2022

Assessing Cancer and Heart Disease Occurrence from Groundwater Contaminated with Volatile Organic Compounds

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This is to certify that the doctoral study by

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has been found to be complete and satisfactory in all respects,
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Abstract

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MBA, Western Governors University, 2015

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Doctoral Study Submitted in Partial Fulfillment

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Doctor of Public Health

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Abstract

This study examined the effects of the toxic chemicals contained in volatile organic compounds (VOCs) on cancer occurrence and heart disease through occupational and environmental exposure to groundwater sources. This study was important because it provided critical insight for the public health community on the association between variations of past and current levels of VOCs in water sources and cancers and heart disease. The key research questions examined what proportion of occupational and nonoccupational individuals in southeastern North Carolina were diagnosed with cancer or heart disease and whether VOCs were associated with the long-term effects of cancer or heart disease based on concentration levels, controlled for age, gender, ethnicity, and preexisting conditions. Using the social ecological model for the theoretical framework, this quantitative, correlational research design with secondary analysis assessed health survey data with 1184 total participants, including men, women, and children. Descriptive analyses, Chi-square test, and binary logistic regression test were used to measure the association and strength of association between the dependent variables of cancer incidence and heart disease incidence and the independent variable is the exposure level of VOCs. The final analyses depicted no significance between all variables tested (p = 0.177-0.466 for cancer, p =0.151-0.454 for heart disease). Although findings in this study were not significant, the integration of this study into professional practice through new research collaborations between state and federal environmental and public health agencies can invoke positive social change. Further examination of VOCs and their effects on cancer and heart disease incidence may also create new studies of significance.

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Dedication

I dedicate my dissertation to my husband, Retired Captain A. Owens (more compassionately known to those close to us as "Chief"), and his 29-year career with the City of Atlanta Fire and Rescue Department. My husband has been, is and continues to be the most supportive confidant and positive influence in my life for over a decade. His cheers and encouragement keep my heart and spirit soaring towards stars I never thought I would be able to reach. Because of his love, all the days I wept tears in frustration and in joy, make completion of this Doctoral journey priceless. To my parents Louis & Bennita, I am a testament to the greatness and hard work you instilled in my sister and me. Mother and father, this proposal serves as a culmination of all the education I promised myself I would obtain in your honor. To my children, Brandon & Breana Watson, you have made me the proudest mother to have lived this life and WE DID IT! To my phenomenally supportive immediate family, especially: my sister Candace, nieces Kemari & Kelby, Aunt Regina and cousins Clarence, Constance, Catherine, Christian, Kia & Jasmine, this journey has also been for you and because of you. To Janice & Felecia, you are my sisters and exhibit the upper echelon of friendship, as each of you deserve your own page in this dedication, just as you have in my life. Janice, my dear friend, and God-sister, you shared your most vital resource and piece of heart with me when I needed her most, so I sincerely thank you. Felecia, you know my levels and understand me like no other has attempted for almost 20 years, becoming my most trusted confidant, protector, and prayer partner. Both individually and collectively, my immediate and extended families, of which I compassionately label "my village", have supported, encouraged, cheered, embraced, nourished this body and soul, kept me from falling often, but picked me up with love and without judgement when I did. I am forever grateful and humbled by their blatant reminders to me of the time and effort spent in this doctoral journey because it is indicative of the future I wish to influence. In loving memory of Christine Taylor-Wade, Loretta Boykin, Barbara Walker, Jean Turner and Rudolph Thomas.

Acknowledgments

I would like to first acknowledge and give special thanks to the Owens, Foreman, Cochran, Horne, Lee, Powell, Evans, Hall & McGee families, respectively, for your unwavering support and love - not just for me, but my passions, dreams, and failures. To some of the irreplaceable and sincerest of people whom I consider to be sisters, brothers & friends, while not truly understanding the impact they have had in my life's journey to date: Donald, Jennifer, Shameka, Dedra & Donna, Eric, Adrian M., Amanda, Kimmi, DeAdrian H., Monica, Darryl, Collette, Santresa, Ronnie & Cassandra, JaMichael, Roderick, Jadrien, Danni, Camilla & Tangi – you have pushed, lifted and carried me through both academia and the highs and lows of survival, and for that, I would like to express my sincerest gratitude and prayers for your respective journeys as well.

To Rising Star Missionary Baptist Church, although the current pandemic separated us physically, the teachings of Pastor Gerrod Duff have anointed and guided my steps, thoughts, and actions through many seasons. To my church family, thank you for blessing my spirit and journey to date. Please continue to keep your faith, walk unshaken and remain steadfast in God.

To the faculty, my program chairs Dr. Melea & Dr. Kadrie, and the rest of my dissertation committee here at Walden University, I am most thankful for your guidance through completion of this Doctoral process.

Table of Contents

List of Tables

List of Figures

Section 1: Foundation of the Study and Literature Review

Trichloroethylene (TCE) and tetrachloroethylene or perchloroethylene (PCE), historically common volatile organic compounds (VOCs), are toxic chemicals that have contaminated both the air and water supplies after their release during industrial manufacturing and disposal processes. Ambient VOCs, such as alkyne and benzene, were found to be associated with an increased risk of heart disease in some foreign populations; however, there are few published epidemiologic studies that show this relationship (Ran et al., 2018). Two particular organochloro compounds, PCE and TCE are often used for dry-cleaning and degreasing (Rastkari et al., 2011). If sufficient levels are present and groundwater is shallow, chlorinated solvent vapors can also move upwards from the water and penetrate though the soil, building foundations, and underground service infrastructure and contaminate indoor air (South Australia Health, 2020). Groundwater sampling identified a larger than expected plume of contaminants, including TCE and PCE, along with lesser amounts of 1-trichloroethane (TCA), dichloroethane, dichloroethene, methylene chloride, vinyl chloride, freon 113, and other VOCs, with total groundwater VOC concentrations ranging from 5 to > 500 µg/L (New York State Department of Environmental Conservation [NYSDEC], 2003). Groundwater has traditionally become polluted when various industries release either TCA, TCE, PCE, dichloroethane, dichloroethene, methylene chloride, vinyl chloride, freon 113, or any other VOC into the environment. While VOCs have been more commonly present in or around industrial areas, military installations have seen water contamination as a result of these chemicals dating back to 1957. Historically, industrial practices on military bases allowed for the repudiation of contaminated solvents into the ground under the assumption that they would eventually evaporate, however, these solvents leaked into soil and were later linked to many adverse health outcomes in former military personnel, residents, and civilian workers at the base.

The United States Marine Corps Base (MCB) in southeastern North Carolina (NC) conducted a sampling program from 1980-1985 in which VOCs, including various chemicals that can create adverse health effects over short- and long-term periods, were discovered in some of the wells that supplied two of the military base's primary water distribution systems, at Hadnot Point and Tarawa Terrace. These two wells were the source of a large contamination that caused adverse health effects for thousands of people from this military installation 20-30 years later due to a local off-base dry cleaner's waste disposal procedures. The primary contaminant in the HP distribution system was TCE. The maximum level of TCE detected in the system was 1,400 parts per billion (ppb; Ruckart et al., 2013). The primary contaminant detected in the TT distribution system was PCE at a maximum of 215 ppb (Ruckart et al., 2013). Contamination levels in the drinking water distribution system varied depending on the wells being used (Ruckart et al., 2013). Thus, when water from the contaminated wells was mixed in the treatment facilities, water delivered to residences and offices caused health risks extending far past the wells' closures in 1985.

According to the Minnesota Department of Health (2018), exposures to TCE/PCE may increase the risk of certain types of cancers (TCE: kidney, possibly non-Hodgkin's lymphoma, and liver; PCE: possibly bladder, non-Hodgkin's lymphoma, multiple myeloma, liver, and leukemias) based on high concentrations in occupational and animal studies, 10 to 100,000 times higher than typical vapor intrusion exposures. The Minnesota Pollution Control Agency (2021) reports that exposure to high levels of ground-level ozone can increase the risk of premature death in individuals already suffering from heart or lung disease. To date, however, there is still minimal scientific data available that directly evaluates the potential association between VOCs and heart failure or any other types of heart disease.

Civilians and residents who were occupationally and nonoccupationally engaged in activities on the MCB began to contact the U.S. Department of Veterans Affairs in the late 1990s and early 2000s to relay their concerns regarding the link between the contamination and their current health issues. The Agency for Toxic Substances and Disease Registry (ATSDR) is a congressionally mandated agency of the U.S. Department of Health and Human Services (ATSDR, 2017). ATSDR was charged with evaluating if the population of civilians and residents at the MCB in southeastern NC were exposed to TCE, PCE and some other chemicals found in drinking water and indoor air sources that may have resulted in various forms of cancer and heart disease. And while there has been some insight into the relationship between chemical exposures and certain cancer risks, there are not an abundance of scientific studies that specifically examine the effects of VOCs in the dry-cleaning industry and health outcomes in children and adults at the MCB in southeastern NC or other military installations.

As a result of ATSDR's initial 1997 Public Health Assessment (PHA) where the agency concluded that many people at the MCB in southeastern NC were exposed to

TCE, PCE and other VOCs in the drinking water, increasing incidence of cancers and heart conditions, and later, the 2017 PHA on the Camp Lejeune Drinking Water where the agency dictated exposure estimates, statistical information and results on the affected population, this study was created to inform communities about the corresponding cancer and heart disease incidence, and morbidity and mortality rates related to these specific contaminants found in the MCB drinking water sources. The U.S. Department of Veterans Affairs (2017) amended its adjudication regulations regarding certain diseases associated with contaminants present at the MCB in southeastern NC from 1957 – 1987 and presumptive service connections, ultimately ruling that the only conditions that were to be treated going forward, based on sufficient scientific and medical evidence, are adult leukemia; bladder, kidney, and liver cancers; aplastic anemia (and all other myelodysplastic syndromes); multiple myeloma; Parkinson's disease; and Non-Hodgkin's lymphoma. The department has stated publicly that it would, however, continue to review relevant scientific information as it became available in future years. Based on the historical content of these health assessments and other substantive publications that discuss the relationship between VOCs and chronic illnesses or diseases, such as cancer, this study focused on the magnitude in which individuals who were exposed to these chemicals from 1957-1987 have had their health statuses negatively affected some 30 years later and the morbidity and mortality rates surrounding related health conditions as a result of the exposure on the MCB. In the ATSDR (2018) Morbidity Study, the agency reported the most prevalent cancers among all affiliations were prostate (4.8%), female breast (4.7%), cervical (2.4%), colon (1.2%), lung (1.1%), bladder (1.0%), and kidney (0.9%).

Examining the relationship between VOCs and incidence rates of cancer and heart disease in both veterans and civilians who were engaged in occupational and nonoccupational activities on the MCB in southeastern NC is important in compiling sufficient scientific data for both state and federal cancer registries and in determining mortality hazard rates or ratios. Examining a causal relationship between exposure estimates and cancer incidence is also vital in explaining and understanding the individual risk factors related to socioeconomic status (SES) of the affected population, the epidemiology of cancers, noncancer diseases, nervous system and autoimmune disorders, and the availability of long-term health care and benefits provided by the Department of Veterans Affairs and the Department of the Navy.

Background of the Study

The use of VOCs in the dry-cleaning industry has caused severe health conditions, primarily cancer, to humans through occupational exposure dating back to 1957 in NC. High chemical exposure levels to VOCs have been proven to induce these adverse health effects, specifically various cancers, and heart diseases or failure, to occupational workers and nonoccupational residents through both drinking water and indoor air sources. In a single cohort study of intra-urban variation of exposure, benzene and hexane were found to be linked to cardiovascular disease (CVD) mortality (Villeneuve et al., 2013). Similarly, exposure to VOCs, such as butadiene, has been suggested to increase the risk of cancer and heart disease (Matanoski et al., 1990). The use of PCE in dry cleaning was introduced during the first half of the 19th century to replace more toxic solvents, such as carbon tetrachloride, and it quickly became the main solvent used worldwide (Omrane et al., 2019). PCE exposure has been classified by the International Agency for Research on Cancer (IARC) as “probably carcinogenic to humans” (Group 2A; IARC, 2014); positive associations have been observed for bladder cancer and also for other cancer sites such as the esophagus, kidney, cervix, and in non-Hodgkin’s lymphoma, even if overall results were considered inconsistent (IARC, 2014). The production of TCE began in the United States during the early 1920s to replace the use of petroleum distillates being used in dry-cleaning processes and later became the solvent of choice in degreasing during the 1930s. Due to toxicity issues, the use of TCE began to drastically decrease during the 1960s when TCA became popular for industrial use.

Marshall et al. (2004) conducted a population-based case-control study to determine whether VOCs affected women in early pregnancy adversely and if they were associated with increased risks of specific heart defects. Modenese et al. (2019) states that new technologies and more effective preventive interventions have been developed and applied over time, leading to a significant decrease of occupational exposure levels, even if high exposures have been occasionally reported. Several studies have explored many adverse health effects related to the exposure of people residing near dry cleaning facilities and TCE- or PCE-emitting sites (Omrane et al., 2019). Prolonged or repeated exposure of TCE causes kidney cancer (National Cancer Institute, 2018) and some scientific evidence suggest that exposure to TCE may also be associated with an increased risk of liver cancer. Lee et al. (2019) determined that seven out of the 31 immune regulation and kidney function markers previously reported on in a cross-sectional study of workers who were exposed to various ranges of TCE were significantly decreased or increased but remained below current occupational standards. A study conducted by Luo et al. (2019) provided vital information necessary for assessing the human health risks of TCE with respect to the kidneys and liver, the role glutathione (GSH) conjugation (metabolites of TCE) plays in toxicity levels, and the degree of individual variability within the kidney tissue. Because TCE is found in water sources, as it is breathed in or consumed orally, it passes from the lungs into the bloodstream, affecting the respiratory system. Between 2010 and 2020, there have been many studies addressing the link between occupational and nonoccupational exposures to VOCs in contaminated drinking water and the incidence of leukemia, with varying and sometimes inconsistent results. Despite the link between VOC exposures to the wide scope of cancerous and noncancerous outcomes, the molecular mechanisms of both chemicals and their respective chemical-induced health effects remain far-reaching and often detrimental in those affected.

Purdue et al. (2017) examined occupational exposure to chlorinated solvents and their association to kidney cancer, particularly PCE. The authors concluded that high exposure to PCE, independent of TCE, is associated to incidence of kidney cancer. Epidemiologic evidence of VOCs groundwater contaminations causing elevated cancer occurrence from 2010 through 2020 is limited, however. Some epidemiologic studies among dry cleaners, but not others, have reported excesses for bladder cancer and, less frequently, cancers of the esophagus, cervix, and kidney and non-Hodgkin lymphoma, although most lacked assessments of workers' solvent exposure levels (Callahan et al., 2019). Callahan et al. (2019) also observed in their study that solvent exposure levels were associated with increases in mortality owing to heart disease and cancers of the bladder, kidney, and the lymphatic/hematopoietic system specifically. As a result of the study by Callahan et al. (2019) and others assessed in this study, there was direct evidence that showed that exposure to VOCs through water sources has created an excess in mortality and as such, there is new evidence within these respective studies that support these solvent exposures as the likely cause for reported excesses among cancers of the kidney, bladder, and lungs and leukemia. The use of these chemicals in dry-cleaning processes was also associated with elevated cancer mortality rates based on the meta-analysis of at least seven cohort studies that are referenced under the Background of the Study, Literature Review Related to Key Variables and/or Concepts, and Studies of Significance headings of Section 1 in this study. PHAs and studies by ATSDR (2017; 2018), and studies by Lee et al. (2019), Modenese et al. (2019), Lindell et al. (2017), Callahan et al. (2019) and Luo et al. (2019) have shown that further research is needed in investigating and clarifying the cancer and heart disease risks and incidence associated with occupational and nonoccupational exposure to VOCs, as well as the morbidity and mortality rates associated with cancer and heart disease through long-term investigation and comprehensive assessments of the exposure effects of groundwater contamination.

Problem Statement

ATSDR integrated the findings from its MCB studies in with findings from studies of other populations exposed occupationally or environmentally to the VOCs detected in the drinking water at the MCB in southeastern NC: TCE, PCE, vinyl chloride and benzene (ATSDR, 2017). VOCs are industrial solvents that are common groundwater contaminants (Minnesota Department of Health, 2018). Because they are volatile, they rise toward the surface as vapors and can contaminate air inside buildings – a process called vapor intrusion (Minnesota Department of Health, 2018). Because of its widespread use as a metal degreasing agent to maintain military equipment, it has been found in the groundwater at many military sites (National Institute of Environmental Health Sciences, 2016). In 1982, the Marine Corps discovered specific VOCs in the drinking water provided by two of the eight water treatment plants on base (ATSDR, 2017). Water from the Tarawa Terrace and Hadnot Point water treatment plants were primarily contaminated with PCE and TCE, respectively. The source of the contamination was the waste disposal practices at ABC One-Hour Cleaners, an off-base dry-cleaning firm (ATSDR, 2014). The ATSDR used a data analysis and modeling approach to reconstruct historical contaminant concentrations (ATSDR, 2014). Using these approaches, ATSDR estimated that PCE concentrations exceeded the current U.S. Environmental Protection Agency (EPA) maximum contaminant level of 5 ppb in drinking water from the Tarawa Terrace water treatment plant for 346 months during November 1957-February 1987 (ATSDR, 2014). While these wells were eventually shut down in early 1985, this groundwater contamination has had ongoing health effects, more specifically, various cancer diagnoses and some cases of heart disease, in the designated population in the 35 years since the initial contamination of the wells due to high concentrations of VOCs. Studies conducted over the last 20 years show that VOCs have been associated with many adverse health outcomes, including CVD. Malovichko et al. (2019) examined the association between the metabolites of 18 different VOCs in 1194 Black subjects as a part of the Jackson Heart Study. Data from Malovichko et al. study suggested among the VOCs examined, two VOCs particularly showed strong, positive associations to aorto-iliac calcifications. Collectively, these human and preclinical data suggest that exposure to VOCs such as acrolein and crotonaldehyde can compromise endothelial repair by depleting crotonaldehyde compounds (CACs); and exacerbate atherogenesis (Malovichko et al., 2019). For cumulative exposures to VOCs in internal analyses, the morbidity study found that contaminated drinking water at Camp Lejeune was associated with increased risk in both Marines and civilian employees for bladder cancer, kidney cancer, and kidney disease and that these results were informed by evidence from other studies (ATSDR, 2018b). According to the Minnesota Department of Health (2018), exposures to TCE/PCE may increase the risk of certain types of cancers (TCE: kidney, possibly non-Hodgkin's lymphoma, and liver; PCE: possibly bladder, non-Hodgkin's lymphoma, multiple myeloma, liver, and leukemias) based on high concentrations in occupational and animal studies (tens to hundreds of thousands of times higher than typical vapor intrusion exposures). Civilians and residents who were occupationally and nonoccupationally engaged in activities on the MCB began to contact the U.S. Department of Veterans Affairs in the late 1990s and early 2000s to relay their concerns regarding the link between the contamination and current health issues. In 2007, the U.S. Government Accountability Office (GAO) reported that former residents and employees of the MCB in southeastern NC had filed more than 750 claims against the federal government related to the contamination (National Center for Biotechnology Information, n.d.). As such, my study assessed current data on the effects of this contamination among the population that left the military installation from 1957-1985 and are suffering from cancer and heart disease.

While there are only two cohort studies available by ATSDR addressing the impact of these chemicals on cancer and heart disease incidence within the last 10 years, additional research is still needed to address health effects that have sufficient evidence for causation in veterans and civilians, occupationally or environmentally, exposed to these chemicals as identified in the drinking water at the MCB in southeastern NC. In April 2018, ATSDR conducted a morbidity and mortality study of residents at the MCB in southeastern NC and civilian occupational individuals who were at the MCB during the 35-year exposure period from 1950 to 1985 and who were exposed to contaminated drinking water. This ATSDR study showed that contaminated drinking water at the MCB in southeastern NC was linked to increased risk for bladder cancer, kidney cancer, and kidney disease (ATSDR, 2018b). Various factors were collected and evaluated in the nearly 80,000 surveys completed by this population and compared to military personnel and civilian employees with some specific health issues at a similarly structured MCB in California, where exposure to contaminated drinking water was not an issue. Using a comparison group with a similar population who was not exposed helps assess if there is a link between exposure to the water and diseases (ATSDR, 2018b). The majority of cancers were reported by Marines (*n*= 2,784, 81.8%); only 12 cancers were reported by civilian workers (ATSDR, 2018b). For all affiliations, the most prevalent cancers were prostate (*n*= 987, 4.8%), female breast (*n*=176, 4.7%), cervical (*n*= 90, 2.4%), colon (*n*= 294, 1.2%), lung (*n*= 263, 1.1%), bladder (*n*= 234, 1.0%), and kidney (*n*= 218, 0.9%; ATSDR, 2018b). Evidence is considered sufficient for causation if there is (a) sufficient evidence from human studies in which chance and biases (including confounding) can be ruled out with reasonable confidence or (b) less than sufficient evidence from human studies but sufficient evidence in animal studies and strong evidence that the chemical acts through a relevant mechanism in humans (ATSDR, 2014). As TCE, PCE, per- and polyfluoroalkyl substances (PFAS) continue to plague water sources across the United States because of their widespread use by private and commercial entities, they also remain heavily immersed within the environment. ATDSR's 2018 mortality study explained that cancer rates continually change, increasing and decreasing over time, therefore, the surviving population from the MCB in southeastern NC is still relatively young and corresponding cancer rates will follow suit as this population's deaths occur. Despite time frame limitations of mortality studies based on the availability of military records, to provide the most comprehensive assessment of the exposure effects from groundwater contamination, long-term investigation of this issue is still necessary.

Purpose of the Study

The intention of this study was to examine the long-term effects of VOCs on cancer and heart disease incidence in both veterans and civilians who were engaged in occupational and nonoccupational activities at the MCB in southeastern NC. Secondary data, that includes scientific evidence and statistics on the association between exposure to these contaminants and development of various cancers and conditions of the heart, were examined. This study is unique because it assessed the specific effects of these chemicals on cancer and heart disease incidence and present data on cancer mortality and heart disease rates within the affected population from the MCB in southeastern NC.

Research Questions and Hypotheses

This study was guided by and answer the two following research questions (RQs):

RQ1: Descriptive: What proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs?

$H_0$1: There is no statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.

$H_1$1: There is a statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.

RQ2: Inferential: Are VOCs associated with elevated risks of cancer incidence in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when controlling for these covariates: age, gender, ethnicity, and pre-existing conditions in 2019?

$H_0$2: There is no statistically significant association between VOCs and the elevated risks of death from cancer in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

$H_1$2: There is a statistically significant association between VOCs and the elevated risks of death from cancer in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

RQ3: Inferential: Are VOCs associated with elevated risks of heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post contamination, when controlling for these covariates: age, gender, ethnicity, and pre-existing conditions in 2019?

$H_0$3: There is no statistically significant association between VOCs and the elevated risks of death from heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

$H_1 3$: There is a statistically significant association between VOCs and the elevated risks of death from heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

I explored whether there was a significant relationship(s) between the amount of exposure to VOCs and cancer incidence, as well as heart disease incidence. I also attempted to control for age, gender, ethnicity, and pre-existing conditions.

Theoretical Foundation for Study

The theoretical framework for this study was Bronfenbrenner's (1977) social ecological model (SEM). The SEM is a framework designed to provide an understanding of the multiple and dynamic levels specific to a society and how society interacts with the environment as a part of a mutually beneficial social system. The SEM also conceptualizes how health is approached in a society while focusing on the various factors that potentially influence health. The SEM was first introduced as a conceptual model for understanding human development by Urie Bronfenbrenner in the1970s and later formalized as a theory in the 1980s (Bronfenbrenner, 1977). Bronfenbrenner's initial theory was significant because it included nesting circles that placed an individual in the center of the model, surrounded by the inner microsystem, then followed by the mesosystem, exosystem, and macrosystem. and lastly, the outer chronosystem. The construct of health was broadly conceptualized in the SEM and focused on the major contributors that might affect health (Kilanowski, 2017). The SEM discloses that health is ultimately affected by specific interaction(s) between the individual, community, and environmental (includes the social, physical, and political elements) characteristics. The CDC adapted the SEM to utilize in various health promotion activities and programs, including the interpersonal, organizational, community, and policy spheres in their model. And while Bronfenbrenner's initial model acknowledged many of the contributions to human development, succeeding revisions and adaptations use the SEM to substantiate multilevel approaches in areas such as public health promotion, sexually transmitted disease prevention, violence prevention, and cancer initiatives, to name a few.

Bronfenbrenner's model has been used in various aspects of public health and other social sciences to examine the complex association between individuals, relationships, communities, and societal factors. Because it best represents the environmental impacts of water contamination on the individual, the community, and society, the SEM addressed the relationship between the individuals affected, their daily activities on the military installation, and how the unsolicited effects of the chemicals VOCs increased prevalence and/or caused the development of various cancers for the individuals in this community.

The SEM is useful in identifying other factors within an individual's environment, such as perceptions of ability and available resources, that might have contributed to chronic illnesses and other health outcomes. I used the SEM in constructing the research questions because it offered a foundational framework that suggests the reciprocal interactions between the individual behaviors and actions of those exposed to the groundwater contamination and the organizational and environmental (ecological) responsibility in the causation of various cancer and heart disease diagnoses at the MCB in southeastern NC. When developing and reviewing approaches to health promotion and disease prevention, this model focuses on integrating approaches that effectively change social and physical environments together rather than simply focusing on individual health behavior. The SEM considers the complex interplay between all of the interpersonal, organizational, community, and policy factors that examine the impact of the amounts of VOCs on cancer and heart disease. The levels of influence that existed as a result of VOC contamination in this study are individual, organizational, community and policy, and thus, these levels were explained and studied below.

Levels of SEM

Individual Level

In this level of the SEM, an individual's knowledge, skillset, self-efficacy, gender, age, racial identity, and attitude regarding the association between the environmental exposure to contaminants and their health outcome(s) are on display. Knowledge about cancer and heart disease help the individual understand how they will affect their lives, inform them about susceptibility to these diseases, severity of these diseases, and the overall exposure and threat of these diseases. Knowledge will help influence the individual's attitudes and decisions about potential actions. Individuals have a responsibility to educate themselves, family members, and social networks about their health status through available, health provider recommended resources. Through prevention activities such as cancer assessments and screenings that can be implemented at this level, the intention is to facilitate individual behavioral changes that overcome level-specific barriers by influencing alterations to social and cultural norms.

Organizational Level

At the organizational level, the community consists of various organizations (schools, companies, and community centers) that can pool resources, ideas, and services together to focus on and improve the community's health. The organizational level allows the opportunity to reach more people in various sectors or levels of the community. These organizations can effectively collaborate with one another to coordinate informational health events/activities for affected individuals and families who need education materials and other resources necessary to handle environmental chemical exposures and the respective health outcomes. The organizational level of this model is instrumental in guiding organizations such as the U.S. military, EPA, and public health entities in developing ideals and behaviors that promote and provide enforcement of regulatory behaviors. The influences of these organizations are significant when it comes to the communication of information regarding chemical exposures, preventive measures, environmental safety, and safe health practices. Organizations including state and federal governments, policy makers, and healthcare facilities can collectively negate future chemical exposures and environmental concerns in their communities because they have the voices and funding necessary to make change. In looking at the social and physical environments where VOCs are most prevalent, organizations with vast networks and support can influence individual and community-wide behavioral changes.

Community Level

In this level, there is an opportunity to reach larger numbers of people in various sectors of a community by engaging as many members as possible in the creation of environmental and prevention-related initiatives. The community level of the SEM includes neighborhood watch groups, coalitions, local media, and research institutions that will look at the social and physical environments where VOCs are prevalent and those relationships and networks within these settings that influence individual behaviors and customs specific to handling environmental and health concerns surrounding these chemicals. To create, prioritize and implement objectives on a scale that maximizes reach across the community, a community-based participatory approach (CBPA) is recommended. This approach is the most appropriate method of addressing and promoting the health inequities that arise from the widespread environmental exposure to VOCs and other contaminants. Further, utilizing this approach will allow individuals and their respective communities to actively participate in community-centered initiatives by providing direct input and becoming vested in relevant interventions.

Policy Level

At the final level of the SEM, public policy is at the forefront because public health and environmental safety policies at all levels affect prevention efforts and governing agencies are in charge of prevention activities. This level of the SEM is most important because of its influence on more of the population than any other level. For example, a law instituting rapid screening tests for people in geographical exposure areas or policies that provide special funding to healthcare organizations that treat the affected population are implemented at this level. The policy level of the SEM model focuses on the broader societal factors of VOCs, such as the potential health consequences, economic impact, and social policies, that will potentially affect large populations. Environmental policies instigated at local and national levels are at the forefront of the SEM. By establishing policies and laws at various levels of government, agencies like the CDC and EPA can continue vital research on chemical exposures in the environment and create more effective ways to deal with health outcomes that affect national morbidity and mortality rates. Policy actions that tackle potential health issues and economic impact to individuals and families require consistent and measurable resources.

The SEM is the theoretical framework that best supported this study because it addresses the relationship and interaction between the individuals affected, their social and societal interactions, the government organizations involved and the environmental factors that facilitated this issue. This model also recognizes the ways in which individuals allow various aspects of their lives to be affected by the interrelations of the levels of the model, meaning issues with their health and personal circumstances are investigated along with those that may exist within their specific communities and societies as a whole prior to attempting to provide any remedies to their respective difficulties (health issues). The SEM model provided understanding of a range of factors that put individuals at risk of water contamination and exposure to VOCs and how factors at any one level may influence factors at another level. In order to be more aware chemical levels in groundwater sources, it may be necessary for individuals to engage across various levels of the SEM simultaneously.

Nature of the Study

The nature of this study was to use quantitative research with secondary data analysis to study the relationship between occupational and nonoccupational individuals at the MCB in southeastern NC who were exposed to VOCs, and the incidence of cancer and heart disease within this population. The quantitative research method with secondary data analysis was used in this study because of its ability to assess the relationships between variables through statistical and numerical data and finalize research results. This research design measured the relationship by quantifying chemical exposure rates and showing the incidence of cancer and heart disease through secondary data analysis projected from the target population. The quantitative research method also measured cancer and heart disease incidence before and after exposure. For RQ2, the independent variable in this study was the amount of exposure to VOCs. The dependent variables are cancer and heart disease. The target population for this study included veterans and civilians who were engaged in occupational and nonoccupational activities at the MCB in southeastern NC from 1957-1987 but diagnosed with cancer and heart disease in 2019. This approach used a combination of geographical correlations, time trends, and occupational influences to assess cancer incidence rates within the time span that the wells were operational and the incidence of existing and new risk factors for VOCs. This quantitative analysis aligned the contextual effects of this population-level chemical exposure to morbidity and mortality rates post-contamination.

Secondary data from several federal government agencies was assessed, including the U.S. Department of Veterans Affairs (VA), the Department of Navy (DON), and

Centers for Disease Control and Prevention's ATSDR. These agencies have collected data and conducted epidemiology and surveillance research specific to the occupational and nonoccupational population from 1999 through present day. Thus, the dataset utilized for both the dependent and independent variables was derived from the ATSDR Child Health Initiative on Polychlorinated Biphenyls (PCB) Contamination. All data was de-identified and provided service history and medical diagnoses required to answer the research question.

Literature Search Strategy

Data and information gathered for this literature review was acquired by searching various electronic databases, websites and journals found electronically on websites, such as the Walden University, the Centers for Disease Control and Prevention (CDC), National Institute of Environmental Health Sciences (NIEHS), the VA, SAGE journals, PubMed and other electronically accessible websites with subject specific information and data. This study brings together relevant secondary data and information from references in published articles, scientific studies, and journals. Selected articles associated with VOCs in groundwater sources and cancer prevalence at the MCB in southeastern NC were searched using the keywords and phrases *TCE and tetrachloroethylene, VOCs in groundwater, VOCs at Camp Lejeune, Camp Lejeune water contamination, veterans with cancer at Camp Lejeune, VOC effects on cancer rates, VOC effects on heart disease, VOC effects on cardiovascular disease, VOCs in dry cleaning materials, dry cleaning at Camp Lejeune* and *cancer and heart disease causes* in the aforementioned databases and search engines. References from both published and unpublished journals; public health policy documents and research reports such as those from the VA, ATSDR and DON; health studies on cancer incidence and chronic diseases, specifically heart and lung disease; and data and literature relating to cancer morbidity and mortality of children and adults on various MCBs were included. Publications and selected articles from the 2017-2022 were included in this literature review and those publications and articles were synthesized to determine an adequate conceptual model for this study and discussed at length in the following section.

Literature Review Related to Key Variables and/or Concepts

This literature review examined local and national background literature associated with VOCs on cancer incidence, heart disease, and resulting mortality rates including the significance, data, and other factors contributing to cancer incidence and heart disease regarding the use of the aforementioned chemicals in groundwater contamination, along with the potential public health and social initiatives that can be instituted by various organizations nationally and globally. This literature review included the few available articles dated within 5 years of this study, and that specifically reference the association between VOCs and heart disease in any capacity. There are/were no research articles available in 2021 that specifically reference the association between VOCs found in groundwater sources and heart disease. In addition, the theoretical framework and conceptual model, related occupational and nonoccupational studies, and individual and community impacts are provided. This literature review reviews the initial studies regarding the study's premise starting in the 1990s, but primarily focuses on the target population's health status post-diagnosis from the last 20 years to present. Various state and federal public health and environmental organizations were discussed along with their respective roles and contributions to chemical and cancer research studies and prevention efforts. The articles used in the explanation of the theoretical foundation and facts regarding cancer incidence and mortality as a result of the water contamination here in the United States have been cited as justification to the study's relevance present day and the necessity for integrated chemical prevention techniques and an environmental control approach. This approach considered the importance and impact of health promotion measures that engage the target population in ongoing decision-making processes and activities that aim to eliminate the presence of VOCs in drinking water across the country.

This study addressed the gaps in literature regarding the relationship between VOCs and cancer incidence in the target population of occupational and nonoccupational individuals on a MCB in southeastern NC, and the effects of VOCs on heart disease, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses. Moreover, longitudinal time-series studies have shown that ambient VOCs, such as alkenes and alkynes, are associated with increased heart failure emergency hospitalizations (Ran et al., 2018b), as well as overall cardiovascular hospitalizations (Ye et al., 2017), and that occupational exposure to VOCs, such as styrene, increases the relative risk of death from ischemic heart disease (Matanoski and Tao, 2003). Additionally, understanding the relationship between individual health status and behaviors regarding water contamination is necessary in effectively developing new strategies that improve public health outcomes on a broader scale.

This section of the study highlighted the literature search strategy for the study, theoretical framework, domestic burden of water contamination, and the adverse health effects of water contamination as a result of these chemical solvents. This section also provided a brief overview of how VOCs were utilized industrially, how they affected the target population and the long-term health effects such as cancer diagnoses, including mortality. The section reviewed the research methodology and rationale for using quantitative analysis in this study and concluded with a brief summary/discussion on the study's overall focus.

Studies of Significance

What are VOCs?

VOCs typically are industrial solvents, such as TCE; fuel oxygenates, such as methyl tert-butyl ether (MTBE); or by-products produced by chlorination in water treatment, such as chloroform (EPA, 2020). TCE is a nonflammable, volatile, and colorless liquid that evaporates quickly into air, emitting a sweet odor. Historically, the two primary uses of TCE were as a grease-removing solvent for metal parts and as a chemical base used for making other chemicals, most notably refrigerant (HFC-134a). TCE has also been used as an agent in the production of pesticides, paints, adhesives, lubricants, and pesticides. PCE is also a nonflammable, colorless liquid that emits a sweet odor and evaporates quickly into air. PCE is also classified as a halogenated volatile organic compound (HVOC). Historically, PCE was primarily used as a degreaser and as a solvent in dry-cleaning operations but was also used largely in some consumer products. Its use in the manufacturing and other industries has been significantly decreased in the past 30 years, reducing PCE levels in air measurements and in occupational exposures.

Exposure Effects of VOCs

An individual can be exposed to VOCs through direct contact with soil, when small amounts are transferred orally, through skin contact, or through inhalation from air or dust. Exposure to the two chemical solvents can also be caused from contaminated water sources, as with the target population in this study. Once the chlorinated solvents enter the bloodstream, they mutate into other chemicals. The health effects of TCE depend on how much TCE you are exposed to and the length of that exposure (ATSDR, 2019). Individuals exposed to large amounts of the chemicals may experience dizziness, nausea, headaches, or itching of the nose, throat, and eyes. Direct contact with skin can cause redness, inflammation and/or blistering.

Environmental Concerns of VOCs

Most VOCs used in the U. S. are released into the atmosphere from degreasing and manufacturing operations through the process of evaporation. Most TCE in surface waters or on soil surfaces evaporates into the atmosphere, although its high mobility in soil may result in it moving into groundwater below the soil surface (ATSDR, 2019). Once these chemical solvents enter the atmosphere, the degradation process (the process in which each of the chemicals reacts with hydroxyl radicals and consisting of an estimated half-life of roughly three to seven days) occurs. For VOCs, a short half-life period indicates that they are not persistent atmospheric compounds. VOCs in subsurface environments are only slowly degraded but may be moderately persistent. TCE, PCE and other VOCs can diffuse from soil and groundwater sources and migrate into air pockets underneath buildings or other structures that contaminate indoor air through the process of vapor intrusion. These chemicals are most often detected in environmental samples as a result of accidental spills or leaks. Environmental monitoring data suggests that TCE levels the public might encounter by direct contact or through air, water, food, or soil, are generally much lower than the levels at which adverse effects are elicited in animal studies (ATSDR, 2019). However, some drinking water sources and working environments have been found to contain levels of TCE that may cause health problems (ATSDR, 2019). McGraw et al. (2021) states that VOCs are major components of environmental pollution, with exposure being associated with high blood pressure, endothelial dysfunction, and increased levels of catecholamines, and consequently may be a significant risk factor in the development of heart disease.

Studies Related to the Constructs of Interest

There are several studies that have been conducted to justify this topic's importance, as well as the need for further research and environmental initiatives that prevent the leakage of hazardous chemicals in water sources. The EPA has found TCE in at least 1,051 of the 1,854 current or former National Priorities List (NPL) sites (ATSDR, 2019). This information is important because these future sites may be sources of exposure, and exposure to TCE may be harmful (ATSDR, 2019). The investigation of cancer associations with solvent exposure through water sources, specifically as a result of the dry-cleaning industry, has shown that there are associations between exposure levels of VOCs and various cancers. Cardiovascular disease (CVD) is the leading cause of death from environmental exposures, surpassing the number of attributable deaths to cancer mortality (Bhatnagar, 2017). Total VOC exposure is often measured indoors and has been associated with increased blood pressure (BP) and heart rate (Jung et al., 2016), heart rate variability (Mizukoshi et al., 2010), and autonomic nervous system changes (Wang et al., 2007). Water authorities often rely on the safe operation of public water supply systems and do not actually make any control of operation and conditions of the infrastructure (Vlček, 2019); however, failure of the infrastructures have often caused detrimental effects for many military families and civilians.

In 2007, the Marine Corps launched notifications and a corresponding registration campaign for former residents of the MCB in southeastern NC to sign up and provide information through telephone and internet surveys regarding their service connection or employment status and related health issues. Nearly 10 years later in January 2017, the VA finalized a new rule that considered eight predominant diseases that were presumed service-connected due to contaminated drinking water and provided disability benefits to veterans and their spouses who had one of these eight diseases from August 1953 to December 1987. These eight diseases included aplastic anemia and other myelodysplastic syndromes, adult leukemia, bladder cancer, liver cancer, kidney cancer, multiple myeloma, non-Hodgkin's lymphoma, and Parkinson's disease. Scientists from the ATSDR (CDC) have conducted the most in depth studies on the target population to date, including a health assessment, morbidity study and toxicological profile, all of which included various quantitative and qualitative analysis that exhibits the effects of VOCs on the human body and cancer morbidity. All research carried out by this agency was unbiased and scientific in nature, contributing to its validity and strengths in research. ATSDR uses existing scientific information, which can include the results of medical, toxicologic and epidemiologic studies and the data collected in disease registries, to determine the health effects that may result from exposures (ATSDR, 2017). Also, because this agency utilized existing scientific information on the health effects of VOCs, and environmental health is ever evolving, these too are limitations in research due to data that is still developing with the target population.

Luo et al. (2019) added to my study’s initial premise by assessing the effects of TCE on kidney toxicity, affecting liver functions. Because VOCs can cause long term damage to the liver, bladder, kidneys and other organs, the author’s research on these solvents was important in providing potentially new approaches to creating health risk assessments. These assessments would set up actionable thresholds for future exposures to hazardous environmental and occupational chemicals in geographical areas where there are still high concentrations. Ruckart et al. (2013) provided information on the prevalence of groundwater contaminants causing childhood cancers and neural tube defects (NTDs). The Ruckart et al. research was prevalent to this study because many in its population were a part of the current target population. Based on scientific literature available at the time the authors conducted their research, the childhood cancers of focus were hematopoietic cancers, including leukemia. Several studies have examined associations between birth defects and childhood cancers among children born to female workers exposed to solvents (Desrosiers, 2012), however, there are no studies of this nature that provide secondary data dated within five years of this study. Only a few studies have evaluated associations between maternal exposure to these contaminants in drinking water and birth defects and childhood cancers (Ruckart et al., 2013). Their research concluded that there was an exposure response relationship between women in their first trimester to TCE and weaker associations between PCE and first trimester pregnancies but suggested the need for policy changes in regulating contaminant levels in drinking water sources.

Studies Related to the Key Independent, Dependent, and Covariate Variables

The ATSDR Morbidity Study (2018a) examined the health statuses of former marines, employees, and dependents who were potentially exposed to contaminated drinking water at the MCB in southeastern NC. By conducting a health survey that collected information on health provider diagnosed diseases from individuals who were stationed or worked at the MCB, data was compiled based on residential and occupational history, female reproductive history, smoking and alcohol consumption, demographics and other diseases/conditions not specifically listed in the survey questionnaire. Janfaza et al. (2019) examined the relationship between VOCs and their effect on cancer cells for diagnostic purposes. The authors of the Janfaza et al. study applied various methods, using cancer-related VOCs to in-turn detect other cancers at earlier stages and potentially yield significantly higher chances for survival. While there were limitations in this study, there was a comprehensive analysis of cancer biomarkers that can help researchers look at cancer incidence effectively through cancer-related VOCs. Strelitz et al. (2019) examined the environmental effects of VOCs on workers engaged in the 2010 Deepwater Horizon oil spill and who faced exposures to various chemicals generated by the oil spill and corresponding cleanup activities. Some of the VOCs that were a part of the oil spill are the same as those contained in the groundwater contamination referenced in this study, and thus, show an association to risks of coronary heart disease (CHD). Forand et al. (2012) examined prevalence of TCE in indoor air through soil vapor intrusion and the effects of these chemicals on birth outcomes in women exposed to contaminated drinking water sources. Self-reported cancers and other diseases of interest were confirmed by medical records, cancer registry information, or death certificates (ATSDR, 2018a). Information reported in the survey on race; sex; education; age at survey, cancer diagnosis, or death; ever smoked cigarettes; and current number of alcoholic drinks was assessed for potential confounding (ATSDR, 2018a). The morbidity study included an exposure assessment that estimated contaminant levels in the base's drinking water source. It was disclosed from current MCB and retired base personnel that most residences and civilian employees received water from the Point water treatment facility.

There is not one study or body of research that addresses both the independent and dependent variables specified in this study, but each of the studies referenced in this review either individually or collectively addresses the levels or amount of exposure on a particular dependent variable. When age, gender, ethnicity, and pre-existing conditions were included as factors significant to a cancer diagnosis in the target population from the time of post-contamination, few epidemiologic studies focused on the long-term morbidity and mortality rates. This study focused on a population of cases, cancer incidence and heart disease as a result of the amount of exposure to VOCs and the population's morbidity occurrence post-contamination. McGraw et al. (2021) examined the vascular effects of exposure to individual VOCs and mixtures of VOCs to assess their respective effects on vascular dysfunction. The authors of the McGraw et al. study concluded that the participants who were at moderate to high risk for CVD had a significant association with VOCs and VOC mixtures. The authors also revealed a consistent, positive, and linear association/relationship between specific VOCs and CVD, suggesting a more significant exposure than initially assumed, and that Black participants involved in the study may be more susceptible to the effects of VOCs. Lindell et al. (2017) states the need to assess actual protective actions of those who have experienced a water contamination emergency because these people made consequential decisions about how to protect their health and safety.

The long-term toxic exposure effects of VOCs on the human body induced cancer in the liver, kidney, and other organs, and in some cases heart disease, primarily via drinking water sources at the MCB in southeastern NC. Riggs et al. (2020) conducted a cross-sectional study to investigate how ambient exposure to VOCs exacerbate CVD. The authors did find some evidence of age and BMI modifying the relationship between VOCs and circulating angiogenic cells (CAC) levels. In addition, they also discovered via research models that age, race, sex, and hypertension were effect modifiers in some of the relationships between VOC metabolite levels and CACs, suggesting that exposure to low levels of VOCs could lead to damage of the endothelium and endothelial repair capacity deficits. The Morbidity Study of Former Marines, Employees, and Dependents

Potentially Exposed to Contaminated Drinking Water at U.S. Marine Corps Base Camp Lejeune (2018) found that contaminated drinking water at Camp Lejeune was associated with increased risk in both Marines and civilian employees for bladder cancer, kidney cancer, and kidney disease and that these results were informed by evidence from other studies. Study results add to the scientific literature and suggest possible associations between the chemicals in the drinking water at Camp Lejeune and these diseases (ATSDR, 2018b). The target population in this study was first affected through one or more of the various water systems, over the course of many years, operated by the MCB in the early 1980s and contains adults who were children at the time of contamination, military retirees and civilian employees who worked on the MCB. While there are no current epigenetic studies on this specific association in TCE exposed humans, Phillips et al. (2019) sought to investigate the differences between DNA methylation and three levels of TCE exposure in its target population – those with higher TCE exposure levels, lower TCE exposure levels and controls, when the exposure status to TCE and other hazardous chemicals were biologically identified and well characterized. In a case-control study conducted by Purdue et al. (2017), the authors examined the association between TCE and kidney cancer risk as a result of occupational exposure in the U.S. By using copies of medical records obtained to confirm kidney cancer diagnosis in the study population and to collect histological information and other clinical factors, the authors of the Purdue et al. study concluded that there was an association between high exposure to PCE and kidney cancer risk (but not with TCE) based on occupational tasks within the dry-cleaning industry and other industries where these solvents were utilized.

Studies Related to Research Questions

Within the last 10 years, data suggests there is decreased occupational and nonoccupational exposure to VOCs through dry-cleaning and other industries where there was traditionally direct seepage into groundwater sources. Accordingly, new technologies and more effective preventive interventions have been developed and applied over time, leading to a significant decrease of occupational exposure levels, even if high exposures have been occasionally reported (ATSDR, 2019). Ran et al. (2018) studied the health effects of ambient VOCs on heart failure, and more specifically, whether they are sufficient or insufficient environmental stressors on heart functions. In addition, the Ran et al. study analyzed the estimated effects of two specific VOCs, alkyne, and benzene, over a short period of time, and whether they affected hospitalizations related to heart conditions. The authors found that the population exposed to alkyne and benzene were associated with emergency hospitalizations for heart failure. There were distinct differences in the rate of heart failure hospitalizations amongst sexes, however, there were no differences observed among older and younger age groups when analyzing the relationship between VOCs and heart failure hospitalizations. These findings implicated that VOCs may have potentially caused environmental risks for heart failure in this population. Modenese et al. (2019) conducted a study aimed at confirming lower exposure levels in a group of dry-cleaning establishments to evaluate current occupational exposure to the VOC TCE. The authors concluded that there were significant differences in environmental concentrations and exposure levels to VOCs based on geographical areas in reference to the location of dry-cleaning shops where the solvents were used. This association coincides with and confirms the environmental negligence of the federal government in regard to monitoring water facilities on the MCB and the preeminent environmental dangers of water contamination for all populations if preventive measures are not modified in the future.

In reviewing the science of the effects of VOCs on the human body and cancer incidence, a recent study by Lee et al. (2019) suggested that occupational exposure to TCE below existing occupational standards may alter levels of key markers of immune function and kidney toxicity and raise additional questions about the safety of current standards. Lee et al. (2019) is also significant because it draws special attention the implication of adjusting the levels of TCE and other chemicals so that exposure incidence falls below current regulatory limits, and thus reduces the chances for loss of immunity functions and potential kidney toxicity. The results of this research study raised important questions regarding 1) how to sufficiently reduce levels of TCE in water and air sources and 2) how to better investigate the health outcomes from occupational and nonoccupational exposures so that the biologic effects negate the onset of cancer diagnoses and other chronic illnesses. The epidemiological data for oral exposure to TCE are much more limited than the inhalation data due to small numbers of studies and small cohort sizes, as well as potential confounding by co-exposure to other chlorinated solvents (ATSDR, 2019). The EPA concluded that TCE is carcinogenic to humans by all routes of exposure based on convincing evidence of a causal association between TCE exposure in humans and kidney cancer (EPA, 2011e). To evaluate cancer incidence and mortality, among other health issues, the toxicological profile completed by ATSDR

(2019) provided written verification of the current study's need to further assess the target population through the end of their lifespans. By following the remaining target population via surveys/questionnaires, placing them in control groups in various cohort studies and case-control studies and through the use of other relevant quantitative analysis methods, VOC exposure can be further observed for more reliable reporting of health outcomes specific to their exposure status, post-contamination. VOC exposure alone may not have contributed to certain health outcomes in the target population, as some studies suggest, however, obtaining new quantitative assessments of exposures to these chemicals through advancements in medical technology and in the recording and reporting of health data indicates a high probability of interest in additional research initiatives on cancer incidence and heart disease.

Definitions of Key Terms

The research questions for this study provided the dependent and independent variables. The independent variables in this study were the amounts of exposure to VOCs (VOC measurements from -0 to 300 in dataset). The dependent variables in this study included cancer incidence (cancer in dataset) and heart disease (heart disease in dataset). Control variables included in this study to provide descriptive statistics are age (<50 years old – 93 years old), ethnicity (Carolinian, Chamorro and Filipino), gender (male or female) and pre-existing health conditions (stroke, hypertension, and melanomas). This study was quantitative in nature and relied on secondary data from the U.S. Department of Veterans Affairs, DON, Minnesota Department of Health and ATSDR conducted through 2019.

The following terms and their respective definitions were utilized throughout the study to make readers aware of terminology specific to the study's premise of examining the relationship between two designated chemicals found in groundwater sources on military installations due to dry-cleaning processes and the associated incidence of cancer and heart disease in both veterans and civilians who were engaged in occupational and npnoccupational activities at these installations.

Age: Age as used in this study refers to the length of time an individual has lived.

Camp Lejeune: Camp Lejeune is a training base that promotes the combat readiness of the operating forces and missions of other tenant commands by providing training venues, facilities, services, and support in order to be responsive to the needs of Marines, sailors, and their families (U.S. Marine Corps, 2020).

Cancer: Cancer is a disease in which some of the body's cells grow uncontrollably and spread to other parts of the body (NIH, 2021). In this study, cancer is utilized in a general sense and includes all forms of cancer caused by groundwater contamination to the population.

Chlorinated solvents (organochlorines): Chemicals used primarily in the production of raw materials and other products. These solvents are commonly found in industrial and household cleaners.

Chronic diseases, specifically heart and lung disease: Chronic diseases, specifically heart and lung disease are defined broadly as conditions that last 1 year or more and require ongoing medical attention or limit activities of daily living or both

(CDC, 2021a). Examples of chronic diseases, specifically heart and lung disease are diabetes, heart disease and cancer, all of which lead the United States as causes of death.

Diabetes: Diabetes is a chronic condition that affects how the human body converts food into energy and can cause heart disease over time. Diabetes is used in this study as a pre-existing condition.

Ethnicity: Ethnicity is defined as an individual who belongs to a specific social group and that has common cultural and/or national traditions. This term as referenced in this study was specific to the ethnic groups that are Carolinian, Chamorro and Filipino.

Gender: Gender as utilized in this study relates specifically to being a male or female in regard to social and cultural roles for men and women.

Groundwater: Groundwater is the water source that exists underneath land in saturated zones or areas but is not formed from underground rivers. Groundwater fills and moves through underground pores and cracks with sand, soil, and rocks.

Morbidity study: This study was a detailed analysis or investigation of the incidence or prevalence of one or multiple diseases and the ratio of sick to well individuals within a population or community.

Heart Disease: The term "heart disease" refers to several types of heart conditions (CDC, 2021b). While coronary artery disease (CAD) is the most common type of heart disease at present time in the United States, this study references heart disease in a general sense and includes all heart conditions that have affected the population.

Hypertension: Also known as high blood pressure (HBP), occurs when the force of blood pushes against the walls of one's blood vessels and is consistently higher than normal. Hypertension is used in this study as a pre-existing condition to heart disease.

Melanoma: Melanoma is cancer that begins in cells that become melanocytes, which are specialized cells that make melanin (NIH, 2021). Melanoma is used in this study as a pre-existing condition that potentially leads to more aggressive forms of cancer.

Per- and ppolyfluoroalkyl substances (PFAS): Per- and polyfluoroalkyl substances are a family of human-made chemicals that are found in a wide range of products used by consumers and industry (U.S. Food and Drug Administration, 2020). While almost 5,000 various types of PFAS have been more widely used than others, many are still being studied because they are known to be resistant to water, oil, and heat.

Polychlorinated biphenyl (PCB): Industrial chemicals or products which belong to the family of man-made organic chemicals also referred to as chlorinated hydrocarbons.

Public health assessment (PHA): A public health assessment is conducted to determine whether and to what extent people have been, are being, or may be exposed to hazardous substances associated with a hazardous waste site and, if so, whether that exposure is harmful and should be stopped or reduced (ATSDR, 2005).

Socioeconomic status (SES): The measure of individual's income, education, occupation, or overall social standing in which inequities in accessing quality resources are revealed.

Volatile organic compounds (VOCs): These are human-made chemical compounds with high vapor pressure and low water solubility, primarily used in the production and manufacturing of industrial solvents such as refrigerants, paint products and pharmaceuticals. The exposure levels of these chemical compounds were also the independent variable in this study.

Assumptions

There were several assumptions noted and made throughout this study, including:

- Age and gender of target population affected cancer incidence through water contamination,
- VOCs largely affected the rates of cancer incidence and mortality in the target population,
- Occupational status was significant to chemical exposure susceptibility at the MCB,
- Access to secondary and population data would be substantially available through each government entity directly associated with the VOCs groundwater contamination research,
- All quantitative research methods were measurable and unbiased.

Scope and Delimitation of the Study

This is a quantitative research study that relied on the use of secondary data from the ATSDR Toxicological Profile for TCE conducted in 2019, the ATSDR Morbidity Study of Former Marines, Employees, and Dependents Potentially Exposed to Contaminated Drinking Water at U.S. Marine Corps Base Camp Lejeune conducted in

2018 and the ATSDR Camp Lejeune Drinking Water U.S. Marine Corps Base Camp Lejeune, NC conducted in 2017. This study was delimited to the improper use of exposure levels of VOCs, cancer incidence and mortality rates. All other variables including age, gender, ethnicity and pre-existing conditions, any health conditions not specifically addressed and factors significant to diagnoses during the designated timeframe in this study were considered beyond the scope of the investigation. As such the subsequent impact of this study, which includes the amount of VOC exposure, cancer incidence, heart disease, morbidity and mortality were not assessed.

Limitations of the Study

This study had limitations that included the availability of research studies conducted by the U.S. Department of Veterans Affairs (VA) and access to service records from the DON prior to 2000, and its reliance on secondary data and cohort studies. This study examined the effects of exposure to VOCs used in the dry-cleaning industry has on the target population and the cancer-causing and heart disease incidence through occupational and nonoccupational exposure to these chemicals. There is concern over the health effects of tetrachloroethylene, classified by IARC as a probable human carcinogen (International Agency for Research on Cancer, 2014), thus, this study also examined whether high chemical exposure levels to VOCs increased incidence of cancers in occupational and nonoccupational individuals at the MCB in southeastern NC through both drinking water and indoor air sources. All secondary data was derived from the ATSDR, the VA and the DON, all of which have respectively conducted their own assessments and studies through 2019 within the target population. The primary research used in this study was conducted using quantitative research with secondary analysis, and all information and statistical data was collected veritably, ensuring only merit-based standards are used during the study's design, data collection and data analysis methods. Data results from the target population was specific to this population only and informed of potential prevention methods and interventions that addressed the reduction of chemical exposure through groundwater and indoor air sources domestically and globally. Because this study targeted occupational and nonoccupational individuals, not excluding dependent children with some affiliation to the MCB in southeastern NC in the early 2000s, an additional limitation of this study was the low response rates to some of the surveys conducted by ATSDR. This limitation affected how the research questions were answered, and therefore limited results regarding the full scope of cancer incidence rates in the target population.

Other limitations of this study specific to secondary data included incorrect reporting of participant information and results, and nonreporting of personal information (e.g., pre-existing health conditions and dates of diagnoses).

Significance of the Study

This study's findings identified linkages between cancer diagnoses and heart disease and current levels of VOCs still affecting many groundwater sources, despite other multi-factorial causes of cancer and heart disease. This study could potentially add to the larger body of evidence that links VOCs to an increase in cancer incidence and heart disease not previously identified by secondary analysis. By using the available cancer outcome and environmental data, individual and group exposure statuses in highly concentrated VOC areas can be identified effectively. Furthermore, newly emerging pollutants like personal care products and pharmaceuticals, pesticides, and industrial and household chemicals, and changing climate patterns represent a new water quality challenge, with still unknown long-term impacts on human health and ecosystems (United Nations Educational, Scientific and Cultural Organization, 2019). With more contaminants at levels that exceed current health guidelines, U.S. government officials are recommending new regulations associated with cancer be implemented.

Based on this study's findings, scientific, environmental, and public health recommendations that specifically addressed the potential chemical threats of groundwater sources that increase cancer incidence and heart disease rates could be made, in addition to the recommendation of potential prevention strategies and activities that can be implemented in industrial areas. Recent research on water consumption advisories provides some insight into the magnitude of the warning noncompliance problem, as well as some explanations why noncompliance occurs (Lindell et al., 2017). This study provides additional exposure warnings for local, national, and global leaders when addressing water system issues. Smaller, rural communities, as opposed to large communities, are contributing significantly to the overall cancer risks and incidence associated with drinking water. If new or revised protective actions are taken, consumption of contaminated drinking water can be limited and eventually eliminated.

Social Change Implications

Social change applies to the changes certain human exchanges and associations have in transforming social institutions over extended periods of time, often with far-reaching societal consequences. The potential social change implications of this study were more deeply permeated in the day-to-day lives of individuals globally because of the societal consequences VOCs have on cancer occurrence and heart disease not only through water sources, but in many cases, air also. As a part of its Sustainable Development Goals (SDGs) and water quality initiatives, the United Nations Educational, Scientific and Cultural Organization (UNESCO) will address best practices for implementing new health goals, reducing poverty, maintaining ecosystems, providing sustainable global consumption through new production processes and acknowledging the associations between water quality and vital socioeconomic, environmental and developmental issues specifically related to human health.

One of the major environmental issues affecting humanity is the increasing worldwide contamination of freshwater systems as a consequence of industrial and chemical compound materials being emptied into their pathways/runways, majorly in form of micro-pollutants (Inyinbor et al., 2018). VOCs such as TCE is found in commonly used products such as spot removers and adhesives and PCE is still frequently used in dry-cleaning processes to remove oil-based substances, both of which are found in local hardware, grocery, and drug stores. Because of the widespread use of these products today, exposure to these chemicals is inevitable outside of the population specified in this study and will therefore potentially increase cancer morbidity and mortality rates over time. From an environmental perspective, potential social change implications also include a larger susceptibility to the health threats imposed by these chemicals through drinking water and air sources if material consumption and global populations continue to increase. Sustainable development in any society is an access to initiate a good standard of living for the populace (Inyinbor et al., 2018).

Through sustainable development, the public health and scientific community can provide attainable solutions for environmental and social challenges without posing threats to the global population and future environmental development. Also, these include social progress and equality, environmental protection, conservation of natural resources, and stable economic growth (Ilin et al., 2016). The contamination of groundwater sources and private wells with VOCs, based on the amount of chemical exposure, length of exposure, and various other factors such as pre-existing health issues, ethnicity, and age, causes severe illness and damage in the reproductive system, kidneys, and liver primarily. These chemicals, which do not ever breakdown, increase health risks, thus making it necessary for environmental researchers and public health officials across various agencies to continue investigating the long-term effects of human exposure on specific cancers and other chronic diseases, specifically heart and lung disease in the living population from the MCB in southeastern NC. The data and analysis provided in this study intends to add to existing literature the impact of these two chemicals in high concentrations on residents and civilians of the MCB in southeastern NC decades later, and the association between the chemicals and the most prevalent illnesses and diseases affecting the remaining population of residents and civilians.

By sharing research and creating awareness of the complex health issues related to chemical contaminants in drinking water, the premise of the study and research was that it could be practically applied to reducing occupational exposure to these and other chemicals present in various drinking water sources, thus reducing the incidence of cancer and heart disease. The existing social costs of contaminated water have been debilitating for many, therefore, examining linkages between exposure and chronic illness provides additional academic support needed for environmental scientists, public health professionals and policy makers to revise standards of practice, provoke broader public discussions about the preservation of clean drinking water, increase public awareness of environmental pollutants and foster more advocacy for this public health issue.

Summary and Conclusions

Water systems on the MCB in southeastern NC were found to be contaminated with various VOCs, which seeped into groundwater sources from the on-base dry cleaners. These water systems were supplied by two primary water treatment plants, TT and HP, which served much, if not all, of the bases' housing, schools, administrative offices, and recreational areas. The target population in this study was initially subjected to the contaminated water systems during service or employment dates between 1957 and 1985 when the wells were finally closed. Some studies examined the levels of exposure to the two chemical solvents to determine whether there was an association between VOCs and adverse health outcomes, including cancer and heart disease. While there is valid research on the effects of exposure amounts of VOCs on cancer incidence and heart disease, the living population from the MCB in southeastern NC requires further study to assess and measure their health outcomes nearly 30 years post-contamination. Additionally, results from more current studies may be used in conjunction with tenets of the SEM to guide policy and regulatory decisions on implementing best practices and issuing controls for the amounts of contaminants still in drinking water. Scientific evidence of occupational and nonoccupational exposures based on biologic changes in the human body as a result of VOC levels should raise specific questions about whether any amount of chemical exposure should be deemed 'safe' and how long after an initial exposure should efforts be continued and warranted in investigating the health outcomes of the affected population.

As this study proceeds into the next section on research design and data collection, there was quantitative analysis provided to substantiate gaps in research and the necessity to increase research efforts by government, academia, and healthcare institutions on the population. There remains a deficiency of information in relation to the federal government's post-contamination follow-up with the population of affected individuals from the MCB. Thus, implementing multi-level and multi-systemic research to investigate this population-specific context is necessary to assist health professionals in diagnosing and treating potential late-stage cancer and chronic disease patients. As the need for advanced cancer controls due to environmental hazards increases, public health organizations that have demonstrated sustainable progress researching the effects of VOC exposure amounts on cancer incidence could close a significant information gap. Through organizational partnerships that address various health issues, including cancer, national and global forums must be better equipped to handle environmental hazards that affect public health at large.

Section 2: Research Design and Data Collection

The intention of this study was to examine the long-term effects of VOCs on cancer incidence rates and heart disease in both veterans and civilians who were engaged in occupational and nonoccupational activities at the MCB in southeastern NC. Secondary data that included scientific evidence and statistics on the association between exposure to these contaminants and development of various cancers were examined. This study is unique because it assessed the specific effects of the chemicals on cancer incidence, predominant cancers caused by the chemicals, and present data on cancer mortality rates within the affected population from the MCB in southeastern NC.

The purpose of this quantitative study was to increase public awareness and provide in-depth analysis of the association between VOCs and cancer incidence and heart disease, and mortality rates. The SEM was used to understand the correlation and outcomes of VOCs on the target population's health and their respective community's engagement in prevention activities post-contamination. The dissemination of information and quantitative data from this study expressed the ongoing need for policymakers to provide public health researchers with extended funding for new toxicological and health studies and individuals who have been exposed to large enough amounts of chemical solvents through water and air sources with access to long-term healthcare resources. This study also included the following variables:

Independent variable (IV):

- Amount of VOCs

Dependent variables (DVs)

- Cancer incidence
- Heart disease incidence

I controlled for age, gender, ethnicity, and pre-existing conditions in the target population in 2019. This section focuses on the research design and rationale, methodology, and threats to validity. The research questions and corresponding hypothesis are restated, including a description of the variables used, after the research design and rationale, followed by the methodology, which discusses the target population, sampling and sampling procedures used in collecting secondary data, instrumentation and operationalization of constructs and data analysis plan. Lastly, the threats to validity and ethical procedures are discussed.

Research Design and Rationale

The correlational quantitative research design utilized secondary information from the CDC/ATSDR and Minnesota Department of Health. The datasets utilized on both the dependent and independent variables were derived from the ATSDR Child Health Initiative PCB Contamination study (2019). Quantitative research is structured and objective, and generally aims to produce conclusions on a population level. It can be used to find patterns and averages, make predictions, test causal relationships, and generalize results to wider populations (Bhandari, 2020). With quantitative research, knowledge is produced through a process of quantifying concepts, followed by the verification and falsification of hypotheses by conducting statistical analyses (European Public Health, 2016). The correlational design was chosen for this study because it measures the relationship between exposure and the outcomes of interest during the specified timeframe and without manipulating variables or the study's environment. Findings from this research design can be used in determining cancer and heart disease prevalence and to forecast social change implications based on the data. Using the data from the cross-sectional health surveys in this study thereby addressed the research questions and provided numeric translations of VOC exposure levels and the incidence of cancers. Additionally, the correlational design assisted in determining any association between variables from selected participants at a single point in time, making the correlational design the most appropriate design based on the secondary data that would be used from resources.

This study used secondary data analysis based on the method's ability to use the given statistical data to measure and analyze associations between the IVs and DVs. The IV in this study was the exposure level of VOCs. The DVs in this study are cancer incidence and heart disease. There are controls for age, gender, ethnicity, and pre-existing conditions in the target population in 2019. Using a secondary research methodology in this study enabled me to collect data previously utilized in national surveys, historical, and medical records. For quantitative data analysis, this study used both descriptive and inferential statistics to answer the three research questions. The descriptive statistics were used to summarize the data and the inferential statistics were also used to test the hypothesis that correlates with examining occupational and nonoccupational individuals who were exposed to VOCs, and the incidence of cancer and heart disease within this population in 2019. The correlational quantitative research design that was used in this study allowed for maximum use of time and resources, as this design facilitates the use of secondary data that has been originally collected from other sources and research purposes. Although limited in terms of collecting data once in a limited time, the correlational research design indicates possible relationships between variables; therefore, it provides an opportunity to generate assumptions for different quantitative research in the future (Levin, 2006). The goal of this research design was to collect data that examined the relationship of a specific disease along with other variables of interest within the target population, providing a general snapshot of cancer incidence in the specified time frame. Thus, using this research design made it possible to assess the target population's burden when they encountered cancers and other chronic diseases, specifically heart and lung disease. This design choice was consistent with other research designs in advancing knowledge of the discipline because it is useful in helping policymakers determine how to allocate resources to the population while also determining best practices for future environmental prevention measures should a contamination of this magnitude occur again.

Research Questions and Hypothesis

This study was based on three research questions (RQs), each generating its own corresponding hypothesis that provides a sufficient comprehension of given variables:

RQ1: Descriptive: What proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs?

The independent variable is the proportion of occupational and nonoccupational individuals at the MCB, and the dependent variables are incidence of cancer and heart disease from VOCs.

$H_0$1: There is no statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.

$H_1$1: There is a statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.

RQ2: Inferential: Are VOCs associated with elevated risks of cancer incidence in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when controlling for these covariates: age, gender, ethnicity, and pre-existing conditions in 2019?

The independent variable is the level of exposure to VOCs, and the dependent variable is incidence of cancer. The outcome variable is also incidence of cancer.

$H_0$2: There is no statistically significant association between VOCs and the elevated risks of death from cancer in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

$H_1$2: There is a statistically significant association between VOCs and the elevated risks of death from cancer in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

RQ3: Inferential: Are VOCs associated with elevated risks of heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post contamination, when controlling for these covariates: age, gender, ethnicity, and pre-existing conditions in 2019?

The independent variable is the level of exposure to VOCs, and the dependent variable is incidence of heart disease. The outcome variable is also incidence of heart disease.

$H_0$3: There is no statistically significant association between VOCs and the elevated risks of death from heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

$H_1$3: There is a statistically significant association between VOCs and the elevated risks of death from heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

Methodology

Study Population

The target population in this study consisted of a similar sample of occupational and nonoccupational individuals as those from the MCB in southeastern NC from 1957 – 1987. The population sample in this study provided evidence of the association between exposure levels of VOCs and incidence of cancer and heart disease, potential mortality rates from cancer and heart disease and the percentage of named cancer and heart disease in the population from any sources other than VOCs. The sample population was derived from an unrelated health study conducted by an unidentified source, in which the organization used the Defense Manpower Data Center (DMDC) personnel databases and an earlier ATSDR survey on birth defects and childhood cancers to identify persons (ATSDR, 2018a) who either lived or worked on the MCB during the timeframe that the drinking water contamination occurred. Additionally, the health survey consisted of 1184 total participants – including a variation of men, women, and children (who were born before 1986 and are now adults). The approved health survey identified individuals who developed cancers and conditions of the heart to obtain population specifics such as the residential history of participants on the MCB, demographic information and other relevant lifestyle factors. Occupational and nonoccupational individuals who lived or worked on the MCB during the water contamination period, and elected to participate in the survey, were required to provide accurate and current personal information on themselves and any other members of their households residing or working on the MCB.

To encourage study participation, individuals were initially mailed pre-notice letters from MCB leadership explaining they would receive a survey via mail and shortly thereafter, personalized letters of invitation, hardcopy surveys (with return envelopes) and emails (where applicable) were sent out. There was an option directing participants to a web-based edition of the survey if preferred. Potential participants who failed to respond to the initial survey were mailed a second time and received telephone reminders. To minimize chances of information bias, none of the correspondence methods specifically mentioned the contaminated drinking water, but rather, the communication materials explained that a research activity to gain knowledge about health effects of environmental exposures to hazardous chemicals in the workplace was being conducted. For individuals who were residents or employed on the MCB during the contamination period and were deceased (based on address tracing services that identified them as deceased), surveys were mailed to the next of kin if their address information was the same and available.

There were various efforts made to inform the population about the health survey and encourage participation, including using local and national media outlets, posting information and materials on the CDC/ATSDR websites, social media, and nongovernmental agencies, in addition to coordinated efforts to conduct outreach directly through the U.S. Marine Corps (USMC). Once surveys were returned, participants were required to complete and return informed consents either electronically or via hardcopy. The information collected for the initial health survey included diseases and pre-existing conditions (including various cancers, severe kidney and liver diseases, and TCE-related skin conditions) individuals' may have already had (and were previously diagnosed with by a healthcare provider) during the time the individual was stationed, first lived, or worked at the MCB and the time at which the survey was received and returned to the agency. To eliminate chances of information bias, information requested for cancers specifically included: date of diagnosis, type of cancer and state of diagnosis. Further, the health survey requested information on residential history on the MCB, occupational history (service or employment dates and facility), female reproductive history, smoking and alcohol consumption, demographics, education level, and other diseases/illnesses/conditions not otherwise mentioned in the questionnaire.

Medical records, cancer registries, and death certificates confirmed self-reported cancers and other chronic diseases, specifically heart and lung disease. Participants who reported a disease of interest were mailed a Health Insurance Portability and Accountability Act (HIPAA) form to facilitate confirmation via medical providers or cancer registries (ATSDR, 2018b). ATSDR received approvals from 13 state cancer registries that had 100 or more participants who reported a cancer (California, Florida, Georgia, Indiana, Michigan, New York, NC, Ohio, Pennsylvania, South Carolina, Tennessee, Texas, and Virginia) to assist in confirming the self-reported cancers; these states accounted for approximately 60% of all cancers reported in the survey (ATSDR, 2018b).

The total sample population was initially 58,115, consisting of 50,684 Marines and 2168 civilian employees from the DMDC and 5263 participants from the previously conducted ATSDR survey including Marines, their spouses, and adult children. The primary exposure to contaminated drinking water for Marines and civilian workers on the MCB was in their respective workplaces. Marines could also be exposed to drinking water contaminants in their residences, during training exercises or other activities on the base. The health survey for Marines included sex, race, education, rank, age at the time of the survey or age of death, whether the individual worked with pesticides, radiation, metals, solvents or other chemicals, number of alcoholic drinks consumed, if the participant smoked cigarettes and if the participant served in Vietnam. The health survey for civilian employees included whether the participant worked in food preparation, in laundry or dry-cleaning facilities, as a painter or other blue-collar jobs, with solvents, radiation, pesticides or polycyclic aromatic hydrocarbons.

Sampling Method

Probability Sampling

Probability sampling is a sampling technique used often in research to determine that each member of the designated population receives an equal opportunity to participate in the study of interest, hence providing true data and/or study representation and probability specifications. Researchers use sampling methods that guarantee each participant has an equal opportunity to be selected through the process of randomization, which removes both sampling and systematic bias. The primary advantage of random sampling is that, if done correctly, the selected sample should be representative of the whole population. Probability sampling typically includes the use of simple random, systematic, stratified, or cluster samples (Laerd Statistics, 2012a). Probability sampling is a technique that should be conducted in research whenever possible. Scholars and researchers use probability sampling aids to provide the most optimal general and statistically sound research evidence possible.

Probability sampling includes simple random (SRS), stratified, systematic, multistage and cluster sampling. SRS is the most fundamental design used in this technique. SRS entails the “procedure that assigns to each of the sampling units of the population an equal and known non-zero probability in being selected” (Frankfort-Nachmias & Nachmias, 2008, p. 169). In SRS, it is important to ensure that all the members of the population are included and that the necessary number of individuals are selected randomly. A systematic sampling design typically holds more convenience and ease when compared to simple random sampling (especially in regard to larger population groups; Laerd Statistics, 2012b). Stratified sampling involves first classifying and separating the population (referred to as strata) into various groups or units (referred to as stratum) based on various specific classifications to be represented in the research study, hence strengthening the study’s accuracy, and assumed parameters. This sampling technique is most useful when there is a necessity to classify the target population within various groups based on a factor or factors which might influence the variable(s) being measured. Additionally, characteristics of the stratum are stronger than characteristics of the strata. In many cases, the size of the population makes it more complicated for researchers to perform SRS. In these cases, cluster sampling is used because it identifies population boundaries and can accommodate using larger population groups (clusters). In cluster sampling, researchers select random clusters through SRS or systematic random sampling to collect and analyze data. Cluster sampling is different from stratified sampling in that it requires data be obtained on each of the sampling units from each of the clusters randomly selected. Systematic sampling is a sampling method that is similar in many ways to that of the SRS, however, this method is slightly easier to employ for researchers because it can still be utilized even if access to the listing of the entire study population is unavailable. For example, if the population is in ascending or descending order, this technique would give the researcher a reasonably representative sample of participants from both ends of the population spectrum. This technique should not be used when the study population is cyclically or periodically ordered because the resulting sample is not guaranteed to be truly representative. Lastly, multistage sampling is a technique that divides large populations into various stages, making the sampling process much more practical for researchers because it uses a combination of other sampling techniques – usually SRS and either stratified or cluster sampling.

Sampling Procedures

A quantitative analysis of VOC-related cancer and heart disease incidence was conducted for this study. This analysis involved the investigation of how current cancer incidence in the target population is affected by these two chemical solvents as well as the strategies necessary to prevent future chemical contaminations in water sources (via the review of secondary data). I used the following IVs: the amounts of VOCs (age, gender, ethnicity, and pre-existing conditions - as these variables are the predetermined controls). This study also consisted of a probability sample using SRS. The purposed audience for this study includes veterans and civilians who were engaged in occupational and nonoccupational activities at the MCB in southeastern NC from 1957 - 1987 but diagnosed with cancer and heart disease as a result of the water contamination in 2019. Although the initial recruitment technique by ATSDR was based on a retrospective cohort morbidity study with a nested case-control sample, the study holds some randomization elements.

Within the initial nested case-control sample, random samples of Marines that did not report having cancer or a noncancerous disease and female Marines that did not report having cancer or a noncancerous disease was used to evaluate individual exposures to specific water contaminants. Through random sampling, participants were filtered through the control series, maintaining a fair and equal chance of participating in the study. For those controls that did not specify if they lived on the MCB (dependents and active-duty personnel who were later married), information from the survey's residential history section and family housing records was used. The rationale for the research design and sampling strategy partly (probability random sampling) was that it would be challenging to use a nonprobability sampling design because all members of the target population wouldn't have a chance to participate in this study and in part, due to the limited availability of research sources and secondary data. Unlike with nonprobability sampling, random probability-based samples of the population may take an extended amount of time to collect survey responses and other pertinent data, such as demographic and medical information. Limitations included associated costs/funding to conduct the health survey, time restraints, availability of information/data (challenges and restrictions) and sufficient manpower necessary for conducting a generalizable study (via any other probability sampling design).

Sampling Estimations and Power Analysis

Sample sizes can be determined in a number of ways, including stratified sampling, power analysis and cumulative distribution to name a few. When attempting to calculate sample sizes in a quantitative research design, several factors should be considered, including the overall/designated population size, number of dependent and independent variables present, the desired confidence level (power = .80), interval (alpha = .05) and effect size (.05). Sufficient power to find statistical significance (i.e., via p□ value) for a given effect size minimizes chance findings and is critical to funding research, conducting statistical analysis, and publishing results (Hunt, 2015). With this study expected to yield a sufficient sample size, it may be assumed that the total sample size would contribute positively to the study's final result and that there would be a smaller standard of error and confidence interval.

Power Analysis

This study utilized all participants included in the dataset provided in order to provide the most actual results possible. A priori power analysis is not needed based on the decision to include all participants from the dataset, however, a post hoc power analysis was conducted after the statistical analysis was completed to confirm that the sample size was sufficient. The intended sample used in this study provided a valid estimation of the study's population characteristics, but also provided the audience with valid representation of the sample within the general population.

Instrumentation and Operationalization of Constructs

Instrumentation

Quantitative research designs can entail various instruments, such as interviews, questionnaires, and experiments, when it is necessary to provide a numerical interpretation of study data, or more specifically, a section of the overall target population's thoughts, feelings, and/or attitudes regarding an issue of interest. Surveys can provide clarity while also being informative and illustrative in nature. Surveys are typically "used for descriptive, explanatory, and exploratory purposes" (Babbie, 2004, p. 243). Surveys are utilized when gathering and evaluating observational data on a specific population. The health survey instrument, used for this study, was used in the initial health study conducted by ATSDR (2011-2012). The advantages of utilizing surveys include providing a generalized assessment of information and a standardized method of conducting data analysis.

Surveys "can reach a large number of people relatively easily and economically, provide quantifiable answers, relatively easy to analyze, and is less time consuming than interview or observation" (Scibd, 2014). The health survey being used in this study was administered through mail, emails (where applicable), a web-based site and telephone methods. While each method contains its own unique advantages and disadvantages, this instrument was the most appropriate based on the population attempting to be reached and because it could be easily analyzed and measured on social and scientific levels. The health survey provided individual health information pertaining to the population's direct encounters with developed cancers and heart conditions based on the residential history of participants on the MCB, in addition to demographic and other relevant lifestyle information such as dietary factors, tobacco and alcohol use and exercise habits.

Operationalization

The scale of measurements included in this study were discrete (ages of target population from less than 50 years through age 93) and nominal (gender and ethnicity). Pre-existing health conditions and cancer and heart disease incidence were also measured on a nominal scale. The variables used in this study were constructed based on the following two research questions: The dependent variables in this study are the incidence of cancer and heart disease from exposure to VOCs, which measured cancer incidence based on the information included in medical and other historical records and reported on the questionnaires and surveys obtained from study participants. The independent variables are the proportion of occupational and nonoccupational individuals at the MCB and the amount of exposure to VOCs. Control variables contributing to and providing descriptive statistics for this study include age, gender, ethnicity, and pre-existing conditions.

The measurement scales for the variables used in this study were nominal and scale. The nominal variables were categorical, polychotomous and dichotomous and the scale variable is continuous. The variables being measured on a categorical scale in this study were the ethnicity and gender of the population. Gender was measured on a dichotomous scale in this study. The variables measured on a continuous scale in this study were the age of the population in years, including the ages of children, women, and men. The variables that defined the incidence of cancer and heart disease from exposure to VOCs were measured as binary categorical variables with only two categories indicating yes or no. The variables that defined the proportion of occupational and nonoccupational individuals at the MCB, the amount of exposure to VOCs, pre-existing conditions and ethnicity are also being measured on a categorical scale with two categories, indicating exposure amounts over 0.0 and under 300. All IVs, DVs and covariate variable names that were utilized from the dataset for this study are identified by parentheses in the following table.

Table 1

Statistical Procedures per Research Question and Hypothesis

Research Question	Alternate Hypothesis (H_1)	Variables	Statistical procedures/analysis
RQ1: Quantitative: What proportion of occupational (Work**)** and n**on**occupational **(**Live) individuals at the MCB in southeastern NC from 1957 – 1987 were diagnosed with cancer (Cancer) versus heart disease (Heart disease) in 2019 from exposure to VOCs?	H_1: There is a statistically significant association between the proportion of occupational (Work) and n**on**occupational (Live) individuals at the MCB in southeastern NC from 1957 – 1987 who were diagnosed with cancer (Cancer) versus heart disease (Heart Disease) in 2019 from exposure to VOCs.	IV: Exposure level of VOCs DVs: Cancer (Cancer) incidence and heart disease (Heart disease) incidence in occupational (Work) and nonoccupational (Live) individuals	Descriptive statistics: mean, median and standard deviation and frequencies.
RQ2: Quantitative: Are VOCs associated with elevated risks of death from cancer (Cancer) in occupational (Work) and nonoccupational (Live) individuals at the MCB in southeastern NC, post-contamination, when age (Age), gender (Gender), Race (Ethnicity), and pre-existing conditions (HTN, Stroke, Melanoma) were designated as factors significant to diagnoses in 2019?	H_1: There is a statistically significant association between VOCs and the elevated risks of death from cancer (Cancer) in occupational (Work) and nonoccupational (Live) individuals at the MCB in southeastern NC, post-contamination, when age (Age), gender (Gender), race (Ethnicity), and pre-existing conditions (HTN, Stroke, Melanoma) were designated as factors significant to diagnoses in 2019.	IV: Exposure level of VOCs DVs: Cancer (Cancer), age (Age), race (Ethnicity), gender (Gender) and pre-existing conditions (HTN, Melanoma, Stroke) in occupational (Work) and nonoccupational (Live) individuals	Bivariate: Chi-square Multivariable analysis: Logistic regression
RQ3: Quantitative: Are VOCs associated with elevated risks of death from heart disease (Heart disease) in occupational (Work) and nonoccupational (Live) individuals at the MCB in southeastern NC, post-contamination, when age (Age), gender (Gender), race (Ethnicity), and pre-existing conditions (HTN, Stroke, Melanoma) were designated as factors significant to diagnoses in 2019?	H_1: There is a statistically significant association between VOCs and the elevated risks of death from cancer (Cancer) in occupational (Work) and nonoccupational (Live) individuals at the MCB in southeastern NC, post-contamination, when age (Age), gender (Gender), race (Ethnicity), and pre-existing conditions (HTN, Stroke, Melanoma) were designated as factors significant to diagnoses in 2019.	IV: Exposure level of VOCs DVs: Heart Disease (Heart Disease), age (Age), race (Ethnicity), gender (Gender) and pre-existing conditions (HTN, Melanoma, Stroke) in occupational (Work) and nonoccupational (Live) individuals	Bivariate: Chi-square Multivariable analysis: Logistic regression

Data Source and Data Collection

This study primarily used health survey data from ATSDR and the ATSDR 2019 Toxicological Profile for TCE to examine data on cancer and heart disease incidence and some demographic factors in the target population. The health survey specifically asked about cancers and diseases that were selected based on an extensive literature review of occupational and drinking water studies involving solvent exposure (ATSDR, 2018a). The ATSDR, part of the CDC, is a federal public health agency and entity of the U. S. Department of Health and Human Services.

Data Storage

The ATSDR health survey and other data is available to the public and may be obtained through written request via the ATSDR website where requests were directed to the proper official. In order to utilize the health survey and demographic data, in addition to respective datasets, all personal identifying information was removed by agency officials. Requested data for this study required me to only provide written request through email to the Epidemiologist who was a part of conducting the initial health survey. I was also required to provide in the email the title of this study, purpose and a brief description of the data requested. This request to obtain the dataset was submitted on March 21, 2021. The dataset I was able to obtain for this study was code encrypted on my personal computer, which is also password/pin protected for access. No access to my personal computer is permitted or will be granted to anyone other than myself at any time during the following five years from the completion date of this study. The dataset that was utilized in this study will be destroyed no later than five years after the completion of this study.

Data Analysis Plan

Data analysis is the process of evaluating data using analytical or statistical tools to discover useful information (Grant, 2020). Once researchers collect data needed for sorting and interpretation, the corresponding results are used for making important decisions that affect various concentrations. In the public health arena, a primary goal of programmatic analysis is to assess program impact and evaluate behavioral changes. This analysis is essential in determining risks and creating messages that can be transmitted, received, and understood by those in which they are intended for. Data for this study was interpreted using data analysis methods including descriptive statistics and linear regression. The level of significance was set up as p .05. This study also used deductive reasoning to focus on the conversion from a generated hypothesis to a specific conclusion that utilizes direct observation. In addition, deductive coding is an effective tool used in quantitative data analysis and may prove vital in interpreting the data in this study. Deductive coding involves the development of coding categories and codebooks, entry of collected data, and the distinction between univariate, bivariate, and multivariate analysis (Babbie, 2004).

The data analysis plans for each of the two research questions, along with the hypotheses, are as follows:

RQ1: Descriptive: What proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs?

The independent variable is the proportion of occupational and nonoccupational individuals at the MCB, and the dependent variables are incidence of cancer and heart disease from VOCs.

> $H_0$1: There is no statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.
>
> $H_1$1: There is a statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.

Data Analysis Plan for RQ1

Descriptive analysis was used to measure the relationship between the IV (proportion of occupational and non-occupational individuals) and the DVs (incidence of cancer and incidence of heart disease from exposure to VOCs). Descriptive analysis is applicable and most appropriate for data analysis of RQ1 because it is effective in showing the frequency and percentage distributions of demographic characteristics in the target population and corresponding sample. This analysis will also provide a conclusion for the distribution of collected data, while detecting possible outliers. Descriptive analysis will enable the identification of similarities among the IV and DVs, thus making it easier to conduct further statistical analyses in the following RQs.

RQ2: Inferential: Are VOCs associated with elevated risks of cancer incidence in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when controlling for these covariates: age, gender, ethnicity, and pre-existing conditions in 2019?

The independent variable is the level of exposure to VOCs, and the dependent variable is incidence of cancer. The outcome variable is also incidence of cancer.

$H_0$2: There is no statistically significant association between VOCs and the elevated risks of death from cancer in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

$H_1$2: There is a statistically significant association between VOCs and the elevated risks of death from cancer in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

Data Analysis Plan for RQ2 and RQ3

The Chi-square test of independence statistical test was used to measure the strength of the relationship between the IV (exposure level of VOCs) and DVs (cancer and heart disease in occupational and nonoccupational individuals). This statistical hypothesis test was used to determine whether the IV and DV were possibly related or not. In addition, crosstabulations was conducted to help determine any potential patterns or trends in the data, and any correlation between the variables. With various potential outcomes between the population and exposure to VOCs, this statistical test will assist in proving, or disproving, a hypothesis, beyond a doubt by drawing correlations and comparisons among mutually inclusive factors within this study. The binary logistic regression test was used to assess and measure the strength of the relationship between the IV (exposure level of VOCs) and DV (cancer in occupational and nonoccupational individuals). Binary logistic regression determines the impact of multiple independent variables presented simultaneously to predict membership of one or other of the two dependent variable categories (Hua, 2021). Binary logistic regression is most useful in estimating the probability of a variable being in a certain outcome category and in cases where there are multiple predictors. This statistical hypothesis test was used to determine whether the IV and DV are possibly related or not. With various potential outcomes between the population and their exposure to VOCs, this statistical test assisted in proving, or disproving, a hypothesis, beyond a doubt by predicting the probability that an observation, or hypothesis, would fall into one of two categories within this study.

RQ3: Inferential: Are VOCs associated with elevated risks of heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post contamination, when controlling for these covariates: age, gender, ethnicity, and pre-existing conditions in 2019?

The independent variable is the level of exposure to VOCs, and the dependent variable is incidence of heart disease. The outcome variable is also incidence of heart disease.

$H_0$3: There is no statistically significant association between VOCs and the elevated risks of death from heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

$H_1$3: There is a statistically significant association between VOCs and the elevated risks of death from heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

Statistical Package for the Social Sciences (SPSS)

In order to further evaluate the data that was used in this study, the IBM statistical analysis software platform SPSS v.25 was used to determine statistically significant associations or relationships through the use of statistical functions (ex: bivariate statistics, frequencies, predictions for identifying groups and cross tabulation). Many research agencies use SPSS for its ability to analyze survey data efficiently and quickly. This software package also helps researchers in various industries with data management, statistics, graphs and tables and regression models (which was used in this study's data analysis). Some of the key advantages of SPSS include its ability to import and/or export data in and/or out of Excel and its capability to proficiently manage and organize data. SPSS also offers the feature solution of data documentation, which allows researchers to store a metadata dictionary (Alchemer, 2020). This metadata dictionary acts as a centralized repository of information pertaining to data such as meaning, relationships to other data, origin, usage, and format (Alchemer, 2020).

Threats to Validity

External validity refers to the extent at which generalization of a study's results can be applicable to the entire population outside of the study's sample population. Internal validity refers to the extent at which there may be a causal relationship between the IV and the DVs. Internal validity also explains the probability that study outcomes that are not fully determined through the performance of actual interventions may not exist. In order to understand the intrinsic trade-off between internal and external validity, one must understand that the broader context the study has, the less extraneous factors can be controlled. The aim of internal validation is to separate uncertain from true cases based on information from secondary data alone or to reproduce known associations within the database (Hoffman et al., 2008). In addition, external validation of secondary data is desirable using original prescriptions, medical records, hospital discharge letters and/or patient or physician interviews as a gold standard (Hoffman et al., 2008). Taking into consideration validity concerns, this study utilized similar secondary data sources, and therefore, had very limited threats to internal validity because it focuses on external validation.

Any threats to internal and external validity associated with this study were a result of the limitations implicit to the use of secondary data. There are many disadvantages pertaining to the use and validity of secondary data, such as its availability, accuracy and the reliability of data collection processes and data sets. This study focused on the internal validity issues (including information bias and instrumentation) and external validity issues. Another important validity issue, specific to this study, was that of bias (particularly information, response, or survey bias). To minimize chances of information bias, survey correspondence did not specifically mention contaminated drinking water, it only sought to gain knowledge about existing health effects from environmental exposures to hazardous chemicals in the workplace, if known. Response bias could have occurred and have been caused by any number of factors including question selection (open-ended/closed-ended, unclear, double-barreled, or irrelevant questions), question formation (contingency/, matrix questions, and order/instructions pertaining to specific questions), incompetent or unwilling respondents, negative or long question items, pretesting of survey items, administration techniques (self-administered, interview, telephone, or computerized) (Laureate Education, 2010).

Ethical Procedures

Ethical issues were strongly considered as this study was conducted. Any research study has the potential to induce harm to human subjects through the intentional or unintentional release of confidential information, thus, in order to address and limit these concerns, ethical consideration and procedures were implemented. These procedures were implemented to protect secondary data confidentiality and the security of all data in use for this study. All personal participant medical, housing, and historical records obtained for this study remains secured on a locked computer that only I have access to. Outside of my access, only the professional staff of Walden University and other supporting entities engaged in the evaluation of this study have access to any confidential or highly sensitive information. All data used in this study was disposed of discretely once it had been assessed and evaluated in accordance with the university's ethical guidelines.

This study used the secondary data from several federal government agencies, including the VA, DON, and the ATSDR. These agencies have collected data and conducted epidemiology and surveillance research specific to the occupational and nonoccupational population for nearly 20 years. Thus, the datasets utilized on both the dependent and independent variables was derived from the ATSDR Child Health Initiative on PCB Contamination (2019). All data was de-identified and provided service history and medical diagnoses required to answer the research question. At the time these organizations conducted their respective surveys, any ethical concerns at the dissemination and collection stages were addressed, therefore removing potential risks for breaking or violating participant confidentiality. Because maintaining the confidentiality of participant information is always a primary concern for researchers, the approved health surveys utilized by ATSDR included protocols for eliminating information and response biases.

Based on privacy efforts implemented throughout the composition of this study, there was not any ethical threats to the participants because informed consent was obtained, and participant privacy was considered at the time of the initial survey in 2011-2012, thus deeming my study safe for the participants and ethical. This assumption was made because there was no experimentation conducted on participants of the initial health surveys nor did the study participants engage in any self-selection process. Using secondary data did not require me to readminister study-related consent forms to study participants, however, all other study-related datasets and personal records underwent the necessary measures required for adhering with Walden University's Institutional Review Board (IRB) processes. The IRB approval number for this study is 02-15-22-0657343.

Summary

This section provides a brief summary on the research design and data collection process that would be employed in this study, including a brief introduction of the study and explanation of the research methodology (study population/sampling, variables, operationalization/instrumentations, data analysis procedures, threats to validity, and ethical issues). This study design was quantitative and correlational, relying on secondary data from the . The sample population included 1184 respondents including Marines, their spouses, and adult children. Each of the headings in this section provided a justification for its respective use in the development of instrumentation and data analysis of secondary data sources being utilized to determine if/how VOCs affected cancer incidence in the target population 30 years post-contamination. Internal validity would not be assessed in this study since I was not looking to prove a cause-and-effect result. The next section, presentation of results and findings, provides an explanation, review, and data analysis based on the study’s hypotheses (including representative tables, charts, and figures).

Section 3: Presentation of the Results and Findings

The purpose of this study was to examine the long-term effects of VOCs on cancer and heart disease incidence in both veterans and civilians who were engaged in occupational and nonoccupational activities at the MCB in southeastern NC, 30 years post-contamination. The intention of this quantitative study was to increase public awareness and provide in-depth analysis of the association between VOCs and cancer and heart disease incidence and mortality, primarily their effects on incidence associated with cancer and heart disease. This study remains unique because it assessed the specific effects of the compounds on cancer incidence, predominant cancers caused by the chemicals and present, available data on cancer mortality rates within the affected population from the MCB in southeastern NC.

This study was based on three research questions (RQs), each generating its own corresponding hypothesis that provides a sufficient comprehension of given variables:

RQ1: Descriptive: What proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs?

$H_0$1: There is no statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.

$H_1$1: There is a statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.

RQ2: Inferential: Are VOCs associated with elevated risks of cancer incidence in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when controlling for these covariates: age, gender, ethnicity, and pre-existing conditions in 2019?

$H_0 2$: There is no statistically significant association between VOCs and the elevated risks of death from cancer in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

$H_1 2$: There is a statistically significant association between VOCs and the elevated risks of death from cancer in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

RQ3: Inferential: Are VOCs associated with elevated risks of heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post contamination, when controlling for these covariates: age, gender, ethnicity, and pre-existing conditions in 2019?

$H_0 3$: There is no statistically significant association between VOCs and the elevated risks of death from heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

$H_1$3: There is a statistically significant association between VOCs and the elevated risks of death from heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

This section focuses on the data collection of the secondary data set, explanation of results and a brief summation. The data collection methods are restated and explained, including the time frame and source utilized for providing secondary data. In addition, the results explain the inferential and descriptive statistics analyzed in this study, as well as the statistical analysis of VOCs on the target population and assumptions made regarding the hypotheses, and final conclusions.

Data Collection of Secondary Data Set

The data collection process for this study commenced roughly at the beginning of 2020, however, based on the availability of real-time secondary data from federal agencies, an alternate option had to be employed. There was a delay, and later a denial in receiving the initially requested dataset from the most recent 2011-2012 health survey conducted by ATSDR due to verification of release from the epidemiologist in-charge of survey data. There was a significant issue presented in using the initially requested secondary datasets from the 2017 ATSDR PHA for Camp Lejeune Drinking Water U.S.

Marine Corps Base Camp Lejeune, NC and the 2018 Morbidity Study of Former Marines, Employees, and Dependents Potentially Exposed to Contaminated Drinking Water at U.S. Marine Corps Base Camp Lejeune. Additionally, the 2009-2018 mortality data and cancer incidence data covering 1996-2017 (most current data) was requested but could not be shared with me due to stipulations and agreements set forth between ATSDR and the National Death Index, the CDC IRB, and state and federal cancer registries. Thus, the primary discrepancy in the use of the secondary dataset from the initial plan presented in Section 2 was the ability to procure the dataset as planned; therefore, an alternative secondary data set had to be used to conduct analysis on a population similarly affected by chemical contamination.

The baseline inclusion and/or exclusion of descriptive and demographic characteristics used in this study are essential in assessing the applicability of its results for the given population and the comparability of this population in any future meta-analysis. The PHA surveys I reviewed aimed to generate a set of baseline descriptive and demographic characteristics for describing the persons who were subjected to the effects of VOCs and their related cancer and heart disease outcomes. The identified baseline demographic characteristics included age, sex, health status, genetics, and nutritional status. The sample used in this study was relatively representative of the target population, as the total sample population includes participants with similar chemical exposure and corresponding analysis conducted based on different exposure scenarios.

Results

This correlational quantitative research analyses includes information on the study's descriptive data as well as hypotheses testing. Various analyses were performed in this study. These analyses included standard descriptive analysis, including frequency and percentages of the outcome variables, and inferential analysis including Chi-square test of independence statistical test with crosstabulations, and binary logistic regression test were used to measure the strength of the association between the IVs (exposure level of VOCs) and DVs (cancer and heart disease in occupational and nonoccupational individuals). The secondary data set I used for this analysis includes approximately 1184 participants, all of which answered questions regarding their household, demographic, and health related information in some capacity to provide data for analysis. The decision was made to include the entire sample amount based on time restraints and the limited availability of population information. The participants include children (ages ranging from birth to 17 years old) and adults ranging in age from 18 to 93 years. The *N* total for participation was 1184. This small *N* total is only 2.04% of the initial total sample population that was going to be analyzed and thus, created a different predictability of cancer and heart disease incidence in occupational and nonoccupational individuals and proving statistical significance.

Descriptive Statistics

Descriptive data includes frequency measures for the predictor variables (IVs) which include proportion of occupational (Work) and nonoccupational (Live) individuals and the exposure level of VOCs; and frequency measures for the outcome variables

(DVs), which include incidence of cancer and heart disease. The population in the dataset included adults over the age of 18; if any adult had children in their home, then those children were included in the total population as well. Hypotheses testing includes relevant information about the underlying assumptions (as it relates to this study) of the statistical test and data outputs and/or results of the study. In the following paragraphs, related tables and corresponding figures are presented, as well as study findings (via performance of the Chi-square test, crosstabulation and binary logistic regression tables). The *N* (sample size) was 1184 (total number of observations).

Test of Hypotheses

This analysis was designed to analyze if, and how, the IVs (exposure level of VOCs) were directly associated to the DVs (cancer and heart disease in occupational and nonoccupational individuals) in the study's total population of 1184 study participants.

Underlying Statistical Assumptions

When performing any type of statistical analysis in research, there are assumptions to be considered. Assumptions are the set of factors that are presumably put in place, and operating properly, for the researcher to achieve validity and acceptability in the study's results. If the assumptions are misrepresented or breached, error in analysis can occur. In this study, the statistical test performed was the Chi-square test of independence and binary logistic regression, therefore, it could be presumed that the initial study assumptions were met. The assumptions of the Chi-square statistical analyses include having data in the cells that are frequencies or case counts, rather than other transformations of data, such as percentages; the categories or levels of the variables are mutually exclusive (a specific subject can fit into only one level of each variable); the study groups must be independent; and there are two variables that are each measured at a nominal level and as categories. These presumptions held true because the IVs (exposure level of VOCs) are categorical and nominal and the DVs (cancer and heart disease in occupational and nonoccupational individuals) are categorical and made up of only two groups that are mutually exclusive, the study group is independent, and only case counts are used in the data cells. Logistic regression assumes that the outcome is a binary variable, there is a relationship between the outcome and predictor variables, and there are no elevated intercorrelations in the predictors. These presumptions also held true because the DVs are binary, there is an association or relationship between the outcome (DVs) and predictor variables (covariates), and there are not any intercorrelations in the predictors (DVs).

Statistical Analysis

The results of the statistical analysis for each of the hypotheses determined whether to accept or reject the null hypothesis for its respective RQ.

RQ1: Descriptive: What proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs?

> $H_0$1: There is no statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.

*H*1: There is a statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957–1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.

The descriptive statistics (Table 2) displays the output statistics, including minimum and maximum exposure levels, mean and standard deviation, for the IV and DVs in RQ1. The minimum, maximum, mean, and standard deviation for the DVs is irrelevant to the analysis alone because these variables are dichotomous (coded 1 for *yes* and 2 for *no*). The minimum (-0.323) and maximum (295.641) exposure levels for VOCs is also listed in the table. The mean (average of minimum and maximum exposure levels) for VOCs is 7.443 and the standard deviation is 27.288. Based on the standard deviation, I could assume that the exposure levels are not largely spread out between the minimum and maximum numbers. The frequency distributions (Tables 3 and 4) display the total number (summary measures) of participants who were diagnosed with one of the DVs (cancer or heart disease). The frequency column in each table respectively showed the total number of participants who answered *yes* (1) or *no* (2) to each condition. The percent column in each table respectively showed the percentage of those responses that correspond to the frequency measures.

Table 2

Descriptive Statistics for VOCs, Cancer and Heart Disease Based on Target Population

	N	Minimum	Maximum	Mean	Std. Deviation
VOCs	625	-0.323	295.641	7.443	27.288
CANCER	1184	1.00	2.00		0.473
HEART DIS	1184	1.00	2.00		0.207
Valid *N*(listwise)	625				

Table 3

Frequency Distribution of Participants with Cancer Diagnosis

Valid	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	400	33.8	33.8	33.8
No	784	66.2	66.2	66.2
Total	1184	100.0	100.0	

Table 4

Frequency Distribution of Participants with Heart Disease Diagnosis

Valid	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	53	4.5	4.5	4.5
No	1131	95.5	95.5	95.5
Total	1184	100.0	100.0	

Based on the type of binary/dichotomous variables used for this study, and to effectively analyze the relationship between the IV, both DVs and occupational status at the time of contamination, I found it necessary to also run a crosstabulation for RQ1. The crosstabulation (Tables 5) addresses the relationship between the IV and the DVs individually, in two separate tables, and determines which hypothesis was valid. In Table 5, the relationship between the IV and DV cancer in occupational and nonoccupational individuals is shown. The EPA has established safe drinking water standards and those standards for many of the VOCs commonly found in water are measured in parts per billion (ppb; Oregon Department of Human Services Public Health Division, n.d.). For all chemicals included in the VOCs specifically referenced in affecting the population in this study (TCE and PCE), the safe drinking water standard is 5 ppb. The portion of the sample population (N) that both lived and worked at the groundwater contamination site with cancer (DV) associations, included a total of 13 individuals (33.3%) affected by the IV (exposure level of VOCs) by less than 2 ppb (safe as deemed by EPA) and 26 (66.7

%) individuals with no effects from the IV. Within the proportion of the population that lived but did not work at the groundwater contamination site with DV associations, there were 21 individuals (36.8%) total affected by the IV. Of these 21 affected, only three individuals were over the established safe ppb level at 25.42 ppb, 64.64 ppb and 69.88 ppb, indicating a definitive cancer diagnosis. The proportion of the population that did not live but did work at the groundwater contamination site with DV associations included only two individuals (33.3%), both of which were within the established safe drinking water levels.

The portion of the sample population (N) that both lived and worked at the groundwater contamination site with heart disease (DV) associations, included a total of nine individuals (23.1%) affected by the IV (exposure level of VOCs), all under the safe drinking water level, and 30 (76.9 %) individuals with no effects from the IV. Within the proportion of the population that lived but did not work at the groundwater contamination site with DV associations, there was only one individual (1.8%) total affected by the IV and this individual was under the safe drinking water level. The proportion of the population that did not live but did work at the groundwater contamination site with DV associations included 18 individuals (3.4%), four of which were over the established safe drinking water ppb levels at 6.68 ppb, 12.64 ppb, 15.53 ppb and 148.78 ppb indicating a definitive heart disease diagnosis.

Based on the results of these analyses, which show each value is larger than the significance level, I failed to reject the null hypothesis (H_0) because there was not enough evidence to conclude that there was a statistically significant association between the proportion of occupational and nonoccupational individuals at the MCB in southeastern NC from 1957 – 1987 who were diagnosed with cancer versus heart disease in 2019 from exposure to VOCs.

RQ2: Inferential: Are VOCs associated with elevated risks of cancer incidence in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when controlling for these covariates: age, gender, ethnicity, and pre-existing conditions in 2019?

$H_0$2: There is no statistically significant association between VOCs and the elevated risks of death from cancer in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

$H_1$2: There is a statistically significant association between VOCs and the elevated risks of death from cancer in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

For RQ2, a crosstabulation and Chi-square test of independence was run to analyze the association between the IV, DV and covariates. In this analysis of the covariate effects, the pre-existing conditions specifically referenced are hypertension (HTN), stroke and melanoma, all of which can be underlying conditions of the DVs. The proportion of the population in their occupational status gives us more descriptive measures of those relationships. From the total sample of the population that reported effects from the IV (*N*=625) in Table 6, 13 of the population who lived and worked in vicinity of the contaminated groundwater, 21 of the population who lived but did not work in the same proximity and 2 of the total population did not live but did work in this same area were directly affected by the IV. This table does not show actual relational effects or how strong the association is between variables.

Table 5

Crosstabulation for Cancer and VOCs

Live	Work	Count	% within VOCs
Yes	Yes	13	33.3%
Yes	No	21	36.8%
No	Yes	2	33.3%

Note. Includes total number and percentage of participants with cancer, exposed to VOCs.

In Table 6, the overall test provided by Pearson Chi-square indicates that the DV categories differ in the proportions depending on the individual's occupational status. This table explained the likelihood that differences between the observed and expected values are either random or affected by some other factor. The *p*-value for this test is 0.05, thus, if the significance of the results is equal to or less than 0.05, the null hypothesis would be rejected. In these results, the Pearson Chi-square statistic for the proportion of the population that lived and worked on the contaminated groundwater site is 300.000 and the *p*-value = 0.466. The *p*-value is greater than the significance level of 0.05, thus, there is not enough evidence to conclude that the IV and DV are associated. The Pearson Chi-square statistic for the proportion of the population that lived but did not work on the contaminated groundwater site is 47.975 and the *p*-value = 0.433. Since the *p*-value is greater than the significance level of 0.05, there is not enough evidence to conclude that the IV and DV are associated. The Pearson Chi-square statistic for the proportion of the population that did not live but did work on the contaminated groundwater site is 60.000 and the *p*-value = 0.177. This *p*-value is also greater than the significance level of 0.05, thus, there is not enough evidence to conclude that the IV and DV are associated. All the *p*-values in this analysis are larger than the significance level, thus, for RQ2, I failed to reject the null hypothesis (H_0) because there was not enough evidence to conclude that the variables were associated. Additionally, the Chi-square test assumption that each cell should have a minimum count of five is violated based on the notes below Table 6.

Table 6

Pearson Chi-square Summary for Cancer and VOCs Association

Live	Work		Value	*df*	Asymptotic Significance (2-sided)
Yes	Yes	Pearson Chi-square	300.000[a]	30	0.466
		Likelihood Ratio	38.191	30	0.145
		Linear-by-Linear Association	0.845	1	0.358
		N of Valid Cases	39		
Yes	No	Pearson Chi-square	47.975[b]	47	0.433
		Likelihood Ratio	62.807	47	0.061
		Linear-by-Linear Association	0.429	1	0.513
		N of Valid Cases	57		
No	Yes	Pearson Chi-square	60.000[c]	5	0.306
		Likelihood Ratio	7.638	5	0.177
		Linear-by-Linear Association	1.425	1	0.233
		N of Valid Cases	6		

Note. [a] 61 cells (98.4%) have expected count less than 5. The minimum expected count is .33. [b] 95 cells (99.0%) have expected count less than 5. The minimum expected count is .37. [c] 12 cells (100.0%) have expected count less than 5. The minimum expected count is .33. [d] 776 cells (99.7%) have expected count less than 5. The minimum expected count is .34.

Table 7 showed the initial results of the regression model without the predictor variables included. This table will serve as the baseline for comparing the regression model later in this analysis and provides an indicator for how well it can predict the correct category when the covariate variables are added to the analysis.

Table 7

Binary Logistic Regression Analysis Block 0 Classification Summary

Live	Work		Observed		Cancer Yes	Cancer No	Predicted Percentage Correct
Yes	Yes	Step 0	Cancer	Yes	0	12	.0
				No	0	20	100.0
			Overall Percentage				62.5
Yes	No	Step 0	Cancer	Yes	0	35	.0
				No	0	65	100.0
			Overall Percentage				65.0
No	Yes	Step 0	Cancer	Yes	0	4	.0
				No	0	15	100.0
			Overall Percentage				78.9

In Table 8, the early statistical association prior to the addition of the covariate variables is shown. Beta (B) is the predicted change in the odds ratio; for each one-unit change in a predictor variable (s), there is also an Exp(B) change in the outcome variable (s) probability. The B coefficients can be either positive or negative. These are also the predicted odds for determining the association between the DV and the covariates.

Table 8

Binary Logistic Regression Analysis Block 0 Covariate Variables Included Summary

Live	Work			B	S.E.	Wald	df	Sig.	Odds Ratio
Yes	Yes	Step 0[a,b]	Constant	0.511	0.365	1.957	1	0.162	1.667
Yes	No	Step 0[a,b]	Constant	0.619	0.210	8.718	1	0.003	1.857
No	Yes	Step 0[a,b]	Constant	0.563	0.563	5.517	1	0.019	3.750

Note. [a] Variable(s) entered on Step 1: GENDER, ETHNICITY, AGE, HTN, STROKE. [b] Variable(s) entered on Step 1: GENDER, ETHNICITY, AGE, HTN.

In the second part of the binary logistic regression, the covariate variables age, gender, ethnicity, HTN, and stroke are added. The covariate variable melanoma was not added by SPSS in the regression model because there was no valid interaction between this covariate and the IV, and thus it could not be tested. In Table 9, the Omnibus Tests of Model Coefficients is shown. The Chi-square was 10.732 on 7 df, and significant beyond 0.151 for the proportion of the population that lived and worked at the contaminated groundwater site. The Chi-square was 9.913 on 10 df, and significant beyond 0.448 for the proportion of the population that lived but did not work at the contaminated groundwater site. The Chi-square was 9.709 on 8 df, and significant beyond 0.286 for the proportion of the population that did not live but did work at the contaminated groundwater site. This test of the H_0 confirmed that adding the covariate variables to the model did not significantly validate or increase the ability to predict the association between risks of death from the DV in occupational and nonoccupational individuals.

Table 9

Binary Logistic Regression Analysis Block 1 Omnibus Test of Model Coefficients Summary

Live	Work			Chi-square	*df*	Sig.
Yes	Yes	Step 1	Step	10.732	7	0.151
			Block	10.732	7	0.151
			Model	10.732	7	0.151
Yes	No	Step 1	Step	9.913	10	0.448
			Block	9.913	10	0.448
			Model	9.913	10	0.448
No	Yes	Step 1	Step	27.359	22	0.198
			Block	27.359	22	0.198
			Model	27.359	22	0.198

In Table 10, the Model Summary showed the -2 Log Likelihood statistic for the proportion of the population that lived and worked at the contaminated groundwater site is 31.608. The -2 Log Likelihood statistic for the proportion of the population that lived but did not work at the contaminated groundwater site is 119.576. The -2 Log Likelihood statistic for the proportion of the population that did not live but did work at the contaminated groundwater site is 9.848. The -2 Log Likelihood statistic measured how poorly the regression model predicted the decisions; the smaller this statistic is the better the model. This table does not explain the variation, but it can be used in approximating any variation in the DV. The Cox & Snell R^2 nor the Nagelkerke R^2 can reach a maximum value of one per their respective rules for validity. Nagelkerke R^2 does show potential changes in the DV, and therefore, in this table showed changes in the DV based on the covariate variables used in the regression. For the proportion of the population that lived and worked at the contaminated groundwater site, there was a 38.8% change in the DV due to the covariate variables used in the regression model. For the proportion of the population that lived but did not work at the contaminated groundwater site, there was a 13.0% change in the DV due to the covariate variables used in the regression model. And lastly, for the proportion of the population that did not live but did work on the contaminated groundwater site, there was a 62.2% change in the DV due to the covariate variables used in this regression model.

Table 10

Binary Logistic Regression Analysis Block 1 Model Summary

Live	Work	Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
Yes	Yes	1	31.608[a]	0.285	0.388
Yes	No	1	119.576[b]	0.094	0.130
No	Yes	1	9.848[c]	0.400	0.622

Note. [a] Estimation terminated at iteration number 20 because maximum iterations has been reached. Final solution cannot be found for split file LIVE = 1.00, WORK = 1.00.

In Table 11, the Hosmer and Lemeshow test is another test of the model's fitness and indicates whether a poor fit exists if/when the statistical significance is less than 0.05. In this table, the model sufficiently fits the data in each of the population proportions because all the significance values are greater than 0.05. This also indicates there were no differences between the observed and predicted models.

Table 11

Binary Logistic Regression Analysis Block 1 Hosmer and Lemeshow Results

Live	Work	Step	Chi-square	*df*	Sig.
Yes	Yes	1	3.140	8	0.925
Yes	No	1	9.935	8	0.270
No	Yes	1	3.299	8	0.914

Table 12 showed the second of the two classification tables in this analysis. This table was compared to the previous classification table to see if and how much improvement there was when the covariate variables were added to the model. The numbers in the first two rows provide statistics about specificity (called true negative rate and is the percentage of observations that fall into the non-target category) and sensitivity (called true positive rate and is the percentage of observations that fall into the target group) of the regression model in order to predict group membership on the DV. The table showed how the decision rule and default threshold from SPSS allows the correct classification for the population where the predicted events (covariates affect cancer risks) were not observed (specificity). The specificity for the proportion of the population that lived and worked on the contaminated groundwater site is 58.3% (7/12 = 58.3%). The specificity for the proportion of the population that lived but did not work on the contaminated groundwater site is 20% (7/35 = 20%). The specificity for the proportion of the population that did not live but did work on the contaminated groundwater site is 75% (3/4 = 75%).

Table 12 also showed the correct classification for the population where the predicted events (covariates affect cancer risks) were observed (sensitivity). The sensitivity for the proportion of the population that lived and worked on the contaminated groundwater site is 41.7% (5/12 = 41.7%). The sensitivity for the proportion of the population that lived but did not work on the contaminated groundwater site is 80% (28/35 = 80%). The sensitivity for the proportion of the population that did not live but did work on the contaminated groundwater site is 25% (1/4 = 25 %). Each of my predictions were correct and were equal to the predicted overall percentage total for each referenced proportion of the population. The overall success rate of each referenced proportion of the population was also higher than the previous model in Table 8.

Table 12

Binary Logistic Regression Analysis Block 0 Classification Summary

				Cancer		Predicted
Live	Work		Observed	Yes	No	Percentage Correct
Yes	Yes	Step 0	Cancer Yes	7	5	58.3
			No	3	17	85.0
			Overall Percentage			75.0
Yes	No	Step 0	Cancer Yes	7	28	20.0
			No	3	62	95.4
			Overall Percentage			69.0
No	Yes	Step 0	Cancer Yes	3	1	75.0
			No	1	14	93.3
			Overall Percentage			89.5

The output in Table 13 indicates that when all covariate variables are included in the model, each significance outcome showed the contribution of individual variables among all other variables shown in the model. Regardless of the proportion of the population in this table, the significance values were consistently higher and not statistically significant ($p > .05$), the same as shown in Table 12 (table of variables not in the model). In this table, the association between the covariate variables and the DV can be definitively seen as well. Included in the output from this test is the Exp(B), also called the odds ratio, the regression coefficients, and the Wald statistic.

The Wald Chi-square statistic is an important statistic because it displays the special contribution each predictor has, in the context of and holding constant, all other predictors while also eliminating potential overlap between all predictors. In the table, the Wald statistics for the proportion of the population that both lived and worked at the contamination site showed that HTN and strokes have some effect or significance on the DV. Wald statistics for the proportion of the population that lived but did not work at the contamination site indicated that strokes and the indicator variables for ethnicity may have had an effect or significance on the DV. Wald statistics also indicated that the proportion of the population that did not live but did work at the contamination site may have been affected by gender, HTN and the ethnicity indicator variables. It is important to note in this table that many of the predictors meet the standard statistical significance of .05. Employing the standard statistical significance, age, gender, indicator (dummy) variables Carolinian (1), Chamorro (2), Filipino (3), HTN, and stroke had noteworthy partial effects in each of the population proportions referenced.

Regardless of either proportion of the population shown in the table, the odds ratios for age, gender, stroke indicated that when holding all other variables constant, these covariate variables were less likely to affect or impact the risk of death from the DV. The covariate ethnicity showed no odds ratio for any of the population that lived or worked at the contaminated groundwater site, however, the indicator variables for ethnicity [Carolinian (1), Chamorro (2), Filipino (3)] are the only covariates in each proportion of the population that show significant odds ratios. Although there was no statistical significance shown in any of the covariate or indicator variables, overall, the effects of gender and ethnicity were all small and relatively close in number. Even if the odds ratios were inverted for the dummy variables, the odds of them significantly affecting the DV was still very small in ratio, and thus, I fail to reject the null hypothesis.

Table 13

Binary Logistic Regression Analysis Block 1 Covariate Variables Inclusion Summary

										95% *CI* for EXP(B)	
LIVE	WORK			B	S.E.	Wald	*df*	Sig.	Odds Ratio	Lower	Upper
Yes	Yes	Step 1[a,b]	GENDER(ref Males)			1.133	1	0.287			
			Females	0.036	0.143	0.065	1	0.798	1.037	0.784	1.371
			ETHNICITY								
			(Ref Carolinian)			3.322	1	0.068			
			Chamorro	1.669	1.387	1.449	1	0.229	5.309	0.350	80.478
			Filipino	1.818	1.955	0.865	1	0.352	6.160	0.133	284.347
			AGE								
			0-18 years old	-0.337	56834	0.000	1	1.000	0.714	0.000	.
			19-36 years old	0.257	56834	0.000	1	1.000	1.293	0.000	.
			37-55 years old	-0.175	56834	0.000	1	1.000	0.840	0.000	.
			(Ref 56-74 years old)			1.549	1	0.213			
			75-93 years old	0.008	0.004	4.043	1	0.044	1.008	1.000	1.016
			HTN (ref Yes)			0.000	1	0.999			
			No	0.018	0.240	0.006	1	0.940	1.018	0.636	1.629
			STROKE(ref Yes)			0.000	1	1.000			
			No	-0.860	0.806	1.137	1	0.286	0.423	0.087	2.056
	No	Step 1[a,b]	GENDER(ref Males)			0.754	1	0.385			
			Females	-0.109	49189	0.000	1	1.000	0.897	0.000	
			ETHNICITY								
			(Ref Carolinian)			0.000	1	1.000			.
			Chamorro	-20.37	40192	0.000	1	1.000	0.000	0.000	.
			Filipino	-20.28	40192	0.000	1	1.000	0.000	0.000	.
			AGE								
			0-18 years old	-20.44	40182	0.000	1	1.000	0.000	0.000	.
			19-36 years old	-20.45	40182	0.000	1	1.000	0.000	0.000	.
			37-55 years old	-42.35	49205	0.000	1	0.999	0.000	0.000	.
			(Ref 56-74 years old)			0.540	1	0.462			
			75-93 years old	-21.18	40192	0.000	1	1.000	0.000	0.000	-21.180
			HTN(ref Yes)			0.297	1	0.586			
			No	-19.44	40192	0.000	1	1.000	0.000	0.000	-19.447
			STROKE(ref Yes)			0.000	1	0.999			.
			No	0.617	49201	0.000	1	1.000	1.853	0.000	.

				B	S.E.	Wald	*df*	Sig.	Odds Ratio	95% *CI* for EXP(B) Lower	Upper
LIVE	WORK										
No	Yes	Step 1[a,b]	GENDER(ref Males)			0.000	1	0.999			.
			Females	-19.98	40182	0.000	1	1.000	0.000	0.000	-19.985
			ETHNICITY								
			(Ref Carolinian)			0.000	1	1.000			.
			Chamorro	18.682	51015	0.000	1	1.000	12982.987	0.000	.
			Filipino	38.313	56934	0.000	1	0.999	430160.000	0.000	.
			AGE								
			0-18 years old	0.224	56834	0.000	1	1.000	1.251	0.000	0.224
			19-36 years old	-20.47	40182	0.000	1	1.000	0.000	0.000	-20.475
			37-55 years old	-0.077	56834	0.000	1	1.000	0.926	0.000	-0.077
			(Ref 56-74 years old)			1.191	1	0.275			
			75-93 years old	0.244	56834	0.000	1	1.000	1.277	0.000	0.244
			HTN(ref Yes)			0.000	1	0.999			.
			No	0.010	42611	0.000	1	1.000	1.010	0.000	

Note. [a] Variable(s) entered on Step 1: GENDER, ETHNICITY, AGE, HTN, STROKE. [b] Variable(s) entered on Step 1: GENDER, ETHNICITY, AGE, HTN.

RQ3: Inferential: Are VOCs associated with elevated risks of heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post contamination, when controlling for these covariates: age, gender, ethnicity, and pre-existing conditions in 2019?

$H_0$3: There is no statistically significant association between VOCs and the elevated risks of death from heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

$H_1$3: There is a statistically significant association between VOCs and the elevated risks of death from heart disease in occupational and nonoccupational individuals at the MCB in southeastern NC, post-contamination, when age, gender, ethnicity, and pre-existing conditions were designated as factors significant to diagnoses in 2019.

For RQ3, a crosstabulation (Table 14) and Chi-square test of independence (Table 16) was run to analyze the association between the variable and covariates. From the total sample of the population that reported effects from the IV, nine (9) from the proportion of the population who lived and worked in vicinity of the contaminated groundwater, one (1) from the proportion of the population who lived but did not work in the same proximity and (6) from the proportion of the total population did not live but did work in this same area were directly affected by the IV.

Table 14

Crosstabulation for Heart Disease and VOCs

Live	Work	Count (with heart disease)	% within VOCs
Yes	Yes	9	9%
Yes	No	1	1%
No	Yes	6	6%

Note. Includes total number and percentage of participants with heart disease, exposed to VOCs.

In Table 15, the overall test provided by the Pearson Chi-square test indicates that the DV categories differ in the proportions depending on the individual's occupational status. The *p*-value for this test is 0.05, thus, if the significance of the results is equal to or less than, the null hypothesis would be rejected. In this analysis, the Pearson Chi-square statistic for the proportion of the population that lived and worked on the contaminated groundwater site is 30.237 and the *p*-value = 0.454. The *p*-value is greater than the significance level of 0.05, thus, there is not enough evidence to conclude that the IV and DV are associated. The Pearson Chi-square statistic for the proportion of the population that lived but did not work on the contaminated groundwater site is 570.000 and the *p*-value = 0.151. Since the *p*-value is greater than the significance level of 0.05, there is not enough evidence to conclude that the IV and DV are associated. The Pearson Chi-square statistic was zero (0) for the proportion of the population that did not live but did work on the contaminated groundwater site. The footnotes at the bottom of the table explained that no statistics were computed due to the DV being a constant in this analysis. The *p*-values shown in this test are larger than the significance level, thus, for RQ3, I failed to reject the null hypothesis (H_0) because there was not enough evidence to conclude that there is a relationship between the IV and DV. Additionally, the Chi-square test assumption that each cell should have a minimum count of five is violated based on the footnotes at the bottom of the table.

Table 15

Pearson Chi-Square Summary for Heart Disease and VOCs

Live	Work		Value	*df*	Asymptotic Significance (2-sided)
Yes	Yes	Pearson Chi-square	30.237[a]	30	0.454
		Likelihood Ratio	32.601	30	0.340
		Linear-by-Linear Association	0.368	1	0.544
		N of Valid Cases	39		
Yes	No	Pearson Chi-square	570.000[b]	47	0.151
		Likelihood Ratio	10.068	47	1.000
		Linear-by-Linear Association	0.176	1	0.675
		N of Valid Cases	57		
No	Yes	Pearson Chi-square	.[c]		
		N of Valid Cases	6		

Note. [a] 61 cells (98.4%) have expected count less than 5. The minimum expected count is .23. [b] 95 cells (99.0%) have expected count less than 5. The minimum expected count is .02. [c] No statistics are computed because HEARTDIS is a constant. [d] 777 cells (99.9%) have expected count less than 5. The minimum expected count is .03.

Table 16 showed the initial results of the binary logistic regression model without the predictor variables included. This table serves as the baseline for comparing the model to the Block 1 table later in this analysis and provides an indicator for how well it can predict the correct category when the predictors are added to the analysis.

Table 16

Binary Logistic Regression Analysis Block 0 Classification Summary

Live	Work		Observed	HeartDis Yes	HeartDis No	Predicted Percentage Correct
Yes	Yes	Step 0	HeartDis Yes	0	1	.0
			No	0	31	100.0
			Overall Percentage			96.9
Yes	No	Step 0	HeartDis Yes	0	2	.0
			No	0	98	100.0
			Overall Percentage			98.0
No	Yes	Step 0	HeartDis Yes	0	2	.0
			No	0	17	100.0
			Overall Percentage			89.5

In Table 17, the early statistical relationship prior to the addition of the covariate variables (predictors) is shown. B, Wald, Sig, and Exp(B) should all change in the model when the covariate variables are added. This table showed the predicted odds for determining the relationship between the DV and the covariates.

Table 17

Binary Logistic Regression Analysis Block 0 Covariate Variables Inclusion Summary

Live	Work			B	S.E.	Wald	*df*	Sig.	Odds Ratio
Yes	Yes	Step 0[a,b]	Constant	3.434	1.016	11.424	1	0.001	310.000
Yes	No	Step 0[a,b]	Constant	3.892	0.714	29.687	1	0.000	490.000
No	Yes	Step 0[a,b]	Constant	2.140	0.748	8.196	1	0.004	8.500

Note. [a] Variable(s) entered on Step 1: GENDER, ETHNICITY, AGE, HTN, STROKE. [b] Variable(s) entered on Step 1: GENDER, ETHNICITY, AGE, HTN.

In the second part of this binary logistic regression, the covariate variables age, gender, ethnicity, HTN, and stroke are again added. The covariate variables stroke and melanoma were not added by SPSS for this DV in the regression model because there was no valid interaction between the covariates and the IV, and thus they could not be tested In Table 18, the Omnibus Tests of Model Coefficients, model fitness is shown. The Chi-square was 8.900 on 7 df, and significant beyond 0.260 for the proportion of the population that lived and worked on the contaminated groundwater site. The Chi-square was 4.241 on 10 df, and significant beyond 0.936 for the proportion of the population that lived but did not work on the contaminated groundwater site. The Chi-square was 12.787 on 8 df, and significant beyond 0.119 for the proportion of the population that did not live but did work on the contaminated groundwater site. This test of the H_0 confirmed that adding the covariate variables to the model did not significantly validate or increase the ability to predict the association between risks of death from the DV in occupational and nonoccupational individuals.

Table 18

Binary Logistic Regression Analysis Block 1 Omnibus Tests of Model Coefficients Summary

Live	Work			Chi-square	*df*	Sig.
Yes	Yes	Step 1	Step	8.900	7	0.260
			Block	8.900	7	0.260
			Model	8.900	7	0.260
Yes	No	Step 1	Step	4.241	10	0.936
			Block	4.241	10	0.936
			Model	4.241	10	0.936
No	Yes	Step 1	Step	12.787	8	0.119
			Block	12.787	8	0.119
			Model	12.787	8	0.119

In Table 19, the Model Summary showed the -2 Log Likelihood statistic for the proportion of the population that lived and worked on the contaminated groundwater site is 0.000. The -2 Log Likelihood statistic for the proportion of the population that lived but did not work on the contaminated groundwater site is 15.366. The -2 Log Likelihood statistic for the proportion of the population that did not live but did work on the contaminated groundwater site is 0.000. The -2 Log Likelihood in this analysis revealed two small statistics, indicating a potentially better model. The Nagelkerke R^2 reached a maximum value of one, per its rule (reached a value of 1), indicating some validity in two of the proportions of the population. Nagelkerke R^2 does show potential changes in the DV, and therefore, in this table showed changes in the DV based on the covariate variables used in the regression. For the proportion of the population that lived and worked on the contaminated groundwater site, there was a 100% change in the DV due to the covariate variables used in the regression model. For the proportion of the population that lived but did not work on the contaminated groundwater site, there was a 23.3% change in the DV due to the covariate variables used in the regression model. And lastly, for the proportion of the population that did not live but did work on the contaminated groundwater site, there was a 100% change in the DV due to the covariate variables used in this regression model.

Table 19

Binary Logistic Regression Analysis Block 1 Model Summary

Live	Work	Step	-2 Log likelihood	Cox & Snell *R* Square	Nagelkerke *R* Square
Yes	Yes	1	0.000[a]	0.243	1.000
Yes	No	1	15.366[b]	0.042	0.233
No	Yes	1	0.000[c]	0.490	1.000

Note. [a] Estimation terminated at iteration number 20 because maximum iterations has been reached. Final solution cannot be found for split file LIVE = 1.00, WORK = 1.00. [b] Estimation terminated at iteration number 20 because maximum iterations has been reached. Final solution cannot be found for split file LIVE = 1.00, WORK = 2.00. [c] Estimation terminated at iteration number 19 because a perfect fit is detected for split file LIVE = 2.00, WORK = 1.00. This solution is not unique.

In Table 20, the Hosmer and Lemeshow test showed the model sufficiently fits the data in each of the population proportions because all the significance values are greater than 0.05. These significance values also indicate there were no differences between the observed and predicted models.

Table 20

Binary Logistic Regression Analysis Block 1 Hosmer and Lemeshow Test Results

Live	Work	Step	Chi-square	*df*	Sig.
Yes	Yes	1	0.000	5	1.000
Yes	No	1	5.344	8	0.720
No	Yes	1	0.000	7	1.000

Table 21 showed the second of the two classification tables in this analysis. This table was compared to the previous classification table (Table 17) to determine if and how much improvement there was when the covariate variables were added to the model. The specificity for the proportion of the population that lived and worked at the contaminated groundwater site is 100% (1/1 = 100%). There is no specificity value for the proportion of the population that lived but did not work on the contaminated groundwater site (0/2 = 0). This table also showed the correct classification for the population where the predicted events (covariates affect heart disease risks) were observed. The sensitivity for the proportion of the population that lived and worked on the contaminated groundwater site is 0 (0/1 = 0). The sensitivity for the proportion of the population that lived but did not work on the contaminated groundwater site is 100% (2/2 = 100%). There was no specificity or sensitivity for the proportion of the population that did not live but did work at the contaminated groundwater site because SPSS failed to provide any analysis for this proportion. My prediction for the proportion of the population that lived but did not work at the contamination site was correct and equal to the predicted overall percentage total; this was also the only proportion of the population with a matching success rate to its matching proportion of the population Table 17.

Table 21

Binary Logistic Regression Analysis Block 1 Classification Summary

Live	Work		Observed		Yes	No	Predicted Percentage Correct
Yes	Yes	Step 0	HeartDis	Yes	1	0	100.0
				No	0	31	100.0
			Overall Percentage				100.0
Yes	No	Step 0	HeartDis	Yes	0	2	0.0
				No	0	98	100.0
			Overall Percentage				98.0

Note. The cut value is .500.

The variables in the equation output in Table 22 indicates that when all covariate variables are included in the model, each significance value showed the contribution of individual covariate variables among all other variables shown in the model. For the two proportions of the population shown in this table, the significance values were consistently higher and not statistically significant ($p > .05$), the mimicking the significance values shown in Table 18. The proportion of the population that did not live but did work at the contaminated groundwater site was not reported by SPSS in this table. The lack of association between the covariate variables and the DV can also be definitively seen in this table. In this table, the Wald statistics for the proportion of the population that both lived and worked at the contamination site indicated significance between all the covariate variables and the DV. Wald statistics for the proportion of the population that lived but did not work at the contamination site indicated significance between all the covariate variables, except for age, and the DV. It is important to note in this table that nearly all the predictors met the standard statistical significance of .05.

Regardless of either proportion of the population shown in the table, the odds ratios for gender, stroke, and HTN indicated that when holding all other variables constant, these covariate variables could have some effect or impact on the DV. The covariate ethnicity showed no odds ratio for either proportion of the population shown. There was no statistical significance shown in any of the covariate variables for this DV, and thus, I fail to reject the null hypothesis for RQ3.

Table 22

Binary Logistic Regression Analysis Block 1 Covariate Variables Inclusion Summary

										95% *CI* for EXP(B)	
LIVE	WORK			B	S.E.	Wald	*df*	Sig.	Odds Ratio	Upper	Lower
Yes	Yes	Step 1[a,b]	GENDER (ref Males)			1.133	1	0.287			
			Females	0.441	0.632	0.487	1	0.485	1.554	0.450	5.362
			ETHNICITY								
			(Ref Carolinian)		0.000	1	1	0.000			
			Chamorro	1.182	20204.012	0.000	1	1.000	3.262	0.000	1.182
			Filipino	1.126	30585.405	0.000	1	1.000	3.084	0.000	1.126
			AGE								
			0-18 years old	-0.392	41417.054	0.000	1	1.000	0.676	0.000	-0.392
			19-36 years old	0.197	49187.232	0.000	1	1.000	1.217	0.000	0.197
			37-55 years old	1.265	56841.745	0.000	1	1.000	3.544	0.000	1.265
			(Ref 56-74 years old)		0.000	1	1	0.000			
			75-93 years old	16.464	48015.415	0.000	1	1.000	14134.979	0.000	16.464
			HTN (ref Yes)			0.000	1	0.998			
			No	17.030	43817.928	0.000	1	1.000	24895.480	0.000	17.030
			STROKE (ref Yes)			0.000	1	0.999			
			No	15.541	43282.820	0.000	1	1.000	5617149.630	0.000	15.541
	Yes No	Step 1[a,b]	GENDER (ref Males)			0.000	1	0.997			
			Females	-0.222	56841.745	0.000	1	1.000	0.801	0.000	-0.222
			ETHNICITY								
			(Ref Carolinian)			0.000	1	1.000			.
			Chamorro	-0.691	40563.345	0.000	1	1.000	0.501	0.000	-0.691
			Filipino	-0.710	40563.345	0.000	1	1.000	0.492	0.000	-0.710
			AGE								
			0-18 years old	0.645	40459.497	0.000	1	1.000	1.906	0.000	0.645
			19-36 years old	0.036	56841.745	0.000	1	1.000	1.036	0.000	0.036
			37-55 years old	-0.905	56841.745	0.000	1	1.000	0.405	0.000	-0.905
			(Ref 56-74 years old)			0.180	1	0.672			
			75-93 years old	-0.013	0.018	0.523	1	0.470	0.987	0.953	1.022
			HTN (ref Yes)			0.000	1	0.999			
			No	1.655	0.682	5.881	1	0.015	5.232	1.373	19.929
			STROKE (ref Yes)			0.000	1	0.999			.
			No	2.606	0.888	8.615	1	0.003	13.547	2.377	77.198

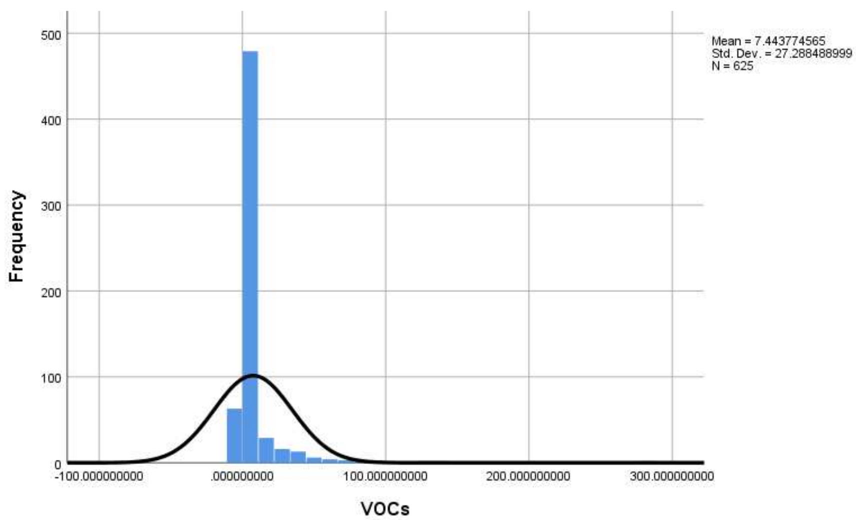
Note. [a] and [b] Variable(s) entered on Step 1: GENDER, ETHNICITY, AGE, HTN, STROKE.

Figures

The histogram for the frequency distribution of VOCs (Figure 1) displayed a normal (typical) bell-shaped curve, therefore showing that the distributions were also normal.

Figure 1

Histogram for Frequency and VOCs



The bar charts for the crosstabulation between cancer and VOCs (Figures 2-4) and heart disease and VOCs (Figures 5-7) below were incorporated to visually depict the data from this statistical test. Each chart showed the amount of exposure to VOCs by the specified proportion of the population, including the count of those participants with a cancer or heart disease diagnosis.

Figure 2

Crosstabulation Bar Chart for Count (Participants) and Cancer (Proportion of population that lived and worked at groundwater contamination site)

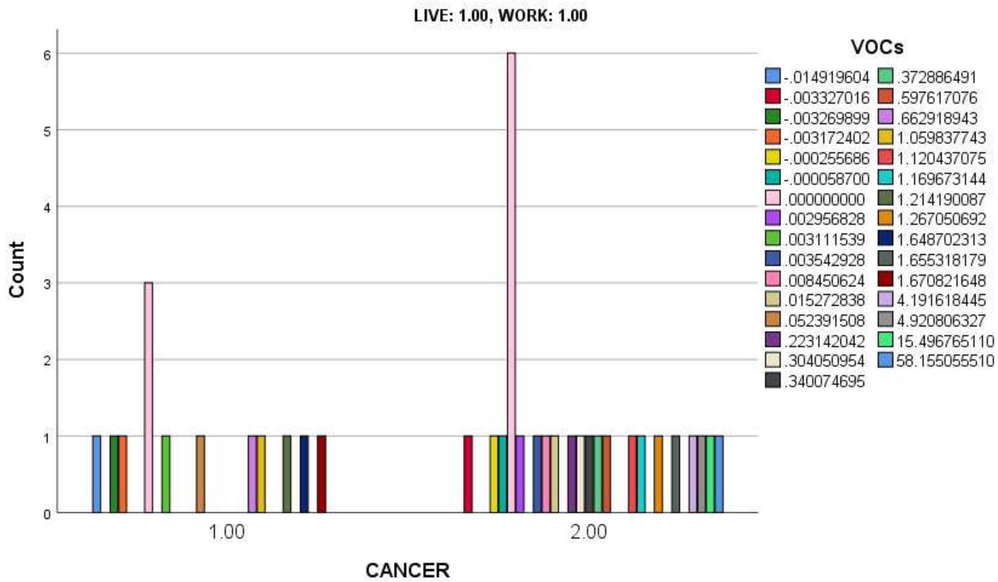
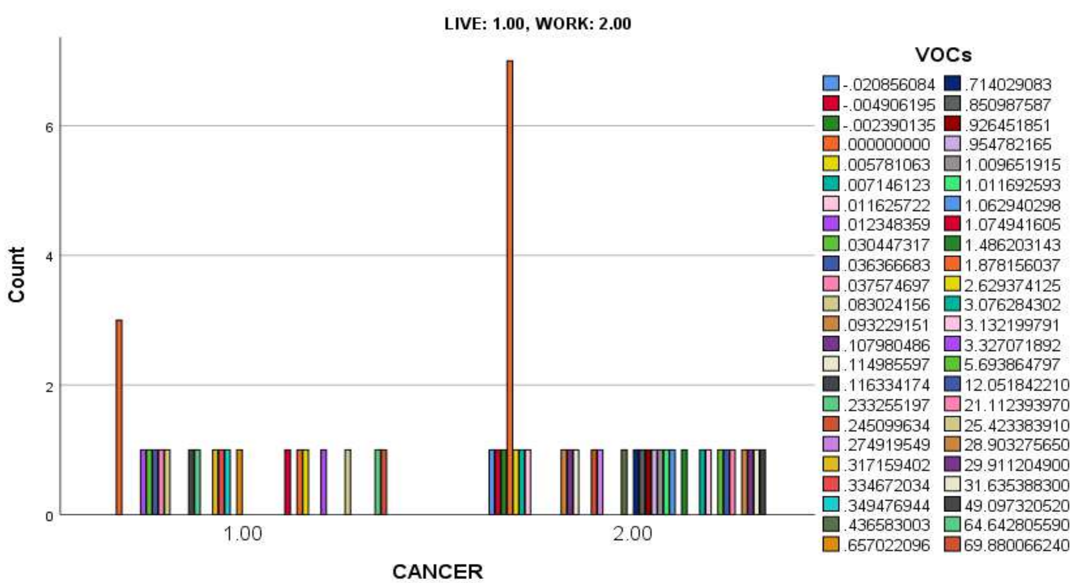


Figure 3

Crosstabulation Bar Chart for Count (Participants) and Cancer (Proportion of population that lived but did not work at groundwater contamination site)



Summary

In Section 3, the results of this correlational, quantitative analyses were examined. Data collection methods and statistical analysis procedures were explained. This examination also includes a presentation of data based on the study's descriptive statistics, in addition to hypotheses testing (proving or disproving data outcomes and underlying assumptions). The descriptive analyses includes and explained frequency measures for the independent and dependent variables and several predictor variables, including occupational and nonoccupational status, age, gender, ethnicity, and pre-existing conditions (specifically HTN, stroke and melanoma). Hypotheses testing for this study included data relevant to underlying assumptions of the statistical tests utilized (as related to this study), data outputs and results of the study. The data outputs achieved included crosstabulations, Chi-square tests, model summaries, tests of coefficients (via performance of the binary logistic regression model analysis), and other residual test statistics. A post hoc power analysis (via G*Power Version 3.1.9.6) was also conducted after completing statistical analysis to confirm sufficient sample size for this study and those results are reported. Related tables, figures (histogram and bar charts), and report findings were also presented. The concluding chapter provides a final discussion of the research including results/findings, potential social change, limitations, and recommendations associated with the study.

Section 4: Application to Professional Practice and Implications for Social Change

The purpose of this study was to examine the long-term effects of VOCs on cancer and heart disease incidence in both veterans and civilians who were engaged in occupational and nonoccupational activities at the MCB in southeastern NC. Secondary data that include scientific evidence and statistics on the association between exposure to these contaminants and development of various cancers and conditions of the heart were examined. This study is unique because it assessed the specific effects of the chemicals on cancer incidence, heart disease and any other predominant conditions caused by the chemicals and present data on cancer mortality and heart disease rates within the affected population from the MCB in southeastern NC.

The nature of this study utilized correlational, quantitative research with secondary data analysis to study the association between occupational and nonoccupational individuals at the MCB in southeastern NC who were exposed to VOCs, and the incidence of cancer and heart disease within this population. The quantitative research method with secondary data analysis was used in this study because of its ability to assess the hypothesis through statistical and numerical data and finalize research results. This research design measured the association by quantifying chemical exposure rates and showing the incidence of cancer and heart disease through secondary data analysis projected from the target population. The quantitative research method also measured cancer and heart disease incidence before and after exposure. The target population for this study included veterans and civilians who were engaged in occupational and nonoccupational activities at the MCB in southeastern NC from 1957-

1987 but diagnosed with cancer and heart disease in 2019. This approach used a combination of geographical correlations, time trends, and occupational influences to assess cancer and heart disease incidence rates within the time span that the wells were operational and the incidence of existing and new risk factors for VOCs. This quantitative analysis aligned the contextual effects of this population-level chemical exposure to morbidity and mortality rates post-contamination.

This study was conducted to examine the impact of chemical solvents, both the past and present health risks, and their effects on cancer and heart disease. It was also important for me to review corresponding environmental safeguards and public health policies that encourage public awareness. By studying the detrimental effects of VOCs for current and future populations, the intent was to offer insight on how researchers can move the global conversation on this issue forward. Increasing domestic and global awareness regarding the long-term effects of chemical solvents is strongly needed based on the current deficiency of available data.

Key Findings of the Analysis

Overall, the analyses depicted many instances of non-significance between the IV, DV, and covariate variables. Descriptive statistics were run for RQ1 and the results for VOCs indicated the minimum (-.323) and maximum (295.641) exposure values were very broad, although the small sample (N = 625) total of those reportedly affected by VOCs was a little more than half the total target population at 53%. The mean (7.443) and standard deviation (27.288) for VOCs revealed how far each exposure level was from the mean, as the standard deviation showed the variability of this distribution (group of levels). There was no minimum, maximum, mean, or standard deviation to report for cancer and heart disease since they only had categorical values of either 1 (*yes*) or 2 (*no*). The frequency statistics for VOCs again reported the mean, median and standard deviation, while the frequency statistics for cancer and heart disease reported the frequency and percent of the target population that reportedly answered *yes* or *no* to these diagnoses, respectively. By initially looking at the frequency percentages for cancer and heart disease, it would have been safe to assume that there must be an association between these illnesses and VOCs, however, that assumption was not supported after further analysis was conducted. Other findings to note include those from the crosstabulations and Chi-square tests. The Chi-square test results from the VOCs and cancer crosstab revealed no statistical significance ($p > .05$) or relationship among any of the proportions of the population. This was also the case for the Chi-square test results from the VOCs and heart disease crosstabulation.

Additionally, after completing the final statistical test of the hypotheses, the results were essentially the same in terms of accepting/rejecting the null hypotheses. When controlling for age, gender, ethnicity, and pre-existing conditions, the binary logistic regression test confirmed that for both cancer and heart disease, none of these covariate variables significantly impacted either of the DVs. None of the predictors used in these analyses had a p-value greater than 0.05 in Block 1 of the regression analysis, thus, it was determined that the covariate variables were all statistically nonsignificant predictors of cancer or heart disease. The Omnibus Test of Model Coefficients, Model Summary, and Hosmer and Lemeshow Test in the binary regression analysis for RQ2 and

RQ3 each presented statistical significance results that determined there was no likelihood of a relationship or association between the IV (VOCs) and the DVs (cancer or heart disease) in either proportion of the population. It is also important to note that SPSS did not include the covariate/predictor variable melanoma in any of the analyses; in the binary logistic regression model for heart disease, SPSS did not report any statistics for the proportion of the population that worked but did not live at the contamination site. Regardless of whether participants lived and worked at the contamination site, lived but did not work at the contamination site or worked but did not live at the contamination site, their direct or indirect exposure to VOCs may not have impacted their cancer and/or heart disease risks.

Interpretation of the Findings

The overall test results indicated that the three alternative hypotheses in this study should not be accepted, and therefore all three null hypotheses should be accepted. There was no significant association between the IV (exposure level of VOCs) and the DV (cancer) or the DV (heart disease). When controlling for age, gender, ethnicity, and pre-existing conditions (covariate variables), there was still no relationship detected between the IV and either DV. In each of the statistical tests (descriptive statistics, crosstabulation with Chi-square test and binary logistic regression) used to determine relational significance, analyses consistently indicated that each null hypothesis was not only proven, but also that additional data and further research on this topic may be required.

A post hoc power analysis was conducted, verifying that the sample size was sufficient for this study (actual power = 1.0). Of the total sample size (1184), the number of participants that provided a response that they were affected by the IV (625) could have various other risk factors which contributed to their cancer or heart disease diagnoses, such as diet, smoking, genetic disorders, or exposure to other toxic substances/chemicals. All the statistical analyses, as well as corresponding tables and charts, collectively showed that the control variables for the DV had *p*-values greater than .05 (or no value at all); thus, presenting the case that if future research is conducted on this subject matter, other controls and predictors should be used in order to potentially reveal valid associations. There was unequivocally a gap in knowledge and research as it pertains to some aspects of this topic. For example, there are no current studies available on the exposure effects from VOCs in predominantly minority communities. Although significant results were unable to be produced, this is an important issue that requires collaboration across various levels of government, including but not limited to rural and urban areas. As previously mentioned in the literature review, there are few available studies dated within five years of this project, and that specifically reference the association between VOCs and heart disease in any capacity. The Minnesota Department of Health (2018) did examine how exposures to the VOCs TCE and PCE potentially increased risks of particular cancers, such as kidney, liver, non-Hodgkin’s lymphoma, bladder, and leukemias, and thus, future research on these particular VOCs might yield information regarding unrealized association with heart disease also. The studies that specifically addressed the association between VOCs and heart disease, including the potentially harmful effects of VOCs on the cardiovascular system, used for reference were Callahan et al. (2019) and Malovichko et al. (2019), making apparent the need for additional research on this association to reduce the impact to public health. There are also no research articles available at present time that specifically reference the association between VOCs found in groundwater sources and heart disease. Villeneuve et al. (2013), however, was used to examine the relationships between some VOCs and the cardiovascular system and cancer mortality. There were some positive associations observed for each of the VOCs studied, but the signals were strongest for cancer. Findings from the Villeneuve et al. (2013) study suggested that ambient concentrations of VOCs were in fact associated with cancer mortality, but not with cardiovascular mortality. The findings from this study should not be misinterpreted or devalued, as they exhibit future opportunities for multi-faceted governmental and community-based interventions that safely consider and protect all communities where chemical solvents are heavily immersed into ground and water sources. Groundwater contamination continues to be an important issue that should remain a priority in health care and public health.

Limitations of the Study

There were delimitations within this study. These delimitations included mortality rates, any health conditions not specifically addressed in the analyses and factors not significant to diagnoses of the DVs during the designated timeframe in this study and outside the scope of the investigation. The population, demographic information of the population and exposure data were obtained from an unidentifiable source. As such, the subsequent impact of this study, which includes the amount of VOC exposure, cancer and heart disease incidence were assessed.

This study had limitations that included the availability of research studies conducted by the EPA, VA, CDC, and its reliance on secondary data and other available correlational studies on this same issue. There was concern regarding the health effects of TCE, PCE, and other VOCs, thus, this study examined whether high chemical exposure levels to VOCs increased incidence of cancers and heart disease in occupational and nonoccupational individuals through drinking water and indoor air sources. This study utilized a correlational, quantitative study design with de-identified secondary data. All information and statistical data were collected veritably, ensuring only merit-based standards were used during the study's design, data collection and data analysis methods. Data results from the target population was specific to this population only but could not specifically or generally inform potential prevention methods and interventions that address the reduction of chemical exposure through groundwater because the data analyses proved to be statistically nonsignificant. Because this study targeted occupational and nonoccupational individuals, not excluding dependent children at the time of chemical exposure, an additional limitation of this study was the actual sample size of the population. This limitation may have affected the full scope of cancer and heart disease incidence rates in the target population. Other limitations of this study specific to secondary data included incorrect reporting of participant demographic information, and the incorrect or nonreporting of personal health information (e.g., pre-existing health conditions).

Recommendations

This study did not produce statistically significant outcomes and the null hypotheses were proven. However, findings from this study can assist with future research and analysis on this topic. While there have been few research studies pertaining to the effects of VOCs on heart disease specifically, state, and federal government agencies have ongoing assessments and evaluation measures in place to monitor the environmental risks of VOCs through vapor intrusion. Therefore, an initial recommendation would be to progress this study (and others similar in nature) by increasing political interventions in toxic substances that affect water and air and cancer and heart disease. The second recommendation would be for political leaders to advocate for more long-term solutions for this public health crisis. For example, future studies on this topic should include and/or review fundamental strategies that build the environmental capacities of public health agencies. By replicating this study's premise and intent on a broader scale, especially in minority communities, the potential to decrease risks of chronic health issues and diseases from air and water sources can be more efficiently and effectively addressed.

Implications for Professional Practice and Social Change

This study was not statistically significant, and the current impact of social change cannot definitively be determined, however, the implications for professional practice and social change based on this study promote future research, scientific and political collaborations among various organizations committed to protecting public health more effectively. Based on the minority population analyzed in this study, there is an opportunity for me to create social change through new community outreach programs in minority communities where water sources are less likely to be treated or have high levels of VOCs. With some modifications, such as a different sample population and location of focus, this study could potentially promote more consistent studies surrounding the effects of VOCs on chronic health conditions, specifically heart disease. The descriptive statistics for both DVs affected by the IV revealed the proportion of populations that both lived and worked at the groundwater contamination site and the proportion of the population that lived but did not work near the contamination site had larger numbers of persons exposed, even though the water consumed was at safe drinking water levels. This data confirms an opportunity for me and other public health professionals to invoke positive social change by advocating for communities specifically around manufacturing facilities and other businesses that use chemical toxins which dump into groundwater sources. Should more research be conducted, this study can be replicated and modified on a broader scale over a new five-year period or timeframe. At that point, this study may have a stronger possibility for impact in susceptible communities (with more statistically significant results). While there was no statistical significance resulting from the statistical tests used for RQ2 and RQ3, there were some small associations observed between the amount of the IV and specific age groups, gender, and ethnicities. This data allowed me to consider best practices for implementing social change in future research, which includes engaging similar communities in positive change through environmental development. By working with communities to integrate research into environmental educational programs, my social change efforts can be translated into more sustainable societies. This can also be achieved through evidence-based actions that translate into both new programs and policies. Over the past decade, the use of many VOCs has declined. For example, by 2012, Methyl tert-butyl ether (MtBE) concentrations were starting to decrease in some groundwater wells, but were unchanged in others, and still increasing in a few (U.S. Department of the Interior, N.d.).

Although there are limited studies currently available on the association between VOCs and the susceptibility of health threats imposed by these chemical solvents through drinking water and air sources, it is vital to domestic and global populations that research continues at minimum, environmentally. Sustainable programs and partnerships from future studies on this topic can solidify impactful social change. This is where the theoretical implications of the SEM are most necessary. I believe professionals in the fields associated with the specific aspects (environment, healthcare, and public health) of this study can use the SEM to effectively connect communities and societies with information, best practices and interventions that make them more accountable for their personal health. On an individual level, the SEM model can provide a multi-level knowledge base and/or understanding of various risk factors caused by water contamination and chemical exposure and how these factors at any one level may influence health outcomes.

The potential impact of social change at the organizational and societal/policy levels includes the creation of sustainable programs, policies and services that will provide attainable solutions for individuals in affected communities. The environmental and social challenges caused by groundwater contamination can impact individuals and their families physically, emotionally, and mentally; thus, being able to apply realistic measures that reduce environmental threats to personal health can provide opportunities to engage in research and create new awareness. Impactful social change efforts by environmental scientists, public health professionals and policy makers should examine the links between chemical exposure and chronic illnesses and provide diverse support that provokes broader public discussions about the preservation of clean drinking water, increasing public awareness regarding air and water pollutants and fostering new advocacy for this topic.

Conclusion

This study's results proved that the analyses conducted were not statistically significant to any of the null hypotheses listed, however, the results from the analyses did provide descriptive statistics that could prove useful in future research (e.g., population occupational count, exposure level of VOCs, variable relationships, and demographic statistics). Based on this study's outcomes and future research on the same or similar chemical solvents, environmental and public health researchers, political factions, physicians, and healthcare specialists would be able to collectively address the effects of groundwater contamination on a more focused spectrum. As technological advancements continue to evolve, new technology-based planning, design, and implementation tools can impact current and future environmental health concerns in much faster and farther-reaching initiatives. The enforcement of new and revised public health marketing strategies, in addition to community-based programs and interventions, can provide a stable foundation for the remediation of chemical solvents from all water sources over the long-term.

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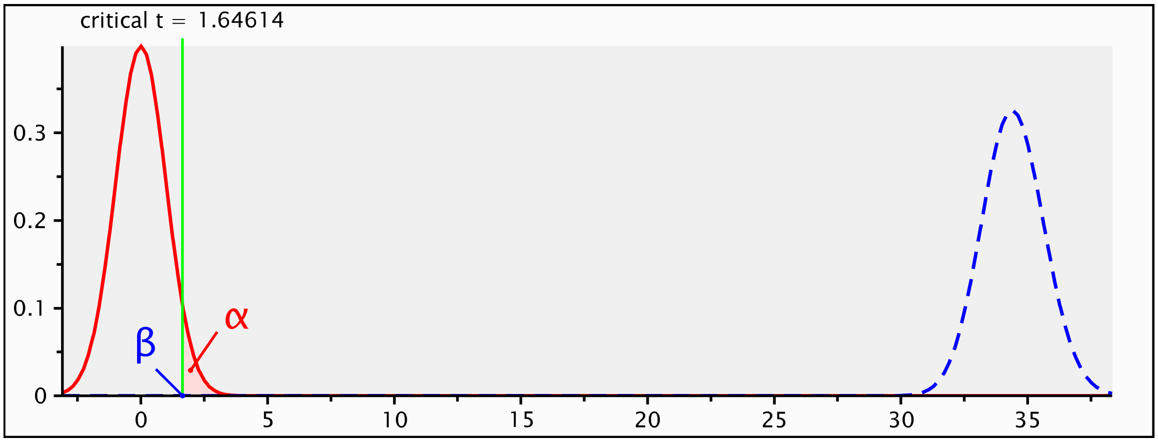
Appendix: Sample Size Calculation

Post Hoc Power Analysis



***t* tests** – Correlation: Point biserial model

Analysis:	Post hoc: Compute achieved power		
Input:	Tail(s)	=	One
	Effect size |ρ|	=	0.7071068
	α err prob	=	0.05
	Total sample size	=	1184
Output:	Noncentrality parameter δ	=	34.4093029
	Critical t	=	1.6461438
	Df	=	1182
	Power (1−β err prob)	=	10.0000000