2019

Hydraulic Fracturing and Cause-Specific Mortality: A Multicity Comparative Epidemiological Study

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Abstract

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Dissertation Submitted in Partial Fulfilment

of the Requirements for the Degree of

Doctor of Philosophy

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Abstract

Cause-specific mortality (CSM), among other global health estimates, has garnered prominence in the contemporary public health field. CSM has been associated with several factors, however, research comparing CSM for prefracking versus postfracking periods is sparse. Hydraulic fracturing or fracking is a technique of extracting oil and gas from deep underground. The purpose of this study was to evaluate the difference among mean CSM scores from 1975 through 2015 in the available cities and counties of residence in Colorado and to determine the impact of gender, marital status, county of residence, and city of residence on CSM scores (prefracking period 1975-1977 versus postfracking period 1999-2015) among adults aged 45-70 years. In this retrospective quantitative study, the socioecological model of health was used to analyze 73,251 cases obtained from the Colorado Department of Public Health and Environment. One-way analysis of variance and multiple regression were used to analyze data. Results showed that Denver County had a higher mean CSM score compared to other counties in Colorado. Regression results revealed a significant but weak association between CSM scores and gender, marital status, city of residence, and county of residence. If gender, marital status, and county of residence can be significant predictors of CSM, this information could have social change implications by influencing decisions regarding CSM and fracking.

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Dedication

To Ngozi Nduka and Somma Onyeoma Nduka

To Canon Jerry Ehosiem and Mercy Mma Nduka

To His Royal Highness Eze Silva Nnanyereugo and Veronica Ibenye-Ugbalar

Acknowledgments

All glory, honor, and adulations to God Almighty, the maker of heaven and earth!

Thanks to Ngozi and Somma, who both have endured my years of silence, depression, isolation, and separation just to get this done!

Thanks to my parents for churning and molding a great mind in me from infancy. Thanks to my father-replica, Moses Obumneme Nduka. Without your understanding and parental presence, I wouldn't be what I am today! Thanks to Lizzy Ibe (Ada nne m), Pepy Utomi, and Lemmy Nduka. Thank you Chinedu and Randy Nduka. Thanks Fred & Uju Nnanna, Afoma Nwagwu, Ageno Otii, and Telke Aida.

Dr. Patrick Tschida, my academic supervisor and dissertation committee chair, you are God-sent! You, and Dr. Raymond Thron, represent the best in what a teacher should be—ever-present, ever-listening, ever-helping, ever-guiding, and ever-humble. Thanks to both of you for seeing me thus far! I cannot forget Dr. Tammy Root and Dr. Nancy Rea.

Monumental thanks go to my University Research Reviewer, Dr. Vasileios Margaritis. Your patience with my reworks; your constant willingness to guide me right; and your understanding of my shortcomings are all appreciated. I also want to thank the staff of the Colorado Department of Public Health and Environment, but most especially Kirk Bol. Kirk, you are special! Thank you Prof. Martins Nwankwo, Dean Student Affairs, Imo State University, Owerri.

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Chapter 1: Introduction to the Study

Introduction

Cause-specific mortality (CSM), among other global health estimates, has garnered prominence in the contemporary public health field. Fine particulate matter 2.5 micrometers or smaller (abbreviated $PM_{2.5}$), ozone (O3), and nitrogen dioxide (NO2) have been associated with nonaccidental and cause-specific mortality in single-pollutant models (Brauer et al., 2015). Cause-specific death has also been associated with overweight and obesity in three large cohorts of health professionals in the United States (Hu et al., 2017). Jin et al. (2015) opined that all cause-specific cardiovascular mortality in Beijing had stronger cold and hot effects than those in Shanghai. Additionally, in the United States, cardiovascular disease (CVD), the leading cause of mortality, has been associated with CSM (Feeser, Fuller, O’Neill, & Sarnat; 2017). Epidemiological, clinical, pathophysiological, and mechanistic studies show that air pollution is associated with general morbidity and mortality resulting from respiratory and CVD.

Air pollution, both indoors and outdoors, constitutes a major threat to global human health. Most sources of air pollution, including industrial production, transportation, heat, power generation, and burning of solid waste, releases harmful chemicals or pollutants such as sulphur dioxides ($S0_2$), nitrogen dioxides (NOx), carbon monoxide (CO), particulate matter (PM), volatile organic compounds (VOCs), and lead (Pb; Balali-Mood, Ghorani-Azam, & Riahi-Zanjani; 2016). Balali-Mood, Ghorani-Azam, & Riahi-Zanjani (2016) posited that air pollution containing $PM_{2.5}$ and particulate manner 10 micrometers or smaller (PM_{10}) may cause premature death in people with heart and/or lung disease including cardiac dysrhythmias, nonfatal heart attacks, aggravated asthma, and decreased lung functions.. Statistically significant associations have been found between PM10 and heart disease and between SO2, NO2, PM10, and CVD mortality (X. Chen et al., 2015).

According to the World Health Organization (WHO, 2017), air pollution constitutes a huge environmental risk, and about 92% of the global population lives in areas where WHO air quality guideline levels are not met. Due to this great risk, WHO came up with guideline values for some pollutants, as shown in Table 1.

Table 1

World Health Organization Air Pollution Guideline Values

$PM_{2.5}$	**PM_{10}**	**NO_2**	**O_3**	**SO_2**
10 $\mu g/m^3$ annual mean	20 $\mu g/m^3$ annual mean	40 $\mu g/m^3$ annual mean	100 $\mu g/m^3$ 8-hour mean	20 $\mu g/m^3$ 24-hour mean
25 $\mu g/m^3$ 24-hour mean	50 $\mu g/m^3$ 24-hour mean	200 $\mu g/m^3$ 1-hour mean		500 $\mu g/m^3$ 10-minute mean

Note. Data from WHO (2017).

Hydraulic fracturing (HF) is becoming a global health problem. Its history in the United States dates to the 1940s (Geological Society of America, n.d.). A budding 21st-century technology, HF has been used for well completion in Colorado since the 1970s (Colorado Oil and Gas Conservation Commission, 2011). There are perceived human health implications associated with this technological means of extracting oil and gas from deep underground (Finkel & Hays, 2016). Governments at all levels (i.e., international, national, and local), the oil and gas industries, private citizens, not-for-profit organizations, and academic institutions have posited and presented various positions on HF.

These multiple points of view range in their focus from perceived population health impacts of HF, economic benefits, social and environmental implications, and effects on the ecosystem (Bugos et al., 2015; Cappa, Moridis, Rinaldi & Rutqvist, 2013). Those who live near fracking sites have complained about adrenal and pituitary tumors, headaches, nausea, joint pain, and respiratory problems (Brown, Bonaparte, Lewis, & Weinberger, 2014).

Proponents of other schools of thought have suggested that HF has economic benefits and the potential of making the United States and the world energy-self-sufficient. In the process of oil and gas exploration, chemicals are released into the ambient air. For example, residents of Porter Ranch, California, have been exposed to benzene from gas leaks, which may cause increased cancer risk (South Coast Air Quality Management District, 2014). Chemicals such as benzene and methane that are used during HF processes could be associated with several human health impacts (Brown et al., 2014). As results of several studies have shown, these chemicals often emitted into the ambient air constitute air pollution. CO, Pb, NO_2, O_3, PM_{10}, $PM_{2.5}$, and SO_2 are some classes of those pollutants. Prior research has shown that there is an association between CO, Pb, NO_2, O_3, PM_{10}, $PM_{2.5}$, and SO_2 and certain human health risks (Cao, Chen, Kan, Xu, & Xu, 2012; Bell et al., 2006; Anderson, Bell, Dominici, Krall, & Peng, 2013; Bell et al., 2009).

CSM, on the other hand, has been compared to coffee consumption (Freedman et al., 2017), travel time (Ghosn, Menvielle, Rey, & Rican, 2017), nut consumption (Aune, 2016), paid sick-leave (Kim, 2017), weight history (Yu et al., 2017), and exposure to crystalline silica (Y. Liu et al., 2017). Mortality was defined as mortality from major cardiovascular diseases (International Classification of Diseases, 10th Revision (ICD-10 Codes I00–I78), which included deaths from diseases of the heart (I00–I09, I11, I13, I20–I51), essential hypertension and hypertensive renal disease (I10, I12, I15), and cerebrovascular disease (CBD; I60–169; Klein & Miniño, 2010). CSM (underlying cause of death) was defined using ICD Code 9 for data from 1975 to1977 and ICD Code 10 for data from 1999-2015.

This study has implications for positive social change, in that it may inform public health planning and policy making and the use of county-level mortality estimates to identify pressing local needs. Certified causes-of-death data, which are neither confidential nor restricted, were obtained from the vital statistics records of the Colorado Department of Public Health and Environment (CDPHE). CSM data included in the CDPHE data were as follows: major CVD (ICD-9; 390-448 and ICD-10; 100-178), chronic lower respiratory disease (ICD-10; J40-J47), asthma (ICD-9; 493 and ICD-10; J45), chronic obstructive pulmonary disease (COPD; ICD-9; 490-496 and ICD-10; J44), CBD (ICD-9; 430-438 and ICD-10; 160-169), and diseases of the heart (ICD-9; 390-398, 402, 404-429 and ICD-10; I00-I09, I11, I13, I20-I51). Data on the underlying cause of death were coded according to ICD-9 (1975-1977) and ICD-10 (1999-2015). The underlying cause of death was carefully chosen according to the coding and selection rules of the ICD in use at the time of death (i.e., ICD-9 for 1975-1977 and ICD-10 for 1999-2015). The purpose of this study was to evaluate the difference among the mean scores for CSM from 1975 through 2015 in all of the available cities and counties of residence in Colorado and to determine the contributions of gender, marital status, county of residence, and city of residence in CSM periods (prefracking period, i.e., 1975-1977, and postfracking period, i.e., 1999-2015) among adults ages 45-70 living in Colorado.

Hydraulic Fracturing Process

During hydrological fracturing, a rig usually drills deep into the gas-bearing shale formation and the well is lined with steel pipe (Taylor & Weltman-Fahs, 2013). After this, the well is sealed with cement at about 1,000 feet. This process prevents groundwater contamination. Then the well is extended horizontally to about 1,000 feet or more, where pores or holes are made through the steel casing and the rocks. Chemicals, sand, and water are coercively injected into the shale. This forceful or pressurized injection of chemicals, sand, and water makes the geologic or shale formation permeable and porous and allows for oil and gas escapes through the fissures. In turn, these chemicals, sand, and water are pushed out of the deep underground up to the surface (Taylor & Weltman-Fahs, 2013). The hydraulic fracturing process involves drilling a well, first vertically and then horizontally.

Background of the Study

It is vital for policymakers in states and counties to understand the CSM of their populations in other to make informed decisions.

In a prospective cohort study, Hu et al. (2017) investigated the risks for all-cause and cause-specific death associated with overweight and obesity in three large cohorts of health professionals in the United States. These authors used diagnostic codes from the eighth ICD revision (ICD-8) to classify deaths as due to CVD (including heart failure, coronary heart disease, stroke, and any other vascular causes; ICD-8 Codes 390 to 459 and 795), coronary heart disease (mainly ischemic heart disease [IHD]; ICD-8 Codes 410 to 414), stroke (ICD-8 Codes 430 to 438), cancer (ICD-8 Codes 140 to 239), respiratory diseases (ICD-8 Codes 460 to 519), and other causes (such as Alzheimer's disease, infectious diseases, and accidents). Study outcomes showed associations for CVD mortality (overweight HR, 1.21 [CI, 1.15 to 1.28]; obese I HR, 1.63 [CI, 1.52 to 1.74]; obese II HR, 2.74 [CI, 2.53 to 2.97]), particularly death due to coronary heart disease (overweight HR, 1.32 [CI, 1.21 to 1.44]; obese I HR, 1.97 [CI, 1.78 to 2.19]; obese II HR, 3.34 [CI, 2.95 to 3.79]).

Jin et al. (2015) determined the associations between extreme temperatures and population mortality for CVD, CBD, IHD, and hypertensive disease (HPD) in Beijing and Shanghai, China. Causes-of-death data were obtained from the Center for Public Health Surveillance and Information Service of China Centre for Disease Control and Prevention (China CDC) and were classified using the International Classification of Diseases, 10th Revision (ICD-10). The outcome of this research showed that all cause-specific cardiovascular mortality in Beijing had stronger cold and hot effects than those in Shanghai. In addition, the effects of extremely low and high temperatures differed by mortality types in the two cities. However, HPD in Beijing was inclined to both extremely high and extremely low temperatures. In Shanghai, people with IHD showed the greatest relative risk (RRs = 1.16, 95% CI: 1.03, 1.34) to extremely low temperature.

It is important to note that many diseases are impacted by weather changes but there have been sparse studies examining the association between some of these diseases and cause-specific mortality in low- and middle-income countries. Researchers conducted a study to estimate the effects of heat and cold days on total and cause-specific mortality in the Vadu Health and Demographic Surveillance System (HDSS) area in western India using a quasi-Poisson regression model allowing for overdispersion to examine the association of total and cause-specific mortality with extremely high (98th percentile, > 39°C) and low temperature (2nd percentile, < 25°C) from January 2003 to December 2012 (Ingole, Juvekar, Rocklov, & Schumann, 2015). Results of this study showed that heat was significantly associated with daily deaths from noninfectious diseases (RR = 1.57; CI: 1.18-2.10). Results also showed that there was an increase in the risk of total mortality for those 12-59 years of age on lag 0 day (RR = 1.43; CI: 1.02-1.99). Further, there was a high increase in total mortality among men at lag 0 day (RR = 1.38; CI: 1.05-1.83). In any case, these researchers did not find any short-term association between total and cause-specific mortality and cold days; rather, there was an immediate association between high temperatures and noninfectious disease mortality in a rural population located in western India during 2003-2012.

Azim, Linhart, Morrrell, Taylor, and Vithana (2014) investigated trends by age and sex through cause-of-death analysis for 1950-2006 in adults aged 15-64 years in Sri Lanka. Data on deaths were obtained from the WHO mortality database for 1950 to 2003, and the Department of Census and Statistics Sri Lanka for 1992-1995 and 2004-2006 where WHO data were unavailable. Adult deaths were categorized by age (15-34 and 35-64 years) and sex into infectious diseases; external causes; circulatory diseases; cancers; digestive diseases; respiratory diseases; pregnancy-related; ill-defined; and other causes. Results of this study showed that mortality declined in females aged 15-34 years by 85% over 1950-2006. Among males aged 15-34 years, the mortality decline was less at 47%, due to a rise in external-cause mortality during 1970-2000. There was 67% mortality decline among females aged 35-65 years over 1950-2006 and a decline in mortality in males aged 35-64 years. This study concluded that significant disparities were demonstrated in Sri Lankan cause-specific adult mortality by sex and age group for 1950-2006. Female mortality progressively declined while male mortality demonstrated periods of increase and stagnation.

Ameling, et al. (2015) aimed at determining relationships between long-term exposure to air pollution and nonaccidental and cause-specific mortality in the Netherlands. These researchers used an existing database on mortality, individual characteristics, residence history, neighborhood characteristics, and national air pollution maps based on land use regression (LUR) techniques for particulates with an aerodynamic diameter ≤ 10 μm (PM_{10}) and NO_2. Study outcomes showed that PM_{10} and NO_2 were associated with nonaccidental mortality (hazard ratio [HR] = 1.08; 95% CI: 1.07, 1.09 and HR = 1.03; 95% CI: 1.02, 1.03, respectively), respiratory mortality (HR = 1.13; 95% CI: 1.10, 1.17 and HR = 1.02; 95% CI: 1.01, 1.03, respectively), and lung cancer mortality (HR = 1.26; 95% CI: 1.21, 1.30 and HR = 1.10 95% CI: 1.09, 1.11, respectively). Overall, the study supported the conclusion that there was an association between PM_{10} and NO_2, and nonaccidental and cause-specific mortality.

With the Cox proportional hazard model, Bernstein et al. (2015) analyzed a statewide cohort of > 100,000 women from the California Teachers Study to estimate the association between pollutants and all-cause, cardiovascular, IHD, and respiratory mortality. The study showed statistically significant ($p < 0.05$) associations of IHD with $PM_{2.5}$ mass, nitrate, elemental carbon (EC), copper (Cu), and secondary organics and the sources of these pollutants: gas - and diesel-fueled vehicles, meat cooking, and high-sulfur fuel combustion. There was also a positive association between IHD and several Ultrafine components, including EC, Cu, metals, and mobile sources.

Cao et al. (2012) analyzed the relationship between $PM_{2.5}$ constituents and mortality. These authors collected daily mortality and daily concentration data on $PM_{2.5}$, organic carbon (OC), and EC from 2004-2008 and measured the concentrations of 15 elements from 2006-2008. Findings showed that huge contributors to $PM_{2.5}$ mass were OC, EC, sulfate, nitrate, and ammonium. The study showed significant associations of total, cardiovascular or respiratory mortality with OC, EC, ammonium, nitrate, chlorine ion, chlorine, and nickel for at least 1 lag day. In addition, nitrate showed stronger associations with cardiovascular mortality than $PM_{2.5}$ mass. However, the study concluded that $PM_{2.5}$ constituents from the combustion of fossil fuel may have an influence on the health effects attributable to $PM_{2.5}$ in Xi'an, where the study population lived. By narrowing the focus on zip codes and location monitors, I sought to distinguish $PM_{2.5}$ from fossil-fuel combustion from $PM_{2.5}$ from fracking.

Brauer et al. (2015) investigated associations between CSM and ambient concentrations of fine particulate matter (≤ 2.5 μm; $PM_{2.5}$), O_3, and NO_2 in a national cohort of about 2.5 million Canadians. The outcome of this research showed that $PM_{2.5}$, O_3, and NO_2 were associated with nonaccidental and cause-specific mortality in single-pollutant models. However, $PM_{2.5}$ exposure alone could not appropriately explicate the risk of mortality associated with exposure to ambient pollution. These researchers concluded that there were positive associations between several common causes of death and exposure to $PM_{2.5}$, O_3, and NO_2.

Bell et al. (2006) examined the risks of cardiovascular and respiratory hospital admissions associated with short-term exposure to $PM_{2.5}$ using daily counts of hospital admissions from 1999-2002 retrieved from the billing claims of Medicare enrollees. More recent studies have validated and furthered these findings (Coull, Kloog, Koutrakis, Ridgway, & Schwartz, 2013). $PM_{2.5}$ data were obtained from the U.S. Environmental Protection Agency (EPA) Air Quality System database. Per these authors, short-term exposure to $PM_{2.5}$ was associated with increases in hospital admission for cardiovascular and respiratory diseases. In the study, heart failure had a 1.28% (95% CI, 0.78%–1.78%) increase in risk per 10-$\mu g/m^3$ (10 micrograms per cubic meter of air) increase in same-day $PM_{2.5}$. Though this is not statistically significant, the implication is that at some point, when $PM_{2.5}$ exceeds > 10-$\mu g/m^3$, the increase in risk would be statistically significant. Ambient air quality guidelines as suggested by the WHO stand at an annual mean $PM_{2.5}$ concentration limit of 10$\mu g/m^3$ and 25$\mu g/m^3$ for the 24-hourly mean (Giannadaki, Lelieveld, & Pozzer, 2016). The clinical significance of this study shows that short-term exposure to $PM_{2.5}$ increases the risk for hospital admission for cardiovascular and respiratory diseases.

Anderson et al. (2013), in a study of short-term PM exposures, looked at the association between mortality effects of $PM_{2.5}$ constituents and concluded that regulating PM total mass may not be sufficient to protect human health. This study obtained data from the EPA Chemical Speciation Network data and National Center for Health Statistics from 2000-2005. The researchers analyzed organic carbon matter (OCM), EC, silicon, sodium ion, nitrate, ammonium, and sulfate, which constituted 79-85% $PM_{2.5}$ mass. Anderson et al. (2013) reported that interquartile range increases in OCM, EC, silicon, and sodium ion were associated with estimated increases in mortality. However, the study did not find any proof that associations between mortality and $PM_{2.5}$ or $PM_{2.5}$ constituents differed by season or region. Bonaparte et al. (2014) reflected on the inadequacy of protocols used in assessing compliance with ambient air standards and further submitted that modeling for air dispersion indicates the effect of local weather on individual exposures. This constituted a study limitation for b my study because I was not able to determine to what degree $PM_{2.5}$ produced in Greeley impacts air quality in Denver-Aurora and vice versa.

Bell et al. (2009) investigated the association between hospital admission for CVD and respiratory disease and the chemical components of $PM_{2.5}$ in the United States. This study illustrated that an interquartile range (IQR) increase in EC was associated with a 0.80% increase in risk of sameday cardiovascular admissions. The study found that ambient levels of EC and OCM from vehicle emissions, diesel engines, and wood burning were associated with the largest risk of emergency hospital admissions for CVD and respiratory disease in both single- and multiple-pollutant models. The study also found an association between OCM and respiratory admissions. For the cardiovascular outcome, all four estimates showed strong evidence of an association between $PM_{2.5}$ and hospital admissions on the same day.

Using a Poisson regression, Schwartz and Zanobetti (2009) examined the association of mean $PM_{2.5}$ and coarse particulate matter (PM) coarse with daily deaths. By applying city- and season-specific Poisson regression in 112 U.S. cities, these researchers examined the association of mean (day of death and previous day) $PM_{2.5}$ and PM coarse with daily deaths. The study found a 0.98% (95% confidence interval [CI], 0.75-1.22) increase in total mortality, a 0.85% (95% CI, 0.46-1.24) increase in CVD, a 1.18% (95% CI, 0.48–1.89) increase in myocardial infarction (MI), a 1.78% (95% CI, 0.96–2.62) increase in stroke, and a 1.68% (95% CI, 1.04–2.33) increase in respiratory deaths for a 10-$\mu g/m^3$ increase in 2-day averaged $PM_{2.5}$. Mortality data were obtained from 2001 through 2005 from each state in the country (except Hawaii and Idaho) through the National Center for Health Statistics (NCHS). In addition, researchers obtained data on $PM_{2.5}$ from the U.S. EPA Air Quality System Technology Transfer Network. Finally, this study concluded that there was an increased risk of mortality for all and specific causes associated with $PM_{2.5}$. This study, though generic for PMs, has practical significance in showing that thousands of early deaths per year could be avoided by reducing particle concentration.

Adgate, McKenzie, Newman, and Witter (2012) reported that cumulative cancer risks were 10 in a million and 6 in a million for residents living ≤ ½ mile and > ½ mile from wells, respectively, with benzene as the major contributor to the risks in rural Colorado. The authors suggested that the noncancer health impact from air emissions from unconventional gas (UNG) production is greater for people living near oil and gas wells. However, though they considered this a preliminary outcome that needs further research, the authors identified higher cancer risk for people living closer to wells than for people located further away from wells. Benzene was identified as the key contributor to the cancer risk.

Y. Liu et al. (2015), using case-crossover design, evaluated the relationship between daily mean concentrations of ambient air pollutants PM_{10}, SO_2, and NO_2 and daily CVD mortality in Wuhan, China. Their study found increases in NO_2 and SO_2

associated with daily CVD mortality. The study also found no statistically significant association for PM_{10}. The study also looked at gender-stratified and age-stratified analysis and found no statistical significance between pollutants and CVD mortality in females but only statistical significance among males when it comes to NO_2 and CVD mortality. On age-stratification analysis, study found that NO_2 was associated with daily CVD mortality among study participants over 65 years of age.

Brief Historical Background

Greeley is a city in Weld County, Colorado. Per the map of Weld County, Greeley is 15 miles east of Interstate 25, about 40 miles from Interstate 76, and 50 miles south of Interstate 80 in Wyoming (Upstate Colorado Economic Development, n.d.). Development of oil and gas dates to the 1970s in Greeley (City of Greeley, n.d.). Moreover, Weld County is the largest oil- and gas-producing county in the Denver-Julesburg Basin, and Greeley has been seen as a hotspot for hydraulic fracturing operations (American Petroleum Institute, 2008). The history of oil and gas development in Colorado dates back to 1862, when the first oil and gas well was drilled (Neslin, 2011).

Almost all of the active wells in Colorado have been fracked or fractured. In the year 2008, the number of applications for permits to drill oil and gas in Colorado rose to 7,870, compared to 2,003 in 1939 (Adgate et al., 2013). The Wattenberg Field covers an area of 978 square miles (2,530 km^2; Nelson & Santos, 2011). Current studies have shown that the Wattenberg Field of oil and gas sits on a 2,000-square-mile field (Carlson, Douglas, Goodwin, Knox, & Rein, 2014).

The Wattenberg Field is in the Denver-Julesburg (DJ) basin. Hydraulic fracturing activity began over three decades ago in the Wattenberg Field, which stretches about 50-

70 miles. In the DJ basin, which houses approximately 20,000 active wells, almost 11,000 of the active wells are in the Wattenberg Field alone (American Petroleum Institute, 2008). The wells in the Wattenberg Field, which has produced about 2.8 trillion cubic feet of natural gas, are between 6,000 and 8,000 feet in depth.

In Colorado, CVD is a leading cause of death (Colorado Department of Public Health and Environment, 2017). CVD encompasses heart attack, stroke, heart failure, hypertensive heart disease, and diseases of the arteries, veins, and circulatory system. Evidence shows that in Colorado in 2002, there were 6,403 deaths due to heart disease, 1,907 deaths due to stroke (the third leading cause of death), and 1,015 deaths due to heart failure, hypertensive heart disease, and diseases of the arteries, veins, and circulatory system (CDPHE, 2017).

Problem Statement

Jin et al. (2015) determined the associations between extreme temperatures and population mortality for CVD, CBD, IHD, and HPD in Beijing and Shanghai, China and reported that all cause-specific cardiovascular mortality in Beijing had stronger cold and hot effects than those in Shanghai. Equally vital is the fact that heat was significantly associated with daily deaths from noninfectious diseases (RR = 1.57; CI: 1.18-2.10; Ingole et al., 2015).

However, there has been no short-term association between total and cause-specific mortality and cold days; rather, there has been an immediate association between high temperatures and noninfectious disease mortality in a rural population located in western India during 2003-2012 (Ingole et al., 2015). Cause-of-death analysis for 1950-2006 in adults aged 15-64 years in Sri Lanka showed that mortality declined in females aged 15-34 years by 85% (Azim et al., 2014). Among males aged 15-34 years, the mortality decline was less at 47%, due to a rise in external-cause mortality during 1970-2000. There was a 67% mortality decline among females aged 35-65 years over 1950-2006 and a decline in mortality in males aged 35-64 years. This study concluded that significant disparities were demonstrated in Sri Lankan cause-specific adult mortality by sex and age group for 1950-2006.

With all of these indices, it has become pertinent for scholars to study gaps that may exist between CSM and environmental factors. Hydraulic fracturing contributes to human health issues. Hence, studies examining associations between and comparing differences in CSM from prefracking periods to postfracking periods are necessary.

Purpose of the Study

The purpose of this study was to evaluate the difference among mean scores for CSM from 1975 through 2015 in all of the available cities and counties of residence in Colorado (CO) and to determine the contributions of gender, marital status, county of residence, and city of residence in CSM periods (prefracking period, i.e., 1975-1977, and postfracking period, i.e., 1999-2015) among adults aged 45-70 years living in Colorado.

Nature of the Study

The research was a retrospective, quantitative study. A retrospective design was used to determine the difference among the mean scores for CSM from 1975 through 2015 in all of the available cities and counties of residence in Colorado, as well as to evaluate the contributions of gender, marital status, county of residence, and city of residence in CSM periods (prefracking period, i.e., 1975-1977, and postfracking period, i.e., 1999-2015) among adults aged 45-70 years living in Colorado. I obtained data from

CDPHE Health Statistics Data on Colorado resident deaths during the years 1975-1977 and 1999-2015 as registered with Colorado's Vital Statistics Program. The choice of this population was based on the limited amount of research evaluating CSM rates from the prefracking period (Pre-FP; 1975-1977) to the postfracking period (Po-FP; 1999-2015) among adults aged 45-70 years living in Colorado. Methods are explained in greater detail in Chapter 3.

Research Questions and Hypotheses

The following were the research questions and hypotheses:

Research Question 1: To what extent or degree are there differences in the mean scores for cause-specific mortality (CSM) from 1975 through 2015 in all of the available cities and counties of residence in CO?

Ha1. There is a significant difference among the mean scores for cause-specific mortality (CSM) from 1975 through 2015 in all of the available cities and counties of residence in CO.

$H_0 1$. There is no significant difference among the mean scores for cause-specific mortality (CSM) from 1975 through 2015 in all of the available cities and counties of residence in CO.

Research Question 2: To what degree are the contributions of gender, marital status, county of residence, and city of residence significant in the cause-specific mortality (CSM) periods (prefracking period, i.e., from 1975 through 1977, and postfracking period, i.e., from 1999-2015)?

Ha2. Gender, marital status, county of residence, and city of residence are significant factors in the cause-specific mortality (CSM) periods (prefracking period, i.e., from 1975 through 1977, and postfracking period, i.e., from 1999-2015).

$H_0 2$. Gender, marital status, county of residence, and city of residence are not significant factors in the cause-specific mortality (CSM) periods (prefracking period, i.e., from 1975 through 1977, and postfracking period, i.e., from 1999-2015).

The above purpose, research questions, and hypotheses are discussed further in Chapter 3.

Theoretical Base

To address the RQs of this study, a sound theoretical construct was needed. As such, for this epidemiological study, I used the social-ecological model of health (SEMH) construct to explain the RQs. The SEMH posits that there are several levels of influence on individual health outcomes or that some characteristics of the environment influence individual health outcomes (Brookmeyer, Harper, & Steiner, 2018; Hal, Kampen, & Nyambe, 2016). Such multilevel interrelated and integrated variables include individual or biological factors (age, sex, and marital status), cultural factors (city and county of residence), and environmental contingencies (policymaking, economy, governance, and cause of death).

I developed the framework in Figure 1 to illustrate the factors that may be used in evaluating the difference among the mean scores for CSM from 1975 through 2015 in all of the available cities and counties of residence in Colorado and determining the contributions of gender, marital status, county of residence, and city of residence in CSM periods (prefracking period, i.e., 1975-1977, and postfracking period, i.e., 1999-2015) among adults ages 45-70 living in Colorado.

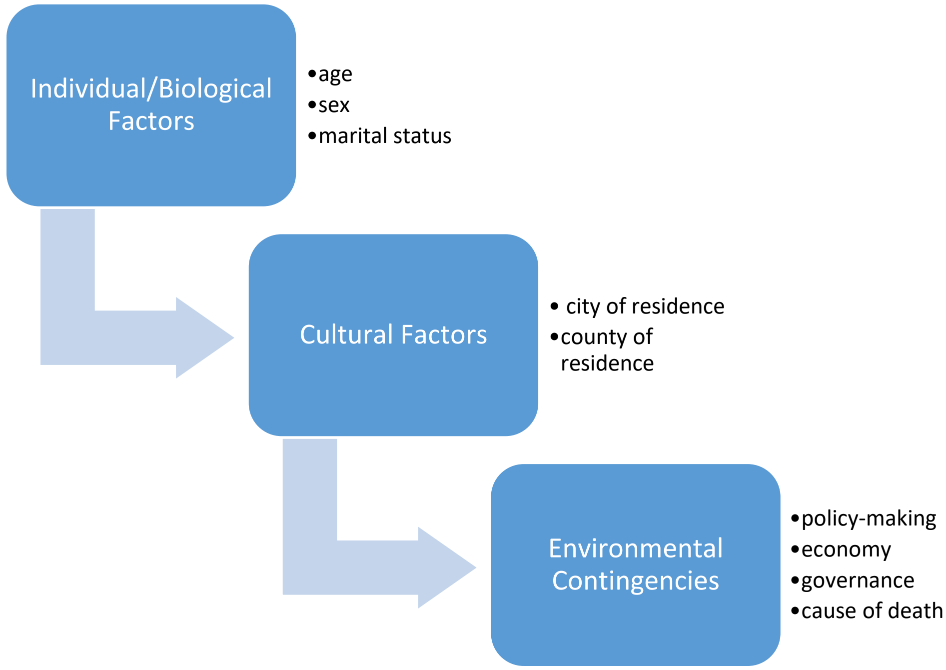

Figure 1. A review framework for applying the socioecological model constructs.

This study did not consider some of the above biocultural and environmental influences as confounding variables because doing so would have resulted in a larger investigation. The application of the SEMH offers explication to issues surrounding the determination of the difference among the mean scores of CSM. Additionally, the difference between CSM scores, Pre-FP and Po-FP, and gender, marital status, city and county of residence may help to identify factors to focus on during interventions (Baral, Beyrer, Grosso, Logie, & Wirtz, 2013; Cairns et al., 2010). Using this framework, I determined the difference among the mean scores for CSM from 1975 through 2015 in all of the cities and counties of residence in Colorado, and I evaluated the contributions of gender, marital status, county of residence, and city of residence in CSM periods (prefracking period, i.e., 1975-1977, and postfracking period, i.e., 1999-2015) among adults aged 45-70 living in Colorado.

In tandem with the SEMH is positivist theory. The positivist philosophical foundation is based upon determining and evaluating an inherent philosophy in which causes affect outcomes. Positivism posits that real problems exist that these are often driven by natural laws. This theoretical paradigm encompasses several forms, such as Comtean positivism, which emphasizes that knowledge comes from experience, experiment, and analysis; logical positivism; and behaviorism. Mostly associated with quantitative research, the positivist paradigm assumes a fixed, orderly reality that can be analyzed and evaluated using statistical tests.

Applying this theoretical construct or paradigm in conjunction with the SEMH framework, I aimed at discovering the general laws applicable to an understanding of the relationship between the phenomena of interest. Hence, the goal of this study using the SEMH and positivism was to determine the difference among the mean scores for CSM from 1975 through 2015 in all of the cities and counties of residence in Colorado, and to determine the contributions of gender, marital status, county of residence, and city of residence in CSM periods (prefracking period, i.e., 1975-1977, and postfracking period, i.e., 1999-2015) among adults aged 45-70 living in Colorado.

Definition of Terms

Age: Age was defined as all of the age-related data obtained from CDPHE regarding study participants aged 45-70 years in Denver-Aurora and Greeley from 1975-1977 and 1999-2015.

Air quality data: These are data collected at outdoor monitors. AirData come from the Air Quality System (AQS) database (EPA, 2017a).

Cause-specific mortality (CSM): For the purposes of this study, I defined CSM using the International Classification of Diseases (ICD), Tenth Revision (ICD-10) I00–I78), which includes deaths from diseases of the heart (ICD–10 Codes I00–I09, I11, I13, I20–I51); and CBD (I60–169; Klein & Miniño, 2010) from 1999-2015 and ICD-9 (from 1975-1977).

Cause of death (CoD): I defined CoD as major cardiovascular disease (MCD), chronic lower respiratory disease (CLRD), asthma, COPD, CBD, or diseases of the heart. CoD refers to the disease that starts the chain of events that ultimately leads to death (Jemal, Ma, Siegel, & Ward, 2015).

City of residence: I defined potential cities of residence as all of the available cities in Colorado based upon the CSM data obtained from the CDPHE.

County of residence: I defined potential counties of residence as all of the available counties in Colorado based upon the CSM data obtained from the CDPHE.

Criteria air pollutants: These are chemicals with the following pollutants: carbon monoxide (CO), lead, nitrogen oxides ($N0_x$, or NO and $N0_2$), ground-level ozone, particle pollution or particulate matter (coarse, PM_{10}, and $PM_{2.5}$), sulfur oxides (SO_2), and volatile organic compounds (EPA, 2016a; Finnbjornsdottir, Olafsson, Rafnsson, Thorsteinsson, & Zoega, 2013).

Fine particulate matter ($PM_{2.5}$) pollutant: Fine particles (Analitis et al., 2012) of 2.5 micrometers or less. Data were obtained from the EPA AirData website for two communities, Greeley and Denver-Aurora. HF occurs in Greeley but not in Denver-

Aurora. This database was defined by pollutant, year, city (as defined by Core Based Statistical Areas [CBSA] monitor site), and exceptional events (EPA, 2014a). Exceptional events were defined, in this study, as unusual or naturally occurring events that may impact air quality but are not reasonably controllable using techniques that tribal, state, or local air agencies may implement to attain and maintain National Ambient Air Quality Standards.

Fracturing, fraccing, fracking, or hydraulic fracturing: This is an operation where high-pressure fluid is pumped into reservoir rock to fracture the rock for inducing artificial permeability (Finkel & Law, 2016). Simply put, small cracks are created in deep underground geological formations to make way for oil and gas to flow up a well (Colorado Oil and Gas Conservation Commission, n.d.). It is also a way of tapping unconventional oil and gas reserves that are otherwise unreachable and inaccessible (Boudet et al., 2014). This is defined as a way of extracting oil and gas from deep underground by forcefully injecting water, sand, and chemicals to allow for underground porosity or create fissures in a tightly shaped shale formation (Adgate et al., 2012). Hydraulic fracturing involves a combination of two drilling techniques to drill shale formations vertically and laterally, in which a slurry of fluids is injected underground at very high pressure to crack open dense shale rock, allowing gas or oil to flow to the surface, where it is captured for use. It is a way of mining gas from deep strata.

Fugitive air emission: Emissions emanating from well-heads and silica sand that are produced from the mixing of hydraulic fracking fluids, the use of hydraulic fracturing machinery at a worksite or drill site, and accumulated effects from diesel trucks traveling to and from fracking sites (EPA, 2016c).

Year of death: In this study, defined as Pre-FP (1975-1977) or Po-FP (1999-2015).

Assumptions

The main assumption in this study was that the mortality data obtained from CDPHE Health Statistics Data were valid and reliable.

Limitations

Data on mortality were obtained from the CDPHE. I did not have control over the data that were provided. The CDPHE data on CSM did not precede the year 1975. Additionally, CSM data were not available from the CDPHE from 1978 to 1998. Furthermore, there may be other confounding variables that this study could not have considered. In addition, the results obtained from this study should not be generalized to the U.S. population; conclusions may only be inferred regarding the studied area. Furthermore, other factors such as socioeconomic status (SES), length of residence, occupation, race, smoking, alcohol consumption, and education that might be associated with CSM were not involved in this study.

Delimitations

This study determined the difference among the mean scores for CSM from 1975 through 2015 in all counties of residence in Colorado among residents aged 45-70, and the contributions of gender, marital status, county of residence, and city of residence in CSM periods (prefracking period, i.e., 1975-1977, and postfracking period, i.e., 1999-2015). This study did not take into consideration the association between the above variables outside the given or defined geographical boundaries.

Significance of the Study

Currently, there is a gap in knowledge regarding the difference among mean scores for CSM from Pre-FP to Po-FP and between CSM scores for the prefracking period (1975-1977) and postfracking period (1999-2015) in relation to gender, marital status, county of residence, and city of residence. With this inadequacy of research, public health practitioners and policymakers are ill equipped to determine and recognize health implications of hydraulic fracturing and to implement changes.

Positive Social Change

This study may support positive social change by doing the following:

1. Help researchers and public health practitioners to make decisions regarding CSM and gender, marital status, county of residence, and city of residence.
2. Assist researchers, state and county health departments, and communities in understanding whether there is any significant relationship between or difference in CSM Pre-FP and Po-FP.

Summary and Transition

In this introductory chapter, I presented a brief analysis of the current state of knowledge about comparing CSM Pre-FP & Po-FP. Definitions of relevant terms were presented. Additionally, the problem, research question, hypotheses, assumptions, and boundaries of the study were explained.

I described positive social changes that may result from comparing CSM Pre-FP and Po-FP. Additional explication and clarification of details are provided in subsequent chapters. This research may provide valuable information to state and county health departments, physicians, researchers, and communities. Future chapters, especially

Chapter 3, provide more in-depth understanding of how I compared CSM Pre-FP and Po-FP. Chapter 3 provides a discussion of the study methodology.

Chapter 2: Literature Review

Background, Introduction, and Description of the Literature Search

It is important for states and counties to have an accurate picture of CSM rates. Comparing CSM data Pre-FP and Po-FP entails a lucid and vivid accounting and clarification of all variables of interest that could possibly lead to the desired research outcome for the population of interest. In order to develop this necessary understanding, a review of a few studies on CSM and human health effects of hydraulic fracturing is presented. The resources used in this study were mainly published from 2013-2018. I conducted numerous searches using bibliographic databases, including MEDLINE with full text, PubMed, CINAHL Plus with full text, Science Citation Index Expanded (ISI Web of Science), Psychological Abstracts, Health Science databases, Educational Resources Information Center (ERIC), University Microfilms International (UMI) Dissertation Abstracts, Walden University Dissertation database, University of Colorado, Anschutz Campus Library database, the *American Journal of Public Health* search engine, Google Scholar, and the Environmental Health Perspectives website. Keywords such as *cause-specific mortality, cause-specific mortality and fracking, hydraulic fracturing and cardiopulmonary disease, fracking and cardiopulmonary disease, cause-specific mortality from hydraulic fracturing, cause-specific mortality from fracking, human health impacts of hydraulic fracturing, fine particulate matters and human health implications, fracking, hydraulic fracturing,* and *hydro-fracking* were applied in most of the literature searches.

For a lucid and basic understanding of the various variables in this study, salient keyword searches were conducted using authoritative websites. For example, the U.S. EPA, Centers for Medicare & Medicaid Services (CMS), Agency for Health Research and Quality (AHRQ), Centers for Disease Control and Prevention (CDC), and CDPHE websites were explored to examine current data on county- and city-level CSM and hydraulic fracturing. Given the richness of these websites, helpful data on the research's variables of interest were gathered. The observations below have been validated, and the points raised by these authors reflect the current state of knowledge on the subject.

The Dominant Themes

CSM has been associated with maximum overweight (Hu et al., 2017). In a prospective cohort study, Hu et al. (2017) investigated the risks for all-cause and cause-specific death associated with overweight and obesity in three large cohorts of health professionals in the United States. These authors used diagnostic codes from the ICD-8 to classify deaths as due to CVD (including heart failure, coronary heart disease, stroke, and any other vascular causes; ICD-8 Codes 390 to 459 and 795), coronary heart disease (mainly IHD; ICD-8 Codes 410 to 414), stroke (ICD-8 Codes 430 to 438), cancer (ICD-8 Codes 140 to 239), respiratory diseases (ICD-8 Codes 460 to 519), and other causes (such as Alzheimer's disease, infectious diseases, and accidents). Study outcomes showed association for CVD mortality (overweight HR, 1.21 [CI, 1.15 to 1.28]; obese I HR, 1.63 [CI, 1.52 to 1.74]; obese II HR, 2.74 [CI, 2.53 to 2.97]), particularly death due to coronary heart disease (overweight HR, 1.32 [CI, 1.21 to 1.44]; obese I HR, 1.97 [CI, 1.78 to 2.19]; obese II HR, 3.34 [CI, 2.95 to 3.79]).

Jin et al. (2015) determined the associations between extreme temperatures and population mortality from CVD, CBD, IHD, and HPD in Beijing and Shanghai, China. Causes-of-death data were obtained from the China CDC and were classified using the ICD-10. The outcome of this research shows that for all cause-specific cardiovascular mortality, Beijing had stronger cold and hot effects than Shanghai. In addition, the effects of extremely low and high temperatures differed by mortality types in the two cities. However, HPD in Beijing was inclined to both extremely high and low temperatures. In Shanghai, people with IHD showed the greatest relative risk (RRs = 1.16, 95% CI: 1.03, 1.34) to extremely low temperature.

Studies have determined that hospital mortality data can inform planning for health interventions and may also assist in the optimization of resource allocation (Gathara, 2017). This study contributed to the understanding of health system performance, the description of mortality and its variabilities, and analysis of the impact of clinical characteristics on inpatient mortality. Study data were obtained from the Clinical Information Network, which spanned 12 county hospitals from September 2013 to March 2015. Study conclusions showed that all-cause mortality is highly variable across hospitals and associated with clinical risk factors identified in disease-specific guidelines.

Some cohort studies in North America have shown an association between increased risk of mortality and long-term exposure to fine particles ($PM_{2.5}$). However, no such studies have been reported in China, where higher levels of exposure are experienced. As a result, researchers estimated the association between long-term exposure to $PM_{2.5}$ with nonaccidental and cause-specific mortality in a cohort of Chinese men (Yin, 2017). Using the Cox proportional hazards regression model, Yin et al. (2017) examined a prospective cohort study of 189,793 men 40 years of age or older during 1990-1991 from 45 areas in China. Results of this study showed that the mean level of $PM_{2.5}$ exposure during 2000-2005 was 43.7 μg/m^3 (ranging from 4.2 to 83.8 μg/m^3) and the mortality HRs (95% CI) per 10-μg/m^3 increase in $PM_{2.5}$ were 1.09 (1.08, 1.09) for nonaccidental causes; 1.09 (1.08, 1.10) for CVD; 1.12 (1.10, 1.13) for COPD; and 1.12 (1.07, 1.14) for lung cancer. Hence, this study concluded that long-term exposure to $PM_{2.5}$ was associated with nonaccidental, CVD, lung cancer, and COPD mortality in China.

Using prospective cohort data from the Third National Health and Nutrition Examination Survey (NHANES III), researchers determined all-cause and cause-specific mortality disparities by race, age, sex, and poverty status (2016). For this study, age, sex, and poverty income ratio-adjusted hazard rates were higher among Non-Hispanic Blacks (NHBs) than among Non-Hispanic Whites (NHW). In addition, income, education, diet quality, allostatic load, and self-rated health were among key mediators explaining NHB versus NHW disparities in mortality. NHBs had higher CVD-related mortality risk compared to NHW, which was explained by factors beyond SES. Conclusively, racial/ethnic disparities in all-cause and cause-specific mortality (particularly cardiovascular and neoplasms) were partly explained by sociodemographic, SES, health-related, and dietary factors, and differentially by age, sex, and poverty strata.

Though about 4.3 million deaths were attributable to exposure to household air pollution in 2012, studies in household coal use remain sparse (Kim, 2016). These researchers investigated the association of cooking coal and all-cause and cause-specific mortality in a prospective cohort of primarily never-smoking women in Shanghai, China. This study showed that ever-use of coal was associated with mortality from all causes [hazard ratio (HR) = 1.12; 95% confidence interval (CI): 1.05, 1.21], cancer (HR = 1.14; 95% CI: 1.03, 1.27), and IHD (overall HR = 1.61; 95% CI: 1.14, 2.27; HR for myocardial infarction specifically = 1.80; 95% CI: 1.16, 2.79) when compared with never-use of coal. Moreover, the risk of cardiovascular mortality increased with increasing duration of coal use compared with the risk in never users, and the association between coal use and IHD mortality diminished with increasing years since cessation of coal use.

It is important to note that although many diseases are impacted by weather changes, there have been sparse studies examining the association between some of these diseases and CSM in low- and middle-income countries. Researchers conducted a study to estimate the effects of heat and cold days on total and cause-specific mortality in the Vadu HDSS area in western India using a quasi-Poisson regression model allowing for overdispersion to examine the association of total and cause-specific mortality with extremely high (98th percentile, > 39°C) and low temperature (2nd percentile, < 25°C) from January 2003 to December 2012 (Ingole, Rocklov, Juvekar, & Schumann; 2015). Result of this study showed that heat was significantly associated with daily deaths from noninfectious diseases (RR = 1.57; CI: 1.18-2.10). Results also showed that there was an increase in the risk of total mortality in the age group 12-59 years on lag 0 day (RR = 1.43; CI: 1.02-1.99). Additionally, there was a high increase in total mortality among men at lag 0 day (RR = 1.38; CI: 1.05-1.83). In any case, these researchers did not find any short-term association between total and cause-specific mortality and cold days; rather, there was an immediate association between high temperatures and noninfectious disease mortality in a rural population located in western India during 2003-2012.

Vithana et al. (2014) investigated trends by age and sex through cause-of-death analysis for 1950-2006 in adults aged 15-64 years in Sri Lanka. Data on deaths were obtained from the World Health Organization (WHO) mortality database for 1950 to 2003, and the Department of Census and Statistics Sri Lanka for 1992-1995 and 2004-2006 where WHO data were unavailable. Adult deaths were categorized by age (15-34 and 35-64 years) and sex into infectious diseases; external causes; circulatory diseases; cancers; digestive diseases; respiratory diseases; pregnancy-related; ill-defined; and other causes.

Results of this study show that mortality declined in females aged 15-34 years by 85% over 1950-2006. Among males aged 15-34 years, the mortality decline was less at 47%, due to a rise in external-cause mortality during 1970-2000. There was a 67% mortality decline among females aged 35-65 years over 1950-2006 and a decline in mortality in males aged 35-64 years. This study concluded that significant disparities were demonstrated in Sri Lankan cause-specific adult mortality by sex and age group for 1950-2006. Female mortality progressively declined while male mortality demonstrated periods of increase and stagnation.

Using a time-stratified case-crossover methodology, Zeka, Browne, McAvoy, and Goodman (2014) assessed the relationship between cold temperature and daily mortality in the Republic of Ireland (ROI) and Northern Ireland (NI). These researchers also examined any differences in population responses between the ROI and NI from 1984 through 2007. Zeka et al. found that in the ROI, the impact of cold weather in winter persisted up to 35 days, with a cumulative mortality increase for all causes of 6.4% (95% CI = 4.8%-7.9%) in relation to every 1°C drop in daily maximum temperature, similar increases for CVD and stroke, and twice as much for respiratory causes. However, in NI, these associations were less pronounced for CVD causes. In conclusion, the study findings indicated strong cold weather-mortality associations in Ireland; these effects were less persistent, and for CVD mortality, smaller in NI than in the ROI.

Kaiser (2007) looked at the impact of the 1995 Chicago heat wave on all-cause and cause-specific mortality. Using Poisson regression, Kaiser et al. modeled excess mortality and mortality displacement over a 50-day period, but with specific focus on the day in which the heat wave temperature peaked. The study estimated that there were 692 excess deaths from June 21, 1995, to August 10, 1995. Of these 692 excess deaths, 26% were owing to mortality displacement. RR for all-cause mortality on the day with peak mortality was 1.74 (95% confidence interval = 1.67, 1.81). In the end, these scholars concluded that the 1995 Chicago heat wave enormously impacted all-cause and cause-specific mortality, but mortality displacement was limited.

Further studies have examined the relationship between CSM and coffee drinking. For instance, Saito (2015) analyzed the association between habitual coffee drinking and mortality from all causes, cancer, heart disease, CBD, respiratory disease, injuries, and other causes in a large-scale, population-based cohort study in Japan. Researchers studied 90,914 Japanese persons aged between 40 and 69 years without a history of cancer, CBD, or IHD at the time of the baseline study using the Cox proportional hazards regression model.

The outcome of this study showed an inverse association between coffee intake and total mortality in both men and women. Thus, coffee was inversely associated with mortality from heart disease, CBD, and respiratory disease. Saito et al. (2015) opined that the habitual intake of coffee is associated with lower risk of total mortality and three leading causes of death in Japan.

Freedman, Park, Abnet, Hollenbeck, and Sinha (2012) examined the association of coffee drinking and total and cause-specific mortality among 229,119 men and 173,141 women in the National Institutes of Health–AARP Diet and Health Study aged 50 to 71 years at baseline. Results showed that coffee appeared to be inversely associated with major causes of death in both men and women, such as heart disease, respiratory disease, stroke, injuries and accidents, diabetes, and infections. However, there was no significant association between coffee consumption and deaths from cancer in women. The study also showed a borderline positive association in men: Among 13,402 deaths from cancer, 880 deaths were reported among men who drank 6 or more cups of coffee per day (hazard ratio for the comparison with men who did not drink coffee, 1.08; 95% CI, 0.98 to 1.19; $P = 0.02$ for trend).

With regard to ambient air pollutants, $PM_{2.5}$ is associated with increased mortality in most cities in the United States (Cao et al., 2012; Dockery et al., 1993; Levy, Diez, Dou, Barr, & Dominici, 2012). Per Levy et al; 2012), 11 all-cause time-series mortality estimates yielded an estimated 1.2% increase in mortality per 10-$\mu g/m^3$ increase in $PM_{2.5}$ concentrations, and individual constituents yielded estimates of 0.4%, 1.4%, 2.8%, and 2.7% per 10-$\mu g/m^3$ increase in EC, organic carbon matter, sulfate, and nitrate concentrations, respectively. Statistically significant association existed between ambient pollution and mortality rate after adjusting for cigarette smoking among study participants (Dockery et al., 1993). With the goal of evaluating the role or impact of ambient air pollution on mortality while putting into consideration confounding variables such as sex, age, educational level, occupational exposure, body-mass index, and smoking status, Dockery et al., (1993) suggested, in their retrospective cohort study, that mortality was highly associated with fine, inhalable, and sulfate particles.

Looking at the difference in air pollution level equal to that between the most polluted and the least polluted cities and with inhalable, fine, and sulfate particles, Dockery et al. (1993) found that the adjusted rate ratios were almost equal at 1.27 (95% CI, 1.08-1.48), 1.26 (95% CI, 1.08-1.47), and 1.26 (95% CI, 1.08-1.47) for inhalable particles, fine particles, and sulfate particles. Moreover, the mixture of combustion products along with constant movement of trucks to and from fracking sites contributed to increased levels of sulfate and fine particulate air pollution (Dockery et al., 1993). Thus, the findings of numerous studies indicate that there is a link between particulate air pollution and lung function and cough, shortness of breath, and asthma (Dockery et al., 1993).

The six United States cities study, which reported on a 14- to 16-year prospective follow-up of > 8,000 adults living in six U.S. cities, found an association between daily mortality counts and $PM_{2.5}$. There was PM-mortality statistical significance between daily mortality counts and air pollution in the study conducted on the eight largest Canadian cities. Mostly, as findings in studies have shown, there has been increasing concentration of fine particulate matter, especially $PM_{2.5}$ components, in cites or locations across the United States where oil and gas activities or development seem to occur

(Petron et al., n.d.). Furthermore, ambient concentration has been associated with 1.3% (95% CI, 0.6%-2%) increase in myocardial infarction risk in a study using 21 United States cities with >300,000 myocardial infarction events.

Benzene (C_6H_6) and volatile organic compounds (VOCs) can be released at any time during unconventional gas development (UGD) or oil and gas processing, production, and exploration (Petron et al., 2012). Approximately 46% of the Denver and Colorado Northern Front Range (DNFR) Federal Non-Attainment Areas' (NAAs') VOC emissions were attributed to oil and gas emissions in 2006. Following that, in 2007, the coalition of the Independent Petroleum Association of Mountain States (IPAMS) and Western Regional Air Partnership (WRAP) built a process-based inventory of total VOC sources involved in oil and gas exploration and production.

When compared to North East (NE) wind sector data (r2 = 0.69), C_6H_6 winter correlation is highest for the South and West wind sectors from Boulder Atmospheric Observatory (BAO) samples (r2 = 0.85 for S; 0.83 for W). Sociodemographics, seasonality, and community area are among the microenvironmental attributes that define individual's exposure to air pollution (Delgado-Saborita, Alama, Pollitta, Starka, & Harrison, 2009). For compounds such as benzene and toluene, home concentration accounts for 60-75% of the variance in personal exposure (PE) while accounting for 40-55% for xylenes and pyridine. Because people spend about 62% of their time in the home microenvironment, home microenvironment affects PE. Air pollutants such as benzene, VOCs, and PMs have been associated with low birth weight and preterm birth (McKenzie et al., 2014). For example, there was 5.3 times likelihood of prevalence of neural crest malformations in children born to 298 mothers who were exposed to benzene compared to children born to parents not exposed to benzene (95% CI: 1.4, 21.1).

Regarding odd ratios, an odd ratio of 1.3 for highest tertile (95% CI: 1.2, 1.5) as prevalence for congenital heart defects (CHD) and odds ratio of 2.0 (95% CI: 1.0, 3.9) as prevalence for neural tube defects (NTDs) increased with exposure to tertiles. Findings in some studies have shown that pre-mature deaths due to $PM_{2.5}$ have been approximated to be between 63,000 to 88,000, and nitrogen oxide (NOx) and VOCs, when combined, forms $O_{3,}$ and leads to important ingredients of $PM_{2.5}$ known as nitrate and secondary organic aerosols (Grabow et al., 2009; Ebersviller et al., 2011). Recognized as criteria air contaminants (CACs) or pollutants are carbon monoxide (CO), lead, nitrogen oxides ($N0_x$, or NO and $N0_2$), ground-level ozone, particle pollution or particulate matter (coarse, PM_{10}, and $PM_{2.5}$), sulfur oxides (SO_2), and volatile organic compounds (EPA, 2014b; Finnbjornsdottir et al., 2013). Particle pollutants or the coarse, PM_{10}, and $PM_{2.5}$ are commonly known to pose widespread health threat and frequent emergency department (ED) visits (EPA, 2016b).

Daily mortality has been associated with $PM_{2.5}$. Outcome of studies have demonstrated that increased count of day-to-day mortality is directly linked to particulate matters with an aerodynamic size under 2.5 µm (Dockery, Laden, Neas, & Schwartz, 2000). For example, a 10 $\mu g/m^3$ increase in $PM_{2.5}$ from mobile sources accounted for a 3.4% increase in daily mortality (Dockery et al., 2000). Here, there is greater propensity for fine particles to lodge or be deposited in the periphery of the lung and inner lining of the arteries (in respiratory bronchioles and alveoli; Flanders, 2005; Schwartz et al., 1996) leading to deaths from ischemic heart disease, chronic obstructive pulmonary disease

(COPD), and atherosclerosis. Results of some studies have suggested also that long-term exposure to fine particulate matter could be associated with cardiovascular incidents in men (8%–43% increase per 10-$\mu g/m^3$ increment) and not in women (Burnett et al., 2014) and like the Harvard Six Cities Study where each 10-$\mu g/m^3$ increment in ambient $PM_{2.5}$ was associated with 26–28%. This finding was associated and consistent with rural $PM_{2.5}$ and men who were farmers. However, reduction in $PM_{2.5}$ exposures could have a concurrent effect in mortality risk (Dockery, Laden, Schwartz, & Speizer, 2006; Coull et al., 2016).

Fugitive air emissions are associated with the hydraulic fracturing process (Adgate et al., 2012). Cumulative cancer risks accounted for 6 in a million for residents >½ from wells and 10 in a million for residents ≤ ½ mile from wells. On the other hand, benzene (84%) and 1,3-butadiene (9%) were the primary contributors to cumulative cancer risk for residents >½ mile from wells. As suggested, fugitive air emissions could emanate from well-heads, silica sand produced during the mixture of fracking fluids, hydraulic fracturing machineries at the worksite or drill site, and accumulated effects from diesel trucks to and from fracking site (American Public Health Association, 2014). Not only that fugitive air emission from hydro-fracking activities constitute occupational hazards, they also add to the local, regional, and national air pollution.

The petroleum hydrocarbons, benzene, ethyl benzene, toluene, and xylene (BTEX) could result into cancer, nonlymphocytic leukemia, anemia, immunological defects, neural tube disorders, eye, nose, and throat irritation, difficulty in breathing, and impairments of the nervous system (Adgate et al., 2012). Metals from particulate matters (PM) are air toxics or hazardous air pollutants and constitute health risk (Charrier, Hafner, McCarthy, & O'Brien, 2009). For instance, concentrations of benzene, arsenic, ethylene oxide, and formaldehyde were above the cancer risk level or benchmark of 10^{-6}.

Chemicals, radionuclides, odors, traffic, noise, seismic operations, and explosions from gas handling are some of the severe hazards associated with UNGD (Fryzek, Garabrant, Jiang, & Pastula, 2013). A before and after drilling analysis for number of cancer found a standardized incidence ratio (SIR) of 0.94; 95% CI, 0.90 to 0.99 and SIR = 1.02; 95% CI, 0.98 to 1.07, respectively. It would have been an interesting study to calculate SIRs relative to CPD incidence temporal trend data and assessing correlation temporal trends in air quality data across the period of this study period but doing this will result into a much larger investigation and could be explored in future studies.

Children are more susceptible or prone to carcinogenic exposure because of chemicals emitted during hydraulic fracturing activities. However, as some studies have suggested, childhood cancer, leukemia, and central nervous system breakdown and tumor did not increase after hydraulic fracturing drilling (Fryzek et al., 2013). SIR for leukemia before drilling = 0.97 [95% CI, 0.88 to 1.06]; SIR for leukemia after drilling = 1.01 [95% CI, 0.92 to 1.11]). In certain HF sites, about 1700 diesel trucks deliver up to 5 million gallons of water needed to fracture a well and another 750 diesel trucks deliver approximately 1.5 million pounds of proppant in a couple of weeks. Such exacerbates the cumulative increase of 6-10 million incidences of lifetime cancer risk for benzene.

Indoor and outdoor particulate matter with aerodynamic diameter of 2.5 ($PM_{2.5}$) have been exhaustively studied (Chow et al., 2008; Al-Maskari et al., 2012). In the presence of domestic animals, personal $PM_{2.5}$ concentrations would increase by 12% (95% CI ¼ 1–25%). With the presence of molds in homes, there would be an increase of

27% (95% CI ¼ 11–48%) in $PM_{2.5}$ concentrations. During cooking, $PM_{2.5}$ individual personal exposures would increase by 27% (CI ¼ 12–43%). And in houses where aerosol was used, personal $PM_{2.5}$ concentrations would increase by 17% (CI ¼ 4–31%) (Chow et al., 2008).

Household SO_2 concentrations in the range of 0.010–0.507 ppm, or 26.2–1327 $\mu g/m^3$ were 1.79-4.6 times likely to report symptoms of asthma. But association between outdoor SO_2 and respiratory symptoms have shown different outcomes; no evidence in SO_2 concentrations ranging from 0.0001 to 0.0166 ppm and evidence was found in increased wheezing (OR 1.17; 95% CI: 1.01, 1.35) per 10-$\mu g/m^3$ increase in SO_2 in a cross-sectional study of 3,045 children (Al-Maskari et al., 2012). Outdoor sources of ambient air pollution might contribute to indoor concentrations of air pollutants (Chen, Hsieh, & Yang, 2005). Levels of BTEX (the acronym for benzene, toluene, ethylbenzene, and xylene) were found to be two times higher at night at market sites in Southern Taiwan (Chen, Hsieh, & Yang, 2005).

Profound and paramount sources of personal exposure to $PM_{2.5}$ are cooking, proximity to smokers, and vacuuming or dusting (Chow et al., 2008). For example, being present during cooking would increase personal $PM_{2.5}$ exposures by 27% (CI ¼ 12–43%). Indoor sources, as well as outdoor sources, of $PM_{2.5}$ have been found to be associated with human health conditions, especially with individuals with pre-existing health conditions like COPD (Chow et al., 2008).

In line with the above viewpoints, studies have expressed the importance of evaluating and assessing the level of $PM_{2.5}$ exposures among highly susceptible sub-populations (Farhood, Forouzanfar, Hosseinpoor, Naieni, & Yunesian, 2005; Box et al., 2003). As seen in Type 2 diabetes mellitus patients, exposure to $PM_{2.5}$ resulted into increase in adipose tissue as exemplified by an increase in F4/80 macrophages and a pro-inflammatory ‘‘M1 phenotype’’ typified by TNF-α, IL-6 and a decrease in IL-10, MgI1 gene expression (Box et al., 2003). Seasonal variations could contribute to $PM_{2.5}$ impact on this population i.e. those in the susceptible bracket. Studies have shown that life stage, genetic polymorphisms, preexisting cardiovascular and respiratory diseases, and SES, may increase the susceptibility of populations to PM-related health effects (Brown et al., 2010).

For instance, there has been evidence of increased CVD hospital admissions among older adults compared with all ages or ages < 65 years and cardiovascular and respiratory hospitalization, and death in adults’ ≥ 75 years of age when exposed to $PM_{2.5}$ (Brown et al., 2010). Exposure to $PM_{2.5}$ has been associated with risk of hospitalization for patients with Parkinson’s disease (3.23%, 1.08, 5.43) and diabetes (1.14% increase, 95% CI: 0.56, 1.73 for a $10 \mu g/m^3$ increase in the 2 days’ average) (Dominici, Schwartz, Wang, & Zanobetti, 2014). Though thorough clarity has been proffered with regards to the impact of ambient pollution on CBD, studies have suggested a relationship between fine particulate matters ($PM_{2.5}$) and rise in blood pressure (BP), decreased brachial artery diameter, increased C-reactive protein and atherosclerosis (Dominici et al., 2014). The above finding is in consonance with another study that assessed the association between long-term exposure to $PM_{2.5}$ and diabetes mortality.

This study concluded that there is a link between long-term exposures to $PM_{2.5}$ and a significant increase in diabetes-related mortality (Brook et al. 2013). About $10 \mu g/m^3$ increase in long-term $PM_{2.5}$ exposures, among 2.1 million Canadians, has the chances of increasing the risk for non-accidental and ischemic heart disease deaths by 15 and 31%, correspondingly. Elderly populations with CVD are prone to hazardous health effects from $PM_{2.5}$. Associations were found between fine particulate matter-associated changes in autonomic nervous system control of heart rate and ventricular re-polarization (Cascio et al., 2010). With an increase in $10 \mu g/m^3$ $PM_{2.5}$, there was a significant association between $PM_{2.5}$ and Interleukin (IL)-6 and tumor necrosis factor alpha. To add, studies have equally revealed that obese populations are highly vulnerable to indoor $PM_{2.5}$ and NO_2. This is particularly true with children who have asthma and are living in cities or urban locations (Aloe et al., 2013). In the absence of a cold, 10-fold increase in $PM_{2.5}$ level could be associated with a 3- to 5- fold increase in the odds of cough among overweight and obese populace. In this vein, due to the relationship between $PM_{2.5}$ and respiratory symptoms, it has been recommended by several investigators that being overweight and increased indoor pollution among children living in urban areas could lead to asthma morbidity and mortality among this population.

Therefore, among African-American children ages 5-17, there have been heightened chances that being obese could make them susceptible to pulmonary effects because of exposure to indoor $PM_{2.5}$ and NO_2 (Aloe et al., 2013). Thus, other studies have suggested an association between exposure to $PM_{2.5}$ and other air pollutants and type 2 diabetes mellitus (DM; Harkema, Liu, Rajagopalan, Sun, & Ying, 2013). Studies, even adjusting for possible confounders like age, gender, body mass index (BMI), waist circumference, physical activity, and healthy eating index, shows that there is a relationship between $PM_{2.5}$ and diabetes prevalence (Harkema et al., 2013). Hence, insulin sensitivity could be worsened via exposure to ambient particulate matters.

Moreover, populations exposed to high levels of $PM_{2.5}$ could have distorted ventricular repolarization and systemic inflation which are often linked to insulin resistance (Cascio et al., 2010). Using a 24-hour electrocardiogram (ECG) time domain parameters, the mean number of times an hour in which change in successive normal sinus (NN) interval is more than 50 ms (Goldberger, Goldsmith, Henry, Mietus, & Peng, 2002) (pNN50) increased with a lag of 2 and 3 days, and root-mean-square of successive differences (RMSSD) increased with a lag of 3 days showing that there was a $PM_{2.5}$ association.

Ischemic heart disease (IHD) has also been linked to exposure to $PM_{2.5}$ (Balluz et al., 2007; Brown et al., 2014). People exposed to higher level of $PM_{2.5}$ air quality index (AQI) have greater chances of ischemic heart disease (adjusted OR 5 1.72, 95% CI 1.11, 2.66). According to Balluz et al., (2007), prevalence of study respondents exposed to annual mean $PM_{2.5}$ AQI increased from 6.9% (>50) as the cutoff value increased (7.2% for >55 and >60). Populations exposed to elevated levels of $PM_{2.5}$ have been found to have health issues relating to heart and lungs. As plaques build up in the arteries, the arteries narrow, and less blood is supplied to the heart. As the most common heart concern as it pertains to long-term exposure to fine particulate matters, ischemic heart disease, otherwise called coronary artery disease (CAD) or coronary heart disease (CHD), may be prevalent in communities with low SES, environmental concerns, and poor lifestyles. IHD has been associated with outdoor air pollution and physical inactivity (Brauer, Hankey, & Marshall, 2012). IHD mortality due to exposure to $PM_{2.5}$ was approximately 30 deaths/100,000/year), but the difference between neighborhoods was 9 more IHD deaths/100,000/year in high- vs. low-walkability. Notably, researchers have also found that certain particles emitted during industrial activities and the burning or combustion of fossil fuel is related to an increased risk of IHD or CAD (Burnett et al., 2009). Relative risk (RR) for fossil fuel combustion has been estimated to be above 1.0 for IHD deaths. Long-term occupational exposure to $PM_{2.5}$ has also been associated with incidents of mortality and morbidity among patients with ischemic heart disease (Brown et al., 2014). Hazard ratio (HR) for $PM_{2.5}$ and incident IHD went up in the fabrication department of a manufacturing process to 1.5 at 1.25 mg/m^3 and was statistically significant throughout most of the exposure range but in the smelters, it rose to an HR of 1.5 at 9 mg/m^3, though only statistically significant around the mean.

Thus, the global fraction of death due to $PM_{2.5}$ for all cause for IHD has been estimated to be about 17.5% as compared to 12.1% for cardiopulmonary disease and 16.8% for lung cancer (Burnett et al., 2012). Furthermore, studies have also shown that there is an association between hospitalization or hospital admissions for IHD and $PM_{2.5}$ (Chiu, Peng, Wu, & Yang, 2013). For example, considerable number of IHD admissions were significantly associated with $PM_{2.5}$ on both warm (> 23°C) and cool days (< 23°C), with an interquartile range increase associated with a 12% (95% CI = 10%–14%) and 4% (95% CI = 2%–6%) increase in IHD admissions, respectively. Similarly, association between fine particulate matters with aerodynamic dimension of about 2.5 ($PM_{2.5}$) and heart failure has been studied (Carll et al., 2010). A 10$\mu g/m^3$ increase $PM_{2.5}$ exposures were related to heart failure by 1.28 (95% CI 0.78% to 1.78%). Evidence has shown that a 14-day lagged average of 10$\mu g/m^3$ $PM_{2.5}$ was associated with a 13.1% (95% confidence interval 1.3 to 26.2) increase in HF admissions. In addition, a 10$\mu g/m^3$ elevation in concurrent-day $PM_{2.5}$ was associated with a 1.28% (95% CI 0.78% to 1.78%) increase in heart failure admissions. In the presence of hypertension, a 10μg/m^3 rise in $PM_{2.5}$ was associated with an adjusted OR of 1.05 (CI 1.00 to 1.10).

The key source of most of these exposures has been seen to be the 30%-70% flow back fluid containing fracking chemicals (American Public Health Association, 2012). Another relevant source of air pollution from hydraulic fracturing activity that could also impact animal health emanate from diesel engines of trucks used to haul heavy duty equipment and oil and gas drilling tools (American Public Health Association, 2012).

The Marcellus and Utica shales, underlying the Appalachian region, are well known for multi-diversity of animal, mammals, and crustacean species including salamanders, stream fishes, freshwater mussels, and crayfishes (Gillen & Kiviat, 2012). Most of these species are confined to a given region, thereby increasing their chances of extinction. With increase in fracking and the occupation of lands for drill pads, pipelines, truck traffics, and multiple other uses, there is greater propensity for extinction of these species of animals, mammals, and crustaceans. Studies have concluded that dispersal of terrestrial salamanders could be decreased by approximately 97% when multiple roads are created (Gillen & Kiviat, 2012). Per Taylor & Weltman-Fahs (2013), about 26% of brook trout habitat intersects with the Marcellus Shale.

Dissolved solids and high concentration of metals from hydraulic fracturing has been associated with diminishing growth of brook trout. Chemical contamination and air pollution from fracking activities could impact the fecundity of brook trout (Taylor & Weltman-Fahs, 2013). Species endangerment, loss and disintegration of habitat, and wildlife mortality, morbidity, and invasion have equally been attributed to large scale oil and gas development (Jones & Pejchar, 2013). Oil and gas accounted for 70.9% habitat loss per plot, 75.5% biomass carbon loss per plot, and 62% of increased fragmentation. Studies have suggested a direct and indirect association between energy development and its effects on ecosystem and biodiversity, especially in Colorado and Wyoming axis (Jones & Pejchar, 2013). Out of the 365 oil and gas wells used in the Jones and Pejchar (2013) study, oil and gas resulted in almost 15.8 tons (+/– 2.98 SE) of carbon lost per plot and approximately 711,228 gallons of water per plot is consumed from oil and gas production annually. Unconventional natural gas development contributed to a monumental degree to the loss of wildlife, decrease in aquatic habitat, and fragmentation of habitat.

There is some evidence of association between UNGD and human health concerns. A study conducted among study population of residents of the Marcellus Shale region indicated a huge concern about health implications linked with hydraulic fracturing or fracking (Emmet, Green-McKenzie, Powers, Propert, & Saberi 2014). Out of the study's 72 respondents, 22% perceived UNGD as a health concern, 13% attributed medical symptoms to UNGD exposures, and 42% attributed some of their medical symptoms to UNGD. Data were gathered through survey questionnaire and concluded that residents have some health concerns in relation to unconventional natural gas development (UNGD). Further studies suggested a relationship between UNGD and perceived health effects. This self-reported health outcome research identified approximately 59 unique health impacts and 13 stressors to Marcellus Shale development (Christen et al., 2013).

In summary, outcome of many studies have shown association between $PM_{2.5}$ and human health concerns such as debilitating lung function, cancer, skin reactions, heart diseases, and headaches. In the United States of America, for instance, fine particulate matters have been linked with increased mortality rate (Barr et al., 2012). This, increased mortality rate and exposure to fine particulate matters, has global impacts as well (Cao et al., 2012). In addition, long-term exposure to ambient fine particulate matters affect the human pathophysiological pathways (Dockery & Pope 111, 2006). With large deposit of fine particulate matters in metropolitan populations and places where oil and gas production occur, there have been unprecedented concerns about human health conditions (Frost et al., 2012).

These concerns mainly arise from incidences and possibilities of fine particulate matters lodging in the periphery of human lungs. To add, fugitive air emissions from hydraulic fracturing could lead to anemia, immunological conditions, difficulty breathing, and breakdown of the human nervous system (Adgate et al., 2012). In sub-populations, especially people with preexisting cardiovascular and respiratory health conditions, exposure to $PM_{2.5}$ have been linked to the exacerbations of these human health diseases (Brown et al., 2010). Accordingly, SES could increase susceptibility to particulate matters-related health situations.

Relevance of Theoretical Concept

In the 1970s, Urie Bronfenbrenner developed the SEMH theory (Eriksson, Ghazinour, & Hammarström; 2018). At the core of the SEMH was the fact that that humans live in, and are exposed to various environments and situations, and these environments or situations could likely affect their behavior and beliefs (Brown, 2015). Bronfenbrenner's theory consists of four different systems: the microsystem, the mesosystem, the exosystem, and the macrosystem. The microsystem was described as the interacting relationships between the individual and the immediate environment. For the mesosystem, Bronfenbrenner saw it as the interrelations between major settings containing an individual. The exosystem comprised of the social structures or the major institutions of the society. Finally, the macrosystem was seen in the light of policies, laws and regulations, and equally all the unprinted rules and norms. In this study, SEMH will be used to guide policymakers, create or increase awareness of the outcome of this study in communities, among organizations, and individuals.

Chan, Loke, and Ma (2017) used the social-ecology model to provide a wholesome understanding of the health seeking behaviors of sex workers and their access to health care services. In this review study, it was founded that the SEMH could be used to categorize the variables which influence health-seeking behaviors of sex workers. As such, this study used SEMH to identify such variables as intrapersonal, interpersonal, institutional, community, and policy level factors. This, in other words, shows that something needs to be done about these barriers.

Elder et al. (2017) noted that the hallmark of ecological theory pertaining to specific health risks and behaviors are environmental and policy-making. Thus, in their study, these researchers used 2 environmental settings, the school and the community, to examine the effectiveness of interventions to reduce the decline of physical activity in adolescent girls. The trial of activity for adolescent girls (TAAG) intervention, a multi-center randomized controlled trial, also targeted policy and organizational change in schools and community agencies. Using the socio-ecological component of policy and organizational change in schools and communities, this study aimed at creating an environment at school, and in the community that facilitate physical activity, enhance social support, and give the girls the opportunity to seek out activity in all settings.

These past studies, like this study, have used the SEMH to illustrate how the environment and policy-making could be used in addressing pertinent health risks and behaviors. In addition, as in this study, past researchers have used SEMH to portray a holistic understanding of health-seeking behaviors.

Summary and Conclusion

In summary, this chapter looked at the relevant literature for comparing CSM to Pre-FP & Po-FPs. In Chapter 3, this researcher will describe research design, study sample, data collection method, and statistical analyses that will be employed in testing the hypotheses.

Chapter 3: Research Method

Introduction

In this chapter, the following are described: the research design, study sample, data collection method, and statistical analyses employed in determining the difference among the mean scores for CSM from 1975 through 2015 in all of the available cities and counties of residence in Colorado as well as evaluating the contributions of gender, marital status, county of residence, and city of residence in CSM periods (prefracking period, i.e., 1975-1977, and postfracking period, i.e., 1999-2015) among adults aged 45-70 years living in Colorado. CSM information was obtained from the CDPHE Vital Health Statistics dataset containing information on deaths among Coloradoans. Before conducting this study, I submitted all required institutional documents to the Walden University Institutional Review Board (IRB). The expectation was that this study would be held to the standards, policies, and procedures required for the protection of human subjects per Walden University.

Research Design and Approach

This study had a retrospective research design that is used when the outcome of an event is already known. Retrospective research design was chosen over other public health research designs because using secondary data would minimize time constraints, be less expensive, maximize sample size, and offer an elegant way of combining novel questions with historical data (Dekker, Euser, Jager & Zoccali, 2009; Demissie, Hamusse, Lindtjorn, & Teshone, 2014). It is a kind of research design that looks backward (i.e., toward the past) and examines exposures to suspected risk or protective factors in relation to an outcome that is established at the start of the study. In this study, I studied a cohort of deaths as well as identified and classified some deaths in the past and followed up to the present to determine incidental rates and associated variables for the deaths. I obtained a dataset containing information on deaths among Coloradoans from the CDPHE. I used SPSS versions 21 and 25 to analyze the data collected.

Research Questions and Hypotheses

Using secondary data obtained from DPHE Health Statistics, I analyzed the following research questions (RQs) and hypotheses (Hs):

Research Question 1: To what extent or degree are there differences in the mean scores for cause-specific mortality (CSM) from 1975 through 2015 in all of the available cities and counties of residence in CO?

Ha1. There is a significant difference among the mean scores for cause-specific mortality (CSM) from 1975 through 2015 in all of the available cities and counties of residence in CO.

$H_0$1. There is no significant difference among the mean scores for cause-specific mortality (CSM) from 1975 through 2015 in all of the available cities and counties of residence in CO.

Research Question 2: To what degree are the contributions of gender, marital status, county of residence, and city of residence in the cause-specific mortality (CSM) periods (prefracking period, i.e., from 1975 through 1977, and postfracking period, i.e., from 1999-2015)?

Ha2. Gender, marital status, county of residence, and city of residence are significant factors in the cause-specific mortality (CSM) periods (prefracking period, i.e., from 1975 through 1977, and postfracking period, i.e., from 1999-2015).

$H_0$2. Gender, marital status, county of residence, and city of residence are not significant factors in the cause-specific mortality (CSM) periods (prefracking period, i.e., from 1975 through 1977, and postfracking period, i.e., from 1999-2015).

Sample Size Estimation

In this study, I used all CSM information obtained from the CDPHE Vital Statistics department. I used all decedent information obtained from CDPHE, which encompassed 73,251 men and women aged 45-70 years. These mortality data were uploaded into Statistical Package for Social Sciences (SPSS) software Versions 21 and 25 for analysis. Using one-way analysis of variance (ANOVA) *F*-test, chi-square test (χ^2) of independence at 5% alpha level, and multiple linear regression, I examined all of the mortality data obtained from CDPHE.

Inclusion and Exclusion Criteria

I used secondary data obtained from CDPHE Health Statistics on CSM based on Colorado resident deaths during 1975-1977 and 1999-2015 as registered with Colorado's Vital Statistics Program. All males and females aged 45-70 years were included in this study. This age bracket was chosen because of the suspected occurrence of hydraulic fracturing and CSM associated with the age bracket. I did not compare all or total mortality data Pre-FP and Po-FP. I excluded mortality due to external causes for all-cause mortality because external causes of mortality are less likely to be related to environmental quality (Grabich, 2017).

Variables

In this study, multiple variables were considered and analyzed. The independent or predictor variables in this study were county of residence for RQ1 and pre- and postfracking periods for RQ2. CSM was the dependent or outcome variable. Gender, marital status, city of residence, and counties of residence were additional predictor variables of interest for this study.

Independent or predictor variables (IVs or PVs): County of residence and pre- and postfracking periods constituted the IVs in this study; the covariates were gender, marital status, city of residence, and county of residence.

Dependent or outcome variable (DV or OV): CSM (underlying cause of death), defined using ICD Code 9 (data from 1975-1977) and ICD Code 10 (data from 1999-2015), was the primary outcome variable.

Data Collection

I obtained cause-specific data spanning 1975-1977 and 1999-2015 from CDPHE Vital Health Statistics. CSM information was obtained from CDPHE Health Statistics data on Colorado residents aged 45-70 years from the prefracking years (1975-1977) and postfracking years (1999-2015) as registered with Colorado's Vital Statistics Program.

Data Analysis

IBM SPSS Statistics Versions 21 and 25 were used to analyze the data collected. Data analysis included descriptive and analytic methods.

Inferential Statistics

Descriptive statistics such as mean, standard deviation, and contingency coefficient statistics were used to answer the research questions. Specifically, Research

Question 1 was answered with mean and standard deviation statistics, while Research Question 2 was answered with contingency coefficient statistics. Mean and standard deviation were used to ascertain the difference and variations among the mean scores for CSM from 1975 through 2015 in all of the countries of residence, while contingency coefficient statistics were used to ascertain the relationship between the variables in the study. Contingency coefficient statistics are used when there is categorization of variables (dependent and independent) in the form of cross-tabulation. ANOVA was used to analyze RQ1, while multiple linear regression was used to analyze RQ2. The hypotheses were tested at 0.05 level of significance.

Protection of Participants

I received all needed IRB approval to conduct the study. The data obtained will be stored for 5 years according to Walden's IRB guidelines. The Walden University IRB approval number for this research is 10-25-18-0365113.

There was minimal risk involved in this study because I had no direct or physical contact with research participants, in that all data were obtained from a secondary source. In addition, the importance of this study in filling a gap in knowledge far outweighed the potential risk when this researcher was comparing CSM with Pre-FP and Po-FP. The thumb drive used for storing a copy of the data from CDPHE has been kept in locked cabinets. Finally, access to the data and research records has been limited to me, the statistician, and other people involved in data authorization.

Internal and External Validity

To support the internal and external validity of the results of this study, I ensured that the instruments measured precisely the characteristics or attributes that they were intentionally designed to measure. I also ensured that all other factors that were not studied in this study could not have any influence on the ones used. However, I used all of the data that were registered with Colorado's Vital Statistics Program for the analysis. This helped in making a broader generalization of the results within the limitations of the study. Consequently, I ensured that both the independent and dependent variables met the assumptions criteria for using the statistics.

Summary and Conclusion

In summary, this chapter addressed the research design, study sample, data collection method, and statistical analyses that were employed in testing the hypotheses. In Chapters 4 and 5, I describe data collection and analysis and the outcomes or results of this study.

Chapter 4: Results

Introduction

In this chapter, I present the results and interpretations of the data for this study according to the research questions.

Findings

Research Question 1

Research Question 1 was as follows: To what extent or degree are there differences in the mean scores for cause-specific mortality (CSM) from 1975 through 2015 in all of the available cities and counties of residence in CO?

Ha1. There is a significant difference among the mean scores for cause-specific mortality (CSM) from 1975 through 2015 in all of the counties of residence.

H_01. There is no significant difference among the mean scores for cause-specific mortality (CSM) from 1975 through 2015 in all of the counties of residence.

Table 2 presents important descriptive statistics for this study, including the mean, standard deviation, and 95% confidence interval (CI) for the dependent variable. The *N* in the first column refers to the number of cases used for calculating the descriptive statistics. As these numbers are equal to my sample sizes it simply means that there are no missing values on the dependent variable. Table 3 indicates that there is a statistically significant difference between the group means. In this ANOVA table, the significance value is .000 (i.e., $p = .000$), which is below 0.05; therefore, there is a statistically significant difference in the mean number for mortality.

Table 2

Descriptive statistics for Arapahoe, Denver, Douglas, El Paso, and Weld counties

					95% confidence interval for mean			
Counties	*N*	Mean	Std. deviation	Std. error	Lower bound	Upper bound	Minimum	Maximum
Arapahoe	20	807.70	219.639	49.113	704.91	910.49	392	1111
Denver	20	1318.85	156.925	35.089	1245.41	1392.29	1134	1663
Douglas	20	205.90	106.315	23.773	156.14	255.66	14	371
El Paso	20	958.05	231.641	51.796	849.64	1066.46	532	1312
Weld	20	372.00	98.440	22.012	325.93	418.07	212	538
Total	100	732.50	437.565	43.757	645.68	819.32	14	1663

Table 3

Between groups and within groups

	Sum of squares	*df*	Mean square	*F*	*p*
Between groups	16152039.500	4	4038009.875	136.865	.000
Within groups	2802837.500	95	29503.553		
Total	18954877.000	99			

In Table 4, I present data analysis for Research Question 1 and Hypothesis 1. As shown in the table, the mean scores for CSM from 1975 through 2015 in all of the counties of residence were 807.70, 1318.85, 205.90, 958.05, and 372.00 for Arapahoe, Denver, Douglas, El Paso, and Weld, respectively. It was shown that Denver County had a higher mean CSM from 1975 through 2015 than any other county. Second in line was El Paso, followed by Arapahoe, then Weld, and finally Douglas County.

Table 4

Sample Size (n), Mean Score ($\bar{X}$), Standard Deviation (S), and One-Way ANOVA F-Test Statistics of Significant Difference Among the Means

County of residence			***n***	***$\bar{X}$***		***S***
Arapahoe			20	807.70		219.639
Denver			20	1318.85		156.925
Douglas			20	205.90		106.315
El Paso			20	958.05		231.641
Weld			20	372.00		98.440
ANOVA	Sum of squares	Degree of freedom	Mean square	F_{cal}	F_{tab}	Remark
Between groups	16152039.500	4	4038009.875			
Within groups	2802837.500	95	29503.553	136.865	2.45	Reject Ho
Total	18954877.000	99				

The results of the analysis in Table 4 also reveal that the degree of freedom for the numerator is 4 while that of the denominator is 95. The F_{cal} (calculated F) is 136.865, and the F_{tab} (tabulated F) is 2.45. Because the F_{cal} (calculated F) of 136.865 is greater than the F_{tab} (tabulated F) of 2.45, the alternative hypothesis is accepted and the null hypothesis is rejected, indicating that there is a significant difference among the mean scores for CSM from 1975 through 2015 in all of the counties of residence.

Evidence for the Assumptions of ANOVA

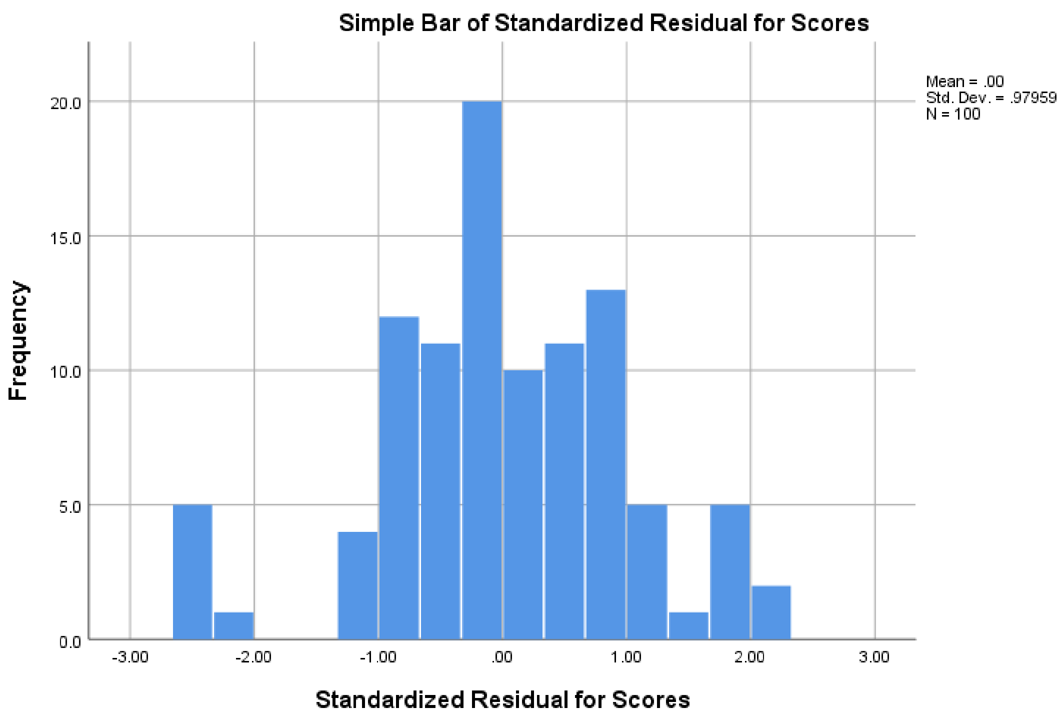

Figure 2. Bar graph of standardized residual scores for assumption of normality.

Figure 2 shows the evidence that the data used for the analysis met the key required assumptions for using one-way ANOVA to carry out this analysis. This simple bar chart graph of standardized residual for scores shows that the assumption of normality was duly met. This is shown in the normal distribution curve shape of the graph.

Research Question 2

Research Question 2 was as follows: To what degree are the contributions of gender, marital status, county of residence, and city of residence significant in the cause-specific mortality (CSM) periods (prefracking period, i.e., from 1975 through 1977, and postfracking period, i.e., from 1999-2015)?

Ha2. Gender, marital status, county of residence, and city of residence are significant factors in the cause-specific mortality (CSM) periods (prefracking period, i.e., from 1975 through 1977, and postfracking period, i.e., from 1999-2015).

$H_0$2. Gender, marital status, county of residence, and city of residence are not significant factors in the cause-specific mortality (CSM) periods (prefracking period, i.e., from 1975 through 1977, and postfracking period, i.e., from 1999-2015).

It is shown in Table 5 that with sample size of 12,098, the multiple correlation coefficient of 0.17 was obtained, which indicates that there was a very low degree of relationship among gender, marital status, country of residence, city of residence, and CSM periods. Additionally, only 2.9% (R2) of the variation in the dependent variable can be explained by the independent variables. Table 6 further shows that, with the degree of freedom of 12097, F = 89.706 is significant, leading to the rejection of the null hypothesis and the conclusion that the coefficient of multiple correlation among gender, marital status, and county of residence and CSM scores was significant.

Table 5

Model Summary for gender, marital status, city of residence and county of residence

Model	***R***	***R* square**	**Adjusted *R* square**	**Std. error of the estimate**
1	.170[a]	.029	.028	6.664

[a]Predictors: (Constant), city of residence, marital status, county of residence, gender.

Table 6

Degree of freedom (df) for gender, marital status, city and county of residence

			ANOVA[a]			
Model		Sum of squares	*df*	Mean square	*F*	*p*
1	Regression	15933.515	4	3983.379	89.706	.000[b]
	Residual	536989.422	12093	44.405		
	Total	552922.937	12097			

[a]Dependent variable: Scores. [b]Predictors: (Constant), city of residence, marital status, county of residence, gender.

Table 7

Coefficients for gender, marital status, city and county of residence

			Coefficients[a]			
		Unstandardized coefficients		Standardized coefficients		
Model		B	Std. error	Beta	*t*	*p*
1	(Constant)	22.811	.250		91.256	.000
	Gender	1.129	.121	.083	9.299	.000
	Marital status	.556	.045	.111	12.413	.000
	County of residence	-.498	.044	-.101	-11.289	.000
	City of residence	-.071	.081	-.008	-.869	.385

[a]Dependent variable: Scores.

Summary of Findings

From the analyses of the study, the following findings were made for the research questions and hypotheses:

1. Denver County had a higher mean CSM scores from 1975 through 2015 than any other county in Colorado. Second in line was El Paso, followed by Arapahoe, then Weld, and lastly Douglas. When tested, the result showed that there was a significant difference among the mean scores for CSM from 1975 through 2015 in all of the counties of residence.

2. The contribution of gender, marital status, and county of residence in CSM scores was significant but also very low in the CSM periods, i.e. prefracking and postfracking.

Chapter 5: Conclusions, Summary, and Recommendations

Introduction

This chapter contains subsections with discussion of the findings, limitations of the study, recommendations, suggestions for further study, a summary of the entire study, and a conclusion.

Discussion of Findings

CSM From 1975 Through 2015 in All of the Counties of Residence

It was revealed that Denver County had a higher mean CSM from 1975 through 2015 than any other county in Colorado. Second in line was El Paso, followed by Arapahoe, then Weld, and lastly Douglas. When tested, the result showed that there was a significant difference among the mean scores for CSM from 1975 through 2015 in all of the counties of residence. This finding is an indication that CSM during the said years differed significantly with respect to county of residence. In other words, county of residence had an influence on CSM. The significance of this finding could not be attributed to chance. The high CSM recorded for Denver could be linked to the environmental nature of the county. This could also be linked to the exposure of some CSM-induced related factors. In addition, Dockery and Pope (2006) stressed that long-term exposure to ambient fine particulate matters affects human pathophysiological pathways. The similarities in the findings could be linked to similar characteristics of the study areas.

Contributions of Gender, Marital Status, and County of Residence in Cause-Specific Mortality (CSM) Periods

According to the regression results, the contributions of gender, marital status, and county of residence in CSM scores was significant but very low. Azim et al. (2014) showed that mortality declined in females aged 15-34 years by 85% over 1950-2006. Among males aged 15-34 years, the mortality decline was less at 47%, due to a rise in external-cause mortality during 1970-2000. There was a 67% mortality decline among females aged 35-65 years over 1950-2006 and a decline in mortality in males aged 35-64 years. This study concluded that significant disparities were demonstrated in Sri Lankan cause-specific adult mortality by sex and age group for 1950-2006. Female mortality progressively declined while male mortality demonstrated periods of increase and stagnation. The contradictions recorded above could be linked to the use of different locations.

The findings indicate that marital status and CSM do not have much association, but the existing association proved to be significant and thus was not by chance. Supporting this, Brauer et al. (2017) showed that the mean level of $PM_{2.5}$ exposure during 2000-2005 was 43.7 $\mu g/m^3$ (ranging from 4.2 to 83.8 $\mu g/m^3$) and the mortality HRs (95% CI) per 10-$\mu g/m^3$ increase in $PM_{2.5}$ were 1.09 (1.08, 1.09) for nonaccidental causes: 1.09 (1.08, 1.10) for CVD, 1.12 (1.10, 1.13) for COPD, and 1.12 (1.07, 1.14) for lung cancer. Hence, this study concluded that long-term exposure to $PM_{2.5}$ was associated with nonaccidental, CVD, lung cancer, and COPD mortality in China.

Beydoun (2016) conclusively revealed that racial/ethnic disparities in all-cause and cause-specific mortality (particularly cardiovascular and neoplasms) were partly explained by sociodemographic, SES, health-related, and dietary factors, and differentially by age, sex, and poverty strata. This could mean that marital status was one of the SES factors studied by Beydoun et al.

In the literature, dissolved solids and high concentration of metals from hydraulic fracturing have been associated with diminishing growth of brook trout. Chemical contamination and air pollution from fracking activities could impact the fecundity of brook trout (Taylor & Weltman-Fahs, 2013). Jones and Pejchar (2013) reiterated that species endangerment; loss and disintegration of habitat; and wildlife mortality, morbidity, and invasion have equally been attributed to large-scale oil and gas development. The findings of the present study proved that county of residence has a significant but very low association with CSM. This implies that geographical location may have a contribution to and link with CSM.

However, the research of Jin (2015) showed that in relation to all cause-specific cardiovascular mortality, Beijing had stronger cold and hot effects than Shanghai. In addition, the effects of extremely low and high temperatures differed by mortality types in the two cities. However, HPD in Beijing was inclined to both extremely high and low temperatures. Moreover, the mixture of combustion products along with constant movement of trucks to and from fracking sites contribute to increased levels of sulfate and fine particulate air pollution (Dockery et al., 1993). Thus, the findings of numerous studies posit that there is a link between particulate air pollution and lung function and cough, shortness of breath, and asthma (Dockery et al., 1993).

Limitations of the Study

Because this study was not an experimental study, the generalization of the findings of this study to other geographical locations that were not incorporated in the study should be done with caution. This implies that what is obtainable in other areas might not be the same in the present area of the study. Consequently, I cannot use the results obtained from this study to generalize the U.S. population; inferences can be made only about the studied area. Moreover, other factors such as socioeconomic status (SES), occupation, race, smoking, alcohol consumption, and education that could be associated to CSM were not involved in this study.

Recommendations

Based on the findings of this study, I recommend the following:

1. Before any policy relating to CSM is made in a county, county of residence should be considered.
2. Policymakers who are concerned about CSM should consider gender, marital status, and county of residence in making decisions that could affect CSM.
3. The present study should be replicated with a national sample to test the generalizability of the findings.
4. Stakeholders need to integrate CSM awareness programs into public health programs involving hydraulic fracturing and routine medical treatment in other to improve public health practice in the state of Colorado.

Implications for Social Change

The findings support Walden's mission by increasing understanding of the difference among mean scores for CSM and determining the contributions of gender, marital status, and county of residence to CSM scores among adults aged 45-70 years living in Colorado from prefracking to postfracking periods. The objective is to use the study's outcomes to raise awareness about CSM and gender, marital status, and county of residence. This investigation suggests that people living in Colorado should be aware that CSM is linked with gender, marital status, and county of residence. At the macro level, there is a need for policymakers to promote programs that will make Colorado residents aware that CSM could be linked with gender, marital status, city of residence and county of residence from prefracking to postfracking times. The results of this study prove that CSM scores have significant links with gender, marital status, and county of residence. This implies that gender, marital status, and county of residence may be significant predictors that could influence every decision regarding CSM. The results of this study also showed that CSM differs significantly with respect to county of residence. This implies that county of residence has an influence on CSM. Therefore, individuals must be aware of these areas that induce CSM.

Conclusion

This study evaluated the difference among mean scores for CSM 1975 through 2015 in all of the available cities and counties of residence in Colorado and determined the contributions of gender, marital status, and county of residence in CSM periods (prefracking period, i.e., 1975-1977, and postfracking period, i.e., 1999-2015) among adults aged 45-70 years living in Colorado.

Results revealed that Denver County had a higher mean CSM score from 1975 through 2015 than any other county in Colorado. Additionally, regression results revealed a significant but weak association between CSM scores and gender, marital status, and county of residence from prefracking period (1975-1977) and postfracking period (1999-2015).

There were some limitations to this study that need to be taken into consideration that could contribute to further literature. Among the limitations were that data on mortality were obtained from the CDPHE, and I did not have control over the data provided. Another crucial limitation was that the CDPHE data on CSM did not precede the year 1975, and CSM data were not available from the CDPHE from 1978 to 1998. Furthermore, other factors such as socioeconomic status (SES), length of residence, occupation, race, smoking, alcohol consumption, and education that could be associated to CSM were not involved in this study.

The results of this study add to the literature on CSM scores in Colorado from 1975-1977 and 1999-2015. The study could also serve as a benchmark for further studies that may be conducted by any researcher in any county in the state of Colorado.

The main conclusion that can be derived from this study is that CSM scores could be significantly associated with the following variables: gender, marital status, and county of residence. Stakeholders need to integrate CSM awareness programs into public health programs involving hydraulic fracturing and routine medical treatment in other to improve public health practice in the state of Colorado.

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