THE EFFECT OF UNCONVENTIONAL GAS AND OIL DRILLING EMISSIONS ON ASTHMA AND RESPIRATORY DISEASES IN THE BARNETT SHALE OF TEXAS

by

STELLA OKOROAFOR, MD, MPH

APPROVED:

A Carson MD

ARCH CARSON, MD, PHD

Stephen H Linder

STEPHEN LINDER, PHD

Julie Graves MD

JULIE GRAVES, MD, MPH, PHD

Kai Zhang

KAI ZHANG, PHD

DEAN, THE UNIVERSITY OF TEXAS
SCHOOL OF PUBLIC HEALTH

DEDICATION

To Chelsea, Karen, Kelechi, Nnenna and Ebuka Okoroafor

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STELLA A.OKOROAFOR
MBBS, Abia State University, 1996
MPH, The University of Texas School of Public Health, 2006

Presented to the Faculty of The University of Texas
School of Public Health
in Partial Fulfillment
of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

THE UNIVERSITY OF TEXAS
SCHOOL OF PUBLIC HEALTH
Houston, Texas
May 2020

PREFACE

With the increasing global demand for energy and the resultant rapid expansion of unconventional oil and gas drilling to meet the demand, there is an urgent need for environmental and public health research geared towards understanding how these activities will affect the host communities. Furthermore, these research may help to guide policies that will protect public health. In response to this need, this paper addresses the impact of unconventional oil and gas drilling on pollution sensitive respiratory diseases. The burden of asthma and COPD is very significant in the United States and around the world. The possibility that unconventional oil and gas drilling could lead to the worsening of these respiratory diseases should be fully explored. It is our expectation that the results of this study will help formulate policies that will foster public health theories and interventions aimed at reducing unconventional oil and gas drilling environmental air pollution and the burden of asthma and other pollution sensitive diseases in the United States.

ACKNOWLEDGEMENTS

I wish to appreciate my academic advisor and dissertation committee chair, Dr. Arch Carson for his guidance and unwavering support throughout the course of my study. I am indebted to my dissertation supervisor, Dr. Stephen Linder, for his support, dedication and the time he devoted to ensure that this research work was successfully completed. I am also grateful to my dissertation committee members, Dr. Kai Zhang, and Dr. Julie Graves, for their immense contributions in this project. I wish to thank Dr. Thomas Reynolds for his kind assistance. I am grateful to my colleagues and friends, especially Joy De Los Reyes and Dr. Nnoli, for their friendship and support during the course of study. Special thanks to Karen Okoroafor for her kind assistance with editing and formatting this project.

The members of my family have been a major source of support for me. My sincere gratitude goes to my dear husband Obi, who has been very supportive in every way throughout the course of my study. My children, Chelsea, Karen, Kelechi, Nnenna and Ebuka, what could I ever do without you? I LOVE YOU ALL. To my parents, Chief Mathew and Lolo Margaret Ajaero, I thank you for all your unconditional love, prayers and support; these have sustained me through the years. I also want to thank my siblings Okey, Ngozi, Patrick, IK, and Chibuzo for their love and support.

My utmost gratitude goes to the almighty God, who has been my source of strength and refuge. Lord I give you all the glory and I owe you my whole life.

UNCONVENTIONAL GAS AND OIL DRILLING EMISSIONS AND HOSPITAL UTILIZATION RATES FOR ASTHMA AND RESPIRATORY DISEASES IN THE BARNETT SHALE REGION

Stella A. Okoroafor, MBBS, MPH, PhD
The University of Texas
School of Public Health, 2020

Dissertation Supervisor: Stephen Linder, PhD

Unconventional gas and oil drilling (UGOD) has increased substantially in the United States for more than a decade. The resultant environmental unsafe air pollution effects of UGOD both locally and regionally have been well documented in the literature. Despite the dramatic increase in unconventional well drilling and the toxicant exposure, the health consequences of UGOD remain largely uncertain. This study assesses the relationship between active wells and healthcare use for respiratory diseases by zip code from 2004 to 2008 in the Barnett shale area of Texas. The first modern shale gas well was drilled in the Barnett shale area of Texas and is a particularly important area to study this relationship because its location is in close proximity to residential areas in the Dallas Fort Worth metropolitan area and Texas is one of the leading states in UGOD practices.

Our study identified spatial locations of Unconventional gas wells and correlated Inpatient hospital admission data from the Texas Department of State Health Services (DSHS) with active wells by zip code in the eight counties of the Barnett shale area in Texas. The relationship between the inpatient prevalence rates for 4 respiratory disease categories,

and the number of active wells per zip code and wells per kilometer squared were estimated using mixed effects negative binomial models.

There was a significant association between well density and Asthma incidence (p = .024) and inpatient prevalence rate per 1,000 for patients 18 years and older (p = .055) and wells density. Additionally, our result shows a higher likelihood of patients being hospitalised for Overall respiratory disease category and COPD per 1,000 people per year in 2008 compared to the baseline year 2004. Further studies are needed to determine specific toxicants or combinations that are associated with organ specific responses.

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BACKGROUND

Literature Review

Unconventional fossil fuels especially shale gas, have seen a huge increase in growth since the 1990s due to changes in drilling technology and fracturing ("fracking") methods. The technological advancements in horizontal drilling and unconventional hydraulic fracturing has made Natural gas to become a major source of energy utilization in the United States (Wang et al., 2014). These advancements have made it possible to access natural gas trapped beneath various shale formations. The United States became the largest producer of natural gas in 2013 and this has led to a drop in the prize of natural oil and gas in over two decades (Belu & Nuno, 2015). There has been a rapid expansion of shale gas development from less than 2 percent of the total US natural gas production in 2000 to over 20 percent in 2010 (EIA, 2013). It is estimated that by 2035, 46 percent of the natural gas supply will come from shale gas (EIA, 2013). Apart from the USA, there are growing increases in production of Unconventional shale gas in other countries across the globe that have rich endowments (Cust and Poelhekke, 2015). Figure 1 shows the growing spread of unconventional shale gas production in the United States..

Shale is usually formed by compaction of mineral particles and cached for several years at the bottom of lakes and seas. It is made up of fine grained clastic sedimentary rock that is characterized by breaks along parallel layers. The accumulation of Shale natural gas resources that have similar geological components are usually referred to as “play” (Appendix C has the glossary of all the Shale gas terminology). The plays are often stationed within geologic depressions known as “basins”. Oil and natural gas are generated by organic material trapped within the pore of the Black Shale rock (Speight, 2013).

The development of shale gas wells involves different stages that includes exploration and site preparation, construction, water procurement, drilling and well construction, hydraulic fracturing, flaring of excess natural gas, extraction of gas and compression. Air pollution can occur during each stage of these processes (Jackson et al., 2013) Studies have shown that levels of air pollutants such as greenhouse gases, volatile organic compounds (VOCs), and hazardous chemicals increase as a result of unconventional natural gas development (GAO, 2012; NRDC, 2014).

Furthermore, the data by the Pennsylvania Department of Environmental Protection (PADEP), natural gas emissions shows that air pollutants emissions levels for carbon monoxide (CO), Nitrogen oxide (NOX) particulate matter (PM2.5, PM10), etc. attributable to unconventional natural gas drilling increased by almost 30% as the number of gas wells increased. Some of the concerns of unconventional development include massive clearing, water consumption, waste management issues, community impacts, and emissions of greenhouse gases and VOCs (Jackson et al., 2013). The emissions of greenhouse gases (primarily methane) contributes to climate change and the local emissions of VOCs affects local air quality (Heath et al., 2014). VOCs include benzene, toluene, ethylbenzene, xylenes, BTEX, and n-hexane, which are toxic precursors to ozone (EPA).

Some studies have found air volatiles at UGOD sites that were either near detection limits or within acceptable limits to protect the public (Bunch et al., 2013; Zavala-Araiza et al., 2014). However, Macey et al. (2014) showed that community-based grab samples had concentrations of VOCs that exceeded the Agency for Toxic Substances and Disease Registry (ATSDR) and/or EPA Integrated Risk Information System (IRIS) threshold levels especially for Hydrogen sulfide, formaldehyde and benzene. These high levels of chemicals were found close to residential areas and were not recorded by previous state of the art monitors as they only capture a snapshot of near field locations (Macey et al., 2014). This shows that previous studies that found acceptable limits of air volatiles near UGOD sites may have used some state monitoring studies that only capture a snapshot of near field locations that are incomplete and thus may provide only a limited sense of potential human health impacts from air emissions (Macey et al., 2014). Furthermore, Hydrocarbons such as Benzene have clinical and non-clinical effects even at very low doses (Lan et al., 2004).

Unconventional gas and oil drilling (UGOD) has expanded in the United States in the last 15years, yet the health consequences of UGOD emission exposure remain largely unclear. Colborn et al. (2011) compiled a list of 632 chemicals used during the fracturing and drilling stages of natural gas development and reported that more than 75 percent of the chemicals could affect the respiratory system.Colborn et al.(2011) further identified some natural gas and hydraulic fracturing chemicals with 10 or more health effects as shown in Appendix D. Five of those chemicals are among the 6 criteria pollutants that the Clean Air Act (CAA) requires EPA to monitor due to the hazardous effects on the pulmonary system.(Appendix

D-F) shows all the air pollutants that are controlled by EPA including the Hazardous air pollutants that cause non cancer health effects on the respiratory system. A similar analysis conducted by the Committee on Energy and Commerce of the U.S. House of Representatives in a congressional report that reviewed the type and volume of hydraulic fracturing products used by 14 leading oil and gas companies between 2005 and 2009, found that the most widely used chemical during that period was methanol; a hazardous air pollutant (Committee on Energy and Commerce, U.S. House of Representatives, 2011). These chemicals are either regulated under the Safe Drinking Water Act for their risks to human health, and/or listed as hazardous air pollutants under the Clean Air Act. For example, each of the BTEX compounds (benzene, toluene, xylene, and ethylbenzene) found in many of the hydraulic products is a regulated contaminant under the Safe Drinking Water Act and a hazardous air pollutant under the Clean Air Act (Committee on Energy and Commerce, U.S. House of Representatives, 2011).

Hazardous air pollutants (HAPs) such as NOx (ground-level ozone precursors), particulate matter (PM), aromatic hydrocarbons, and volatile organic compounds are emitted in all the stages involved in UGOD development (Jackson et al., 2013). These stages include Site exploration, construction (access roads, well pad, holding ponds and infrastructure), drilling, Hydraulic fracturing, well completion, production, midstream processing, storage, and transport of end products (Jackson et al., 2013).

The respiratory health impacts of these pollutants including ozone, PM, benzene, and formaldehyde are well known and documented in the scientific literature (Zanobetti &

Schwartz, 2006; Xing et al., 2016; Anderson JO et al., 2012; Ko et al., 2012). Shale gas development and production may pose a threat to public health through air pollution (NRDC, 2014). A major source of air pollution in well development is the dust and engine exhaust emissions from increased traffic of diesel engines that power heavy equipment used to build roads, clear well sites, construct wells, drill, transport water and sand and inject fracking fluid into the wells. This makes horizontal well followed by hydraulic fracturing to be more intensive than traditional vertical drilling as shown in the typical process of hydraulic fracturing as shown in figure 2.The diesel engines used to pump fracking fluid commonly exceed 2000 bhp (Treida, 2010). The UGOD site involves a lot of mobile equipment such as fracture fluid storage tanks, sand storage units, chemical trucks, blending equipment and pumping equipment which are controlled from a single truck referred to as the Data Monitoring Van.

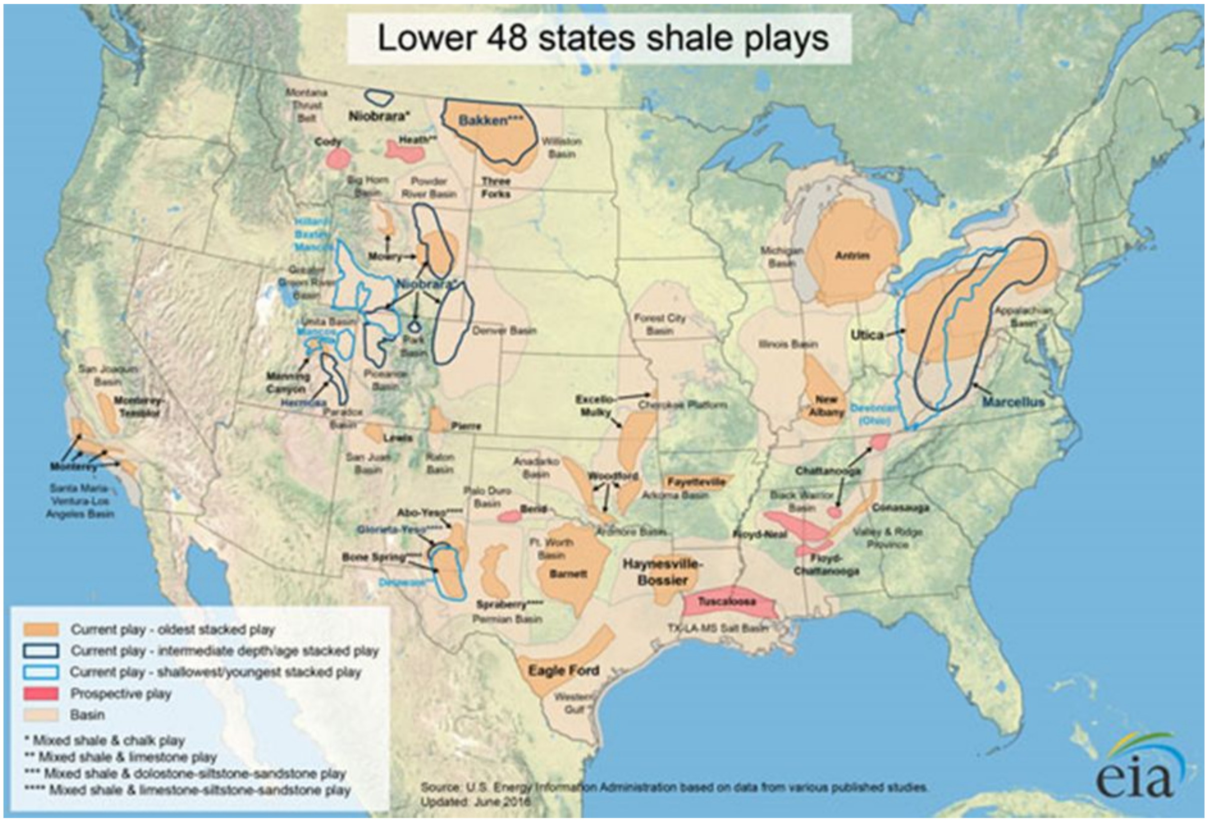
In addition to emissions from diesel powered pumps, the intentional process of flaring (burning) or venting (direct release into the atmosphere) of natural gas for operational uses during the development and production stage also leads to emissions of carbon dioxide and the release of methane and volatile organic compounds (Jackson et al., 2013).

Additionally, unintentional emissions of air pollutants from faulty equipment or impediments are sources of air pollution. Lastly, evaporation of fracturing fluid and produced water may also emit hazardous chemicals into the atmosphere (Jackson et al., 2013). Previous studies have found consistent evidence that air pollution is associated with respiratory problems (Zanobetti & Schwartz, 2006; Xing et al., 2016; Anderson JO et al., 2012; Ko et al., 2012). Some of the air pollutants and chemicals from the drilling and gas production activities may be associated with respiratory outcomes. For example, NOX can form small particles through reactions with ammonia, moisture, and other compounds. These particles penetrate deeply into the sensitive part of lungs and cause or worsen respiratory diseases (EPA, 1998). Furthermore, NOX can form ground-level Ozone (smog) when reacting with VOCs in the presence of heat and sunlight (Kontra, 2017). The smog irritates the respiratory system, reduces lung function, worsens chronic conditions such as asthma and chronic bronchitis, and could potentially result in permanent lung damage (EPA, 2009). Short-term exposure to fine particles (PM) has been shown to cause asthma attacks and acute bronchitis (Xing et al., 2016; Anderson JO et al., 2012). Ko et al. (2012) found that levels of major air pollutants (NO2, O3, PM10, and PM2.5) in Hong Kong were associated with increased hospital admissions, with O3 being the most important contributor. Likewise, Zanobetti and Schwartz (2006) showed that air pollution in the greater Boston area was associated with a higher risk of hospitalization for pneumonia among individuals aged 65 and older. Papas et al. (2000) showed that exposure to VOCs could lead to respiratory illnesses such as asthma. Figure 2, is a schematic illustration of the various processes involved in UGOD and the potential air emission and toxicants detrimental to the respiratory system that is associated with it.

Asthma is a complex chronic disease that affects the airways and causes airway inflammation, reversible airway obstruction and bronchial hyper responsiveness (National asthma education and prevention program (NAEPP), 2007). It is a common disease with a prevalence rate of 8.4% in the United States in 2010 affecting 25.7 million people (NAEPP, 2007). It manifests with varying and recurring symptoms such as shortness of breath, chest tightness, coughing and wheezing (Dougherty & Fahy (2009). Outdoor air pollution is a recognized cause of asthma exacerbations (Ramussen et al., 2016).

A large body of literature links asthma exacerbations to exposure to air pollutants, including ozone, particulate matter, NOX, formaldehyde and benzene. Studies have shown that chronic obstructive pulmonary disease (COPD), pneumonia, and upper respiratory infections as well as asthma are air pollution sensitive diseases (Kelly et al., 2011). Jemielita et al. (2015) found that unconventional natural gas development was associated with a significant increase in rates of URI among the elderly and increased the hospitalization rate for pneumonia among the elderly. These findings are consistent with higher levels of air pollution. Acute respiratory diseases such as asthma is a suitable outcome because it is a prevalent disease with short latency period and patients usually seek immediate care for exacerbations and are thus documented by health records. Furthermore, the activities of UGOD have community and environmental impacts that could affect asthma such as stress and changes in air quality.

Figure 1: Lower 48 states shale gas plays in the United States



Lower 48 states shale plays

* Mixed shale & chalk play

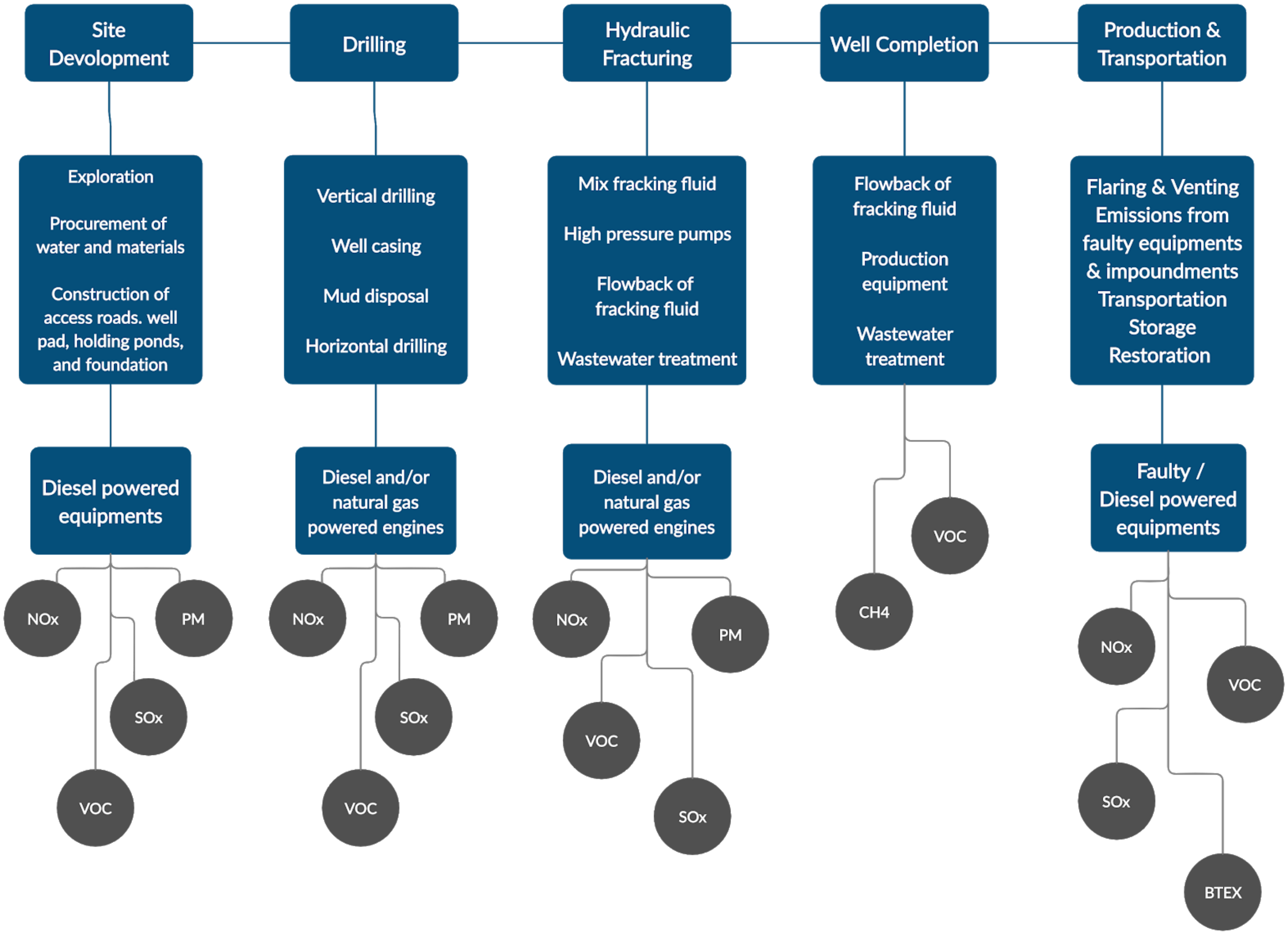
** Mixed shale & limestone play

*** Mixed shale & dolostone-siltstone-sandstone play

**** Mixed shale & limestone-siltstone-sandstone play

Source: U.S. Energy Information Administration based on data from various published studies.
Updated: June 2016

Figure 2: Diagram of Shale gas development activities and potential air emissions and toxicants



Public Health Significance

The use of unconventional gas and oil drilling methods for gas production has significantly elevated the level of drilling activity across various regions in the United States (Rabinowitz et al., 2015). As a result, there have been concerns that this increase in oil and gas production may pollute water supplies and ambient air which could result in adverse public health effects (Goldstein et al., 2012). Unconventional oil and gas drilling methods involves the drilling and casing of deep wells, insertion of underground explosives, transport and injection of large quantities of water containing sand, and introduction of several chemical additives into the wells at high pressures to extract gas from the shale deposits (Jackson et al., 2013). Examples of chemical additives used in this method of drilling include inorganic acids, polymers, petroleum distillates, anti-scaling compounds, microbicides, and surfactants (Vidic et al., 2013). Some of these chemical additives are recovered as flow back water during the drilling process. However, a substantial amount of these chemicals remain under the ground. The recovered flow back water which contains several chemical additives may be stored in holding ponds or transported offsite to treatment plants or disposed (Vidic et al., 2013).

Chemicals used in the drilling process, as well as other substances present in the flow back water can potentially enter the drinking water supplies (Chapman et al., 2012). This can occur through spills during transport of chemicals and flow back water, well casing leakages (Kovats et al., 2014), leaks through underground fissures in rock formations, and through runoffs emanating from drilling sites (Rozell & Reaven, 2012). Some researchers have identified high levels of methane in drinking water from wells located less than 1 km from natural gas drilling sites due to potential contamination of water wells from the oil drilling sites (Jackson RB et al., 2013; Osborn et al., 2011), and through natural movement of methane and brine from shale deposits into water wells (Warner et al., 2012). If chemical contaminants from unconventional oil and gas drilling activities find their way into drinking water supplies and surface water bodies, public health may be threatened due potential exposure of humans to these chemical contaminants.

Furthermore, chemical toxicants may be released into the atmosphere through evaporation and off-gassing from drilling activities and completion of gas wells, as well as from the storage of waste fluids in holding ponds (Olaguer, 2012). In addition, gas well flaring, diesel equipment and vehicles operation, and other point sources for air toxics around drilling activities may be an important source of respiratory pollutants such as nitrogen oxides, VOCs, and particulate matter (Olaguer, 2012). The completion of wells and the transportation of gas products may result in leakages capable of releasing methane and other greenhouse gases into the environment (Allen, 2014). Similarly, ambient ozone levels may be increased if ozone precursors are released into the environment during unconventional oil and gas drilling activities (Olaguer, 2012). Ozone has been shown to be associated with the incidence and exacerbation of acute respiratory diseases like asthma even at low concentrations (Stern et al., 2003).

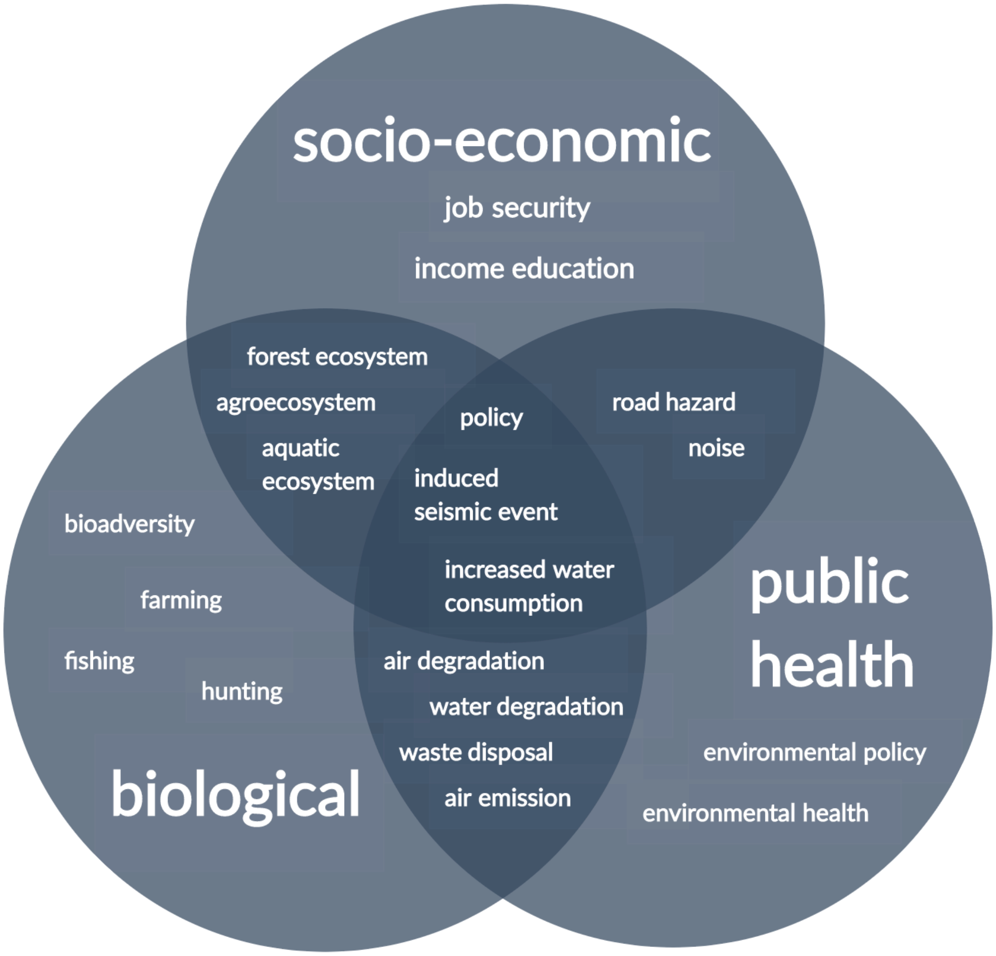
Communities located close to unconventional oil and gas drilling sites may face various public health challenging including; the potential contamination of groundwater by chemicals pollutants; wastewater disposal; release of air toxics, ozone precursors, and diesel particles into the air; and noise pollution due to mechanical activities and heavy truck movement (Adgate, Goldstein, & McKenzie, 2014; Shonkoff, Hays, & Finkel, 2014). Wastewater from the drilling sites is difficult to clean and is often disposed of by dumping it into pits or injection into deep waste-disposal wells which can potentially pollute surface and underground waters (Haynes et al., 2017).

As shown in figure 3, the public health concerns regarding the impact of unconventional oil and gas drilling on nearby communities' center on the potential contamination of water and ambient air in addition to noise pollution and social disturbance (Witter et al., 2013). A case series study reported incidences of respiratory, skin, neurological, and gastrointestinal symptoms among individuals living close to gas wells (Bamberger & Oswald, 2012). Likewise, a survey of 14 counties in Pennsylvania among individuals who were concerned about the potential hazards from gas production activities revealed that several self-reported symptoms were higher among people who live near gas production facilities. The observed symptoms include throat and nasal irritation, eye burning, sinus problems, headaches, skin problems, loss of smell, cough, nosebleeds, and painful joints (Steinzor et al., 2013).

Similarly, many studies have shown that unconventional oil and gas drilling can impact reproductive health, including increases in congenital heart defects (McKenzie et al., 2014), preterm births (Casey et al., 2016), and low birth weight (Stacy et al., 2015). It has also been reported that unconventional oil and gas drilling activities can increase hospital utilization rates in neighboring communities (Jemielita et al., 2015). Asthma attacks, acute bronchitis, and reduced lung function may result from exposure to particulate matters emitted from unconventional oil and gas drilling activities (OSHA, 2013). Likewise, asthma exacerbation (Rasmussen et al., 2016), infant mortality (Busby and Mangano, 2017), and childhood acute lymphocytic leukemia (McKenzie et al., 2017) has been associated with unconventional oil and gas production. Migraine, chronic rhinosinusitis, and fatigue symptoms have also been associated with unconventional oil and gas drilling activities in one self-report study (Tustin et al., 2017).

Finally, exhaust fumes generated by diesel trucks and offsite diesel engines during gas production activities may also affect ambient air quality with potential impact on health (Macy et al., 2014; McKenzie et al., 2014; McKenzie et al., 2012). An increased noise pollution, truck traffic, and psychosocial stress due to community change, which occur as a result of increased oil production activity due to unconventional oil and gas drilling, could equally pose a significant public health challenge (Macy et al., 2014). Unconventional oil and gas drilling is thus a matter of serious public health concern due to its potential for environmental degradation and pollution, as well as its potential for adverse effect on human health.

Figure 3: Overview of Unconventional Gas & Oil Drilling Effects



Hypothesis, Research Question, Specific Aims or Objectives

Review of the reason for our study

A large body of literature links asthma exacerbations to exposure to air pollutants, including ozone, particulate matter, NOX, formaldehyde and benzene. Studies have shown that chronic obstructive pulmonary disease (COPD), pneumonia, and upper respiratory infections as well as asthma are air pollution sensitive diseases (Kelly et al., 2011).

UGOD has been shown to affect air quality, cause psychosocial stress and also have social impacts on the community (Mckensie et al., 2012; Adgate et al., 2014; Yonas et al., 2012) The activities of UGOD have community and environmental impacts that could affect asthma such as stress and changes in air quality. Exposure to air pollution, psychosocial stress and reduced socioeconomic status are conditions that are biologically feasible for UGOD to have respiratory effects.

Jemielita et al. (2015) found that unconventional natural gas development was associated with a significant increase in rates of upper respiratory tract infection (URI) among the elderly and increased the hospitalization rate for pneumonia among the elderly. These findings are consistent with higher levels of air pollution.

In addition, Rabinowitz et al. (2015) showed that airborne irritants related to natural gas extraction activities could be the reason for increased reporting of upper respiratory symptoms among those living less than one kilometer from a natural gas well. This study presents an important spatial dimension because those living closer to the wells had greater adverse impacts. The authors stated the need for further studies on the impact of natural gas activities on respiratory health of nearby communities

Hypothesis

Hospitalization for asthma and respiratory illnesses will differ according to the unconventional oil and gas rig activity and resulting air emissions.

Research Question

What is the relationship between Unconventional Gas and Oil Drilling activity and Hospital Utilization Rates for respiratory diseases in the Barnett Shale, Texas?

Specific Aims

We aimed to identify spatial patterns of active wells location in the Barnett Shale region at the Zip code level. Additionally, we wanted to identify the relationship between drilling activity and asthma/COPD Hospital utilization at the Barnett Shale region at the Zip code level. Finally, we aimed to determine the average annual rate of active wells in the Barnett Shale, the annual change in respiratory disease related hospitalizations, and the yearly trend.

METHODS

Study Design

This is an ecological study that seeks to analyze existing data collected over five years, from 2004 to 2008 and retrospectively assess the association between unconventional oil and gas drilling activity and health care utilization for respiratory illnesses. In patient counts for respiratory diseases in the counties of Johnson, Tarrant, Parker, Ellis, Hood, Wise, Dallas and Coryell was sourced and utilized to represent the Barnett Shale region. Using international Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) codes included patients with Asthma and Chronic Obstructive Pulmonary Diseases (COPD). Other Inclusion criteria are inpatient admission for asthma and other respiratory diseases for the years 2004 to 2008 in the counties of Johnson, Tarrant, Parker, Ellis Hood, Wise, Dallas and Coryell that are between the ages 5 and 90 years and with recorded information on sex, race and ZIP code average income per household. Patients that were treated in hospitals in these 8 counties but who did not reside in the county were excluded from the analysis.

Study Setting

The Barnett Shale is a geological formation that is rich in natural gas and located at the Fort Worth Basin of North Texas. The currently defined boundaries of the shale spans about 5,000 square miles and lies within a 25-county region in North Texas (TRRC) (Figure 4). It is one of the largest onshore natural gas fields in the United States and consists of sedimentary rock that is made of clay and quartz. It was named after the Barnett Stream after a thick black organic-rich shale was found close to it in the early 20th century. The Barnett Shale in Texas has been producing natural gas for more than a decade. Information gained from developing the Barnett Shale provided the initial technology template for developing other shale plays in the United States. The counties are namely Archer, Bosque, Clay, Comanche, Cooke, Coryell, Dallas, Denton, Eastland, Ellis, Erath, Hamilton, Hill, Hood, Jack, Johnson, Montague, Palo Pinto, Parker, Shackle ford, Somervell, Stephens, Tarrant, Wise, Young (TRRC).The urban counties of Barnett Shale are the home of the shale revolution. Modern hydraulic fracturing was developed here, and combining this technology with horizontal drilling created a boom in natural gas production that continued for more than a decade.

Variable Descriptions: Dependent Variables

The hospitalization rate (incidence) for Asthma and COPD is the outcome variable. However, to adjust for the differences in geographic size and population density between these different zip codes, we computed zip code specific rates per 1,000 population to make the healthcare utilization by zip codes comparable. The zip code specific inpatient prevalence rates for each respiratory disease category (and overall for a total of 4 categories) were calculated by dividing the zip code specific number of inpatient counts per year by the population of the zip code. The inpatient prevalent rates were further converted into inpatient prevalence rates per year per 1000 people. Therefore, for this study, prevalence rate refers to the prevalence rate per year per 1000 people. Both the incidence rate and the prevalence rates were utilized in the analysis but the prevalence rate is the primary outcome variable

Variable Descriptions: Independent Variables

The well count is defined as the number of wells per year within a particular zip code. Only the wells that are active were included in the well count. For this study, the well count is defined as the number of wells for the given year within a particular zip code. Since it's not feasible to accurately determine the date a well goes from active to inactive, for this study we assumed that once a well is active, it remains active for the rest of the study period. For example we assumed that if a well became active in 2006, it remained active for the time period of 2006-2008. Likewise, if it was active in 2004, the assumption is that it remained active from 2004-2008. Furthermore, it is feasible that once a well becomes inactive, it could still affect the environment for some time and since we studied a relatively short time period of time, we assumed that every active well remained active for the duration of the study from the year it became active.

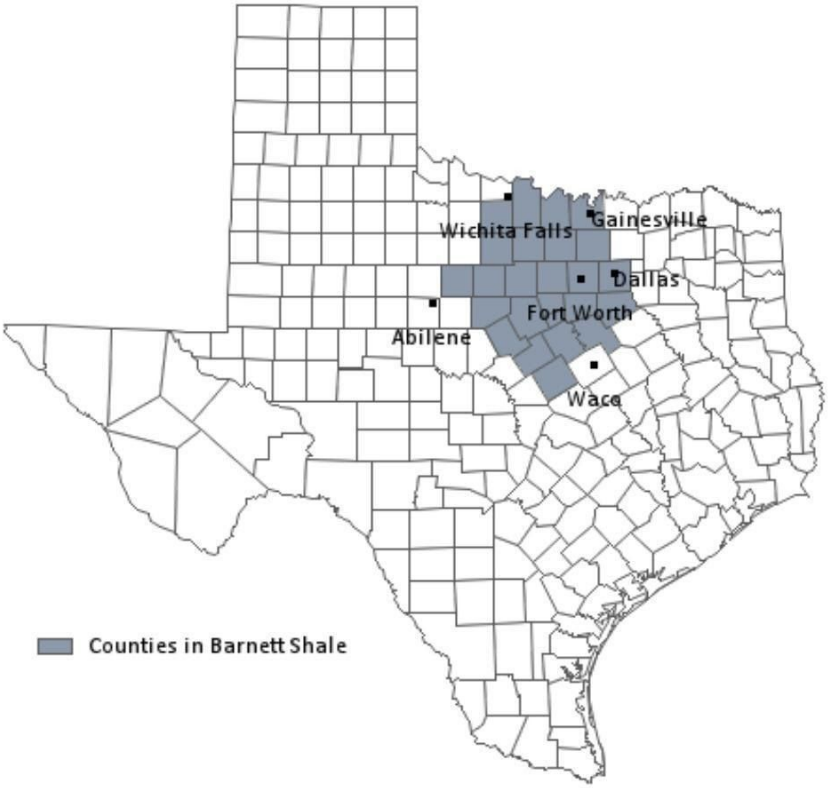
In addition to the well count, well density was generated by dividing the number of wells by the total area per square km at the zip code level. The data for the population and total area per square Kilometer (KM) for each of the zip codes was obtained from the 2000 US Census. Both the well count and the well density was used as the exposure variable to determine which of the variables will have a stronger association with the health outcomes. We assumed that the prevalence rate per zip code was stable since the time period of 2004-2008 (5 years) is relatively short. As stated above, due to the large number of zeros for well density (Table 3), a categorical version of well density was created to assess well density in terms of the absence of well density or the presence of well density. We analyzed both exposure variables. Namely, well count and well density.

Table 1: Study Variables

Variable	**Description**	**Variable Type**	**Variable Source**
Dependent Variable			
Primary Outcome Variable	**Description**	**Type**	**Source**
Inpatient Prevalence Rate (IPR) for Asthma in patients 17 years and younger	The prevalence rate of asthma in 17 years and under per year per 1000 people.	Continuous	DSHS
Inpatient Prevalence Rate (IPR) for Asthma in patients 18 years and older	The prevalence rate of asthma in patients 18 years and older per year per 1000 people per zip code.	Continuous	DSHS
Inpatient Prevalence Rate (IPR) for COPD patients	The prevalence rate of COPD patients hospitalized per year per 1000 people.	Continuous	DSHS
Inpatient Prevalence Rate (IPR) for overall respiratory diseases	The prevalence rate of overall number of patients hospitalized for respiratory diseases per year per 1000 people.	Continuous	DSHS
Inpatient Prevalence Rate (IPR) for Asthma 17 years and younger	The prevalence rate of asthma in 17 years and under per year per 1000 people.	Continuous	DSHS
Outcome variable	Description		
Asthma Incidence in patients 17 years and under	The number of patients hospitalized for Asthma in patients 17 years and younger per year per zip code	Continuous	DSHS
Asthma Incidence in patients 17 years and under	The number of patients hospitalized for Asthma in patients 17 years and younger per year per zip code	Continuous	DSHS
Asthma Incidence in patients 17 years and under	The number of patients hospitalized for Asthma in patients 17 years and younger per year per zip code	Continuous	DSHS

Asthma Incidence in patients 17 years and under	The number of patients hospitalized for Asthma in patients 17 years and younger per year per zip code	Continuous	DSHS
Independent Variables	**Description**		
Well Count	The number of active wells per year within a particular zip code	Continuous	Drilling info
Well Density	The number of active wells per the total area per square km at the zip code level.	Continuous	Drilling info
Well Density quantile	Absence of well density or the presence of well density	Categorical	Drilling info

Figure 4: Barnett Shale counties and location

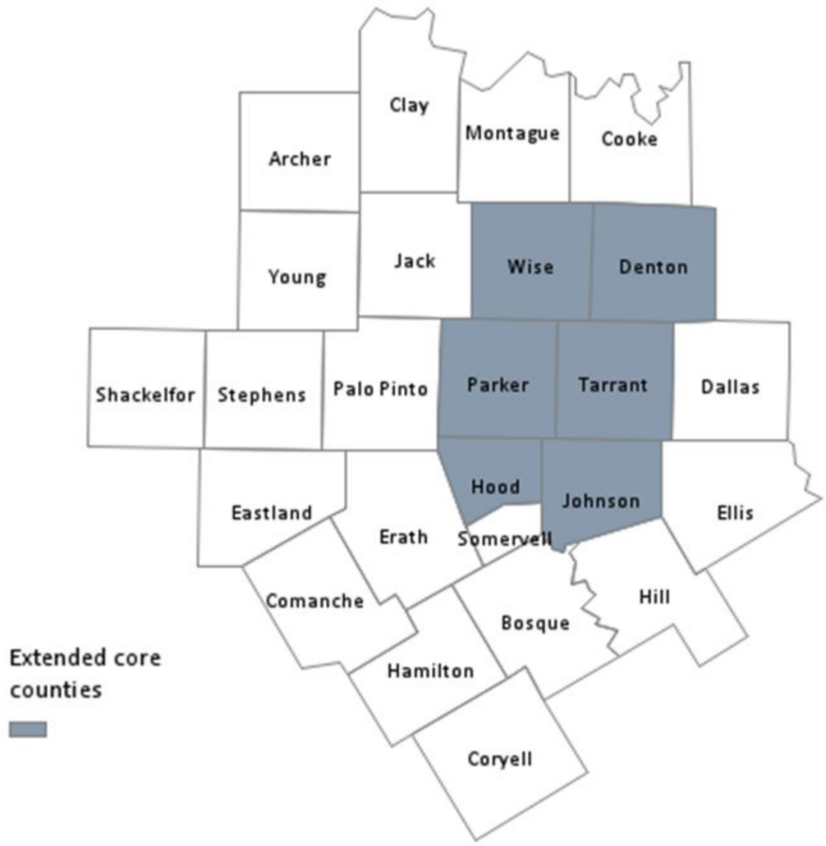


Source: Texas Railroad Commission

Discussion of the justification for the choice of counties for intended study

The Texas Railroad Commission (TRRC) identifies four core counties that account for more than 80 percent of the region's output, namely Wise, Denton, Tarrant, and Johnson. Parker and Hood counties also produce a substantial amount of natural gas and when added to these TRRC core counties yields six extended core counties as shown in Figure 5.

Figure 5: Barnett Shale Extended Core Counties



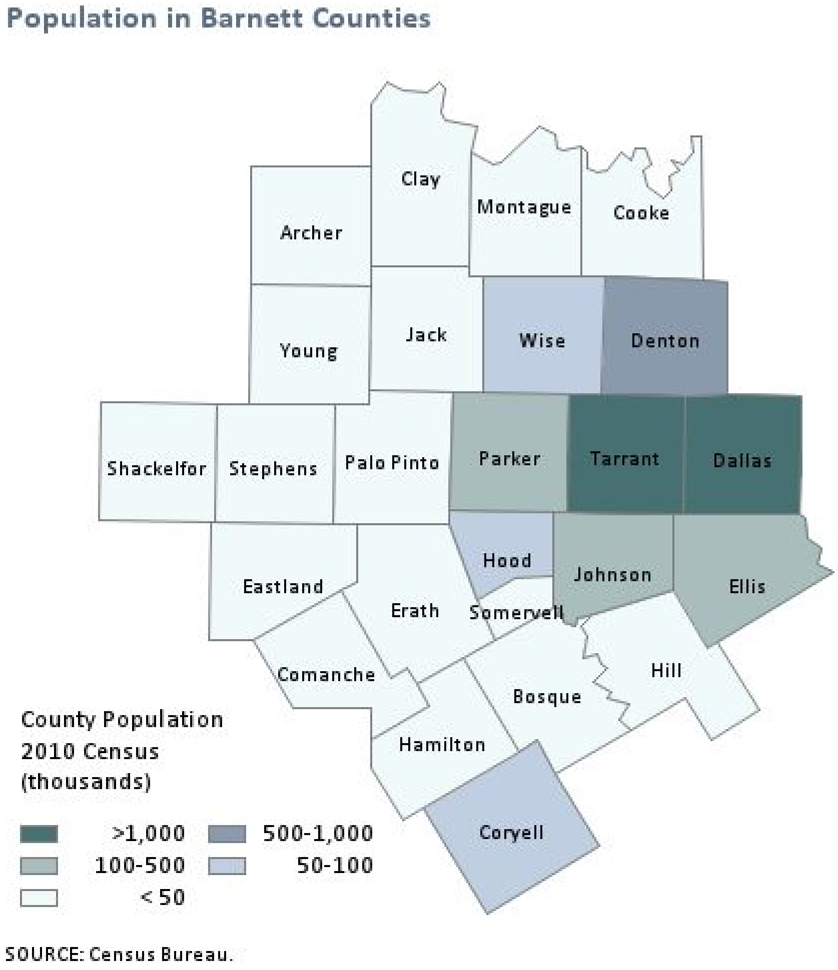
Location of Extended Core Barnett Counties

SOURCE: Federal Reserve Bank of Dallas.

Well and hospitalization data for Wise, Parker, Johnson, Hood, Tarrant, Dallas, Ellis and Coryell Counties will be used for this study to represent areas with high, medium and low well activity matrices. Wise, Parker, Tarrant, Johnson and Hood are urban counties that are part of the six extended core counties. These five counties had increases in active wells over the time period 2004 to 2008. Coryell County which had no active wells from 2004 to 2008 is a unique control population with demographics comparable to Wise and Hood counties. Ellis

County had little or no active wells in the time period and has demographics comparable to Johnson and Parker Counties (Figure 6). Dallas likewise had few active wells in the time period and has demographics comparable to Tarrant County.

Figure 6: Population of Barnett Shale Counties

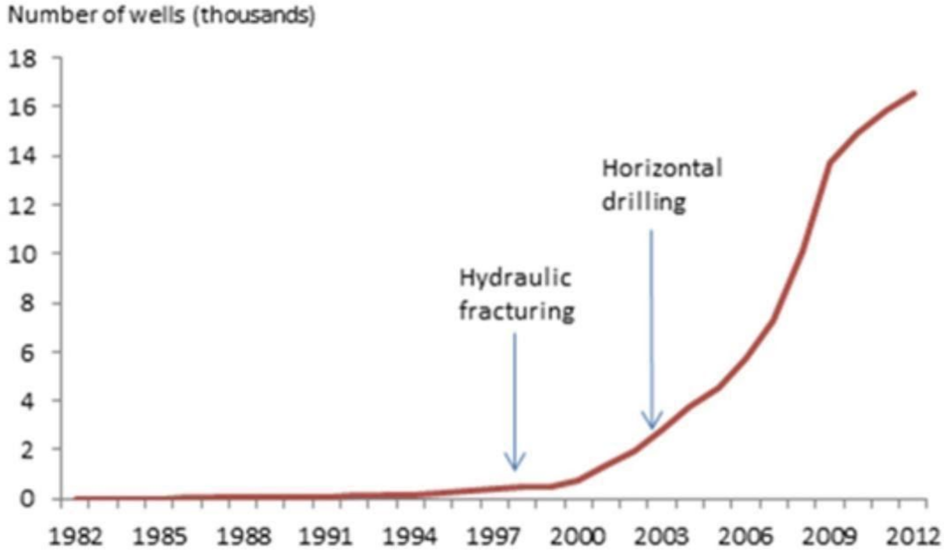


SOURCE: Census Bureau.

Johnson County has about 10; Ellis County has 12; Parker has 8; Tarrant has 60, Dallas has 82, Wise has 9 zip codes; Hood County has 5 and Coryell County has 6 zip codes respectively making a total of 192 zip codes for this ecological study.

The time period of 2004 to 2008 was chosen to capture the immediate effects of Hydraulic fracturing and horizontal drilling. Hydraulic fracturing which started in the Barnett Shale in the late 1990s led to increase in the number of wells. When hydraulic fracturing was paired with horizontal drilling in early 2000, it led to rapid expansion of the number of wells in the region (Figure 8). Furthermore, production in the Barnett shale region peaked in 2008

Figure 7: Barnett Shale Technological innovations timing



Source: Railroad Commission of Texas; Barnett Shale Energy Education Council

Data Collection

A total of 5 data sources were utilized for this study. Description of the datasets used are as follows; firstly, the dataset for hospital admissions for respiratory diseases for the years 2004 to 2008 by zip code. The origin of this hospital admission dataset was the Texas Department of State Health Services (DSHS). It was established by Dr. Kai Zhang of UTSPH with the DSHS's IRB# 14-0783. The DSHS datasets contain all inpatient hospital discharge records for patients hospitalized in Texas. Transitional care unit, 23 hour observation, skilled nursing facility and hospice records are not included. The aggregate hospitalizations by zip code of patient residence per month for respiratory diseases within the principal diagnosis of ICD-9 code 490-496 (Appendix A) for Asthma and COPD were generated using this dataset.

Zip code specific hospital admissions per month for asthma and chronic obstructive pulmonary diseases (COPD) for the calendar years 2004, 2005, 2006, 2007 and 2008 for the counties of Johnson, Tarrant, Parker, Ellis, Hood, Wise, Dallas and Coryell were considered. These counties were of interest because Coryell, Dallas and Ellis counties had little or no hydro fracking activity between 2004 and 2008, while Wise, Johnson, Tarrant, Parker and Hood counties had increased hydro fracking activity for the same time period. ICD-9-CM codes were utilized for the main diagnosis to be included. Although a lot of possible respiratory carcinogenic chemicals are used in the process of unconventional well development, they were not included in our study because five years is a short time frame to study carcinogenic effects.

The second dataset has the U.S Census 2000 zip code demographics for Johnson, Parker, Ellis, Hood, Tarrant, Dallas, Coryell and Wise counties respectively. This data is publicly available on the U.S bureau website.

The third dataset for this study is the well data that was donated by DrillingInfo.com, a commercially available site that is currently known as Enverus Drilling info, and accessible at https://app.drillinginfo.com/production/#/default. Our focus is on unconventional gas production in the Barnett shale, so our query excluded wells that do not meet up with that definition. Sample wells were limited to wells drilled between January 1st. 2004 to December 31st. 2008 that the railroad commission of Texas denotes as horizontal or unconventional wells. Vertical wells or wells drilled through conventional methods were excluded. Additionally, unconventional wells that were inactive were also excluded. Furthermore, UGOD wells that got permits for drilling but have not yet been drilled were not included in this study. Data for all active UGOD wells in the Barnett Shale between 1st. January 2004 and 31st. December 2008 were included to characterize the unconventional drilling activity in the Barnett Shale for that period.

For each UGOD well in the 8 Barnett Shale counties we obtained the following information; production type, surface latitude, surface longitude, producing status (active or inactive), Well Count, Months Produced, Spud Date, Field, Geologic Province API/UWI, Operator and Company Name, Well/Lease Name, Well Number, Entity Type, County/Parish, Basin, DI Play, Reservoir, Surface Latitude, Surface Longitude, Cumulative Gas, Operator Name, First and Last Production Date and Completion date. For the 5 year period in the 8 counties studied, 8,036 unique UGOD wells were identified.

The fourth data set contains the U.S. Census 2000 profile of general demographics characteristics for Johnson, Tarrant, Dallas, Parker, Hood, Ellis, Coryell and Wise counties respectively. This demographic data is publically available on the U.S. Census bureau website.

The fifth data set utilized contains the shape file for the Johnson, Tarrant, Dallas, Parker, Hood, Ellis, Coryell and Wise counties respectively. These shape files are publicly available and were downloaded from the county data portal and utilized to generate Zip code specific County maps. The Barnett Shale shape file was created from the United States county shape file by clipping the Barnett shale area counties. This was also publically available from the United States census bureau. Stata 16 was used for the statistical analysis and ArcGIS 10.4.1 was used for spatial mapping of the dataset.

Data Analysis

Spatial analysis

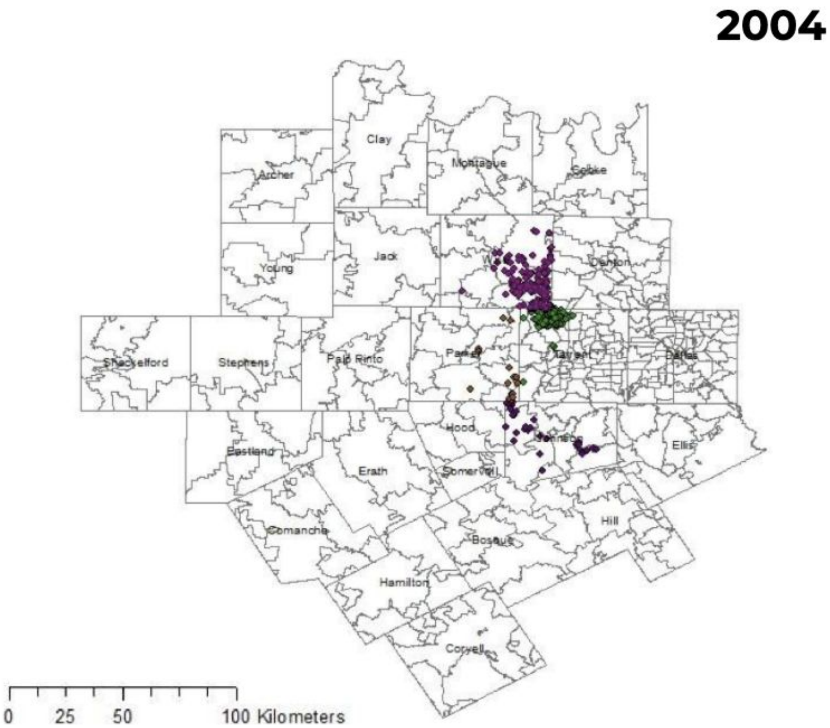
We used ArcGIS for the mapping and visualization of the geographic locations of the unconventional gas wells. ArcGIS is a computer based Geographic Information System (GIS) that provides unique capabilities for working with maps and geographic datasets and information. For this study, a zip code shape file was utilized to represent various zip codes within Johnson, Tarrant, Parker, Hood, Ellis, Dallas, Coryell and Wise counties respectively. The shape file for the Barnett Shale and specific counties studied namely Johnson, Tarrant, Parker, Hood, Ellis, Dallas, Coryell and Wise counties respectively are publicly available. They were downloaded from the county specific data portal and utilized to generate Zip code specific County maps. The study utilized the State of Texas Categorization of Unconventional gas wells or unconventional fracture treated fields ("UFT Fields"). A UFT Field is a field where the drainage of a wellbore is dependent on the area reached by the hydraulic fracturing treatments as opposed to conventional flow patterns (TRRC, 2016). The Railroad commission of Texas further states that this designation includes the Barnett Shale where horizontal drilling and hydraulic fracturing techniques are utilized to recover resources from all or part of the field. The complete well dataset for the years 2004 to 2008 for each of the eight counties was donated by drilling info. The data was downloaded and imported into ArcGIS as comma separated values to map the locations of the producing wells. Only the unconventional wells that were produced in the stated year were included.

Mapping of the Unconventional wells in Johnson, Tarrant, Parker, Hood, Ellis, Dallas, and Wise counties

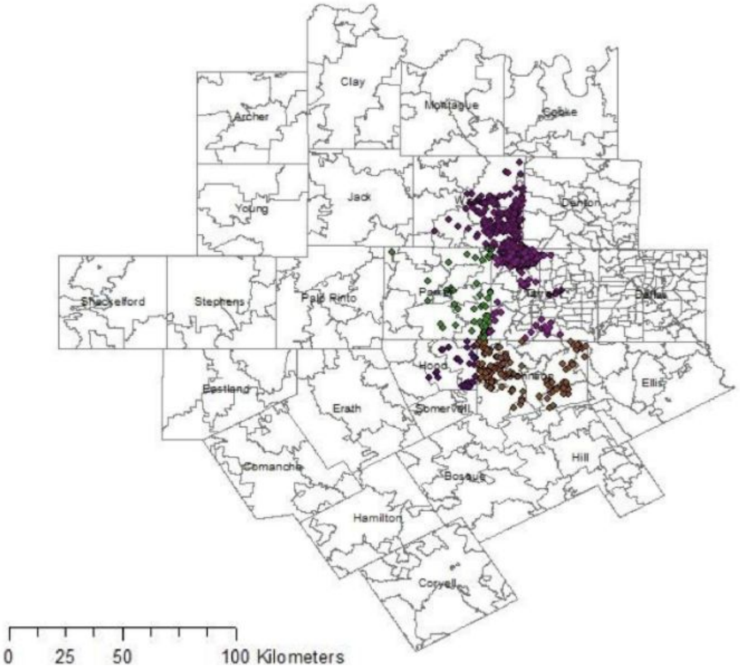
The complete well dataset for the years 2004 to 2008 for each of the eight counties was downloaded and imported into ArcGIS as comma separated values from Enverus drilling info website to map the locations of the producing wells. For Fig 3, only the data for active unconventional drilled wells as characterized by The State of Texas Categorization of Unconventional gas wells or unconventional fracture treated fields ("UFT Fields") was used. Unconventional gas well is thus defined as a field where the drainage of a wellbore is dependent on the area reached by the hydraulic fracturing treatments as opposed to conventional flow patterns. The dataset was queried for monthly production by county and exported as a CSV file from the Enverus drilling info website and imported into ESRI ArcGIS 10.4.1 to map the locations of the producing wells for each year. The exported CSV data table contained latitude-longitude for each well, together with other queried data for mapping. The table was added as an X-Y event table in ArcMap. Since this table had each well’s coordinates, it was added to the map as a layer. The data from the Enverus drilling info was filtered for unconventional drilled gas wells that produced gas in the queried year per county and not by zip codes. ArcGIS was utilized to geocode the wells to the specific zip codes per county and utilized to generate data for zip code specific well locations. As shown in Figure 8, only wells that were active in the particular year are shown.

Barnett Shale active wells in Parker, Hood, Johnson and Tarrant Counties increased markedly from 2004 to 2008. Wells are shown as colored dots. From 2004 to 2008, Coryell county had no active wells. Ellis county had no wells until 2007 while Dallas county had the it’s first well in 2008.

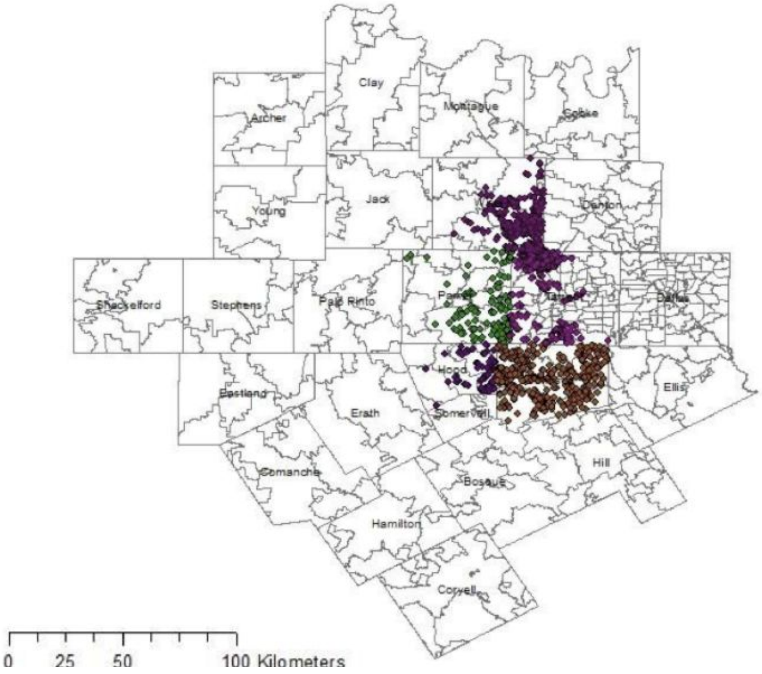
Figure 8: Barnett Shale active wells from 2004-2008



2005


Clay
Montague
Cooke
Archer
Young
Jack
Denton
Shackelford
Stephens
Palo Pinto
Parker
Tarrant
Dallas
Hood
Johnson
Ellis
Eastland
Erath
Somervell
Comanche
Bosque
Hill
Hamilton
Coryell
0 25 50 100 Kilometers

2006


Clay
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Parker
Tarrant
Dallas
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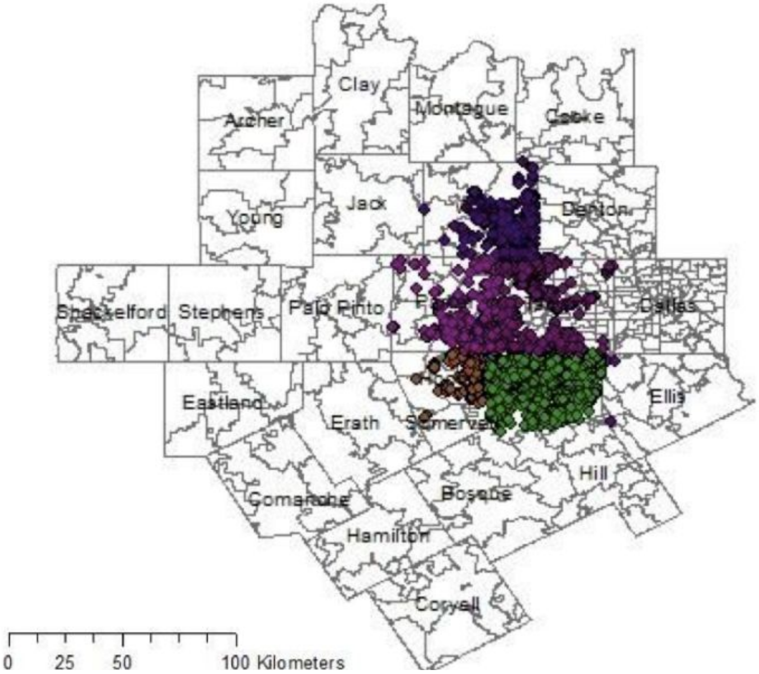
Ellis
Eastland
Erath
Somervell
Comanche
Bosque
Hill
Hamilton
Coryell
0 25 50 100 Kilometers

2007


Clay
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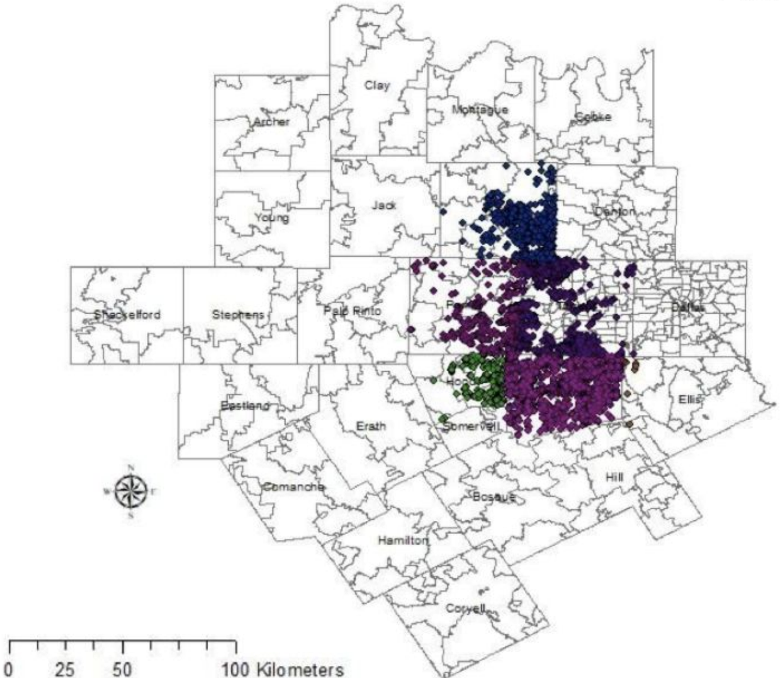
Palo Pinto
Dallas
Eastland
Erath
Somervell
Ellis
Hill
Comanche
Bosque
Hamilton
Coryell
0
25
50
100 Kilometers

2008


Clay
Archer
Montague
Cooke
Young
Jack
Denton
Shackelford
Stephens
Palo Pinto
Dallas
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Somervell
Ellis
Hill
Comanche
Bosque
Hamilton
Coryell
0
25
50
100 Kilometers

Statistical Analysis

This study proposed that increased numbers of active unconventional wells would increase inpatient prevalent rate in response to increased exposure to toxicants and the stressors of unconventional drilling and increased diesel engine usage. Therefore, this study evaluated the relationship between wells and healthcare use for asthma and respiratory diseases by zip code from 2004 to 2008 in the Barnett shale area in Texas. The monthly hospital admission data for asthma and other respiratory illnesses (from the Texas Department of State Health Services.) were correlated with active wells data by zip code in eight counties in the Barnett shale region of Texas.

Our data comprised the total number of active wells in the eight counties and in patient counts for the specified respiratory diseases for the years 2004 -2008 (five years) for a total of 192 zip codes. The unit of analysis is the zip code and there are a total of 192 zip codes in the eight counties. To adjust for the differences in geographic size and population density between these different zip codes, we computed zip code specific rates per 1,000 population to make the healthcare utilization by Zip codes comparable. The zip code specific inpatient prevalence rates for each respiratory disease category (and overall for a total of 4 categories) were calculated by dividing the zip code specific number of inpatient counts per year by the population of the zip code. The inpatient prevalent rates were converted into inpatient prevalence rates per year per 1000 people. For this study, prevalence rate refers to the prevalence rate per year per 1000 people. Both the incidence rate and the prevalence rates were utilized in the analysis but the prevalence rate is the primary outcome variable. The well count is defined as the number of wells per year within a particular zip code. Only the wells that are active were included in the well count. For this study, the well count is defined as the number of wells for the given year within a particular zip code. Since it's not feasible to accurately determine the date a well goes from active to inactive, for this study we assumed that once a well is active, it remains active for the rest of the study period. For example we assumed that if a well became active in 2006, it remained active for the time period of 2006-2008. Likewise, if it was active in 2004, the assumption is that it remained active from 2004 -2008. Furthermore, it is feasible that once a well becomes inactive, it could still affect the environment for some time and since we studied a relatively short time period of time, we assumed that every active well remained active for the duration of the study from the year it became active.

In addition to the well count, well density was generated by dividing the number of wells by the total area per square km at the zip code level. The data for the population and total area per square Kilometer (KM) for each of the zip codes was obtained from the 2000 US Census. Both the well count and the well density was used as the exposure variable to determine which of the variables will have a stronger association with the health outcomes. We assumed that the prevalence rate per zip code was stable since the time period of 2004-2008 (5 years) is relatively short. The study variables of interest are continuous. However due to the large number of zero's for well density (Table 3), a categorical version of well density was created to assess well density in terms of the absence of well density or the presence of well density. Descriptive analysis was conducted using frequencies and percentages for categorical variables and observing the means and standard deviations for the continuous variables (Table 4) Univariate diagnostics using histograms, showed a right-skewed Poisson distribution with variances that far exceeded their means. Conversion of incidence measures into prevalence rates retained the skewed distributions. These skewed distributions made analysis using standard OLS or parametric techniques non-viable due to assumptions violations that would bias estimates and impact the validity of inference (Tabachnick and Fidel, 2007). Poisson regression modeling is typically used as it has some extensions that are useful for count models. However, Poisson regression models retain the assumption that the outcome variable's mean must equal its variance in order to achieve proper inference. When summarizing our study descriptives, the continuous variable's means did not approximate their variances and as a result, negative binomial regression analysis was chosen. Negative binomial regression model could be considered as a generalization of Poisson regression because it has the same mean structure as Poisson regression and provides an additional parameter during estimation that accounts for over dispersion (Cameron and Trivedi 1998). Furthermore, the longitudinal structure of the data has a clustering effect that violates the assumption of independence of observations. Specifically, our study variables were measured for each year within zip codes with time nested within zip codes. Longitudinal data often has an intrinsic dependency with variable values being correlated over time within subjects. To account for this, hierarchical linear modeling (multilevel modeling) was used to control for this dependency (Raudenbush and Bryk 2002). Our study primary analysis was conducted using negative-binomial mixed model regression using the predictors of interest and a time variable as fixed effects and designating zip code as a random effect (Cameron and Trivedi 1998).

Our data was collected on 192 zip codes measured over 5 years (2004 through 2008). To fit our analysis, the data was reshaped to properly analyze mixed model data from wide format (each outcome variable has its own yearly data) to long format (there is only one outcome variable and a year variable is created to capture time). The reshaping of the data changed the unit of observation from zip codes ($N = 192$) to zip code-years ($N = 960$). The negative binomial regression models estimate a coefficient called an incidence rate ratio (IRR) that is analogous to an odds ratio in logistic regression in terms of interpretation. An IRR with a coefficient of 1 is equivalent to no relationship between a predictor and the outcome, a coefficient greater than one indicates a greater likelihood of incidence over time and a coefficient less than one indicating a lower likelihood of incidence over time. Model fit statistics for these analyses were reported using Wald χ^2 overall test and associated p-value for significance of the model and the log-likelihood relative fit statistic (Cameron and Trivedi 1998). Stata version 16 (StataCorp. 2019) was used for the analysis using the *menbreg* command. The alpha level was set at .05.

Human Subjects Considerations

This project involved secondary data analysis with data that had no personal information and identifiers, thus the study qualified as minimum risk as it does not impose any risk on human subjects. Our study received expedited review from the University of

Texas School of Public Health Institutional Review Board (IRB) for exempt status under study number HSC-SPH-18-0726 by the UT Health committee for the protection of human subjects with reference number 176565 (See Appendix E). All study variables were cleaned and stored on password protected computers.

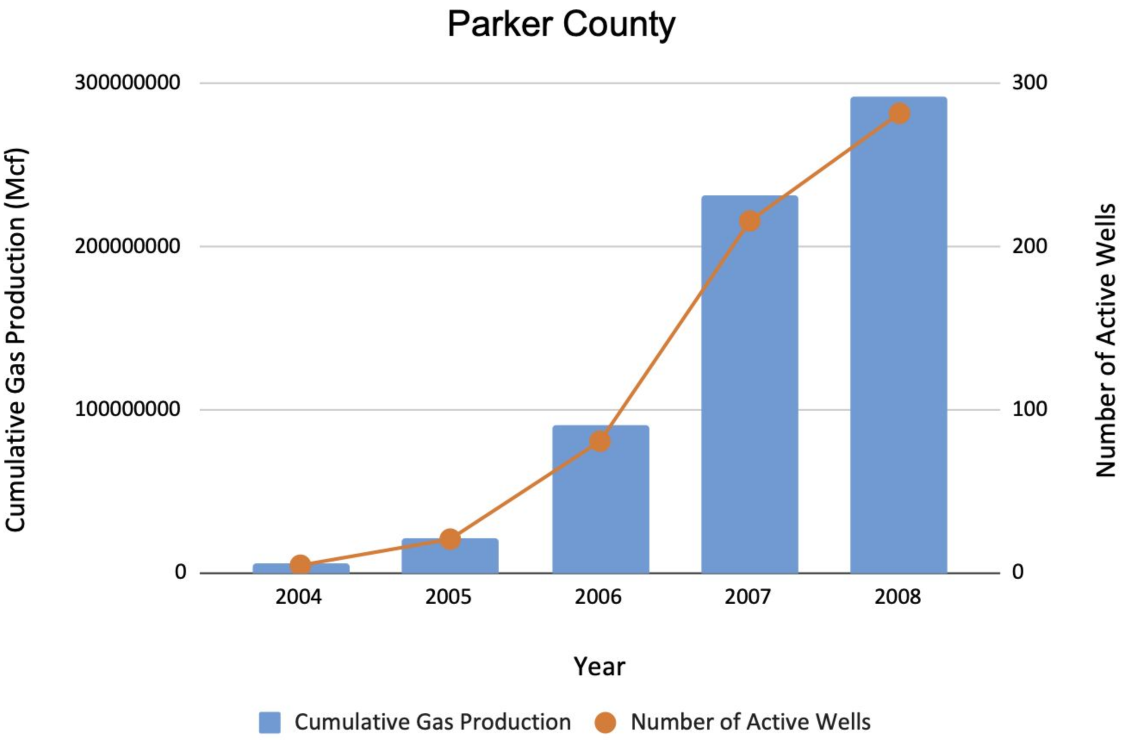
RESULTS

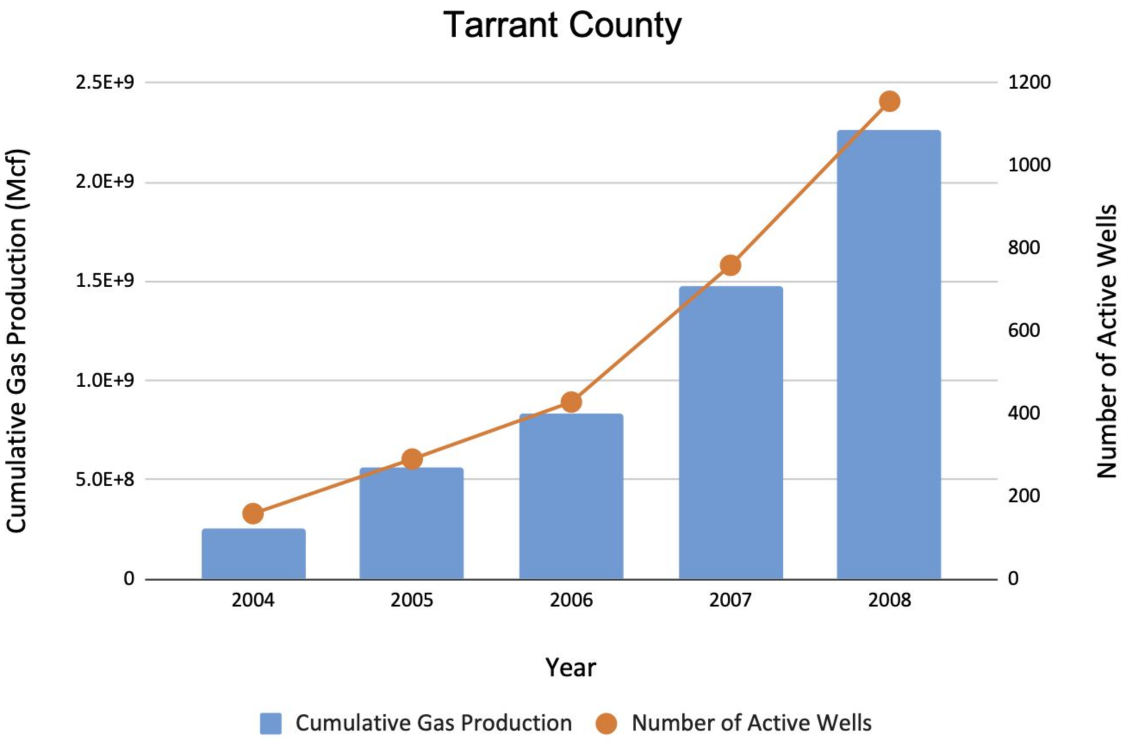
All 8 Barnett Shale County zip code demographics were obtained from the 2000 United States Census data. The Johnson, Wise, Parker, Tarrant and Hood counties also had large increases in active well activity over this five year time period (Figures 9 & 10). Conversely, the Coryell, Dallas and Ellis counties had none or few active wells respectively in the five year time period and served as a remarkable control population with comparable demographics to the counties with active wells. Additionally these counties had complete healthcare utilization data from 2004 to 2008. Some zip codes in the counties were not included in the study because these zip codes were not in the County in the five years of the study according to the U.S. Census 2000 demographics or did not have complete and detailed demographic information. Therefore, only the zip codes that had complete and detailed demographic information in the U.S Census 2000 data and represented appropriately on the available Barnett Shale county Shapefile were used in our analysis. The Johnson county shapefile has a total of 16 zip codes. 6 zip codes (76035, 76049, 76070, 76033, 76036 and 76063) were excluded. Therefore, a total of 10 zip codes which had complete and detailed demographic information in the U.S Census 2000 data and represented appropriately on the available Barnett Shale and Johnson Shapefile were used in our analysis. The Hood county shapefile has a total of 9 zip codes but only 5 zip codes were included in our study. 4 zip codes (76433, 76087, 76033, and 76087) were excluded. The Wise county shapefile has a total of 16 zip codes but 9 zip codes were included in the study. 7 zip codes (76270, 76487, 76082, 76266, 76249 and 76259, 76052) were excluded. The Parker county shapefile has a total of 18 zip codes but only 8 zip codes were included in our study.10 zip codes (76486, 76067, 76462, 76049, 76035, 76126, 76085, 76108, 76020, and 76023) were not included in the study. Although Ellis county shapefile has a total of 24 zip codes, only 12 zip codes were included. 12 zip codes (76063, 75104, 76055, 76084, 76050, 76055, 76641, 76626, 76623, 75158, 75105 and 75146) were not included in the study. The Coryell county shapefile has a total of 15 zip codes but only 6 zip codes were included. 9 zip codes (76035, 76049, 76070, 76033, 76036 and 76063) were excluded. The Tarrant county shapefile has a total of 92 zip codes, but only 60 zip codes were used in the study. 33 zip codes (76121, 76122, 76124, 76130, 76185, 76190, 76191, 76192, 76193, 76195, 76181,76196, 76197, 76198, 76199, 76244, 76248, 76003, 76004, 76005, 76007, 76003, 76004, 76005, 76007, 76019, 76095, 76096, 76099, 76101, 76094, 7600, 76004, 76005) were excluded. The Dallas county shapefile has a total of 157 zip codes. 78 zip codes were not included in the study. Therefore a total of 82 zip codes that were in the Dallas County in the five years of the study with complete and detailed demographic information represented appropriately on the available Barnett Shale and Wise County Shapefile were used in our analysis. Table 2. shows the characteristics table for the 8 barnett counties studied. Although the counties can not be statistically compared as each county is a unit data point, the summary demographics of the counties were comparable according to the population classifications used as shown in figure 6. Furthermore the subjects in all the counties were predominantly caucasians and the median age in years are comparable and all the counties are in Urban areas. Table 2 also shows how the hydro fracking activity increased from 2004 to 2008 for the Johnson, Wise, Parker, Tarrant and Hood counties respectively. By 2008 52% of Tarrant county had at least one well (up from 12%) while 89% of Wise county had at least one well. Additionally, by 2008, 75% of Parker county had at least one well while 100% Johnson counties had at least one well.

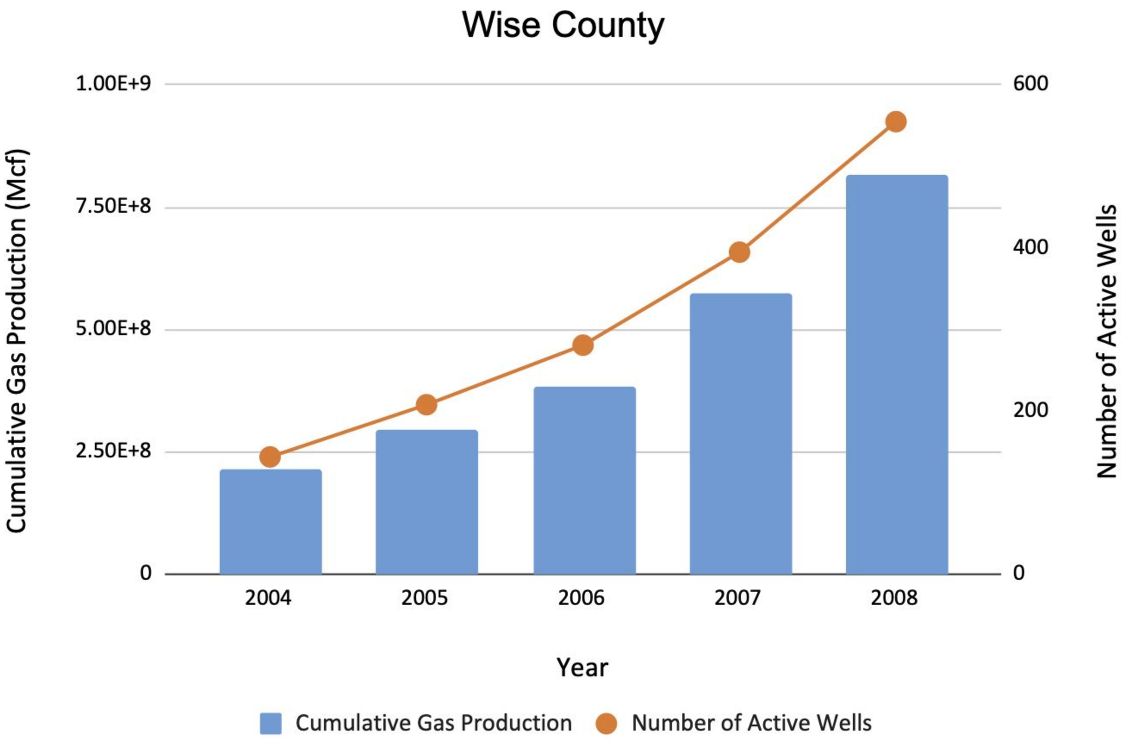
Table 2: Summary demographics of Barnett Shale, Texas Counties

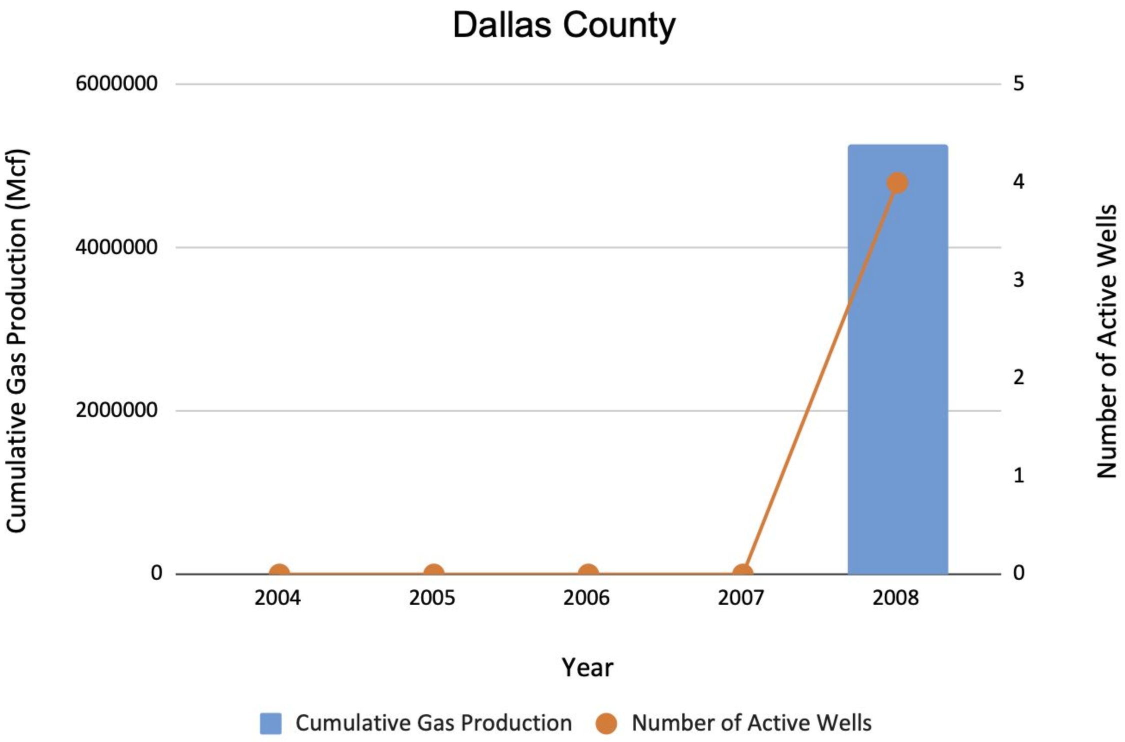
County		Coryell	Wise	Hood	Dallas	Tarrant	Johnson	Parker	Ellis
Population		74,978	48,793	41,100	2,218,899	1,446,219	126,811	88,495	111,360
Total housing units (%) 2004–2008		100	100	100	100	100	100	100	100
Occupied Housing(%)		91	89	85	94	94	94	91	94
Median Age (years)		27.8	35.5	41.5	31.1	32.3	34.3	36.5	33.2
Age 18 and over (%)		73.8	71.7	76.4	72.1	71.9	71.2	72.5	69.8
Male (%)		51.3	50.4	49.0	49.9	49.5	49.9	51.0	49.6
Median Income 2000 ($)		36,277	43,209	44,772	43,550	47,660	44,372	46,638	50,312
Race %	White	65.3	91.0	94.8	58.4	71.2	90.0	92.6	80.6
	Black	21.8	1.2	0.3	20.3	12.8	2.5	1.8	8.6
	Asian	1.8	0.2	0.3	4.0	3.6	0.5	0.3	0.4
	American indian	0.9	0.8	0.8	0.6	0.6	0.6	0.7	0.6
Median Number of Wells	2004	0	1	0	0	0	0.5	0	0
	2005	0	2	2	0	0	3.5	1	0
	2006	0	8	3	0	0	23	2	0
	2007	0	13	10	0	0	47	6	0
	2008	0	22	12	0	1	81.5	8.5	0
Number of Zip Codes with >0 Wells (%)	2004	0(0)	5(55)	0(0)	0(0)	7(12)	5(50)	3(38)	0(0)
	2005	0(0)	6(67)	3(60)	0(0)	16(27)	7(70)	4(50)	0(0)
	2006	0(0)	7(78)	4(80)	0(0)	20(33)	9(90)	5(63)	0(0)
	2007	0(0)	8(89)	4(80)	0(0)	28(47)	9(90)	6(75)	1(8)
	2008	0(0)	8(89)	4(80)	2(2)	31(52)	10(100)	6(75)	1(8)

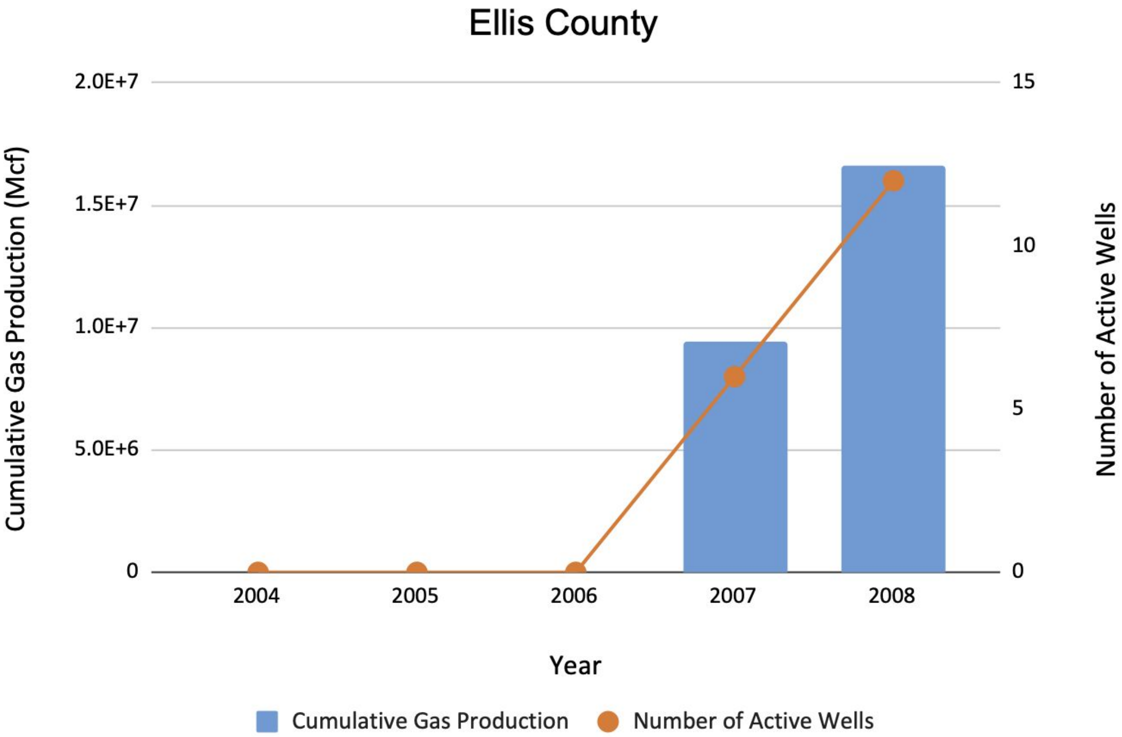
Figure 9: 2004-2008 Cumulative gas production histogram with active well numbers (circles)

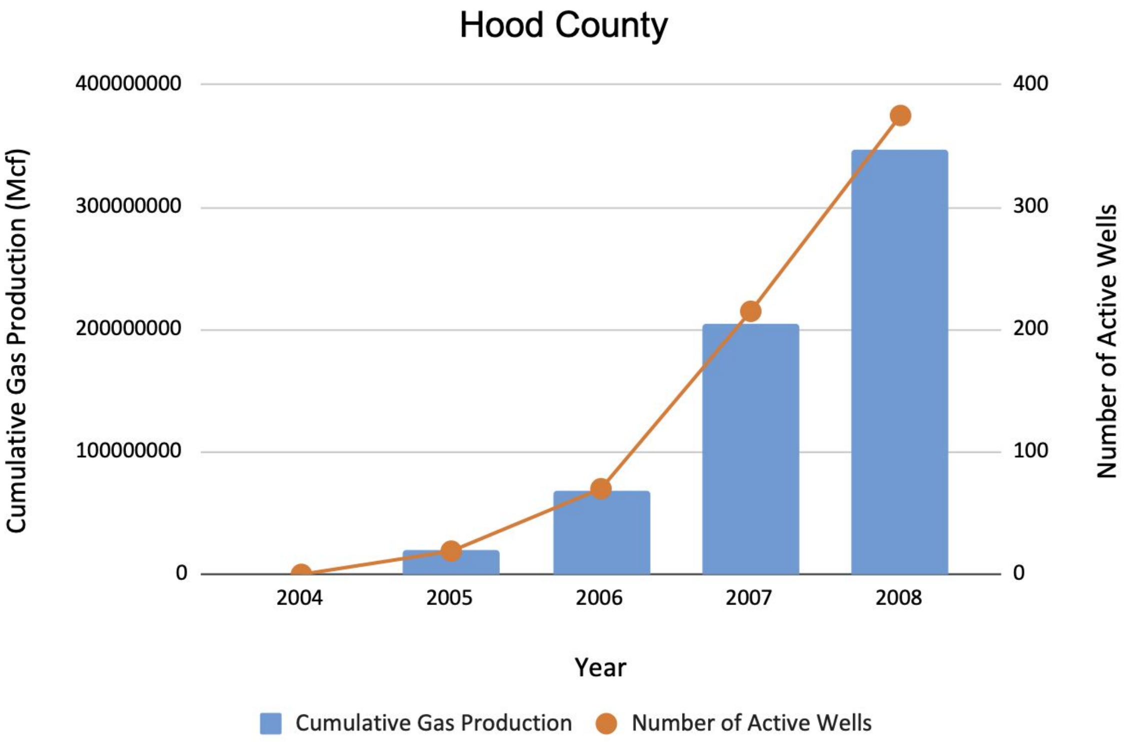


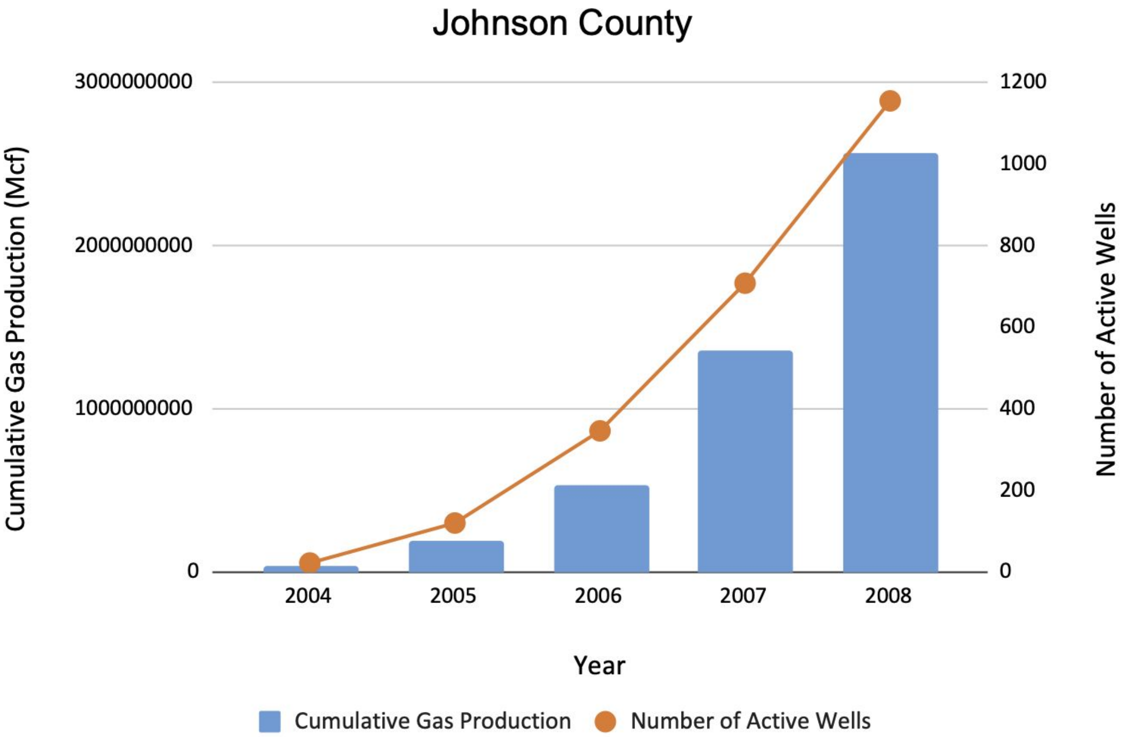

Tarrant County
Cumulative Gas Production (Mcf)
2.5E+9
2.0E+9
1.5E+9
1.0E+9
5.0E+8
0
Number of Active Wells
1200
1000
800
600
400
200
0
2004
2005
2006
2007
2008
Year
Cumulative Gas Production
Number of Active Wells


Wise County
1.00E+9
7.50E+8
5.00E+8
2.50E+8
0
600
400
200
0
Cumulative Gas Production (Mcf)
Number of Active Wells
2004
2005
2006
2007
2008
Year
Cumulative Gas Production
Number of Active Wells


Dallas County
Cumulative Gas Production (Mcf)
6000000
4000000
2000000
0
Number of Active Wells
5
4
3
2
1
0
2004
2005
2006
2007
2008
Year
Cumulative Gas Production
Number of Active Wells


Ellis County
Cumulative Gas Production (Mcf)
2.0E+7
1.5E+7
1.0E+7
5.0E+6
0
Number of Active Wells
15
10
5
0
2004
2005
2006
2007
2008
Year
Cumulative Gas Production
Number of Active Wells

Hood County
Cumulative Gas Production (Mcf)
400000000
300000000
200000000
100000000
0
Number of Active Wells
400
300
200
100
0
2004
2005
2006
2007
2008
Year
Cumulative Gas Production
Number of Active Wells



Spatial Locations of the Wells from 2004 to 2008

Using ArcGIS to map the spatial locations of the wells by zip code shows important information about the rapid increase in the number of active wells from 2004 to 2008 as shown in Figure 8.The extended core counties saw substantial increases in the total number of active wells. Coryell county had no active wells from 2004 to 2008, Ellis county had no active wells until 2007 and 2008, and Dallas county had the first active well in 2008. Cumulative gas production (McF) linearly tracked with increasing active well numbers as shown in Figure 9 illustrates that well densities will likely continue to rise if the UGOD well activity continues to increase at the same rate as in 2004-2008.

Statistical Analysis

Descriptives conducted on all study variables include frequencies and percentages for the categorical variable while means and standard deviations were used to describe the continuous variables. As explained above,in addition to the well count, well density was generated by dividing the number of wells by the total area per square km at the zip code level using data obtained from the 2000 US Census. Both the well count and the well density was used as the exposure variable to determine which of the variables will have a stronger association with the health outcomes.. However due to the large number of zero's for well density (Table 3), a categorical version of well density was created to assess well density in terms of the absence of well density or the presence of well density.A large percentage of the zip code-years had no well density (77.2%) compared to zip code-years that had the presence of well-density activity (22.8%). Table 3 shows the frequencies and percentages of the well density categorical variable.

Table 3: Frequencies and Percentages for Well Density Categorical Variable

Well density categorical	*n*	%
No well density	741	77.2
Well density activity	219	22.8

Accordingly, summary of the descriptives for the continuous variables shows that the number of active wells ranged from 0 to 326 per zip code with a mean of 8.37 (*SD* = 32.95) while well density per zip code ranged from 0 to 2.27 with a mean of .06 (*SD* = .21). Table 4 shows the summary statistics of all the continuous variables of the different respiratory medical categories studied including the overall respiratory diseases.

Table 4: Means, Medians, and Standard Deviations for Study Variables

Variable	*n*	*M*	*Mdn*	*SD*	*Min*	*Max*
Active wells	960	8.37	.00	32.95	.00	326.00
Well density	960	.06	.00	.21	.00	2.27
COPD Incidence	960	24.81	17.00	24.02	.00	125.00
COPD Prevalence rate	960	1.92	1.08	7.49	.00	185.71
Asthma Incidence 17 years and under	960	10.47	8.00	11.28	.00	69.00
Asthma Prevalence 17 years and under	960	.52	.38	.86	.00	19.69
Asthma 18 years incidence	960	15.52	11.00	15.85	.00	101.00
Asthma under 18 years prevalence rate	960	.83	.62	1.12	.00	22.22
Overall respiratory disease incidence	960	50.80	38.50	45.84	.00	259.00
Overall respiratory disease prevalence	960	3.28	2.22	7.80	.00	185.71

Inpatient Prevalence rates by respiratory disease categories

The median in patient prevalence rate for the 4 respiratory disease categories studied and the corresponding median inpatient counts are shown in Table 6. The 3 respiratory disease categories studied as well as the overall respiratory disease category. The value of these variables are interpretable only at the zip code level.COPD has the highest inpatient prevalence rate/median inpatient counts (1.08/17.00) without counting the overall inpatient prevalence rate /inpatient count.As shown in figure 10, the inpatient prevalence rate for asthma in patients 18 and above per 1,000 people per year is stable within a zip code Figure 10 also shows some zip codes had high inpatient prevalence rates compared to the others.

Table 5: Median Inpatient Prevalence rates per 1,000 people and Median Inpatient Counts by Medical Category.

Medical Category	Median Inpatient Prevalence Rate	Median Inpatient Counts
Overall respiratory disease	2.22	38.50
COPD	1.08	17.00
Asthma 17 and under	.38	8.00
Asthma 18 and older	.62	11.00

Note: Median IPR/Median inpatient count are interpretable only at the zip code level.

Results of our negative binomial mixed linear regression models

Results of our negative binomial mixed linear regression models testing the relationship between the numbers of active wells per with COPD incidence shows that there was no significant relationship between active wells and COPD incidence, $p > .05$. Table 6 presents the results. For Model 1, the model fit statistics were Wald χ^2 (5) = 101.85, p < .001, Loglikelihood = -3253.60. However, there was a significant trend in the year variable showing that there was a higher likelihood of COPD incidence in 2007 (*IRR* = 1.087, *p* = .003) and

2008 (*IRR* = 1.232, $p < .001$), compared to the baseline year 2004. For Model 2, the model fit statistics were Wald χ^2 (5) = 31.62, $p < .001$, Loglikelihood = -1396.18. The results indicate that there was no significant relationship between active wells and COPD prevalence rate per 1,000, $p > .05$. Similarly, there was a significant trend in the year variable showing that there was a higher likelihood of COPD hospitalization rate per 1,000 people the year in 2008 (*IRR* = 1.358 $p < .001$), compared to the baseline year 2004.

Table 6: Summary of Negative Binomial Mixed Model Regression Predicting COPD Incidence and Prevalence Using Active Wells

	Model 1 (DV: COPD Incidence)				Model 2 (DV: COPD Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Active wells	1.001	.148	1.000	1.002	1.000	.862	.997	1.002
Year								
2005	1.045	.121	.988	1.104	.902	.276	.750	1.086
2006	.970	.280	.917	1.025	.906	.294	.753	1.090
2007	1.087	.003	1.028	1.149	1.169	.080	.981	1.391
2008	1.232	< .001	1.164	1.303	1.358	< .001	1.143	1.613
Constant	13.317	< .001	11.179	15.865	1.103	.258	.931	1.306

Note. Model 1: COPD Incidence, $N = 960$, Wald $\chi^2(5) = 101.85$, $p < .001$, Loglikelihood = -3253.60. Model 2: COPD Prevalence, $N = 960$, Wald $\chi^2(5) = 31.62$, $p < .001$, Loglikelihood = -1396.18. [a]Compared to baseline year 2004.

The results indicate that there was also no significant relationship between well density and COPD incidence and COPD prevalence rates per 1,000 people $p > .05$ (Table 7). However, in Model 1, there was a significant trend in the year variable showing that there was a higher likelihood of COPD incidence in 2007 (*IRR* = 1.092, $p = .002$) and 2008 (*IRR* = 1.241, $p < .001$), compared to the baseline year 2004. In Model 2, there was a significant trend in the year variable showing that there was a higher likelihood of COPD prevalence in 2008 (*IRR* = 1.320 $p = .002$), compared to the baseline year 2004.

Table 7: Summary of Negative Binomial Mixed Model Regression Predicting COPD Incidence and Prevalence Using Well Density

	Model 1 (DV: COPD Incidence)				Model 2 (DV: COPD Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density	1.028	.724	.881	1.200	1.170	.420	.798	1.715
Year								
2005 [a]	1.045	.117	.989	1.105	.900	.265	.748	1.083
2006 [a]	.971	.311	.918	1.027	.900	.263	.748	1.083
2007 [a]	1.092	.002	1.032	1.155	1.148	.127	.962	1.370
2008 [a]	1.241	<.001	1.171	1.315	1.320	.002	1.104	1.578
Constant	13.354	<.001	11.213	15.904	1.102	.260	.931	1.305

Note. Model 1: COPD Incidence, $N = 960$, Wald $\chi^2(5) = 99.18$, $p < .001$, Loglikelihood = -3254.58. Model 2: COPD Prevalence, $N = 960$, Wald $\chi^2(5) = 32.24$, $p < .001$, Loglikelihood = -1395.88. [a]Compared to baseline year 2004.

The results of the negative binomial mixed linear regression models testing the relationship between categorical well density with COPD incidence and prevalence rate per 1,000 people also showed no significance $p > .05$. As shown in Table 8, in Model 1 there was a significant trend in the year variable showing that there was a higher likelihood of COPD incidence in 2007 (*IRR* = 1.092, $p = .003$) and 2008 (*IRR* = 1.242, $p < .001$), compared to the baseline year 2004. In Model 2, there was a significant trend in the year variable showing that there was a higher likelihood of COPD prevalence in 2008 (*IRR* = 1.315, $p = .002$), compared to baseline.

Table 8: Summary of Negative Binomial Mixed Model Regression Predicting COPD Incidence and Prevalence Using Categorical Well Density

	Model 1 (DV: COPD Incidence)				Model 2 (DV: COPD Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density								
Categorical	1.013	.780	.928	1.105	1.124	.278	.910	1.389
Year								
2005 [a]	1.044	.128	.988	1.105	.892	.230	.741	1.075
2006 [a]	.971	.306	.917	1.028	.888	.216	.736	1.072
2007 [a]	1.092	.003	1.031	1.156	1.137	.161	.950	1.359
2008 [a]	1.242	<.001	1.172	1.316	1.315	.002	1.103	1.567
Constant	13.342	<.001	11.200	15.893	1.092	.312	.921	1.294

Note. Model 1: COPD Incidence, $N = 960$, Wald $\chi^2(5) = 99.10$, $p < .001$, Loglikelihood = -3254.60. Model 2: COPD Prevalence, $N = 960$, Wald $\chi^2(5) = 32.72$, $p < .001$, Loglikelihood = -1395.61. [a]Compared to baseline year 2004.

Results of our negative binomial mixed linear regression models testing the relationship between the numbers of active wells with Asthma 17 years and under incidence shows that there was no significant relationship between active wells and Asthma incidence, p > .05 . Table 9 presents the results. For Model 1, the model fit statistics were Wald $\chi2$ (5) = 92.69, p < .001, Loglikelihood = -2577.01. However, there was a significant trend in the year variable showing that there was a higher likelihood of Asthma incidence in 2008 (IRR = .800, p =< .001) compared to the baseline year 2004. For Model 2, the model fit statistics were Wald $\chi2$ (5) = 31.62, p < .001, Loglikelihood = -1396.18. The results indicate that there was no significant relationship between active wells and Asthma prevalence rate per 1,000, p > .05. Similarly, there was no significant trend in the year variable compared to the baseline year 2004.

Table 9: Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in Children 17 Years and Younger Using Active Wells

	Model 1 (DV: As17 Incidence)				Model 2 (DV: As17 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Active well	1.001	.147	1.000	1.003	1.000	.838	.996	1.003
Year								
2005 [a]	.788	<.001	.736	.845	.819	.177	.613	1.094
2006 [a]	1.001	.834	.943	1.075	1.200	.176	.922	1.561
2007 [a]	.957	.197	.896	1.023	1.048	.738	.797	1.377
2008 [a]	.800	<.001	.746	.858	.873	.359	.654	1.166
Constant	6.049	<.001	4.966	7.369	.442	<.001	.356	.549

Note. Model 1: As 17 Incidence, *N* = 960, Wald χ^2 (5) = 92.69, $p < .001$, Loglikelihood = -2577.01. Model 2: As17 Prevalence, *N* = 960, Wald χ^2 (5) = 9.29, $p < .098$, Loglikelihood = -790.66. [a]Compared to baseline year 2004.

Results of our negative binomial mixed linear regression models testing the relationship between the numbers of active wells with COPD incidence shows that there was no significant relationship between active wells and COPD incidence, $p > .05$. Table 10 presents the results. For Model 1, the model fit statistics were Wald χ^2 (5) = 90.83, $p < .001$, Loglikelihood = -2577.83. However, there was a significant trend in the year variable showing that there was a higher likelihood of COPD incidence in 2008 (*IRR* = .803, $p < .001$), compared to the baseline year 2004. For Model 2, the model fit statistics were Wald χ^2 (5) = 9.35, $p < .001$, Loglikelihood = -2577.83. The results indicate that there was no significant relationship between well density and Asthma 17 and under prevalence rate per 1,000, $p > .05$.

Similarly, there was no significant trend in the year variable compared to the baseline year 2004.

Table 10: Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in Children 17 years and Younger Using Well Density

	Model 1 (DV: As17 Incidence)				Model 2 (DV: As17 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density	1.075	.508	.868	1.331	1.094	.744	.637	1.880
Year								
2005 ^{a}	.789	.<.001	.736	.845	.818	.173	.612	1.092
2006 ^{a}	1.008	.809	.944	1.076	1.195	.186	.918	1.092
2007 ^{a}	.959	.227	.897	1.026	1.037	.794	.788	1.365
2008 ^{a}	.803	<.001	.747	.864	.859	.310	.641	.547
Constant	6.071	<.001	4.986	7.393	.441	<.001	.355	.547

Note. Model 1: As17 Incidence, $N = 960$, Wald χ^2 (5) = 90.83, $p < .001$, Loglikelihood = -2577.83. Model 2: As17 Prevalence, $N = 960$, Wald χ^2 (5) = 9.35, $p < .096$, Loglikelihood = -790.63. ^{a}Compared to baseline year 2004.

Table 11: Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in Children 17 years and younger Using Categorical Well Density

	Model 1 (DV: A17 Incidence)				Model 2 (DV: As17 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density								
Categorical	1.007	.820	.949	1.068	.905	.170	.785	1.044
Year								
2005 [a]	.788	<.001	.736	.845	.831	.210	.621	1.110
2006 [a]	1.008	.804	.944	1.077	1.223	.135	.939	1.595
2007 [a]	.962	.262	.898	1.030	1.078	.591	.819	1.420
2008 [a]	.807	<.001	.751	.868	.902	.484	.675	1.205
Constant	6.030	<.001	4.883	7.445	.500	<.001	.379	.659

Note. Model 1: As17 Incidence, $N = 960$, Wald $\chi^2(5) = 90.69$, $p < .001$, Loglikelihood = -2578.02. Model 2: As17 Prevalence, $N = 960$, Wald $\chi^2(5) = 11.12$, $p < .049$, Loglikelihood = -789.74. [a]Compared to baseline year 2004.

Table 12: Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in adults 18 years and older Using Active Wells

	Model 1 (DV: As18 Incidence)				Model 2 (DV: As18 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Active Well	1.001	.149	1.000	1.002	1.001	.582	.998	1.003
Year								
2005 [a]	1.101	.001	1.040	1.166	1.120	.316	.897	1.401
2006 [a]	.981	.520	.925	1.040	.904	.400	.714	1.143
2007 [a]	1.088	.004	1.027	1.154	1.059	.623	.844	1.329
2008 [a]	1.120	<.001	1.056	1.189	1.217	.084	.974	1.521
Constant	8.385	<.001	7.002	10.041	.689	<.001	.576	.825

Note. Model 1: As18 Incidence, $N = 960$, Wald χ^2 (5) = 38.78, $p < .001$, Loglikelihood = -2866.74. Model 2: As18 Prevalence, $N = 960$, Wald χ^2 (5) = 8.57, $p < .0.128$, Loglikelihood = -1054.51. [a]Compared to baseline year 2004.

The results of the negative binomial mixed linear regression models testing the relationship between well density with asthma 18 years or older incidence and prevalence rates per 1,000 people also showed significance $p < .05$. As shown in Table 13, in Model 1 there was a significant association between well density and asthma for 18 year-olds or older incidence (*IRR* = 1.212, $p = .024$) indicating that as well density increases the likelihood of asthma for 18 year-olds increases by a factor of 1.212. In addition, trend in the year variable showing that there was a higher likelihood of asthma for 18 year-olds incidence in 2005 (*IRR* = 1.099, $p = .001$), 2007 (*IRR* = 1.080, $p = .009$) and 2008 (*IRR* = 1.107, $p = .001$), compared to the baseline year 2004. In Model 2, there was a marginally significant association between well density and asthma for 18 year-olds or older incidence (*IRR* = 1.472, $p = .055$). However, there was no significant trend in the year variable, $p > .05$

Table 13: Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in Adults 18years and Over Using Well Density

	Model 1 (DV: As18 Incidence)				Model 2 (DV: As18 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density	1.212	**.024**	1.025	1.432	1.472	**.055**	.991	2.184
Year								
2005 ^{a}	1.099	.001	1.039	1.165	1.116	.333	.893	1.395
2006 ^{a}	.979	.474	.923	1.038	.895	.355	.707	1.132
2007 ^{a}	1.080	.009	1.019	1.145	1.031	.790	.821	1.296
2008 ^{a}	1.107	.001	1.042	1.175	1.165	.187	.929	1.461
Constant	8.372	<.001	6.991	10.027	.686	<.001	.573	.821

Note. Model 1: As18 Incidence, $N = 960$, Wald $\chi^2(5) = 42.07$, $p < .001$, Loglikelihood = -2865.26. Model 2: As18 Prevalence, $N = 960$, Wald $\chi^2(5) = 12.15$, $p < .0328$, Loglikelihood = -1052.90. ^{a}Compared to baseline year 2004.

Table 14: Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in Adults 18 Years and Older Using Categorical Well Density

	Model 1 (DV: As18 Incidence)				Model 2 (DV: As18 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density								
Categorical	1.038	.126	.990	1.089	1.037	.515	.930	1.1549
Year								
2005 [a]	1.095	.002	1.034	1.160	1.115	.339	.892	1.394
2006 [a]	.975	.408	.919	1.035	.898	.375	.709	1.138
2007 [a]	1.081	.010	1.019	1.148	1.052	.663	.837	1.323
2008 [a]	1.116	<.001	1.050	1.185	1.213	.090	.971	1.517
Constant	8.028	<.001	6.638	9.709	.661	<.001	.528	.826

Note. Model 1: As18 Incidence, $N = 960$, Wald $\chi^2(5) = 39.37$, $p < .001$, Loglikelihood = -2866.61. Model 2: , $N = 960$, Wald $\chi^2(5) = 8.67$, $p < .123$, Loglikelihood = -1054.44.
[a]Compared to baseline year 2004.

Table 15 presents the results of the negative binomial mixed linear regression models testing the relationship between active wells and well density with overall respiratory disease incidence. For Model 1, the model fit statistics were Wald χ^2 (5) = 63.91, $p < .001$. The results indicate that there was a statistically significant relationship between active wells and overall incidence (*IRR* = 1.001, $p = .009$). However, the effect size (*IRR*) is very close to 1.00 meaning no effect, suggesting that though this is statistically significant, this may not be a meaningful effect. In addition, there was a significant trend in the year variable showing that there was a higher likelihood of overall incidence in 2007 (*IRR* = 1.061, $p = .003$) and 2008 (*IRR* = 1.096, $p < .001$), compared to the baseline year 2004. For Model 2, the model fit statistics were Wald χ^2 (5) = 60.55, $p < .001$, Loglikelihood = -3719.87. The results indicate that there was a statistically significant relationship between well density and overall incidence (*IRR* = 1.117, $p = .049$). Thus, as well density increases, the likelihood of overall incidence increases by a factor of 1.12. In addition, there was a significant trend in the year variable showing that there was a higher likelihood of overall incidence in 2007 (*IRR* = 1.06, $p = .003$) and 2008 (*IRR* = 1.096, $p < .001$), compared to the baseline year 2004

Table 15: Summary of Negative Binomial Mixed Model Regression Predicting Overall Respiratory Disease Incidence Using Active Wells and Well Density

	Model 1 (DV: Overall Incidence)				Model 2 (DV: Overall Incidence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Active wells	1.001	.009	1.000	1.002				
Well density					1.117	.049	1.000	1.248
Year								
2005 [a]	1.004	.844	.966	1.043	1.004	.851	.966	1.043
2006 [a]	.981	.322	.944	1.019	.981	.326	.944	1.019
2007 [a]	1.061	.003	1.021	1.102	1.060	.003	1.019	1.102
2008 [a]	1.096	< .001	1.054	1.140	1.096	< .001	1.052	1.141
Constant	29.409	< .001	24.813	34.857	29.456	< .001	24.858	34.905

Note. Model 1: Overall, $N = 960$, Wald $\chi^2(5) = 63.91$, $p < .001$, Loglikelihood = -3718.38.
Model 2: Overall, $N = 960$, Wald $\chi^2(5) = 60.55$, $p < .001$, Loglikelihood = -3719.87.
[a] Compared to baseline year 2004.

Table 16 presents the results of the negative binomial mixed linear regression models testing the relationship between active wells and well density with overall respiratory disease prevalence. For Model 1, the model fit statistics Wald $\chi^2(5) = 25.81$, $p < .001$, Loglikelihood = -1786.28. The results indicate that there was not a statistically significant relationship between active wells and overall prevalence ($p = .820$). However, there was a significant trend in the year variable showing that there was a higher likelihood of overall prevalence in 2008 (*IRR* = 1.221, $p = .002$), compared to the baseline year 2004. For Model 2, the model fit statistics were Wald χ^2 (5) = 27.83, $p < .001$, Loglikelihood = -1785.32. The results indicate that there was not a statistically significant relationship between well density and overall prevalence ($p = .160$). In addition, there was a significant trend in the year variable showing that there was a higher likelihood of overall prevalence in 2008 (*IRR* = 1.188, $p = .011$), compared to the baseline year 2004.

Table 16: Summary of Negative Binomial Mixed Model Regression Predicting Overall Respiratory Disease Prevalence Using Active Wells and Well Density

	Model 1 (DV: Overall Prevalence)				Model 2 (DV: Overall Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Active wells	1.000	.820	.998	1.002				
Well density					1.234	.160	.920	1.655
Year								
2005	.938	.350	.821	1.072	.936	.330	.819	1.069
2006	.939	.354	.822	1.073	.933	.307	.816	1.066
2007	1.115	.097	.980	1.269	1.096	.166	.962	1.249
2008	1.221	.002	1.074	1.389	1.188	.011	1.040	1.357
Constant	2.356	< .001	2.074	2.676	2.354	< .001	2.073	2.672

Note. Model 1: Overall, $N = 960$, Wald χ^2 (5) = 25.81, $p < .001$, Loglikelihood = -1786.28.
Model 2: Overall, $N = 960$, Wald χ^2 (5) = 27.83, $p < .001$, Loglikelihood = -1785.32.
[a]Compared to baseline year 2004.

DISCUSSION

We conducted a mixed effect negative binomial regression analysis of respiratory disease related hospitalizations in Texas using in patient hospitalizations records from the DSHS database from 2004 to 2008. This study time period represents the time period of initial introduction of horizontal drilling and hydraulic fracturing at the Barnett Shale, Texas and we believe it captured the resultant rapid development of wells that took place as a result of that technological advancement.We postulated that the increased number of active hydraulic fracturing wells would increase the rate of hospitalizations of pollution sensitive respiratory diseases due to the increase in the activities of UGOD and the resultant increased exposure to toxicants, noise and stress.

The activities of UGOD have been associated with social impacts in the community as well as with air pollution.(Litovitz et al., 2013; Mckenzie et al., 2012; Roy AA et al., 2014; Sangamoorthy et al., 2016).The adverse health effect of UGOD is well documented in the literature. Despite the preponderance of documented facts that the air pollution effects of UGOD is associated with adverse health effects, very few epidemiologic studies have focused on air pollution sensitive respiratory outcomes of UGOD.

Respiratory health effects like asthma are appropriate outcomes to examine possible health impacts of UGOD because they are common, easily linked to air pollution and stress, and have a short latency between exposure and health effects. The combination of these factors make it more likely for patients to seek medical care and so are captured by health system data. As previously stated, some of the Possible sources of respiratory stressors from UGOD include exposure to air pollution from well development activities (Brunekreef et al., 2012; Guarneri et al., 2014) and also pollution from heavy truck traffic at UGOD sites (Guarneri et al., 2014). All these in addition to psychosocial stress (Yonas et al., 2012) and sleep disruption (Hanson et al., 2008; Daniel et al., 2012) are scientifically proven precursors to acute respiratory events such as asthma exacerbations.

The precise cause for the increase in respiratory disease outcome from exposure to UGOD remains unknown. Although the time frame of five years is relatively short to capture significant health effects, this time frame captures a unique time period of the onset of horizontal drilling and hydraulic fracturing in the Barnett Shale and serves as a baseline for future studies. The results of the negative binomial mixed linear regression models testing the relationship between well density with incidence of asthma in persons 18 years and older and prevalence rates per 1,000 people also showed significance $p < .05$. As shown in Table 13, in Model 1 there was a significant association between well density and asthma incidence for 18 year-olds and older ($IRR = 1.212$, $p = .024$) indicating that as well density increases the likelihood of asthma hospitalization for 18 year-olds increases by a factor of 1.212. In addition, there was a trend in the year variable showing that there was a higher likelihood of asthma hospitalization for patients 18 year-olds and older in 2005 ($IRR = 1.099$, $p = .001$), 2007 ($IRR = 1.080$, $p = .009$) and 2008 ($IRR = 1.107$, $p = .001$), compared to the baseline year 2004. In Model 2, there was a marginally significant association between well density and asthma hospitalization rate per 1,000 people per year for patients 18 years-old or older ($IRR =$

1.472, *p* = .055). However, there was no significant trend in the year variable, *p* > .05. Although there was a significant association between well density and asthma incidence for 18 year-olds and older (*IRR* = 1.212, *p* = .024), we interpret this result with caution as incidence rate is not our primary outcome variable (inpatient prevalence rate per 1,000 persons per year) and thus is not generalizable.

Our result is supported by a study done by Ramusen et al (2016) that found residential UGOD activity metrics to be statistically associated with increased risk of mild, moderate, and severe asthma exacerbations. The study included 3-level adjusted models, and showed that there was a correlation between the highest group of the activity metric for each UGOD phase compared with the lowest group for 11 of 12 UGOD-outcome pairs. The authors stated that the findings of their study were robust to increasing levels of covariate control and evaluation of some possible sources of unmeasured confounding in sensitivity analysis. Similarly, Willis et al. (2018) reported that community-level UGOD exposure metrics were associated with increased odds of pediatric asthma related hospitalization among young children and adolescents. This study provides evidence that additional regulations may be necessary to protect children's respiratory health from UGOD activities.

The result of our mixed effect negative binomial regression analysis predicting the relationship between active wells and well density with overall respiratory disease prevalence is shown in Table 16. For Model 1, the model fit statistics Wald χ^2 (5) = 25.81, *p* < .001, Loglikelihood = -1786.28. The results indicate that there was not a statistically significant relationship between active wells and overall prevalence (*p* = .820). However, there was a significant trend in the year variable showing that there was a higher likelihood of overall prevalence in 2008 (*IRR* = 1.221, *p* = .002), compared to the baseline year 2004. For Model 2, the model fit statistics were Wald χ^2 (5) = 27.83, *p* < .001, Log Likelihood = -1785.32. The results indicate that there was not a statistically significant relationship between well density and overall prevalence (*p* = .160). In addition, there was a significant trend in the year variable showing that there was a higher likelihood of overall prevalence in 2008 (*IRR* = 1.188, *p* = .011), compared to the baseline year 2004. Furthermore, as shown in Tables 17 and 18, there was also a positive year trend for the year 2008 for COPD in both the active wells and well density models, showing that there is increased likelihood of COPD hospitalization rate in 2008 compared to the baseline year 2004. This was consistent with all the models we ran that were not shown in tables 17 and 18. One possible explanation is that for respiratory diseases, a longer time period of toxicant exposure needs to be studied to properly assess a direct impact on health in the surrounding community. It's possible that cumulative exposure to toxicants for a longer period of time may have led to increased hospitalization rate in the year 2008 compared to the baseline year 2004. Willis et al. (2008) further supports our assumption. The author noted that the intensity of pollution from UGOD is more important than the initial introduction of UGOD into a community. Gas production peaked in 2008 for our current study as shown in figure 9 and therefore it is likely that the intensity of pollution in that year was also higher and may have led to the increased likelihood of having COPD and overall hospitalization rate per 1,000 persons in year 2008 compared to the baseline year 2004. We presume that if activity continues to increase,the association found in this study may be even stronger.

A study by Jemelita et al. (2015) found no statistical significance for pulmonary diseases for a time frame of 5 years. However, results from the same study suggest that cardiology inpatient prevalence rates were significantly associated with number of wells and well density, while neurology inpatient prevalence rates were significantly associated with well density. These findings were observable within a short period of five years from 2007–2011.One possible explanation is that some respiratory diseases may require a longer time period of toxicant exposure before the health effect of toxicant exposure is seen in the surrounding community. It's possible that cumulative exposure for a longer period of time is needed to see an effect as shown by our result of increased likelihood of hospitalization rate in 2008 compared to 2004 baseline.

A study by Peng et al. (2016) also supports our study findings for COPD. The authors investigated the health impacts of unconventional natural gas development of Marcellus shale in Pennsylvania between 2001 and 2013 by comparing changes in hospitalization rates over time for air pollution-sensitive disease in counties with unconventional gas wells to changes in hospitalization rates in non-well counties. The result of the study shows that UGOD accelerates COPD hospitalizations, but does not cause a significant association for overall hospitalization rate. The study also noted that among individuals aged 20-44, well development in the current year was associated with an increase of 0.06 admissions for COPD per one thousand people, but was offset by well development associated with a decrease of

0.08 admissions per one thousand people in the previous year. Although they found a statistically significant result, for individuals aged 20-44, the sensitivity analyses showed the result to be spurious for asthma hospitalization.The authors further stated that the time period for the study may be too short to capture the changes.

Although the air pollution effects of UGOD activities are well documented in the literature, the precise cause for the increase in inpatient prevalence rate for specific medical categories remain unknown. Furthermore, different studies have conflicting findings. Our study findings add to the body of knowledge of the health effects of UGOD. It is our expectation that the results of this study will help foster further research and also help in the formulation of policies that will foster public health theories and interventions aimed at reducing unconventional oil and gas drilling environmental air pollution and the burden of asthma and other pollution sensitive diseases in the United States.

Table 17: Negative Binomial Mixed Linear Regression Models: IPR and Number of wells

	Wells IRR (p-value)	**2005 IRR (p-value)**	**2006 IRR (p-value)**	**2007 IRR (p-value)**	**2008 IRR (p-value)**
Overall	1.000(.820)	.938(.350)	.939(.354)	1.115(.097)	1.221(.002)
COPD	1.000(.862)	.902(.276)	.906(.294)	1.169(.080)	1.358(.001)
Asthma 17 and under	1.000(.838)	.819(.177)	1.200(.176)	1.048(.738)	.873(.359)
Asthma 18 and above	1.001(.582)	1.120(.316)	.904(.400)	1.059(.623)	1.217(.084)

Table 18: Negative Binomial Mixed Linear Regression Models: IPR and Well density

	Wells IRR (p-value)	**2005 IRR (p-value)**	**2006 IRR (p-value)**	**2007 IRR (p-value)**	**2008 IRR (p-value)**
Overall	1.234(.160)	.936(.330)	.933(.307)	1.096(.166)	1.188(.011)
COPD	1.170(.420)	.900(.265)	.900(.263)	1.148(.127)	1.320(.002)
Asthma 17 and under	1.094(/.744)	.818(.173)	1.195(.186)	1.037(.794)	.859(.310)
Asthma 18 and above	1.472(.055)	1.116(.333)	.895(.355)	1.031(.790)	1.165(.187)

CONCLUSION

We postulated that the increased number of active hydraulic fracturing wells would increase the rate of hospitalizations of pollution sensitive respiratory diseases due to the increase in the activities of UGOD and the resultant increased exposure to toxicants, noise and stress. The precise cause for the increase in respiratory disease outcome from exposure to UGOD remains unknown. The time frame of five years is relatively short to capture significant health effects,however, the time frame captures a unique time period of the onset of horizontal drilling and hydraulic fracturing in the Barnett Shale and serves as a baseline for future studies with a detailed time frame. Our positive finding of association between density and asthma hospitalization rate per 1,000 persons in patients 18 years and older adds to the body of knowledge that will help foster future research and shape policies. Additionally, the positive trend in the year 2008 which coincides with our peak gas production year in our study needs to be further explored. There is a huge public health significance of asthma and COPD respiratory diseases and UGOD, therefore more studies are needed to determine a specific toxicant exposure to an increase in a specific pollution sensitive respiratory disease category requiring hospitalization.

Limitations

Despite our findings, our study has some limitations. We had a limited time frame and data. The association between our calculated well density and inpatient prevalence rates was largely dependent on some outlier values that made up less than 1% of our total observations. It is unclear if our findings will be validated over time but a short time period may forebode bigger negative effects over time.

Having exposure and outcome examined at the zip code level contributes to potential exposure misclassification. A zip code which had no wells could neighbor another zip code that has many wells. Additionally, our model approach only included patients that resided within the study zip codes and thus did not detect demographic changes within zip codes. For example, influx of people to a zip code or transient workers that had no local address were omitted. Therefore the data we used may be an underestimate of hospital use by those that spend the bulk of their work days at the UGOD. Furthermore, using zip code as the unit of measurement has the assumption that all the wells are centrally located which is not so in real life. Also some zipcodes are in more than one counties or states and this led to some zip codes not being included.

Furthermore, we used de-identified hospitalization data therefore we had no information on the patient's address in relation to the UGOD sites. Consequently, we could not extract patient sex, race, ethnicity, and insurance status for inclusion in our models and these are important covariates. Additionally this type of data did not permit the investigation of morbidity or mortality and how patients with less severe asthma treated as outpatients may be affected as they are not captured by inpatient hospital data.

Our model used active well as a measure of exposure and as such its not possible to associate a specific toxicant to the respiratory disease category.

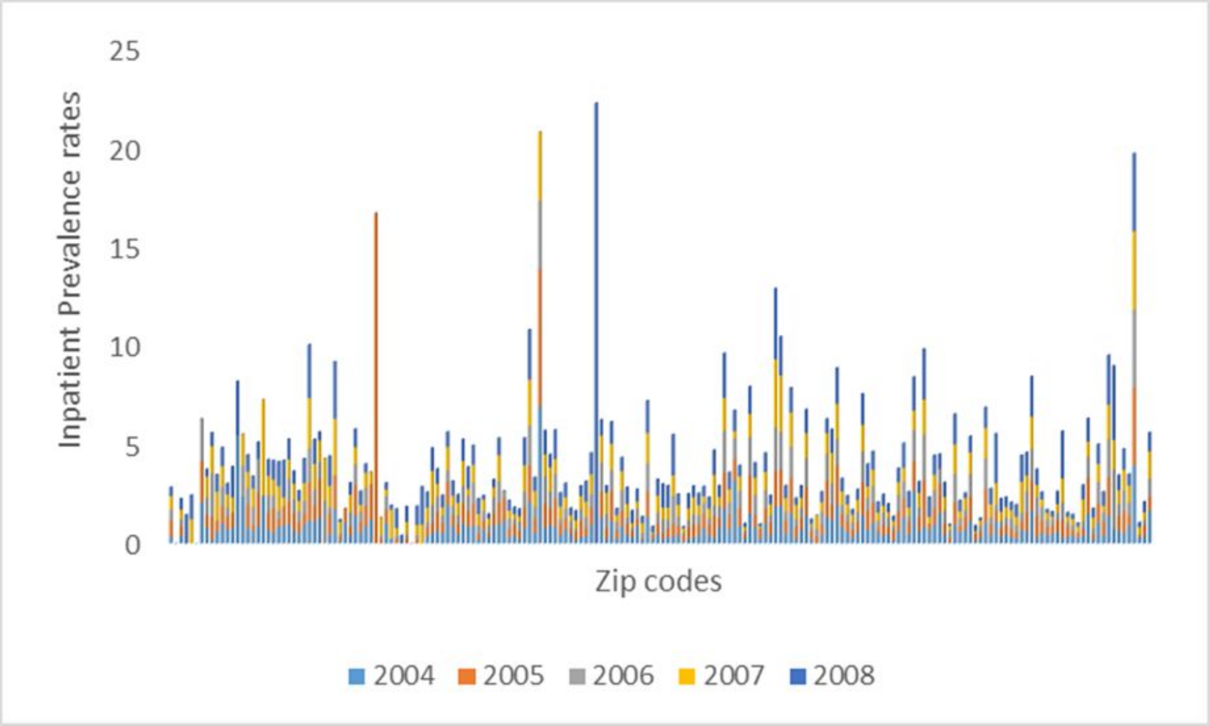
Strengths

Review of the current literature shows that only 3 published studies have been documented that sought to explore solely respiratory outcomes for exposure to UGOD as documented from hospital records. These 3 studies were done in the states of New York, Colorado and Pennsylvania. To the best of our knowledge, this is the first study to explore the relationship between UGOD exposure on asthma and respiratory illnesses using hospital inpatient records in an important Shale region like Barnett Shale which is the origin of the modern day shale, and second largest producer of natural gas. We examined over 48,700 in patient records for asthma and COPD and to the best of our knowledge represents a comprehensive study to access these respiratory diseases.Although the time frame of five years is relatively short to capture significant health effects, our time frame captures a unique time period of the onset of horizontal drilling and hydraulic fracturing in the Barnett Shale and serves as a baseline for future studies with a longer time frame. Our study helps to build strong scientific evidence on the relationship between Shale gas development and health. These evidence help to inform future regulatory policy on unconventional natural gas development by providing evidence on the link between Barnett shale gas development and health. This is most Important because, shale gas drilling in the Barnett shale is in close proximity to residential areas in the Dallas Fort Worth area and has the potential to impact large numbers of unsuspecting citizens, Our study found a significant time trend for a higher likelihood of having respiratory disease in year 2008 representing increased number of wells and production as shown in Table 1. If the clinical effect of our study is reproducible in real life and the well counts and well density increases then there is increased likelihood of increased hospitalization for respiratory diseases as the years of exposure increase.

Future Studies

Future research is needed to incorporate a larger data set and more detailed exposure assessment to understand pathways and development phases that pose the most risk. In addition, it’s important to identify the proximity of the patients to the active wells by incorporating spatial factors and important covariates in future studies.

Figure 10: Inpatient Prevalence Rates



APPENDICES

Appendix A: ICD-9 diagnosis codes for COPD and Asthma

ICD-9-CM COPD DIAGNOSIS CODES:

490 BRONCHITIS NOS*
4910 SIMPLE CHR BRONCHITIS
4911 MUCOPURUL CHR BRONCHITIS
49120 OBS CHR BRNC W/O ACT EXA
49121 OBS CHR BRNC W ACT EXA
4918 CHRONIC BRONCHITIS NEC
4919 CHRONIC BRONCHITIS NOS
4920 EMPHYSEMATOUS BLEB
4928 EMPHYSEMA NEC
494 BRONCHIECTASIS
4940 BRONCHIECTASIS W/O AC EXAC
4941 BRONCHIECTASIS W AC EXAC
496 CHR AIRWAY OBSTRUCT NEC

*Must be accompanied by a secondary diagnosis code of COPD

ICD-9-CM ASTHMA DIAGNOSIS CODES:

49300 EXT ASTHMA W/O STATUS ASTH ASTH
49301 EXT ASTHMA W STATUS ASTH
49302 EXT ASTHMA W/ACUTE EXAC
49310 INT ASTHMA W/O STATUS ASTH
49311 INT ASTHMA W STATUS ASTH
49312 INT ASTHMA W/ACUTE EXAC
49320 CH OB ASTH W/O STAT ASTH
49321 CH OB ASTHMA W STAT
49322 CH OBS ASTH W ACUTE EXAC
49381 EXERCISE IND BRONCHOSPASM
49382 COUGH VARIANT ASTHMA
49390 ASTHMA W/O STATUS ASTH
49391 ASTHMA W STATUS ASTH
49392 ASTHMA W ACUTE EXACERBTN

Appendix B: PowerPoint Presentation on UGOD Emissions on Asthma and COPD in the Barnett Shale

Dissertation Defense

BY STELLA A. OKOROAFOR

MAY 1, 2020

Committee members:

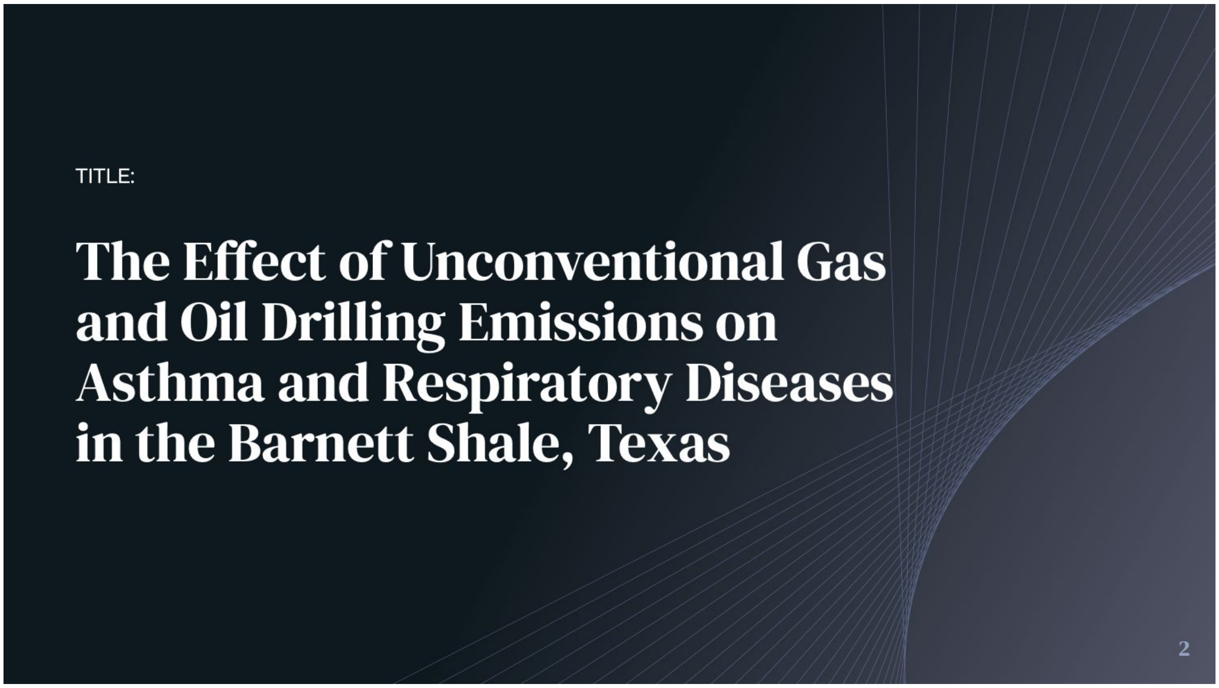
Arch I. Carson MD, PHD
(Dissertation Chair/Academic Advisor)

Stephen H. Linder, PHD (Dissertation Supervisor)

Kai Zhang PHD (Committee Member)

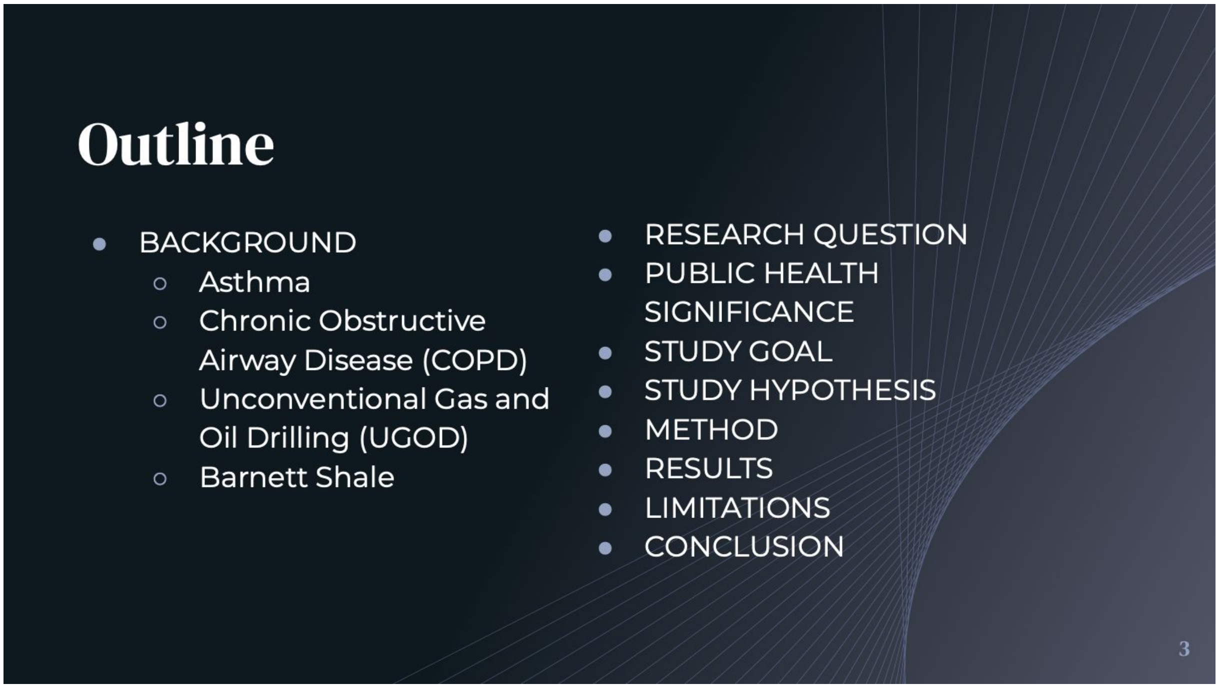
Julie Graves MD,MPH,PHD (Committee Member)

Zhi-Dong Jiang MD, DrPH (External Reviewer)



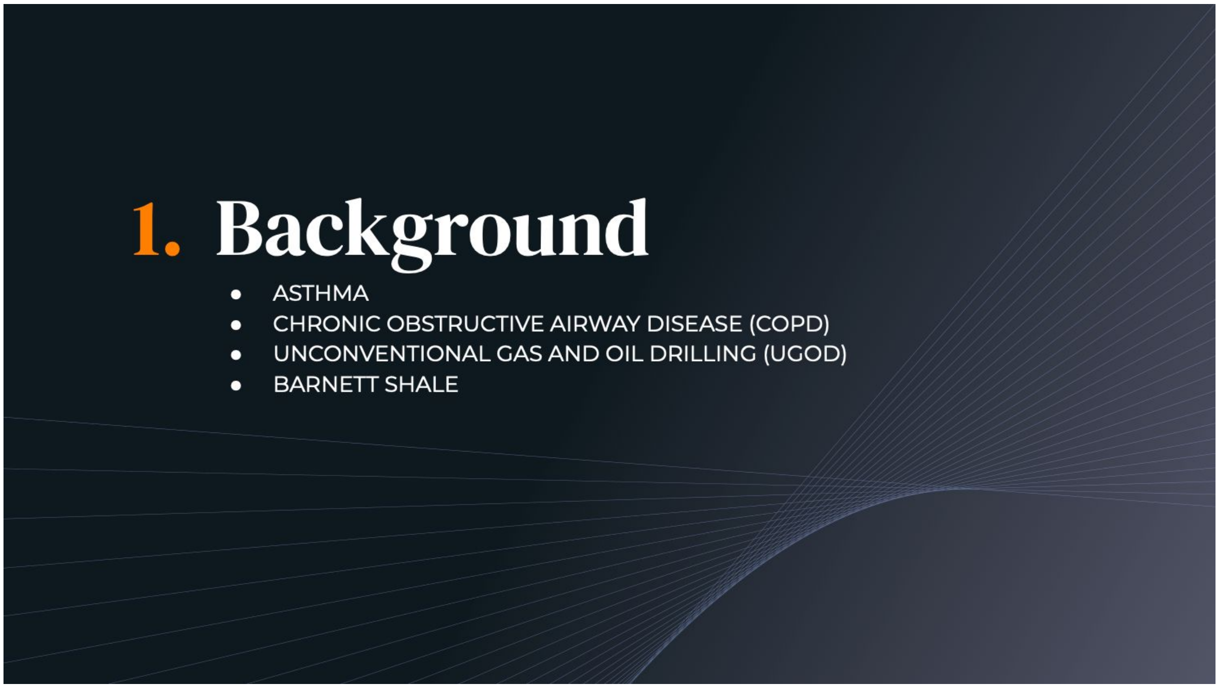
TITLE:

The Effect of Unconventional Gas and Oil Drilling Emissions on Asthma and Respiratory Diseases in the Barnett Shale, Texas



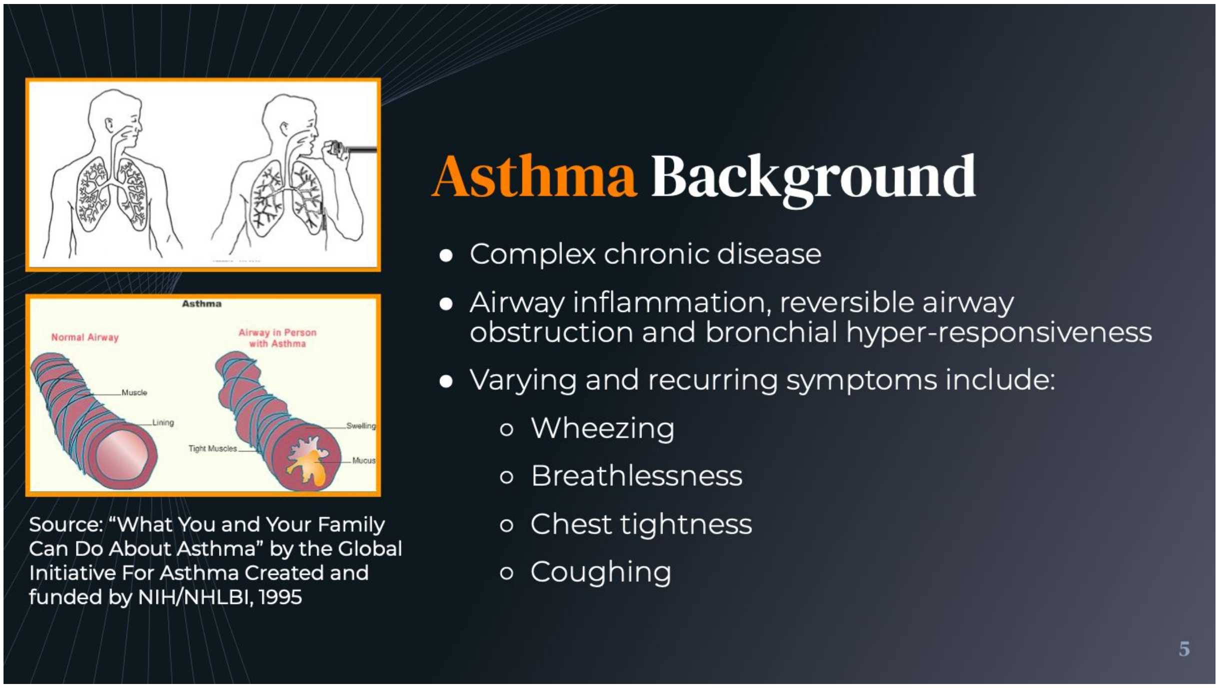
Outline

- BACKGROUND
  - Asthma
  - Chronic Obstructive Airway Disease (COPD)
  - Unconventional Gas and Oil Drilling (UGOD)
  - Barnett Shale
- RESEARCH QUESTION
- PUBLIC HEALTH SIGNIFICANCE
- STUDY GOAL
- STUDY HYPOTHESIS
- METHOD
- RESULTS
- LIMITATIONS
- CONCLUSION



1. Background

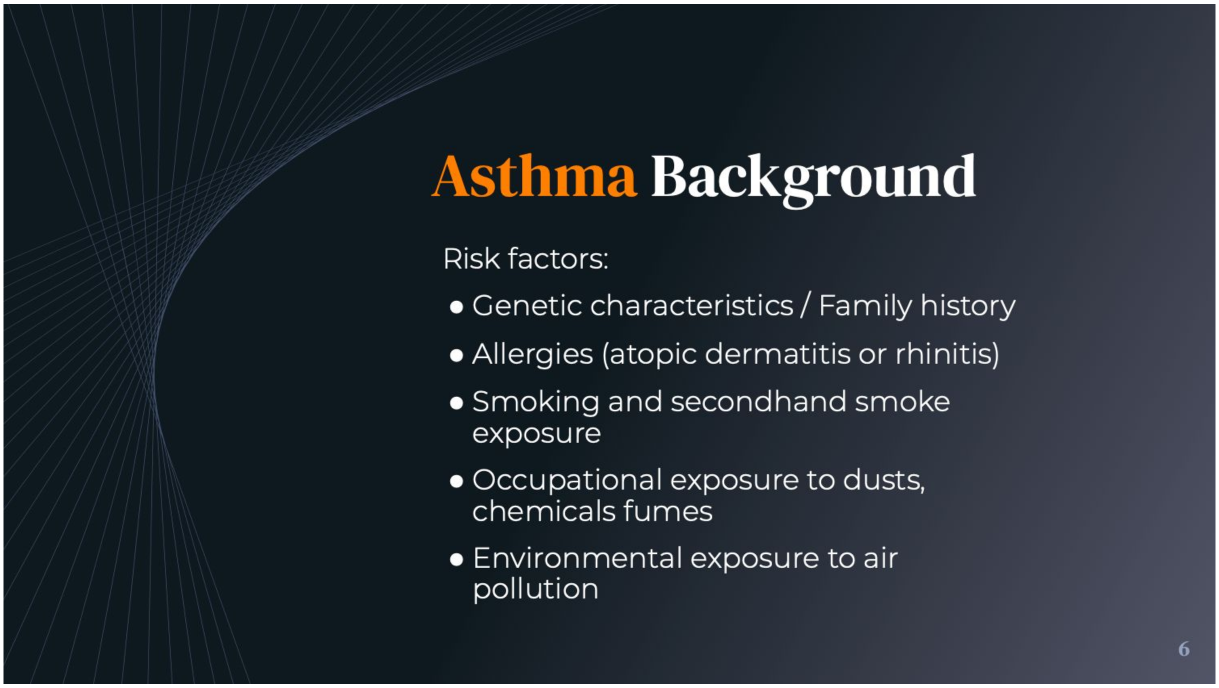
- ASTHMA
- CHRONIC OBSTRUCTIVE AIRWAY DISEASE (COPD)
- UNCONVENTIONAL GAS AND OIL DRILLING (UGOD)
- BARNETT SHALE



Source: “What You and Your Family Can Do About Asthma” by the Global Initiative For Asthma Created and funded by NIH/NHLBI, 1995

Asthma Background

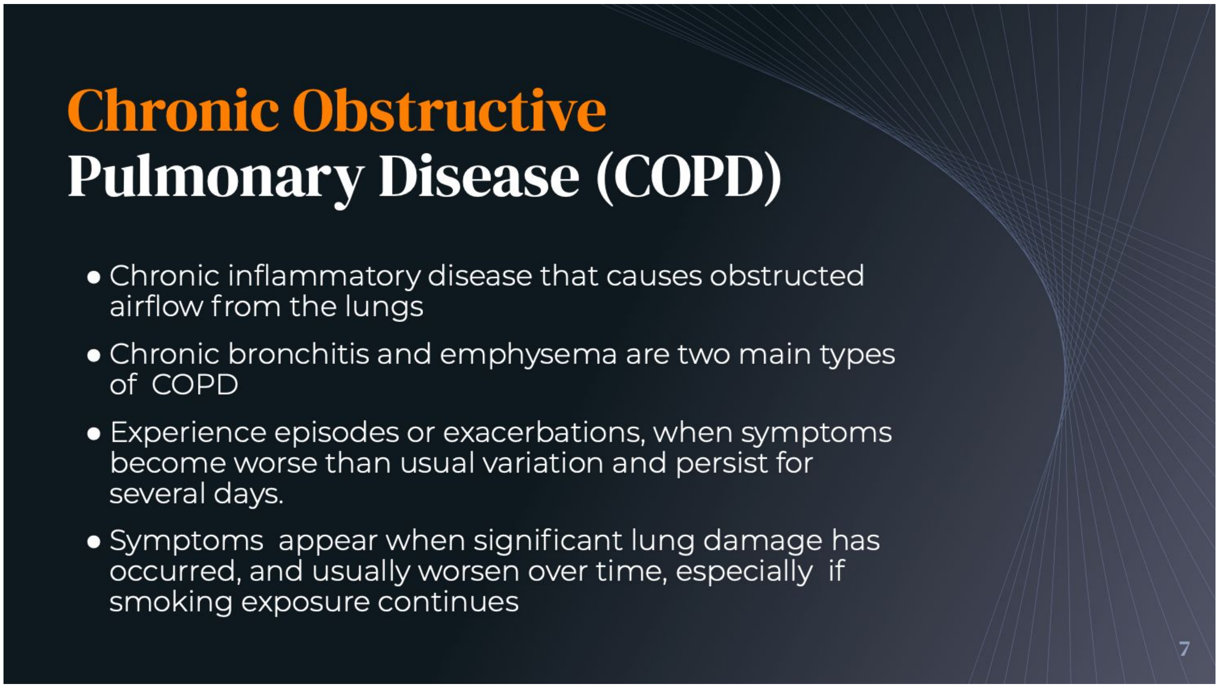
- Complex chronic disease
- Airway inflammation, reversible airway obstruction and bronchial hyper-responsiveness
- Varying and recurring symptoms include:
  - Wheezing
  - Breathlessness
  - Chest tightness
  - Coughing



Asthma Background

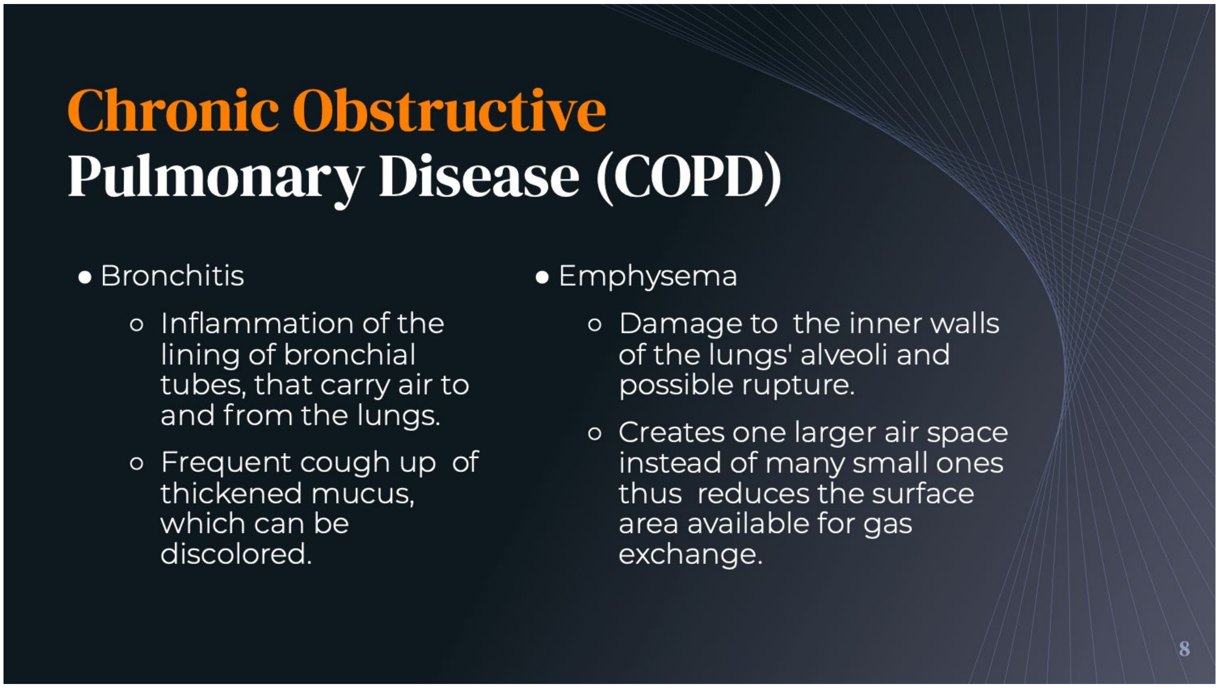
Risk factors:

- Genetic characteristics / Family history
- Allergies (atopic dermatitis or rhinitis)
- Smoking and secondhand smoke exposure
- Occupational exposure to dusts, chemicals fumes
- Environmental exposure to air pollution



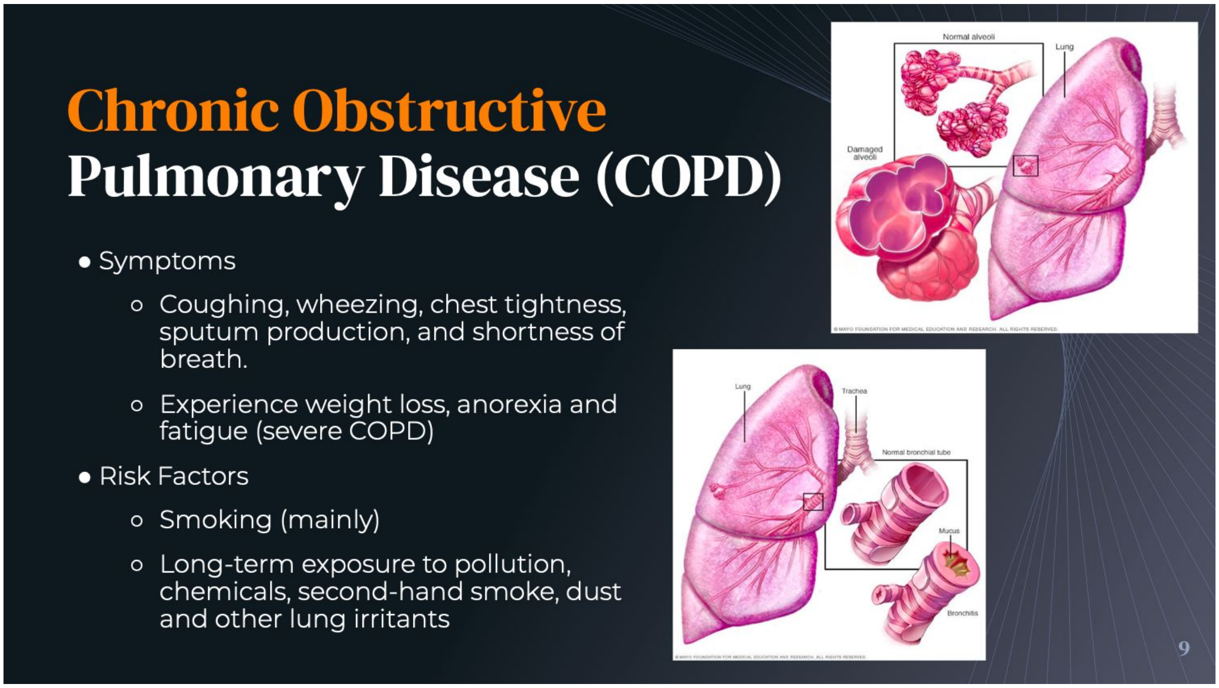
Chronic Obstructive Pulmonary Disease (COPD)

- Chronic inflammatory disease that causes obstructed airflow from the lungs
- Chronic bronchitis and emphysema are two main types of COPD
- Experience episodes or exacerbations, when symptoms become worse than usual variation and persist for several days.
- Symptoms appear when significant lung damage has occurred, and usually worsen over time, especially if smoking exposure continues



Chronic Obstructive Pulmonary Disease (COPD)

- Bronchitis
    - Inflammation of the lining of bronchial tubes, that carry air to and from the lungs.
    - Frequent cough up of thickened mucus, which can be discolored.
- Emphysema
    - Damage to the inner walls of the lungs' alveoli and possible rupture.
    - Creates one larger air space instead of many small ones thus reduces the surface area available for gas exchange.



Chronic Obstructive Pulmonary Disease (COPD)

- Symptoms
    - Coughing, wheezing, chest tightness, sputum production, and shortness of breath.
    - Experience weight loss, anorexia and fatigue (severe COPD)
- Risk Factors
    - Smoking (mainly)
    - Long-term exposure to pollution, chemicals, second-hand smoke, dust and other lung irritants

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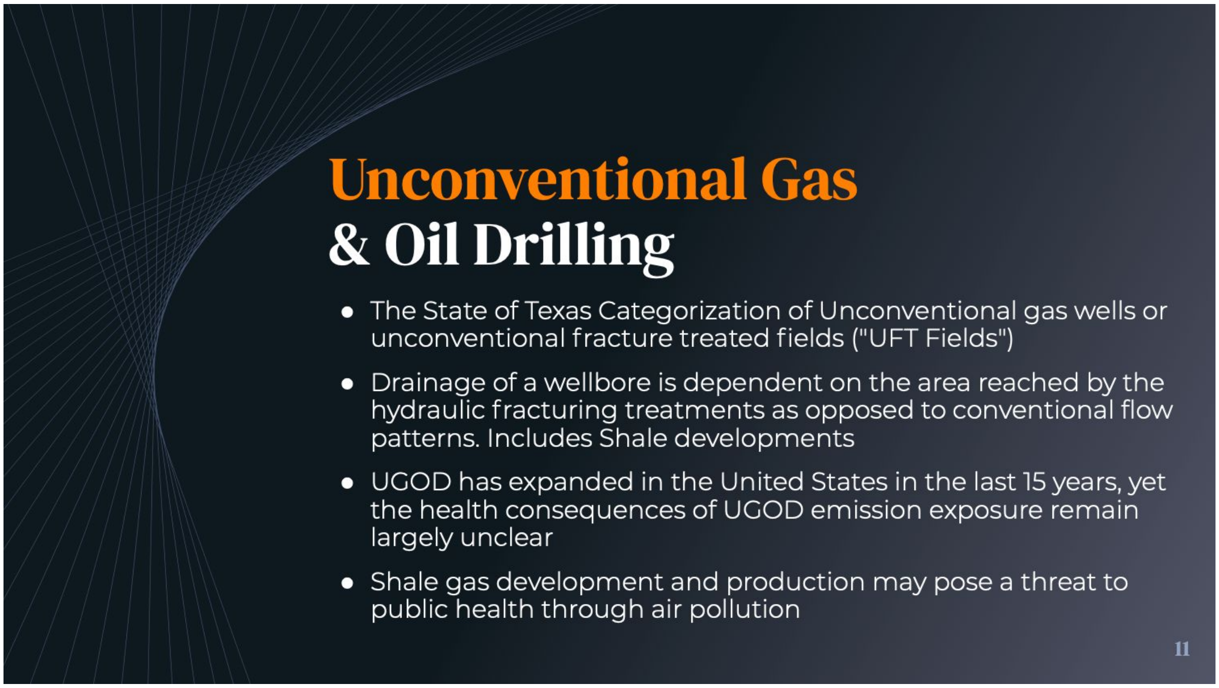
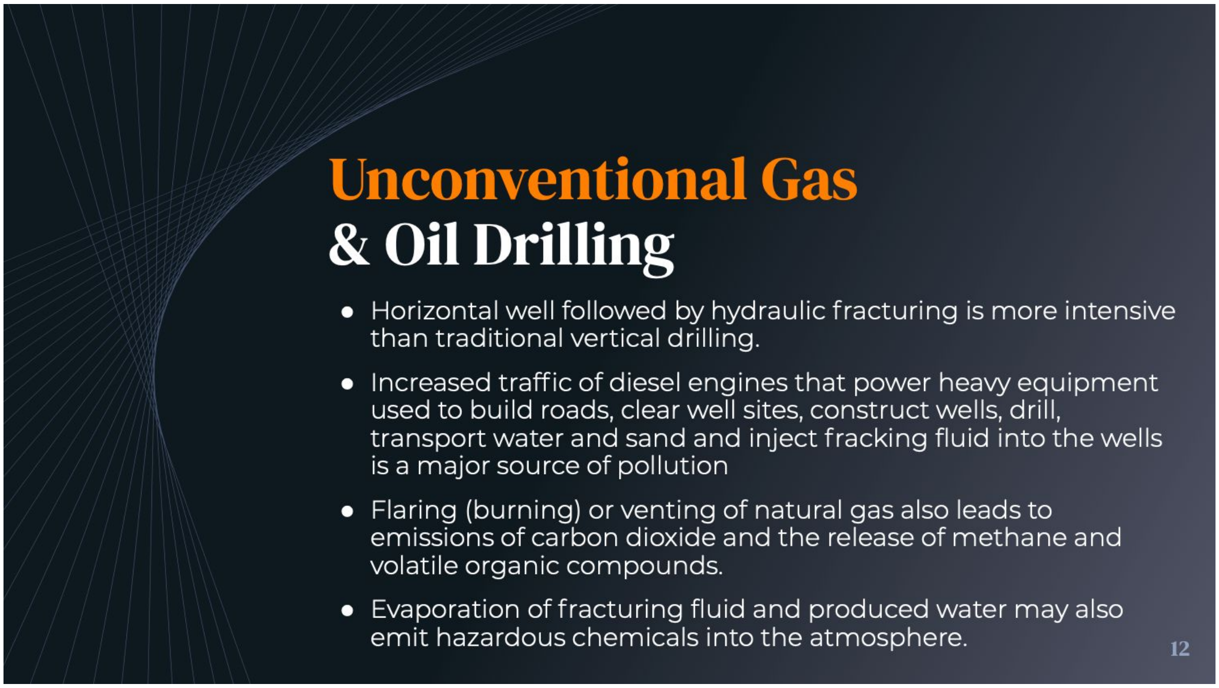
Unconventional Gas & Oil Drilling

- The use of natural gas has become a major source of energy utilization in the United States
- United States became the largest producer of natural gas in 2013 and this has led to a drop in the prize of natural oil and gas in over two decades
- Due to the technological advancements in horizontal drilling and unconventional hydraulic fracturing it is possible to access natural gas trapped beneath various shale formations.
- A rapid expansion from less than 2 percent of the total US natural gas production in 2000 to over 20 percent in 2010



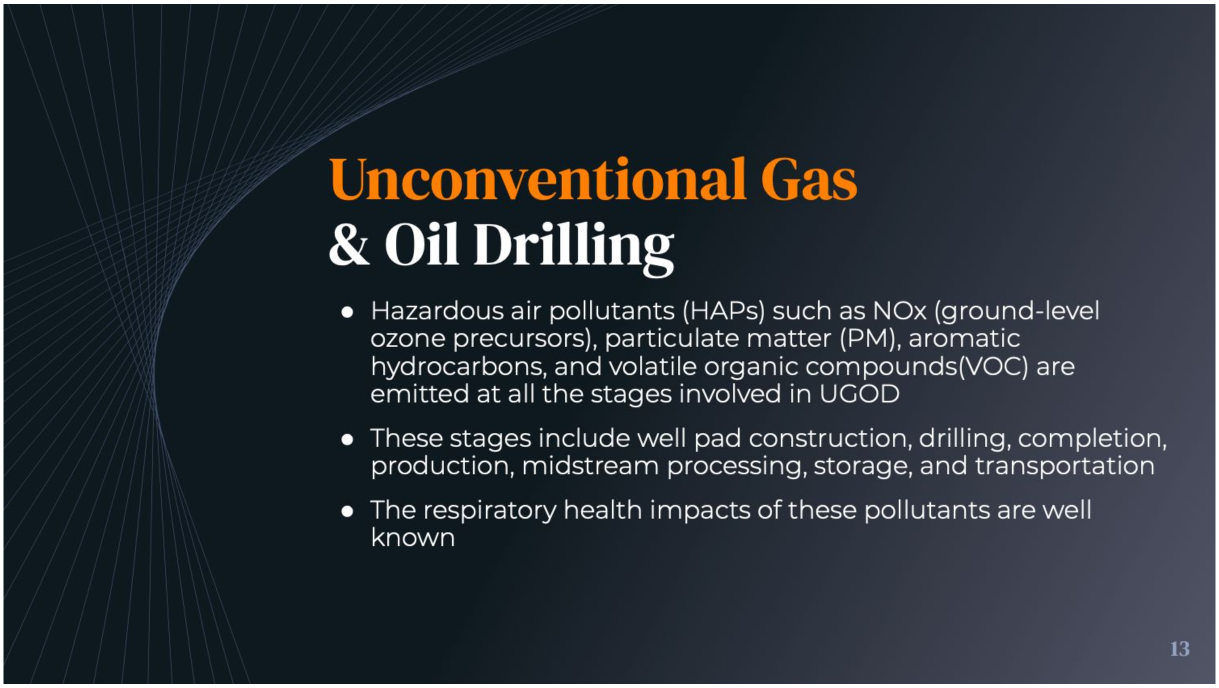
Unconventional Gas & Oil Drilling

- The State of Texas Categorization of Unconventional gas wells or unconventional fracture treated fields ("UFT Fields")
- Drainage of a wellbore is dependent on the area reached by the hydraulic fracturing treatments as opposed to conventional flow patterns. Includes Shale developments
- UGOD has expanded in the United States in the last 15 years, yet the health consequences of UGOD emission exposure remain largely unclear
- Shale gas development and production may pose a threat to public health through air pollution



Unconventional Gas & Oil Drilling

- Horizontal well followed by hydraulic fracturing is more intensive than traditional vertical drilling.
- Increased traffic of diesel engines that power heavy equipment used to build roads, clear well sites, construct wells, drill, transport water and sand and inject fracking fluid into the wells is a major source of pollution
- Flaring (burning) or venting of natural gas also leads to emissions of carbon dioxide and the release of methane and volatile organic compounds.
- Evaporation of fracturing fluid and produced water may also emit hazardous chemicals into the atmosphere.

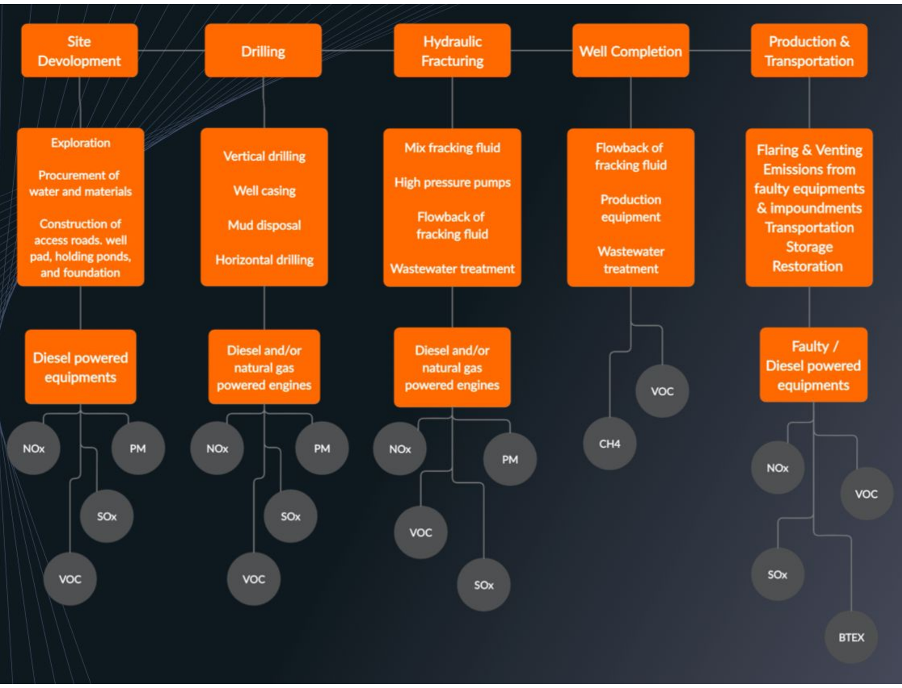


Unconventional Gas & Oil Drilling

- Hazardous air pollutants (HAPs) such as NOx (ground-level ozone precursors), particulate matter (PM), aromatic hydrocarbons, and volatile organic compounds(VOC) are emitted at all the stages involved in UGOD
- These stages include well pad construction, drilling, completion, production, midstream processing, storage, and transportation
- The respiratory health impacts of these pollutants are well known

Unconventional Gas & Oil Drilling

- NOX can form small particles through reactions with ammonia, moisture, and other compounds.
- These particles penetrate deeply into the sensitive part of lungs and cause or worsen respiratory diseases
- NOX can also form ground-level Ozone (smog)when reacting with VOCs in the presence of heat and sunlight
- The smog irritates the respiratory system, reduces lung function, worsens chronic conditions such as asthma and chronic bronchitis, and could potentially results in permanent lung damage



Site Devolopment

Exploration

Procurement of water and materials

Construction of access roads. well pad, holding ponds, and foundation

Diesel powered equipments

NOx
PM
SOx
VOC

Drilling

Vertical drilling

Well casing

Mud disposal

Horizontal drilling

Diesel and/or natural gas powered engines

NOx
PM
SOx
VOC

Hydraulic Fracturing

Mix fracking fluid

High pressure pumps

Flowback of fracking fluid

Wastewater treatment

Diesel and/or natural gas powered engines

NOx
PM
VOC
SOx

Well Completion

Flowback of fracking fluid

Production equipment

Wastewater treatment

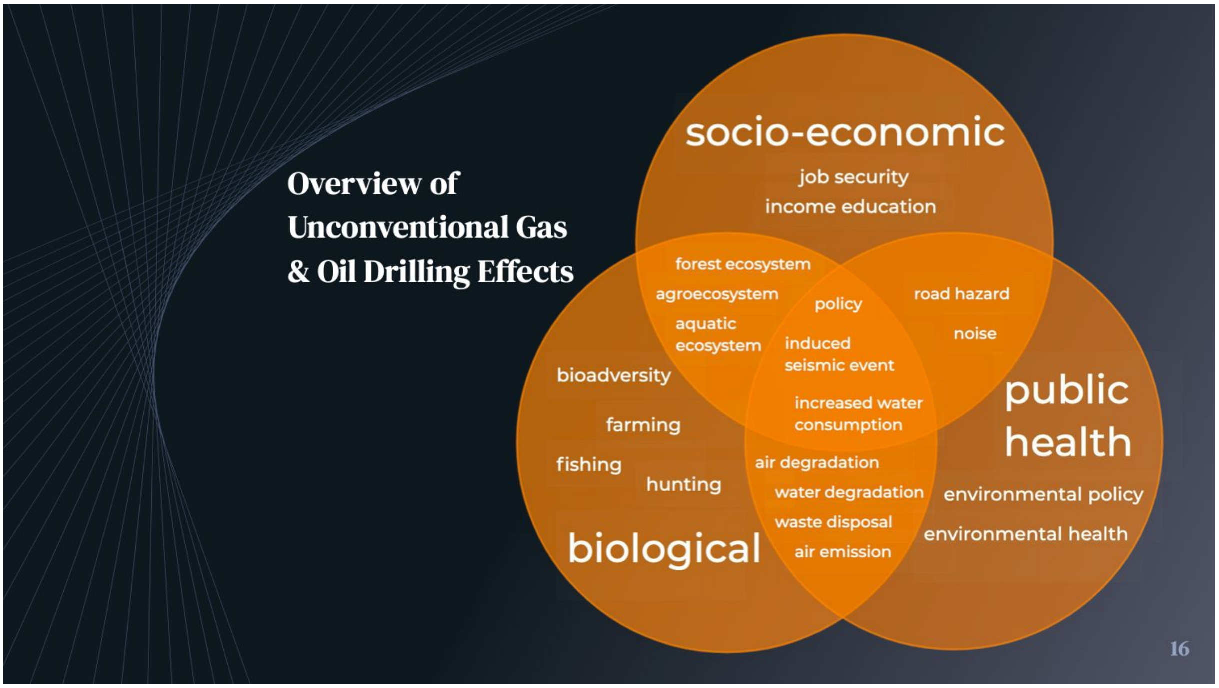
VOC
CH4

Production & Transportation

Flaring & Venting
Emissions from faulty equipments & impoundments
Transportation
Storage
Restoration

Faulty / Diesel powered equipments

NOx
VOC
SOx
BTEX



Overview of Unconventional Gas & Oil Drilling Effects

socio-economic

job security

income education

forest ecosystem

agroecosystem

aquatic ecosystem

policy

road hazard

noise

induced seismic event

bioadversity

increased water consumption

public health

farming

fishing

hunting

air degradation

water degradation

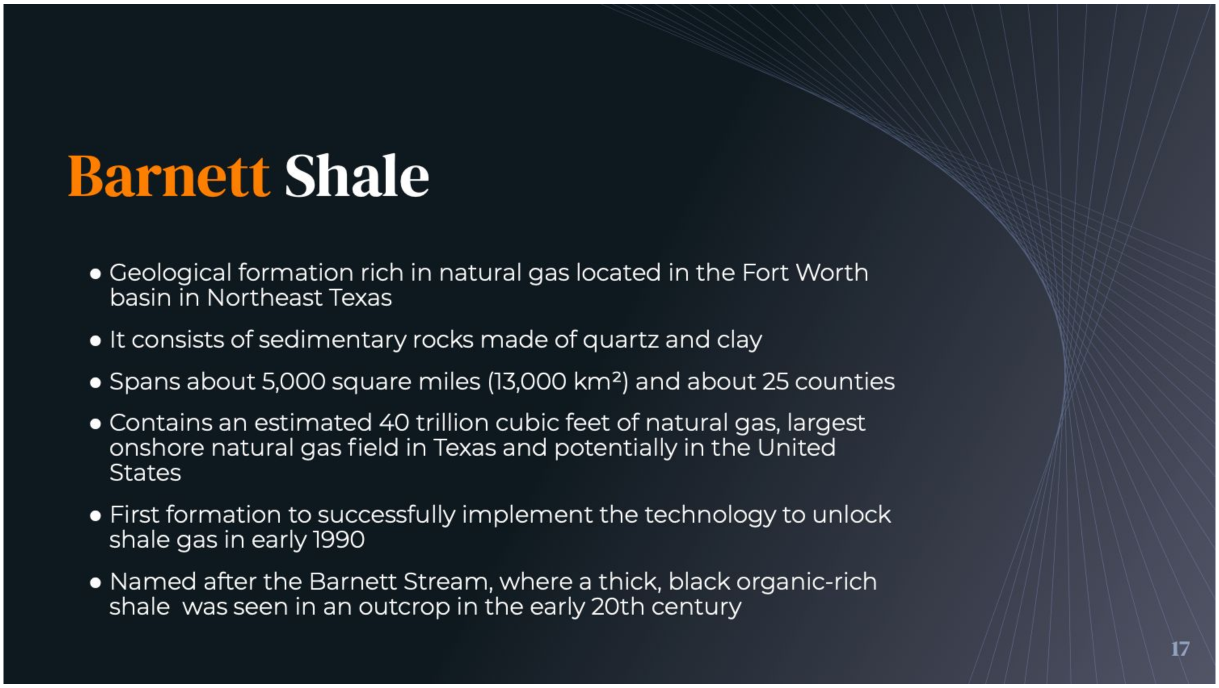
waste disposal

air emission

environmental policy

environmental health

biological

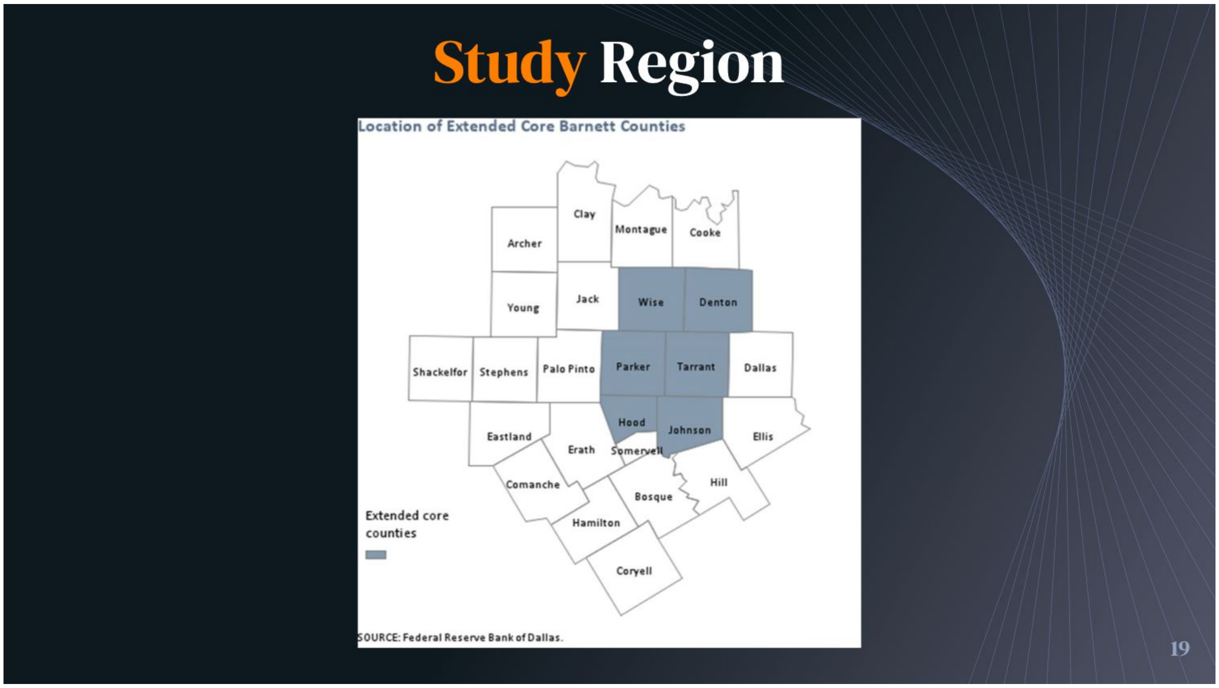


Barnett Shale

- Geological formation rich in natural gas located in the Fort Worth basin in Northeast Texas
- It consists of sedimentary rocks made of quartz and clay
- Spans about 5,000 square miles (13,000 km²) and about 25 counties
- Contains an estimated 40 trillion cubic feet of natural gas, largest onshore natural gas field in Texas and potentially in the United States
- First formation to successfully implement the technology to unlock shale gas in early 1990
- Named after the Barnett Stream, where a thick, black organic-rich shale was seen in an outcrop in the early 20th century

Barnett Shale

- TRRC identifies four core counties that produce more than 80 percent of the region's output namely Wise, Denton, Tarrant, and Johnson.
- Parker and Hood counties also produce a substantial amount of natural gas and when added to these TRRC core counties yields six extended core counties
- Counties of Johnson, Parker, Hood, Wise Ellis, and Coryell
- Johnson, Parker, Hood, Wise counties had increase in drilling
- Ellis and Coryell had little or no drilling activity



Study Region

Location of Extended Core Barnett Counties

SOURCE: Federal Reserve Bank of Dallas.

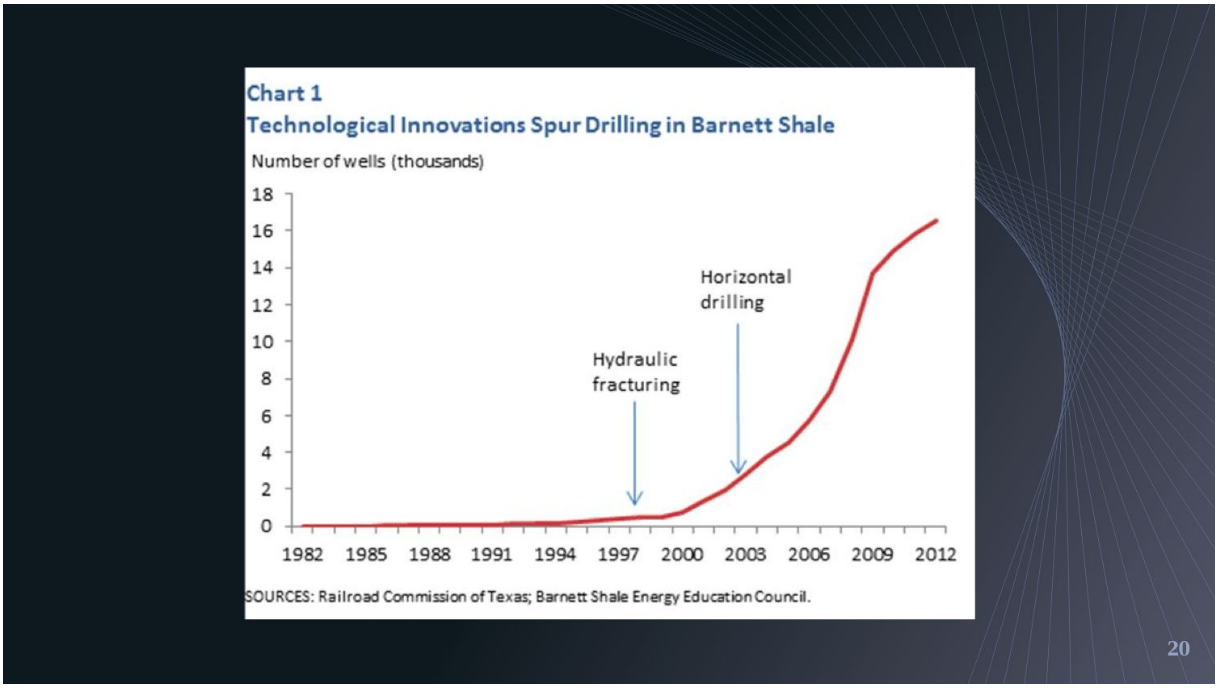


Chart 1

Technological Innovations Spur Drilling in Barnett Shale

SOURCES: Railroad Commission of Texas; Barnett Shale Energy Education Council.

20

2. Research Question

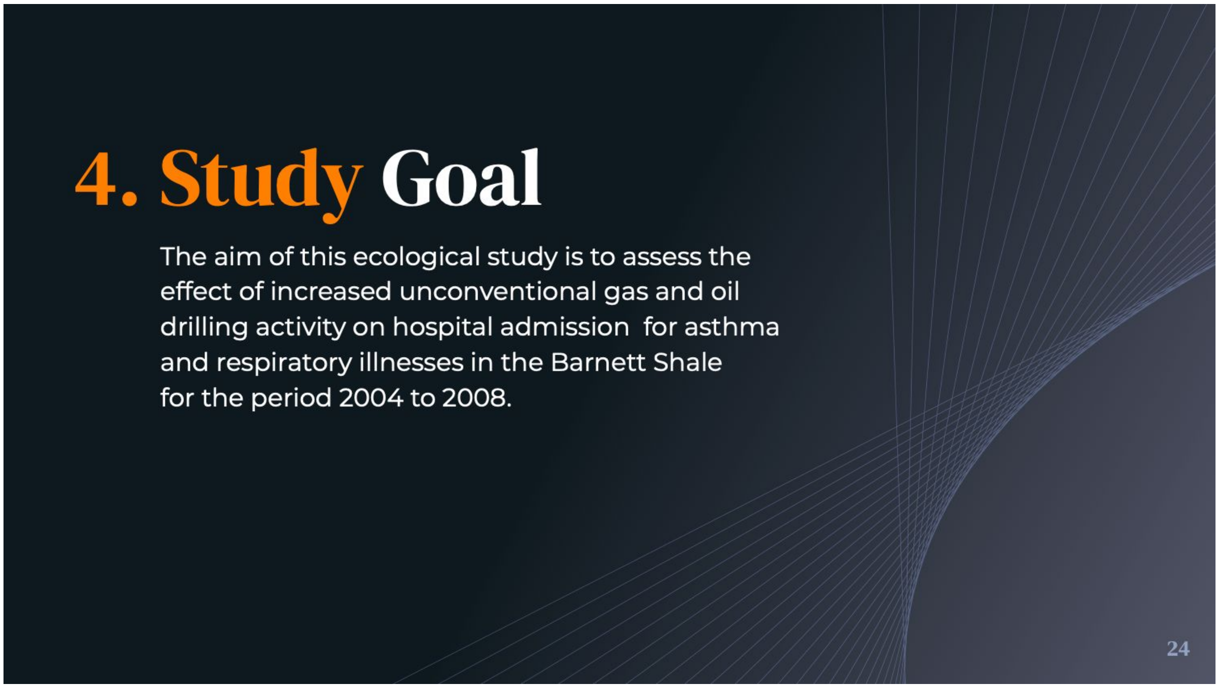
What is the relationship between Unconventional Gas and Oil Drilling activity and Hospital Utilization Rates for respiratory diseases in the Barnett Shale, Texas?

3. Public Health Significance

- Unconventional oil and gas drilling has potential for adverse effect on human health
- Potential for environmental degradation, air and water pollution
- Asthma/COPD are prevalent chronic diseases associated with significant morbidity, mortality, and health care use
- Asthma-related morbidity covers a spectrum
- Reduced physical activity
- Absent days at work/ school
- Physician office visits, emergency care, and hospitalization

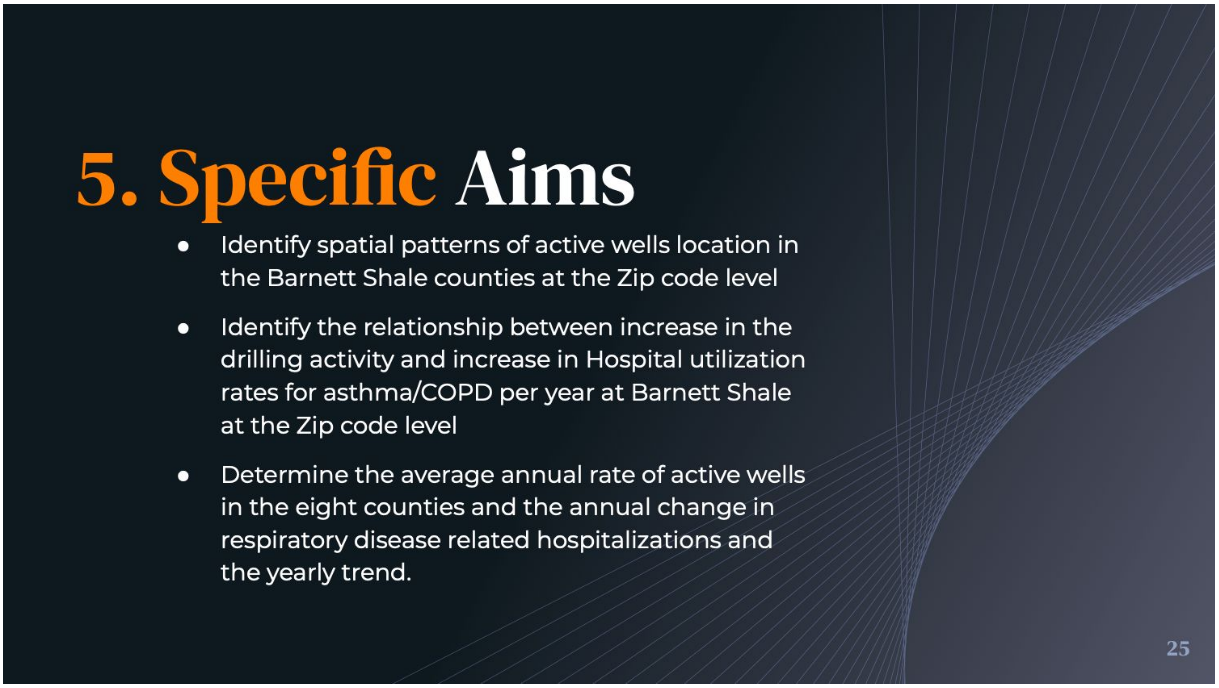
3. Public Health Significance

- Common disease with a prevalence of 8-4% in the US (2010)
- 25.7 million people, including 7.0 million children under 18
- 1.8 million people visited an emergency room for asthma-related care
- 439,000 people were hospitalized because of asthma
- Significant health and economic burden



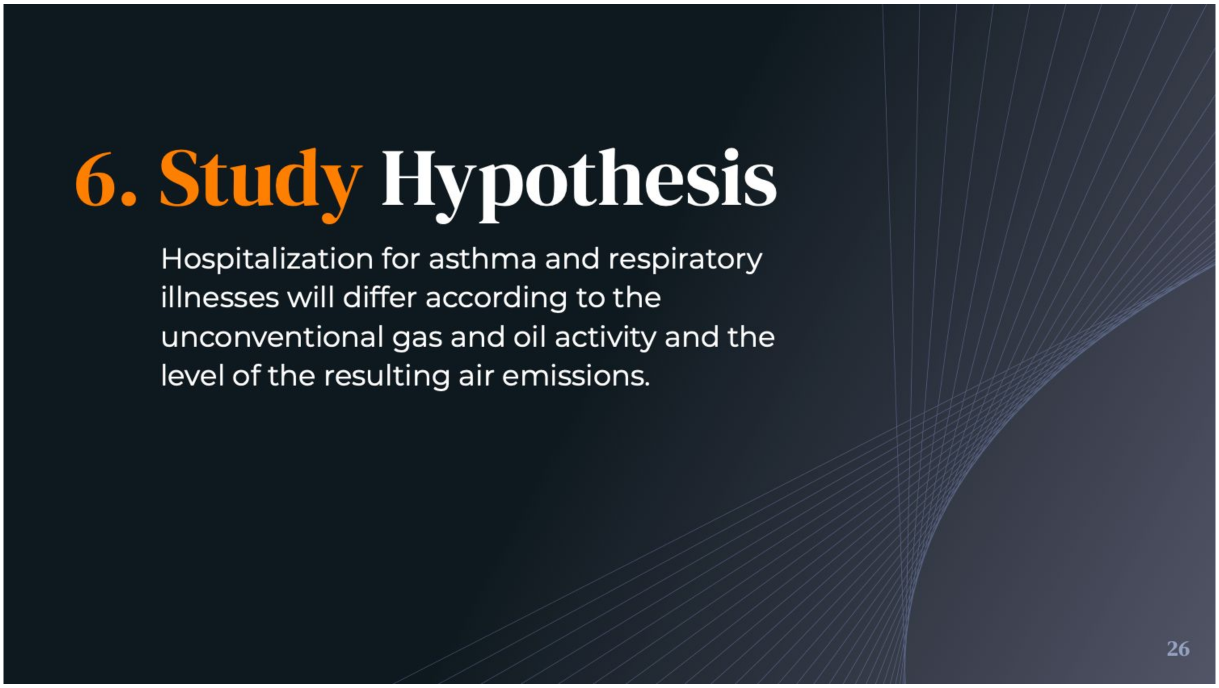
4. Study Goal

The aim of this ecological study is to assess the effect of increased unconventional gas and oil drilling activity on hospital admission for asthma and respiratory illnesses in the Barnett Shale for the period 2004 to 2008.



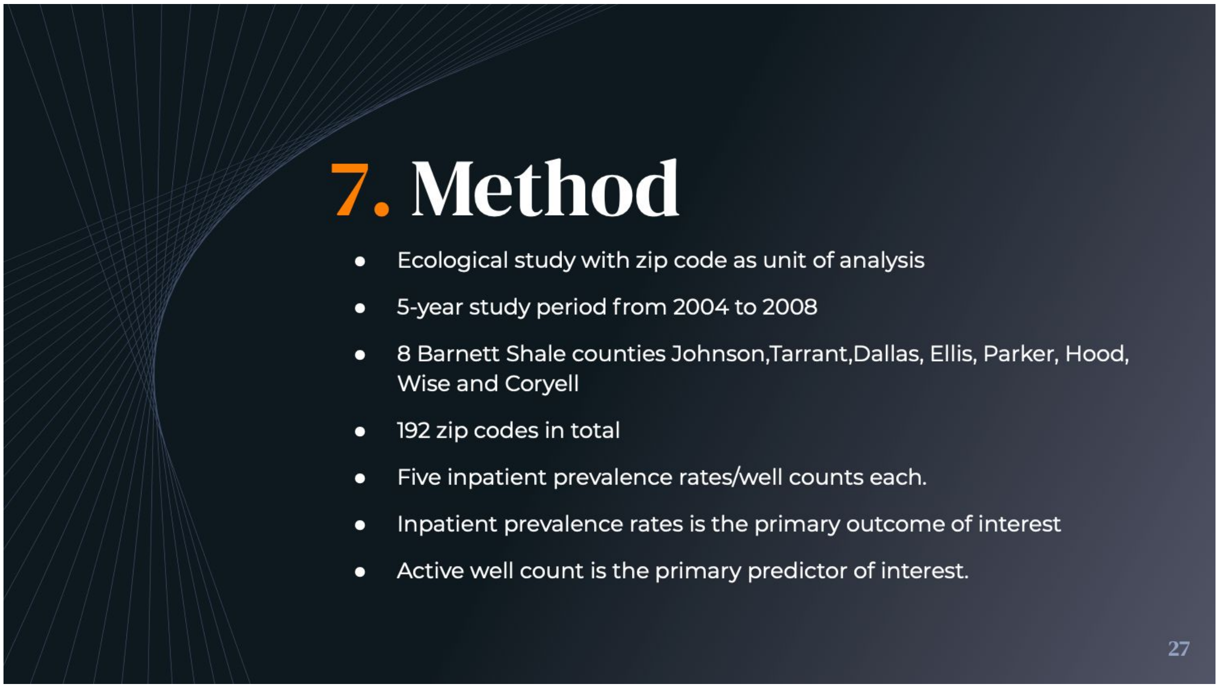
5. Specific Aims

- Identify spatial patterns of active wells location in the Barnett Shale counties at the Zip code level
- Identify the relationship between increase in the drilling activity and increase in Hospital utilization rates for asthma/COPD per year at Barnett Shale at the Zip code level
- Determine the average annual rate of active wells in the eight counties and the annual change in respiratory disease related hospitalizations and the yearly trend.



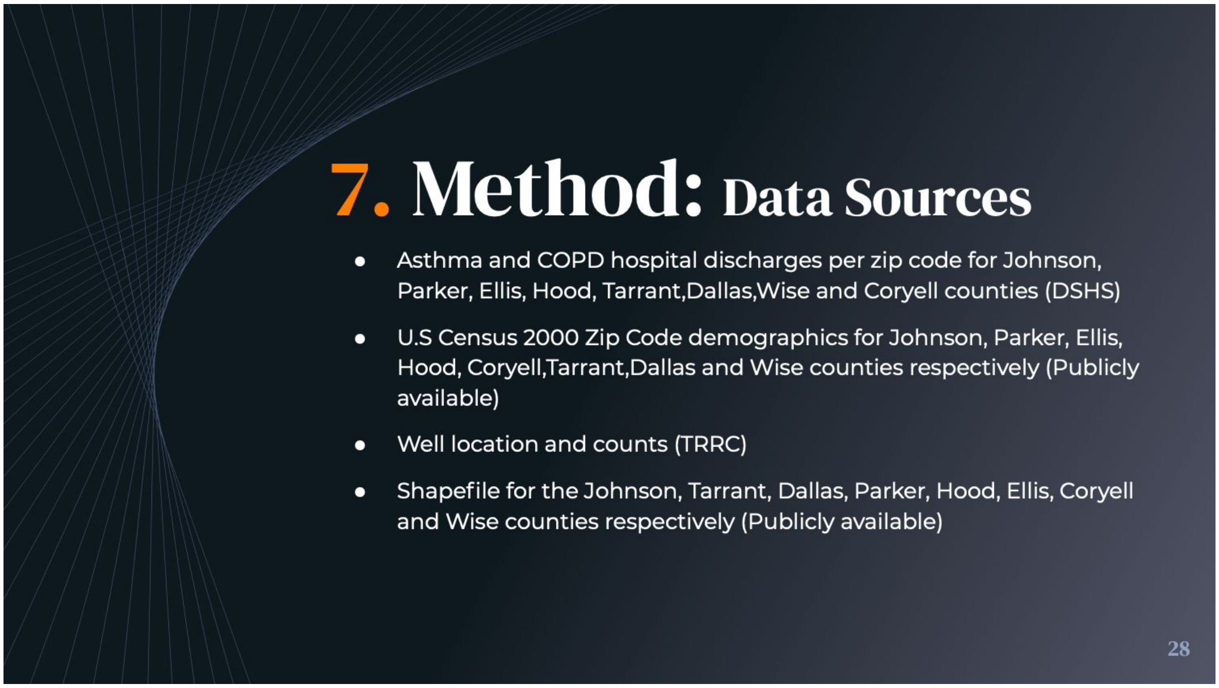
6. Study Hypothesis

Hospitalization for asthma and respiratory illnesses will differ according to the unconventional gas and oil activity and the level of the resulting air emissions.



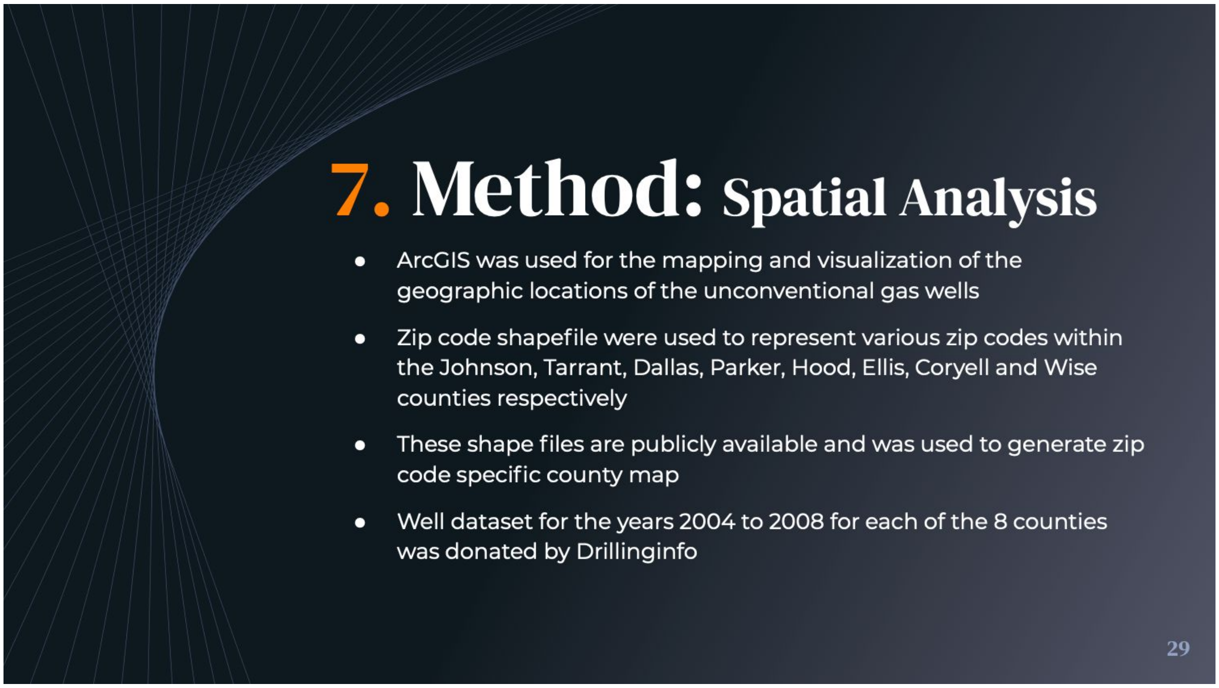
7. Method

- Ecological study with zip code as unit of analysis
- 5-year study period from 2004 to 2008
- 8 Barnett Shale counties Johnson,Tarrant,Dallas, Ellis, Parker, Hood, Wise and Coryell
- 192 zip codes in total
- Five inpatient prevalence rates/well counts each.
- Inpatient prevalence rates is the primary outcome of interest
- Active well count is the primary predictor of interest.



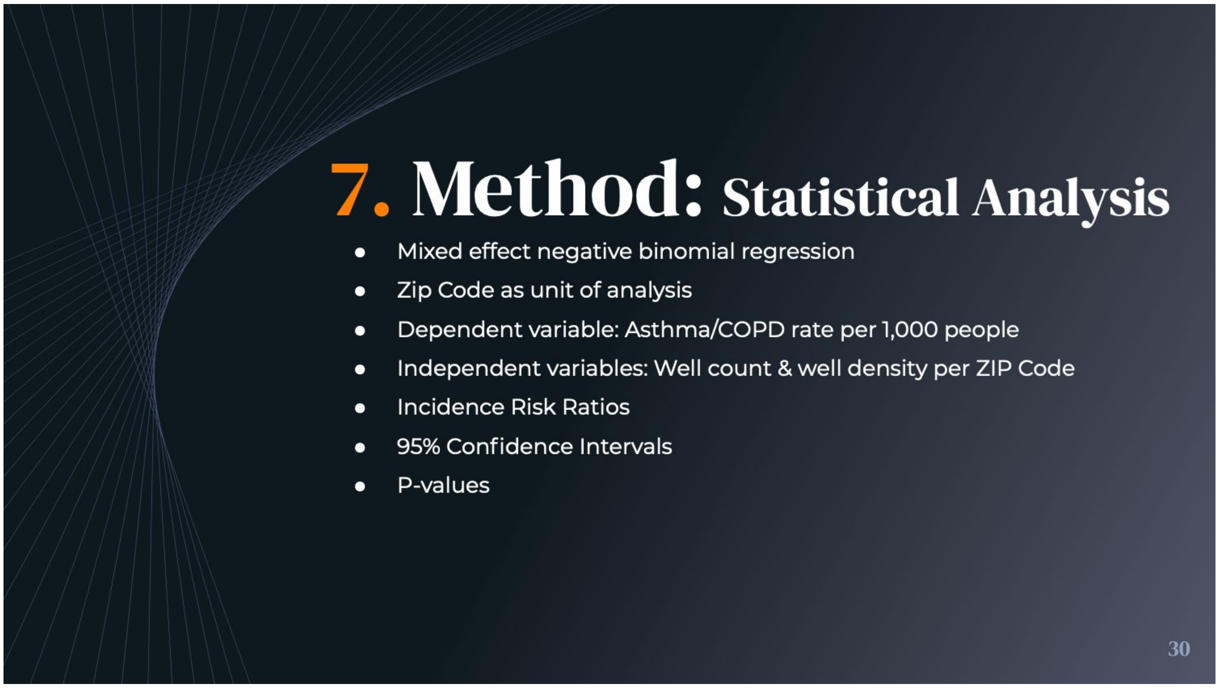
7. Method: Data Sources

- Asthma and COPD hospital discharges per zip code for Johnson, Parker, Ellis, Hood, Tarrant,Dallas,Wise and Coryell counties (DSHS)
- U.S Census 2000 Zip Code demographics for Johnson, Parker, Ellis, Hood, Coryell,Tarrant,Dallas and Wise counties respectively (Publicly available)
- Well location and counts (TRRC)
- Shapefile for the Johnson, Tarrant, Dallas, Parker, Hood, Ellis, Coryell and Wise counties respectively (Publicly available)



7. Method: Spatial Analysis

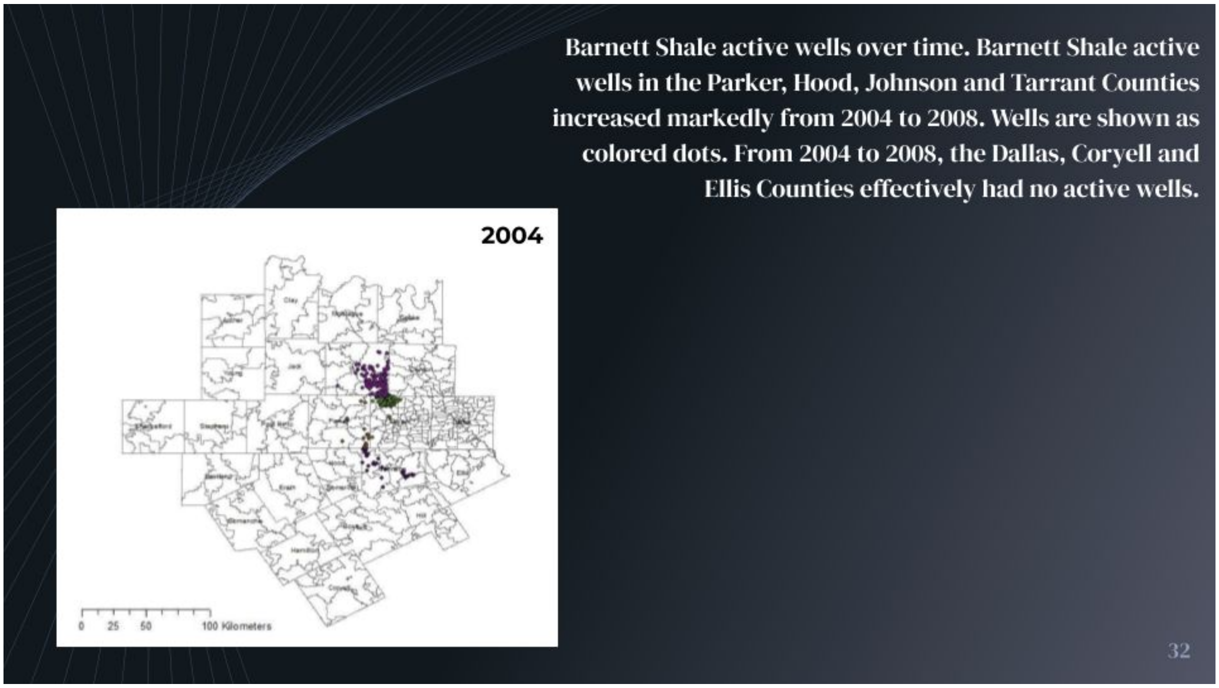
- ArcGIS was used for the mapping and visualization of the geographic locations of the unconventional gas wells
- Zip code shapefile were used to represent various zip codes within the Johnson, Tarrant, Dallas, Parker, Hood, Ellis, Coryell and Wise counties respectively
- These shape files are publicly available and was used to generate zip code specific county map
- Well dataset for the years 2004 to 2008 for each of the 8 counties was donated by Drillinginfo



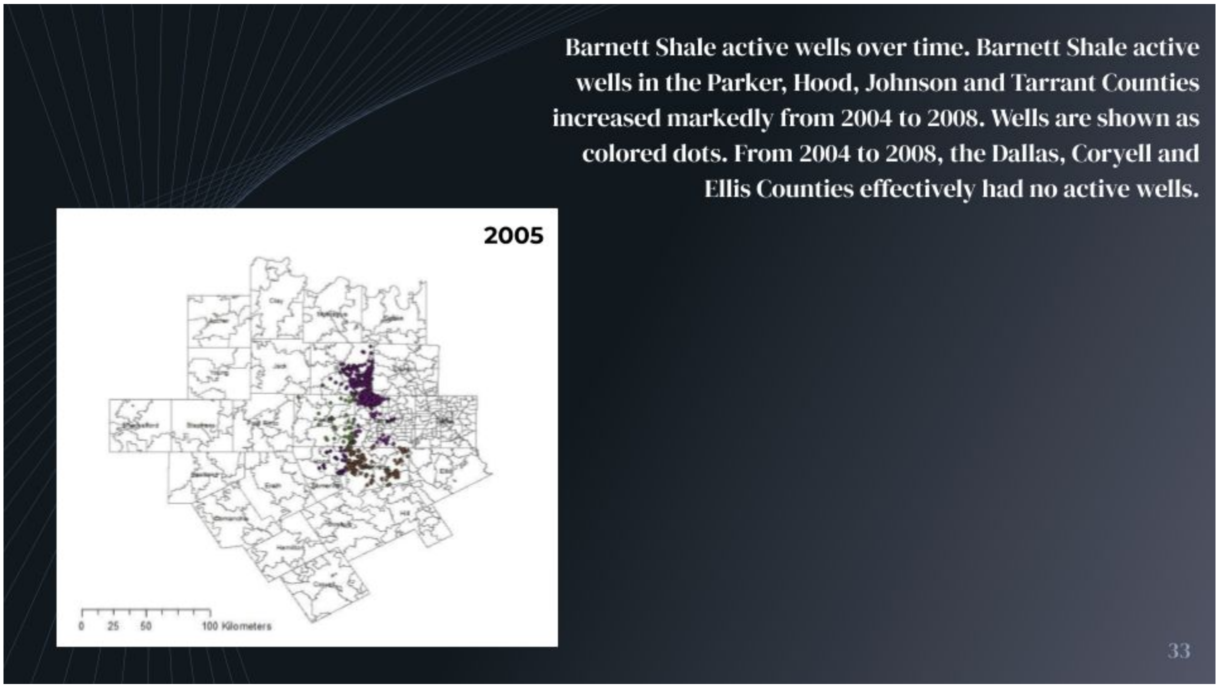
7. Method: Statistical Analysis

- Mixed effect negative binomial regression
- Zip Code as unit of analysis
- Dependent variable: Asthma/COPD rate per 1,000 people
- Independent variables: Well count & well density per ZIP Code
- Incidence Risk Ratios
- 95% Confidence Intervals
- P-values

8. Results



Barnett Shale active wells over time. Barnett Shale active wells in the Parker, Hood, Johnson and Tarrant Counties increased markedly from 2004 to 2008. Wells are shown as colored dots. From 2004 to 2008, the Dallas, Coryell and Ellis Counties effectively had no active wells.



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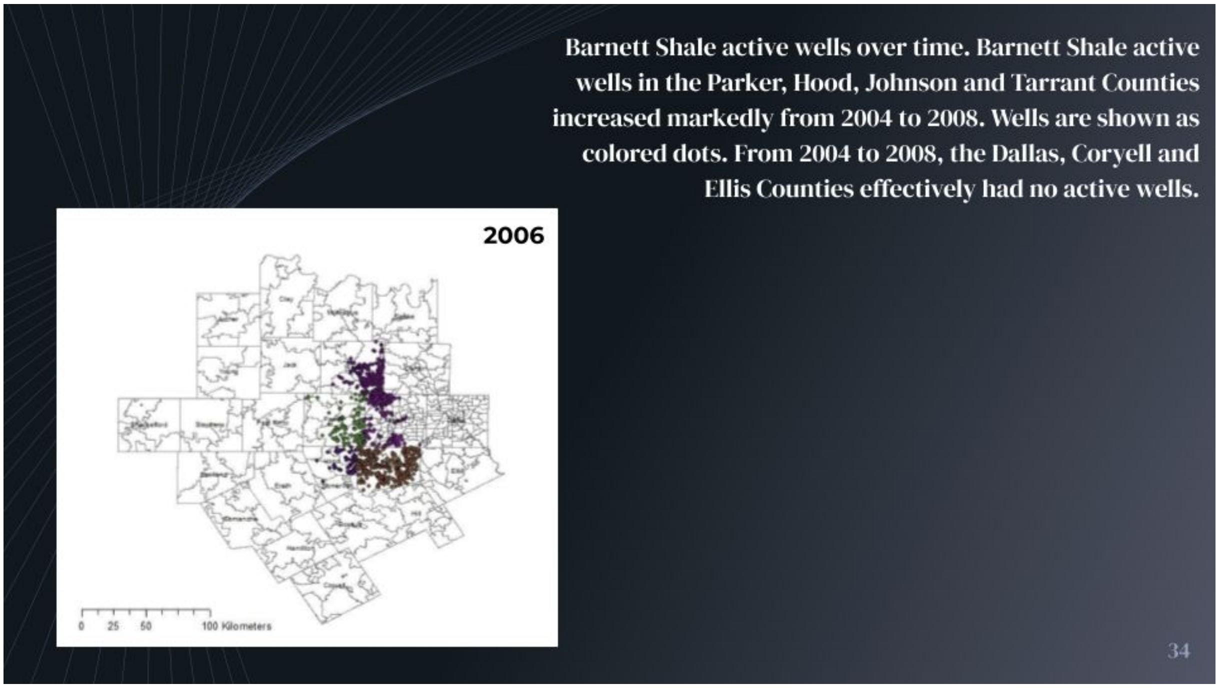

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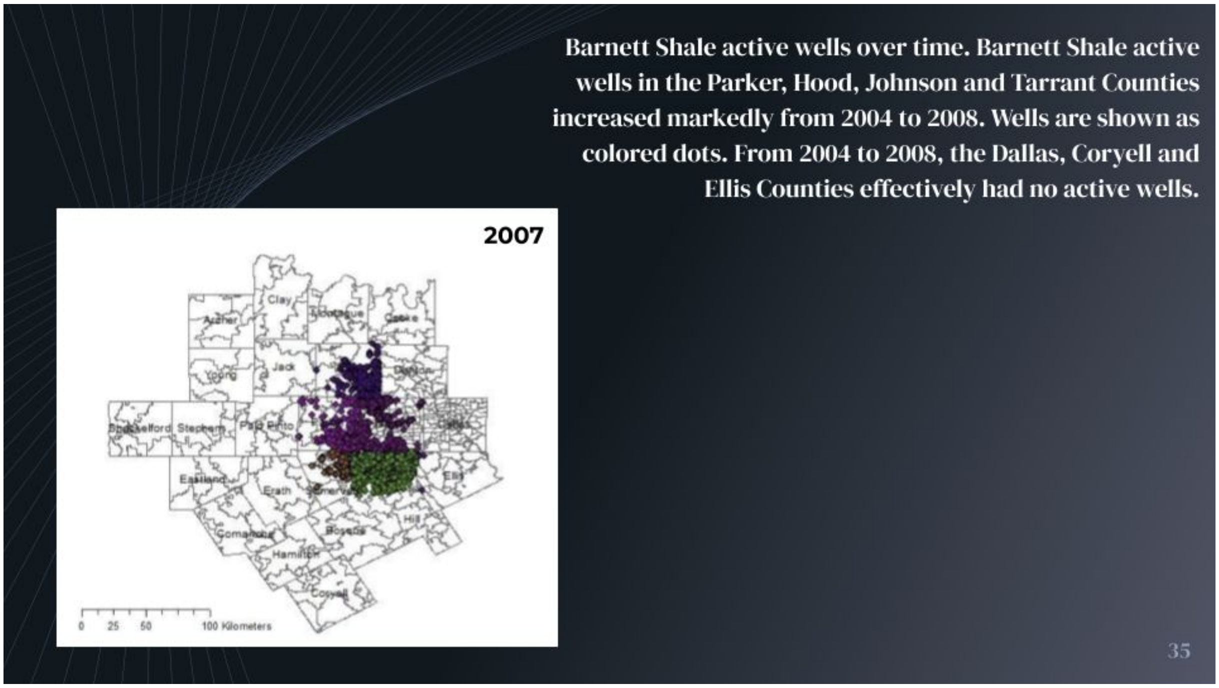

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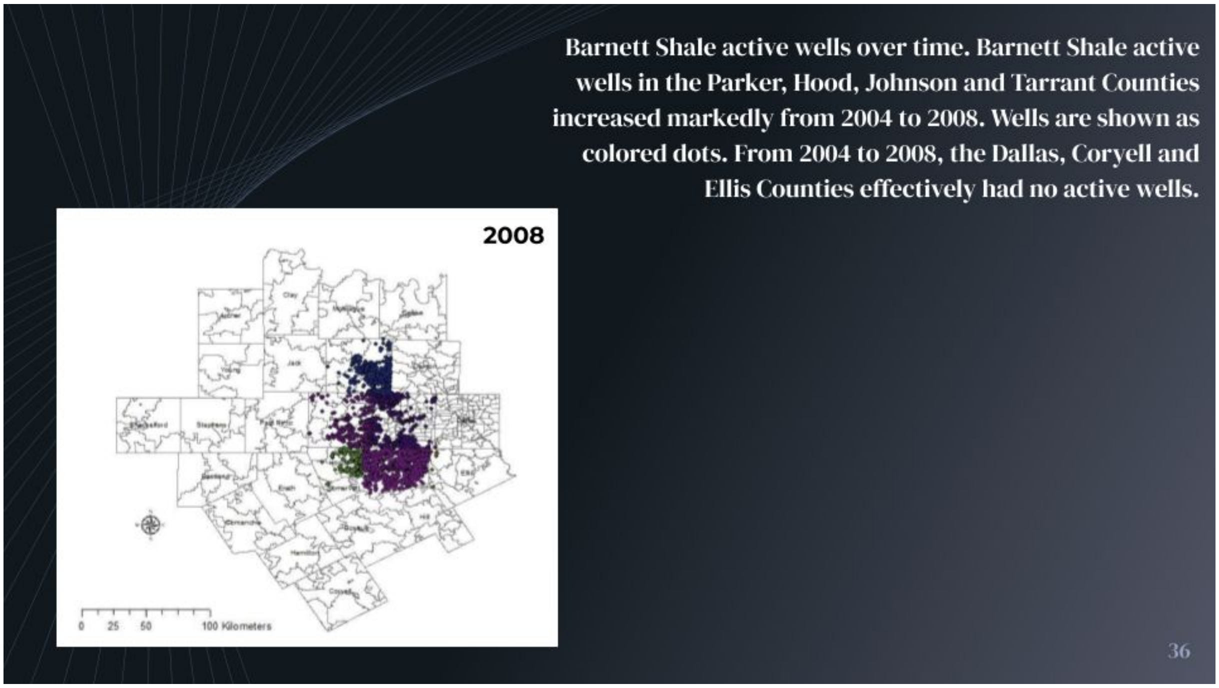

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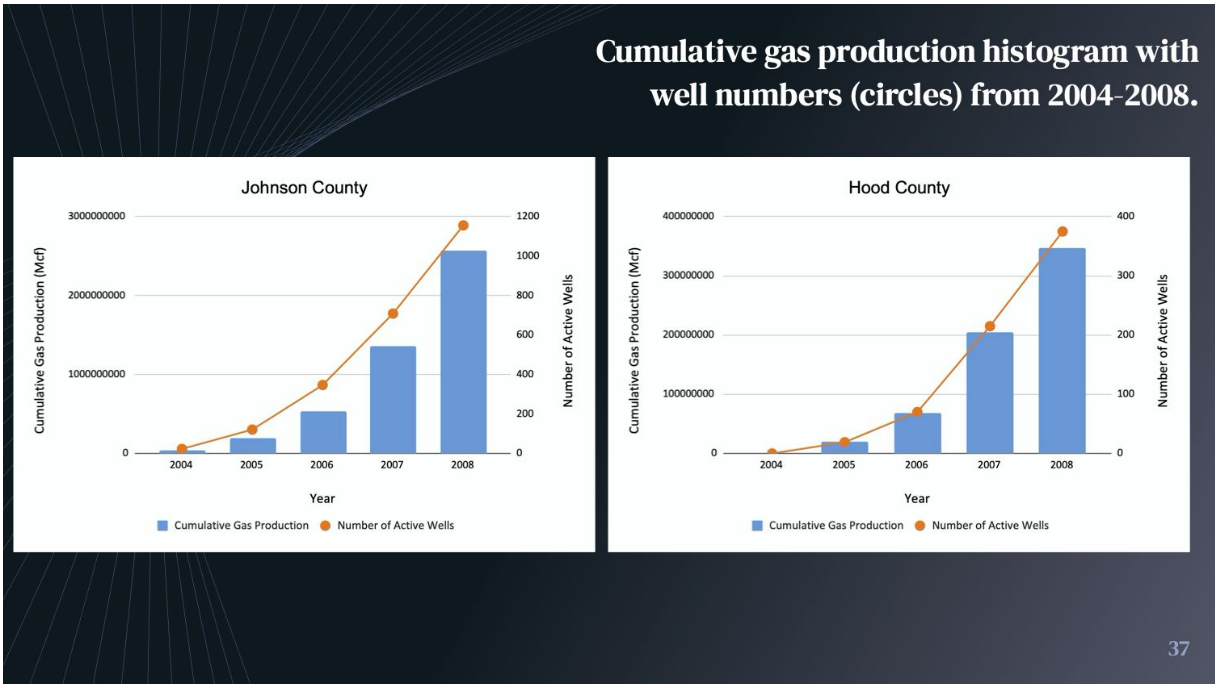
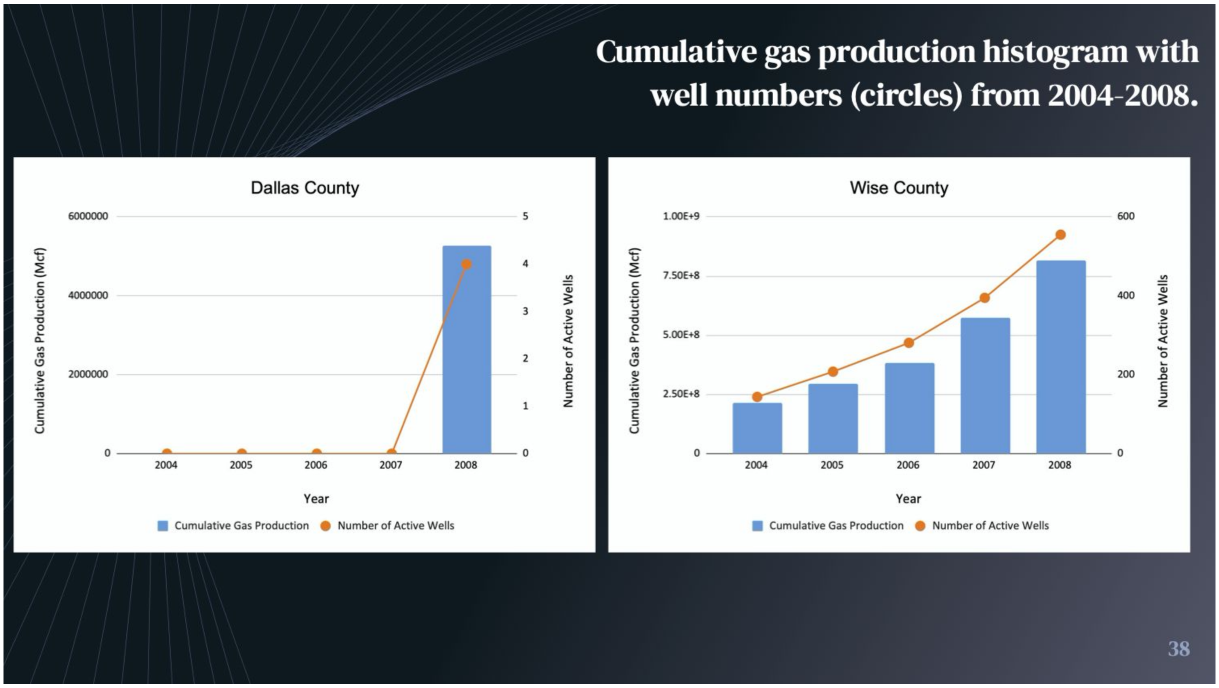
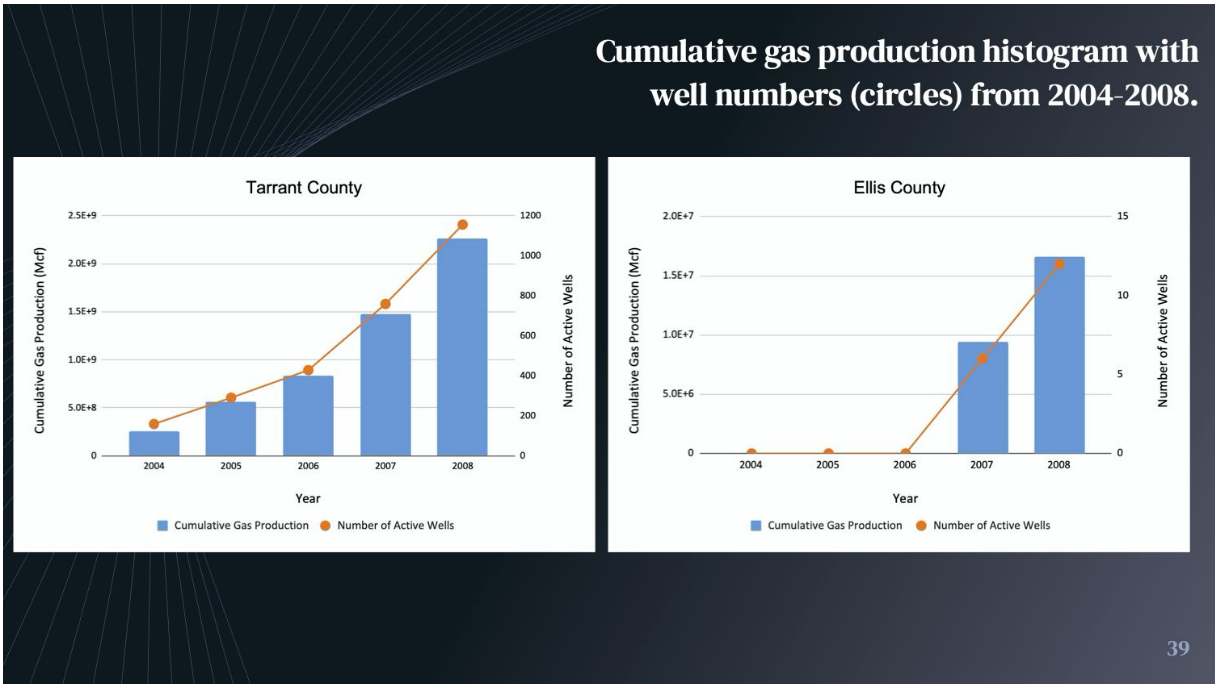


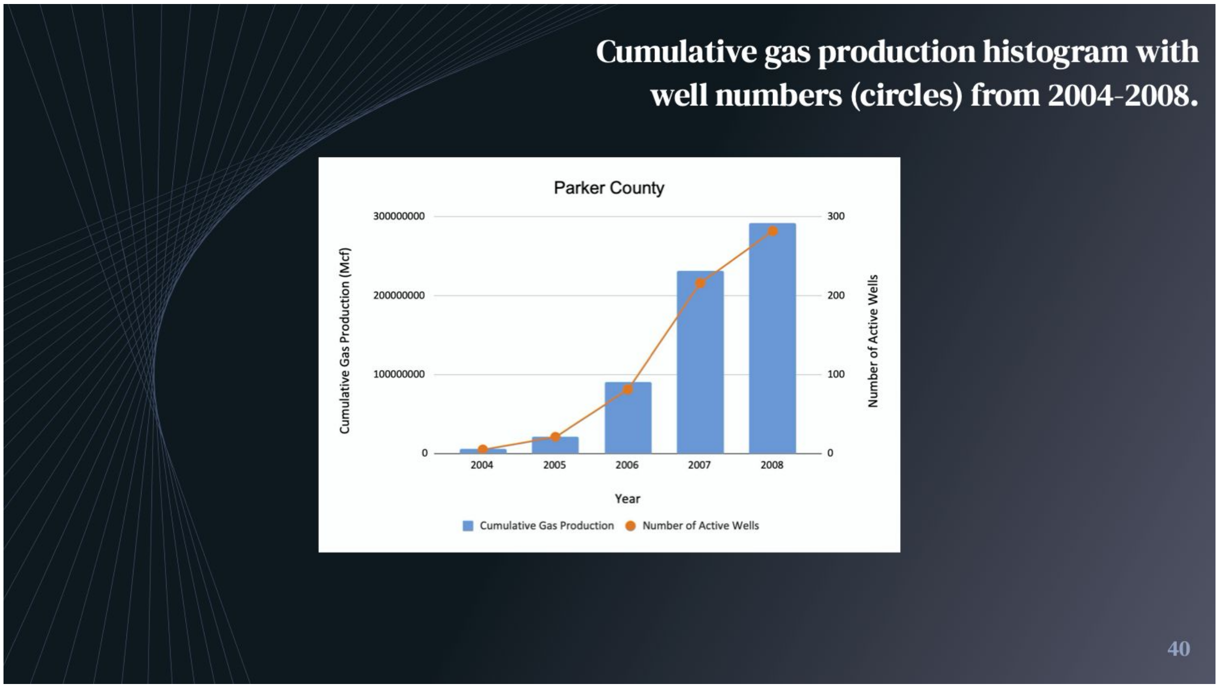
Cumulative gas production histogram with well numbers (circles) from 2004-2008.



Cumulative gas production histogram with well numbers (circles) from 2004-2008.



Cumulative gas production histogram with well numbers (circles) from 2004-2008.



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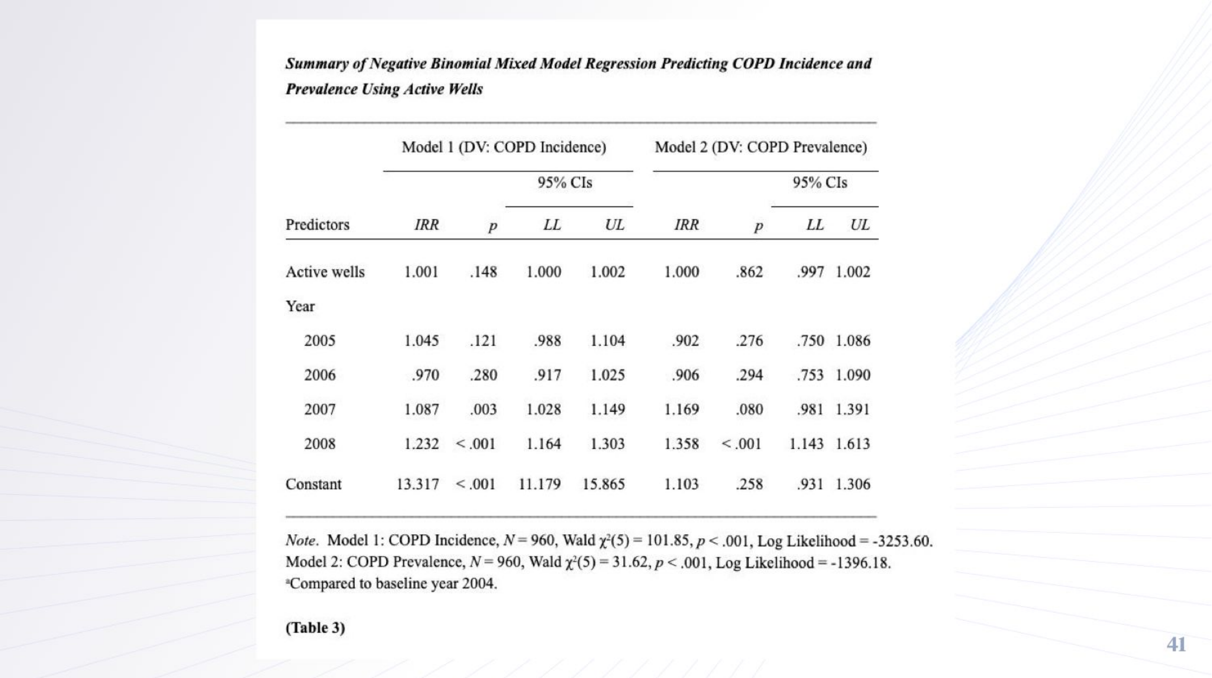
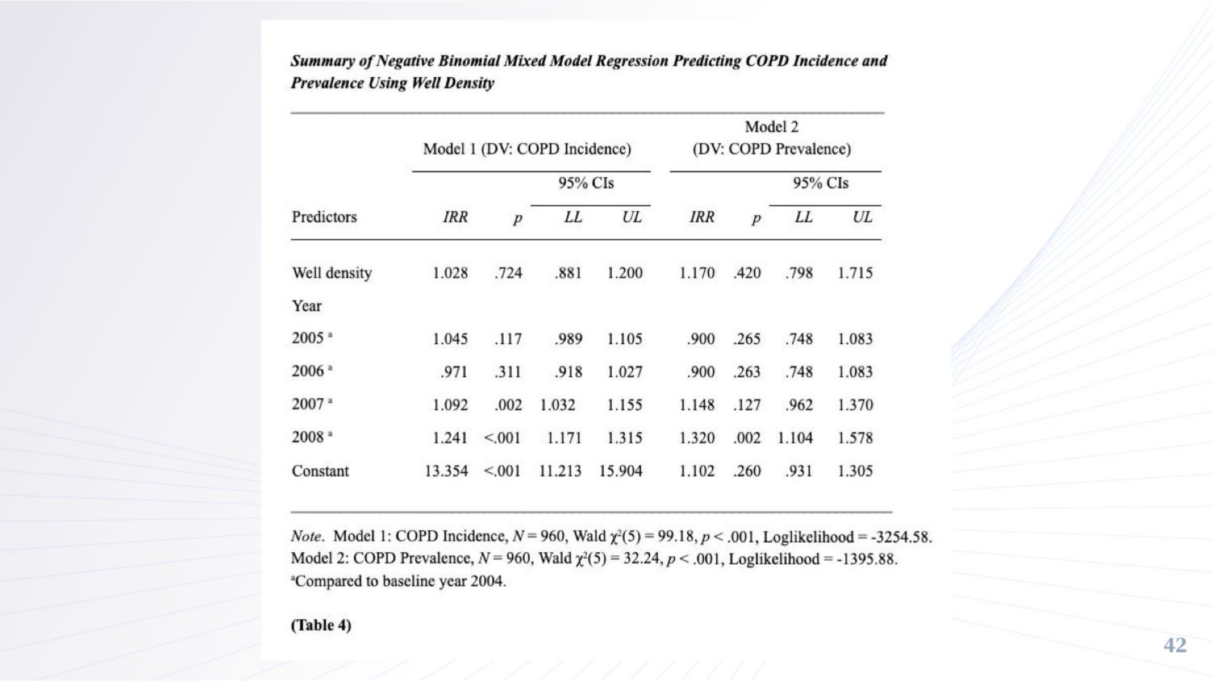


Summary of Negative Binomial Mixed Model Regression Predicting COPD Incidence and Prevalence Using Active Wells

	Model 1 (DV: COPD Incidence)				Model 2 (DV: COPD Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Active wells	1.001	.148	1.000	1.002	1.000	.862	.997	1.002
Year								
2005	1.045	.121	.988	1.104	.902	.276	.750	1.086
2006	.970	.280	.917	1.025	.906	.294	.753	1.090
2007	1.087	.003	1.028	1.149	1.169	.080	.981	1.391
2008	1.232	< .001	1.164	1.303	1.358	< .001	1.143	1.613
Constant	13.317	< .001	11.179	15.865	1.103	.258	.931	1.306

Note. Model 1: COPD Incidence, $N = 960$, Wald $\chi^2(5) = 101.85$, $p < .001$, Log Likelihood = -3253.60.
Model 2: COPD Prevalence, $N = 960$, Wald $\chi^2(5) = 31.62$, $p < .001$, Log Likelihood = -1396.18.
[a]Compared to baseline year 2004.

(Table 3)

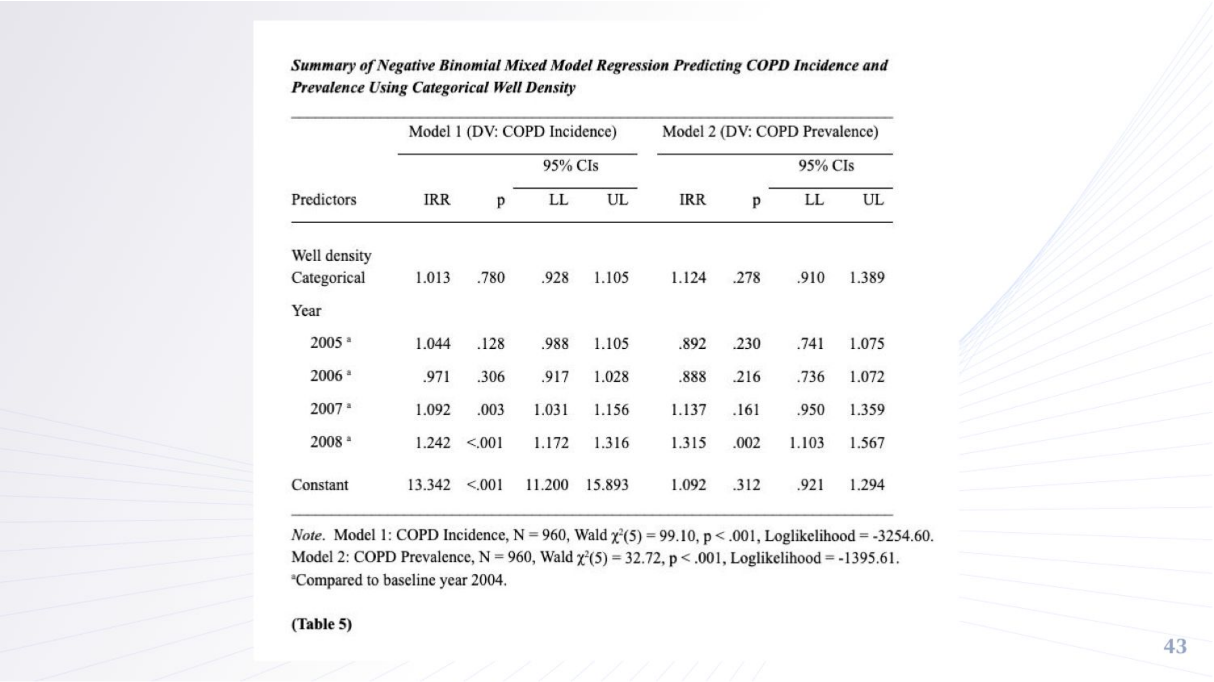


Summary of Negative Binomial Mixed Model Regression Predicting COPD Incidence and Prevalence Using Well Density

	Model 1 (DV: COPD Incidence)				Model 2 (DV: COPD Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density	1.028	.724	.881	1.200	1.170	.420	.798	1.715
Year								
2005 [a]	1.045	.117	.989	1.105	.900	.265	.748	1.083
2006 [a]	.971	.311	.918	1.027	.900	.263	.748	1.083
2007 [a]	1.092	.002	1.032	1.155	1.148	.127	.962	1.370
2008 [a]	1.241	<.001	1.171	1.315	1.320	.002	1.104	1.578
Constant	13.354	<.001	11.213	15.904	1.102	.260	.931	1.305

Note. Model 1: COPD Incidence, $N = 960$, Wald $\chi^2(5) = 99.18$, $p < .001$, Loglikelihood = -3254.58.
Model 2: COPD Prevalence, $N = 960$, Wald $\chi^2(5) = 32.24$, $p < .001$, Loglikelihood = -1395.88.
[a]Compared to baseline year 2004.

(Table 4)

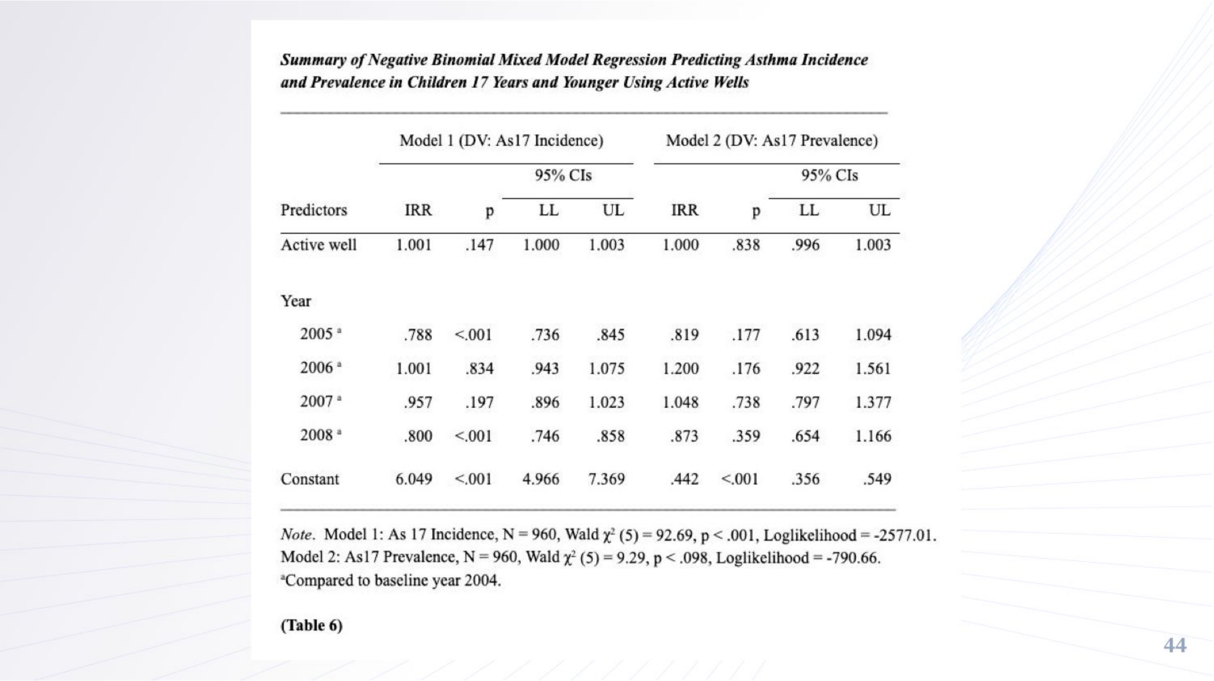


Summary of Negative Binomial Mixed Model Regression Predicting COPD Incidence and Prevalence Using Categorical Well Density

	Model 1 (DV: COPD Incidence)				Model 2 (DV: COPD Prevalence)			
			95% CIs				95% CIs	
Predictors	IRR	p	LL	UL	IRR	p	LL	UL
Well density Categorical	1.013	.780	.928	1.105	1.124	.278	.910	1.389
Year								
2005 [a]	1.044	.128	.988	1.105	.892	.230	.741	1.075
2006 [a]	.971	.306	.917	1.028	.888	.216	.736	1.072
2007 [a]	1.092	.003	1.031	1.156	1.137	.161	.950	1.359
2008 [a]	1.242	<.001	1.172	1.316	1.315	.002	1.103	1.567
Constant	13.342	<.001	11.200	15.893	1.092	.312	.921	1.294

Note. Model 1: COPD Incidence, N = 960, Wald $\chi^2(5) = 99.10$, $p < .001$, Loglikelihood = -3254.60.
Model 2: COPD Prevalence, N = 960, Wald $\chi^2(5) = 32.72$, $p < .001$, Loglikelihood = -1395.61.
[a]Compared to baseline year 2004.

(Table 5)

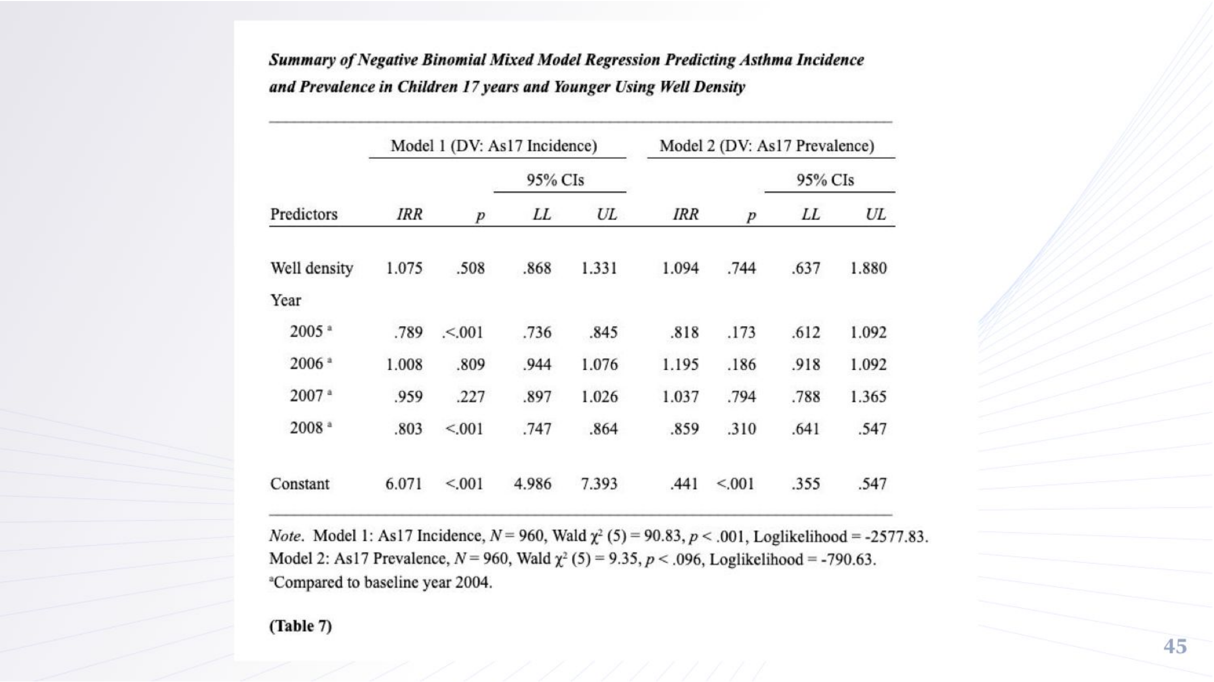


Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in Children 17 Years and Younger Using Active Wells

	Model 1 (DV: As17 Incidence)				Model 2 (DV: As17 Prevalence)			
			95% CIs				95% CIs	
Predictors	IRR	p	LL	UL	IRR	p	LL	UL
Active well	1.001	.147	1.000	1.003	1.000	.838	.996	1.003
Year								
2005 ^{a}	.788	<.001	.736	.845	.819	.177	.613	1.094
2006 ^{a}	1.001	.834	.943	1.075	1.200	.176	.922	1.561
2007 ^{a}	.957	.197	.896	1.023	1.048	.738	.797	1.377
2008 ^{a}	.800	<.001	.746	.858	.873	.359	.654	1.166
Constant	6.049	<.001	4.966	7.369	.442	<.001	.356	.549

Note. Model 1: As 17 Incidence, N = 960, Wald χ^2 (5) = 92.69, p < .001, Loglikelihood = -2577.01. Model 2: As17 Prevalence, N = 960, Wald χ^2 (5) = 9.29, p < .098, Loglikelihood = -790.66.
^{a}Compared to baseline year 2004.

(Table 6)

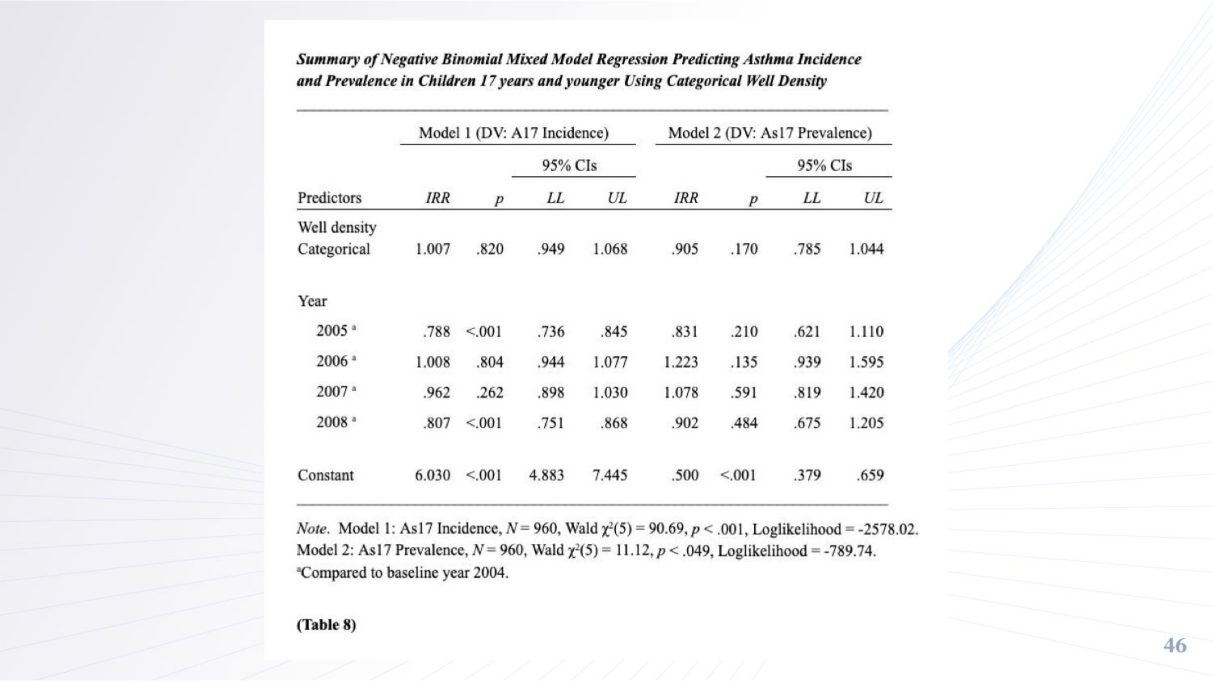


Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in Children 17 years and Younger Using Well Density

	Model 1 (DV: As17 Incidence)				Model 2 (DV: As17 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density	1.075	.508	.868	1.331	1.094	.744	.637	1.880
Year								
2005 ^{a}	.789	.<.001	.736	.845	.818	.173	.612	1.092
2006 ^{a}	1.008	.809	.944	1.076	1.195	.186	.918	1.092
2007 ^{a}	.959	.227	.897	1.026	1.037	.794	.788	1.365
2008 ^{a}	.803	<.001	.747	.864	.859	.310	.641	.547
Constant	6.071	<.001	4.986	7.393	.441	<.001	.355	.547

Note. Model 1: As17 Incidence, N = 960, Wald χ^2 (5) = 90.83, p < .001, Loglikelihood = -2577.83. Model 2: As17 Prevalence, N = 960, Wald χ^2 (5) = 9.35, p < .096, Loglikelihood = -790.63.
^{a}Compared to baseline year 2004.

(Table 7)

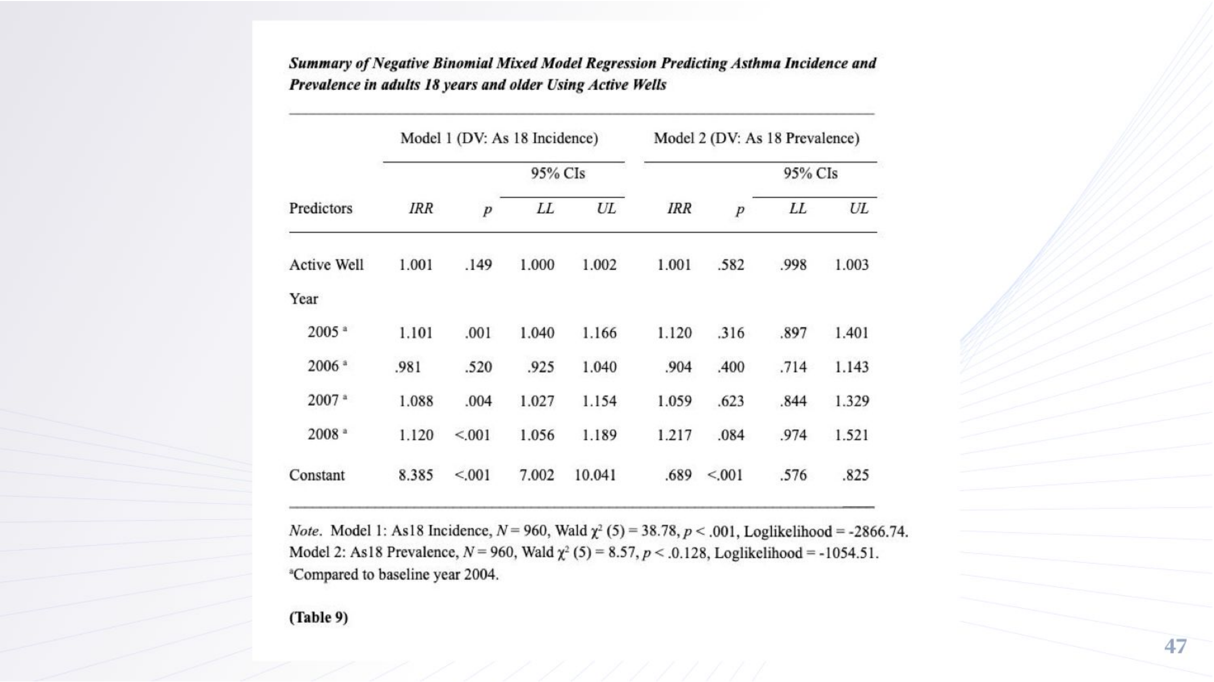


Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in Children 17 years and younger Using Categorical Well Density

	Model 1 (DV: A17 Incidence)				Model 2 (DV: As17 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density Categorical	1.007	.820	.949	1.068	.905	.170	.785	1.044
Year								
2005 [a]	.788	<.001	.736	.845	.831	.210	.621	1.110
2006 [a]	1.008	.804	.944	1.077	1.223	.135	.939	1.595
2007 [a]	.962	.262	.898	1.030	1.078	.591	.819	1.420
2008 [a]	.807	<.001	.751	.868	.902	.484	.675	1.205
Constant	6.030	<.001	4.883	7.445	.500	<.001	.379	.659

Note. Model 1: As17 Incidence, $N = 960$, Wald $\chi^2(5) = 90.69$, $p < .001$, Loglikelihood = -2578.02. Model 2: As17 Prevalence, $N = 960$, Wald $\chi^2(5) = 11.12$, $p < .049$, Loglikelihood = -789.74.
[a]Compared to baseline year 2004.

(Table 8)

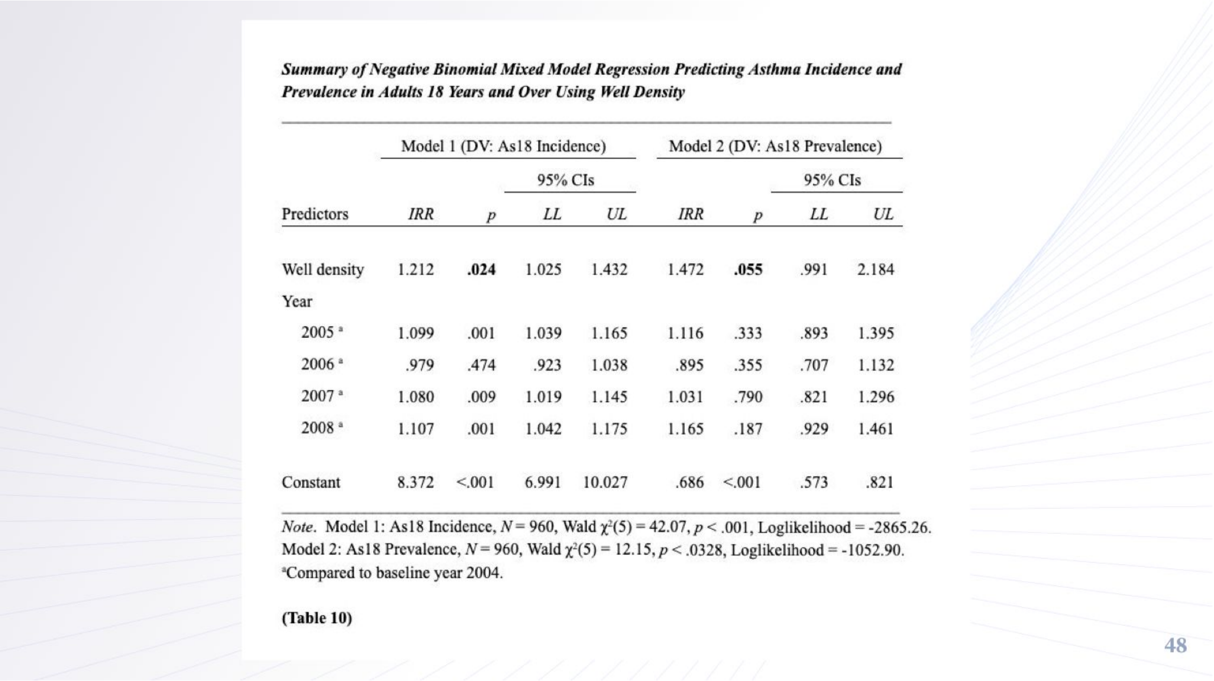


Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in adults 18 years and older Using Active Wells

	Model 1 (DV: As 18 Incidence)				Model 2 (DV: As 18 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Active Well	1.001	.149	1.000	1.002	1.001	.582	.998	1.003
Year								
2005 [a]	1.101	.001	1.040	1.166	1.120	.316	.897	1.401
2006 [a]	.981	.520	.925	1.040	.904	.400	.714	1.143
2007 [a]	1.088	.004	1.027	1.154	1.059	.623	.844	1.329
2008 [a]	1.120	<.001	1.056	1.189	1.217	.084	.974	1.521
Constant	8.385	<.001	7.002	10.041	.689	<.001	.576	.825

Note. Model 1: As18 Incidence, $N = 960$, Wald χ^2 (5) = 38.78, $p < .001$, Loglikelihood = -2866.74. Model 2: As18 Prevalence, $N = 960$, Wald χ^2 (5) = 8.57, $p < .0.128$, Loglikelihood = -1054.51.
[a]Compared to baseline year 2004.

(Table 9)

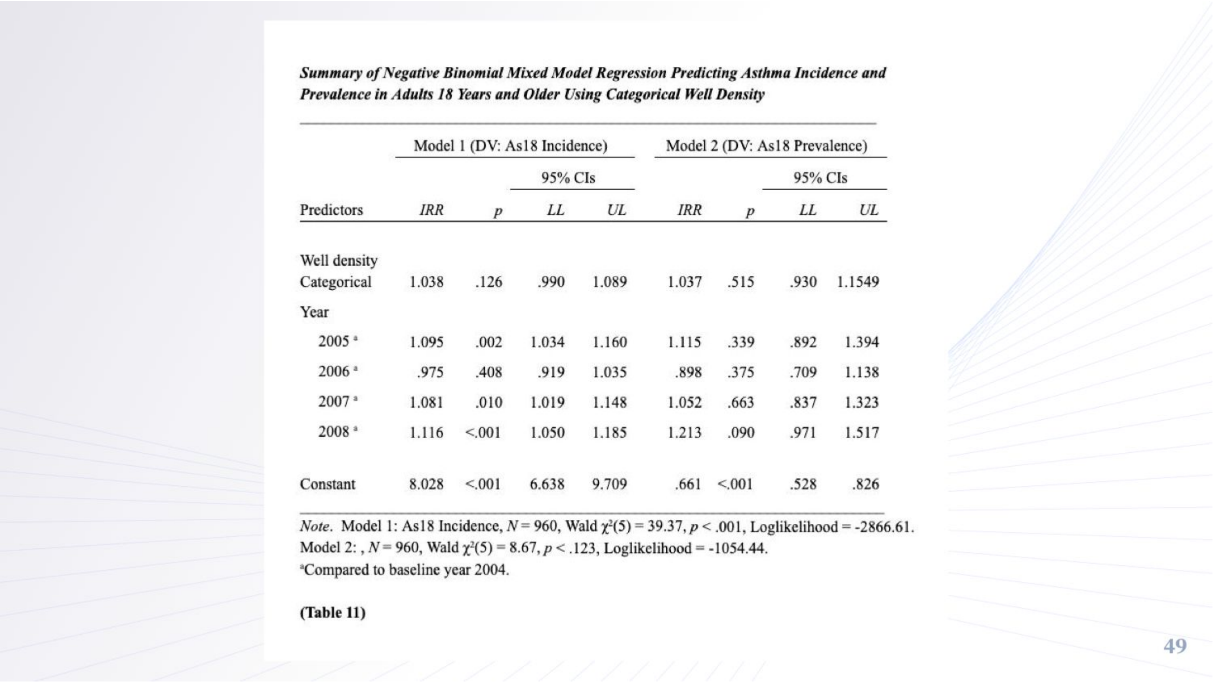


Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in Adults 18 Years and Over Using Well Density

	Model 1 (DV: As18 Incidence)				Model 2 (DV: As18 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density	1.212	**.024**	1.025	1.432	1.472	**.055**	.991	2.184
Year								
2005 [a]	1.099	.001	1.039	1.165	1.116	.333	.893	1.395
2006 [a]	.979	.474	.923	1.038	.895	.355	.707	1.132
2007 [a]	1.080	.009	1.019	1.145	1.031	.790	.821	1.296
2008 [a]	1.107	.001	1.042	1.175	1.165	.187	.929	1.461
Constant	8.372	<.001	6.991	10.027	.686	<.001	.573	.821

Note. Model 1: As18 Incidence, $N = 960$, Wald $\chi^2(5) = 42.07$, $p < .001$, Loglikelihood = -2865.26.
Model 2: As18 Prevalence, $N = 960$, Wald $\chi^2(5) = 12.15$, $p < .0328$, Loglikelihood = -1052.90.
[a]Compared to baseline year 2004.

(Table 10)

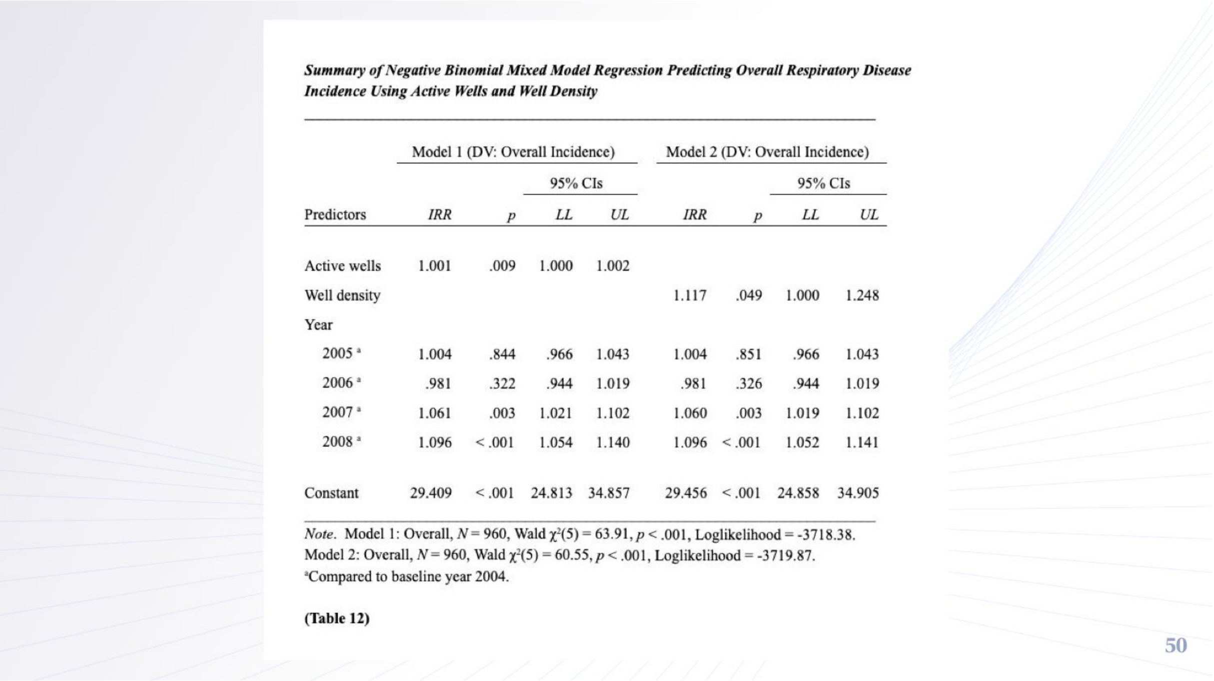


Summary of Negative Binomial Mixed Model Regression Predicting Asthma Incidence and Prevalence in Adults 18 Years and Older Using Categorical Well Density

	Model 1 (DV: As18 Incidence)				Model 2 (DV: As18 Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Well density Categorical	1.038	.126	.990	1.089	1.037	.515	.930	1.1549
Year								
2005 [a]	1.095	.002	1.034	1.160	1.115	.339	.892	1.394
2006 [a]	.975	.408	.919	1.035	.898	.375	.709	1.138
2007 [a]	1.081	.010	1.019	1.148	1.052	.663	.837	1.323
2008 [a]	1.116	<.001	1.050	1.185	1.213	.090	.971	1.517
Constant	8.028	<.001	6.638	9.709	.661	<.001	.528	.826

Note. Model 1: As18 Incidence, $N = 960$, Wald $\chi^2(5) = 39.37$, $p < .001$, Loglikelihood = -2866.61.
Model 2: , $N = 960$, Wald $\chi^2(5) = 8.67$, $p < .123$, Loglikelihood = -1054.44.
[a]Compared to baseline year 2004.

(Table 11)

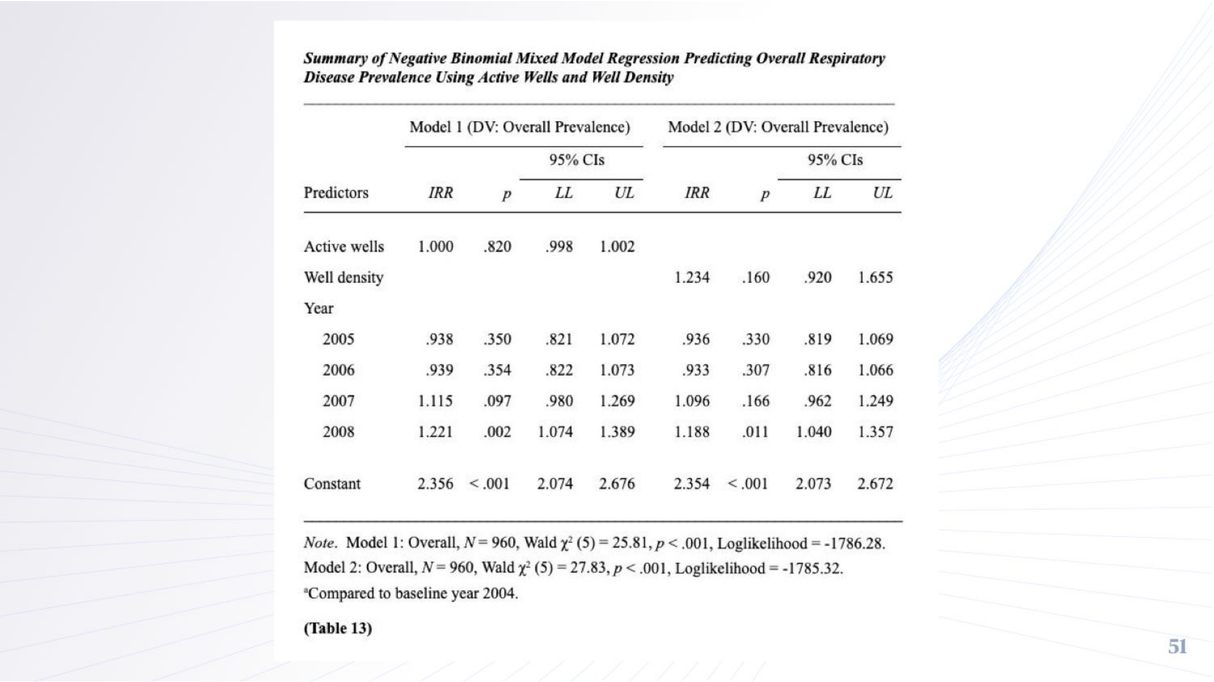


Summary of Negative Binomial Mixed Model Regression Predicting Overall Respiratory Disease Incidence Using Active Wells and Well Density

	Model 1 (DV: Overall Incidence)				Model 2 (DV: Overall Incidence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Active wells	1.001	.009	1.000	1.002				
Well density					1.117	.049	1.000	1.248
Year								
2005 [a]	1.004	.844	.966	1.043	1.004	.851	.966	1.043
2006 [a]	.981	.322	.944	1.019	.981	.326	.944	1.019
2007 [a]	1.061	.003	1.021	1.102	1.060	.003	1.019	1.102
2008 [a]	1.096	< .001	1.054	1.140	1.096	< .001	1.052	1.141
Constant	29.409	< .001	24.813	34.857	29.456	< .001	24.858	34.905

Note. Model 1: Overall, $N = 960$, Wald $\chi^2(5) = 63.91$, $p < .001$, Loglikelihood = -3718.38.
Model 2: Overall, $N = 960$, Wald $\chi^2(5) = 60.55$, $p < .001$, Loglikelihood = -3719.87.
[a]Compared to baseline year 2004.

(Table 12)

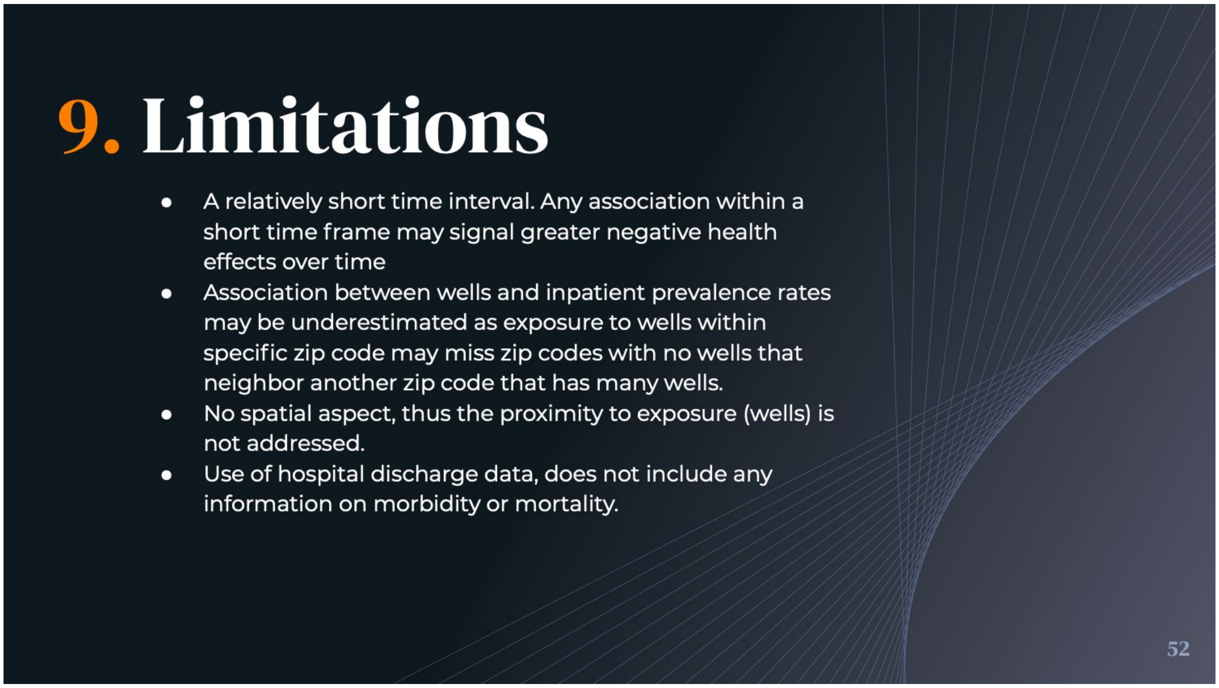


Summary of Negative Binomial Mixed Model Regression Predicting Overall Respiratory Disease Prevalence Using Active Wells and Well Density

	Model 1 (DV: Overall Prevalence)				Model 2 (DV: Overall Prevalence)			
			95% CIs				95% CIs	
Predictors	*IRR*	*p*	*LL*	*UL*	*IRR*	*p*	*LL*	*UL*
Active wells	1.000	.820	.998	1.002				
Well density					1.234	.160	.920	1.655
Year								
2005	.938	.350	.821	1.072	.936	.330	.819	1.069
2006	.939	.354	.822	1.073	.933	.307	.816	1.066
2007	1.115	.097	.980	1.269	1.096	.166	.962	1.249
2008	1.221	.002	1.074	1.389	1.188	.011	1.040	1.357
Constant	2.356	< .001	2.074	2.676	2.354	< .001	2.073	2.672

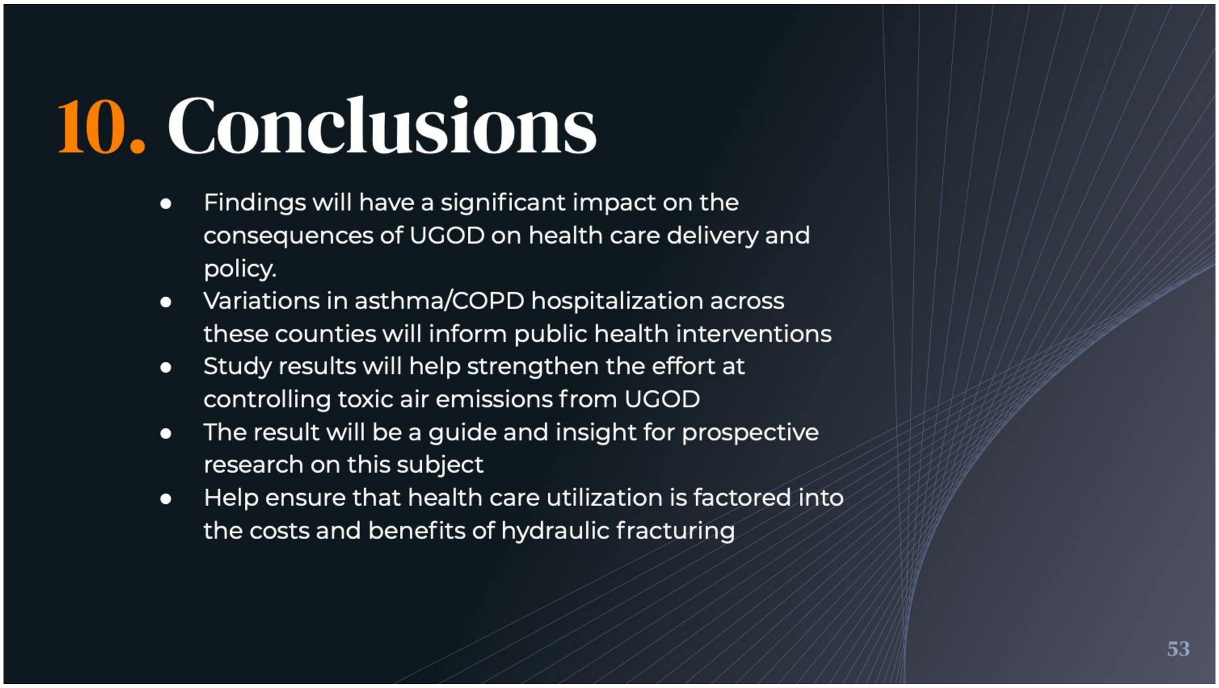
Note. Model 1: Overall, $N = 960$, Wald χ^2 (5) = 25.81, $p < .001$, Loglikelihood = -1786.28.
Model 2: Overall, $N = 960$, Wald χ^2 (5) = 27.83, $p < .001$, Loglikelihood = -1785.32.
[a]Compared to baseline year 2004.

(Table 13)



9. Limitations

- A relatively short time interval. Any association within a short time frame may signal greater negative health effects over time
- Association between wells and inpatient prevalence rates may be underestimated as exposure to wells within specific zip code may miss zip codes with no wells that neighbor another zip code that has many wells.
- No spatial aspect, thus the proximity to exposure (wells) is not addressed.
- Use of hospital discharge data, does not include any information on morbidity or mortality.



10. Conclusions

- Findings will have a significant impact on the consequences of UGOD on health care delivery and policy.
- Variations in asthma/COPD hospitalization across these counties will inform public health interventions
- Study results will help strengthen the effort at controlling toxic air emissions from UGOD
- The result will be a guide and insight for prospective research on this subject
- Help ensure that health care utilization is factored into the costs and benefits of hydraulic fracturing

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Thank you!

Questions?

Appendix C: Glossary for Shale Gas Terminology

Aquifer – A single underground geological formation, or group of formations, containing water.

Antrim Shale – A shale deposit located in the northern Michigan basin that is a Devonian age rock formation lying at a relatively shallow depth of 1,000 feet. Gas has been produced from this formation for several decades primarily via vertical, rather than horizontal, wells. The Energy Information Administration (EIA) estimates the technically recoverable Antrim shale resource at 20 trillion cubic feet (tcf).

Appalachian Basin – The geological formations that roughly follow the Appalachian Mountain range and contain potentially exploitable shale gas resources. The U.S. Department of Energy (DOE) associates the Appalachian Basin with the Marcellus Shale, the Devonian Shale and the Utica Shale.

Barnett Shale – A newly developed major play within the Fort Worth Basin in Northeast Texas. Wells are in the 6,000-to-8,000 foot depth range and the EIA estimated technically recoverable resource is 43 tcf.

Borehole – The hole or shaft in the earth made by a well drill; also, the uncased drill hole from the surface to the bottom of the well.

Caney Shale – Located in Arkoma Basin of Northeastern Oklahoma; has only recently been developed following the success of the Barnett Shale in Texas.

Casing – Pipe cemented in an oil or gas well to seal off formation fluids and to keep the borehole from caving in. Smaller diameter "strings" of casing are cemented inside larger diameter strings as a well is deepened.

Clean Water Act – The federal law that regulates discharges into waterways.

Coal Bed Methane (CBM) – A form of natural gas extracted from coal beds. Along with tight and shale gas, CBM is considered an unconventional natural gas resource.

Conasauga Shale – Cambrian Age shale deposits located in north central Alabama currently being evaluated for development.

Conventional Natural Gas Reservoir – A geological formation in which the natural gas is in interconnected pore spaces, much like a kitchen sponge, that allows easier flow to a well.

Department of Energy – The federal agency whose Office of Fossil Energy (FE) and National Energy Technology Laboratory (NETL) have played a significant role in advancing research and development related to hydraulic fracturing, horizontal drilling, and improved environmental practices.

Devonian Shale – The general term used to describe the thick sequence of shales in the Appalachian Basin that has been produced for more than a century. Development was greatest in the 1930s-through-1980s, using vertical wells and explosive fracturing. However, any shale deposited during the Devonian geologic period (360 million to 406 million years ago) is considered Devonian shale.

Drilling Rig – Usually a large-standing structure employing a drill that creates holes or shafts in the ground for purposes of accessing and producing natural gas or oil from subsurface deposits.

Eagle Ford Shale – A newly discovered (2009) shale play located in several counties in south Texas. The average gross thickness of the shale is 350 feet and it produces depths varying from 4,000 to 14,000 feet. Eagle Ford is the most active shale play in the world, with about 250 rigs operating at any single time and the technically recoverable resource is estimated by EIA to be 21 tcf.

Eastern Gas Shales Project – A program initiated by the U.S. Department of Energy in the late-1970s to evaluate the gas potential of – and to enhance gas production from – the extensive Devonian and Mississippian black shales located in the Appalachian, Illinois and Michigan basins of the eastern United States. The program not only identified and classified shales throughout the three basins, but also focused on developing and implementing new drilling, stimulation and recovery technologies to increase production potential. Between 1978 and 1992, DOE spent about $137 million on the program, which helped develop and demonstrate directional and horizontal drilling technology.

Fayetteville Shale – Newly developed shale deposit located in the Arkoma Basin of Arkansas, lying at a depth of 1,500-to-6,500 feet. Previously produced from vertical wells but all current wells are horizontal. Technically recoverable resources are estimated by EIA to be 32 tcf.

Flaring – The controlled burning of natural gas that can't be processed for sale or used because of technical or economic reasons.

Flowback – Water used as a pressurized fluid during hydraulic fracturing that returns to the surface via the well. This occurs after the fracturing procedure is completed and pressure is released.

Floyd Shale – A shale deposit from the Mississippian geologic age located in the resource-rich Black Warrior Basin of Mississippi and Alabama.

Fossil Energy – Energy derived from crude oil, natural gas or coal. Shale gas is a form of fossil energy.

Fracturing Fluid – The primarily water-based fluid used to fracture shale. It is basically composed of 99 percent water, with the remainder consisting of sand and various chemical additives. Fracturing fluid is pumped into wells at very high pressure to break up and hold open underground rock formations, which in turn releases natural gas.

FracFocus – A joint effort by the GroundWater Protection Council (GWPC) and the Interstate Oil and Gas Compact Commission (IOGCC) that is an online registry for companies to publicly disclose the chemicals used in their hydraulic fracturing operations. As of November 2012, more than 30,000 well sites and 200 companies were registered on the site (http://fracfocus.org/).

Fugitive Emissions – According to a study by DOE's Argonne National Laboratory, a primary air quality concern from natural gas production (including shale gas) is leaking and venting throughout the supply chain (see Hydraulic Fracturing and Shale Gas Production: Technology, Impacts, and Policy, September 10, 2012, page 5). These fugitive emissions can potentially result in releases of methane, the primary constituent of natural gas and a potent greenhouse gas (GHG). In addition, fugitive emissions of natural gas can release volatile organic compounds (VOCs) and hazardous air pollutants (HAPs), according to the study.

Geological Formation – A body of earth material with distinctive and characteristic properties and a degree of homogeneity in its physical properties.

Gothic Shale – A newly exploited shale formation located in the Paradox Basin of Colorado. Only a few wells have been drilled, one testing to 5,700 mcf (million cubic feet) per day.

Groundwater – The supply of usually fresh water found beneath the surface usually in aquifers, which are a body of permeable rock containing water and supplying wells and springs with drinking water.

Haynesville Shale – Along with the Marcellus and Barnett, this is one of the major shale plays. Located in Northwestern Louisiana, Haynesville is a Jurassic Age formation where vertical wells were drilled as far back as 1905; but it was not considered a major natural gas source until the advent of directional drilling.

Horizontal Drilling – The process of drilling the deeper portion of a well horizontally to enable access to more of the target formation. Horizontal drilling can be oriented in a direction that maximizes the number of natural fractures present in the shale, which provide pathways for natural gas to escape once the hydraulic fracturing operation takes place. The more generic term, “directional drilling,” refers to any non-vertical well.

Hydraulic Fracturing – The use of water, sand and chemical additives pumped under high pressure to fracture subsurface non-porous rock formations such as shale to improve the flow of natural gas into the well. Hydraulic fracturing is a mature technology that has been used for 60 years and today accounts for 95 percent of all new wells drilled.

Marcellus Shale – A large play that underlies most of the U.S. Northeast, the Marcellus is a Devonian-age shale that is estimated by the Energy Information Administration to contain at least 410 tcf of unproved, technically recoverable gas. Most of the play is at the 5,000-to-8,000 foot level below the surface and was long considered too expensive to access until advances in drilling and fracturing technology.

Natural gas – A naturally occurring mixture of hydrocarbon and non-hydrocarbon gases beneath the surface, the principal component of which (50-to-90 percent) is methane.

New Albany Shale – This Devonian to Mississippian age shale deposit is located in the Illinois Basin and has been a producer of natural gas for over 100 years. Most wells are shallow, between 120 and 2,100 feet; new drilling and completion technologies and competitive prices have resulted in energy companies revisiting old leases and drilling new wells. Estimated by EIA to contain 11 tcf of technically recoverable resources.

On-Site Water Treatment – A practice employed by many shale gas producers to facilitate reuse of flowback fluids. In this instance, mobile and fixed treatment units are employed using processes such as evaporation, distillation, oxidation, and membrane filtration for recycling and reuse. On-site treatment technologies may be capable of returning 70-80 percent of the initial water to potable water standards, making it immediately available for reuse.

Pearsall Shale – Located in the Maverick Basin of southwestern Texas. Located about 2,500 feet below the Eagle Ford Shale and is approximately 500-600 feet in thickness.

Permeability – The measure of the ability of a material, such as rock, to allow fluids to pass through it.

Produced Water – Naturally occurring water found in shale formations; it generally flows to the surface during the entire lifespan of a well, often along with natural gas. Produced water and flowback from natural gas extraction may be reused in hydraulic fracturing operations; disposed of through underground injection (see definition); discharged to surface waters as long as it doesn’t degrade water quality standards; or transferred to a treatment facility if necessary, processed and discharged into a receiving water body in compliance with effluent limits.

Proppant – A granular substance, often sand, that is mixed with and carried by fracturing fluid pumped into a shale well. Its purpose is to keep cracks and fractures that occur during the hydraulic fracturing process open so trapped natural gas can escape.

Reclamation – The clean up or restoring a well site to its pre-existing condition after drilling operations cease. Reclamation activities, which are governed by state, federal and local laws and regulations, can include soil replacement, compacting and re-seeding of natural vegetation.

Royalty – A payment received by a lessor or property owner from an oil, gas or minerals-producing company, based on the production of a well or other extraction process and market prices.

Safe Water Drinking Act – A federal law whose provisions also apply to shale production activities related to wastewater disposal through underground injection and discharge to surface waters.

Shale – A fine-grained sedimentary rock composed mostly of consolidated clay or mud. Some large shale gas formations were formed more than 300 million years ago during the Devonian period of Earth's history, where conditions were particularly favorable for the preservation of organic material within the sediment. Methane that remained locked in the shale layers is the source of today's shale gas.

Shale Gas – Natural gas produced from shale formations. Shale gas is widely distributed in the United States and is currently being produced in 16 states. Although data are being constantly revised, the Energy Information Administration currently estimates the recoverable U.S. shale gas resource is 482 trillion cubic feet; domestic shale gas production has increased 12-fold over the past decade and led to a new abundance of natural gas supply in the United States.

Shale Gas Play – A set of discovered, undiscovered or possible natural gas accumulations that exhibit similar geological characteristics. Shale plays are located within basins, which are large-scale geologic depressions, often hundreds of miles across, which also may contain other oil and natural gas resources. For a map detailing the location of major shale gas plays in the lower 48 states, see: http://www.eia.gov/oil_gas/rpd/shale_gas.pdf.

Surface Water – Water that is open to the atmosphere, such as rivers, lakes, ponds, reservoirs, streams, impoundments, seas and estuaries.

Tcf – Trillion cubic feet.

SOURCE: U.S. Energy Information Administration, accessed on 02-01-2020 at:
https://www.energy.gov/fe/downloads/shale-gas-glossary

Appendix D: Natural gas drilling and hydraulic fracturing chemicals with 10 or more health effects

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- 2,2′,2″-Nitrilotriethanol
- 2-Ethylhexanol
- 5-Chloro-2-methyl-4-isothiazolin-3-one
- Acetic acid
- Acrolein
- Acrylamide (2-propenamide)
- Acrylic acid
- Ammonia
- Ammonium chloride
- Ammonium nitrate
- Aniline
- Benzyl chloride
- Boric acid
- Cadmium
- Calcium hypochlorite
- Chlorine
- Chlorine dioxide
- Dibromoacetonitrile 1
- Diesel 2
- Diethanolamine
- Diethylenetriamine
- Dimethyl formamide
- Epidian
- Ethanol (acetylenic alcohol)
- Ethyl mercaptan
- Ethylbenzene
- Ethylene glycol
- Ethylene glycol monobutyl ether (2-BE)
- Ethylene oxide
- Ferrous sulfate
- Formaldehyde
- Formic acid
- Fuel oil #2
- Glutaraldehyde
- Glyoxal
- Hydrodesulfurized kerosene
- Hydrogen sulfide
- Iron
- Isobutyl alcohol (2-methyl-1-propanol)
- Isopropanol (propan-2-ol)
- Kerosene
- Light naphthenic distillates, hydrotreated
- Mercaptoacetic acid
- Methanol
- Methylene bis(thiocyanate)
- Monoethanolamine
- NaHCO3
- Naphtha, petroleum medium aliphatic
- Naphthalene
- Natural gas condensates
- Nickel sulfate
- Paraformaldehyde
- Petroleum distillate naphtha
- Petroleum distillate/ naphtha
- Phosphonium, tetrakis (hydroxymethyl)-sulfate
- Propane-1,2-diol
- Sodium bromate
- Sodium chlorite (chlorous acid, sodium salt)
- Sodium hypochlorite
- Sodium nitrate
- Sodium nitrite
- Sodium sulfite
- Styrene
- Sulfur dioxide
- Sulfuric acid
- Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2- thione (Dazomet)
- Titanium dioxide
- Tributyl phosphate
- Triethylene glycol
- Urea
- Xylene

Appendix E: The 6 Criteria Pollutants and Their Harmful Effects on the Pulmonary System

Pollutant	Effects on the lung
Sulfur oxides	Can aggravate asthma, decrease lung function via inflammation; tendency develop allergies
Particulate matter	Depending on specific particle, causes decreased lung function, bronchitis, and pneumonia; can aggravate asthma; some can cause fibrosis; increase deaths
Carbon monoxide	Can cause death or damage to lung cells by passing into the bloodstream inhibiting the ability of red blood cells to carry oxygen to cells of the body
Ozone	Can irritate and inflame the lungs, cause shortness of breath, increased susceptibility to respiratory infections, accelerated aging of the lungs, and emphysema; fatal at high concentrations (effects have been shown below the current standard
Nitrogen dioxide	Can cause acute respiratory disease at high concentrations, increased susceptibility to viral infections; can aggravate asthma; can cause inflammation
Lead	Lung acts as site of entry for lead which in turn can damage the nervous system, kidneys, and reproductive system

SOURCES: 40 CFR 50, July 1, 1991; U.S. Congress, *United States Code Congressional and Administrative News, 95th Congress, 1st Sess. 1977* (St. Paul, MN: West Publishing Co., 1977), pp. 1187-88; U.S. Congress, *United States Code Congressional and Administrative News*, *10lst Congress*, *2d Sess*., *1990* (St. Paul, MN: West Publishing Co., 1990), pp. 3392-94.

Appendix F: Hazardous Air Pollutants regulated under the Clean Air Act Due to Non-Cancer health effects on the respiratory System

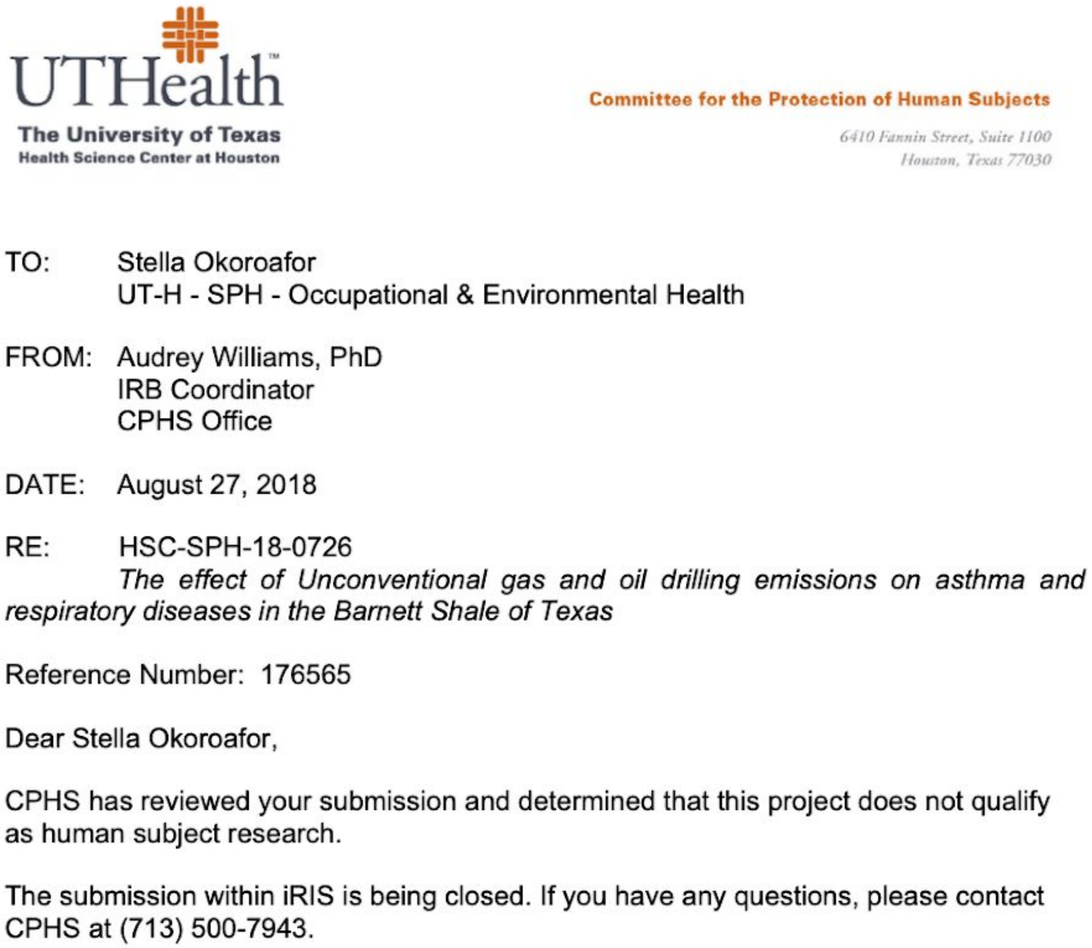
Chemical	Pulmonary health effect
Acetaldehyde	Respiratory tract irritation
Acrolein	Respiratory tract irritation
Acrylic acid	Lung injury, and possibly death
Allyl chloride	Pulmonary irritation and histologic lesions of the lung
Asbestos	Asbestosis
Benzene	Pulmonary edema and hemorrhage; tightness in chest, breathlessness; unconsciousness may occur and death may follow due to respiratory paralysis in cases of extreme exposure
Benzylchloride	Lung damage and pulmonary edema
Beryllium compounds	Non-malignant respiratory disease and berylliosis
Caprolactam	Upper respiratory tract irritation and congestion
Catechol	Acute respiratory toxicity and upper respiratory tract irritation
Chlorine	Necrosis of tracheal and bronchial epithelium, bronchitis, bronchopneumonia and fatal pulmonary edema
2-Chloroacetophenone	Difficulty in breathing
Chloroprene	Lung irritation
Chromium	Pulmonary disease (unspecified)
Cresol (o-, m-,& p-)	Obliterative bronchiolitis, adenomatosis, and hypersensitivity reactions, chronic interstitial pneumonitis and occasional fatalities

Diazomethane	Chest pain, respiratory irritation, damages to mucous membranes
Dichloroethyl ether	Respiratory system irritation and pulmonary damage
1,3-Dichloropropene	Respiratory irritation
Dimethyl sulfate	Lung edema
2,4-Dinitrophenol	Respiratory collapse
l,4-Dioxane (l,4-Diethleneoxide)	Lung edema; can cause death
l,2-Epoxybutane	Lung irritation, edema, and pneumonitis
Epichlorohydrin	Lung edema, dyspnea, bronchitis, and throat irritation
Ethyl acrylate	Respiratory irritation, pneumonia and pulmonary edema
Ethyl benzene	Lung congestion
Ethylene glycol	Throat and respiratory irritation
Ethylene imine (Aziridine)	Lung edema and secondary bronchial pneumonia
Ethylene oxide	Respiratory irritation and lung injury (unspecified)
Formaldehyde	Difficulty breathing, severe respiratory tract injury leading to pulmonary edema, pneumonitis, and bronchial irritation which may lead to death
Hexachlorobutadiene	Pulmonary irritation
Hexachlorocyclopentadiene	Pulmonary irritation, bronchitis, and bronchiolitis
Hexamethylene-1,6-diisocyanate	Pulmonary edema, chronic bronchitis, chronic asthma; pulmonary edema; may be fatal

Hydrochloric acid	Pulmonary edema
Hydrogen fluoride	Respiratory tract irritation and lung damage
Hydrogen sulfide	Pulmonary edema
Maleic anhydride	Chronic bronchitis
Methyl bromide	Bronchopneumonia
Methyl ethyl ketone	Upper respiratory tract irritation
Methyl iodide (Iodomethane)	Lung irritation
Methyl isocyanate	Pulmonary edema and lung injury
Methyl methacrylate	Fatal pulmonary edema
Methylene diphenyl diisocyanate (MDI)	Restricted pulmonary function
Naphthalene	Lung damage
2-Nitropropane	Pulmonary edema
p-Phenylenediamine	Allergic asthma and inflammation of larynx and pharynx
Phosgene	Extreme lung damage; severe pulmonary edema after a latent period of exposure; bleeding and painful breathing; death
Phosphine	Pulmonary edema and acute dyspnea
Phthalic anhydride	Respiratory irritation and pulmonary sensitization
Propionaldehyde	Fatal pulmonary edema
Propoxur (Baygon)	Severe bronchoconstriction and paralysis of respiratory muscles
Propylene oxide	Pulmonary irritation
l,2-Propyleneimine (2-Methyl aziridine)	Diphtheria-like mutations of trachea and bronchi; bronchitis, lung edema, secondary

	bronchial pneumonia
Styrene	Abnormal pulmonary function, upper respiratory tract irritation, wheezing, chest tightness, and shortness of breath
Tetrachloroethylene (Perchloroethylene)	Acute pulmonary edema
2,4-Toluene diisocyanate	Pulmonary sensitization and long-term decline in lung function
Toxaphene (Chlorinated camphene)	Lung inflammation
1,2,4-Trichlorobenzene	Lung and upper respiratory tract irritation
Trichloroethylene	Lung adenomas
Triethylamine	Vapors cause severe coughing, difficulty breathing, and chest pain; pulmonary edema
2,2,4-Trimethylpentane	Pulmonary lesions
Vinyl acetate	Upper respiratory tract imitation

Appendix G: Copy of Study IRB Approval Letter



UTHealth
The University of Texas
Health Science Center at Houston

Committee for the Protection of Human Subjects
6410 Fannin Street, Suite 1100
Houston, Texas 77030

TO: Stella Okoroafor
UT-H - SPH - Occupational & Environmental Health

FROM: Audrey Williams, PhD
IRB Coordinator
CPHS Office

DATE: August 27, 2018

RE: HSC-SPH-18-0726
The effect of Unconventional gas and oil drilling emissions on asthma and respiratory diseases in the Barnett Shale of Texas

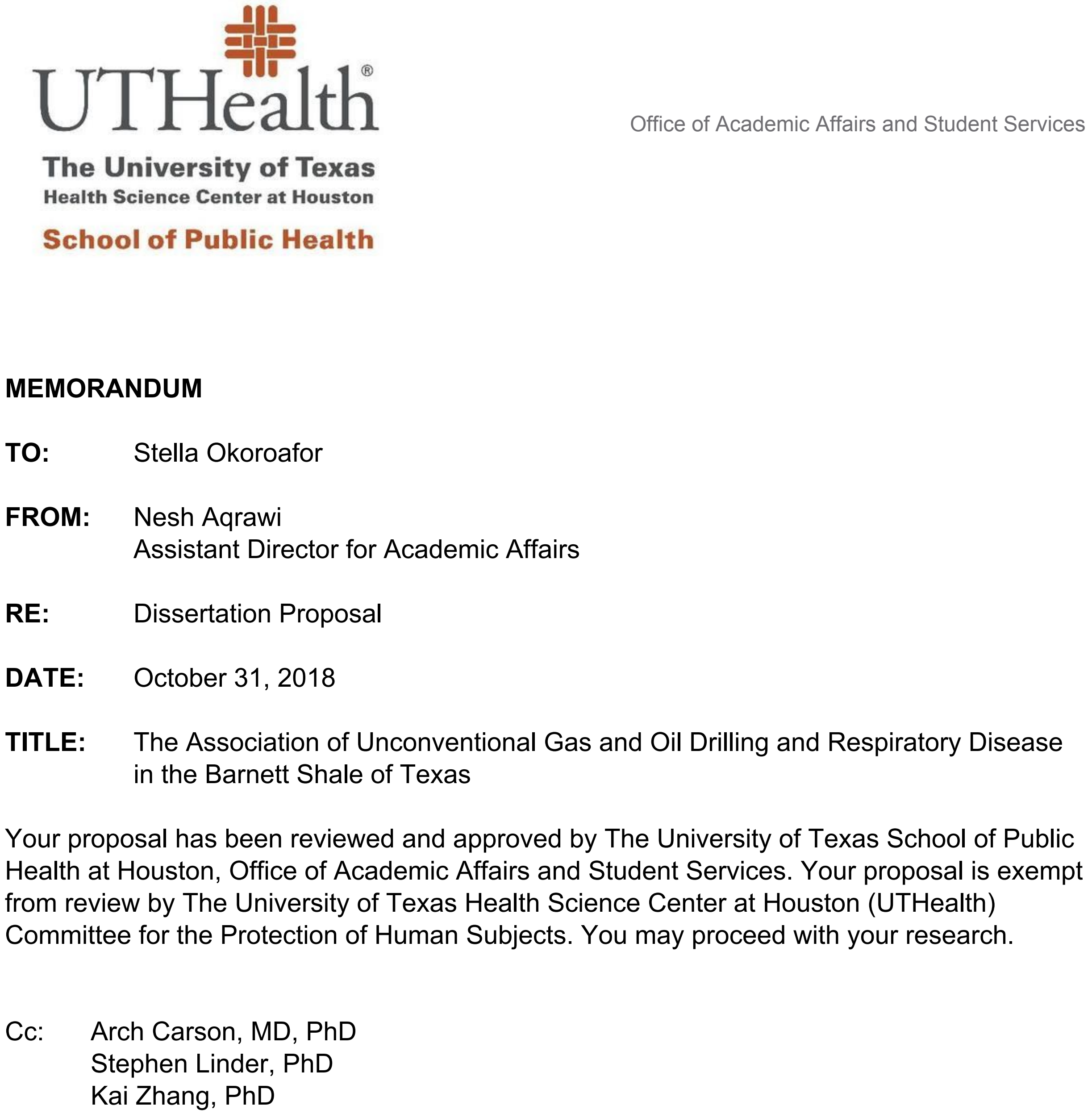
Reference Number: 176565

Dear Stella Okoroafor,

CPHS has reviewed your submission and determined that this project does not qualify as human subject research.

The submission within iRIS is being closed. If you have any questions, please contact CPHS at (713) 500-7943.

Appendix H: Copy of Study Proposal Approval Letter



UTHealth®
The University of Texas
Health Science Center at Houston
School of Public Health

Office of Academic Affairs and Student Services

MEMORANDUM

TO: Stella Okoroafor

FROM: Nesh Aqrawi
Assistant Director for Academic Affairs

RE: Dissertation Proposal

DATE: October 31, 2018

TITLE: The Association of Unconventional Gas and Oil Drilling and Respiratory Disease in the Barnett Shale of Texas

Your proposal has been reviewed and approved by The University of Texas School of Public Health at Houston, Office of Academic Affairs and Student Services. Your proposal is exempt from review by The University of Texas Health Science Center at Houston (UTHealth) Committee for the Protection of Human Subjects. You may proceed with your research.

Cc: Arch Carson, MD, PhD
Stephen Linder, PhD
Kai Zhang, PhD

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