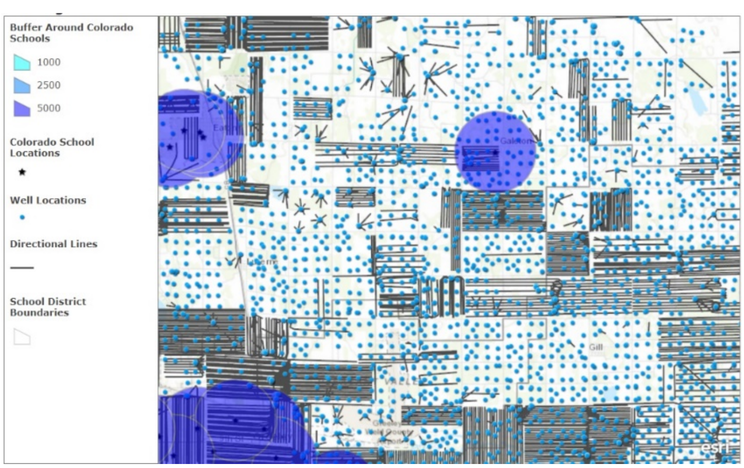


Figure 2: Close Up View of Buffers, Wells, and Directional Lines



While the initial CDE dataset contained information on multiple ethnic groups, in this paper I focus on the two largest ethnic groups in the state of Colorado: Non-Hispanic White and Hispanic/Latino. Because the populations of Asian American, Native American, and African American students are so small, they did not yield significant results.

Previous research has demonstrated the utility of free and reduced lunch eligibility as a proxy for SES, particularly when the analysis is carried out at the school-level. Thus, the present study includes a measure of the percentage of students receiving free and reduced lunch during each school year spanning from 2011 to 2017. I then take the mean of all seven years and utilize this variable in the analyses.

Existing studies also suggest that certain settings may be more likely to be subjected to O&G drilling, and preliminary models demonstrated that district setting is a significant predictor of well siting. The CDE recognizes five district setting types: urban-suburban, Denver-Metro, outlying town, outlying city, and remote. These settings are defined in Table 2.

Table 2: School District Settings as Defined by the Colorado Department of Education

Setting Classification	Definition
Denver Metro	Districts located within the Denver-Boulder standard metropolitan statistical area which compete economically for the same staff pool and reflect the regional economy of the area.
Urban-Suburban	Districts which comprise the state's major population centers outside of the Denver metropolitan area and their immediate surrounding suburbs.
Outlying City	Districts in which most pupils live in population centers of 7,000 persons but less than 30,000 persons.
Outlying Town	Districts in which most pupils live in population centers in excess of 1,000 persons but less than 7,000 persons.
Remote	Districts with no population centers in excess of one thousand persons and characterized by sparse widespread populations.

These indicators are weighted and aggregated to generate an overall score out of 100 possible points. Schools are then assigned a one of four possible ratings based upon this score, which designates a plan moving forward (performance plan; improvement plan; priority improvement plan; turnaround plan).[2] Schools assigned a performance plan have met or exceeded statewide attainment on the three performance indicators, while the lowest-scoring schools are assigned a turnaround plan. See Table 3 for a description of the four possible plan assignments. It should also be noted that schools with low participation (without parent excusals) were subject to a one-level decrease in rating.

Table 3: School Performance Plan Assignments

Plan Assignment	Percentage of Possible Framework Points Earned	Plan Description
Performance Plan	≥ 53.0%	Schools with a Performance Plan are meeting expectations on the majority of performance metrics.
Improvement Plan	≥ 42.0%	These schools are identified as lower performing. They may be meeting expectations on some performance metrics, but they are not meeting or are only approaching expectations on many.
Priority Improvement Plan	≥ 34.0%	These schools are identified as low performing. They are not meeting or are only approaching expectations on most performance metrics. The state will provide support and oversight to these schools until they improve.
Turnaround Plan	≥ 25.0%	These schools are identified as among the lowest performing schools in the state. They are not meeting or are only approaching expectations on most performance metrics. The state will provide support and oversight to these schools until they improve.

Because I am primarily interested in whether or not a school meets performance standards, the SPF data for each year are operationalized as a dichotomous variable. Schools assigned a performance plan are coded as 0, while those assigned an improvement, priority improvement, or turnaround plan are coded as 1. To track the number of years that a school has underperformed, I aggregate the data from each year to create a count variable representing the total years on an improvement or turnaround plan. This is the variable utilized in the analyses.

[2] School-level scores were not available for all years, though final ratings were available for all years except for the 2013-2014 school year, at which time a legislative hold on school accountability was in effect.

Following the precedent set by previous research on school-level inequality (for example, (Pastor, Jr. et al. 2002; Pastor et al. 2004), I include additional variables that have been shown to be related to school performance: average truancy rate, student-teacher ratio, and enrollment (as a measure for school size).   These data were also publicly available from the CDE website. Like the ethnic minority and SES data, these variables are included in the models as the average values across the years for which data were available (2010-2017).

Research Questions and Hypotheses

This research aims to answer the following question: Are certain schools more likely to be subjected to O&G drilling within 5,000 feet or 2,500 feet of school grounds, and if so, do certain school-level characteristics (e.g. a higher percentage of students from low SES backgrounds, a history of poor academic performance, etc.) increase this likelihood? With this question guiding the analysis, the null hypothesis (H_0) is that school-level poor academic performance, as well as student body demographic and SES measures, will have zero effect on the likelihood of O&G well siting within buffer distances. The three research hypotheses, therefore, are:

Hypothesis 1 (H_1): The odds of being located near oil and gas drilling will be higher for schools possessing a higher percentage of low SES students.

Hypothesis 2 (H_2): The odds of being located near oil and gas drilling will be higher for schools enrolling a higher percentage of Hispanic/Latino students.

Hypothesis 3 (H_3): Schools that are underserved or underperforming will be more likely to be sited near oil and gas drilling.

Analytic Strategy

Given the dichotomous nature of the dependent variable (the presence of at least one well within the buffer distance), this paper utilizes multivariate logistic regression to test these hypotheses. Additionally, logistic regression is able to handle data where the majority of observations possess a zero value for the dependent variable, which is the case here. Just over 75% of schools had no well within either buffer distance.

I conduct four analyses, two at each buffer distance. Model 1 examines the likelihood of a school having any well (either conventional or unconventional) within a 5,000 feet buffer. Model 2 repeats this analysis for the 2,500 feet buffer distance. Model 3 then explores the likelihood of a school having a directional well drilled within 5,000 feet, while Model 4 looks at the likelihood of a directional well within 2,500 feet. To assess the significance of each model, I utilize a postestimation Wald test to test the significance of the explanatory variables.

RESULTS

In total, 117,233 wells have been drilled in the state of Colorado at the time of writing, 3,898 of which are directional wells. The results of Models 1 and 2 show 165 schools have at least one well (conventional or directional) located within 2,500 feet, while 366 have a well within 5,000 feet. Models 3 and 4 show that 99 schools have at least one well within 5,000 feet, while 48 have at least one well with 2,500 feet. Table 4 shows the breakdown of schools with and without wells at both distances, as well as for all wells and directional wells only.

Table 4 also provides summary statistics for all independent variables used in this study. The differences between schools with and without wells within each distance are quite small. However, for both datasets, the mean percentage of students eligible for free or reduced lunch is slightly higher in schools with no wells nearby, while the mean percentage of Hispanic and Latino students is slightly lower among these schools. The data do not seem to support the hypothesis that schools with a higher percentage of low SES students are more likely to be located near O&G drilling (H_1), but it does support the second hypothesis, which suggests that schools with a higher percentage of minority students are more likely to have drilling nearby.

Tables 5 and 6 show the results of the four models. For clarity, the results are presented in terms of log odds. The first logistic regression model takes into account all wells, both conventional and directional, with a buffer distance of 5,000 feet. The model shows that an increased Hispanic and Latino population slightly and significantly increases the odds (by 1.7%) of being located near O&G drilling. Interestingly, a higher percentage of students eligible for free and reduced lunch decreases the odds slightly but significantly. School setting proves to be an important factor; schools in outlying towns and remote locations show an increase in odds of over 100%.

The second model repeats the first analysis for a buffer distance of 2,500 feet. Once again, free and reduced lunch eligibility and percentage of Hispanic and Latino students proved significant, with the former decreasing (with an odds ratio of 0.968, p=0.000) and the latter increasing (with an odds ratio of 1.027, p=0.000) the likelihood of being situated near drilling. Being located in an outlying town also significantly increased the odds, with an odds ratio of

Table 4: Summary Statistics

	Variable	Observations	Mean	Std. Dev.	Min	Max	Observations	Mean	Std. Dev.	Min	Max
		Buffer Distance of 5,000 Feet					Buffer Distance of 2,500 Feet				
At Least One Directional Well Within the Buffer Zone	Average Percentage of Students Eligible for Free and Reduced Lunch	99	42.26481	22.99597	2.590723	94.70703	48	40.68049	23.04164	4.135783	88.4703
	Average Percentage of Hispanic and Latino Students	99	35.28846	22.11192	5.810096	92.18887	48	35.86476	22.53032	8.252649	85.14729
	Average Student -Teacher Ratio	99	84.49367	197.138	11.24288	1016.563	48	20954.44	15739.43	3088.917	80115.54
	Average Truancy Rate	99	1.28005	1.291102	0.0035798	9.044216	48	1.181624	1.195799	0.0035798	6.075738
	Average Enrollment	99	55377.02	29502.83	13812.5	213512.5	48	53380.47	25354.6	13812.5	143475
	Years on Improvement Plan	99	2.316327	2.331306	0	7	48	2.446809	2.234206	0	7
No Directional Wells Within the Buffer Zone	Average Percentage of Students Eligible for Free and Reduced Lunch	1,465	44.54971	25.95984	0	99.35433	1,516	44.52301	25.86175	0	99.35433
	Average Percentage of Hispanic and Latino Students	1,465	31.05906	24.21176	0	97.13759	1,516	31.18309	24.14078	0	97.13759
	Average Student -Teacher Ratio	1,465	31.03265	108.2185	1.019585	2000.19	1,516	16065.67	13533.08	102.8192	209105.3
	Average Truancy Rate	1,465	2.010077	2.994071	0	34.54733	1,516	1.988634	2.956142	0	34.54733
	Average Enrollment	1,465	49870.92	40047.12	662.5	349425	1,516	50119.37	39845.62	662.5	349425
	Years on Improvement Plan	1,465	1.898601	2.230631	0	7	1,516	1.908845	2.237683	0	7
At Least One Well (Conventional or Directioanl) Within the Buffer Zone	Average Percentage of Students Eligible for Free and Reduced Lunch	366	43.66304	23.63749	0.1058201	96.84886	165	40.01846	22.99662	0.1058201	96.84886
	Average Percentage of Hispanic and Latino Students	366	31.79501	23.81575	2.083333	97.13759	165	31.47886	22.02089	5.015344	97.13759
	Average Student -Teacher Ratio	366	40.96311	124.7975	4.15725	1052.267	165	51.16686	145.8412	4.793895	1016.563
	Average Truancy Rate	366	1.764575	2.745086	0	21.04079	165	1.511907	2.031802	0.0035798	13.206
	Average Enrollment	366	47141.31	35633.79	662.5	261025	165	53498.18	34924.85	2175	213512.5
	Years on Improvement Plan	366	1.941667	2.206475	0	7	165	1.95092	2.235536	0	7
No Wells (Conventional or Directional) Within the Buffer Zone	Average Percentage of Students Eligible for Free and Reduced Lunch	1,198	44.63178	26.40722	0	99.35433	1,399	44.92244	26.04933	0	99.35433
	Average Percentage of Hispanic and Latino Students	1,198	31.18372	24.19388	0	97.02112	1,399	31.30884	24.34043	0	97.02112
	Average Student -Teacher Ratio	1,198	32.4167	113.8444	1.019585	2000.19	1,399	32.44116	112.4539	1.019585	2000.19
	Average Truancy Rate	1,198	2.024752	2.971223	0	34.54733	1,399	2.017171	3.00477	0	34.54733
	Average Enrollment	1,198	51159.86	40548.06	1150	349425	1,399	49832.76	39975.07	662.5	349425
	Years on Improvement Plan	1,198	1.920377	2.249554	0	7	1,399	1.922344	2.239961	0	7

3.14 (p=0.000). However, the odds ratio for remotely-situated schools no longer proves significant. The number of years that a school has spent on an improvement plan also shows a significant increase in the odds ratio (with an odds ratio of 1.140, p=0.011).

Models three and four examine the more controversial directionally-drilled wells. In the third model, the buffer distance is set to 5,000 feet. With an odds ratio of 0.959, free and reduced lunch eligibility is a significant negative predictor (p=0.000) of a school being located within 5,000 feet of a well. Likewise, the average truancy rate also appears to be a significant negative predictor variable (odds ratio = 0.684, p=0.001). With odds ratios of 1.045 and 1.308, respectively, the percentage of Hispanic/Latino students and number of years that a school has spent on an improvement plan are both significant (p=0.000) predictors of having a well within this buffer distance. Average enrollment is also statistically significant, but the odds ratio is negligibly small (1.00001).

In model four, I decrease the buffer distance to 2,500 feet. Once again, average free and reduced lunch eligibility rates and average truancy rates have a significant and negative impact on the likelihood of a school being located within the buffer distance. The average percentage of Hispanic/Latino students and the number of years on an improvement plan have a significant positive impact, with odds ratios of 1.046 and 1.341, respectively.

Table 5: Logistic Regression Outputs for All Wells (Models 1 and 2)

	Odds Ratio	Std. Err.	z	P>z	[95% Conf.	Interval]	Odds Ratio	Std. Err.	z	P>z	[95% Conf.	Interval]
	Buffer Distance of 2,500 Feet						Buffer Distance of 5,000 Feet					
Average Percentage of Students Eligible for Free and Reduced Lunch	0.9660654*	0.0073039	-4.57	0.000	0.9518556	0.9804873	0.9820061*	0.0050302	-3.54	0.000	0.9721965	0.9919147
Average Percentage of Hispanic and Latino Students	1.028372*	0.0075628	3.8	0.000	1.013656	1.043302	1.017939*	0.0051826	3.49	0.000	1.007832	1.028147
Average Student -Teacher Ratio	0.9999991	5.71E-06	-0.15	0.881	0.999988	1.00001	0.9999981	4.97E-06	-0.38	0.702	0.9999884	1.000008
Average Truancy Rate	0.8620077*	0.0501036	-2.55	0.011	0.7691936	0.9660211	0.9587471	0.0277112	-1.46	0.145	0.9059438	1.014628
Average Enrollment	1.000004	2.41E-06	1.65	0.099	0.9999992	1.000009	1	1.87E-06	0.05	0.96	0.9999964	1.000004
Years on Improvement Plan	1.174096*	0.0636862	2.96	0.003	1.055679	1.305795	1.058998	0.0409348	1.48	0.138	0.9817307	1.142346
Setting												
Outlying City	1.168955	0.4813432	0.38	0.705	0.5215511	2.619986	1.085579	0.3164304	0.28	0.778	0.613124	1.922092
Outlying Town	3.20767*	0.7720663	4.84	0.000	2.001294	5.141249	2.313783*	0.4445877	4.37	0.000	1.587692	3.371933
Remote	1.841945	0.5999541	1.88	0.061	0.9728041	3.487612	2.688752*	0.5898181	4.51	0.000	1.74915	4.133088
Urban-Suburban	0.852585	0.2096186	-0.65	0.517	0.5265738	1.380435	0.8398876	0.1451222	-1.01	0.313	0.5986101	1.178415
_cons	0.1263085	0.0328324	-7.96	0	0.075888	0.210229	0.3011428	0.0589758	-6.13	0	0.2051507	0.4420504

* denotes a statistically significant (p<.05) result

Table 6: Logistic Regression Outputs for Directional Wells (Models 3 and 4)

	Odds Ratio	Std. Err.	z	P>z	[95% Conf.	Interval]	Odds Ratio	Std. Err.	z	P>z	[95% Conf.	Interval]
	Buffer Distance of 2,500 Feet						Buffer Distance of 5,000 Feet					
Average Percentage of Students Eligible for Free and Reduced Lunch	0.9372383*	0.0148825	-4.08	0.000	0.9085183	0.9668662	0.9570228*	0.0100168	-4.2	0.000	0.9375903	0.9768582
Average Percentage of Hispanic and Latino Students	1.061644*	1.54E-02	4.12	0.000	1.031824	1.092325	1.045657*	0.0100032	4.67	0.000	1.026234	1.065448
Average Student -Teacher Ratio	0.9999973	7.89E-06	-0.34	0.737	0.9999819	1.000013	1.000005	6.09E-06	0.76	0.449	0.9999927	1.000017
Average Truancy Rate	0.5719944*	1.04E-01	-3.07	0.002	0.4001974	0.8175406	0.6531296*	0.0737606	-3.77	0.000	0.5234433	0.8149464
Average Enrollment	1.000008*	4.75E-06	1.62	0.104	0.9999984	1.000017	1.000011*	3.17E-06	3.33	0.001	1.000004	1.000017
Years on Improvement Plan	1.482632*	0.145578	4.01	0.000	1.22308	1.797264	1.340544*	0.0919987	4.27	0.000	1.17183	1.533547
Setting												
Outlying City	0.5761859	0.6242868	-0.51	0.611	0.0689131	4.817523	0.9852452	0.6563524	-0.02	0.982	0.2669865	3.635794
Outlying Town	7.100516*	2.810736	4.95	0.000	3.268453	15.42544	8.3804	2.570444*	6.93	0.000	4.593921	15.28784
Remote	1.205087	0.975504	0.23	0.818	0.2465929	5.889199	3.001725	1.398062*	2.36	0.018	1.204818	7.478603
Urban-Suburban	1.16206	0.5422351	0.32	0.748	0.4656338	2.900095	1.872584	0.580323*	2.02	0.043	1.020116	3.437422
_cons	0.0236867	0.0120399	-7.36	0	0.0087466	0.0641461	0.0277344	0.0105747	-9.4	0	0.0131362	0.0585555

* denotes a statistically significant (p<.05) result

DISCUSSION AND CONCLUSIONS

Through the use of spatial and statistical modelling, this study attempts to identify inequality in the potential for exposure to oil and gas drilling among Colorado schoolchildren. Even when controlling for school setting, some notable findings emerge.

The findings from the present research seem to align with the broader environmental inequality literature, in that schools with a higher percentage of Hispanic and Latino are more likely to be situated near O&G drilling. However, at the same time, this study finds no evidence that lower-SES increases the likelihood of proximity to O&G drilling. There could be several possible explanations for this result.

One such explanation draws from the work of Frickel and Elliott (2019), who suggest that conventional narratives of environmental inequality, while valid, represent just “the tip of the iceberg” (Frickel & Elliott 2019: 133). Frickel and Elliott (2019), in their study of four cities, suggest that industries and communities turnover and change, or “churn”, as the authors put it, at different rates. Moreover, the expansion of industrial harms into new regions often takes place more quickly than demographic changes in the surrounding communities. It is my contention that this is what is currently happening with the oil and gas industry, as new technologies allow for the drilling of previously untouched regions in Colorado.

Existing studies of environmental inequality tend to deal with the known, or the documented toxic releases and hazards distributed among communities. Frickel and Elliott (2019), however, suggest that there remains a significant amount of work to be done in understanding “the unknown.” While they are referring specifically to what they refer to as “relic industrial sites” (historic industrial sites that no longer appear hazardous), I would extend this argument to the current O&G industry, which represents some hybrid of known and unknown, of old and new. Certain regions of Colorado have a lengthy history of O&G development, while others are less familiar with the industry. However, the rise of unconventional drilling has enabled the spread of O&G development into new neighborhoods. Thus, it may be, as Frickel and Elliott (2019) argue, that poor and minority communities are not any less at risk than previously thought. Rather, it may be that more affluent and non-minority communities are *more* at risk than previously understood.

A second explanation stems from the development of unconventional drilling techniques, which allow for the extraction of previously inaccessible oil and gas reserves. What this means is that more affluent communities, which were built atop geological formations thought to be to difficult to extract from, are now drilling hotspots. Gullion (2015) speaks to a similar phenomenon among Texas residents. Middle-to-upper-middle-class residents of Texas communities find themselves facing O&G activity, which they reluctantly come to oppose, at least within their own neighborhoods. It may be that a similar pattern of events is unfolding within Colorado communities.

However, it may also be that the jobs created by the O&G industry do benefit local economies, and that this is being reflected in the findings presented here. As discussed at the beginning of this paper, the industry plays an important role in the Colorado economy, employing more than 200,000 people. While the data used in this study cannot speak directly to the relationship between industry employment and school-level SES, future research might investigate whether or not proximity to drilling is related to a greater number of parents being gainfully employed by O&G companies. Future research should further investigate the findings presented here, in order to determine whether or not any of these explanations truly fit.

A second finding of interest is the way in which the effects of the percentage of Hispanic and Latino students and the percentage of students eligible for free and reduced lunch change between the two buffer distances. The effect of minority status appears to increase as the buffer distance decreases. However, the negative effect of SES on the likelihood of being situated near a well also increases. It appears that in more affluent schools, the effect of ethnicity is increased at smaller distances. This finding may have important implications for environmental inequality research, particularly for scholars interested in race and ethnicity related to O&G development.

A third finding worth noting is that of the effect of poor school performance on the likelihood of being exposed to O&G drilling. While this finding only pertains to the buffer distance of 2,500 feet, it may be of interest to policymakers when considering appropriate setback distances. Future research should investigate the relationship between poor academic performance and proximity to O&G activity.

Finally, as with any study, the findings presented above must be interpreted with caution. This study utilizes a dichotomous dependent variable, rather than a count variable, and is thus unable to account for the presence of multiple wells within a buffer zone. Future research should investigate whether or not certain school-level characteristics make an individual school more vulnerable to a higher density of drilling in the surrounding area. Additionally, the present research focuses only on Colorado, which possesses a unique history of O&G development, which has produced a particular regulatory environment (Ryder 2017). These findings should not be generalized to other regions with differing histories or policies (e.g. regions overlying the Marcellus Shale formation, which do not possess the same lengthy history of O&G development).

Furthermore, and perhaps most importantly, these findings do not account for the status of the wells. While it may be true that most of the directional wells have been drilled relatively recently, the same cannot be said for conventional wells. Well status (for example, producing, abandoned, permitted, etc.) may have significant implications for the risk to the surrounding area, thus future research should account for this variable. Future research should also consider the distribution of risk for specific age groups (e.g. elementary, middle, or high school students), as this dataset does not speak to this particular variable.

Of equal importance, it should be noted that this research does not represent an attempt to measure the health or environmental impacts associated with O&G drilling. What I present here is an analysis of unequal potential for exposure via proximity to wells. More research must be done to determine what, if any, types (e.g. air pollution, water pollution, noise pollution) of risk are at play in the areas surrounding O&G drilling.

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