

EXAMINING THE RELATIONSHIP BETWEEN SAFE DRINKING WATER ACT
VIOLATIONS AND ADVERSE BIRTH OUTCOMES IN VIRGINIA

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ABSTRACT

The Safe Drinking Water Act (SDWA) was established to protect consumers from potential exposure to over 90 water contaminants. Each contaminant is assigned a health-based standard meant to reflect the maximum level at which an adverse human health outcome is unlikely; measurements beyond that level have greater potential to result in an adverse health outcome. While extensive research has been done on the human health implications of water contaminants, few studies have specifically examined the risk to fetal health under real world monitoring conditions. Therefore, the objective of this study is to assess whether drinking water violations are related to fetal health in the Commonwealth of Virginia, by examining the association between SDWA violations and preterm birth (PTB), low birth weight (LBW), and term-low birth weight (tLBW).

Singleton births (n=665,984) occurring between 2007 and 2015 in Virginia were geocoded and assigned to their corresponding water service area. Health-based (HB) and monitoring and reporting (MR) violations for 12 contaminants were acquired from the USEPA Safe Drinking Water System, and exposure to contaminants was defined at the service area level to limit exposure misclassification. A logistic regression model for each birth outcome was performed to evaluate potential relationships with water contaminants.

When examining the relationship between individual monitoring and reporting violations and PTB, Nitrate-Nitrite and Disinfectant Byproducts Stage 2 violations were both positively associated with the birth outcome. When examining the relationship between health-based violations and birth outcomes, total coliform rule violations were negatively associated with tLBW. These findings indicate that monitoring and reporting requirements may need to be more stringent to reduce MR violation occurrence.

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GENERAL AUDIENCE ABSTRACT

The Safe Drinking Water Act (SDWA) was established to protect consumers from potential exposure to over 90 water contaminants. Each contaminant is assigned a health-based standard, called the maximum contaminant level (MCL), meant to reflect the maximum level at which an adverse human health outcome is unlikely; measurements beyond that level have greater potential to result in an adverse health outcome. If a contaminant exceeds the MCL or if the water system fails to treat contaminants, then a health-based violation is issued. These health-based violations are a good indication of the water quality within a public water system. In addition to meeting these health-based requirements, public water systems are required to perform regular monitoring and reporting. When a system fails to evaluate water samples or report results, a monitoring and reporting violation is issued. While extensive research has been done on the human health implications of water contaminants, few studies have specifically examined the risk to fetal health under real world monitoring conditions. Therefore, the objective of this study is to assess whether drinking water violations (health-based and monitoring and reporting) are related to fetal health in the Commonwealth of Virginia, by examining the association between SDWA violations and preterm birth (PTB), low birth weight (LBW), and term-low birth weight (tLBW).

Singleton births (n=665,984) occurring between 2007 and 2015 in Virginia were geocoded and assigned to their corresponding water service area. Health-based and monitoring and reporting (MR) violations for 12 contaminants were acquired from the USEPA Safe Drinking Water Information System, and exposure to contaminants was defined at the service area level to limit exposure misclassification. A logistic regression model for each birth outcome was performed to evaluate potential relationships with water contaminants.

When examining the relationship between individual monitoring and reporting violations and PTB, mothers who resided in a service area that had at least one Nitrate-Nitrite or Disinfectant Byproducts Stage 2 violation were more likely to have a PTB than mothers who lived in a service area where these violations did not occur. When examining the relationship between health-based violations and tLBW, mothers who resided in a service area that had at least one total coliform rule violation were less likely to have a tLBW infant than mothers who lived in a service area where these violations did not occur. These findings indicate that monitoring and reporting requirements may need to be more stringent to reduce MR violation occurrence.

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CHAPTER I: PROBLEM STATEMENT

In the United States in 2018, there were 3,791,712 births (NVSS, 2019), with 10% of those preterm and 8.3% at a low birth weight (CDC, n.d.). Preterm birth (PTB) is defined as an infant born prior to 37 weeks of pregnancy (March of Dimes, n.d.), while an infant born between 37 and 42 weeks of pregnancy is considered full term. Low birth weight (LBW) infants can include babies born preterm or carried to full term. Low birth weight is divided into three subcategories: low birth weight <2500grams, very low birth weight <1500grams, and extremely low birth weight <1000grams (March of Dimes, n.d.). Term low birth weight (tLBW) is classified as an infant born full term (>37 weeks) and <2500 grams. There is evidence that infants born preterm or at a low birth weight have an increased risk of developing adverse outcomes as they age (Hack et al., 1995; Soleimani et al., 2014). Babies born at a low birth weight that lack a congenital birth defect have higher rates of long-term negative developmental outcomes such as illnesses, subnormal growth, and neurodevelopmental issues when compared to normal birth weight infants (Hack et al., 1995). Similarly, there is evidence that infants born prematurely (<37 weeks of pregnancy) are more prone to neurodevelopmental disorders such as intellectual disabilities, cerebral palsy, and visual and hearing impairments (Soleimani et al., 2014).

While our genetic makeup affects birth outcomes, exposure to external factors also contributes. Typically, a combination of factors increases risk, such as smoking, alcohol and drug use, medications, and environmental exposures during pregnancy (CDC, 2018). Exposure to some of these factors is unavoidable while others can be prevented through behavioral change. The environment, however, is a unique agent affecting birth outcomes for its ability to silently harm gestating infants. “Environment,” for the purpose of this research, is rooted in exposures originating outside the home and can be defined as the air, water, and land that people interact with and therefore environmental exposures may often be unavoidable.

According to the World Health Organization, by 2025 half of the world's population is expected to be living in water-stressed areas (WHO, 2019). Currently, 2.2 billion people globally are without access to safe drinking water (WHO, 2019), and water scarcity is only projected to grow as global population increases. It is estimated that the demand for water will grow by 50% by 2030, yet freshwater availability is decreasing (Guppy et al., 2017). Worldwide, 842,000 deaths per year are attributed to unsafe drinking water, hygiene, and sanitation (WHO, 2019). Water scarcity and lack of clean drinking water can lead to increases in hepatitis A, dysentery, cholera, typhoid, diarrhea, and polio (WHO, 2019). Significant reductions in these deaths are possible with access to clean drinking water. In addition to the presence of infectious agents, metals and organic toxins in water can affect human health. Thus, it can be hypothesized that water quality influences the health of a gestating infant. Potential relationships between water quality and birth outcomes have been researched to some extent (e.g., Bove, 1996; Dodds et al., 1999; Yang et al., 2003), but additional and more recent studies are needed. Therefore, this study identifies exposure at the service area level, unlike previous studies that utilize census tract boundaries (Padula et al., 2021), reducing exposure misclassification. No studies linking Safe Drinking Water Act (SDWA) violations and birth outcomes in Virginia have been published, and further research is needed to identify possible associations.

An improved understanding of how drinking water violations potentially impact birth outcomes will assist the work of health officials and policy makers as they work to improve upon national drinking water quality standards and prioritize infrastructure investments. It is crucial to improve understanding of potential links between certain contaminants and increased risk for adverse birth outcomes because current and future water quality regulations may unknowingly have an adverse effect on health or miss opportunities for large scale health interventions.

Considering the previously stated basic and applied research needs, I will examine the following research questions:

- Does an association exist between SDWA violations (MR and/or HB) and adverse birth outcomes within service areas in Virginia?
- If there is an association between violations and adverse birth outcomes in Virginia, where can water quality officials focus their attention to decrease incidence of adverse birth outcomes?

The first research question regarding the presence of an association between water contaminant violations and adverse birth outcomes will be answered through development of a logistic regression model to identify how/whether the chosen contaminants individually affect each response variable (i.e. PTB, LBW, tLBW). We will then determine in what part of the state water quality officials should focus their attention to decrease incidence of adverse birth outcomes by evaluating which contaminant violations significantly impact the response variables and where those violations occur.

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CHAPTER II: LITERATURE REVIEW

2.1 Medical Geography

This research lies at the intersection of medical geography and environmental health. The study contributes to the sub-discipline of medical geography, which is the study of spatial patterns of health and disease and analysis of underlying processes to explain those spatial patterns (Dummer, 2008). Jacques May officially coined the term “medical geography” in the 1950s when he examined cultural and environmental conditions related to health, but the sub-discipline has a much older history (May, 1950). In 400 B.C., Hippocrates wrote *Airs, Waters, and Places*. The emphasis on place and health in this text marked the first written record of concepts that later became part of medical geography. In 1854, during the London, England cholera epidemic, John Snow disproved the long-accepted miasma theory when he discovered that the outbreak was caused by micro-organisms in part with the use of maps and spatial analysis (Snow, n.d.). This discovery contributed to the development of germ theory, which recognizes that people can become sick from things they cannot see, including contaminants in drinking water. For years, scientists have been using medical geography theories and concepts to solve health related issues, aware of it or not. The boundaries of medical geography have since evolved to focus less on disease and more on overall health. There are now six main established themes for medical geographers: disease ecology, health services, spatial analysis, women’s health, mental health, and health in developing countries (Gesler, 2004). When trying to understand health-related issues, consulting medical geographers is often a necessary step before determining what to do next. It is crucial for health officials to understand the *why*, *how*, and *where* behind an issue before taking action to protect society.

2.1.1 Environmental Health

This work additionally contributes to the sub-discipline of environmental health, which is the branch of public health that studies the relationship between people and their environment (CDC, 2016). The World Health Organization (2016) defines environmental health as addressing “all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviors. It encompasses the assessment and control of those environmental factors that can potentially affect health. It is targeted towards preventing disease and creating health-supportive environments. This definition excludes behavior not related to environment, as well as behavior related to the social and cultural environment, as well as genetics.” There are four main themes that shape the sub-discipline of environmental health: environmental science, environmental and occupational medicine, toxicology, and epidemiology (APHA, n.d.). This research resides most specifically within the theme of epidemiology, which studies the distribution and determinants of diseases and health related issues (CDC, 2016). Through examining the relationship between the natural and built environment, public health officials can aid in creating healthy and safe communities to promote overall well-being.

2.2 Contaminants of Interest

Past studies suggest that a variety of contaminants in water, ranging from chemical to microbial, affect human health and birth outcomes. The Safe Drinking Water Act (SDWA) establishes health-based drinking water standards (i.e., maximum contaminant levels, or MCLs) for over 90 contaminants. The maximum contaminant levels selected by the Environmental Protection Agency (EPA) are meant to reflect the maximum level that limits the risk of human health impacts, but also may reflect the realities of available treatment technology. In this section, the following regulated contaminants, chosen for their potential to have a negative impact on birth outcomes, are reviewed: arsenic, atrazine, coliform, disinfection byproducts, lead and copper, nitrate/nitrite, and

radionuclides.

2.2.1 Chemical Contaminants and Birth Outcomes

Arsenic

Arsenic, found in rocks and soil, occurs naturally (CDC, 2015), but can also be present in water from industrial, agricultural, and mining processes and is typically more prevalent in ground water sources than surface water (CDC, 2015). In water, arsenic has no taste, smell, or color, making it impossible to identify without laboratory analysis (MassDEP, n.d.). According to the World Health Organization (WHO), inorganic arsenic is a confirmed carcinogen and is the most significant non-infectious water-borne contaminant in the world (WHO, 2018). The WHO estimates that at least 140 million people in 50 different countries are drinking water containing arsenic at levels exceeding WHO guidelines (WHO, 2018). In the United States, the Environmental Protection Agency (EPA) has set the MCL for arsenic at 10 ppb (EPA, 2001). This MCL was reduced in 2001 from its previous MCL of 50 mg/L (EPA, 2001). This change intended to decrease the public health risk from arsenic exposure. Exposure to arsenic in drinking water has many short-term and long-term effects (WHO, 2018), and specifically, many associations have been made between arsenic and adverse birth outcomes. Claus Henn et al. (2016) observed decreases in birth weight, gestational length, head circumference, and fetal growth with increasing prenatal exposure to arsenic. Claus Henn et al. (2016), AlMBERG et al. (2017), and Yang et al. (2003), all found associations between arsenic exposure and low birth weight. An association between arsenic exposure and preterm birth was also found by AlMBERG et al. (2017), Yang et al. (2003), and Ahmad et al. (2001). In the same study done by AlMBERG et al. (2017), no associations were found between small for gestational age (smaller than the average for the number of weeks of pregnancy) and very preterm birth. Still, the association AlMBERG et al. (2017) found with very low birth

weight, preterm birth, and term low birth weight, at arsenic levels below EPA guidelines, supports concerns regarding the effects of this contaminant on the developing fetus.

Atrazine

Atrazine is a common herbicide used frequently on corn, soybeans, pineapple, pine trees, sugar cane, and other crops (WHO, 2003). Although it is commonly identified as an environmental health concern in examinations of surface and groundwater, its impact on fetal health remains uncertain. It is strongly absorbed by soil, eventually leaching into and potentially contaminating the water supply (WHO, 2003). In surface water, atrazine is the most detected pesticide in the U.S., and it is also found in groundwater (Almberg et al., 2018). The EPA has set the MCL for atrazine at 3.0 ppb. Rinsky et al. (2012) reported an increase in preterm birth with increasing exposure to atrazine concentrations; however Villanueva et al. (2005) found no association between contaminant exposure and small for gestational age. Similarly, Almberg et al. (2018) found no associations between atrazine exposure and preterm birth, as well as small for gestational age, and very low birth weight. Almberg et al. (2018) did, however, find an association with term low birth weight, when exposed to atrazine during the entire gestational period.

Lead and Copper

Lead and copper primarily contaminate drinking water through the corrosion of plumbing materials; therefore, determining accurate measures of lead and copper exposure requires systems to monitor at customer taps (EPA, n.d.). The EPA recognizes that there are no safe levels for these contaminants and thus has set an action level rather than an MCL. The action level for lead is 10 ppb and 1.3 ppm for copper (EPA, n.d.). If more than 10% of taps sampled exceeds these action levels, then a violation is issued. In 2001, Washington D.C. experienced a lead crisis, and research indicates that the fetal death rate increased 32-63% and remained high until public health interventions were made in 2004 to limit maternal exposure to lead (Edwards, 2013). A study done

by Ugwuja et al. (2011) shows a correlation between maternal ingestion of lead contaminated water and low birth weight. Additionally, the lead crisis in Flint, Michigan led to an increased incidence in low birth weight infants (Abouk et al., 2018). Another study found that pregnant women who had the maximum blood lead level recommended ($\geq 10\mu\text{g}/\text{dl}$) were three times more likely to have a preterm birth and four times more likely to have an infant that is small for gestational age than those with lower blood lead levels (Jelliffe-Pawlowski et al., 2006).

Nitrate and Nitrite

Nitrate is found in fertilizers and manure is nitrate (WA DOH, n.d.), and through runoff can reach surface water and leach into ground water. The EPA has recognized that nitrate in drinking water has significant health impacts and thus has set the maximum contaminant level (MCL) at 10 ppm (EPA, n.d.). It is important to note that nitrate often contaminates water seasonally, especially during planting and fertilization periods in spring, with excess rainfall causing runoff to occur. Nitrate in water is primarily a risk when digested, after which it transforms into nitrite, which can result in an oxygen deficiency called methemoglobinemia, or “blue baby syndrome” (Jakucionyte et al., 2001). Though few epidemiologic studies have researched the risks associated with nitrate in drinking water and adverse birth outcomes, there have been observations of an association at levels below EPA drinking water standards. A study done by Jakucionyte et al. (2001), found that exposure to increasing nitrate concentrations increased risk for low birth weight. A study done by Croen et al. (2001) observed that maternal exposure to nitrates above the MCL resulted in a fourfold increase in their child’s risk for neural tube defects. Additionally, Stayner et al. (2017), found that nitrate was associated with very preterm birth and very low birth weight at nitrate levels below EPA drinking water regulations.

2.2.2 Radionuclides and Birth Outcomes

Radioactive elements, called radionuclides, occur naturally in rocks and soil, and dissolve in water (USGS, n.d.). Four radionuclides are regulated in drinking water by the EPA: uranium, beta/photon emitters, gross alpha particle, and combined radium 226/228 (EPA, 2001). Gross alpha particle represents overall radioactivity in water (MCL: 15 pCi/L) (USGS, n.d.; EPA, 2001). Uranium represents common trace elements found in rocks (MCL: 30 ppb) (USGS, n.d.; EPA, 2001). Combined radium-226/228 are daughter products of uranium decay and common isotopes of radium (MCL: 5 pCi/L) (USGS, n.d.; EPA, 2001). Beta and photon emitters are primarily manmade and are associated with processes that use or dispose of radioactive material (MCL: 4 mrem/yr) (USGS, n.d.; EPA, 2001). It has been recognized that increased radionuclide exposure can have significant health impacts such as damage to kidneys and an increased risk of cancer (EPA, 2001). Few studies have researched the effects of radionuclides on fetal health. A study done by Langlois et. al. (2015) found an increased prevalence of Down syndrome, cleft lip, and cystic hygroma/lymphangioma when maternal residence was in an area with high levels of atmospheric radon. Additionally, a study in Texas at the zip code level found that elevated uranium and radium levels in drinking water are associated with an increased prevalence of orofacial birth defects (Cech et. al., 2007). No studies have examined the relationship between radionuclides and PTB, tLBW, or LBW. Since radionuclides have a significant impact on human health, further research is needed to determine the possible effects on birth outcomes.

2.2.3 Disinfectants and Disinfection Byproducts and Birth Outcomes

Chlorination is the most common method for removing pathogens and toxic chemicals from municipal drinking water in the United States (CDC, 2016). Disinfection byproducts (DBPs) are the result of chlorine reacting with natural organic matter (Toledano et al., 2005). The four most common DBPs are bromate, chlorite, haloacetic acids, and total trihalomethanes (TTHMs) (CDC,

2016). These contaminants can pose a potential health risk and are found in high levels in water systems that use surface water as a primary water source (Bove, 1996). The EPA has set MCL for TTHM (0.080 ppm), five haloacetic acids (HAA5) (0.060 ppm), bromate (0.010 ppm), chlorite (1.0 ppm) (EPA, 2010). In addition to these four regulated contaminants, the EPA also regulates the disinfectants chlorine and chlorine dioxide (EPA, 2010). Associations between chlorination byproducts and adverse birth outcomes have been found among animals, but when looking at the association with chlorination byproducts and adverse birth outcomes among human infants, there is a lack of clarity in the literature (Dodds et al., 1999). A study done in England showed a small excess risk for stillbirths, low birth weight, and very low birth weight in areas with high TTHM concentrations (Toledano et al., 2005). Studies looking specifically at term low birth weight found an increased risk with exposure to TTHM (Bove et al., 1995; Gallagher et al., 1998; Hwang et al., 2003). Alternatively, a few studies found no association between TTHM exposure and birth defects. However, the studies that found no association with TTHM exposure and adverse birth outcomes consistently lacked a large sample size or failed to consider concentration levels, looking only at exposure (Hoffman et al., 2008; Källén et al., 2000; Yang et al., 2007). Results from studies investigating TTHM exposure and preterm birth varied: Gallagher et al. (1998) found no association between preterm birth and TTHM exposure whereas Yang et al. (2007) found an increased risk for preterm birth when exposed to TTHM. In addition, associations have been found between increasing exposure to haloacetic acids (HAA5) and term low birth weight (Hinckley et al., 2005). Research has primarily focused on fetal exposure to TTHM or a combination of all byproducts. There is a lack of research on the individual effects of HAA5, bromate, and chlorite, as well as the disinfectants chlorine and chlorine dioxide, likely because these contaminants are often concurrently present in water.

2.2.4 Microbial Contaminants and Birth Outcomes

Coliform

The EPA monitors and regulates fecal indicator bacteria (FIB), specifically total coliform, and *E. coli*, to reduce risks from fecal-oral diseases. Total coliform is a family of bacteria found both in mammalian feces and in soil and vegetation (Leclerc et. al., 2001). Though most bacteria in the total coliform group present no infectious risk, detection of these bacteria in drinking water may indicate that disinfection processes are not working properly, there is a pipe break, or other potential sources of contamination. *E. coli* is a specific species of coliform solely found in the feces of warm-blooded animals that are considered a direct sentinel of infectious risk (Paruch et. al., 2012). The monitoring requirements related to coliform enforced by the EPA are divided into two levels. Level one tests for the presence of total coliform; if the results are positive then level two sampling must occur (EPA, n.d.). Level two tests for the presence of *E. coli*; if the results are positive (MCL: 0) then a violation is reported (EPA, n.d.). Though there are epidemiological relationships directly linking FIB and health impacts, none focus on the potential fetal health effects of exposure to FIB in drinking water. Mahande et al. (2016) found that pregnant women who had amebiasis, caused by a gastrointestinal parasite, were 79% more likely to have a preterm birth. Additionally, there have been cases where exposure to gastrointestinal organisms during the third trimester of pregnancy developed into *E. coli* sepsis, leading to the preterm rupture of the amniotic sac, suggesting the potential risk for preterm birth and low birth weight (Jones et al., 2004) and a need for evaluation of the potential relationship.

2.3 Conclusion

Based on the literature reviewed thus far, the impact water contaminants have on birth outcomes is unclear. Evidence exists that certain water contaminants are associated with preterm birth, low birth weight, and term low birth weight but further research is needed to establish a relationship. Few studies have examined associations between water contaminants and adverse birth outcomes, especially at an individual level, and no studies have investigated the relationship between municipal drinking water violations and birth outcomes in the commonwealth of Virginia. This research will address this gap in the literature to aid in determining if there is a correlation between water contaminant violations and preterm birth, low birth weight, and term low birth weight in Virginia. Additionally, this research improves upon previous research by utilizing service area boundaries, rather than political boundaries, to reduce exposure misclassification.

This research has the potential to better equip water quality officials with evidence regarding the impact of contaminants on fetal health. If there is an association between adverse birth outcomes and certain water contaminant violations, then public health officials can focus their attention on those contaminants to decrease the incidence of adverse birth outcomes. By displaying spatially where the violations occur, public health officials will be able to target intervention methods in specific regions.

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Examining the Relationship Between Safe Drinking Water Act Violations and Adverse Birth Outcomes in Virginia

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Abstract

The Safe Drinking Water Act (SDWA) was established to protect consumers from potential exposure to over 90 water contaminants. Each contaminant is assigned a health-based standard meant to reflect the maximum level at which an adverse human health outcome is unlikely; measurements beyond that level have greater potential to result in an adverse health outcome. While extensive research has been done on overall human health implications of water contaminants, few studies have specifically examined the risk to fetal health under real world monitoring conditions. Therefore, the objective of this study is to assess whether drinking water violations are related to fetal health in the Commonwealth of Virginia by examining the association between SDWA violations and preterm birth (PTB), low birth weight (LBW), and term-low birth weight (tLBW).

Singleton births (n=665,984) occurring between 2007 and 2015 in Virginia were geocoded and assigned to a corresponding approximated water service area. Health-based (HB) and monitoring and reporting (MR) violations for 12 contaminants were acquired from the USEPA Safe Drinking Water System, with exposure defined at the service area level to limit exposure misclassification. A logistic regression model for each birth outcome assessed potential relationships with water contaminants.

When examining the relationship between individual monitoring and reporting violations and PTB, Nitrate-Nitrite and Disinfectant Byproducts Stage 2 violations were both positively associated with the birth outcome. When examining the relationship between health-based violations and birth outcomes, the total coliform rule was negatively associated with tLBW. These findings indicate that monitoring and reporting requirements may need to be more stringent to reduce MR violation occurrence or

infrastructure investments should be made.

Keywords: medical geography, environmental health, spatial epidemiology, water quality, birth outcome

1. Introduction

According to the World Health Organization, half of the world's population will be living in water-stressed areas by 2025 (WHO, 2019). As of 2019, 2.2 billion people globally are without access to safe drinking water (WHO, 2019), and water scarcity is only projected to grow as global population increases. Worldwide, 842,000 deaths are attributed to unsafe drinking water, sanitation, and hygiene every year (WHO, 2019). Lack of clean drinking water can lead to increases in cholera, typhoid, hepatitis A, dysentery, diarrhea, and polio (WHO, 2019). Significant reductions in these deaths are possible with access to clean drinking water. In addition to the presence of infectious agents, metals and organic toxins in water can affect human health.

Given the wide variety of potential harmful exposures vectored by water, it can be hypothesized that water quality influences the health of a gestating infant. Potential relationships between water quality and birth outcomes have been researched to some extent (e.g., Bove, 1996; Dodds et al., 1999; Yang et al., 2003), but additional and more recent studies are needed. This study identifies exposure at the approximated service area level, unlike previous studies that utilize census tract boundaries (Padula et al., 2021), reducing exposure misclassification. No studies linking Safe Drinking Water Act (SDWA) violations and birth outcomes in Virginia have been published, and further research is needed to identify possible associations.

An improved understanding of how drinking water violations potentially impact birth

outcomes will assist the work of health officials and policy makers as they work to improve upon national drinking water quality standards. It is crucial to improve understanding of potential links between certain contaminants and increased risk for adverse birth outcomes because current and future water quality regulations may unknowingly have an adverse effect on health.

Considering the previously stated basic and applied research needs, we will examine the following research questions:

- Does an association exist between SDWA violations (MR and/or HB) and adverse birth outcomes within service areas in Virginia?
- If there is an association between violations and adverse birth outcomes in Virginia, where can water quality officials focus their attention to decrease incidence of adverse birth outcomes?

The first research question regarding the presence of an association between water contaminant violations and adverse birth outcomes will be answered through logistic regression to determine whether the chosen contaminants are associated with the response variable (i.e. PTB, LBW, tLBW). We will then determine in what part of the state water quality officials should focus their attention to decrease incidence of adverse birth outcomes by evaluating which contaminant violations significantly impact the response variables and where those violations occur.

2. Background

Contaminants of Interest

Past studies suggest that a variety of contaminants, ranging from chemical to microbial, may affect human health and birth outcomes. The Safe Drinking Water Act

establishes health-based drinking water standards (i.e. maximum contaminant levels, or MCLs) for over 90 contaminants. The maximum contaminant levels selected by the Environmental Protection Agency (EPA) are meant to reflect the maximum level that limits the risk of human health impacts, but also may reflect the realities of available treatment technology. This study considers two violation types: health-based and monitoring and reporting. Health-based violations are issued when a contaminant exceeds its corresponding MCL (see table 1) or when a system fails to follow minimum treatment technique requirements to reduce the contaminant. When a system fails to evaluate water samples, or submit monitoring results to the EPA, a monitoring and reporting violation is issued. In this section, the following regulated contaminants, chosen for their potential to have a negative impact on birth outcomes, are reviewed: arsenic, atrazine, coliform, disinfection byproducts, lead and copper, nitrate/nitrite, and radionuclides.

Table 1: Contaminants of interest and their corresponding maximum contaminant level (MCL).

Contaminant Type	Contaminant	MCL
Chemical Contaminant	arsenic	10 ppb
	atrazine	3 ppb
	lead	10 ppb*
	copper	1.3 ppm*
	nitrate	10 ppm
	nitrite	1 ppm
Radionuclides	uranium	30 ppb
	gross alpha particle	15 (pCi/L)
	combined radium 226/228	5 (pCi/L)
Disinfectant Byproducts	haloacetic acids (HAA5)	0.06 ppm
	total trihalomethanes (TTHM)	0.08 ppm
Microbial Contaminant	total coliform	0
	<i>E. coli</i>	0

* Indicates action level, MCL for these contaminants is 0. Violation is issued if more than 10% of tap samples exceeds action levels.

Chemical Contaminants and Birth Outcomes

The chemical contaminants examined in this study are arsenic, atrazine, lead, and nitrate. Maternal exposure to arsenic is associated with low birth weight (Henn et al., 2016; AlMBERG et al., 2017; Yang et al., 2003) and preterm birth (AlMBERG et al., 2017; Yang et al., 2003; Ahmad et al. 2001). Atrazine exposure increases the risk for preterm birth and term low birth weight (Rinsky et al., 2012; AlMBERG et al., 2018). Lead contaminated drinking water is correlated with low birth weight (UgwuJa et al., 2011).

Additionally, nitrate concentrations below EPA drinking water standards can increase the risk for very preterm birth and very low birth weight (Stayner et al., 2017).

Radionuclides and Birth Outcomes

No studies have examined the relationship between radionuclides and PTB, tLBW, or LBW. However, Langlois et al., (2015) found an increased prevalence of Down syndrome, cleft lip, and cystic hygroma/lymphangioma when exposed to high levels of radon. Additionally, Cech et al. (2007), found that elevated uranium and radium levels in drinking water are associated with an increased prevalence of orofacial birth defects.

Disinfectants and Disinfection Byproducts and Birth Outcomes

Chlorination is the most common method for removing pathogens and toxic chemicals from municipal drinking water in the United States (CDC, 2016). Disinfection byproducts (DBPs) are the result of chlorine reacting with natural organic matter (Toledano et al., 2005). Toledano et al. (2005), found an excess risk for low birth weight and very low birth weight infants in areas with high TTHM concentrations. TTHM can also result in term low birth weight and preterm birth (Bove et al., 1995; Gallagher et al., 1998; Hwang et al., 2003; Yang et al. (2007)). In addition, increasing exposure to haloacetic acids (HAA5) is associated with term low birth weight (Hinckley et al., 2005).

Microbial Contaminants and Birth Outcomes

No research has specifically examined the potential fetal health effects of exposure to fecal indicator bacteria (FIB) in drinking water. Mahande et al. (2016), found that pregnant women who had amebiasis, caused by a gastrointestinal parasite, were 79% more likely to have a preterm birth. Additionally, Jones et al. (2004), found that exposure to FIB during the third

trimester of pregnancy developed into *E. coli* sepsis, leading to the preterm rupture of the amniotic sac, suggesting the potential risk for preterm birth and low birth weight.

3. Data and Methods

Public Water System Data

Public water system (PWS) data for the Commonwealth of Virginia from 2007 to 2015 was obtained from the Safe Drinking Water Information System (SDWIS) database, which is a publicly available database containing information on all PWS in the United States. The following variables were acquired from the dataset: PWS ID and name, PWS type, counties and cities served, number of violations, rule name, violation type, contaminant name, and date (see table 1). Estimated service areas for 662 water distribution systems were delineated by Marcillo et al. (2020) and were used in this study (see figure 1). Service areas were estimated by Marcillo et al. (2020), by assigning populations to PWS based on proximity to the system and population served. Zip codes were utilized to determine proximity to PWS, and zip codes closest to a PWS were assigned to the corresponding system until the population that the system served was fully assigned. It is important to note that service area delineations are not publicly available and while these estimates do present potential exposure bias, it is believed to be less so than the utilization of political boundaries.

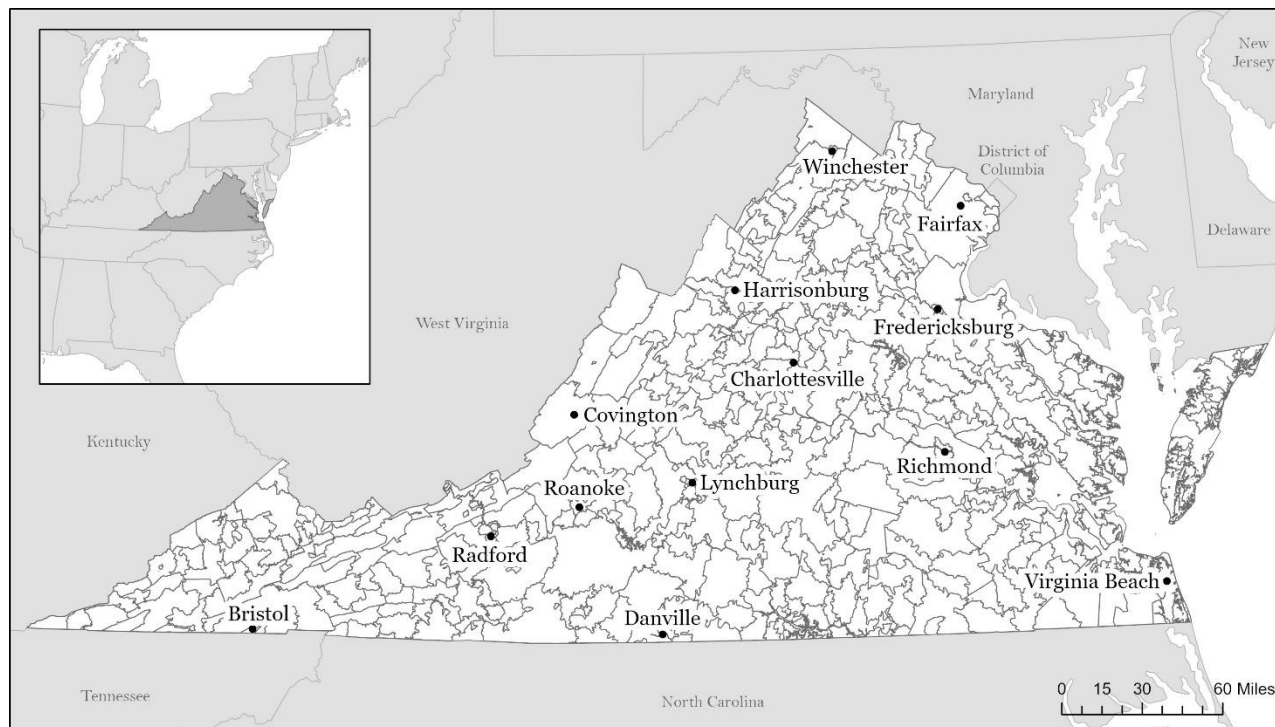


Figure 1: Estimated service area boundaries in Virginia.

Birth Outcome Data

Virginia birth records (n=869,523) from 2007 to 2015 were acquired for the Commonwealth of Virginia from the Virginia Department of Health (VDH). All data analyses were conducted according to protocols to protect confidentiality approved by Virginia Tech IRB (VT IRB #17-1190) and Virginia Department of Health IRB (VDH IRB #40221). The following information was acquired from the birth records: mother’s address, mother’s demographics (age, race, education, if mother is of Hispanic origin), child’s information (weight, gestational length, sex), parity, plurality, and maternal behaviors (e.g., tobacco use during pregnancy). A total of 665,984 births were included in the study after processing (explained below).

Data Processing

For birth records, exposure period was classified by the majority gestational year. To determine majority gestational year, the gestational age and birth date were used to estimate the midpoint of the gestational period. The majority gestational year was assigned to the year in which the midpoint occurred. Birth records were examined to determine gestational length and birthweight to identify PTB, LBW, and tLBW, which were generated as follows: PTB= <37 weeks of pregnancy, LBW= <2500 grams, tLBW= <2500 grams *and* >37 weeks of pregnancy. Each outcome was given a binomial classification. During the study period, the original birth record coding structure changed for race, payment, and education. For consistency between the years, a new coding structure was created, and all covariates were categorized accordingly. Plural births have an increased risk of morbidity and perinatal mortality (Warner et al., 2000). Thus, they were removed, and the study only included singleton births. Birth records with any of the following were removed from the study: incomplete street address, P.O. box address, unknown gestational age, and unknown birth weight (see figure 2), resulting in a final sample size of 665,984. Birth records with complete addresses were then geocoded using Esri's 2013 StreetMap dataset.

To limit exposure misclassification, service areas were used as the unit of analysis for this study. SDWA violations were aggregated at the service area level and were then categorized into (0) having no violations in a service area or (1) having one or more violations during each year. Quantities of violations were not considered due to inconsistencies in sampling frequency between individual water systems. Each birth record was joined spatially to its corresponding service area for analysis.

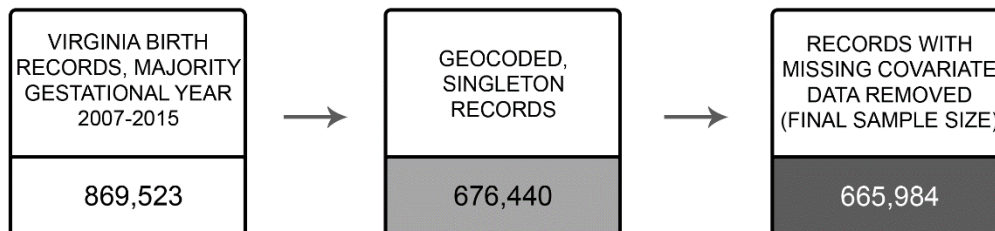


Figure 2: Data processing for individual birth records within Virginia.

Statistical Analyses

Statistical analyses were conducted to determine if a relationship exists between adverse birth outcomes and water contaminant violations. The violations of interest include contaminants regulated by the EPA that have the potential to impact birth outcomes (see table 1). MR and HB violations were examined separately using a logistic regression model for each birth outcome (PTB, LBW, tLBW), for a total of six models. To understand the relationship between the outcome of interest and SDWA violations, odds ratios and confidence intervals (CI) at 95% were calculated to determine significance.

The following covariates were entered into the regression model: mother’s age, race, education, if mother is of Hispanic origin, tobacco use during pregnancy (yes/no), infant’s sex, payment method, and parity/birth order. For the race variable, mother’s race was only recorded for half of the study period. When mother’s race was unavailable, child’s race was used. Due to the potential errors in the race variable, a separate model was run excluding race (see appendix). Similarly, inconsistencies exist over the study period with the tobacco use variable. Between 2007-2012 there was no unknown option for tobacco use. After 2012, unknowns for tobacco are present in the data. Due to this disconnect, a

separate model was run excluding all unknown tobacco variables (see appendix). All analyses were done using JMP statistical software.

For each of the three birth outcome variables, logistic regression was performed using the following sample model:

$$\gamma(\text{response}) = \beta_0 + \beta_1(\text{contaminant}) + \beta_2(\text{covariate}) + \beta_3(\text{covariate}) + \dots + \epsilon_i$$

4. Results

A total of 665,984 births from 662 service areas were included in the study. Out of the 665,984 births that were analyzed, 51,261 were PTB (7.7%), 40,638 LBW (6.1%), and 14,052 tLBW (2.1%). Characteristics of the distribution of demographic variables exposed and unexposed to SDWA violations can be found in table 2. Within the sample over the nine-year study period, there were 60,983 births that were exposed to at least one monitoring and reporting (MR) violation and 53,354 births that were exposed to at least one health-based (HB) violation.

Table 2: Characteristics of singleton births exposed and unexposed to SDWA violations in their corresponding service area.

Characteristic (%)	Monitoring and Reporting		Health-Based	
	≥1 MR Violation Occurred, n = 60,983, n (%)	0 MR Violation Occurred, n = 605,001, n (%)	≥1 HB Violation Occurred, n = 53,354, n (%)	0 HB Violation Occurred, n = 612,630, n (%)
<u>Infant Sex</u>				
M (51.2)	31312 (51.3)	309448 (51.1)	27385 (51.3)	313375 (51.2)
F (48.8)	29671 (48.7)	295553 (48.9)	25969 (48.7)	299255 (48.8)
<u>Mother's Hispanic Origin</u>				
Hispanic (12.8)	5898 (9.7)	79452 (13.1)	3793 (7.1)	81557 (13.3)
Not Hispanic (87.1)	54990 (90.2)	524778 (86.7)	49502 (92.8)	530266 (86.6)
Unknown (0.1)	95 (.16)	771 (.13)	59 (.1)	807 (.1)
<u>Race</u>				
White (66.6)	44684 (73.3)	398952 (65.9)	37702 (70.7)	405934 (66.3)
Black (20.6)	11560 (19.0)	125553 (20.8)	12385 (23.2)	124728 (20.4)
Other (12.8)	4739 (7.8)	80496 (13.3)	3267 (6.1)	82128 (13.4)
<u>Mother's Age</u>				
18-35 (85)	52455 (86.0)	513552 (84.9)	46846 (87.8)	519161 (84.7)
<18 (1.7)	1263 (2.1)	10629 (1.8)	1200 (2.2)	10692 (1.7)
>35 (13.3)	7265 (11.9)	80820 (13.4)	5308 (9.9)	82777 (13.5)
<u>Mother's Education</u>				
Some secondary schooling* (39.2)	27001 (44.3)	234088 (38.7)	24107 (45.2)	236982 (38.7)
Some college or college degree (59.7)	33372 (54.7)	364421 (60.2)	28869 (54.1)	368924 (60.2)
Unknown (1.1)	610 (1.0)	6492 (1.1)	378 (.7)	6724 (1.1)
<u>Payment</u>				
Medicaid (28)	19584 (32.1)	167113 (27.6)	18294 (34.3)	168403 (27.5)
Private Insurance (65.5)	36989 (60.7)	399292 (66.0)	31635 (59.3)	404646 (66.1)
Self-Pay (5.1)	3807 (6.2)	30271 (5.0)	2219 (4.2)	31859 (5.2)
Unknown (1.3)	603 (.99)	8325 (1.4)	1206 (2.3)	7722 (1.3)
<u>Tobacco</u>				
No (87.3)	51581 (84.6)	529570 (87.5)	44525 (83.5)	536626 (87.6)
Yes (5.6)	5043 (8.3)	32239 (5.3)	4708 (8.8)	32574 (5.3)
Unknown (7.1)	4359 (7.1)	43192 (7.1)	4121 (7.7)	43430 (7.1)
<u>Parity</u>				
1 (42)	25317 (41.5)	254277 (42.0)	22287 (41.8)	257307 (42.0)
2 (32.3)	19236 (31.5)	195936 (32.4)	16699 (31.3)	198473 (32.4)
3 (15.9)	9966 (16.4)	95964 (15.9)	8575 (16.1)	97355 (15.9)
4 or more (9.8)	6464 (10.6)	58824 (9.7)	5793 (10.9)	59495 (9.7)

*includes High School diploma or GED

Monitoring and Reporting Violations

Within the study sample, there were 60,983 births that were exposed to at least one monitoring and reporting (MR) violation. Three logistic regression models (one for each outcome) were employed to examine 13 monitoring and reporting violations in relation to PTB, LBW, and tLBW. Nitrate violations were excluded due to insufficient frequency of occurrence. Characteristics of the distribution of demographic variables exposed and unexposed to individual monitoring and reporting violations can be found in the appendix.

Preterm Birth

When examining PTB in relation to individual monitoring and reporting violations, disinfectant byproduct stage 2 was found to be significant with an OR of 1.115 (95% CI: 1.00-1.24); nitrate-nitrite was also significant with an OR of 1.095 (95% CI: 1.02-1.18) (see table 3). All other violations were found to be insignificant at a CI of 95% in relation to PTB (see table 3).

Table 3: Odds ratios (CI 95%) for associations between monitoring and reporting violations and PTB. Adjusted for mother’s race, mother’s age, mother’s education, parity, majority gestational year, infant’s sex, and tobacco use during pregnancy.

SDWA Violation	Preterm Birth			
	OR	P	Lower 95 %	Upper 95 %
Arsenic	1.081	0.325	0.925	1.264
Atrazine	0.844	0.690	0.367	1.942
Total Coliform Rule	0.984	0.406	0.949	1.022
Combined Radium	1.083	0.297	0.933	1.257
Combined Uranium	1.099	0.225	0.944	1.279
Disinfectant Byproduct Stage 1	1.146	0.484	0.783	1.678
Disinfectant Byproduct Stage 2	1.115	0.041	1.004	1.238
<i>E. coli</i>	0.931	0.274	0.819	1.058
Gross Alpha Exc.	1.095	0.235	0.949	1.273
Lead and Copper Rule	1.034	0.407	0.956	1.118
Nitrate-Nitrite	1.095	0.014	1.019	1.176
TTHM	0.931	0.237	0.828	1.048
HAA5	0.965	0.532	0.865	1.078

Low Birth Weight

When examining LBW in relation to individual monitoring and reporting violations, no violations were found to be significant at a CI of 95%.

Term Low Birth Weight

When examining tLBW in relation to individual monitoring and reporting violations, no violations were found to be significant at a CI of 95%.

Health-Based Violations

Within the study sample, there were 53,354 births that were exposed to at least one health-based (HB) violation. Three logistic regression models (one for each outcome) were employed to examine eight health-based violations in relation to PTB, LBW, and tLBW. Nitrate-nitrite and gross alpha including radon and uranium were both excluded due to insufficient frequency of occurrence. Characteristics of the distribution of demographic variables exposed and unexposed to individual health-based violations can be found in the appendix.

Preterm Birth

When examining PTB in relation to health-based violations, all violations were found to be insignificant at a CI of 95%.

Low Birth Weight

When examining LBW in relation to health-based violations, all violations were found to be insignificant at a CI of 95%.

Term Low Birth Weight

When examining tLBW in relation to health-based violations, Total Coliform Rule was found to be significant with an OR of .929 (95% CI: 0.87-1.00), i.e. the occurrence of Total Coliform Rule violations was associated with a decrease in tLBW. All other violations were found to be insignificant at a CI of 95% (see table 4).

Table 4: Odds ratios (CI 95%) for associations between health-based violations and tLBW. Adjusted for mother's race, mother's age, mother's education, parity, majority gestational year, infant's sex, and tobacco use during pregnancy.

SDWA Violation	Term Low Birth Weight			
	OR	<i>P</i>	Lower 95 %	Upper 95 %
Arsenic	0.943	0.716	0.689	1.292
Total Coliform Rule	0.929	0.041	0.867	0.997
Combined Radium	1.242	0.463	0.696	2.217
Gross Alpha Exc.	0.990	0.989	0.242	4.051
Disinfectant Byproduct Stage 1	0.815	0.139	0.621	1.068
Lead and Copper Rule	1.300	0.304	0.788	2.144
HAA5	1.087	0.502	0.852	1.386
TTHM	1.104	0.225	0.941	1.295

Spatial Distribution of Violations

Disinfectant Byproduct Stage 2 (MR)

Disinfectant byproduct stage 2 (DBPst2) violations occurred only in 2009, 2010, and 2011 (see figure 3). In 2009, violations were concentrated in the northern most corner of the state, near Washington D.C., with a few violations occurring south of Richmond. In 2010, violations occurred in the outer D.C. area, near Fredericksburg, and southwest of Lynchburg. In 2011, violations occurred in southwest Virginia, west of Radford. Violations occurred primarily in urban areas with a few occurring in small towns and rural areas.

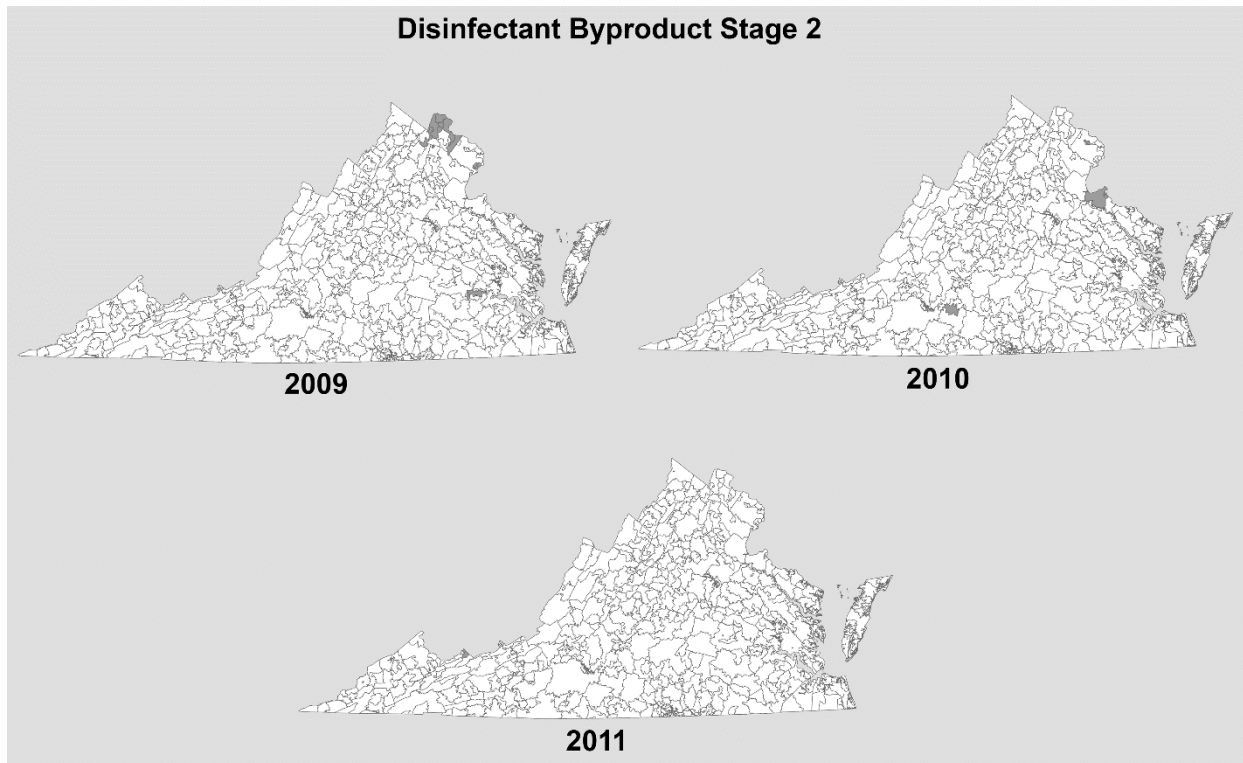


Figure 3: Disinfectant byproduct stage 2 (MR) violations in service areas. No violations occurred in 2007, 2008, and 2012-2015.

Nitrate-Nitrite (MR)

Nitrate-nitrite violations remained consistent throughout the study period. Violations primarily occurred in northern Virginia near Harrisonburg and Fredericksburg. Violations were mainly concentrated in urban areas and large towns with a few occurring in more rural areas.

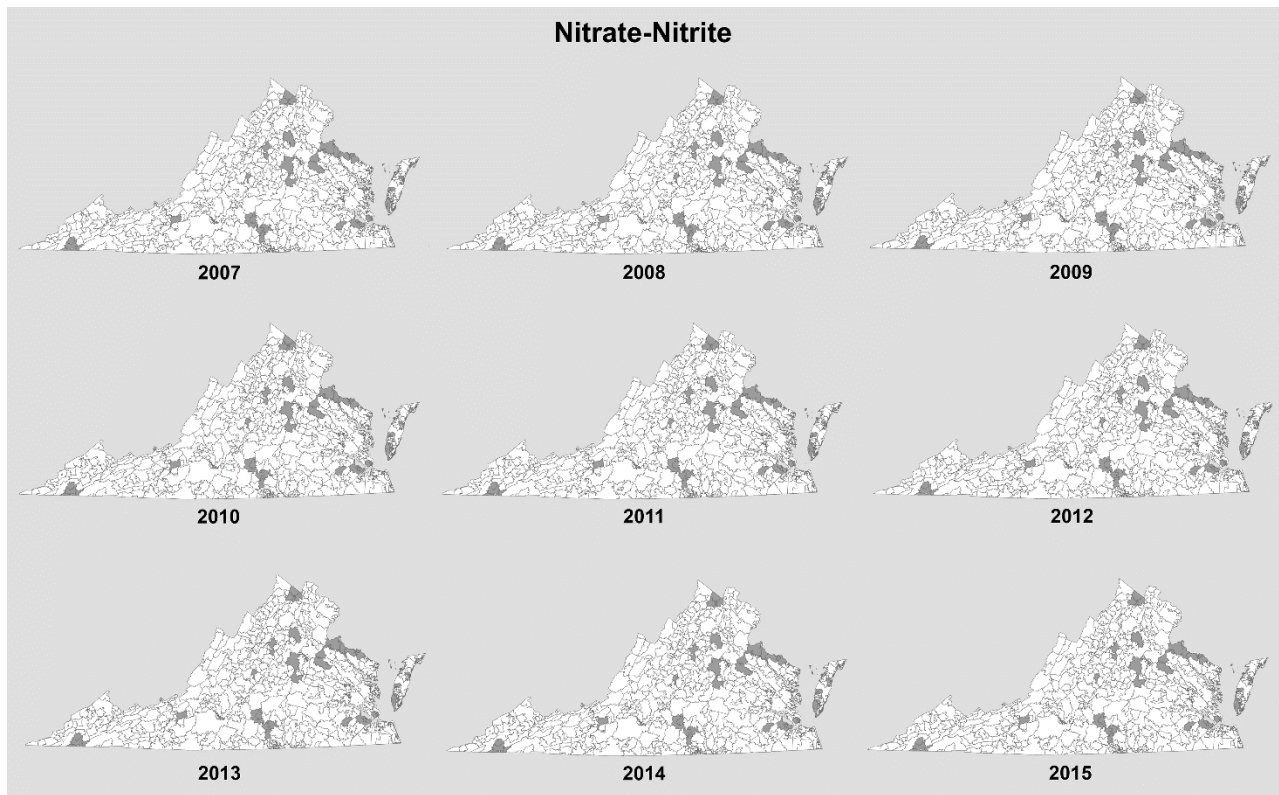


Figure 4: Nitrate-Nitrite (MR) violations in service areas.

Total Coliform Rule (HB)

Total coliform rule violations were distributed throughout Virginia (see figure 5). Throughout the study, violations were concentrated on the eastern side of the state with fewer violations as you move south through the state. Violations were mainly concentrated in urban areas and large towns apart from some violations occurring in more rural areas in the south-west.

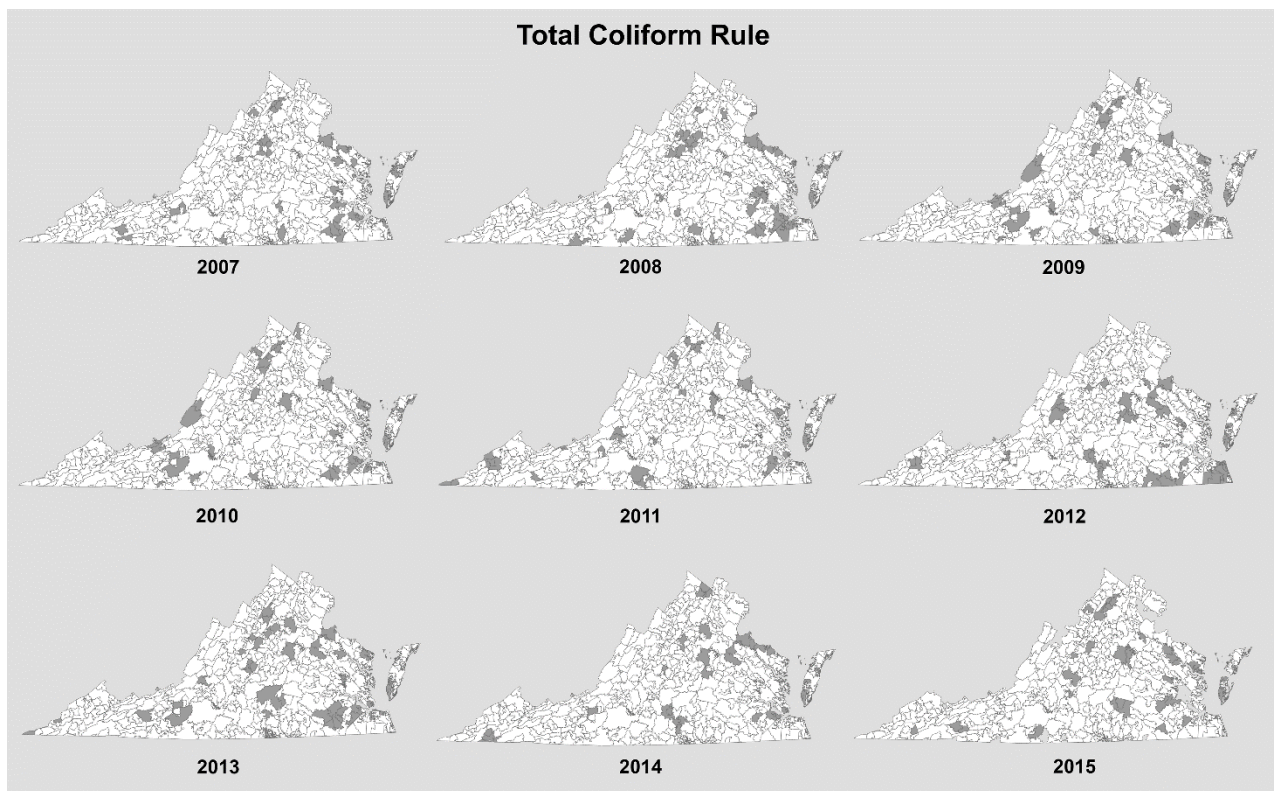


Figure 5: Total Coliform Rule (HB) violations in service areas.

5. Discussion

These results suggest that specific monitoring and reporting violations are significantly associated with adverse birth outcomes. The monitoring and reporting (MR) violation for disinfectant byproduct stage 2 was found to have a positive relationship with preterm birth, indicating that mothers who live in a service area that had at least one disinfectant byproduct stage 2 MR violation are 1.115 times or 11.5% more likely to experience a preterm birth than those who did not live in a service area where the violation occurred. Nitrate-nitrite MR violation was also found to have a positive relationship with preterm birth, indicating that mothers who live in a service area that had at least one nitrate-nitrite MR violation were 1.095 times or 9.5% more likely to experience a preterm birth than those that did not live in a service area where the violation occurred. Additionally, results show a negative relationship between the health-based (HB) total coliform rule violation and term-low birth weight, suggesting that the risk of term-low birth weight is reduced by 7% when a mother lives in a service area where at least one HB total coliform rule violation occurred. No other violations were found to be statistically significant.

Our results indicate that disinfectant byproduct (DBP) stage 2 monitoring and reporting violations may increase the risk for PTB. Results from studies examining the effects of disinfectant byproducts on birth outcomes have varied. Hoffman et al. (2008) found that the probability of preterm birth did not increase with increasing DBP exposure, however this study had a small sample size and a limited spatial scale. Yang et al. (2007) found an increased risk for PTB when examining exposure to TTHM. While the Yang et al. (2007) study does examine TTHM exposure and not an aggregate of DBP, our results

support the findings that DBP violations may increase the risk for PTB.

Few epidemiologic studies have researched the risks associated with nitrate in drinking water and adverse birth outcomes, and our findings indicate that nitrate-nitrite violations may increase the risk for PTB. These results support the findings from Stayner et al. (2017) that maternal exposure to nitrate in drinking water is associated with very preterm birth.

Total coliforms are not typically harmful to humans. Instead, they are used as an indicator to determine if disinfection processes are working properly and that the water system is functioning adequately. It is difficult to explain why a HB TCR violation may decrease the risk for tLBW. Since no studies have looked at the potential fetal health effects of exposure to total coliform, evidence to support our findings cannot be found, indicating a need for future research.

Limitations and Future Research

Several important limitations exist within the study, which we attempted to address. Geocoding addresses presents limitations due to locational error at the individual level. Additionally, geocoded addresses often have a higher error when locating rural addresses as opposed to addresses in a city, and portions of Virginia are considered to be rural although much of the population lives in a more easily geocoded urban area.

Majority gestational year (MGY) was used to define the exposure period and SDWA violations were aggregated yearly. If exposure occurred during the minority gestational year but *not* during the majority gestational year, then SDWA violations that occurred in the minority gestational year were not compared to that birth outcome. For example, an

infant born at full-term in June of 2012 would be assigned to 2012 for its MGY. The birth record for that infant is paired with the SDWA violations that occurred in 2012. If exposure occurred in December of 2011 resulting in an adverse birth outcome, then the results of the study could be skewed.

Covariates were considered and the study was adjusted to consider all possible known covariates. Race was represented differently on original birth records from 2007-2012 and 2013-2015. From 2007-2012 the mother's race was not recorded so instead child's race was used. From 2013-2015 mother's race was recorded and used. It is important to recognize that though mother's race and child's race may not be the same, to include race as a potential confounding variable, child's race was used when mother's race was unavailable. Additionally, despite the careful consideration of covariates, unknown covariates could still exist.

Water systems often monitor at a frequency proportional to the number of people served, and each violation requires a different monitoring frequency. Because of monitoring differences, violations for this study were represented as binomial variables (yes = at least one violation occurred; no = no violations occurred). Due to this limitation, we are unable to consider how a greater frequency of violations impact birth outcomes. These results do reveal a potential risk for adverse birth outcomes when a violation occurs, raising a warning that monitoring and reporting violations may indicate decreased effectiveness of treatment facilities, posing a potential risk to fetal health. Further research is needed to examine the relationship between birth outcomes and individual water contaminant violations; looking individually at each violation type can allow the researcher to see the effect of violation frequency. Furthermore, future research

examining municipal drinking water contaminants can benefit from making water system service area delineations publicly available.

6. Conclusion

Our results indicate that some monitoring and reporting violations may be associated with increased risk for adverse birth outcomes. Specifically, we found that disinfectant byproduct 1 and nitrate-nitrite MR violations may increase the risk for PTB. Additionally, we found that total coliform rule HB violation may decrease the risk for tLBW. The three violations that were found to be significant occur primarily in northern Virginia and on the eastern side of the state, primarily decreasing in occurrence as you move south-west, with a few exceptions. By identifying exposure at the service area level, we were able to reduce exposure misclassification that may have been introduced had we utilized census tract boundaries instead. While we were only able to consider violation occurrence as binomial, future research can benefit from considering the individual quantity of violations, to see the effect these violations may have on birth outcomes. This research provides valuable insight that drinking water violations may pose a risk to fetal health, and that more research on individual violations should be done to look at the health implications of municipal drinking water violations.

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10. Appendix

Table I: Characteristics of singleton births exposed and unexposed to MR violations.

Characteristic	Arsenic		Atrazine		Total Coliform Rule		Combined Radium	
	≥1 Violation Occurred, n = 2,118, n (%)	0 Violation Occurred, n = 663,866, n (%)	≥1 Violation Occurred, n = 83, n (%)	0 Violation Occurred, n = 665901, n (%)	≥1 Violation Occurred, n = 42972, n (%)	0 Violation Occurred, n = 623012, n (%)	≥1 Violation Occurred, n = 2368, n (%)	0 Violation Occurred, n = 663616, n (%)
Infant Sex								
M	1140 (53.8)	339620 (51.2)	38 (45.8)	340722 (51.2)	22046 (51.3)	318714 (51.2)	1237 (52.2)	339523 (51.2)
F	978 (46.2)	324246 (48.8)	45 (54.2)	325179 (48.8)	20926 (48.7)	304298 (48.8)	1131 (47.8)	324093 (48.8)
Mother's Hispanic Origin								
Hispanic	108 (5.1)	85242 (12.8)	13 (15.7)	85337 (12.8)	4038 (9.4)	81312 (13.1)	151 (6.4)	85199 (12.8)
Not Hispanic	2006 (94.7)	577762 (87)	70 (84.3)	579698 (87.1)	38879 (90.5)	540889 (86.8)	2214 (93.5)	577554 (87)
Unknown	4 (0.2)	862 (0.1)	0 (0)	866 (0.1)	55 (0.1)	811 (0.1)	3 (0.1)	863 (0.1)
Race								
White	1623 (76.6)	442013 (66.6)	48 (57.8)	443588 (66.6)	31584 (73.5)	412052 (66.1)	1937 (81.8)	441699 (66.6)
Black	391 (18.5)	136722 (20.6)	35 (42.2)	137078 (20.6)	8471 (19.7)	128642 (20.6)	325 (13.7)	136788 (20.6)
Other	104 (4.9)	85131 (12.8)	0 (0)	85235 (12.8)	2917 (6.8)	82318 (13.2)	106 (4.5)	85129 (12.8)
Mother's Age								
18-35	1773 (83.7)	564234 (85)	72 (86.8)	565935 (85)	37047 (86.2)	528960 (84.9)	1993 (84.2)	564014 (85)
<18	52 (2.5)	11840 (1.8)	3 (3.6)	11889 (1.8)	869 (2)	11023 (1.8)	42 (1.8)	11850 (1.8)
>35	293 (13.8)	87792 (13.2)	8 (9.6)	88077 (13.2)	5056 (11.8)	83029 (13.3)	333 (14.1)	87752 (13.2)
Mother's Education								
Some secondary schooling	820 (38.7)	260269 (39.2)	48 (57.8)	261041 (39.2)	19297 (44.9)	241792 (38.8)	999 (42.2)	260090 (39.2)
Some college or college deg	1288 (60.8)	396505 (59.7)	35 (42.2)	397758 (59.7)	23212 (54)	374581 (60.1)	1355 (57.2)	396438 (59.7)
Unknown	10 (0.5)	7092 (1.1)	0 (0)	7102 (1.1)	463 (1.1)	6639 (1.1)	14 (0.6)	7088 (1.1)
Payment								
Medicaid	666 (31.4)	186031 (28)	48 (57.8)	186649 (28)	13757 (32)	172940 (27.8)	698 (29.5)	185999 (28)
Private Insurance	1349 (63.7)	434932 (65.5)	30 (36.2)	436251 (65.5)	25699 (59.8)	410582 (65.9)	1555 (65.7)	434726 (65.5)
Self-Pay	98 (4.6)	33980 (5.1)	5 (6)	34073 (5.1)	3009 (7)	31069 (5)	103 (4.4)	33975 (5.1)
Unknown	5 (0.2)	8923 (1.3)	0 (0)	8928 (1.3)	507 (1.2)	8421 (1.4)	12 (0.5)	8916 (1.3)
Tobacco								
No	1847 (87.2)	579304 (87.3)	82 (98.8)	581069 (87.3)	35906 (83.6)	545245 (87.5)	2157 (91.1)	578994 (87.3)
Yes	221 (10.4)	37061 (5.6)	1 (1.2)	37281 (5.6)	3524 (8.2)	33758 (5.4)	196 (8.3)	37086 (5.6)
Unknown	50 (2.4)	47501 (7.2)	0 (0)	47551 (7.1)	3542 (8.2)	44009 (7.1)	15 (0.6)	47536 (7.2)
Parity								
1	827 (39.1)	278767 (42)	30 (36.2)	279564 (42)	18131 (42.2)	261463 (42)	911 (38.5)	278683 (42)
2	697 (32.9)	214475 (32.3)	33 (39.8)	215139 (32.3)	13407 (32.2)	201765 (32.4)	763 (32.2)	214409 (32.3)
3	375 (17.7)	105555 (15.9)	13 (15.7)	105917 (15.9)	6926 (16.1)	99004 (15.9)	413 (17.4)	105517 (15.9)
4 or more	219 (10.3)	65069 (9.8)	7 (8.4)	65281 (9.8)	4508 (10.5)	60780 (9.8)	281 (11.9)	65007 (9.8)

Table I continued:

Uranium		Disinfectant Byproduct Stage 1		Disinfectant Byproduct Stage 2		<i>E. Coli</i>	
≥1 Violation Occurred, n = 2250, n (%)	0 Violation Occurred, n = 663734, n (%)	≥1 Violation Occurred, n = 350, n (%)	0 Violation Occurred, n = 665634, n (%)	≥1 Violation Occurred, n = 4881, n (%)	0 Violation Occurred, n = 661103, n (%)	≥1 Violation Occurred, n = 3639, n (%)	0 Violation Occurred, n = 665984, n (%)
1176 (52.3)	339584 (51.2)	188 (53.7)	340572 (51.2)	2550 (52.2)	338210 (51.2)	1898 (52.2)	338862 (50.9)
1074 (47.7)	324150 (48.8)	162 (46.3)	325062 (48.8)	2331 (47.8)	322893 (48.8)	1741 (47.8)	323483 (48.6)
149 (6.6)	85201 (12.8)	16 (4.6)	85334 (12.8)	787 (16.1)	84563 (12.8)	223 (6.1)	85127 (12.8)
2098 (93.2)	577670 (87)	334 (95.4)	579434 (87.1)	4077 (83.5)	575691 (87.1)	3415 (93.8)	576353 (86.5)
3 (0.1)	863 (0.1)	0 (0)	866 (0.13)	17 (0.4)	849 (0.1)	1 (0.1)	865 (0.1)
1831 (81.4)	441805 (66.6)	297 (84.9)	443339 (66.6)	3392 (69.5)	440244 (66.6)	2919 (80.2)	440717 (66.2)
313 (13.9)	136800 (20.6)	41 (11.7)	137072 (20.6)	505 (10.3)	136608 (20.7)	531 (14.6)	136582 (20.5)
106 (4.7)	85129 (12.8)	12 (3.4)	85223 (12.8)	984 (20.2)	84251 (12.7)	189 (5.2)	85046 (12.8)
1892 (84.1)	564115 (85)	306 (87.4)	565701 (85)	3924 (80.4)	562083 (85)	3141 (86.3)	562866 (84.5)
38 (1.7)	11854 (1.8)	9 (2.6)	11883 (1.8)	61 (1.3)	11831 (1.8)	51 (1.4)	11841 (1.8)
320 (14.2)	87765 (13.2)	35 (10)	88050 (13.2)	896 (18.3)	87189 (13.2)	447 (12.3)	87638 (13.2)
942 (41.9)	260147 (39.2)	156 (44.6)	260933 (39.2)	1309 (26.8)	259780 (39.3)	1587 (43.6)	259502 (39)
1294 (57.5)	396499 (59.7)	194 (55.4)	397599 (59.7)	3522 (72.2)	394271 (59.6)	2017 (55.4)	395776 (59.4)
14 (0.6)	7088 (1.1)	0 (0)	7102 (1.1)	50 (1)	7052 (1.1)	35 (1)	7067 (1.1)
659 (29.3)	186038 (28)	103 (29.4)	186594 (28)	896 (18.4)	185801 (28.1)	1121 (30.8)	185576 (27.9)
1481 (65.8)	434800 (65.5)	246 (70.3)	436035 (65.5)	3882 (79.5)	432399 (65.4)	2300 (63.2)	433981 (65.2)
99 (4.4)	33979 (5.1)	1 (0.3)	34077 (5.1)	86 (1.8)	33992 (5.1)	160 (4.4)	33918 (5.1)
11 (0.5)	8917 (1.3)	0 (0)	8928 (1.3)	17 (0.3)	8911 (1.3)	58 (1.6)	8870 (1.3)
2050 (91.1)	579101 (87.3)	319 (91.1)	580832 (87.3)	4753 (97.4)	576398 (87.2)	3130 (86)	578021 (86.8)
185 (8.2)	37097 (5.6)	29 (8.3)	37253 (5.6)	128 (2.6)	37154 (5.6)	230 (6.3)	37052 (5.6)
15 (0.7)	47536 (7.1)	2 (0.6)	47549 (7.1)	0 (0)	47551 (7.2)	279 (7.7)	47272 (7.1)
860 (38.2)	278734 (42)	152 (43.4)	279442 (42)	1910 (39.1)	277684 (42)	1392 (38.3)	278202 (41.8)
729 (32.4)	214443 (32.3)	104 (29.7)	215068 (32.3)	1681 (34.4)	213491 (32.3)	1153 (31.7)	214019 (32.1)
396 (17.6)	105534 (15.9)	50 (14.3)	105880 (15.9)	833 (17.1)	105097 (15.9)	650 (17.9)	105280 (15.8)
265 (11.8)	65023 (9.8)	44 (12.6)	65244 (9.8)	457 (9.4)	64831 (9.8)	444 (12.2)	64844 (9.7)

Table I continued:

Gross Alpha Exc. Radon and Uranium		Lead and Copper Rule		Nitrate-Nitrite		HAA5		TTHM	
≥1 Violation Occurred, n = 2309, n (%)	0 Violation Occurred, n = 663675, n (%)	≥1 Violation Occurred, n = 8437, n (%)	0 Violation Occurred, n = 657547, n (%)	≥1 Violation Occurred, n = 9766, n (%)	0 Violation Occurred, n = 656218, n (%)	≥1 Violation Occurred, n = 4777, n (%)	0 Violation Occurred, n = 661207, n (%)	≥1 Violation Occurred, n = 4316, n (%)	0 Violation Occurred, n = 661668, n (%)
1206 (52.2)	339554 (51.2)	4331 (51.3)	336429 (51.2)	4975 (50.9)	335785 (51.2)	2454 (51.4)	338306 (51.2)	2221 (51.5)	338539 (51.2)
1103 (47.8)	324121 (48.8)	4106 (48.7)	321118 (48.8)	4791 (49.1)	320433 (48.8)	2323 (48.6)	322901 (48.8)	2095 (48.5)	323129 (48.8)
151 (6.5)	85199 (12.8)	781 (9.3)	84569 (12.9)	517 (5.3)	84833 (12.9)	277 (5.8)	85073 (12.9)	243 (5.6)	85107 (12.9)
2155 (93.3)	577613 (87)	7647 (90.6)	572121 (87)	9239 (94.6)	570529 (86.9)	4485 (93.9)	575283 (87)	4059 (94)	575709 (87)
3 (0.1)	863 (0.1)	9 (0.1)	857 (0.1)	10 (0.1)	856 (0.1)	15 (0.3)	851 (0.1)	14 (0.3)	852 (0.1)
1887 (81.7)	441749 (66.6)	5839 (69.2)	437797 (66.6)	6815 (69.8)	436821 (66.6)	4065 (85.1)	439571 (66.5)	3646 (84.5)	439990 (66.5)
316 (13.7)	136797 (20.6)	1964 (23.3)	135149 (20.6)	2439 (25)	134674 (20.5)	519 (10.9)	136594 (20.7)	504 (11.7)	136609 (20.6)
106 (4.6)	85129 (12.8)	634 (7.5)	84601 (12.9)	512 (5.2)	84723 (12.9)	193 (4)	85042 (12.9)	166 (3.8)	85069 (12.9)
1943 (84.2)	564064 (85)	7294 (86.5)	558713 (85)	8389 (85.9)	557618 (85)	4086 (85.5)	561921 (85)	3667 (85)	562340 (85)
40 (1.7)	11852 (1.8)	248 (2.9)	11644 (1.8)	237 (2.4)	11655 (1.8)	82 (1.7)	11810 (1.8)	76 (1.8)	11816 (1.8)
326 (14.1)	87759 (13.2)	895 (10.6)	87190 (13.3)	1140 (11.7)	86945 (13.2)	609 (12.7)	87476 (13.2)	573 (13.3)	87512 (13.2)
969 (42)	260120 (39.2)	4134 (49)	256955 (39.1)	4201 (43)	256888 (39.1)	2067 (43.3)	259022 (39.2)	1939 (44.9)	259150 (39.2)
1326 (57.4)	396467 (59.7)	4248 (50.3)	393545 (59.9)	5514 (56.5)	392279 (59.8)	2653 (55.5)	395140 (59.8)	2344 (54.3)	395449 (59.8)
14 (0.6)	7088 (1.1)	55 (0.7)	7047 (1.1)	51 (0.5)	7051 (1.1)	57 (1.2)	7045 (1.1)	33 (0.8)	7069 (1.1)
673 (29.1)	186024 (28)	3208 (38)	183489 (27.9)	3228 (33.1)	183469 (28)	1594 (33.4)	185103 (28)	1399 (32.4)	185298 (28)
1523 (66)	434758 (65.5)	4690 (55.6)	431591 (65.6)	6137 (62.8)	430144 (65.5)	2946 (61.7)	433335 (65.5)	2709 (62.8)	433572 (65.5)
101 (4.4)	33977 (5.1)	496 (5.9)	33582 (5.1)	337 (3.5)	33741 (5.1)	206 (4.3)	33872 (5.1)	191 (4.4)	33887 (5.1)
12 (0.5)	8916 (1.3)	43 (0.5)	8885 (1.4)	64 (0.7)	8864 (1.4)	31 (0.6)	8897 (1.3)	17 (0.4)	8911 (1.3)
2104 (91.1)	579047 (87.2)	7118 (84.4)	574033 (87.3)	8784 (89.9)	572367 (87.2)	3934 (82.4)	577217 (87.3)	3552 (82.3)	577599 (87.3)
190 (8.2)	37092 (5.6)	882 (10.5)	36400 (5.5)	828 (8.5)	36454 (5.6)	498 (10.4)	36784 (5.6)	433 (10)	36849 (5.6)
15 (0.6)	47536 (7.2)	437 (5.2)	47114 (7.2)	154 (1.6)	47397 (7.2)	345 (7.2)	47206 (7.1)	331 (7.7)	47220 (7.1)
883 (38.2)	278711 (42)	3528 (41.8)	276066 (42)	3885 (39.8)	275709 (42)	1873 (39.2)	277721 (42)	1665 (38.6)	277929 (42)
750 (32.5)	214422 (32.3)	2630 (31.2)	212542 (32.3)	3187 (32.6)	211985 (32.3)	1466 (30.7)	213706 (32.3)	1354 (31.4)	213818 (32.3)
402 (17.4)	105528 (15.9)	1354 (16)	104576 (15.9)	1615 (16.5)	104315 (15.9)	835 (17.5)	105095 (15.9)	760 (17.6)	105170 (15.9)
274 (11.9)	65014 (9.8)	925 (11)	64363 (9.8)	1079 (11)	64209 (9.8)	603 (12.6)	64685 (9.8)	537 (12.4)	64751 (9.8)

Table II: Characteristics of singleton births exposed and unexposed to HB violations

Characteristic	Arsenic		ColiformTCR		CombinedRadium		DBPst1	
	≥1 Violation Occurred, n = 2312, n (%)	0 Violation Occurred, n = 663672, n (%)	≥1 Violation Occurred, n = 41542, n (%)	0 Violation Occurred, n = 624442, n (%)	≥1 Violation Occurred, n = 408, n (%)	0 Violation Occurred, n = 665576, n (%)	≥1 Violation Occurred, n = 2966, n (%)	0 Violation Occurred, n = 663018, n (%)
Infant Sex								
M	1206 (52.2)	339554 (51.2)	21358 (51.4)	319402 (51.1)	209 (51.2)	340551 (51.2)	1484 (50)	339276 (51.2)
F	1106 (47.8)	324118 (48.8)	20184 (48.6)	305040 (48.9)	199 (48.8)	325025 (48.8)	1482 (50)	323742 (48.8)
Mother's Hispanic Origin								
Hispanic	360 (15.6)	84990 (12.8)	2681 (6.5)	82669 (13.2)	15 (3.7)	85335 (12.8)	241 (8.1)	85109 (12.8)
Not Hispanic	1950 (84.3)	577818 (87.1)	38820 (93.4)	540948 (86.6)	392 (96.1)	579376 (87)	2723 (91.8)	577045 (87)
Unknown	2 (0.1)	864 (0.1)	41 (0.1)	825 (0.1)	1 (0.2)	865 (0.1)	2 (0.1)	864 (0.1)
Race								
White	1859 (80.4)	441777 (66.6)	28406 (68.4)	415230 (66.5)	294 (72.1)	443342 (66.6)	2446 (82.5)	441190 (66.5)
Black	206 (8.9)	136907 (20.6)	10447 (25.1)	126666 (20.3)	96 (23.5)	137017 (20.6)	353 (11.9)	136760 (20.6)
Other	247 (10.7)	84988 (12.8)	2689 (6.4)	82546 (13.2)	18 (4.4)	85217 (12.8)	167 (5.6)	85068 (12.8)
Mother's Age								
18-35	2007 (86.8)	564000 (85)	36450 (87.7)	529557 (84.8)	356 (87.3)	565651 (85)	2560 (86.3)	563447 (85)
<18	37 (1.6)	11855 (1.8)	898 (2.2)	10994 (1.8)	8 (2)	11884 (1.8)	61 (2.1)	11831 (1.8)
>35	268 (11.6)	87817 (13.2)	4194 (10.1)	83891 (13.4)	44 (10.8)	88041 (13.2)	345 (11.6)	87740 (13.2)
Mother's Education								
Some secondary schooling	1100 (47.6)	259989 (39.2)	17836 (42.9)	243253 (39)	187 (45.8)	260902 (39.2)	1540 (51.9)	259549 (39.1)
Some college or college deg	1188 (51.4)	396605 (59.8)	23471 (56.5)	374322 (59.9)	219 (53.7)	397574 (59.7)	1413 (47.6)	396380 (59.8)
Unknown	24 (1)	7078 (1.1)	235 (0.6)	6867 (1.1)	2 (0.5)	7100 (1.1)	13 (0.4)	7089 (1.1)
Payment								
Medicaid	607 (26.3)	186090 (28)	13570 (32.7)	173127 (27.7)	167 (40.9)	186530 (28)	1055 (35.6)	185642 (28)
Private Insurance	1470 (63.6)	434811 (65.5)	25378 (61.1)	410903 (65.8)	222 (54.4)	436059 (65.5)	1671 (56.3)	434610 (65.6)
Self-Pay	234 (10.1)	33844 (5.1)	1429 (3.4)	32649 (5.2)	18 (4.4)	34060 (5.1)	233 (7.9)	33845 (5.1)
Unknown	1 (0)	8927 (1.3)	1165 (2.8)	7763 (1.2)	1 (0.2)	8927 (1.3)	7 (0.2)	8921 (1.3)
Tobacco								
No	2042 (88.3)	579109 (87.3)	34602 (83.3)	546549 (87.5)	306 (75)	580845 (87.3)	2517 (84.9)	578634 (87.3)
Yes	92 (4)	37190 (5.6)	3290 (7.9)	33992 (5.4)	44 (10.8)	37238 (5.6)	390 (13.1)	36892 (5.6)
Unknown	178 (7.7)	47373 (7.1)	3650 (8.8)	43901 (7)	58 (14.2)	47493 (7.1)	59 (2)	47492 (7.2)
Parity								
1	872 (37.7)	278722 (42)	17315 (41.7)	262279 (42)	168 (41.2)	279426 (42)	1240 (41.8)	278354 (42)
2	732 (31.7)	214440 (32.3)	13072 (31.5)	202100 (32.4)	119 (29.2)	215053 (32.3)	940 (31.7)	214232 (32.3)
3	403 (17.4)	105527 (15.9)	6662 (16)	99268 (15.9)	65 (15.9)	105865 (15.9)	487 (16.4)	105443 (15.9)
4 or more	305 (13.2)	64983 (9.8)	4493 (10.8)	60795 (9.7)	56 (13.7)	65232 (9.8)	299 (10.1)	64989 (9.8)

Table II continued:

GrossAlphaEx		HAA5		LCR		TTHM	
≥1 Violation Occurred, n = 85, n (%)	0 Violation Occurred, n = 665899, n (%)	≥1 Violation Occurred, n = 2657, n (%)	0 Violation Occurred, n = 663327, n (%)	≥1 Violation Occurred, n = 587, n (%)	0 Violation Occurred, n = 665397, n (%)	≥1 Violation Occurred, n = 5847, n (%)	0 Violation Occurred, n = 660137, n (%)
43 (50.6)	340717 (51.2)	1373 (51.7)	339387 (51.2)	315 (53.7)	340445 (51.2)	3005 (51.4)	337755 (51.2)
42 (49.4)	325182 (48.8)	1284 (48.3)	323940 (48.8)	272 (46.3)	324952 (48.8)	2842 (48.6)	322382 (48.8)
0 (0)	85350 (12.8)	159 (6)	85191 (12.8)	28 (4.8)	85322 (12.8)	548 (9.4)	84802 (12.8)
85 (100)	579683 (87.1)	2492 (93.8)	577276 (87)	558 (95.1)	579210 (87)	5290 (90.5)	574478 (87)
0 (0)	866 (0.1)	6 (0.2)	860 (0.1)	1 (0.2)	865 (0.1)	9 (0.2)	857 (0.1)
61 (71.8)	443575 (66.6)	2107 (79.3)	441529 (66.6)	472 (80.4)	443164 (66.6)	4365 (74.7)	439271 (66.5)
23 (27)	137090 (20.6)	477 (18)	136636 (20.6)	96 (16.4)	137017 (20.6)	1306 (22.3)	135807 (20.6)
1 (1.2)	85234 (12.8)	73 (2.7)	85162 (12.8)	19 (3.2)	85216 (12.8)	176 (3)	85059 (12.9)
70 (82.4)	565937 (85)	2360 (88.8)	563647 (85)	513 (87.4)	565494 (85)	5254 (89.9)	560753 (84.9)
6 (7.1)	11886 (1.8)	95 (3.6)	11797 (1.8)	12 (2)	11880 (1.8)	161 (2.8)	11731 (1.8)
9 (10.6)	88076 (13.2)	202 (7.6)	87883 (13.2)	62 (10.6)	88023 (13.2)	432 (7.4)	87653 (13.3)
47 (55.3)	261042 (39.2)	1447 (54.5)	259642 (39.1)	267 (45.5)	260822 (39.2)	3299 (56.4)	257790 (39)
38 (44.7)	397755 (59.7)	1180 (44.4)	396613 (59.8)	320 (54.5)	397473 (59.7)	2439 (41.7)	395354 (59.9)
0 (0)	7102 (1.1)	30 (1.1)	7072 (1.1)	0 (0)	7102 (1.1)	109 (1.9)	6993 (1.1)
36 (42.4)	186661 (28)	1189 (44.7)	185508 (28)	217 (37)	186480 (28)	2755 (47.1)	183942 (27.9)
46 (54.1)	436235 (65.5)	1311 (49.3)	434970 (65.6)	353 (60.1)	435928 (65.5)	2762 (47.2)	433519 (65.7)
3 (3.5)	34075 (5.1)	154 (5.8)	33924 (5.1)	15 (2.6)	34063 (5.1)	299 (5.1)	33779 (5.1)
0 (0)	8928 (1.3)	3 (0.1)	8925 (1.3)	2 (0.3)	8926 (1.3)	31 (0.5)	8897 (1.3)
76 (89.4)	581075 (87.3)	2112 (79.5)	579039 (87.3)	509 (86.7)	580642 (87.3)	4773 (81.6)	576378 (87.3)
9 (10.6)	37273 (5.6)	373 (14)	36909 (5.6)	56 (9.5)	37226 (5.6)	786 (13.4)	36496 (5.5)
0 (0)	47551 (7.1)	172 (6.5)	47379 (7.1)	22 (3.7)	47529 (7.1)	288 (4.9)	47263 (7.2)
37 (43.5)	279557 (42)	1112 (41.9)	278482 (42)	256 (43.6)	279338 (42)	2526 (43.2)	277068 (42)
27 (31.8)	215145 (32.3)	809 (30.4)	214363 (32.3)	163 (27.8)	215009 (32.3)	1757 (30)	213415 (32.3)
15 (17.6)	105915 (15.9)	432 (16.3)	105498 (15.9)	93 (15.8)	105837 (15.9)	940 (16.1)	104990 (15.9)
6 (7.1)	65282 (9.8)	304 (11.4)	64984 (9.8)	75 (12.8)	65213 (9.8)	624 (10.7)	64664 (9.8)

Table III: MR results without race and without tobacco unknowns

	PTB				tLBW				LBW				
		1	0		1	0			1	0			
Without Race	Arsenic	1.048428	0.5518	0.897199	1.225149	1.027353	0.853	0.772417	1.366358	0.970297	0.7403	0.811829	1.159698
	Atrazine	0.893837	0.7915	0.38889	2.054421	1.00766	0.9915	0.246857	4.113219	0.889357	0.8002	0.358735	2.04851
	Total Coliform Rule	0.962143	0.0404	0.927285	0.998312	0.923455	0.0222	0.862544	0.988667	0.930306	0.0006	0.892752	0.969439
	Combined Radium	1.021288	0.7816	0.879976	1.185293	0.974332	0.8551	0.737008	1.288076	0.905782	0.2662	0.760778	1.078423
	Uranium	1.038351	0.6271	0.892087	1.208598	0.968807	0.8291	0.726612	1.29173	0.914809	0.3281	0.765289	1.093542
	DBPst1	1.059683	0.7656	0.723929	1.551158	0.889487	0.76	0.419644	1.885378	0.896753	0.638	0.56954	1.411956
	DBPst2	1.85303	0.1248	0.977586	1.20489	0.788847	0.05	0.622262	1.000028	0.896039	0.1005	0.78602	1.021458
	<i>E. Coli</i>	0.87967	0.0498	0.773898	0.999897	1.007504	0.9476	0.806106	1.259219	0.940863	0.3888	0.819069	1.080766
	GrossAlphaEx	1.033863	0.6638	0.889702	1.201384	0.962986	0.7951	0.724384	1.280181	0.919304	0.3483	0.771085	1.096013
	LCR	1.026503	0.5121	0.949282	1.110005	0.947289	0.4625	0.819875	1.094504	1.036038	0.415	0.95149	1.1281
	NitrateNitrite	1.093795	0.0144	1.018014	1.175217	0.930466	0.3108	0.809412	1.069625	1.032699	0.4371	0.952205	1.119997
	HAA5	0.894557	0.0472	0.801317	0.998648	0.923718	0.4295	0.758668	1.124676	0.852505	0.0115	0.753244	0.964846
	TTHM	0.86712	0.0173	0.771062	0.975146	0.992087	0.9382	0.811506	1.212853	0.850839	0.0154	0.746658	0.969557
	Without Tobacco Unknowns	Arsenic	1.080844	0.3344	0.923026	1.265647	1.047695	0.7567	0.780237	1.406834	1.013119	0.8887	0.84409
Atrazine		0.846878	0.696	0.367964	1.949109	0.959301	0.9539	0.234388	3.926213	0.821998	0.6735	0.330248	2.045982
Total Coliform Rule		0.985584	0.4605	0.9483	1.024333	0.971275	0.4245	0.904228	1.043294	0.964252	0.1008	0.923227	1.0071
Combined Radium		1.080015	0.3141	0.929702	1.254631	1.03691	0.8051	0.777526	1.382825	0.983761	0.857	0.823259	1.175556
Uranium		1.095637	0.2414	0.940372	1.276538	1.022843	0.8816	0.759839	1.376881	0.987871	0.8957	0.823193	1.185493
DBPst1		1.112611	0.5893	0.755259	1.639044	1.050556	0.8976	0.495516	2.227312	1.001422	0.9952	0.628674	1.595175
DBPst2		1.112328	0.0462	1.001789	1.235065	0.801545	0.068	0.632072	1.016456	0.927128	0.2592	0.812937	1.05736
<i>E. Coli</i>		0.907282	0.1576	0.762758	1.03835	1.066705	0.5958	0.840269	1.354159	0.990923	0.9044	0.853914	1.149916
GrossAlphaEx		1.092664	0.2504	0.939401	1.270932	1.020845	0.8906	0.760824	1.369726	0.996815	0.9722	0.832981	1.192873
LCR		1.039546	0.3429	0.959473	1.126308	0.964969	0.6366	0.832282	1.118809	1.047327	0.3022	0.959242	1.143501
NitrateNitrite		1.083963	0.03	1.007818	1.165862	0.925963	0.2885	0.803362	1.067275	1.016533	0.6988	0.935513	1.10457
HAA5		0.954844	0.4308	0.95116	1.071159	1.070424	0.514	0.872572	1.313139	0.986099	0.8317	0.866646	1.122018
TTHM		0.927461	0.2283	0.820522	1.048336	1.142485	0.2114	0.927112	1.407889	0.98954	0.8793	0.863965	1.133367

Table IV: HB results without race and without tobacco unknowns

	PTB				tLBW				LBW				
		1	0		1	0			1	0			
Without Race	Arsenic	0.893258	0.1674	0.760985	1.048521	0.910418	0.2804	0.767776	1.079584	0.817227	0.0352	0.677306	0.986054
	Total Coliform Rule	1.033705	0.0776	0.996342	1.072468	1.039219	0.05	0.999999	1.079982	0.987867	0.5623	0.947908	1.029511
	Combined Radium	0.671156	0.0638	0.440241	1.023199	0.548812	0.0195	0.331793	0.90778	0.885853	0.5596	0.589579	1.33101
	DBPst1	0.966224	0.6158	0.844893	1.10498	1.04706	0.5054	0.914539	1.198786	0.859366	0.0526	0.737257	1.001699
	LCR	1.034794	0.8192	0.771733	1.387524	1.118738	0.4589	0.83134	1.505492	1.111719	0.5068	0.813165	1.519886
	GrossAlphaEx	1.010961	0.978	0.465554	2.195323	0.931837	0.9217	0.228215	3.804844	0.829432	0.6866	0.334419	2.057171
	HAA5	1.02362	0.7385	0.89249	1.174017	0.975288	0.8399	0.765116	1.243194	0.984919	0.8424	0.847881	1.144106
	TTHM	1.015334	0.7476	0.925469	1.113925	1.031882	0.6998	0.879741	1.210335	0.97312	0.5981	0.879372	1.076862
	Without Tobacco Unknowns	Arsenic	0.910418	0.2804	0.767776	1.079584	0.944571	0.7323	0.681258	1.309658	0.882736	0.2227	0.722375
Total Coliform Rule		1.039219	0.05	0.999999	1.079982	0.948918	0.1578	0.882325	1.020537	1.012542	0.5717	0.969736	1.057239
Combined Radium		0.548812	0.0195	0.331793	0.90778	0.980827	0.9571	0.484088	1.987283	0.773272	0.2935	0.478598	1.249378
DBPst1		1.04706	0.5054	0.914539	1.198786	0.797975	0.1095	0.605271	1.052328	0.972671	0.7273	0.83241	1.136566
LCR		1.118738	0.4589	0.83134	1.505492	1.347363	0.2432	0.81663	2.223022	1.295049	0.1073	0.945414	1.773986
GrossAlphaEx		1.038136	0.9247	0.477551	2.256778	0.993368	0.9926	0.242841	4.063472	0.879681	0.7828	0.353591	2.188515
HAA5		1.046194	0.5387	0.90593	1.208175	1.05297	0.6911	0.816332	1.358206	1.077896	0.3484	0.921477	1.260867
TTHM		1.030017	0.5452	0.9359	1.335994	1.092377	0.2927	0.926599	1.287814	1.010941	0.8398	0.909745	1.123393