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IMPACTS OF EXTRACTIVE ACTIVITIES ON DRINKING WATER AND POPULATION HEALTH

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Abstract

Extractive activities such as coal mining and hydraulic fracturing (fracking) are common throughout the United States. Much research has found that extractive activities have negative impacts on both ecosystem health and population health. To understand the impacts that coal mining and fracking pose, two studies were conducted. Both studies used a spatial econometric model, spatial lag of X (SLX), to control for spatial spillover effects in the regression analyses. The first study analyzed the relationship between coal mining and fracking and drinking water quality in the United States from 2010-2019. It was found that year-on-year within county changes in coal mining and fracking are not associated with drinking water quality violations. The second study analyzed the impacts of abandoned coal mines on mortality in West Virginia from 1990-2020. Within county models were not found to be statistically significant, but between county models were in the cases of age-adjusted circulatory and respiratory disease mortality. Overall, there appears to be possible factors or specific characteristics, such as the presence of active mining or housing prices, of a place that may be influencing the results. Future research in coal mining and fracking must look to determine these factors or characteristics.

Chapter 1: Introduction

Extractive activities such as coal mining and hydraulic fracturing (fracking), have negative impacts on the environment and public health (Mueller, 2022; Acharya & Kharel, 2020; Fitzpatrick, 2018; Busby & Mangano, 2017; Hendryx, 2015; Kuwayama et al., 2015; Adgate et al., 2014; Vengosh et al., 2014). This thesis will look at the impacts of coal mining and fracking on drinking water quality, as well as the impacts of abandoned coal mines on mortality in West Virginia. The literature surrounding mining, fracking, and population health has often been international, or in the form of small-scale case studies in the United States—meaning that a national image of the associations is still lacking. The few papers that do discuss natural resource extraction and health outcomes, such as *Natural Resource Extraction and Mortality in the United States* by Matheis (2019), have found important relationships. Matheis analyzed the consequences of natural resource extraction (mining and oil and gas extraction) on public health using mortality data from 1964 to 1988 and found extraction led to increases in mortality over the long-term (Matheis, 2019). As such, it is important to understand how specific forms of extraction, such as coal mining and fracking, impact population health.

Much of the research on mining focuses on a specific resource or a specific location. An example of this comes from Hendryx et al, where they looked specifically at mountaintop removal mining in Appalachia and found a significant relationship between mountaintop removal mining and poor population health (Hendryx et al., 2019). The mining literature has historically used Appalachia as a case study region, due to the long history of coal mining in the region. This thesis will expand this historic focus by assessing the impact of abandoned wells on previously untested population health outcomes. The approach I have taken, wherein I assess the impacts of extraction at multiple scales of analysis, national and state-level, is in line with prior research. For example, Rabe (2014) analyzed shale plays in relation to politics and governance and demonstrated the importance of understanding policies on a federal and state scale, due to problems of cross-border and cross-scale policy making (Rabe, 2014).

Research has also historically only focused on active mining in relation to health, but part of this thesis will be focusing on abandoned mines. Abandoned mines can be extremely dangerous for the environment and therefore public health. Of major concern is acid mine drainage (AMD), which is acidified runoff (Fields, 2003). AMD can contaminate water sources, which in turn can harm population health. The reason so many mines are abandoned and not cleaned up is due to difficulty of determining the responsible party (Fields, 2003). Even when the responsible party is known, consequences are not enforced (Fields, 2003). As such, it is important to understand the impacts of abandoned mines on water quality and ecosystem health, to ensure that effective policies for public health are being developed.

This thesis is made up of two separate but related papers, presented in two chapters. Chapter 2 of this thesis is a national comparative analysis of the impacts of coal mining and fracking on drinking water quality. This chapter aims to answer the research question, what is the difference in the association between coal mining and fracking on drinking water quality? Previous literature has shown evidence of the negative impacts of coal mining and fracking on drinking water, but comparative analyses of the two are not often found at the national level. Data for coal mining came from the Mine Safety and Health Administration (MSHA) through the Mine Data Retrieval System. Fracking site data came from FracFocus. The drinking water quality violation data came from the EPA Safe Drinking Water Information System (SDWIS). The time period of this study is 2010-2019. The spatial lag of X model (SLX) is used in the analyses. I found that there is not a statistically significant relationship between fracking and coal mining and drinking water quality, when looking at the within county models. There was a statistically significant relationship in the between county models, but it is dependent on model formulation. This leads to the conclusion that there may be other factors that are influencing the results.

Chapter 3 is an analysis of the relationship between abandoned coal mines and public health in West Virginia. Previous research has shown the possible health effects that abandoned coal mines can cause, through processes such as acid mine drainage (EPA, 2023b). The main research question is: is there an association between abandoned coal mines and mortality in West Virginia? The time frame of this study is 1990-2020. In order to answer this question, SLX was used. Between and within county changes were both analyzed for three different underlying causes of death: circulatory disease, respiratory disease, and cancer. Data on abandoned coal mines was retrieved from the MSHA Mine Data Retrieval System. Mortality data was obtained from the Centers for Disease Control and Prevention – Wide ranging Online Data for Epidemiologic Research (CDC WONDER). I found that year-on-year within county changes in abandoned coal mines are not statistically significant in relation to any of the three forms of mortality. There was a statistically significant relationship in the between county models and age-adjusted circulatory and respiratory diseases. This leads to the conclusion that there may be some other factors or characteristics of a place that are influencing the results.

Chapter 4 is the conclusion of this thesis, where both studies are synthesized, and final overall conclusions are drawn.

Chapter 2: National Comparative Analysis of Coal and Fracking on Drinking Water Quality

Section 2.1. Introduction

Access to clean drinking water is important for the health and well-being of all people. However, throughout the United States, community water systems are found to have health-based maximum contaminant level (MCL) violations. MCL is “the highest level of a contaminant that is allowed in drinking water,” set by the United States Environmental Protection Agency (EPA) (EPA, 2024b). Some of these community water systems (CWS) are found in areas where natural resource extraction is present. Contamination of drinking water sources from natural resource extraction is a threat to public health. The purpose of this study is to compare the difference between the association between coal mining and fracking and drinking water quality.

Natural resource extraction for energy has a long history in the United States. Coal, oil, and natural gas have long been major energy sources for the United States, with the first documented commercial coal mining in the United States beginning in 1701 (National Academies of Sciences, Engineering, and Medicine, 2018). Though coal mining has been around for hundreds of years in the United States, it has fallen out of favor as an energy source. According to the US Energy Information Administration (EIA), the consumption of coal has decreased from around 36% of total US energy consumption in 1950, to 10% in 2022 (EIA, 2023).

Hydraulic fracturing, commonly referred to as ‘fracking,’ had a slow start in the oil and gas industry. Fracking is a process in which fractures are created in a rock formation through the high-pressure injection of fluids, to stimulate the flow of natural gas or oil (EPA, 2024c).

Experimenting with hydro-fracturing began in the Southern Plains states of Kansas, Oklahoma, and Texas in the late 1940s, but industrial use began in the late 1900s (Heinberg, 2013). Shale gas plays were discovered throughout the United States. A shale gas play is “a set of discovered, undiscovered or possible natural gas accumulations that exhibit similar geological characteristics” (US Department of Energy, 2013). The geologic characteristics make it difficult to extract natural gas from shale plays, this is where the use of unconventional natural gas extraction methods, such as fracking, are preferred (US Department of Energy, 2013). The fracking boom ramped up in the late 2000s, though the exact time is dependent on geography (Heinberg, 2013). Figure 2.1. shows the distribution of coal mining and fracking throughout the United States by county.

Alongside the extraction of energy sources, specifically through mining and fracking, comes negative impacts on both the environment and public health. An important environmental harm is the contamination of drinking water from the extraction of both coal and natural gas (Acharya & Kharel, 2020; Hill & Ma, 2017; Jasechko & Perrone, 2017; Kuwayama et al., 2015; Fontenot et al., 2013; Howarth et al., 2011; Osborn et al., 2011), leading to violations of the Safe Drinking Water Act (SDWA) in community water systems. As such, the contamination of drinking water sources from these activities could harm the health of those who rely on that water source.

Drawing on the above known problems of contamination from extractive activities, this study asks three specific research questions:

- Research Question 1: What is the association between coal mining and drinking water quality?

- Research Question 2: What is the association between fracking and drinking water quality?
- Research Question 3: What is the difference between the association between coal mining and fracking on drinking water quality?

In this study, I evaluate all research questions for both (1) all states and (2) just the states where fracking or mining is present. Further, I also evaluate the differences between models estimating within-county and between-county associations between extraction and water quality. This is done because increased health-based drinking water quality violations have been shown to be associated with increased levels of coal mining and fracking activity. However, it is not clear if year-on-year within-county changes in activity are actually associated with increased levels of health-based drinking water quality violations.

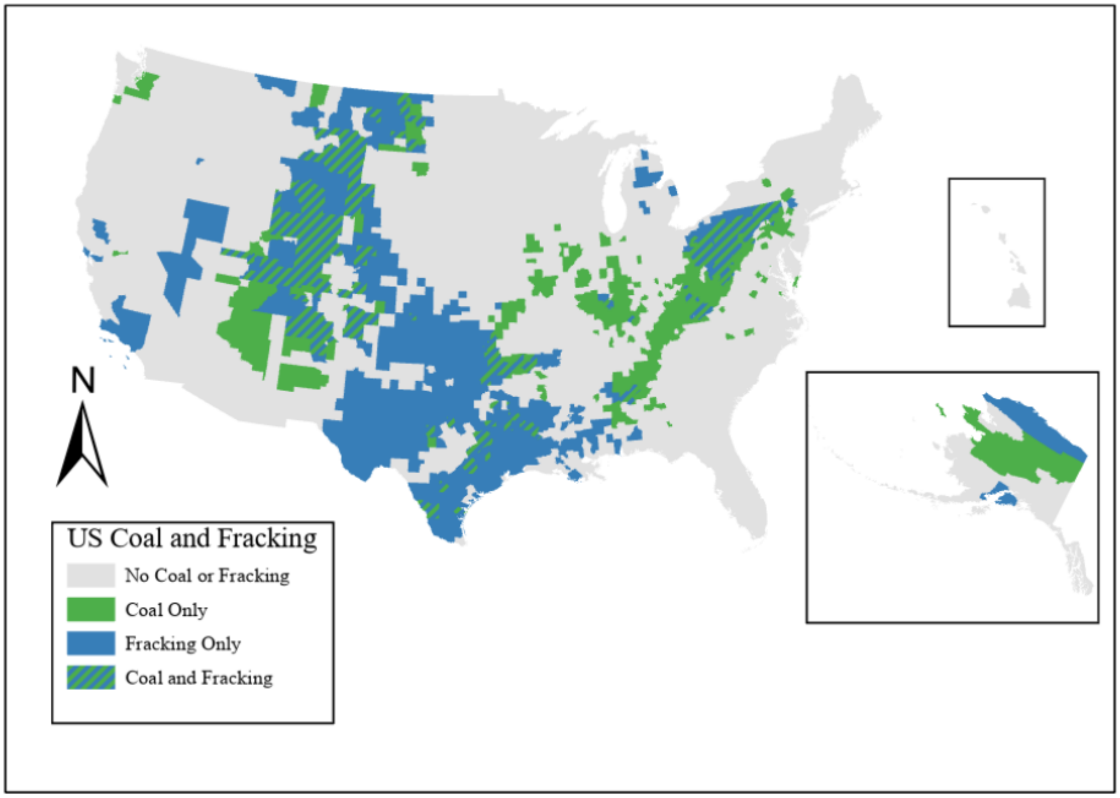

Figure 2.1. U.S. coal and fracking distribution

Section 2.2. Literature Review

Section 2.2.1 General Water Quality in the United States

There are different types of water systems that exist in the United States. There are public water systems which include three different types, community water systems, non-transient non-community water systems, and transient non-community water systems (EPA, 2021). A community water system is a public system that supplies water to the same amount of people all year-round; a non-transient non-community water system is similar to a community water system, but it only requires that 25 people are on it for 6 months of the year; and a transient non-community water system provides water to places that people do not stay for long periods of time (EPA, 2021). Aside from public water systems, the other type of water system to note is the private water system, which includes private drinking water wells.

About 90% of people in the United States rely on drinking water from public water systems (Strosnider et al., 2017; Allaire et al., 2018). While a large majority of people in the United States have access to clean drinking water, there are still many lacking access. The exact number of people who do not have access to clean and safe drinking water in the United States is not clear. That said, an estimation can be made from data on usage and violations among community water systems. The EPA found that around 92% of people in the United States (~300 million people) rely at least partially on a community water system (EPA, 2022). Further, it was estimated that 15.6 million people (~ 5%) relied on a community water system that had health standard violations (EPA, 2022). These estimates only focus on public community water systems, but there are many more people either on private water systems or private well water (EPA, 2022).

A contributor to increased regulations on water contamination was the Safe Drinking Water Act of 1974. The SDWA set regulations that contributed greatly to the decline in contaminated public water systems (Weinmeyer et al., 2017). There was one major federal law that attempted to address water pollution, the Federal Water Pollution Control Act of 1948 (EPA, 2013). This act led to the creation of the Clean Water Act (CWA) (EPA, 2013). Importantly, this law did not address drinking water quality and there does not appear to have been any federal regulations for drinking water quality before the introduction of SDWA. Industrialization led to an increase in concern over possible contamination of drinking water sources from industrial pollution (Weinmeyer et al., 2017). Early studies done in the 20th century found that the majority of community water systems were contaminated over an acceptable level (Weinmeyer et al., 2017). In the early 1970s, concerns about cancer grew because of several cancer cases and deaths that were linked to unsafe and contaminated drinking water (Weinmeyer et al., 2017; Marcillo & Krometis 2019). Although the SDWA is not without its issues, the implementation of the act led to an increase in safe drinking water in community water systems.

Under the SDWA, there is a fund that can be used to "achieve or maintain SDWA compliance" (Weinmeyer et al., 2017, p. 1023). This fund is called the Drinking Water State Revolving Fund (DWSRF). The Drinking Water State Revolving Fund (DWSRF) is a fund established under the Safe Drinking Water Act in 1996 (Tiemann, 2018). The DWSRF is intended to help fund public water system infrastructure projects (Tiemann, 2018). The funding is provided through the Environmental Protection Agency and a certain amount of money is provided to each state every year (Tiemann, 2018). The state then provides this money in the form of subsidized loans from the federal funding to drinking water system infrastructure projects that will bring public water systems into compliance with the SDWA (Tiemann, 2018).

This fund has provided around $32.5 billion between 1998 and 2016 (Weinmeyer et al., 2017). Estimates have found that almost one trillion dollars are needed for upgrades and maintenance, so the $32.5 billion is nothing compared to what is needed in order to provide access to safe drinking water (Weinmeyer et al., 2017). Funding now falls on the state or local government to fix and maintain their community water systems. Many water systems have become noncompliant due to this lack of funding.

A study conducted by Allaire, Wu, & Lall (2018) focused on drinking water quality at a national scale. Most of the literature on drinking water quality has focused on scales smaller than the nation, but there is not a lot of analysis that looks at the possible trends that there are throughout the United States. This study by Allaire et al. (2018) is attempting to start to fill the gap in the literature. Allaire et al. (2018), discusses the state of drinking water quality in the United States and the importance of access, “Ensuring access to safe drinking water poses a challenge for US water systems in the face of aging infrastructure, impaired source water, and strained community finances” (Allaire et al., 2018, 2078). These are some of the reasons that the United States is still struggling to provide safe drinking water for all. Allaire et al. ran statistical tests to find possible trends in drinking water quality violations throughout the United States and found that rural areas have substantially higher instances of drinking water quality violations than in urban areas (Allaire et al., 2018). They also discovered hotspots elsewhere throughout the United States that likely have other contributing factors than studied in their paper.

Another study conducted by Mueller & Gasteyer (2021), fills in some of the gaps that the Allaire et al. paper left out. The authors found that 489,836 households lack complete plumbing, 1,165 community water systems in serious violation of the Safe Drinking Water Act, and 9,457 Clean Water Act permittees are in Significant noncompliance (Mueller & Gasteyer, 2021).

Mueller & Gasteyer also found that it is regionally clustered and there are several groups that are more likely to run into water hardship, such as rural and poor individuals (Mueller & Gasteyer, 2021). Much still needs to be studied to understand access to safe drinking water on a national scale. There also needs to be studies done in order to understand why hotspots are located where they are.

The policies and regulations presented in the last section of the review are applicable to public water systems, however millions of Americans rely on private water systems—usually domestic wells—which are not regulated through the federal government (CDC, 2018). In 2015 it was estimated that around 43 million people, or 1 in 8 people rely on private wells in the United States (USGS, 2018). Research shows that an estimated 1 in 5 private wells are contaminated with chemicals that could negatively impact health (CDC, 2018). It is often up to the owner of the well to test their water. This means that the financial burden of testing is on the private well owner. This could be potentially dangerous to those living in areas without community water systems. Unfortunately, there is no other federal policy under the SDWA or any other law that requires anything such as testing, but states can set their own regulations. This means that the impact of factors that damage drinking water quality, such as mining and fracking, cannot be assessed with existing data.

Section 2.2.2. Coal Mining, Water Quality, and Health

Research shows that mining can impact water quality and public health; coal mining, specifically, has been found to impact both (Hendryx et al., 2019; Hendryx & Ahern, 2008; Shiber, 2005). Surface coal mining is the most studied method of coal mining in relation to water quality and health. Surface coal mining includes mountaintop removal, contour, area, highwall, and auger mining (EPA, 2016). Around two-thirds of coal in the United States comes from surface mines (EIA, 2023). Underground mining is another method of mining coal, but less studied in relation to public health. The literature surrounding coal mining, water quality, and health is abundant.

Studies indicate that coal mining generally impacts water quality. There are several methods in which coal mining can harm water quality. Acharya & Kharel (2020) study the impacts of acid mine drainage from coal mining. Acid mine drainage is, “water discharged from active, inactive, or abandoned mine and reclaimed areas with relatively higher total acidity compared with total alkalinity” (Acharya & Kharel, 2020, 3). They found that acid mine drainage reduces surface water and groundwater quality. Pollution of streams is found in areas where acid mine drainage is common (Acharya & Kharel, 2020). Acid mine drainage is difficult and costly to treat, so many coal mines do not treat the water they are discharging (Acharya & Kharel, 2020). A study by Tozsin et al. (2022), also analyzed acid mine drainage, but specifically at abandoned mines. Analyzing both active and abandoned mines is important to know the long-term effects of coal mining on water quality. Knowing the long-term effects of coal mining can help to understand how water quality can be continually affected by abandoned mines, due to acid mine drainage (Tozsin et al., 2022).

The impacts of coal mining on water quality and public health are evident. Scientific literature provides evidence of coal mining having negative impacts on water quality. The literature also provides evidence of coal mining having negative impacts on public health. However, much of the literature on coal mining comes from the 2010s, with less literature being found in the 2020s. Therefore, continued research is necessary to understand the current state of the impacts of coal mining on water quality and public health. The review of literature on this topic provides a better understanding of these relationships. It also provides a direction for future research to move towards a better understanding of how coal mining impacts public health and isolating it to how the environmental factors associated with mining impact public health. Overall, there is plenty of evidence to suggest that coal mining has negative impacts on water quality and public health, but the extent of this impact via drinking water nationwide remains absent.

Section 2.2.3. Fracking, Water Quality, Health

Hydraulic fracturing, commonly referred to as fracking, is defined by the United States Geological Survey: Water Resources Mission Area as, "the process of injecting water, sand, and/or chemicals into a well to break up underground bedrock to free up oil or gas reserves" (USGS Water Resources Mission Area, 2019). Fracking is a highly controversial practice, due to concerns over both environmental and public health (Howarth et al., 2011). As such, waste from fracking is a major concern. The waste that comes from fracking is often toxic and there is more wastewater from fracking than from conventional oil wells (Schmidt, 2013). For this reason, the treatment and disposal of this waste is of great importance. Wastewater is often stored underground or treated and returned to surface waters (Schmidt, 2013). These disposal methods are still risky, as it is more difficult to treat wastewater from fracking and the reinjection of waste deep underground could still cause contamination (Schmidt, 2013). The effects of fracking on groundwater quality have been less studied, so authors have used the term "potential for contamination" (Kuwayama et al., 2015). Fracking could create pathways for contaminants to get to groundwater. Fracking well integrity is another possible issue for water quality, as poor integrity could allow the movement of methane to groundwater wells (Kuwayama et al., 2015).

Many academics such as Howarth, Ingraffea, & Engelder, believe that the risks outweigh the benefits and the practice should be stopped because of the risk to the environment (Howarth et al., 2011). Significant amounts of water are needed for every well, around 20 million gallons on average (Howarth et al., 2011). Several chemicals and toxic additives, such as acids (hydrochloric acid) and solvents (aromatic hydrocarbons), are used in the fracking process, which is concerning for the health and safety of the public (Howarth et al., 2011; Adgate et al., 2014). There are also many worries about the impacts of fracking on environmental health, as multiple studies have shown impacts on air and water quality.

The topic of fracking and water quality has received significant attention, leading to many papers, with significant growth in research in the 2010s after the start of the US fracking boom in 2010. Much of the literature surrounding both fracking and water quality focuses not only on water quality, but water quantity as well. A paper by Kuwayama et al. (2015) found that the impacts of fracking on water quantity is not significant, but this does not mean that specific locations are not significantly impacted (Kuwayama et al., 2015). The authors found that there is evidence from previous literature that water quality is significantly impacted by fracking (Kuwayama et al., 2015). Each well in the Marcellus Shale—which underlies Pennsylvania and West Virginia—requires 2 to 4 million gallons of water; the Barnett Shale (in north central Texas) requires around 5 million gallons of water per well; and the median number of gallons for each well in the Denver-Julesburg Basin (underlying parts of Colorado, Wyoming, and Nebraska) is 2.9 million (Kuwayama et al., 2015). Kuwayama et al. (2015) discussed fracking impacts on both surface and groundwater quality. Surface water can be affected through the release of "fracking fluid, flowback, or produced water, as well as liquid waste storage, treatment, and disposal" (Kuwayama et al., 2015).

While there are a variety of studies that have been conducted on the environmental health impacts of fracking, including water quality, these studies have often focused on water pollution broadly and not specifically on drinking water quality. A popular study from Vengosh et al. (2014), *A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States*, provides a comprehensive review of the impacts of fracking on water quality. Like the Kuwayama et al. (2015) study, Vengosh et al. (2014) looked at both groundwater and surface water (Vengosh et al., 2014). In the Vengosh et al. (2014) study, stray gas contamination is an issue that could impact drinking water wells (Vengosh et al., 2014). Methane, ethane, and propane appear to be most worrisome for stray gas contamination, as shallow aquifers can be contaminated by the gas itself or the fracturing fluids (Vengosh et al., 2014). Groundwater can also be contaminated with salts (Vengosh et al., 2014). Surface water contamination can be impacted by hydraulic fracturing fluids which contain numerous chemicals that have the potential to pollute surface water. Spills, leaks, and wastewater disposal are another problem associated with water contamination from fracking (Vengosh et al., 2014). Vengosh et al. (2014) also found evidence that there are possible long-term effects of unconventional well sites on water quality, even after they are no longer active—this shows the importance of studying both active and inactive well sites. Contamination of groundwater and surface water from fracking can lead to impacted private drinking water wells.

There have been a few studies looking at impacts of hydraulic fracturing near private drinking water wells. Jasechko & Perrone (2017) and Fontenot et al. (2013) both evaluated water quality in drinking water wells. Jasechko & Perrone (2013) analyzed the entire United States and specifically focused on hydraulic fracturing. Fontenot et al. (2013) analyzed the Barnett Shale Formation in Texas and looked at natural gas extraction in general. The authors concluded that there is a need for more studies. Osborn et al. (2011) studied methane contamination of drinking water from conventional and unconventional wells in the Northeast United States. They found possible evidence of contamination but noted that more research is needed that also comes to the same conclusion (Osborn et al., 2011). Although there is literature on the impacts of fracking on drinking water quality, it is limited, mostly focusing on impacts to private drinking water wells. There are some articles that study how fracking impacts public water systems; however, it is still limited. A 2017 study by Hill & Ma analyzed if shale gas development impacts drinking water quality in community water systems in Pennsylvania (Hill & Ma, 2017). The estimate was that "drilling an additional well pad within 1 km of groundwater intake locations increases gas-related contaminants by 1.5-2.7 percent, on average" (Hill & Ma, 2017). The authors did conclude that more studies need to be done to understand the health impacts of the water contaminants (Hill & Ma, 2017).

Several studies have been conducted that look at the impacts of fracking on public health. Adgate et al. (2014) analyzed several possible exposure pathways and health effects: occupational, air pollution, community exposure, water pollution, socioeconomic impacts, psychosocial effects, and human health (Adgate et al., 2014). Although this study shows significant evidence of these impacts, they are hard to quantify. This is due to several uncertainties that Adgate et al. (2014) presents in their paper, for example frequency and duration of exposure (Adgate et al., 2014). This shows the need for more research into the relationship between public health and fracking.

An analysis of literature about the impacts of unconventional natural gas development on environmental and public health conducted by Hays & Shonkoff (2016) provides an insight into the scientific literature on the topic (Hays & Shonkoff, 2016). The assessment provides valuable information on the state of the literature surrounding public health, water quality, and air quality. The results of the study show that 84% of the 685 studies found evidence of public health hazards, while the rest of the studies found no statistically significant relationship (Hays & Shonkoff, 2016). The results of the analysis of studies on water quality found that 69% of the studies found a potential positive association between unconventional natural gas development, whereas 31% found no statistically significant relationship (Hays & Shonkoff, 2016). Overall, there is clear evidence that fracking impacts water quality and public health.

Section 2.2.4. Comparison of Coal and Fracking

There are few pieces of literature that compare coal mining and fracking in the United States. Through searching for literature, only two articles were found comparing coal and fracking: a briefing paper and a study paper. The briefing paper comes from the Worldwatch Institute and is authored by Grubert & Kitasei (2010), the paper is called *How Energy Choices Affect Fresh Water Supplies: A Comparison of U.S. Coal and Natural Gas*. Importantly, this study was conducted before the fracking boom, so it only looked at conventionally extracted natural gas. They determined that natural gas will likely be a better option, as it decreases air emissions and water usage (Grubert & Kitasei, 2010). The second paper from Jenner & Lamadrid (2013) is titled *Shale gas vs. coal: Policy implications from environmental impact comparisons of shale gas, conventional gas, and coal on air, water, and land in the United States*. Jenner & Lamadrid determined that conventional gas is the best option for energy, as it produces fewer emissions and requires less water (Jenner & Lamadrid, 2013). They determined that the conventional gas supply is decreasing, so there is a need to determine if shale gas or coal is the better option. They recommend shale gas, as studies show fewer emissions and that the practice is more beneficial to public health (Jenner & Lamadrid, 2013). More research needs to be done in order to understand the comparison of coal mining and hydraulic fracturing in the

United States. As such, in this study I will be analyzing the relationships between coal mining and fracking and drinking water quality, to compare the differences and similarities between the two forms of extractive industry.

Section 2.3. Methods

Data. Several datasets were compiled to create a comprehensive dataset of fracking, coal mining, drinking water quality violations, and demographics for the years of 2010-2019. Hydraulic fracturing well data was obtained from FracFocus, an organization that created a hydraulic fracturing chemical disclosure registry (FracFocus, 2023). Twenty-five separate CSV files were downloaded and appended together to create a full dataset of the well sites. The dataset recorded the state and county that a well was located in using Federal Information Processing Series (FIPS) codes—which identifies both the state and county of residence via a numeric code. This dataset also includes the job start date for each well. To conduct analyses, the total number of fracking wells per county was calculated. Due to county boundary changes over time, FIPS codes had to be recoded for some of the observations and this was done after appending all the CSV files together. Some counties had to be combined to be time consistent if a county split in a later year. A count variable was created; each observation was assigned the value 1. The data was collapsed by county, summing the count variable to determine the number of fracking well sites in a county.

Data from the American Community Survey (ACS) were extracted from the Integrated Public Use Microdata Series – National Historical Geographical Information System (IPUMS-NHGIS) (Manson et al., 2023). ACS data was taken for the years 2008-2012, 2009-2013, 2010-2014, 2011-2015, 2012-2016, 2013-2017, 2014-2018, 2015-2019, 2016-2020, and 2017-2021.

The five-year estimates were used due to the survey being conducted on a rolling sampling structure. The one-year estimates are much less accurate, especially for smaller geographical areas and population groups, such as rural counties (US Census Bureau, 2017). All data was extracted at the county level. A year variable was created for each of the binned years and coded as the midpoint year (ex. 2008-2012=2010). The variables total population, race, poverty, income, and education were kept. The data for all years was appended together into a full demographic dataset. A 2020 national county-level shapefile was also extracted from IPUMS-NHGIS to facilitate spatial modeling.

The coal mine site data was obtained from the Mine Safety and Health Administration, through the Mine Data Retrieval System (MSHA, 2023). This data provides information on all types of mines in the United States, including coal. The dataset begins in 1970 and is updated every Friday. All mines that were not coal mines were removed from the dataset and FIPS codes were used to identify the county each mine was located in. To facilitate analyses, the cumulative number of coal mines per county was calculated.

Drinking water quality data was retrieved from the United States Environmental Protection Agency (EPA) Safe Drinking Water Information System (SDWIS) (EPA, 2023a). The Violations and Water System Summary datasets were used to create the dataset. The Violations dataset required an advanced search, and the search terms included health-based violations, national scope, located in a community water system (CWS), and active water systems at that time. This was repeated for years 2010 to 2019. In the initial dataset each observation represents a violation. To link violations to their system and county, the 2020 water system summary dataset was downloaded and merged with the violations datasets. Some county FIPS codes had to be recoded, as the county FIPS code had changed or the county split over the time period of the study. The specific FIPS code changes are shown in Table A.1. in the appendix.

Independent Variables. In order to conduct regression modeling, several variables were used and/or created. In terms of the independent variables for coal mining and fracking, I estimated models using continuous measures of the total count of mines or fracking sites. Further, two new binary variables were created for coal mines and fracking. If coal mines or fracking sites were coded as 1, they were present in a county. If they were not present, they were coded as 0. Therefore, there were binary and continuous versions of the coal mine and fracking site variables.

Dependent Variables. The drinking water quality violations took on three different forms, continuous, binary, and threshold. The continuous version was the number of violations in a county. The binary variable was coded as 1 if a drinking water quality violation was present and coded 0 if it was not. The threshold variable was created using the median number of violations present. The median was determined to be 5. If a county had more than 5 violations, it was coded as 1. If a county had less than 5 it was coded as 0.

Control Variables. For all the models, percent Black, percent Latino, percent with a bachelor's degree, poverty rate, total population (per thousand) and year were included. These variables were chosen as they are viewed as likely confounders, meaning they are likely influencing both the independent and dependent variables in this study. The variables were chosen due to research on the demographics of those who live near coal and fracking sites, as well as those who experience a greater degree of water quality violations independent of proximity to resource extraction. Research has shown that environmental harms tend to be closer to people of lower socioeconomic status or a marginalized race (Brulle & Pellow, 2005; Evans &

Kantrowitz, 2002). There is also research that shows that minorities and people of lower socioeconomic status are more likely to experience drinking water quality violations (Schaider et al., 2019; McDonald & Jones, 2018; Switzer & Teodoro, 2018).

Analytic Approach. The datasets were all combined and collapsed by FIPS and year (2010-2019). The race, education, and poverty variables were transformed into a percentage. The recodes of the FIPS codes were run again to ensure that all FIPS codes were coded properly before creating the spatial weights matrices. There were two separate geographies used in the analysis. One included all states and counties in the United States. The second, which I call state-limited, is limited to only the states in which fracking and/or coal mining occurs. All states that do not have either were removed from this state-limited analysis. The states that were kept are shown in red in Figure 2. 2..

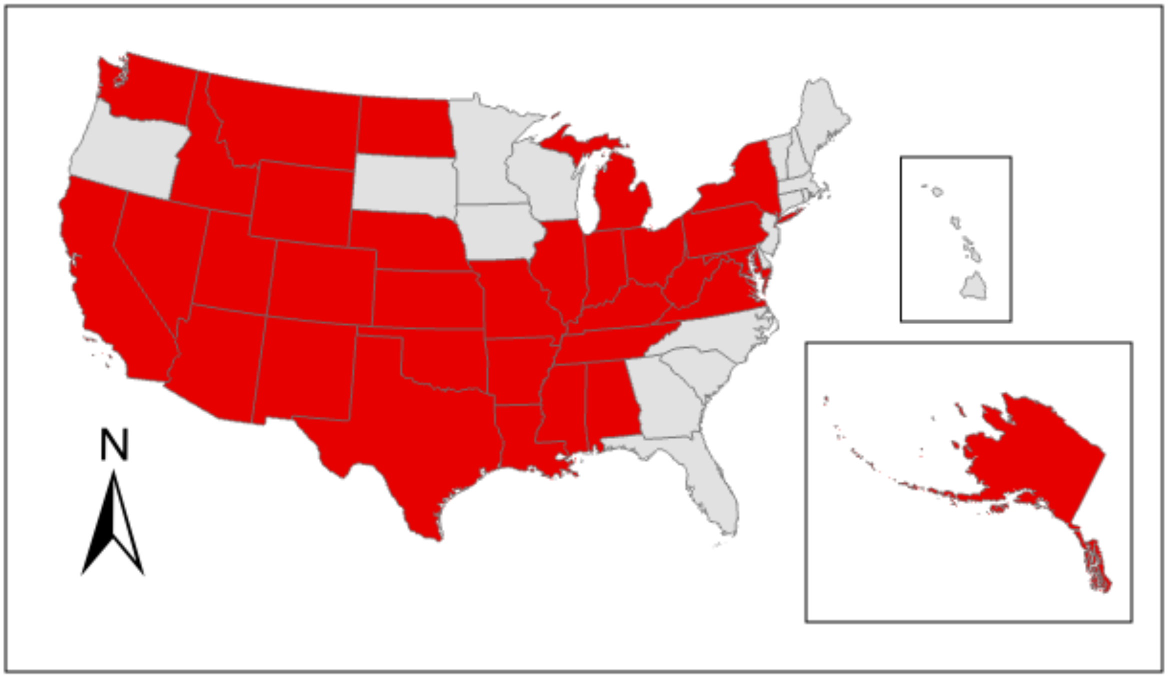

Figure 2.2. States with coal and/or fracking

Stata was used to run multiple regression models. These regressions helped to determine the relationship between health-based drinking water quality violations and coal mines and fracking. A spatial econometric model known as a spatial lag of X model (SLX), was used to control for spatial spillover effects. SLX accounts for local spillover effects, rather than global. This form of model includes spatial lags of all independent variables and is a recommended starting point for applied spatial econometrics (Vega & Elhorst, 2015). The standard errors were cluster-robust and a queen's first order contiguity spatial weights matrices was used. A total of 24 regression models were run. 12 of the models were for the national scale analysis and the other 12 models were for the state-limited analysis. The coal mines, fracking sites, and drinking water quality violations variables changed between the models. The fracking and coal mining variables were also in two different forms, continuous and binary. Fixed effects with unit and period fixed effects were used. This allows for the isolation of the within-county associations. Unit fixed effects control for time-invariant factors. Year fixed effects are included as dummy variables to control for time and general trends. Dummy variables are appropriate in this instance as it cannot be assumed that the trend is linear. This approach is rather conservative

Section 2.4. Results

The results of the analyses are shown through tables comparing the different models. The results are split into two sections, the first is the state-limited analysis, only including the counties in states where fracking and/or mining occurred during the study period. The second section includes all states and counties in the United States. All primary within-county models are summarized in Tables 2.9 and 2.10.

Section 2.4.1. State-Limited Within Analysis:

The state-limited SLX models are presented in Tables 2.1 through 2.4. Although I present a detailed description of each model below, the overall finding is that there is not a clear within-county relationship between mining and water quality violations, nor between fracking and water quality violations.

Table 2.1. State-Limited: Within County Regression of Drinking Water Quality Violations on Fracking Sites (Binary)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Fracking Sites (Binary)	0.11	0.19	0.0021	0.014	0.011	0.011
% Black	-0.11*	0.051	-0.0085	0.0046	-0.0058	0.0036
% Latino	-0.037	0.028	0.0041	0.0031	-0.00020	0.0015
% w/ Bachelors	-0.027	0.019	-0.0017	0.0021	-0.0034*	0.0013
Poverty Rate	0.011	0.015	0.0014	0.0017	0.0011	0.0011
Population (thousands)	-0.023*	0.0090	0.00014	0.00027	-0.00048	0.00033
Year [2010 ref]						
2011	-0.22**	0.079	-0.022*	0.011	-0.012	0.0065
2012	-0.28**	0.11	-0.045***	0.012	-0.020*	0.0080
2013	-0.30*	0.12	-0.054***	0.013	-0.028**	0.0088
2014	0.16	0.14	0.00033	0.014	-0.0033	0.010
2015	0.78***	0.17	0.015	0.016	0.031**	0.012
2016	0.66	0.34	-0.13***	0.032	-0.031	0.020
2017	0.20	0.22	-0.16***	0.019	-0.012	0.014
2018	0.25	0.27	-0.17***	0.022	-0.016	0.016
2019	0.41	0.31	-0.17***	0.023	-0.016	0.017
Indirect Effects						
Fracking Sites (binary)	1.53***	0.38	0.076**	0.026	0.030	0.019
% Black	-0.29*	0.13	-0.023*	0.011	-0.0078	0.0067
% Latino	-0.40***	0.088	-0.0071	0.0070	-0.013**	0.0049
% w/ Bachelors	-0.15**	0.055	-0.0093*	0.0046	-0.0095**	0.0032
Poverty Rate	0.016	0.015	-0.0014	0.0016	-0.0020	0.0011
Population (thousands)	-0.00071	0.018	-0.00019	0.00053	0.000070	0.00039
Constant	15.3***	2.24	0.99***	0.16	0.71***	0.11
Observations	23129		23129		23129	

Standard errors in second column

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Analysis only includes 31 states with fracking and/or coal mining

Table 2.1. shows regression models of drinking water quality violations on the binary fracking variable. There are three models, with the drinking water quality violations variable coded as continuous, binary, and threshold. Fracking as a binary variable is not statistically

significantly related to drinking water quality violations in any of the three forms. With the indirect effects, fracking was statistically significantly related to drinking water quality violations when coded as continuous or binary.

Table 2.2. State-Limited: Within County Regression of Drinking Water Quality Violations on Coal Mines (Binary)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Coal Mines (binary)	-0.13	0.16	0.00067	0.025	0.00035	0.015
% Black	-0.11*	0.051	-0.0085	0.0046	-0.0058	0.0036
% Latino	-0.032	0.027	0.0044	0.0031	-0.000057	0.0015
% w/ Bachelors	-0.028	0.019	-0.0018	0.0021	-0.0034*	0.0013
Poverty Rate	0.010	0.015	0.0014	0.0017	0.0010	0.0011
Population (thousands)	-0.023*	0.0090	0.00013	0.00027	-0.00048	0.00033
Year [2010 ref]						
2011	-0.048	0.065	-0.014	0.011	-0.0073	0.0063
2012	-0.017	0.094	-0.032**	0.011	-0.013	0.0075
2013	-0.035	0.12	-0.041***	0.013	-0.022*	0.0084
2014	0.42**	0.15	0.013	0.014	0.0031	0.010
2015	1.00***	0.18	0.025	0.016	0.036**	0.011
2016	0.81*	0.35	-0.12***	0.031	-0.027	0.020
2017	0.38	0.24	-0.15***	0.019	-0.0071	0.014
2018	0.43	0.29	-0.16***	0.022	-0.011	0.016
2019	0.57	0.33	-0.17***	0.023	-0.012	0.017
Indirect Effects						
Coal Mines (binary)	0.37	0.39	0.0022	0.049	0.0018	0.033
% Black	-0.29*	0.13	-0.023*	0.011	-0.0078	0.0067
% Latino	-0.36***	0.086	-0.0052	0.0069	-0.012*	0.0048
% w/ Bachelors	-0.16**	0.056	-0.0099*	0.0046	-0.0098**	0.0032
Poverty Rate	0.014	0.015	-0.0014	0.0016	-0.0021	0.0011
Population (thousands)	-0.00072	0.018	-0.00019	0.00053	0.000065	0.00039
Constant	15.2***	2.24	0.99***	0.16	0.71***	0.11
Observations	23129		23129		23129	

Standard errors in second column
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Analysis only includes 31 states with fracking and/or coal mining

Table 2.2. shows three regression models of drinking water quality violations of the binary coal mines variable. There are three models tested, the dependent variable form of drinking water quality violations changes. In the first model the violations variable is continuous. The binary form of the coal mines variable is not statistically significant, and neither are the controls. The violations variable is binary in the second model. The coal mine variable is not statistically significant in this model. The third model has the violations variable as a threshold. The coal mine variable is not statistically significant.

Table 2.3. State-Limited: Within County Regression of Drinking Water Quality Violations on Fracking Sites (Count)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Fracking Sites (count)	-0.000025	0.000060	0.0000028	0.000003	0.000005*	0.000002
% Black	-0.11*	0.051	-0.0084	0.0046	-0.0058	0.0036
% Latino	-0.032	0.027	0.0043	0.0030	-0.00010	0.0015
% w/ Bachelors	-0.028	0.019	-0.0018	0.0021	-0.0035*	0.0013
Poverty Rate	0.010	0.015	0.0014	0.0017	0.0011	0.0011
Population (thousands)	-0.023*	0.0090	0.00013	0.00027	-0.00049	0.00033
Year [2010 ref]						
2011	-0.050	0.065	-0.014	0.010	-0.0074	0.0063
2012	-0.015	0.094	-0.032**	0.011	-0.013	0.0075
2013	-0.038	0.12	-0.045***	0.013	-0.021*	0.0084
2014	0.41**	0.15	0.0079	0.014	0.0038	0.010
2015	1.00***	0.18	0.023	0.016	0.037**	0.011
2016	0.81*	0.35	-0.12***	0.032	-0.028	0.020
2017	0.38	0.24	-0.15***	0.019	-0.0071	0.014
2018	0.43	0.29	-0.16***	0.022	-0.011	0.016
2019	0.57	0.33	-0.17***	0.023	-0.012	0.017
Indirect Effects						
Fracking Sites (count)	0.000028	0.000075	0.000009*	0.000004	-0.000006	0.000004
% Black	-0.29*	0.13	-0.023*	0.011	-0.0077	0.0067
% Latino	-0.36***	0.085	-0.0069	0.0070	-0.011*	0.0049
% w/ Bachelors	-0.16**	0.056	-0.0099*	0.0046	-0.0098**	0.0032
Poverty Rate	0.014	0.015	-0.0013	0.0016	-0.0021*	0.0011
Population (thousands)	-0.00076	0.018	-0.00018	0.00054	0.000074	0.00039
Constant	15.3***	2.24	1.00***	0.16	0.71***	0.11
Observations	23129		23129		23129	

Standard errors in second column

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Analysis only includes 31 states with fracking and/or coal mining

Table 2.3. shows three regression models of drinking water quality violations on fracking sites as a count variable. In the first model the dependent violations variable is continuous. The number of fracking wells is not statistically significant in relation to the number of drinking water quality violations. The second model uses the binary form of the drinking water quality violations variable. The number of fracking sites is not statistically significant in relation to the

binary drinking water quality violations variable. However, the indirect effects for the fracking wells variable are statistically significant in relation to the binary violation's variable. The final model is drinking water quality violations coded as a threshold variable. Unlike the other models thus far, the number of fracking wells is statistically significant in relation to the violation's threshold variable, meaning that as fracking increases within a county, the likelihood of five or more violations increased.

Table 2.4. State-Limited: Within County Regression of Drinking Water Quality Violations on Coal Mines (Count)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Coal Mines (count)	-0.041	0.036	-0.0087	0.0064	-0.0059	0.0037
% Black	-0.11*	0.051	-0.0086	0.0046	-0.0058	0.0036
% Latino	-0.032	0.027	0.0045	0.0031	-0.0000064	0.0015
% w/ Bachelors	-0.028	0.019	-0.0017	0.0021	-0.0034*	0.0013
Poverty Rate	0.010	0.015	0.0014	0.0017	0.0011	0.0011
Population (thousands)	-0.023**	0.0090	0.00013	0.00027	-0.00048	0.00033
Year [2010 ref]						
2011	-0.052	0.066	-0.016	0.011	-0.0081	0.0063
2012	-0.015	0.094	-0.032**	0.011	-0.013	0.0075
2013	-0.039	0.12	-0.043***	0.012	-0.022**	0.0084
2014	0.41**	0.15	0.011	0.014	0.0024	0.010
2015	1.00***	0.18	0.023	0.016	0.035**	0.011
2016	0.80*	0.35	-0.13***	0.031	-0.029	0.020
2017	0.38	0.24	-0.16***	0.019	-0.0087	0.014
2018	0.43	0.29	-0.16***	0.022	-0.013	0.016
2019	0.57	0.33	-0.17***	0.023	-0.014	0.017
Indirect Effects						
Coal Mines (count)	0.0086	0.062	-0.022	0.012	-0.0078	0.0050
% Black	-0.29*	0.13	-0.023*	0.011	-0.0078	0.0067
% Latino	-0.36***	0.086	-0.0046	0.0069	-0.011*	0.0048
% w/ Bachelors	-0.16**	0.056	-0.0094*	0.0046	-0.0096**	0.0032
Poverty Rate	0.014	0.015	-0.0016	0.0016	-0.0021*	0.0011
Population (thousands)	-0.00072	0.018	-0.00020	0.00053	0.000063	0.00039
Constant	15.2***	2.24	0.98***	0.16	0.71***	0.11
Observations	23129		23129		23129	

Standard errors in second column

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Analysis only includes 31 states with fracking and/or coal mining

Three model's coefficient results are shown in Table 2.4. of regressions of drinking water quality violations on coal mines. The first model uses the continuous drinking water quality violations variable. The number of coal mines is not statistically significant in relation to the number of violations. The second model is the regression of violations as a binary variable on the number of coal mines. The model is not statistically significant. The third model uses the variable drinking water quality violations coded as a threshold variable. The number of coal mines is not statistically significant in relation to drinking water quality violations as a threshold variable.

Section 2.4.2. All States Within:

This section presents the results of the models for the national, all counties included analysis.

Table 2.5. All States: Within County Regression of Drinking Water Quality Violations on Fracking Sites (Binary)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Fracking Sites (binary)	0.12	0.19	0.0024	0.014	0.012	0.011
% Black	-0.080*	0.035	-0.0075*	0.0035	-0.0049	0.0026
% Latino	-0.036	0.025	0.0034	0.0029	-0.00036	0.0015
% w/ Bachelors	-0.035*	0.016	-0.0023	0.0018	-0.0031**	0.0011
Poverty Rate	0.0075	0.012	0.0015	0.0014	0.00096	0.00093
Population (thousands)	-0.023**	0.0077	0.00011	0.00026	-0.00056	0.00030
Year [2010 ref]						
2011	-0.23***	0.065	-0.023*	0.0094	-0.010	0.0055
2012	-0.27**	0.088	-0.043***	0.010	-0.018**	0.0067
2013	-0.25*	0.10	-0.043***	0.011	-0.023**	0.0074
2014	0.12	0.12	-0.0094	0.012	-0.0028	0.0086
2015	0.61***	0.14	0.013	0.014	0.027**	0.0096
2016	0.15	0.27	-0.15***	0.026	-0.041*	0.016
2017	0.060	0.18	-0.17***	0.016	-0.015	0.012
2018	0.15	0.23	-0.17***	0.019	-0.015	0.013
2019	0.35	0.26	-0.16***	0.020	-0.010	0.014
Indirect Effects						
Fracking Sites (binary)	1.54***	0.37	0.075**	0.025	0.031	0.019
% Black	-0.24**	0.092	-0.018*	0.0085	-0.0067	0.0049
% Latino	-0.40***	0.081	-0.0051	0.0064	-0.015**	0.0046
% w/ Bachelors	-0.17***	0.046	-0.010**	0.0038	-0.012***	0.0027
Poverty Rate	-0.0033	0.012	-0.0020	0.0013	-0.0022**	0.00082
Population (thousands)	0.000076	0.015	-0.00047	0.00049	0.000046	0.00038
Constant	15.6***	1.79	1.02***	0.13	0.77***	0.095
Observations	31419		31419		31419	

Standard errors in second column
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.5. shows the three models used in the regression of drinking water quality on fracking sites (binary). The model with the continuous dependent variable of drinking water quality violations. The binary fracking variable is not statistically significant in relation to the continuous violation's variable. However, the indirect effects for the fracking variable is statistically significant. The second model has the binary violations variable as the dependent.

The binary fracking variable is not statistically significant in relation to the binary violation's variable. The indirect effects of the binary fracking variable is statistically significant. The third model uses the threshold form of the violation's variable. The fracking binary variable is not statistically significant in relation to the threshold drinking water quality violations variable.

Table 2.6. All States: Within County Regression of Drinking Water Quality Violations on Coal Mines (Binary)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Coal Mines (binary)	-0.13	0.16	0.00053	0.025	0.00032	0.015
% Black	-0.080^{*}	0.035	-0.0076^{*}	0.0035	-0.0049	0.0025
% Latino	-0.031	0.025	0.0037	0.0029	-0.00022	0.0015
% w/ Bachelors	-0.037^{*}	0.016	-0.0024	0.0018	-0.0032^{**}	0.0011
Poverty Rate	0.0066	0.012	0.0014	0.0014	0.00094	0.00094
Population (thousands)	-0.023^{**}	0.0076	0.00010	0.00026	-0.00056	0.00030
Year [2010 ref]						
2011	-0.098	0.058	-0.017	0.0092	-0.0071	0.0053
2012	-0.073	0.080	-0.034^{***}	0.0099	-0.013^{*}	0.0064
2013	-0.057	0.10	-0.034^{**}	0.011	-0.018^{*}	0.0072
2014	0.30^{*}	0.12	-0.00069	0.012	0.0020	0.0086
2015	0.78^{***}	0.15	0.020	0.013	0.031^{**}	0.0096
2016	0.25	0.28	-0.14^{***}	0.026	-0.038^{*}	0.016
2017	0.19	0.19	-0.16^{***}	0.016	-0.011	0.012
2018	0.28	0.23	-0.16^{***}	0.019	-0.012	0.013
2019	0.46	0.27	-0.16^{***}	0.020	-0.0073	0.014
Indirect Effects						
Coal Mines (binary)	0.36	0.38	0.0036	0.049	0.0021	0.033
% Black	-0.24^{**}	0.092	-0.018^{*}	0.0085	-0.0067	0.0049
% Latino	-0.36^{***}	0.079	-0.0033	0.0064	-0.014^{**}	0.0046
% w/ Bachelors	-0.18^{***}	0.047	-0.011^{**}	0.0038	-0.012^{***}	0.0027
Poverty Rate	-0.0046	0.012	-0.0021	0.0013	-0.0023^{**}	0.00082
Population (thousands)	-0.000066	0.015	-0.00048	0.00049	0.000038	0.00038
Constant	15.5^{***}	1.78	1.02^{***}	0.13	0.77^{***}	0.095
Observations	31419		31419		31419	

Standard errors in second column

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.6. presents three regression models of drinking water quality violations on coal mines (binary). The first model shows the use of the continuous violations variable and the binary coal mines data. The binary coal mines are not statistically significant in relation to the number of drinking water quality violations. The second model includes the binary drinking water quality violations variable. The binary coal mines independent variable is not statistically significant in relation to the binary violations data. The final model uses the threshold drinking water quality violations variable. The binary coal mines variable is not statistically significant in relation to the threshold violations variable.

Table 2.7. All States: Within County Regression of Drinking Water Quality Violations on Fracking Wells (Count)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Fracking Sites (count)	-0.000024	0.000060	0.000003	0.000003	0.000005**	0.000002
% Black	-0.080*	0.035	-0.0075*	0.0035	-0.0049	0.0025
% Latino	-0.030	0.025	0.0036	0.0028	-0.00026	0.0015
% w/ Bachelors	-0.037*	0.016	-0.0024	0.0018	-0.0032**	0.0011
Poverty Rate	0.0066	0.012	0.0015	0.0014	0.00096	0.00094
Population (thousands)	-0.023**	0.0076	0.00010	0.00026	-0.00057	0.00030
Year [2010 ref]						
2011	-0.099	0.058	-0.017	0.0092	-0.0072	0.0053
2012	-0.072	0.080	-0.034***	0.0099	-0.013*	0.0064
2013	-0.062	0.10	-0.037***	0.011	-0.018*	0.0072
2014	0.30*	0.13	-0.0041	0.012	0.0022	0.0086
2015	0.77***	0.15	0.019	0.013	0.031**	0.0096
2016	0.25	0.28	-0.14***	0.026	-0.039*	0.016
2017	0.19	0.19	-0.16***	0.016	-0.011	0.012
2018	0.28	0.23	-0.16***	0.019	-0.012	0.013
2019	0.46	0.27	-0.16***	0.020	-0.0074	0.014
Indirect Effects						
Fracking Sites (count)	0.000042	0.000075	0.0000095*	0.0000037	-0.0000053	0.0000037
% Black	-0.24**	0.092	-0.018*	0.0085	-0.0066	0.0049
% Latino	-0.37***	0.079	-0.0049	0.0064	-0.014**	0.0046
% w/ Bachelors	-0.18***	0.047	-0.011**	0.0038	-0.012***	0.0027
Poverty Rate	-0.0044	0.012	-0.0020	0.0013	-0.0023**	0.00082
Population (thousands)	-0.000081	0.015	-0.00046	0.00049	0.000045	0.00038
Constant	15.6***	1.79	1.03***	0.13	0.77***	0.095
Observations	31419		31419		31419	

Standard errors in second column
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Three regression models of drinking water quality violations on fracking wells are shown in table 2.7. The first model has the continuous violations variable and the continuous fracking well independent variable. The number of fracking wells is not statistically significant in relation to the number of drinking water quality violations. The second model has the binary dependent variable of drinking water quality violations on fracking wells. Fracking is not statistically significant in relation to violations. However, the indirect effects for the fracking variable are statistically significant. The third model includes the threshold drinking water quality violations as the dependent variable. The number of fracking wells is statistically significant in relation to the threshold violations variable.

Table 2.8. All States: Within County Regression of Drinking Water Quality Violations on Coal mines (Count)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Coal Mines (count)	-0.042	0.037	-0.0087	0.0064	-0.0060	0.0037
% Black	-0.080*	0.035	-0.0076*	0.0035	-0.0049	0.0025
% Latino	-0.031	0.025	0.0038	0.0029	-0.00018	0.0015
% w/ Bachelors	-0.037*	0.016	-0.0023	0.0018	-0.0032**	0.0011
Poverty Rate	0.0067	0.012	0.0015	0.0014	0.00094	0.00094
Population (thousands)	-0.023**	0.0076	0.000099	0.00026	-0.00056	0.00030
Year [2010 ref]						
2011	-0.10	0.058	-0.018*	0.0092	-0.0077	0.0054
2012	-0.073	0.080	-0.034***	0.0099	-0.013*	0.0064
2013	-0.060	0.10	-0.036***	0.011	-0.019**	0.0072
2014	0.30*	0.13	-0.0019	0.012	0.0014	0.0086
2015	0.77***	0.15	0.018	0.013	0.030**	0.0096
2016	0.24	0.28	-0.15***	0.026	-0.040*	0.016
2017	0.19	0.19	-0.17***	0.016	-0.013	0.012
2018	0.27	0.23	-0.16***	0.019	-0.013	0.013
2019	0.46	0.27	-0.16***	0.020	-0.0086	0.014
Indirect Effects						
Coal Mines (count)	0.0014	0.062	-0.022	0.012	-0.0077	0.0050
% Black	-0.24**	0.092	-0.018*	0.0085	-0.0067	0.0049
% Latino	-0.36***	0.079	-0.0028	0.0063	-0.014**	0.0046
% w/ Bachelors	-0.18***	0.047	-0.010**	0.0038	-0.012***	0.0027
Poverty Rate	-0.0048	0.012	-0.0022	0.0013	-0.0023**	0.00083
Population (thousands)	-0.000068	0.015	-0.00048	0.00049	0.000035	0.00038
Constant	15.5***	1.79	1.01***	0.13	0.77***	0.095
Observations	31419		31419		31419	

Standard errors in second column
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.8. shows the results of three regression models of drinking water quality violations on coal mines. The first model has the continuous variable of drinking water quality violations. The number of coal mines is not statistically significant in relation to violations. The second model uses the binary drinking water quality violations variable. The number of coal mines is not statistically significant in relation to violations. The final model includes the threshold drinking water quality violations variable as the dependent. The number of coal mines is not statistically significant, in relation to violations.

Table 2.9. Within County: Regression Result Summary Direct Effects

	DW Violations (Continuous)	DW Violations (Binary)	DW Violations (Threshold)
State-Limited			
Coal Mines (Count)	n.s.	n.s.	n.s.
Coal Mines (Binary)	n.s.	n.s.	n.s.
Fracking (Count)	n.s.	n.s.	+
Fracking (Binary)	n.s.	n.s.	n.s.
All States			
Coal Mines (Count)	n.s.	n.s.	n.s.
Coal Mines (Binary)	n.s.	n.s.	n.s.
Fracking (Count)	n.s.	n.s.	+
Fracking (Binary)	n.s.	n.s.	n.s.

Table 2.10. Within County: Regression Result Summary Indirect Effects

	DW Violations (Continuous)	DW Violations (Binary)	DW Violations (Threshold)
State-Limited			
Coal Mines (Count)	n.s.	n.s.	n.s.
Coal Mines (Binary)	n.s.	n.s.	n.s.
Fracking (Count)	n.s.	+	n.s.
Fracking (Binary)	+	+	n.s.
All States			
Coal Mines (Count)	n.s.	n.s.	n.s.
Coal Mines (Binary)	n.s.	n.s.	n.s.
Fracking (Count)	n.s.	+	n.s.
Fracking (Binary)	+	+	n.s.

Section 2.4.3. Sub-analysis State-Limited: No county fixed effects

Due to the lack of within-county effects, this section presents a sub-analysis where year-on-year county fixed effects are removed from the model. The fixed effects model is conservative and removes variation, meaning that it is possible the use of fixed effects is underestimating relationship. Thus, this was done to see if the lack of an effect continues to be seen with the removal of county fixed effects and just looking at the between county differences. I first present the state-limited sub-analysis, followed by the all-states sub-analysis. As shown in the tables, there is a significant between county effect for both coal mining and fracking, depending on the model formulation. All between-county model results are summarized in Tables 2.19 and 2.20.

Table 2.11. State-Limited: Between County Regression of Drinking Water Quality Violations on Frack Sites (Binary)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Fracking Sites (binary)	1.02^{*}	0.42	0.023	0.014	0.029^{*}	0.012
% Black	-0.012	0.0064	-0.00090	0.00050	-0.00046	0.00032
% Latino	0.058^{***}	0.016	0.0037^{***}	0.00051	0.0022^{***}	0.00041
% w/ Bachelors	0.0098	0.0077	0.0041^{***}	0.00047	0.0011^{***}	0.00032
Poverty Rate	0.059^{***}	0.011	0.00046	0.00074	0.0014^{**}	0.00052
Population (thousands)	0.0017^{***}	0.00036	0.000060^{***}	0.000009	0.000082^{***}	0.000009
Year [2010 ref]						
2011	-0.50^{*}	0.26	-0.040^{**}	0.015	-0.035^{**}	0.011
2012	-0.77^{**}	0.25	-0.074^{***}	0.015	-0.058^{***}	0.011
2013	-0.93^{***}	0.24	-0.087^{***}	0.015	-0.073^{***}	0.011
2014	-0.58^{*}	0.25	-0.036^{*}	0.015	-0.054^{***}	0.011
2015	-0.073	0.25	-0.024	0.015	-0.023^{*}	0.011
2016	-0.12	0.32	-0.083^{***}	0.022	-0.0012	0.016
2017	-0.85^{***}	0.24	-0.20^{***}	0.014	-0.073^{***}	0.010
2018	-0.91^{***}	0.24	-0.21^{***}	0.014	-0.084^{***}	0.010
2019	-0.86^{***}	0.24	-0.22^{***}	0.014	-0.089^{***}	0.010
Indirect Effects						
Fracking Sites (binary)	1.65^{***}	0.47	0.17^{***}	0.019	0.14^{***}	0.016
% Black	-0.0011	0.0081	-0.00023	0.00057	0.000017	0.00037
% Latino	0.027	0.021	-0.0012^{*}	0.00058	0.0010^{*}	0.00046
% w/ Bachelors	-0.095^{***}	0.014	-0.0052^{***}	0.00075	-0.0021^{***}	0.00051
Poverty Rate	0.026	0.016	0.0040^{***}	0.0011	0.0034^{***}	0.00078
Population (thousands)	0.0045^{***}	0.0010	0.00011^{***}	0.000021	0.000071^{***}	0.000019
Constant	1.95^{***}	0.36	0.42^{***}	0.026	0.084^{***}	0.018
Observations	23129		23129		23129	
R^2	0.079		0.065		0.072	

Standard errors in second column

$^{*} p < 0.05$, $^{**} p < 0.01$, $^{***} p < 0.001$

Note: Analysis only includes 31 states with fracking and/or coal mining

There is a significant relationship between fracking and drinking water quality violations in two of the models shown in table 2.11. When the violations variable is continuous and threshold, there is statistically significant positive relationship between fracking activity and violations. Increased fracking activity is associated with increased violations. When the violations variable is in a binary format, it is not statistically significant. The indirect effects are statistically significant for all three versions of the drinking water quality violation variable.

Table 2.12. State-Limited: Between County Regression of Drinking Water Quality Violations on Coal Mines (Binary)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Coal Mines (binary)	0.073	0.17	0.057**	0.021	0.016	0.013
% Black	-0.012	0.0065	-0.00085	0.00051	-0.00042	0.00033
% Latino	0.058***	0.016	0.0037***	0.00050	0.0021***	0.00041
% w/ Bachelors	0.0058	0.0079	0.0039***	0.00047	0.00089**	0.00032
Poverty Rate	0.059***	0.012	0.00027	0.00074	0.0013*	0.00053
Population (thousands)	0.0018***	0.00036	0.000060***	0.000008	0.000082***	0.000009
Year [2010 ref]						
2011	-0.22	0.25	-0.020	0.015	-0.016	0.011
2012	-0.32	0.25	-0.042**	0.014	-0.029**	0.011
2013	-0.50*	0.25	-0.056***	0.014	-0.045***	0.011
2014	-0.14	0.25	-0.0052	0.015	-0.025*	0.011
2015	0.32	0.25	0.0044	0.015	0.0026	0.011
2016	0.23	0.32	-0.066**	0.022	0.016	0.016
2017	-0.49*	0.24	-0.18***	0.014	-0.050***	0.011
2018	-0.53*	0.25	-0.19***	0.014	-0.060***	0.010
2019	-0.51*	0.25	-0.20***	0.014	-0.067***	0.010
Indirect Effects						
Coal Mines (binary)	-2.43***	0.27	-0.15***	0.031	-0.12***	0.020
% Black	-0.0054	0.0082	-0.00039	0.00058	-0.00016	0.00038
% Latino	0.043*	0.021	0.00012	0.00057	0.0022***	0.00045
% w/ Bachelors	-0.11***	0.014	-0.0063***	0.00075	-0.0031***	0.00052
Poverty Rate	0.027	0.016	0.0037***	0.0011	0.0032***	0.00080
Population (thousands)	0.0043***	0.0010	0.000093***	0.000020	0.000060**	0.000019
Constant	2.38***	0.36	0.45***	0.026	0.11***	0.018
Observations	23129		23129		23129	
R^2	0.074		0.058		0.060	

Standard errors in second column

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Analysis only includes 31 states with fracking and/or coal mining

There is a statistically significant positive relationship between drinking water quality violations as a binary variable and coal mining, as shown in table 2.12. However, when the violations variable is continuous or threshold, the relationship is not statistically significant. The indirect effects are statistically significant for all versions of the violations variable. The relationship is negative.

Table 2.13. State-Limited: Between County Regression of Drinking Water Quality Violations on Frack Sites (Count)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Fracking Sites (count)	0.00029*	0.00013	0.000008***	0.000002	0.0000028	0.000002
% Black	-0.011	0.0065	-0.00079	0.00051	-0.00035	0.00033
% Latino	0.056***	0.016	0.0037***	0.00051	0.0022***	0.00041
% w/ Bachelors	0.0071	0.0076	0.0040***	0.00047	0.00091**	0.00032
Poverty Rate	0.054***	0.011	0.000079	0.00074	0.0010	0.00052
Population (thousands)	0.0017***	0.00035	0.000060***	0.000008	0.000081***	0.000008
Year [2010 ref]						
2011	-0.21	0.25	-0.019	0.015	-0.016	0.011
2012	-0.32	0.25	-0.042**	0.015	-0.029**	0.011
2013	-0.47	0.25	-0.056***	0.015	-0.044***	0.011
2014	-0.12	0.25	-0.0062	0.015	-0.025*	0.011
2015	0.33	0.25	0.0035	0.015	0.0022	0.011
2016	-0.024	0.33	-0.075***	0.022	0.0061	0.016
2017	-0.51*	0.24	-0.18***	0.014	-0.052***	0.011
2018	-0.58*	0.24	-0.19***	0.014	-0.063***	0.010
2019	-0.55*	0.25	-0.20***	0.014	-0.070***	0.010
Indirect Effects						
Fracking Sites (count)	-0.00031*	0.00015	-0.0000055	0.000004	-0.0000024	0.000003
% Black	0.000037	0.0081	-0.00018	0.00058	0.000066	0.00038
% Latino	0.051*	0.021	0.00030	0.00057	0.0024***	0.00046
% w/ Bachelors	-0.11***	0.014	-0.0061***	0.00075	-0.0030***	0.00051
Poverty Rate	0.012	0.016	0.0032**	0.0011	0.0026**	0.00079
Population (thousands)	0.0042***	0.00100	0.000089***	0.000020	0.000055**	0.000019
Constant	2.45***	0.35	0.45***	0.026	0.11***	0.018
Observations	23129		23129		23129	
R^2	0.075		0.057		0.059	

Standard errors in second column

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Analysis only includes 31 states with fracking and/or coal mining

Table 2.13. shows the results of three regressions of drinking water quality violations on fracking sites. There is a statistically significant relationship between fracking sites and violations. For every unit increase in fracking sites, there is an expected 0.00029 unit increase in the number of violations. When the violations variable is binary, the relationship is still statistically significant. It is not statistically significant when the violations variable is a threshold.

Table 2.14. State-Limited: Between County Regression of Drinking Water Quality Violations on Coal Mines (Count)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Coal Mines (count)	0.014	0.028	0.010^{*}	0.0048	0.0015	0.0028
% Black	-0.011	0.0065	-0.00082	0.00051	-0.00040	0.00033
% Latino	0.059^{***}	0.016	0.0037^{***}	0.00050	0.0022^{***}	0.00041
% w/ Bachelors	0.0063	0.0078	0.0039^{***}	0.00047	0.00092^{**}	0.00032
Poverty Rate	0.057^{***}	0.012	0.00018	0.00074	0.0012^{*}	0.00052
Population (thousands)	0.0017^{***}	0.00036	0.000060^{***}	0.000008	0.000081^{***}	0.000009
Year [2010 ref]						
2011	-0.23	0.25	-0.020	0.015	-0.017	0.011
2012	-0.32	0.25	-0.042^{**}	0.014	-0.029^{**}	0.011
2013	-0.50^{*}	0.25	-0.056^{***}	0.014	-0.045^{***}	0.011
2014	-0.14	0.25	-0.0052	0.015	-0.025^{*}	0.011
2015	0.31	0.25	0.0039	0.015	0.0020	0.011
2016	0.16	0.32	-0.069^{**}	0.022	0.014	0.016
2017	-0.51^{*}	0.24	-0.18^{***}	0.014	-0.051^{***}	0.011
2018	-0.56^{*}	0.24	-0.19^{***}	0.014	-0.062^{***}	0.010
2019	-0.54^{*}	0.25	-0.20^{***}	0.014	-0.068^{***}	0.010
Indirect Effects						
Coal Mines (count)	-0.39^{***}	0.047	-0.024^{***}	0.0064	-0.018^{***}	0.0038
% Black	-0.0035	0.0082	-0.00031	0.00058	-0.000084	0.00038
% Latino	0.045^{*}	0.021	0.00018	0.00056	0.0023^{***}	0.00045
% w/ Bachelors	-0.11^{***}	0.014	-0.0062^{***}	0.00075	-0.0031^{***}	0.00052
Poverty Rate	0.024	0.016	0.0036^{**}	0.0011	0.0030^{***}	0.00080
Population (thousands)	0.0043^{***}	0.0010	0.000091^{***}	0.000020	0.000058^{**}	0.000019
Constant	2.35^{***}	0.36	0.45^{***}	0.026	0.11^{***}	0.018
Observations	23129		23129		23129	
R^2	0.074		0.057		0.059	

Standard errors in second column

${}^{*} p < 0.05$, ${}^{**} p < 0.01$, ${}^{***} p < 0.001$

Note: Analysis only includes 31 states with fracking and/or coal mining

Table 2.14. shows the regressions of violations on coal mines as a count variable. The relationship between coal mines and violations is statistically significant when the violations variable is binary. For every unit increase in coal mines, there is an expected 0.010 unit increase in violations. There is not a statistically significant relationship when the violations variable is

continuous or threshold. However, the indirect effects are statistically significant for all violation variables. The relationship is negative in all three cases.

Section 2.4.4. Sub-analysis All States: No county fixed effects

Due to concerns that the two-way fixed effects models were overly-conservative given the possible small amount of variation found within the variables of interest, to further understand the relationship between fracking and coal mining and health-based drinking water quality violations between counties, the county fixed-effects were removed, and twelve regression models were run. Tables 15-18 include all counties in all states.

Table 2.15. All States: Between County Regression of Drinking Water Quality Violations on Frack Sites (Binary)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Fracking Sites (binary)	1.04^{*}	0.42	0.024	0.014	0.031^{**}	0.012
% Black	-0.013^{**}	0.0048	-0.0011^{*}	0.00042	-0.00066^{*}	0.00026
% Latino	0.047^{***}	0.013	0.0033^{***}	0.00046	0.0016^{***}	0.00036
% w/ Bachelors	0.019^{**}	0.0060	0.0042^{***}	0.00040	0.0016^{***}	0.00027
Poverty Rate	0.044^{***}	0.0085	0.00041	0.00061	0.0013^{**}	0.00041
Population (thousands)	0.0018^{***}	0.00033	0.000079^{***}	0.000010	0.000089^{***}	0.000009
Year [2010 ref]						
2011	-0.53^{**}	0.20	-0.042^{***}	0.012	-0.033^{***}	0.0093
2012	-0.80^{***}	0.19	-0.075^{***}	0.012	-0.057^{***}	0.0092
2013	-0.94^{***}	0.19	-0.081^{***}	0.012	-0.070^{***}	0.0090
2014	-0.70^{***}	0.19	-0.052^{***}	0.013	-0.056^{***}	0.0091
2015	-0.33	0.19	-0.034^{**}	0.013	-0.033^{***}	0.0093
2016	-0.21	0.25	-0.088^{***}	0.019	-0.0090	0.013
2017	-1.12^{***}	0.19	-0.22^{***}	0.012	-0.085^{***}	0.0086
2018	-1.19^{***}	0.19	-0.23^{***}	0.012	-0.096^{***}	0.0085
2019	-1.14^{***}	0.19	-0.23^{***}	0.012	-0.099^{***}	0.0085
Indirect Effects						
Fracking Sites (binary)	1.92^{***}	0.47	0.19^{***}	0.019	0.15^{***}	0.016
% Black	-0.010	0.0061	-0.00055	0.00048	-0.00026	0.00030
% Latino	0.034	0.018	-0.00052	0.00052	0.0016^{***}	0.00041
% w/ Bachelors	-0.063^{***}	0.011	-0.0011	0.00064	-0.00039	0.00043
Poverty Rate	0.041^{***}	0.012	0.0050^{***}	0.00090	0.0039^{***}	0.00062
Population (thousands)	0.0040^{***}	0.00091	0.00011^{***}	0.000021	0.000071^{***}	0.000019
Constant	1.30^{***}	0.29	0.31^{***}	0.022	0.034^{*}	0.015
Observations	31419		31419		31419	
R^2	0.079		0.071		0.073	

Standard errors in second column
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

There is a statistically significant association between the number of drinking water quality violations and fracking sites. For every unit increase in fracking sites, there is an expected 1.04 unit increase in drinking water quality violations. For the threshold model the association with fracking sites is also statistically significant. The indirect effects are positively associated with the violations variables.

Table 2.16. All States: Between County Regression of Drinking Water Quality Violations on Coal Mines (Binary)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Coal Mines (binary)	0.14	0.17	0.064**	0.021	0.020	0.013
% Black	-0.012*	0.0048	-0.00097*	0.00042	-0.00059*	0.00026
% Latino	0.048***	0.013	0.0033***	0.00045	0.0017***	0.00036
% w/ Bachelors	0.015*	0.0061	0.0040***	0.00040	0.0014***	0.00027
Poverty Rate	0.041***	0.0086	0.000074	0.00062	0.0011**	0.00041
Population (thousands)	0.0018***	0.00033	0.000078***	0.000010	0.000088***	0.000009
Year [2010 ref]						
2011	-0.30	0.20	-0.024*	0.012	-0.018	0.0093
2012	-0.43*	0.20	-0.049***	0.012	-0.034***	0.0091
2013	-0.58**	0.19	-0.055***	0.012	-0.047***	0.0090
2014	-0.34	0.19	-0.026*	0.012	-0.034***	0.0091
2015	-0.011	0.20	-0.011	0.012	-0.013	0.0093
2016	0.061	0.25	-0.077***	0.019	0.0045	0.013
2017	-0.83***	0.19	-0.20***	0.012	-0.068***	0.0087
2018	-0.88***	0.19	-0.21***	0.012	-0.078***	0.0086
2019	-0.86***	0.20	-0.21***	0.012	-0.083***	0.0086
Indirect Effects						
Coal Mines (binary)	-1.81***	0.26	-0.086**	0.031	-0.082***	0.019
% Black	-0.016*	0.0062	-0.00075	0.00048	-0.00052	0.00031
% Latino	0.054**	0.018	0.0011*	0.00051	0.0029***	0.00040
% w/ Bachelors	-0.077***	0.011	-0.0020**	0.00064	-0.0012**	0.00043
Poverty Rate	0.042***	0.012	0.0046***	0.00091	0.0037***	0.00063
Population (thousands)	0.0038***	0.00091	0.000092***	0.000020	0.000057**	0.000018
Constant	1.66***	0.29	0.34***	0.022	0.057***	0.015
Observations	31419		31419		31419	
R^2	0.073		0.063		0.060	

Standard errors in second column
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.16. presents the regression results of drinking water quality violations on coal mines (binary). The relationship between coal mining and violations is not statistically significant when the violations variable is continuous or threshold. The relationship is statistically significant when the violations variable is binary. The indirect effects of coal mines is negatively associated with all versions of the drinking water quality violations variable.

Table 2.17. All States: Between County Regression of Drinking Water Quality Violations on Frack Sites (Count)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Fracking Sites (count)	0.00029*	0.00013	0.000009***	0.000002	0.0000032	0.000002
% Black	-0.012*	0.0048	-0.00097*	0.00042	-0.00056*	0.00026
% Latino	0.046***	0.013	0.0032***	0.00045	0.0017***	0.00036
% w/ Bachelors	0.016**	0.0059	0.0041***	0.00040	0.0014***	0.00027
Poverty Rate	0.040***	0.0085	0.000100	0.00062	0.0010*	0.00041
Population (thousands)	0.0018***	0.00032	0.000078***	0.000010	0.000088***	0.000009
Year [2010 ref]						
2011	-0.29	0.20	-0.024*	0.012	-0.018	0.0093
2012	-0.44*	0.20	-0.049***	0.012	-0.034***	0.0091
2013	-0.58**	0.19	-0.056***	0.012	-0.048***	0.0090
2014	-0.34	0.19	-0.028*	0.013	-0.035***	0.0091
2015	-0.017	0.20	-0.012	0.013	-0.013	0.0093
2016	-0.081	0.25	-0.077***	0.019	-0.00031	0.013
2017	-0.86***	0.19	-0.20***	0.012	-0.069***	0.0087
2018	-0.92***	0.19	-0.21***	0.012	-0.080***	0.0086
2019	-0.90***	0.20	-0.21***	0.012	-0.084***	0.0086
Indirect Effects						
Fracking Sites (count)	-0.00027	0.00014	-0.0000035	0.000004	-0.0000010	0.000003
% Black	-0.012*	0.0061	-0.00071	0.00048	-0.00040	0.00031
% Latino	0.059**	0.018	0.0011*	0.00052	0.0030***	0.00041
% w/ Bachelors	-0.075***	0.011	-0.0020**	0.00064	-0.0011**	0.00043
Poverty Rate	0.033**	0.012	0.0046***	0.00091	0.0034***	0.00062
Population (thousands)	0.0037***	0.00090	0.000092***	0.000020	0.000054**	0.000018
Constant	1.66***	0.28	0.34***	0.022	0.057***	0.015
Observations	31419		31419		31419	
R^2	0.074		0.063		0.060	

Standard errors in second column
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

There is a statistically significant relationship between violations and the number of fracking sites. For every unit increase in the number of fracking sites in a county, the number of violations is expected to increase 0.00029 violations. When the model uses the binary form of violations, there is a statistically significant relationship. When violations is a threshold variable, the relationship is not significant.

Table 2.18. All States: Between County Regression of Drinking Water Quality Violations on Coal Mines (Count)

	Continuous		Binary		Threshold	
Direct Effects	Coef.	SE	Coef.	SE	Coef.	SE
Coal Mines (count)	0.021	0.028	0.011*	0.0049	0.0018	0.0028
% Black	-0.012*	0.0048	-0.00096*	0.00042	-0.00058*	0.00026
% Latino	0.048***	0.013	0.0033***	0.00045	0.0017***	0.00036
% w/ Bachelors	0.016*	0.0061	0.0040***	0.00040	0.0014***	0.00027
Poverty Rate	0.041***	0.0086	0.000058	0.00062	0.0011**	0.00041
Population (thousands)	0.0018***	0.00033	0.000077***	0.000010	0.000088***	0.000009
Year [2010 ref]						
2011	-0.30	0.20	-0.024*	0.012	-0.018*	0.0093
2012	-0.44*	0.20	-0.049***	0.012	-0.034***	0.0091
2013	-0.59**	0.19	-0.055***	0.012	-0.048***	0.0090
2014	-0.34	0.20	-0.026*	0.012	-0.034***	0.0091
2015	-0.019	0.20	-0.011	0.012	-0.013	0.0093
2016	0.021	0.25	-0.077***	0.019	0.0035	0.013
2017	-0.85***	0.19	-0.20***	0.012	-0.069***	0.0087
2018	-0.90***	0.19	-0.21***	0.012	-0.079***	0.0086
2019	-0.88***	0.20	-0.21***	0.012	-0.083***	0.0086
Indirect Effects						
Coal Mines (count)	-0.30***	0.046	-0.014*	0.0064	-0.013***	0.0037
% Black	-0.015*	0.0062	-0.00074	0.00048	-0.00049	0.00031
% Latino	0.055**	0.018	0.0011*	0.00051	0.0029***	0.00040
% w/ Bachelors	-0.076***	0.011	-0.0021**	0.00064	-0.0012**	0.00043
Poverty Rate	0.040**	0.012	0.0046***	0.00091	0.0037***	0.00063
Population (thousands)	0.0037***	0.00091	0.000092***	0.000020	0.000056**	0.000018
Constant	1.64***	0.29	0.34***	0.022	0.056***	0.015
Observations	31419		31419		31419	
R^2	0.072		0.063		0.060	

Standard errors in second column
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

There is a statistically significant positive relationship between coal mines and drinking water quality violations as a binary variable. For every unit increase in the number of coal mines, there is an expected 0.011 unit increase in violations. When the model uses the continuous or threshold variable for violations, the relationship is not statistically significant. The results shown in this section provide evidence to answer the research questions stated in the introduction of the paper. The indirect effects for coal mines are negatively associated with drinking water quality violations.

Table 2.19. Between: Regression Result Summary Direct Effects

	DW Violations (Continuous)	DW Violations (Binary)	DW Violations (Threshold)
State-Limited			
Coal Mines (Count)	n.s.	+	n.s.
Coal Mines (Binary)	n.s.	+	n.s.
Fracking (Count)	+	+	n.s.
Fracking (Binary)	+	n.s.	+
All States			
Coal Mines (Count)	n.s.	+	n.s.
Coal Mines (Binary)	n.s.	+	n.s.
Fracking (Count)	+	+	n.s.
Fracking (Binary)	+	n.s.	+

Table 2.20. Between: Regression Result Summary Indirect Effects

	DW Violations (Continuous)	DW Violations (Binary)	DW Violations (Threshold)
State-Limited			
Coal Mines (Count)	-	-	-
Coal Mines (Binary)	-	-	-
Fracking (Count)	-	n.s.	n.s.
Fracking (Binary)	+	+	+
All States			
Coal Mines (Count)	-	-	-
Coal Mines (Binary)	-	-	-
Fracking (Count)	n.s.	n.s.	n.s.
Fracking (Binary)	+	+	+

Section 2.5. Discussion

Coal mining and fracking have the potential to negatively impact drinking water quality and therefore public health. However, in this study, year-on-year within county changes in coal mining and fracking were not broadly found to be associated with increasing levels of drinking water quality violations. This finding suggests that there is a strong protective effect of community water systems in the United States. Although this finding is positive for public health, when looking between counties, I did find an association, dependent on model formulation. This suggests that there could be other factors that could be influencing the results. After running models without the county fixed effects, there appears to be a relationship between fracking and health-based drinking water quality violations between counties. Removing the county fixed effects allowed for more variation in the model. As the number of fracking wells increases, the number of drinking water quality violations also increases. Similar to fracking, year-on-year within county changes of coal mining also do not appear to have an association with increased levels of health-based drinking water quality violations. In some models without county fixed effects, coal mining activity is positively associated with increased levels of health-based drinking water quality violations. This means that as the number of coal mines increases, the number of health-based drinking water quality violations increases.

To answer the final research question, what is the difference between the association between coal mining and fracking on drinking water quality? There does not appear to be a major difference between the association of coal mining and fracking on health-based drinking water quality violations.

I am unable to conclude that increased levels of health-based drinking water quality violations are due to increased fracking or coal mining, or just other characteristics of the place they are located. These characteristics could include migration patterns associated with property values, the health characteristics of the mining and fracking workforce, or the pre-existing health characteristics of those living in areas with high concentrations of minerals and/or natural gas (Liu & Liu, 2020; Lockwood et al, 2018; Coffee et al., 2013; McKenzie et al., 2012). Although I cannot draw this conclusion, these results are still important. Based on previous works and the sub-analysis in this paper, there is an association between the presence of fracking and coal mining in a county on increased violations. This shows that an association possibly exists, however, based on the results of this analysis I cannot conclude that the year-on-year within county changes are associated with increased violations.

There are possible limitations in this study that should be addressed. The datasets used are secondary sources. Observations had to be removed from the FracFocus dataset due to information being missing or incorrect. At the time the study was conducted American Community Survey data had only been released for 2017-2021, so the study had to end in 2019. Private drinking water wells are also not included in this study, just community water systems. The water quality in private wells may also be affected by coal mining and fracking, but there is limited data on the water quality of private wells. Time is also a limitation in this study, more models should be conducted in the future. The use of two-way fixed effects is conservative and removes variation in the model. This could mean that some spatial effects are being suppressed due to the lack of variation in the model.

In the future, research should look to understand what is driving the between county effects, as they appear to have more practical significance. Fracking and coal mining are associated with increased health-based drinking water quality violations, but not with year-on-year within county changes.

Chapter 3: The Effects of Abandoned Coal Mines on Public Health in West Virginia

Section 3.1. Introduction

Coal mining is an important part of West Virginia life and history. Coal was first discovered in West Virginia in 1742, but commercial coal mining did not begin until the early 1800s (WV Office of Miners' Health Safety & Training, n.d.). Since then, coal mining has not only been important economically, but culturally as well in many West Virginia communities. With growing needs for energy, the rise of the coal industry in West Virginia began in the late 1800s (Rice & Brown, 1993). With this, the coal mining industry took over several rural areas in West Virginia, where (or in which) rural farmers leased or sold land to coal companies (Rice & Brown, 1993). As a result, coal mining changed the socioeconomic structure of West Virginia (Lewis, 1993; Rice & Brown, 1993). With tens of thousands of coal mines, there are many left abandoned. Thus, communities with this history are stuck with the consequences of what is left. Figure 3.1. shows the distribution and density of abandoned coal mines in West Virginia.

Abandoned mines pose several health risks due to chemicals from abandoned mine drainage (EPA, 2023b). The purpose of this paper is to determine how the presence of abandoned coal mines impacts mortality rate in West Virginia. Three different underlying causes of mortality were chosen for this study, diseases of the circulatory system, diseases of the respiratory system, and neoplasms (cancer). These three forms of mortality were chosen due to past studies conducted that link coal mines with these specific public health concerns (EPA, 2023b; EPA, 2023c; Cortes-Ramirez et al., 2022). Methane air pollution is another major health risk from abandoned coal mines that can lead to respiratory diseases and mortality (EPA, 2023c). The following research questions are analyzed in this study:

Research Question 1: What is the association between abandoned coal mines and circulatory related mortality in West Virginia?

Research Question 2: What is the association between abandoned coal mines and respiratory related mortality in West Virginia?

Research Question 3: What is the association between abandoned coal mines and cancer mortality in West Virginia?

The research questions were tested in this study using a spatial econometric model, SLX, to find the answers. These questions are grounded in the theory of the treadmill of production, and it is invoked in this study, where in a capitalist society the push for growth leads to negative environmental outcomes (Gould, Pellow, & Schnaiberg, 2010). While I do not test the theory explicitly, the logic of this study is grounded in its tenets. Abandoned coal mine data was extracted from the Mine Safety and Health Administration's (MSHA) Mine Data Retrieval System. Mortality data was taken from the Centers for Disease Control and Prevention (CDC) – Wide-ranging Online Data for Epidemiologic Research (WONDER). The age adjusted rate per 100,000 for cancer deaths in West Virginia is 203.5 (CDC, 2021). The age adjusted rate per 100,000 deaths for circulatory illness related deaths in West Virginia is 302.8 (CDC, 2021). The age adjusted rate per 100,000 deaths for respiratory related deaths in West Virginia is 102.4 (CDC, 2021). I used data for the years 1990, 2000, 2010, and 2020. All data was at the county level.

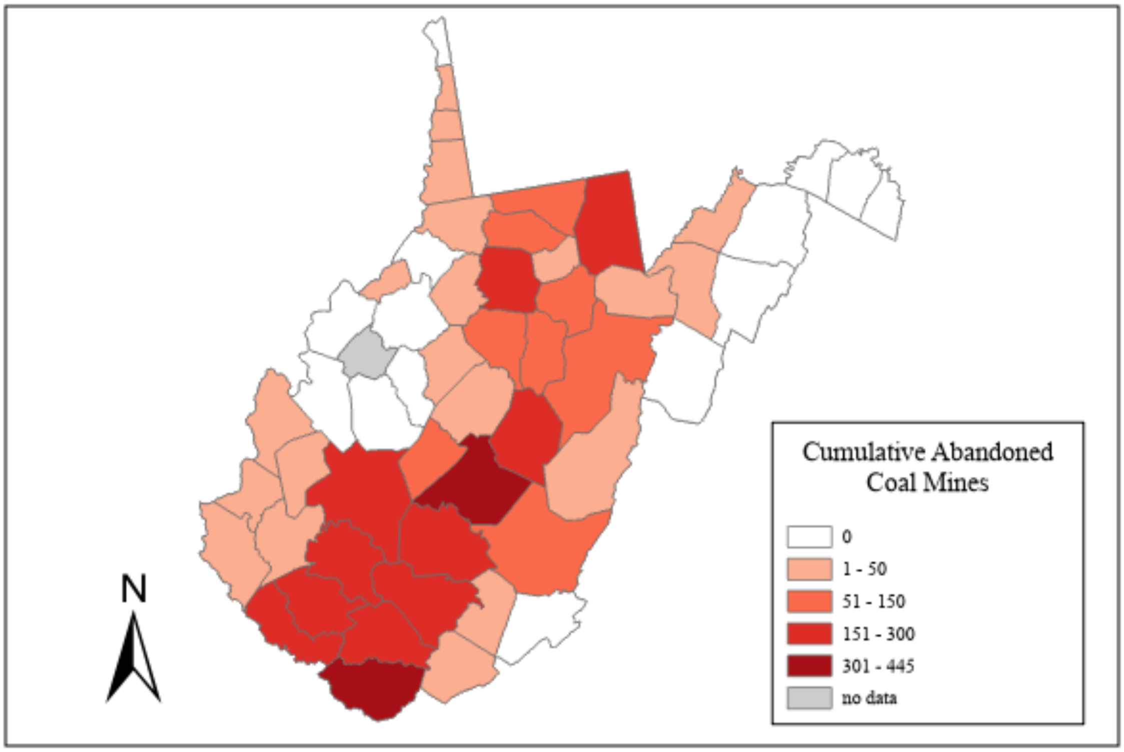

Figure 3.1. Cumulative abandoned coal mines in West Virginia

Section 3.2. Literature Review

Section 3.2.1. The Case of West Virginia:

A now-common form of surface mining that emerged in the 1970s is mountaintop removal (Hendryx et al., 2019). Mountaintop removal mining buries headwaters of streams, contaminates the water quality of the streams, and changes the flow of the stream (Lindberg et al., 2011). Lindberg et al. (2011) found that the more mines located in a watershed, the higher the concentration of contaminants located in the rivers and streams (Lindberg et al., 2011). Another important finding from this study shows that even mines that have been reclaimed for decades still have an impact on water quality (Lindberg et al., 2011). This shows that, as researchers, we should not only be concerned about active coal mines but abandoned coal mines as well. Negative impacts on water quality due to coal mines was also seen in a study by Bulltail & Walter (2020), who analyzed the impacts of coal on surface water quality in watersheds in the western United States, including abandoned and reclaimed mines (Bulltail & Walter, 2020). Based on the studies analyzed, it is clear that coal mining has an impact on water quality.

West Virginia is home to many reserves of bituminous coal (WV Office of Miners' Safety and Training, n.d.). Bituminous coal is a middle rank coal which is used for electricity (USGS, n.d.). Mountaintop removal (MTR) mining is common practice in West Virginia and Central Appalachia. MTR is a method of surface coal mining in which, "upper elevation forests are cleared and stripped of topsoil, and explosives are used to break up rocks to access buried coal" (Palmer et al., 2010; Holzman, 2011). The waste from the mining is dumped into the valleys, changing the landscape of the valley (Palmer et al., 2010; Holzman, 2011). MTR mining is a controversial method of coal extraction, mostly due to its environmental impacts (Palmer et al., 2010).

West Virginia has a rich history of coal mining, with mines opening in the early 1800s (WV Office of Miners' Safety and Training, n.d.). Coal mining has also served as the economic base in West Virginia for many years, providing many job opportunities. However, there has been a decrease in the number of people working in the coal mining industry, most significantly since 2011 (Lego et al., 2022; Nicewarner et al., 2020; Fritsch, 2019; Bell & York, 2010). Bell & York blame this decrease on the changes in the economy and the treadmill of production in their 2010 paper, Community Economic Identity: The Coal Industry and Ideology Construction in West Virginia (Bell & York, 2010). The theory of the treadmill of production tries to explain how environmental degradation is intrinsic to the modes of production in a capitalist society (Bell & York, 2010). Even as we move away from the extreme extraction of natural resources to development of technology, we still see environmental degradation, so the theory of the treadmill of production theorizes that no matter where we invest, environmental degradation is inevitable under capitalism (Gould, Pellow, & Schnaiberg, 2010; Bell & York, 2010). The more coal that is produced does not mean more coal employment, in many cases employment decreased with an increase in production (Bell & York, 2010). There has been innovation in mining technology, one of the likely causes of the decrease in mining employment, while the amount of coal produced increases in West Virginia (Bell & York, 2010). However, in more recent literature there has also been a decrease in the production of coal, along with employment decreases (Lego et al., 2022).

In 2021, it was found that only 11,333 people in West Virginia work in the mining industry (WV Office of Miners' Health Safety & Training, 2021). This is around half of the number of employees in the coal sector in 2011 in West Virginia (Lego et al., 2022). Researchers project that employment in the coal industry will continue to decrease (Lego et al., 2022). Although the coal sector in West Virginia appears to be decreasing, coal mining in some ways is part of the identity of residents in historic coal mining communities. There are a couple reasons that coal mining is important in West Virginia such as economic benefits and cultural significance. Economic benefits are a common driver of coal mining in West Virginia and Central Appalachia in general (Cordial et al., 2012). Economic benefits are enticing, especially in many West Virginia coal mining communities that struggle with poverty and unemployment. (Cordial et al., 2012). Many of the coal mines are located in areas which are already in a disadvantaged state (Cordial et al., 2012; Bell & York, 2010).

MTR is a popular method of coal mining in West Virginia. MTR is controversial because of the possible negative impacts on ecological health (Palmer et al., 2010). Even with the controversy, MTR mining became a popular practice in the mid-1990s, moving away from underground mining, and has continued on this way (Holzman, 2011; Hendryx, 2015; Woods &

Gordon, 2012). Early literature on mountaintop removal mining, such as that of Fox (1999), Mountaintop Removal in West Virginia: An Environmental Sacrifice Zone, discusses these environmental impacts. Fox calls mountaintop removal mining, “the most ecologically and socially destructive strip-mining techniques” (Fox, 1999, 163). Modern research into mountaintop removal mining continues to show these negative environmental impacts, as well as public health impacts. Researchers are concerned about the ecosystem damages that MTR mining inevitably causes. A major concern for researchers is the possible ecological impacts of valley filling from MTR (Palmer et al. 2010). The use of valley filling completely changes the ecosystem of the valley and has the ability to impact streamflow (Palmer et al., 2010). MTR mining with valley filling impacts water quality, as chemicals can infiltrate the stream system (Palmer et al., 2010).

There have been several studies done that show that there are impacts on water quality in West Virginia from coal mining. This includes a study of Central Appalachia, looking at the impacts of mountaintop removal mining on degradation of rivers (Bernhardt et al., 2012). The study site was located in southern West Virginia and included 223 streams (Bernhardt et al., 2012). They took water samples to look at the quality of each river, and what kind of pollutants are found in the streams and rivers (Bernhardt et al., 2012). The study found evidence of river and stream degradation as a result of surface coal mining in southern West Virginia (Bernhardt et al., 2012). A case study of Monongalia County, West Virginia from 1977 discusses how coal mining impacts ground and surface water quality (Corbett, 1977). This article shows that the environmental impacts of coal mining were already worrying almost five decades ago. Literature on coal mining and water quality often analyzes areas such as Appalachia, due to the area being a major producer of coal in the United States. These analyses provide a good understanding of the state of coal mining, water quality, and public health while isolating an area that includes West Virginia.

Several studies conducted by Michael Hendryx use West Virginia as a case study looking at coal mining, most frequently mountaintop removal mining, effects on health, drinking water violations, and determining how distance impacts health. These are all separate papers that are not synthesized together to understand how they all can impact one another. It is important to understand the results, even separately, as they provide insight into how coal mining impacts drinking water and health in a general sense. The first study that was conducted by Hendryx & Ahern (2008) looked at how proximity to coal mining impacted health in West Virginia. They found that an increase in coal production led to poorer health status (Hendryx & Ahern, 2008). The specific disease categories that they found had a relationship with increased coal production included cardiopulmonary disease, lung disease, cardiovascular disease, diabetes, kidney disease, hypertension, and chronic obstructive pulmonary disease (COPD) (Hendryx & Ahern, 2008). In a 2012 study, by Hendryx et al., public drinking water violations in West Virginia in areas where mountaintop coal mining was active. This study is the only study to my knowledge that looked specifically at public drinking water in relation to coal mining in West Virginia (Hendryx et al., 2012). The authors found that there were significantly more violations in MTR areas than in areas with non-MTR coal mining and areas with no mining (Hendryx et al., 2012).

Hendryx & Luo (2015) published a study in Virginia, An Examination of the Effects of Mountaintop Removal Coal Mining on Respiratory Symptoms and COPD using Propensity Scores (Hendryx & Luo, 2015). In this study the authors found that people exposed to mountaintop removal mining are more likely to have respiratory symptoms and COPD (Hendryx & Luo, 2015). The study only included two rural areas of Virginia, with a survey response of 682 adults (Hendryx & Luo, 2015). Another paper that was published in 2015 by Hendryx, reviewed several papers that studied the effects of surface coal mining on public health (Hendryx, 2015). Hendryx focused mostly on mountaintop removal mining in the United States. Hendryx states in this paper that there are plenty of studies showing how surface coal mining impacts ecosystem health, but less trying to find the impacts on public health (Hendryx, 2015). Hendryx concludes with the determination that mountaintop removal mining should be discontinued due to the known effects that it has on environmental and public health (Hendryx, 2015). The final paper by Hendryx et al. (2019), uses community health surveys from mountaintop removal communities and non-mining communities and conducted a latent class analysis of multiple diseases. The authors found that the population in residential proximity to a mountaintop removal mine has a higher rate of intermediate and high multi-symptom probabilities (Hendryx et al., 2019). Overall, the work of Hendryx is beneficial for understanding how coal mining in West Virginia effects public health and drinking water quality.

Current literature has shown that public health is impacted by coal mining in West Virginia. Fitzpatrick (2018) analyzed surface coal mining's impact on public health in West Virginia. They did so by looking at the rate of asthma hospitalizations per county. Fitzpatrick found that there were 9.85 more asthma hospitalizations per 100,000 people in a given quarter with an increase in surface coal mining (Fitzpatrick, 2018). The author also determined that children and elderly residents are more at risk for asthma hospitalizations, as compared to the rest of the population in West Virginia (Fitzpatrick, 2018).

There is an overlap in literature between the specific case of West Virginia and the literature on the rest of the United States. This shows the possible similarities in outcomes between West Virginia and the nation, but it also provides an understanding of the differences, such as West Virginia’s reliance on mountaintop removal mining, as well as the long history of coal mining in the state. Given that the literature provides evidence that coal mining has negative impacts on water quality and public health, the following analysis will evaluate the within-county extent of that impact as it relates to abandoned mines. Focusing on circulatory, respiratory, and cancer forms of mortality, I estimated the impact of abandoned mines on mortality from 1990 to 2020.

Section 3.3. Methods

Data. Abandoned coal mine data was obtained from the Mine Safety and Health Administration’s (MSHA) Mine Data Retrieval System. This dataset includes data for all mines in all US states. It contains all mines under MSHA’s jurisdiction since 1970 and is continuously updated (MSHA, 2023). Only coal mines in West Virginia with an abandoned status were kept in the dataset.

Demographic data for 1990, 2000, 2010, and 2020 was retrieved from the Integrated Public Use Microdata Series – National Historical Geographical Information System (IPUMS-NHGIS) (Manson et al., 2023). The demographic data for 1990 and 2000 came from the United States Decennial Census. Data for 2010 and 2020 came from the American Community Survey (ACS). These were taken at 5-year pools, 2008-2012 for 2010 and 2018-2022 for 2020. This was done because the ACS uses a rolling sampling structure. One-year estimates are less accurate (US Census Bureau, 2017). All were county-level. Race, education, and poverty status were the variables downloaded from this system.

Mortality data was downloaded from the United States Centers for Disease Control and Prevention (CDC) – Wide-ranging Online Data for Epidemiologic Research (CDC WONDER) database. Cause of death mortality data was downloaded in four-year pools for 1990, 2000, 2010, and 2020. A compressed mortality dataset was used from the CDC WONDER database for the four years pooled for 1990 (CDC, 2003). This was done because the dataset used for 2000, 2010, and 2020 starts in 1999 (CDC, 2021). Both datasets were in the same format. The data is county-level, and all rates were age-adjusted. Data was downloaded for neoplasms (cancer), diseases of the circulatory system, and diseases of the respiratory system. For all mortality outcomes, age adjusted values were extracted and are what was used in the analysis.

Analysis. The datasets were all merged and collapsed in county aggregate estimates by FIPS and year. The dataset contained the years 1990, 2000, 2010, and 2020. Race and poverty were transformed into percentages. Education for those with a bachelor's degree and above was also transformed into a percentage variable. Wirt County, West Virginia was removed from the analysis, as it included missing health data. A West Virginia shapefile was created from a county shapefile downloaded from IPUMS-NHGIS (Manson et al., 2023).

Twelve regression models were run in Stata. Six of the models included a 10-year lag and six did not. The 10-year lag was added to allow for possible latency in mortality associated with the increase in abandoned mines. Both the 10-year lag and the simultaneous models included a spatial econometric model, a spatial lag of X (SLX) model. The SLX model was chosen as it is useful for controlling for spatial spillover effects (Vega & Elhorst, 2015). The spatial spillover effects are local in the SLX model. Unlike other spatial econometric models, SLX allows for estimation using conventional regression techniques and simple interpretation of direct and indirect effects (Vega & Elhorst, 2015). The spatial weights matrix used was a queen's first order contiguity. The standard errors used were cluster-robust. For each circulatory related mortality, respiratory related mortality, and cancer mortality, two regression models were run, one estimating within-county effects (within models) and one estimating between-county effects (between models). Unit fixed effects were included to control for time-invariant factors. Year fixed effects were also included in the model, but they were included as dummy variables to control for time. All the models included the variables percent Black, percent Latino, percent with a bachelor's degree, and poverty rate. These variables were included because previous research shows that the sighting of environmental harms is related to factors such as race, education, and poverty status (Brulle & Pellow, 2005; Evans & Kantrowitz, 2002). These variables are likely confounders, meaning that they influence both the independent and dependent variables. Tables 3.1 and 3.2 present the results of each of the regression models that were run.

Section 3.4. Results

Two tables are presented in this section, showing the regression results. The first table does not include the 10-year lag. The second table shows the regression results with the 10-year lag added.

Simultaneous:

Table 3.1. provides the regression results for six different models. The first part of the table shows the results of the regression of abandoned coal mines on age-adjusted circulatory disease related mortality rate. For every unit increase in the number of abandoned coal mines in a county, there is an expected 0.12 unit increase in age-adjusted circulatory disease related mortality rates, in the between model. There is not a statistically significant relationship seen in the within model.

The second section of the regression results shows the relationship between abandoned coal mines and age-adjusted respiratory related mortality rates. There is a statistically significant relationship between abandoned coal mines and age-adjusted respiratory related mortality in the between-county model. For every unit increase in the number of abandoned coal mines, there is an expected 0.086 unit increase in the age-adjusted respiratory disease-related mortality rate. In the within-county model, the relationship is no longer statistically significant.

The final section of table 3.1. presents the results of the regression of cancer related mortality on abandoned coal mines. A statistically significant relationship is not seen, in either the within or between county models.

Table 3.1. Regression results of abandoned coal mines on mortality

	Circulatory		Respiratory		Cancer	
	Between	Within	Between	Within	Between	Within
Direct Effects						
Abandoned Coal Mines	0.12*	0.030	0.086**	0.11	0.058	-0.096
	[0.051]	[0.20]	[0.027]	[0.12]	[0.036]	[0.12]
% Black	0.69	-0.59	0.030	-0.40	0.95	-0.14
	[1.27]	[3.32]	[0.67]	[1.08]	[0.92]	[1.10]
% Latino	-3.42	-8.17	-2.06	-2.43	-1.77	1.55
	[4.07]	[6.94]	[2.36]	[2.29]	[3.55]	[2.80]
% w/ Bachelors	-1.33*	1.60	-0.67*	0.57	-0.82	-0.96
	[0.60]	[1.11]	[0.31]	[0.61]	[0.43]	[0.79]
Poverty Rate	0.66	0.10	0.62	-0.59	0.42	-1.38
	[0.73]	[0.97]	[0.37]	[0.50]	[0.59]	[0.86]
Year [1990 ref]						
2000	-63.1***	-66.0***	3.00	-3.01	-4.87	-1.33
	[7.53]	[10.7]	[3.42]	[4.06]	[3.85]	[6.02]
2010	-173.5***	-176.0***	7.09	-1.90	-24.0***	-14.6
	[8.74]	[16.2]	[4.28]	[6.79]	[5.35]	[10.3]
2020	-182.6***	-187.0***	6.87	-11.5	-39.5***	-21.8
	[11.0]	[23.8]	[7.03]	[11.1]	[7.92]	[16.8]
Indirect Effects						
Abandoned Coal Mines	-0.032	0.14	0.057	-0.35	0.0057	0.19
	[0.087]	[0.47]	[0.051]	[0.22]	[0.064]	[0.23]
% Black	0.51	-8.58	2.57	-1.25	-0.68	-0.89
	[3.24]	[5.70]	[1.62]	[2.97]	[1.88]	[3.07]
% Latino	-6.60	0.033	-4.66	-1.41	5.92	3.20
	[6.16]	[10.5]	[3.67]	[3.79]	[5.23]	[5.14]
% w/ Bachelors	0.58	-1.73	0.12	0.88	0.14	-2.41
	[1.20]	[2.15]	[0.60]	[0.78]	[0.69]	[1.30]
Poverty Rate	-0.97	-0.49	0.26	-0.67	0.71	1.89
	[1.21]	[1.74]	[0.47]	[0.78]	[0.79]	[1.05]
Constant	464.5***	473.3***	81.3***	135.4***	204.6***	245.2***
	[35.6]	[54.8]	[16.1]	[27.9]	[21.8]	[33.5]
Observations	216	216	216	216	216	216

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Ten-year lag:

Table 3.2. shows the regression results of six different models with the 10-year lag. The first section of the table presents the results of the between and within county models for age-adjusted circulatory disease related mortality rates. In the between model, a statistically significant relationship between age-adjusted circulatory related mortality rate and abandoned coal mines. For every unit increase in the number of abandoned mines in a county, there is an expected 0.14 unit increase in age-adjusted circulatory related mortality rate. The results of the within-county model shows that the relationship is not statistically significant.

The relationship between age-adjusted respiratory related mortality rates and abandoned coal mines is statistically significant in the between-county model. For every unit increase in the number of abandoned mines, there is an expected 0.079 unit increase in age-adjusted respiratory related mortality rate. The relationship is not statistically significant in the within-county model.

The final part of table 3.2. shows the regression results of the between and within models of age-adjusted cancer mortality rates on abandoned mines. There is not a statistically significant relationship between cancer mortality and abandoned coal mines. This is true for both the within and between models.

Overall, the results show a statistically significant relationship between abandoned coal mines and respiratory and circulatory related mortality when county fixed effects are not included in the model. This is true for both the simultaneous and 10-year lagged models. There is not a statistically significant relationship when county fixed effects are included in the regression model.

Table 3.2. 10-year lagged regression of abandoned coal mines on mortality

	Circulatory		Respiratory		Cancer	
	Between	Within	Between	Within	Between	Within
Direct Effects						
Abandoned Coal Mines	0.14**	-0.32	0.079**	0.097	0.066	-0.45
	[0.050]	[0.48]	[0.028]	[0.19]	[0.039]	[0.24]
% Black	-0.43	-0.46	0.27	-0.15	0.32	-1.10
	[1.42]	[4.26]	[0.69]	[1.00]	[1.07]	[0.94]
% Latino	-1.96	-4.47	-2.21	-3.69	-0.77	1.80
	[3.87]	[6.76]	[2.51]	[2.14]	[3.70]	[3.09]
% w/ Bachelors	-1.02	2.52	-0.73*	0.89	-0.82	-0.71
	[0.58]	[1.61]	[0.30]	[0.69]	[0.45]	[0.83]
Poverty Rate	0.19	-0.50	0.45	-0.85	0.59	-1.18
	[0.87]	[1.39]	[0.43]	[0.43]	[0.63]	[0.92]
Year [1990 ref]						
2000	-110.2***	-130.3***	4.02	1.68	-19.6***	-12.4
	[5.75]	[13.9]	[3.11]	[4.63]	[3.67]	[6.79]
2010	-119.1***	-167.7***	3.45	-7.14	-35.8***	-18.4
	[8.63]	[28.3]	[4.93]	[9.49]	[6.45]	[15.0]
Indirect Effects						
Abandoned Coal Mines	0.0077	1.41	0.064	-0.25	-0.016	0.53
	[0.090]	[0.90]	[0.053]	[0.30]	[0.063]	[0.40]
% Black	0.98	-4.76	1.60	-3.39	-1.05	-2.50
	[3.39]	[7.79]	[1.66]	[3.44]	[2.12]	[3.89]
% Latino	-7.81	-1.66	-3.99	0.26	7.73	-0.18
	[5.95]	[8.81]	[3.78]	[3.82]	[5.30]	[5.13]
% w/ Bachelors	-0.28	2.78	0.22	0.18	0.33	-1.92
	[1.11]	[3.42]	[0.57]	[0.88]	[0.68]	[1.22]
Poverty Rate	-1.76	-0.88	0.34	-0.77	1.64	3.08
	[1.31]	[2.16]	[0.61]	[0.95]	[1.00]	[1.56]
Constant	429.5***	289.4*	86.6***	141.3***	177.6***	214.8***
	[34.3]	[109.2]	[16.7]	[31.0]	[27.9]	[44.1]
Observations	162	162	162	162	162	162

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Section 3.5. Discussion

Year-on-year within county changes in abandoned coal mines were not found to be statistically significantly related to circulatory, respiratory, and cancer related mortality in West Virginia. There was a statistically significant relationship between abandoned coal mines and circulatory and respiratory related mortality in West Virginia when county fixed effects were removed from the model. Abandoned coal mines were not found to be associated with cancer mortality in any of the models. Due to the lack of a statistically significant relationship between abandoned coal mines and public health when county fixed effects are included, this could suggest that there is another factor influencing the results.

When analyzing the relationship between counties, there is a statistically significant relationship between abandoned coal mines and circulatory and respiratory related mortality in West Virginia. This is the case in both the simultaneous and the 10-year lagged models. There is no statistically significant relationship within or between counties relating to the relationship between abandoned coal mines and cancer mortality.

Using the results of the study to answer the research questions presented in the introduction of this study, first, what is the association between abandoned coal mines and circulatory related mortality in West Virginia? The results do not provide evidence of a statistically significant relationship between abandoned coal mines and circulatory related mortality year-on-year within county. Therefore, I cannot say that there is an association. However, there is a statistically significant relationship between counties. The next question is, what is the association between abandoned coal mines and respiratory related mortality in West Virginia? Similarly, to circulatory related mortality, there is no evidence of year-on-year within county changes of respiratory related mortality. There was a statistically significant relationship when county fixed effects were removed from the model. The final question, what is the association between abandoned coal mines and cancer mortality in West Virginia? Based on the results of the study there appears to be no statistically significant relationship between abandoned coal mines and cancer mortality both within and between counties. I am unable to conclude that increased mortality rate related to the underlying causes of mortality, circulatory diseases, respiratory diseases, or cancer, is due to exposure to abandoned coal mines, or just the characteristics of the place in which they are located.

The results of this study, although not expected, are important. The study was informed by the framework of the treadmill of production, which argues that in a capitalist society the push for growth leads to environmental degradation (Gould, Pellow, & Schnaiberg, 2010). Here, I find support for this model in between-county models, which suggests that even if there is not a year-on-year impact of abandoned mines, their presence on the landscape is associated with negative impacts on environmental public health.

Even though I am unable to conclude that year-on-year within county changes in abandoned coal mines was not found to be associated with changes in mortality, this shows that there are possible other factors contributing to this result. Some possible factors include the price of houses and land near coal mines may be less than land further away. House price has been found to be correlated with socio-economic status and health outcomes (Lockwood et al., 2018; Coffee et al., 2013). A study by Fitzpatrick and Parmeter (2021) found evidence that housing prices near surface coal mines were significantly discounted as compared to comparable properties located at a further distance from the mine (Fitzpatrick & Parmeter, 2021). Another study conducted in Chile by Rivera (2020) also found that housing prices are less near mining activity, especially when pollution was able to be visually seen (Rivera, 2020). None of these studies mentioned abandoned mines specifically, as related to housing and land price.

Another possible reason that I did not see year-on-year within county changes in abandoned coal mines associated with circulatory, respiratory, and cancer related mortality is because it is more related to active coal mining. Health impacts from coal mining may be more related to active mining. Future research should consider controlling for current mining activity when studying the impacts of abandoned coal mines.

Limitations do exist in this study. First, Wirt County had to be removed from the study due to missing 1990 respiratory related mortality data. The years chosen for the study were limited due to lack of ACS or Census data for 2005. The abandoned coal mining data was limited to beginning in the late 1970s, due to the creation of the Mine Safety and Health Administration (MSHA), so some early mine's that were abandoned may be missing. Another possible limitation lies in the model itself. The use of two-way fixed effects is very conservative, so it is possible that there are effects being suppressed.

In this study I found that the year-on-year within county changes in abandoned coal mines are not statistically significantly associated with circulatory, respiratory, and cancer mortality. However, abandoned coal mines are statistically significantly associated with mortality from circulatory and respiratory diseases between counties. Even with the absent year-on-year changes within counties, these models provide strong evidence that those living near abandoned mines in West Virginia have elevated mortality from circulatory and respiratory illnesses. Thus, there remains an association between mining and poor health. It will be important for future research to disentangle this relationship so we can learn if it is being driven by abandoned mines but not detected by models due to low variation, if it is driven by active mining, or if it reflects the population distribution of those already with worse health outcomes.

Chapter 4: Conclusion

This thesis contains two separate but related studies. The first was a national comparative analysis of the impacts of coal mining and fracking on drinking water quality from 2010-2019. This study was conducted because national scale comparative studies on coal mining and fracking are not common. The second study focused specifically on the impacts of abandoned coal mines on mortality in West Virginia from 1990-2020. This analysis was also much more focused on understanding the health impacts using age-adjusted mortality as an outcome.

Though both analyses were separate, there was a common goal. The interest was in understanding how different extractive activities impact people and the environment. Both papers had similar findings. Year-on-year within county changes were not found to be statistically significant in either study. However, there were statistically significant relationships between counties depending on the model. This means that there could be some other factor or simply the characteristics of a place that influence the results. What are the characteristics? How does policy influence these relationships? Thus, there is a new direction for future research.

Future research should be conducted to determine the possible underlying characteristics or factors that may be found that could influence why within county effects are not seen, but between county effects are in some cases. In future research it may also be useful to include private drinking water wells into the analysis, as in many of the areas in which extractive activities take place, private drinking water wells are also present in the county. This is more difficult however, as there are no federal regulations over private drinking water wells and systems and therefore, water quality reports are not recorded. Previous smaller scale studies have used water quality data from private drinking water wells and found evidence of chemicals related to extractive activities (Fontenot et al., 2013; Shiber, 2005). Other types of models could also be investigated further, as the two-way fixed effect approach could possibly be too conservative.

Populations are directly impacted by the environments that they live in. The aftereffects of extractive activity should be studied further. Future studies could look at specific case studies of specific communities, as policies change dependent on the scale of the study. Many of the cases of clean up cannot be generalized because of the lack of strong federal policies holding companies accountable for the clean-up of waste. As the United States transitions away from coal mining and fracking, how do we ensure that the legacies of these practices are not harming communities? How do we keep attention on policies and regulations surrounding coal mining and fracking moving forward? Although the United States is transitioning away from coal mining and fracking, policies and funding must be put towards cleaning up locations where coal mining and fracking have occurred. Population health is of the utmost importance, but in order to ensure health, policies must be created to protect the environment as well. Contamination of the environment, such as drinking water, leads directly to the health of the population relying on that water. It is essential researchers continue to work to understand the relationship between extraction, water, and population health so we can mitigate impacts in the future.

Appendix

County Boundary Changes:

Table A.1. County FIPS code changes

State	Counties
Alaska	Chugach Census Area (2063) + Valdez-Cordova Census Area (2261) + Copper River Census Area (2066) Wade Hampton Census Area (2270) + Kusilvak Census Area (2158)
South Dakota	Shannon (46113) + Oglala Lakota (46102)
Virginia	Bedford City (51515) + Bedford (51019)

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