Correlation Between Heart Disease and the Hardness of Drinking Water

by

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ABSTRACT

This study investigates the possible correlation between heart disease mortality and the hardness of drinking water to determine if there are protective factors associated with hard water that may reduce heart disease. The study attempts to see if such a correlation can be found in the population that is supplied by 31 public water treatment plants spread across 17 counties in Ohio. The 31 public water treatment plants, which maintain a hardness with little variance from year to year, serve an estimated total 2,658,000 customers, about 25% of the total population of Ohio. Surface-water supplies 69% of the population, groundwater 30% and 1% is supplied by a mixture of surface-water and groundwater. The total hardness, expressed in mg/l $CaCO_3$, of the study area ranges from an annual average of 93 mg/l to 448 mg/l. To test for a correlation, total hardness data is acquired on the drinking water supplied by the water treatment plants and is compared to heart disease mortality data, for the year 2007, obtained from the Ohio Department of Health, Center for Public Health Statistics and Information. Analysis shows that a positive correlation of 0.427 exists, with changes in total water hardness accounting for 18.3% of the variance found in heart disease mortality rate. An age adjusted analysis, for individuals over 35 years of age also resulted in a positive correlation with total water hardness accounting for 15.4% of the variance in heart disease mortality. In order to eliminate possible confounding factors from the study, 16 additional examinations were done on the original data; all but three resulted in positive correlations.

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1.0 Introduction

According to the Center for Disease Control (CDC), heart disease is the leading causes of death in the United States and in Ohio (CDC, 2012). The Ohio Department of Health ranks Ohio number 14 in the nation among the 50 states and the District of Columbia (ODH, 2012). The mortality rate per 100,000 for those over 35 years of age between 2007 and 2009 was 388.8 in Ohio compared to the national rate of 359.1. Because of the prevalence of heart disease, major efforts have been made and continue to be made to identify and reduce the risk factors associated with heart disease (CDC, 2007-2009).

A significant variation in the mortality rate can be seen across Ohio; with rates ranging from 288 to 584.6 (CDC, 2007-2009). The lower rates tend to bisect Ohio running from the northeast corner to the southwest corner. As can be seen in Figure 1.1, a large cluster of high heart disease mortality rates are found in the bottom southeast portion of the state. Similar geographical variance has also been observed in many areas both in the United States and around the world. This occurrence has led to an increasing amount of studies looking at environmental exposure factors, specifically the role that the mineral content of drinking water could play in cardiovascular health. Some studies examine the protective factors of hard water while others examine the toxic properties of soft water. The factor that seems the most prevalent is found in the presence of magnesium, a major component of hard water. An increase in dietary magnesium alone has been shown in many studies to reduce sudden death from cardiovascular disease (Singh, 1990).

Approximately 55% of residents in Ohio obtain their drinking water from surface sources and 45% groundwater (Brown & Coltman, 1990). In general raw groundwater undergoes less of a water treatment process before it is distributed to customers and has a higher total hardness than surface-water due to its contact with minerals found in its geologic environment. Hard water is water that has a high concentration of cations, primarily calcium and magnesium. The hardness of drinking water is most commonly associated with an unfavorable scum or scale that is left behind on water heating surfaces (Middleton, Blaser, Reynolds, & Dreger, 2010).

To combat this scum, private water softeners can be employed that uses an ion exchange process replacing the calcium and magnesium with sodium ions. Because of the increased amount of sodium being consumed, this process is generally not recommended for those individuals with high blood pressure or those on a restricted sodium diet since sodium consumption has long been associated with hypertension.

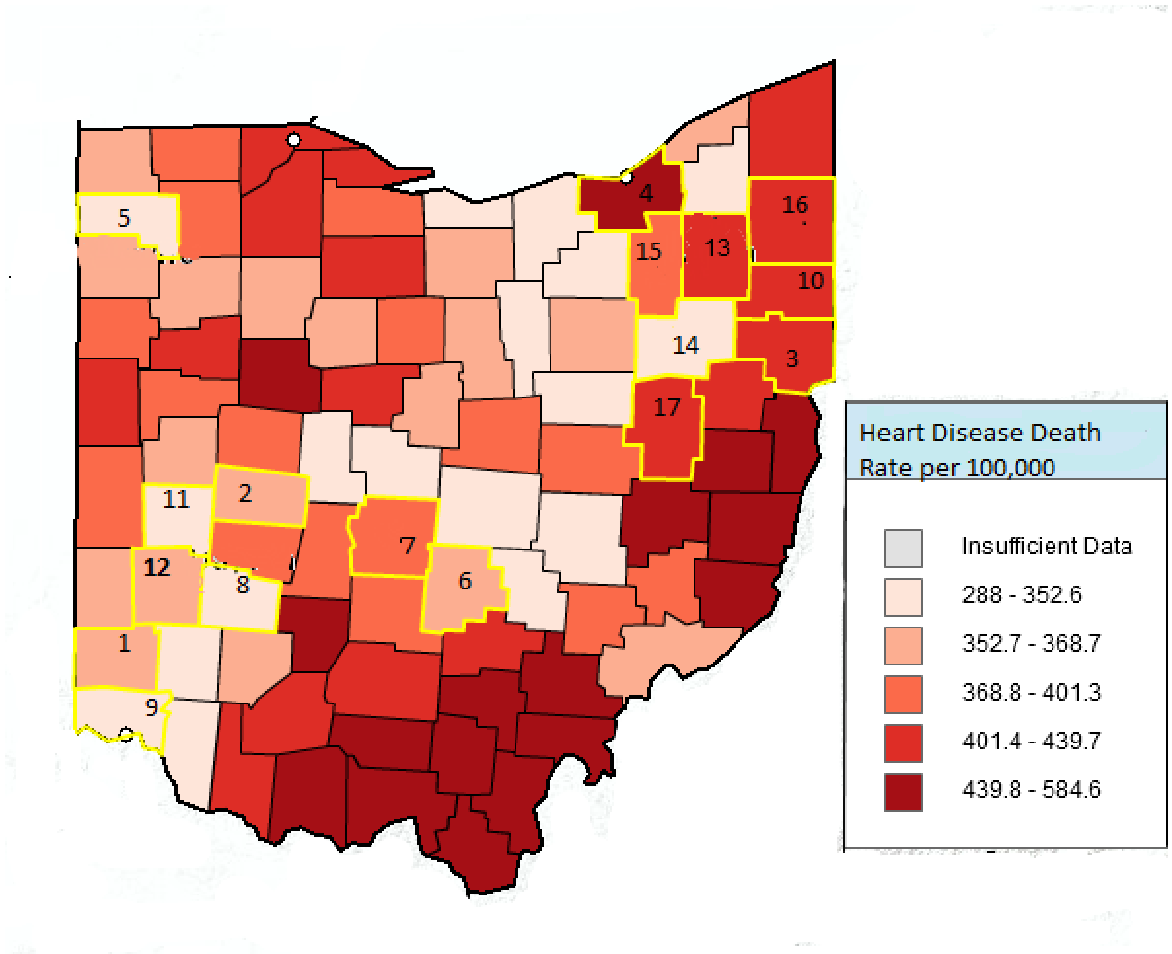

Figure 1.1: Counties in study area: 1.Butler, 2.Champaign, 3.Columbiana, 4.Cuyahoga, 5.Defiance, 6.Fairfield, 7.Franklin, 8.Greene, 9.Hamilton, 10.Mahoning, 11.Miami, 12.Montgomery, 13.Portage, 14.Stark, 15.Summit, 16.Trumbull, 17.Tuscarawas

*This map modified from a map that was created using the *Interactive Atlas of Heart Disease and Stroke*, a website developed by the Centers for Disease Control and Prevention, Division for Heart Disease and Stroke Prevention. http://www.cdc.gov/dhdsp/maps[2]

1.1 Past Research

Many past studies have found a relationship supporting the premise that hard water or factors associated with hard water can lead to a decrease in heart disease. In 2005, the World Health Organization (WHO) published a review entitled *Nutrients in Drinking* Water and included the question: "What conclusion can be drawn about the relationship between calcium, magnesium and other trace elements in water and mortality from certain types of cardiovascular disease?" Most, but not all, of the studies found an inverse relationship between water hardness and heart disease. The WHO concluded that the largest reduction was reported in ischemic heart disease, heart disease that is characterized by a reduction in blood flow to the heart muscle, often leading to what is commonly known as a heart attack. The health benefits were mainly attributed to the magnesium concentrations found in hard water. There was a lesser amount of evidence supporting calcium concentrations. It was the suggestion of the WHO that the remineralization of calcium and magnesium in demineralized water would provide health benefits. This suggestion took into consideration that there are no known harmful health effects associated with the consumption of calcium and magnesium in a large range, but the harmful effects of a deficiency of the two elements is linked to a wide variety of diseases, (WHO, 2005).

A 2008 study, examined well water, specifically the presence of magnesium, and myocardial infarction (AMI) incidence in rural Finland. Finland overall has groundwater ranging from soft to very soft. There AMI data was obtained through the Finnish Cardiovascular Disease Register. Water data was obtained from the groundwater database of Geological Survey of Finland. On average it was found that a 1mg/l increment increase in magnesium concentration was associated with a 2% lower incidence of acute myocardial infarction. The calcium concentration did not have a clear association with incidence of AMI (Kousa et al., 2008).

A 1977 study done by Elwood, St. Ledger, and Morton in England and Wales examined the concentrations of elements in tap water and the effect it had on heart disease mortality along with the connection of air temperature. Samples of tap water were taken from 61 county boroughs and examined for calcium and 12 other elements. A 1971 census was used to provide the information on the number of and cause of death. Calcium alone seemed to account for 42% of the variance in ischemic heart disease deaths for ages 55-64. Little association was found between temperature and ischemic heart disease (Elwood et al., 1977).

Scotland has one of the highest mortality rates from coronary disease in the world and also had a large amount of geographic variance of this mortality rate. In a 1987 study, 56 government districts were used as the study area. A standardized mortality rate was determined for men ranging between 34 to 65 years of age in each district. Total water hardness for the principal water suppliers in the district was obtained from the Department of Water Services of the Scottish Regional Council. The data was in the form of an annual mean total hardness in milligrams per liter for the year 1983. In a few districts the same data for an adjacent year was used. These values were then weighted by the size of the population supplied to produce a weighted mean annual value for total hardness for each local district. A correlation of -0.17 was found between the coronary heart disease and total hardness for the study area. This demonstrated weak negative association that did not explain the geographic variance in mortality from heart disease that was observed in the Country (Smith & Crombie, 1987).

Other studies were not as definitive. A 1975 Australian study comparing two major cities Brisbane, with a hard water supply and Melbourne with a very soft water supply. Brisbane had an average total hardness of about 80 mg/l and Melbourne an average around 11 mg/l. Both cities had similar population demographics, and fairly uniform medical standards. Mortality rates were obtained from the Commonwealth Bureau of Statistics. Populations were grouped in 10 year age groups from 25 years of age up between 1968 and 1970. Water quality was obtained from the Department of Water Supply and Sewage. For all age groups and both sexes, the death rate for all categories of ischemic heart disease and for acute myocardial infarction alone was higher in Brisbane than in Melbourne. This resulted in a positive correlation between hard water and heart disease. But despite the positive results, the study did not rule out that the hardness protective factors do not exist, just that it may be offset by other unidentified heart disease factors (Meyers, 1975).

2.0 Materials and Methods

As in past ecological studies examining the relationship between water hardness and cardiovascular disease, this study used publically available data to make correlations about a relationship found in many large scale studies since the 1960s. Many of these studies grouped heart disease rate and drinking water hardness by counties or boroughs according to their main drinking water supplier. This type of grouping occasionally led to heterogeneity in the drinking water quality in study areas that were clustered together. This heterogeneity was greatly reduced in this study by using the WTP as the basis of grouping instead of counties and boroughs. Cities and townships were grouped together by public water provider, regardless of county location. Cities and townships in the county that were not supplied by public water were eliminated from the study.

2.1 Study Area

Initially five counties in Ohio were chosen based on their location, population and variability in water hardness. The intent was to compare spatially located cities and townships across each county according to their drinking water hardness and heart disease mortality rates. Unfortunately for the study, many areas, especially in rural Ohio, are supplied by private wells that do not require monitoring and can have varying degrees of hardness. The location focus was switched and public water treatment plants located in the five counties were used as the grouping bases. Ohio has 1,262 community water systems serving around 10,350,734 individuals (EPA, 2009). According to the Ohio State Extension report on Ohio's Hydrologic Cycle, approximately 83.5% of Ohioans receive their water from Public Water Systems (Brown & Coltman, 1990). This switch allowed for a larger population to be included in the study area and also allowed for the fact that plants can often supply cities and townships across county lines. After grouping the cities and townships based on their public drinking water supplier, eight data sets remained. In order to increase reliability of the study, the area was expanded to encompass 31 public water treatment plants (WTPs) across 17 counties (Figure 1.1) that had published water hardness reports on their drinking water. The counties consisted of Butler, Champaign, Columbiana, Cuyahoga, Defiance, Hamilton, Fairfield, Franklin, Greene, Mahoning, Miami, Montgomery, Portage, Stark, Summit, Trumbull and Tuscarawas. The study area encompassed 86 cities and townships and had a total population of approximately 2,657,785, about 25% of Ohio's total population. By choosing a study area located within a single state many of the geographical complications such as considerably different climate and latitude that affected much larger study areas are reduced.

Typically, surface-water is softer than groundwater since the hardness of the water is a reflection of the geological nature of the rocks that the water has come into contact with. In Ohio, approximately 55% of the drinking water is from surface-water and 45% is from groundwater supplies (Brown & Coltman, 1990). In this study approximately 69% of the population of the study area is supplied by surface-water, 30% is supplied by groundwater and 1% supplied by a mixture of both. (Table 2.1.1)

A breakdown of the demographics by percent of the population over 35 years of age and percent of African American and percent of Caucasians in the total population were found for each of the WTP population areas and summarized in Table 2.1.2. The majority of the population in the study was Caucasian. Approximately half of each WTP supply area was found to be over 35 years of age. Across the 17 counties the heart disease mortality rate per 100,000 individuals, 35 years of age or over for the years 2007 to 2009, ranges from 329.9 found in Hamilton County to 446.7 in Cuyahoga. The location of the counties and the average heart disease mortality rate for each can be seen in Figure 1.1.

Table 2.1.1: WTP population breakdown by water source

Water Treatment Plant	Population	Water Source	% of population
Groundwater Plants			
Brimfield System	10,460	GW	0.4
Canton WTP	83,572	GW	3.1
Cincinnati: Bolton Plant	110,561	GW	4.2
Columbiana WTP	5,635	GW	0.2
Columbus: Parsons Avenue WTP	3,865	GW	0.1
Cuyahoga Falls WTP	57,707	GW	2.2
Dayton WTP	232,980	GW	8.8
Dover WTP	12,210	GW	0.5
East Palestine WTP	4,917	GW	0.2
Fairfield WTP	42,097	GW	1.6
Hicksville WTP	3,649	GW	0.1
Hudson City WTP	22,439	GW	0.8
Lancaster City PWS	35,335	GW	1.3
Little Walnut Water System	6,374	GW	0.2
New Philadelphia WTP	17,056	GW	0.6
North Canton WTP	16,369	GW	0.6
Shalersville Water System	31,843	GW	1.2
Troy WTP	26,644	GW	1.0
Tussing Road Water System	26,914	GW	1.0
Urbana WTP	11,613	GW	0.4
Xenia WTP	24,164	GW	0.9
Total	**786,404**		**29.6**
Mixed Plants			
Westerville WTP	35,318	MIX	1.3
Total	**35,318**		**1.3**
Surface-water Plants			
Akron WTP	305,048	SW	11.5
Alliance WTP	23,253	SW	0.9
Barberton WTP	27,899	SW	1.1
Cincinnati: Miller Plant	521,047	SW	19.6
Cleveland Division of Water	478,403	SW	18.0
Columbus: Dublin Rd WTP	51,305	SW	1.9
Columbus: Hap Cremean WTP	111,234	SW	4.2
MVSD	261,280	SW	9.7
Warren WTP	56,594	SW	2.1
Total	**1,836,063**		**69.1**
Total Study Area	2,657,785		100.0

Table 2.1.2: Demographics by WTP supply area

Water Treatment Plant	Population	% pop over 35	% Caucasian	% AA*
Akron WTP	305,048	50.66	74.82	21.14
Alliance WTP	23,253	49.00	85.50	11.20
Barberton WTP	27,899	53.10	92.40	5.30
Brimfield System	10,460	53.75	67.76	0.28
Canton WTP	83,572	49.40	75.18	20.42
Cincinnati: Bolton Plant	110,561	52.44	79.93	17.23
Cincinnati: Miller Plant	521,047	48.95	66.00	30.14
Cleveland Division of Water	478,403	46.90	41.50	51.00
Columbiana WTP	5,635	64.30	98.90	0.10
Columbus: Dublin Rd Water plant	51,305	48.35	94.59	1.51
Columbus: Hap Cremean Water Plant	111,234	52.53	85.62	9.45
Columbus: Parsons Avenue Water Plant	3,865	53.10	92.90	3.60
Cuyahoga Falls WTP	57,707	54.97	96.06	1.68
Dayton WTP	232,980	48.89	58.90	37.84
Dover WTP	12,210	57.50	97.10	1.30
East Palestine WTP	4,917	55.30	98.50	0.40
Fairfield WTP	42,097	50.30	89.90	6.10
Hicksville WTP	3,649	50.00	96.90	0.10
Hudson City WTP	22,439	56.20	94.70	1.50
Lancaster City PWS	35,335	51.40	97.40	0.60
Little Walnut Water System	6,374	57.90	98.10	0.30
MVSD	261,289	55.55	80.95	15.99
New Philadelphia WTP	17,056	54.40	96.90	1.00
North Canton WTP	16,369	59.30	96.90	1.10
Shalersville Water System	31,843	53.62	95.75	1.93
Troy WTP	26,644	50.43	92.78	3.99
Tussing Road Water System	26,914	51.90	93.90	3.40
Urbana WTP	11,613	53.10	91.00	6.00
Warren WTP	56,594	52.87	76.47	21.01
Westerville WTP	35,318	54.10	93.50	3.20
Xenia WTP	24,164	49.30	83.30	13.50
Total Population	**2,657,785**	**50.51**		

AA* = African American

Of the 17 counties that were included in the study not all of the WTPs in each county were included. The WTPs were chosen based on their available water quality data and the consistency in their water source and quality over the years. The total hardness recorded for nearly all of the WTPs came from the publically available consumer confidence reports that are released annually. The reported total hardness is for each WTP is recorded at mg/l, representing mg/l $CaCO_3$. The heart disease mortality rate for each county is provided from the CDC interactive atlas map and is given per 100,000 individuals, 35 years of age or over for the years 2007 to 2009 (CDC, 2007-2009). A summary of heart disease rate, source of water and WTPs in the seventeen counties is given below.

2.1.1. Butler County

Butler County has a heart disease rate of 360.9. Nearly all of the residents of Butler rely on groundwater for their drinking water supply (Bartels, Boone, & Brown, 1993). The city of Fairfield WTP was the only WTP located in Butler County to be selected. The source water is drawn from the sand and gravel, Great Miami Aquifer. Water is softened by calcium precipitation to 132mg/l of total hardness.

2.1.2 Champaign County

Champaign County has a heart disease rate of 365.2 All of the predominately rural population in Champaign County utilizes groundwater as their drinking water source. The highest yielding aquifer is sand and gravel (Dobbels, Sommers, Ricker, & Brown, 1995). In Champaign County the City of Urbana was the only WTP used. The City of Urbana, the largest public water system in the county, received a new water treatment plant that went online in 2009. Prior to that the city used water obtained from shallow aquifer with a high susceptibility to contamination. A total water hardness of 342 mg/l from a water quality report in 2008, before the new plant went online, was used for this study.

2.1.3 Columbiana County

Columbiana County has a heart disease rate of 404.8 Groundwater provides drinking water to 65% the total population in Columbiana. Aquifers are typically thick sand and gravel with glacial meltwater. Aquifers near East Palestine can be as large as 100 feet thick. Smaller aquifers comprised of sand, gravel, silt and clay can be found near northern Knox Township, from Leetonia to Columbiana, Minerva, Salem, and Lisbon (Stamm, Ricker, & Brown, 1997a). Two WTP were used in Columbiana: Columbiana City and East Palestine WTP.

Columbiana City uses groundwater drawn from Allegheny aquifer. Lime soda is used for softening to 114 mg/l of total hardness. The plant has been using the same process for over 70 years.

East Palestine draws water from three wells ranging in depth from 50 to 75 feet located in an alluvial sand and gravel aquifer flowing in from the Northwest. Iron and manganese are removed but no softening takes place and it retains its original total hardness of 225 mg/l.

2.1.4 Cuyahoga County

Cuyahoga County has a heart disease rate of 446.7. The entire county receives drinking water from Lake Erie, where water intakes are located far enough offshore to minimize pollution runoff. The Cleveland Division of Water, the only public water supplier chosen in the county, uses surface-water drawn from four intakes located in Lake Erie and distributes water with a total hardness of approximately 120mg/l.

2.1.5 Defiance County

The heart disease rate of Defiance County is 348.4. Only one WTP, Hicksville WTP, was used in Defiance County. Defiance is a predominately rural area where approximately 44% of residents rely on groundwater. Private wells provide for 31% of residents and 13% use public water supplies from municipal wells. The remaining population uses surface water as their water source (Hoorman, Boone, & Brown, 1992). Hicksville WTP is the second largest public water supplier in the county and uses three wells drawing groundwater from a sand and gravel aquifer. The total hardness of the treated water is approximately 280 mg/l.

2.1.6 Fairfield County

Fairfield County has a heart disease rate of 355.0. Nearly 100% of all households in Fairfield rely on groundwater for their drinking water, with 57% relying on public water supplies (Anderson, Ricker, & Brown, 1995). Three WTPs; The City of Lancaster, The Little Walnut Water System, and The Tussing Road Water Treatment System were used in the study.

The City of Lancaster draws drinking water from the Hocking Hill River Valley Aquifer, an unconsolidated aquifer of sand, gravel, and silt. A second water treatment plant finished in 2005 draws water from the same aquifer. Water is softened using an ion exchange method. Treated water has a total hardness between 119mg/l to 145 mg/l.

The Little Walnut Water System, located in Bloom Township, is supplied by a well field located in a moderately sensitive to contamination aquifer. The total hardness of the drinking water is around 119 mg/l.

The Tussing Road Water Treatment System also uses groundwater but is supplied by two distinct aquifers. The combined hardness of the two aquifers is approximately 131 mg/l.

2.1.7 Franklin County

Franklin County has a heart disease rate of 374.7. In Franklin County, 22% of the households rely on groundwater as their drinking water source. Two public water systems were used in Franklin County; Columbus City and City of Westerville. Columbus City is made up of three separate water treatment plants: Dublin Road, Hap Cremean and Parsons Avenue.

The largest public water system in the county is Columbus city (House, Ricker, & Brown, 1994). Columbus City's customers are separated and served by three different water treatment plants. Dublin Road WTP has a total hardness of 122 mg/l and serves northwestern and southwestern residents using surface-water obtained from Griggs and O'Shaughnessy Reservoirs. Hap Cremean Water Plant utilizes water from Hoover Reservoir and serves Ohio State University and northern residents. The total water hardness is 108 mg/l. Parsons Avenue Water Plants draws water from wells located in a sand and gravel aquifer and serves residents in the southwest. Water is softened using sodium carbonate or caustic soda and hydrated lime to a level of 122 mg/l of total hardness.

The City of Westerville's drinking water plant is provided mainly by surface-water drawn from Alum Creek. Two wells are also utilized to augment the surface-water supply. Water is treated with ferric chloride for clarification and softened with lime and caustic soda to an average of 144 mg/l. Carbon dioxide is used for pH adjustment and chlorine for disinfection.

2.1.8 Greene County

Greene County has a heart disease rate of 344.9. Approximately 98% of the population in Greene relies on groundwater for their drinking water. Xenia City WTP is the only plant used in the county (Mahan, Boone, & Brown, 1992). The WTP is supplied by groundwater obtained through a well field located in the Little Miami Buried Aquifer. The groundwater is not softened before distribution and has a total hardness of around 400 mg/l.

2.1.9 Hamilton County

Hamilton County has heart disease rate of 329.9. Most of the county is served by the Greater Cincinnati Water Works (GCWW). This includes the City of Cincinnati. GCWW is composed of two water treatment plants; the Miller Plant and the Bolton Plant. The Miller Plant supplies 88% of the customers of GCWW with surface-water from the Ohio River. This water is not softened and maintains a level around 137 mg/l total hardness. The remaining 12% of the GCWW's customers are supplied by the Bolton Plant which treats groundwater from the Great Miami Aquifer. This unconfined sand and gravel aquifer does not contain a protective clay layer and is vulnerable to contamination. Lime is added to the groundwater for softening to a level of 147 mg/l.

2.1.10 Miami County

Miami County has a heart disease rate of 346.8. The only WTP with available data on water hardness in Miami County is the City of Troy. One of three main public water suppliers in the County, the City of Troy WTP has 10 production wells ranging from 44ft to 132 ft in depth that draw water from the Greater Miami aquifer. The raw water has a hardness ranging from 330 mg/l to 420 mg/l. This water is softened to a range of 120mg/l to 130 mg/l of total hardness at the plant through lime soda softening and distributed to Troy City and neighboring West Milton Village.

2.1.11 Mahoning County

Mahoning County has a heart disease rate of 431.9. In Mahoning, 92% of the population receives its drinking water from surface-water. The only WTP used in the study from Mahoning County is the Mahoning Valley Sanitary District (MVSD). This is the largest supplier of drinking water in the county serving an estimated 300,000 people in Mahoning and neighboring Trumbull County. The MVSD obtains water from Meander Creek Reservoir and treats approximately 28 million gallons per day of raw water (Stamm, Ricker, & Brown, 1997b). The raw water treatment includes lime soda softening, disinfection and fluoridation. One of the lowest in the study area, the water is softened to an average of 94mg/l of total hardness. This water is pumped to Youngstown, Niles and McDonald. Youngstown distributes to surrounding residents as well as Austintown, Boardman Township, and Liberty in addition to selling water in bulk to Mineral Ridge, Girard and the City of Canfield.

2.1.12 Montgomery County

Montgomery County has a heart disease rate of 362.8. Nearly all of the households in the county use groundwater as a source. The only WTP used in the study from Montgomery County is the City of Dayton. Dayton distributes water to a large portion of Montgomery County, and is supplied by groundwater from the Great Miami Buried Valley Aquifer comprised of sand and gravel glacial outwash (Lane, Brown, Raab, & N'Jie, 1998). Dayton uses recharge lagoons to help maintain the water table. 104 production wells take raw water to the WTP where it is softened using calcium oxide to a total hardness of 155 mg/l.

2.1.13 Portage County

Portage County has a heart disease rate of 403.6. Portage County relies on groundwater for 90% of their drinking water supply. The primary groundwater source is from consolidated sandstone (O'Reilly, N'Jie, & Brown, 1998). Water hardness data from two WTPs, Shalersville and Brimfield were used from Portage.

The Shalersville WTP relies on groundwater from 5 deep wells located near the treatment plant. An ion exchange is utilized on the raw water to soften the water from a total hardness of 300mg/l to 150mg/l. Water is then distributed to Shalersville Township, Aurora and Streetsboro.

Brimfield WTP also uses groundwater as its source and distributes to Rootstown. Iron and manganese are removed but the water is not softened and is distributed at an average of 319 mg/l of total hardness.

2.1.14 Stark

Stark County has a heart disease rate of 349.5 Groundwater supplies 93% of the population in Stark with drinking water. The primary aquifers are comprised of sand and gravel deposits and sandstones (Oelker, Boone, & Brown, 1993a). Canton, North Canton and Alliance City WTPs have hardness data available for use in the study.

Canton WTP, the largest public supplier in the county, uses groundwater from wells located in sand and gravel aquifers. Canton has three treatment plants supplied by three separate well fields. Canton does not soften their water and is one of the highest in hardness in the study area, with an average total hardness of 428 mg/l. In addition to Canton City, the WTP also distributes to East Canton and Beach City.

North Canton WTP uses groundwater from six wells and softens raw water with lime soda to achieve a finished total hardness of about 150 mg/l.

Alliance City uses surface-water from connected reservoirs, Walborn and Deer Creek. Back up connections are available with Mahoning River and Westerville Lake. The WTP does not treat for hardness and has averaged 150 mg/l for finished water hardness over the last 5 years.

2.1.15 Summit

Summit County has a heart disease rate of 370.7. Summit has a predominately urban population with approximately 55% percent relying on surface-water for their drinking water supplies. Aquifers in Summit County are not uniform in composition or yield. The best aquifers are composed of sand and gravel and are traversed by major streams. Other aquifers contain pockets of sand and gravel interlaced with clay and silt (Oelker, Boone, & Brown, 1993b). Four WTPs Akron, Barberton, Cuyahoga Falls, and Hudson were all included in the study.

Akron Water Treatment Plant, the largest public water supplier in Summit County, supplies to Akron as well as neighboring cities and townships. Source water is obtained from the upper Cuyahoga through 3 reservoirs. The treatment at the plant does not include any water softening with finished water distributed at a total hardness of 121 mg/l.

Barberton water treatment plant, serves all of Barberton, and part of neighboring locations. It is supplied by surface-water from Barberton Reservoir, but also has a backup supply from 3 groundwater wells from a sand and gravel aquifer. The WTP has an average total hardness of 151 mg/l.

Cuyahoga Falls WTP also supplies water to Monroe Falls and Silver Lake. Groundwater is drawn from 18 wells located in Water Works Park on the south bank of the Cuyahoga River. The withdrawal area is part of a buried valley where permeable outwash gravels are traversed by major streams. The Cuyahoga Rivers contributes to the aquifer flow in addition to man-made channels and lagoons. The supply area is surrounded by two protection zones. Approximately 2/3 of the water after iron removal is softened using ion exchange softener to give a total hardness of approximately 160 mg/l.

Hudson city water treatment plant uses softened groundwater from wells located in a confined sand and gravel aquifer overlaid by a protective layer of clay. The wells are also protected by a well head protection plan. The finished water has a total average hardness of 135 mg/l.

2.1.16 Trumbull County

Trumbull County has heart disease rate of 429.1. The county has two major water suppliers: MVSD and City of Warren. MVSD is located in Mahoning County but serves areas in neighboring Trumbull County. Warren City serves Warren and neighboring townships. Water is drawn from Mosquito Creek Reservoir and distributed with a total hardness of 93 mg/l.

2.1.17 Tuscarawas County

Tuscarawas County has a heart disease rate of 411.0. Groundwater supplies 88% of the population in Tuscarawas with drinking water (Zoller, Ricker, & Brown, 1994). Two cities, Dover and New Philadelphia were included in the study.

The City of Dover water department uses groundwater from the Sugar Creek Basin Aquifer, consisting primarily of sandstone rock. Raw water is filtered, chlorinated, and iron and manganese are removed. Water is not softened and has a finished total hardness of 448 mg/l the highest in the study area.

The City of New Philadelphia Water Department is the largest WTP in the county and obtains water from four wells located in an unconsolidated sand and gravel aquifer. The total hardness of the drinking water is reported around 117 mg/l.

2.2 Drinking Water Data

Public Water Supplies are required to distribute a consumer confidence report (CCR) annually to their customers. Most of the information on the drinking water hardness values and the water source and treatment for each plant used in this study was obtained from the publically available CCRs. Due to the fact that water hardness is not a primary water standard required to be reported, it was not found on all CCRs. Additional information was obtained through directly contacting the water treatment plant and from water quality records held at the North East District of the Ohio EPA, located in Twinsburg, Ohio.

For consistency, the annual mean of total hardness on published CCRs between 2008 and 2010 were used if available. This value was then checked with reported water hardness values from other years to check for any significant variance. Water hardness typically does not vary greatly with time. WTPs that had a significant change in hardness were excluded from the study. The total water hardness of each plant and the type of water source are listed in Table 2.2.1.

Locations in each county that were mainly served by private water wells were disregarded in the study because of the lack of data due to no requirement for monitoring water quality in private wells. Cities and townships were grouped together based on their reported public water supply. Locations were eliminated if they were only partly supplied by the water treatment plant. The remaining locations and their associated demographics were then calculated together to represent the demographics for each WTP. A chart of the cities and townships that were used in determining the demographics for each WTP supply area is shown in Table 2.2.2.

Table 2.2.1: WTP Total Hardness and Water Source

Water Treatment Plant	Total Hardness (mg/l)	Water Source
Akron WTP	121	SW
Alliance WTP	150	SW
Barberton WTP	151	SW
Brimfield System	319	GW
Canton WTP	428	GW
Cincinnati: Bolton Plant	147	GW
Cincinnati: Miller Plant	137	SW
Cleveland Division of Water	120	SW
Columbiana WTP	114	GW
Columbus: Dublin Rd WTP	122	SW
Columbus: Hap Cremean WTP	108	SW
Columbus: Parsons Avenue WTP	123	GW
Cuyahoga Falls WTP	160	GW
Dayton WTP	155	GW
Dover WTP	448	GW
East Palestine WTP	225	GW
Fairfield WTP	132	GW
Hicksville WTP	280	GW
Hudson City WTP	135	GW
Lancaster City PWS	135	GW
Little Walnut Water System	119	GW
MVSD	94	SW
New Philadelphia WTP	117	GW
North Canton WTP	150	GW
Shalersville Water System	150	GW
Troy WTP	125	GW
Tussing Road Water System	131	GW
Urbana WTP	342	GW
Warren WTP	93	SW
Westerville WTP	144	MIX
Xenia WTP	400	GW

*GW= groundwater, SW= surface-water, MIX= mixture of both surface-water and groundwater

Table 2.2.2: Supply Area of Water Treatment Plants

WTP	Cities/Twp.
Akron WTP	Akron Hudson Twp. Stow Twinsburg City
Alliance WTP	Alliance City
Barberton WTP	Barberton
Brimfield System	Brimfield City Rootstown
Canton WTP	Tallmadge City Beach City Canton East Canton
Cincinnati Bolton WTP	Crosby Twp. Colerain Twp. North College Hill City Springfield Twp.
Cincinnati Miller WTP	Amberley Village Anderson Twp. Cincinnati City Deer Park City Delhi Twp. Elmwood Place Evendale Fairfax village Golf Manor Kenwood Lincoln Heights Madeira City Mariemont village Montgomery City Norwood Reading City St. Bernard Silverton Symmes Twp. Woodlawn
Cleveland Division of Water	Cleveland City
Columbiana WTP	Columbiana City
Columbus: Dublin Road WTP	Hilliard Grove City
Columbus: Hap Cremean WTP	Bexley Gahanna Reynoldsburg Whitehall Worthington
Columbus Parsons Avenue WTP	Groveport

Table 2.2.2: Continued

WTP	Cities/Twp.
Cuyahoga Falls WTP	Cuyahoga Falls Munroe Falls Silver Lake
Dayton WTP	Dayton City
	Brookville
	Miamisburg
	Trotwood
	Vandalia
Dover WTP	Dover City
East Palestine WTP	East Palestine City
Fairfield WTP	Fairfield City
Hicksville WTP	Hicksville Village
Hudson City WTP	Hudson City
Lancaster City PWS	Lancaster City PWS (Fairfield)
Little Walnut Water System	Bloom Township
MVSD	Austintown Twp. Boardman Twp. Canfield City. Girard City Jackson Twp. Liberty Mineral Ridge McDonald Niles Poland Twp. Struthers City Youngstown
New Philadelphia WTP	New Philadelphia City
North Canton WTP	North Canton
Shalersville Water System	Shalersville Twp. Streetsboro City of Aurora
Troy WTP	Troy City West Milton Village
Tussing Road Water System	Violet Township
Urbana WTP	Urbana City
Warren	Warren City Champion Twp.
Westerville WTP	Westerville City
Xenia WTP	Xenia City

2.3 Mortality Data

Mortality information on heart disease for the study area was obtained from the Ohio Department of Health, Center for Public Health Statistics and Information, located in Columbus Ohio. The number of deaths from heart disease in 2007 was given by city and township for each county covered in the study. Cities and townships were grouped according their drinking water supply area. The total number of deaths from heart disease mortality was found for each grouping. Standard vital statistic techniques have been used in computing mortality rates using the most recent census data available at the time from the 2000 U.S. Census Bureau database.

The heart disease mortality rate per 100,000 was found for each city and township individually by dividing the reported heart disease mortality by the population of each city and township and multiplying it by 100,000. The WTP heart disease mortality rate was taken by totaling heart disease mortality for each city and township in the group and dividing it by total population of the drinking water supply area and multiplying it by 100,000. The population of the drinking water supply area was found from totaling the populations of the cities and townships used in the WTP grouping (U.S. Census Bureau, 2000).

An age adjusted heart disease mortality rate was also determined by dividing the heart disease mortality rate by the total number of individuals over 35 years of age instead of the total population for each WTP in the study area and multiplying it by

100,000. The total population heart disease rate and the age adjusted heart disease rate for each WTP supply are included in Table 2.3.1.

For each city and township only the total number of deaths attributed to heart disease was given. No specification on age race or sex was given in the report, nor were there any specifications of the type of heart disease such as acute myocardial infarction, congestive heart failure, or even congenital heart diseases. This study did make the assumption that heart disease predominately affects individuals over 35 years of age and for this reason the age adjusted heart disease rate was calculated. The lack of defined groups made this study comparable to the previous study done in Scotland (Smith, & Crombie, 1987).

Table 2.3.1: Heart Disease Mortality Rates by WTP Supply Area

Water Treatment Plant	HD* mortality	Population	pop over 35	HDR*	AA HDR*
Akron WTP	616	305,048	154,525	201.94	398.64
Alliance WTP	59	23,253	11,365	253.73	519.14
Barberton WTP	91	27,899	14,800	326.18	614.86
Brimfield System	21	10,460	5,622	200.76	373.53
Canton WTP	203	83,572	41,288	242.90	491.67
Cincinnati: Bolton Plant	97	110,561	57,979	87.70	167.30
Cincinnati: Miller Plant	1016	521,047	255,060	194.99	398.34
Cleveland Division of Water	1317	478,403	224,899	275.29	585.60
Columbiana WTP	15	5,635	3,622	266.19	414.14
Columbus: Dublin Rd WTP	97	51,305	24,808	189.07	391.00
Columbus: Hap Cremean WTP	177	111,234	58,434	159.12	302.91
Columbus: Parsons Avenue WTP	6	3,865	2,053	155.24	292.26
Cuyahoga Falls WTP	147	57,707	31,723	254.74	463.39
Dayton WTP	532	232,980	113,904	228.35	467.06
Dover WTP	57	12,210	7,008	466.83	813.36
East Palestine WTP	11	4,917	2,716	223.70	405.01
Fairfield WTP	83	42,097	20,763	197.16	399.75
Hicksville WTP	7	3,649	1,828	191.83	382.93
Hudson City WTP	25	22,439	12,589	111.41	198.59
Lancaster City PWS	99	35,335	18,178	280.18	544.61
Little Walnut Water System	7	6,374	3,681	109.82	190.17
MVSD	531	261,280	145,145	203.23	365.84
New Philadelphia WTP	54	17,056	9,262	316.60	583.03
North Canton WTP	59	16,369	9,701	360.44	608.18
Shalersville Water System	70	31,843	17,075	219.83	409.96
Troy WTP	53	26,644	13,436	198.92	394.46
Tussing Road Water System	19	26,914	13,975	70.60	135.96
Urbana WTP	39	11,613	6,172	335.83	631.89
Warren WTP	145	56,594	29,923	256.21	484.58
Westerville WTP	43	35,318	19,057	121.75	225.64
Xenia WTP	63	24,164	11,962	260.72	526.67
Total Population	5,759	2,657,785	1,342,553	216.68	425.18

HD * = Heart Disease, HDR * = Heart Disease Rate per 100,000(total population), AA HDR *= Age-Adjusted Heart Disease Rate (over 35 years of age)

3.0 Difficulties in Environmental Exposure Studies

There are many difficulties in a population study such as this one. One issue is that the movement of the population is not controlled. The death certificate generally indicates the place of residence of the individual at the time the death occurred but gives no indication on how much time the individual had spent at that residence or in the case of mortality at a nursing home or hospital, how long they had been away from that residence. It can only be assumed in large ecological studies that the variance in population migration will be similar across the study area (Meyers, 1975).

The water hardness of WTPs tends to vary little from year to year but there can still be complications in reporting the total water hardness for each city and township in the supply area. Many cities and townships can be supplied by more than one supplier, new water treatment plants have been built and systems have been revised over the years. Emergency connections are also provided between different water treatment plants. The cities and townships in the supply area can also change. All attempts were made to exclude townships and cities that were not completely supplied by one main drinking water supplier. By doing this, customers that may have been completely supplied by only one WTP but lived in a partially supplied demographic were eliminated.

Despite fundamental limitations, studies involving correlations between population mortality and environmental exposure factors are commonly used to support or discredit geochemical hypotheses.

4.0 Statistics

Microsoft Excel 2010 was used to create a scatter plot of the heart disease mortality data rates versus the total hardness of WTPs listed in Table 4.1. A linear regression using Microsoft Excel Data Analysis Package, 2010 was used to find the correlation along with the R^2 value and adjusted R^2 value. The R^2 values represent the percent of variance of the data explained by the fitted line. In this case the R^2 values represent the variance in heart disease rates that can be explained by the change in drinking water hardness. The adjusted R^2 value is dependent on the number of points within the data. The significance of the R^2 value was determined by the resulting p values. The test was considered significant is the p value was less than 0.05. WTPs were further divided by levels of hardness into moderately hard, hard, and very hard classifications included in Table 4.2 to check for correlations within classifications. Linear regressions were then run on each classification. The entire statistical analysis is shown in the Appendix.

Table 4.1: Total Hardness versus Heart Disease Mortality Rates

Water Treatment Plant	Total Hardness (mg/l)	HDR*	AA HDR*
Akron WTP	121	201.94	398.64
Alliance WTP	150	253.73	519.14
Barberton WTP	151	326.18	614.86
Brimfield System	319	200.76	373.53
Canton WTP	428	242.90	491.67
Cincinnati: Bolton Plant	147	87.70	167.30
Cincinnati: Miller Plant	137	194.99	398.34
Cleveland Division of Water	120	275.29	585.60
Columbiana WTP	114	266.19	414.14
Columbus: Dublin Rd WTP	122	189.07	391.00
Columbus: Hap Cremean WTP	108	159.12	302.91
Columbus: Parsons Avenue WTP	123	155.24	292.26
Cuyahoga Falls WTP	160	254.74	463.39
Dayton WTP	155	228.35	467.06
Dover WTP	448	466.83	813.36
East Palestine WTP	225	223.70	405.01
Fairfield WTP	132	197.16	399.75
Hicksville WTP	280	191.83	382.93
Hudson City WTP	135	111.41	198.59
Lancaster City PWS	135	280.18	544.61
Little Walnut Water System	119	109.82	190.17
MVSD	94	203.23	365.84
New Philadelphia WTP	117	316.60	583.03
North Canton WTP	150	360.44	608.18
Shalersville Water System	150	219.83	409.96
Troy WTP	125	198.92	394.46
Tussing Road Water System	131	70.60	135.96
Urbana WTP	342	335.83	631.89
Warren WTP	93	256.21	484.58
Westerville WTP	144	121.75	225.64
Xenia WTP	400	260.72	526.67

HDR * = Heart Disease Rate per 100,000(total population), AA HDR *= Age-Adjusted Heart Disease Rate (over 35 years of age)

Table 4.2: WTPs Divided by Level of Hardness

Water Treatment Plant	H_2O hardness mg/l	HDR /100,000
Warren WTP	*93*	*256.21*
MVSD	*94*	*203.23*
Columbus: Hap Cremean WTP	*108*	*159.12*
Columbiana WTP	*114*	*266.19*
New Philadelphia WTP	*117*	*316.60*
Little Walnut Water System	*119*	*109.82*
Cleveland Division of Water	*120*	*275.29*
Akron WTP	121	201.94
Columbus: Dublin Rd WTP	122	189.07
Columbus: Parsons Avenue WTP	123	155.24
Troy WTP	125	198.92
Tussing Road Water System	131	70.60
Fairfield WTP	132	197.16
Hudson City WTP	135	111.41
Lancaster City PWS	135	280.18
Cincinnati: Miller Plant	137	194.99
Westerville WTP	144	121.75
Cincinnati: Bolton Plant	147	87.70
Alliance WTP	150	360.44
North Canton WTP	150	219.83
Shalersville Water System	150	253.73
Barberton WTP	152	326.18
Dayton WTP	155	228.35
Cuyahoga Falls WTP	160	254.74
East Palestine WTP	225	223.70
Hicksville WTP	280	191.83
Brimfield System	319	200.76
Urbana WTP	342	335.83
Xenia WTP	400	260.72
Canton WTP	428	242.90
Dover WTP	448	466.83

HDR * = Heart Disease Rate per 100,000(total population), AA HDR *= Age-Adjusted Heart Disease Rate (over 35 years of age), **Moderately hard = 61-120mg/l*, Hard = 121-180mg/l**, Very Hard = >180mg/l**

5.0 Results

The range of water hardness of the 31 WTPs varied from 93 mg/l to 448 mg/l of total hardness with an average value of 180 mg/l. Of the 31 plants 17 had a total hardness between 120mg/l and 160mg/l, accounting for 58% of the study area (Table 2.2.1). Figure 5.1 shows the values of hardness reported by the 31 WTPs used in this study.

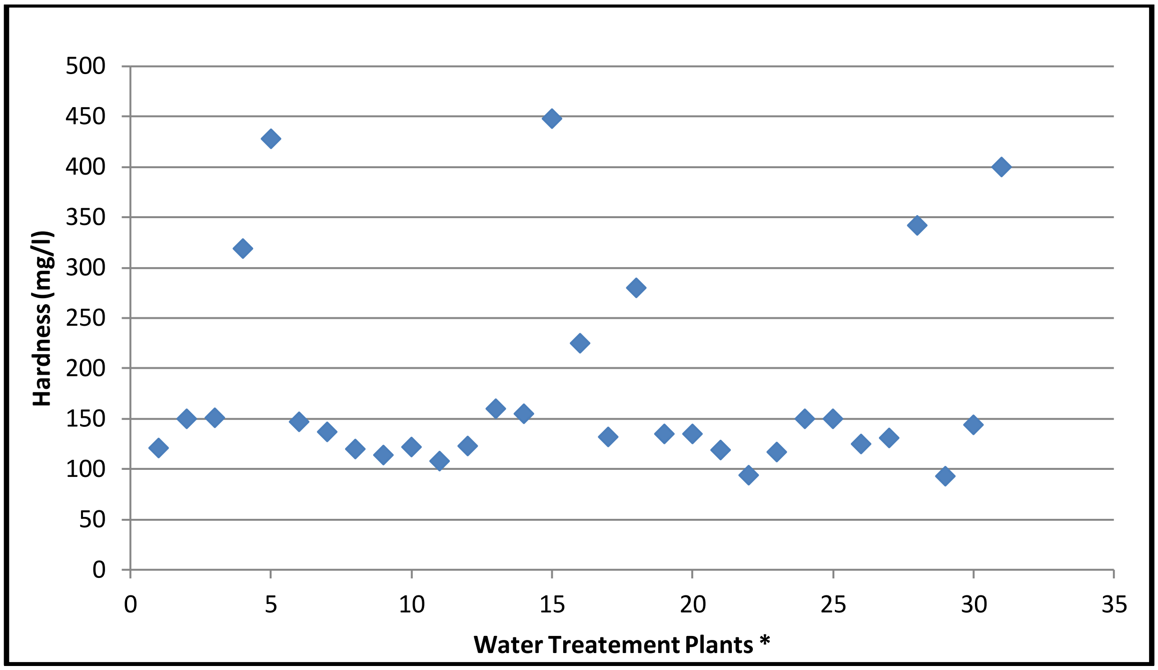

Figure 5.1: Total water hardness of plants (mg/l) from study area. * Order of WTPs corresponds to order of WTPs from Table 6

The total population heart disease mortality rate versus water hardness was first analyzed and a positive correlation of 0.427 was obtained. The R^2 value was found to be 0.183 indicating that 18.3% of the variance in heart disease mortality rate that is observed among the Ohio population serviced by the different public water plants can be explained by the change in total water hardness. The adjusted R^2 value was slightly lower at 0.154. This indicated 15.4% of the variance found in the heart disease mortality rate in the study area is a result of the change in water hardness. The resulting p value was 0.017, indicating a significant correlation. The graph of the data is shown in Figure 5.2. Despite the positive correlation found, a visual examination of Figure 5.2 seems to indicate that heart disease could be independent of water hardness, as 24 of the 31 data points show varying heart disease rates for a constant water hardness of about 130 mg/l.

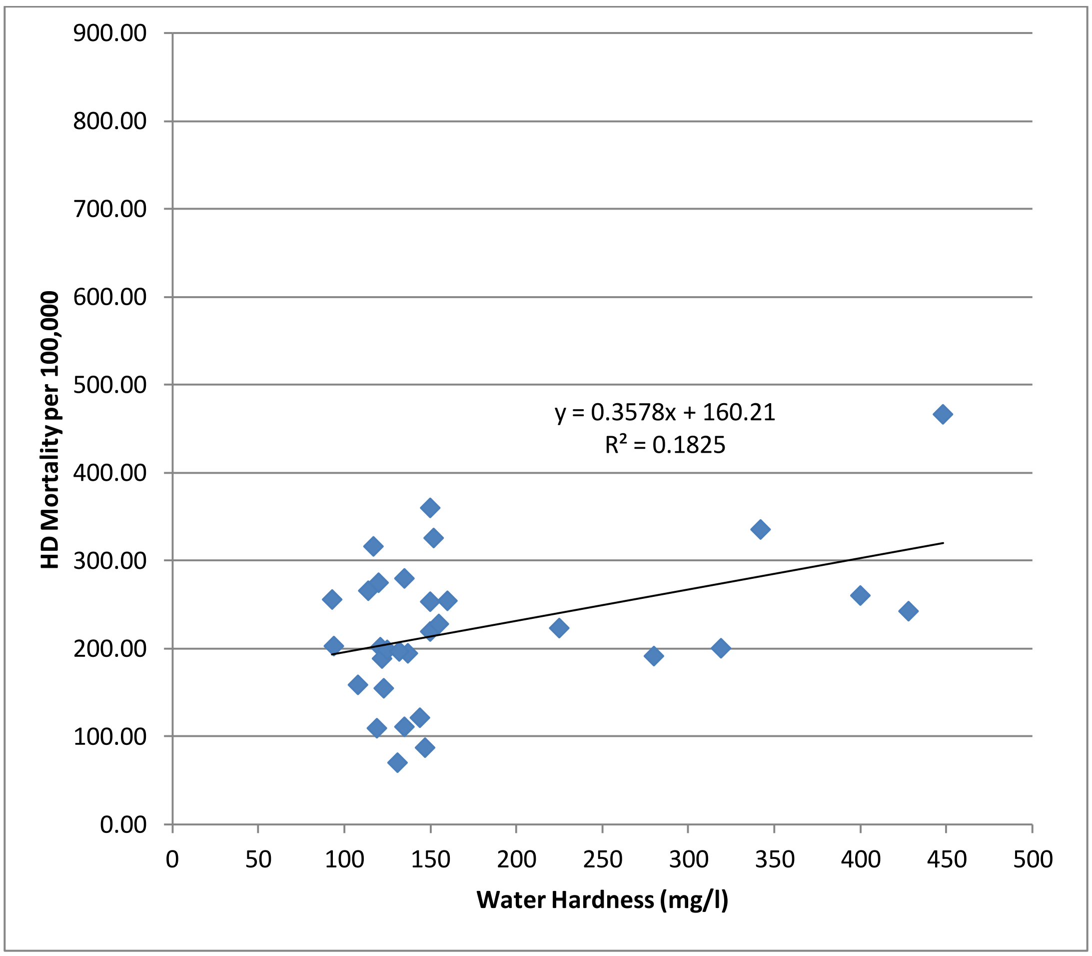

Figure 5.2: Total hardness versus heart disease (HD) mortality rate; calculated using the entire population for each study area.

To determine if the age breakdown of the each study area had an effect on the results, an age-adjusted heart disease mortality rate was determined using the number of deaths from heart disease divided by the number of people in each location area over 35 years of age. This had the effect of increasing the heart disease mortality rate from 216.68 to 425.18 per 100,000 causing the rate to be closer to the CDC's published rate for Ohio of 388.8 (CDC, 2007-2009). The age adjusted mortality rates were also graphed (Figure 5.3) versus the total hardness of the WTPs yielding a correlation of 0.439. An R^2 value of 0.193 was found indicating that 19.3% of the variance seen in the heart disease mortality can be explained by the hardness of the drinking water. As in the total population, the adjusted R^2 value was also slightly lower at 0.165. A p value of 0.013 made the findings significant. The same pattern of Figure 5.2, hinting that heart disease mortality rate is independent of water hardness, is also shown by Figure 5.3 with 24 of the 31 data points with a water hardness of about 130 mg/l having varying heart disease rates.

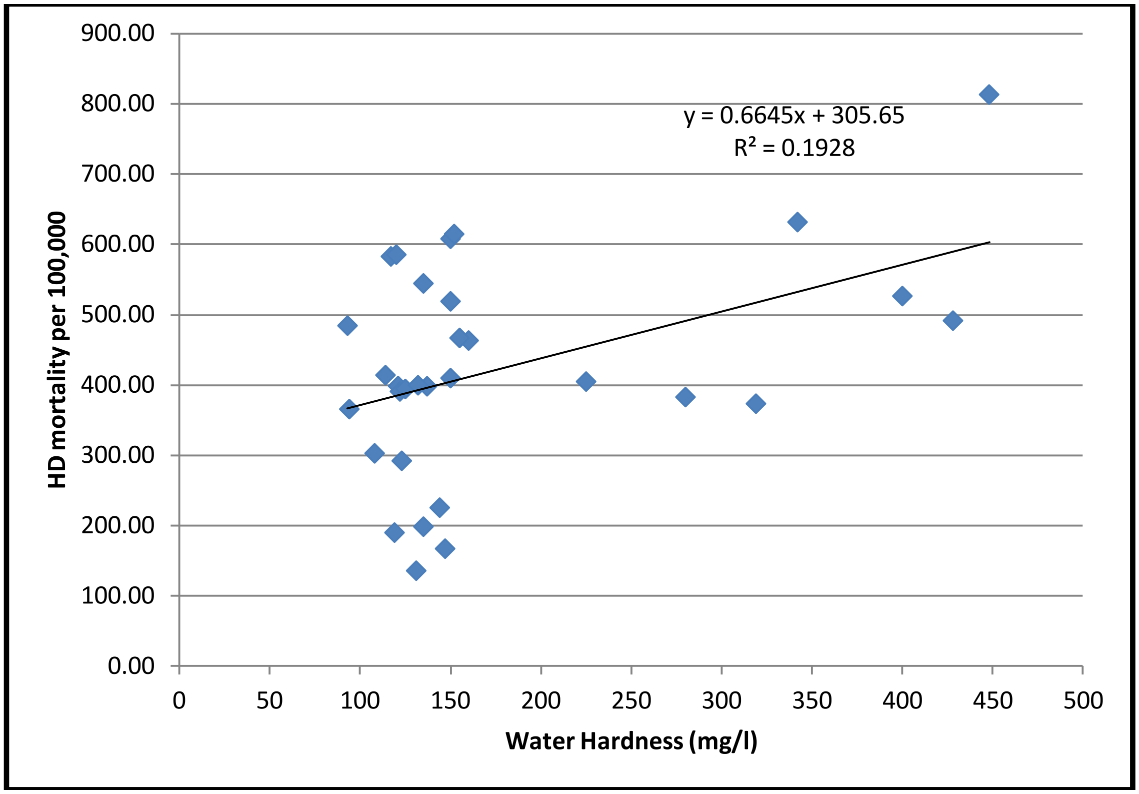

Figure 5.3: Total water hardness versus HD mortality rate calculated using population 35 years of age and over.

The age adjustment did not significantly change the correlation or R^2 value, due to the similar age demographics for each study area. A comparison of the statistics from the total population to the age-adjusted is presented in Table 5.1.

Table 5.1: Comparison of statistical results of linear regression of the total water hardness vs. total population HD morality rates and age adjusted (35+) HD mortality rates

	Total Population	35 + Population
Intercept	160.205	305.650
Slope	0.358	0.665
STEYX[a]	77.739	139.601
CORREL[b]	0.427	0.439
RSQ[c]	0.183	0.193
RSQ[c] adjusted	0.154	0.165
p-value	0.017	0.013

[a]STEYX = standard error of the predicted y value for each x in a regression, [b]CORREL= correlation [c]RSQ= R squared

All of the WTPs in the study area reported total water hardness that range from moderately hard to very hard. To see if a link could be established between heart disease mortality and small changes in water hardness that were found in WTPs within the same hardness classification, WTPs were broken down into 3 groups according to their total hardness found in Table 4.2; moderately hard (60-120mg/l), hard (121-180 mg/l) and very hard (>180mg/l). Figures 5.4, 5.5 and 5.6 show the resulting trend lines and corresponding R^2 values.

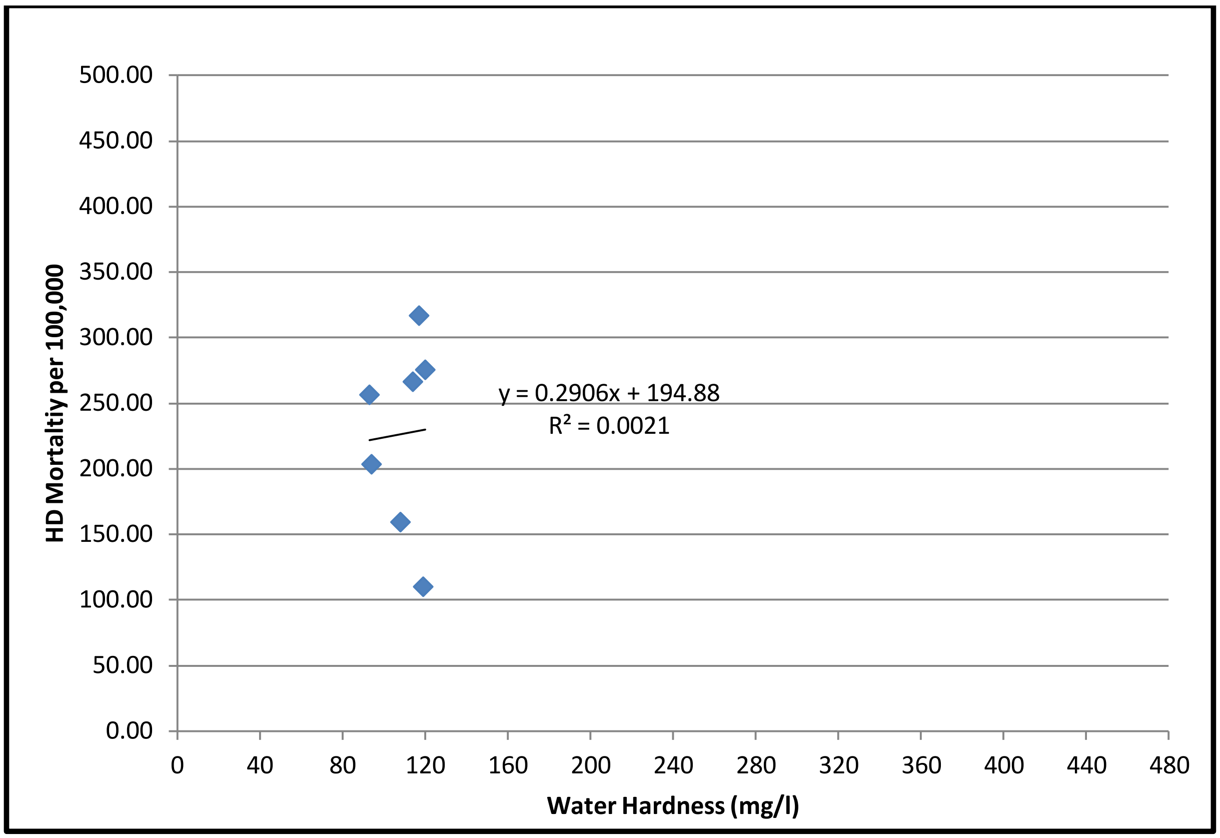

Figure 5.4: Moderately Hard WTPs (60-120mg/l) versus total population HD mortality

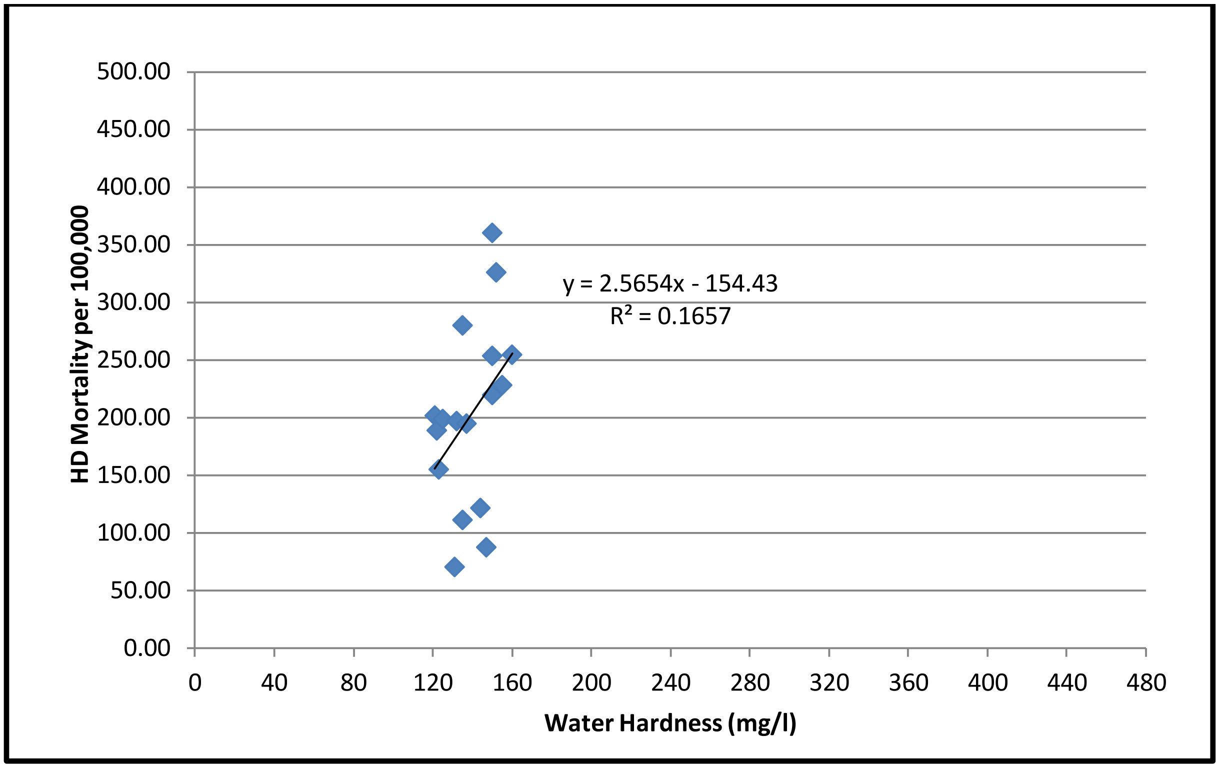

Figure 5.5: Hard Water WTPs (121-180 mg/l) versus total population HD mortality

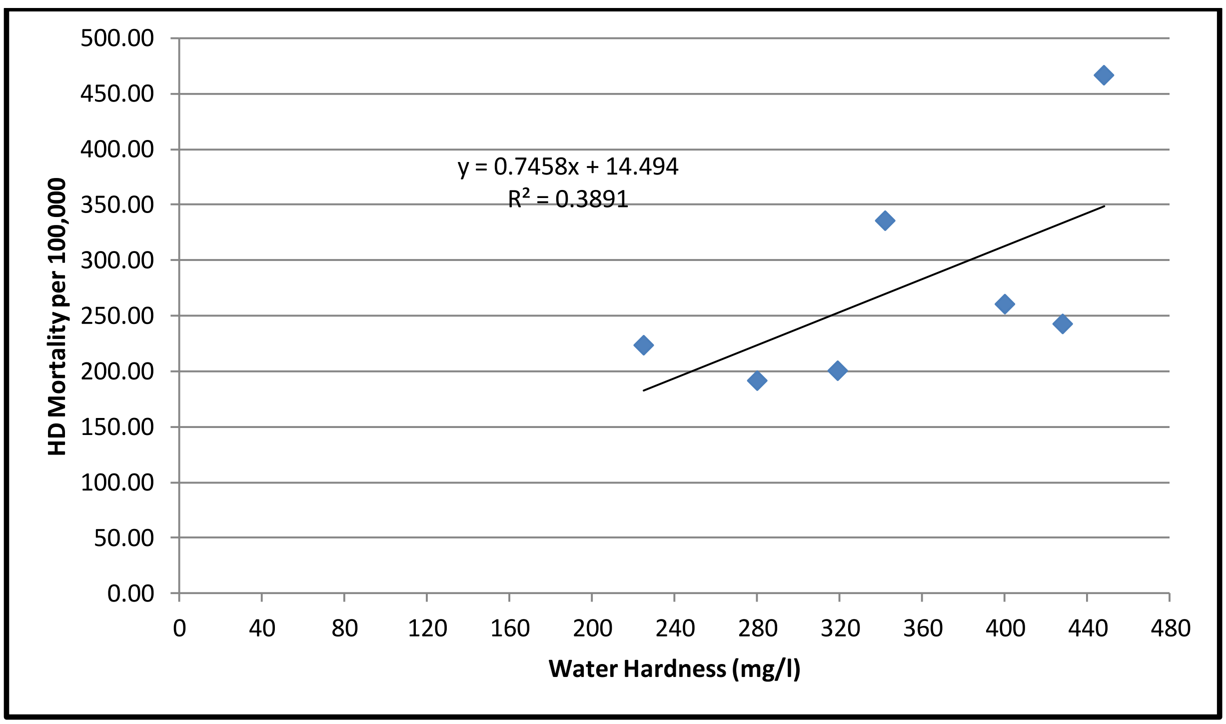

Figure 5.6: Very Hard WTPs (>180mg/l) versus total population in HD mortality.

Each of the classifications resulted in positive R^2 values following along with the positive trend found in the initial investigation using all WTPs in one correlation. And in fact the mean of the R^2 values found in each classification is similar to the R^2 value found analyzing all WTPs together. The moderately hard classification group had an R^2 value of 0.002. This value translates to the water hardness accounting for 0.2% of the variance, and in this case the increase, seen in the heart disease mortality rate. The adjusted R^2 value was the only inverse relationship found at -0.197. The hard and very hard classifications both had larger R^2 values 0.166 and 0.389 respectively. Both also maintained a positive adjusted R^2 values with the 0.110 for hard water and 0.267 for the very hard water analysis. Comparison of the analyses of the three classifications is located in Table 5.2. A complete regression analysis is found in the Appendix.

Table 5.2: Statistical results of linear regression of moderately hard (60-120 mg/l), hard (121-181 mg/l) and very hard (>180mg/l) WTP total hardness versus total population HD mortality rates

	Moderately Hard	**Hard**	**Very Hard**
Intercept	194.881	-154.431	14.494
Slope	0.291	2.565	0.746
STEYX[a]	79.48	74.765	83.303
CORREL[b]	0.046	0.407	0.624
RSQ[c]	0.002	0.166	0.389
RSQ[c] adjusted	-0.197	0.11	0.267
p-value	0.922	0.105	0.134

[a]STEYX = standard error of the predicted y value for each x in a regression, [b]CORREL= correlation
[c]RSQ= R squared

6.0 Discussion

The results of the correlation between the total population and age adjusted heart disease mortality rates and the hardness of drinking water shows a very weak positive correlation hinting that an increase in total drinking water hardness leads to an increase in heart disease mortality rate, contradicting the hypothesis supporting the protective factors against heart disease associated with hard water. Further investigation examined the relationship between heart disease mortality and the drinking water hardness of WTPs within the same hardness classification. This also resulted in slightly positive correlations.

Overall this study examined the total population versus the total water hardness. To see if similar correlations were present upon additional investigation, the data sets were separated according to grouping factors chosen to eliminate possible confounding factors.

The first correlation divided the WTPs' total hardness into three groups moderately hard, hard and very hard shown in Table 4.2. The mean, presented in Table 6.1, of the water hardness and heart disease rate was taken for each group without an attempt to weigh these values according to the populations using the particular water supply. The hard cluster overall had the lowest heart disease rate and the very hard water cluster the highest. A linear regression of these values resulted in a positive slope with an R^2 value of 0.815.

Table 6.1: WTPs Hardness Mean

WTP Hardness Groups	**Mean H_2O Hardness**	**Mean HDR*/100,000**
Moderately Hard	109.29	226.64
Hard	139.35	203.07
Very Hard	348.86	274.65

HDR* Heart Disease Rate per 100,000 (total population)

Two correlations grouped the data according to the source of raw water that was shown in Table 2.1.1. The water treatment process is similar among surface-water WTPs and groundwater WTPs. Grouping them according to their source eliminates possible confounding factors that could be associated with the water treatment process. The surface-water supplied plants and groundwater supplied plants were analyzed separately. The one WTP that received mixed water was eliminated. The surface water grouping resulted in a R^2 value of 0.280, similar to that found in the original investigation. The groundwater grouping had a small negative R^2 of -0.005.

The Size of each WTPs total customer population reported in Table 2.1.2 was then used as a grouping factor. WTPs were divided into two groups those that had a total customer population over 50,000 and those under 50,000 individuals. A third cluster was analyzed using WTPs with populations over 100,000 individuals. Choosing WTPs that supplied to a large population set ranging from 51,305 to 521, 047 and then from 100,561 to 521,047 decreased the number of data points but made the study more similar to a previous Australian study that analyzed two major cities with populations of 850,000 and 2,500,000 people. With the large numbers involved in this analysis it is hoped death rates will be more stable and that certain factors such as change in residence will be similar between WTPs and have less of an effect on the heart disease rate (Meyers, 1975). The population clusters of all WTPs below 50,000 and all WTPs above 50,000 found positive correlations of 0.232 and 0.033 respectively. The WTP grouping with populations above 100,000 resulted in an R^2 value of -0.035. This indicated that 3.5% of the variance in heart disease could be attributed by the increase in water hardness, which is a very weak association.

Some of the heart disease rates of the WTPs varied significantly from the county average heart disease rate provided by the Center for Disease Control and Prevention. This comparison is shown in Table 6.2. In these locations it was assumed that a factor other than total water hardness could be playing a significant role in the heart disease rate. Based on this assumption a grouping examined the WTPs that had a heart disease rate that was not significantly different than the heart disease rate given for that county. Table 6.2 shows that the absolute deviation of the WTP's heart disease rate compared to the county's average heart disease rate ranges from 0.2 to 402.4. Those WTPs that did not have a deviation greater than 100 deaths per 100,000 individuals were used in the correlation. This brought the total sample size down from 31 WTPs to 16. An R^2 value of -0.002 was found.

Another possible explanation for the significantly different heart disease rate in the WTP customer area compared to the county average could possibly be a result of the hardness of the drinking water for that population. With this in mind, WTPs that had an absolute deviation greater than 100 deaths per 100,000 individuals was also analyzed separately. This included a total of 15 plants. The resulting R^2 value was found to be 0.234, continuing with the positive trend.

Table 6.2: WTPs HDR compared to the County HDR as given by the CDC for year 2007-2009.

Water Treatment Plant	H_2O hardness mg/l	AA HDR*	County HDR*	Abs Deviation
East Palestine WTP	225	405.0	404.8	0.2
Shalersville Water System	150	410.0	403.6	6.4
Columbiana WTP	114	414.1	404.8	9.3
Columbus: Dublin Rd WTP	122	391.0	374.7	16.3
Akron WTP	121	398.6	370.7	27.9
Brimfield System	319	373.5	403.6	30.1
Hicksville WTP	280	382.9	348.4	34.5
Dayton WTP	155	467.1	431.9	35.2
Fairfield WTP	132	399.7	360.9	38.8
Troy WTP	125	394.5	346.8	47.7
Warren WTP	93	484.6	429.1	55.5
MVSD	94	365.8	431.9	66.1
Cincinnati: Miller Plant	137	398.3	329.9	68.4
Columbus: Hap Cremean WTP	108	302.9	374.7	71.8
Columbus: Parsons Avenue WTP	123	292.3	374.7	82.4
Cuyahoga Falls WTP	160	463.4	370.7	92.7
Cleveland Division of Water	120	585.6	446.7	138.9
Canton WTP	428	491.7	349.5	142.2
Westerville WTP	144	225.6	374.7	149.1
Little Walnut Water System	119	190.2	355.0	164.8
Alliance WTP	150	519.1	349.5	169.6
New Philadelphia WTP	117	583.0	411.0	172.0
Hudson City WTP	135	198.6	370.7	172.1
Xenia WTP	400	526.7	344.9	181.8
Lancaster City PWS	135	544.6	355.0	189.6
Tussing Road Water System	131	136.0	355.0	219.0
Cincinnati: Bolton Plant	147	167.3	392.9	225.6
Barberton WTP	152	614.9	370.7	244.2
North Canton WTP	150	608.2	349.5	258.7
Urbana WTP	342	631.9	365.2	266.7
Dover WTP	448	813.4	411.0	402.4

HDR * = Heart Disease Rate per 100,000(total population), AA HDR *= Age-Adjusted Heart Disease Rate (over 35 years of age)

The percent of individuals over 35 years of age for each WTP was similar, as can be seen in Table 2.1.2, ranging from 46.9% to 64.3%. To check for any variations that may be associated with the percent of the population over 35 years of age, the WTPs were broken down into three groups. This grouping helped to eliminate confounding factors associated with heart disease linked to increasing age. The first group consisted of WTPs with 45% to 50% of the population over 35 years of age. The largest group was comprised of 17 WTPs with 50% to 55% of the population over 35 years of age. The final group consisted of WTPs with 55% to 60% over the age of 35. One WTP with 64.3% over 35 years of age was not used. All three groups resulted in positive correlations.

Many of the WTP groups were made up of more than one city or township displayed in Table 2.2.2. To see if correlations were lost when the cities and townships were grouped together, the WTPs were ungrouped and the individual cities and townships with their own individual heart disease rates and the total water hardness provided by the plant were analyzed. Overall 83 cities and townships were used. The cities and townships were further broken down by the population size reported by the 2000 census bureau. Table 6.3 shows the breakdown of cities and townships with corresponding water hardness and population size. An R^2 value of 0.0113 was found. Cities and townships were also broken down by population size as was done in the WTP grouping, but because of smaller population numbers, groups included all cities and townships with populations over 5,000, 10,000, 30,000 and finally 50,000 total populations. All groups resulted in positive correlations.

Table 6.3: Individual Cities and Townships with corresponding total water hardness (mg/l) population size and HDR per 100,000.

Cities & Townships	Population	H_2O hardness mg/l	HDR*/100,000
Beach city	1,137	428	87.95
East Canton	1,629	428	122.77
Fairfax village	1,938	138	206.40
Elmwood Place	2,681	138	298.40
Crosby Twp.	2,748	148	254.73
Woodlawn	2,816	138	248.58
Silver Lake	3,019	160	132.49
Evendale	3,090	138	129.45
Brimfield city	3,248	319	184.73
Mariemont village	3,408	138	176.06
Amberley Village	3,425	138	204.38
Hicksville Village	3,649	280	191.83
Groveport	3,865	122	155.24
Golf Manor	3,999	138	250.06
Lincoln Heights	4,113	138	267.44
West Milton Village	4,645	125	64.59
East Palestine City	4,917	225	223.71
St. Bernard	4,924	138	243.70
Silverton	5,178	138	212.44
Brookville	5,289	155	302.51
Munroe Falls	5,314	160	263.46
Columbiana City	5,635	114	266.20
Shalersville Twp.	5,976	150	117.14
Deer Park City	5,982	138	451.35
Bloom Twp.	6,374	119	109.82
Rootstown	7,212	319	207.99
Canfield city.	7,374	94	176.30
Kenwood	7,423	138	538.87
Madeira city	8,923	138	179.31
champion Twp.	9,762	93	92.19
North College Hill city	10,082	148	218.21
Montgomery city	10,163	138	177.11
Girard city	10,902	94	339.38
Reading city	11,292	138	177.11
Urbana city	11,613	342	335.83
Struthers city	11,756	94	408.30
Dover City	12,210	448	466.83
Streetsboro	12,311	150	251.81
Bexley	13,203	102	128.76

Table 6.3 Continued

Cities & Townships	Population	H_2O hardness mg/l	HDR*/100,000
City of Aurora	13,556	150	236.06
Worthington	14,125	102	283.19
Vandalia	14,603	155	184.90
Poland Twp.	14,711	94	211.06
Symmes Twp.	14,771	138	216.64
North Canton	16,369	151	360.43
Tallmadge city	16,390	121	262.35
Twinsburg City	17,006	121	158.77
New Philadelphia city	17,056	117	316.60
Whitehall	19,201	102	239.57
Miamisburg	19,489	155	261.69
Norwood	21,675	138	253.75
Troy City	21,999	125	227.28
Hudson Twp.	22,439	121	111.41
Hudson City	22,439	135	111.41
Alliance City	23,253	150	253.73
Liberty	23,522	94	199.81
Xenia City	24,164	400	260.72
Hilliard	24,230	123	127.94
Violet Township	26,914	131	70.60
Grove City	27,075	123	243.77
Trotwood	27,420	155	306.35
Barberton	27,899	151	326.18
Delhi Twp.	30,104	138	232.53
Reynoldsburg	32,069	102	143.44
Stow	32,139	121	205.36
Gahanna	32,636	102	85.79
Westerville City	35,318	128	121.75
Lancaster City	35,335	160	280.18
Springfield Twp.	37,587	148	135.69
Austintown Twp.	38,001	94	55.261
Fairfield City	42,097	132	197.16
Boardman Twp.	42,508	94	58.81
Anderson Twp.	43,857	138	22.80
warren city	46,832	93	290.39
Cuyahoga Falls	49,374	160	261.27
Colerain Twp.	60,144	148	28.27
Hamilton City	60,690	152	281.76
Canton	80,806	428	247.50
Youngstown	82,026	94	315.75

Table6.3 continued

Cities & Townships	Population	H_2O hardness mg/l	HDR*/100,000
Dayton City	166,179	155	213.02
Akron	217,074	121	209.61
Cincinnati City	331,285	138	195.60
Cleveland City	478,403	120	275.082

HD * = Heart Disease, HDR * = Heart Disease Rate per 100,000(total population),

The resulting R^2 values of all of the additional analyses along with the sample size are shown below in Table 6.4. As can be seen from the results nearly all R^2 values were positive. Of the 16 new groupings only 3 were found to be negative and these negative values were quite insignificant.

Table 6.4: RSQ values of additional analyses of WTPs and cities and townships in the study area

Grouping	RSQ[a]	N[b]
Average clusters	0.815	3
Surface Water WTPs	0.280	9
Ground Water WTPs	-0.005	21
Population over 50,000 by WTP	0.033	11
Population under 50,000 by WTP	0.232	20
Population over 100,000 by WTP	-0.035	7
WTP with HDR not significantly different	-0.002	16
WTP with HDR significantly different	0.2343	15
WTP Population 45% to 50% over 35 yrs of age	0.118	7
WTP population 50% to 55% over 35 years of age	0.053	17
WTP population 55% to 60% over 35 years of age	0.607	7
Individual Cities & Townships (C&T)	0.011	83
C&T Population over 5,000	0.078	66
C&T Population over 10,000	0.120	53
C&T Population over 30,000	0.042	21
C&T Population over 50,000	0.001	8

RSQ[a]: R squared, N[b]: sample size

This has not been the first study to find a positive correlation or no correlation between water hardness and cardiovascular disease. A 1964 Oklahoma study, like this one, chose an area inside a single state for analysis. The counties across Oklahoma reported a wide ranging cardiovascular death rate as well as a large difference in water hardness and mineral concentrations in municipal drinking water. The water supply of 368 communities across the state was analyzed. Mean values were calculated for each of the 77 counties without an attempt to weigh these values according to the populations using the water supply. Correlations were computed for all white males over the age of 25 and for white males age 45-64. The study found no significant negative correlation between cardiovascular disease and water hardness with a resulting correlation coefficient of -0.01 for males over age 25 and -0.09 for males age 45-64. The only factor that was seen to be geographically significant to the heart disease rate is the urban areas tended to have a higher heart disease rate (Lindeman, & Assenzo, 1964).

A 1971 Study done in Washington County Maryland made use of a private census study done in 1963 to examine the water hardness, heart disease relationship along with socioeconomic characteristics. Over the course of three years, 189 deaths were attributed to arteriosclerotic and degenerative heart disease among white males ranging from 45 to 64 years of age. For each case, 2 controls that matched each case for race, sex and year of birth were randomly selected and matched. Water samples were taken for both the case and control and analyzed for total hardness. No significant correlation was found between drinking water and heart disease. Deaths were found to be more common among those of lower socioeconomic status, cigarette smokers, and among people who attended church more infrequently (Comstock, 1971).

A common trend that may be seen between the Oklahoma study, Maryland study and this study is that perhaps the negative correlation is not as dominant when investigating smaller areas located within one state.

A possible explanation for the results seen in this study is that the level of total hardness in drinking water may have threshold level over which possible beneficial factors may no longer increase as the total hardness increases. Over this threshold the protective values may not necessarily be detrimental, but will no longer add the beneficial properties that are looked for with hard water.

All of the water treatment plants in the study area had total water hardness values that are considered to be moderately hard to very hard. If the beneficial threshold of water hardness is already met by a large portion of the WTPs, any correlation found could have been greatly influenced by one of the many other known factors such as abdominal obesity, smoking, diabetes and family history. It could also be affected by some other geochemical environmental factors, such as temperature or amount or rainfall.

A 1980 study done in Great Britain suggested that the water hardness effect occurs in the range of 0-170 mg/l. And that the correlation curve tends to flatten out as it approaches 150mg/l (Pocock et al., 1980). The softest water in this study had a value of 93 mg/l which classifies the water as moderately hard. 17 of the 31 water treatment plants are classified in the hard range of 121-180 mg/l.

To check for a similar threshold relationship in this study, water treatment plants over 150 mg/l of total water hardness were eliminated and a new linear regression was plotted using the remaining 21 WTPs shown in Table 6.5, with a range of 93mg/l to 150 mg/l (Figure 6.1). This resulted in a negative, correlation of -0.063 and a very small R^2 value of 0.004. Indicating that 0.4% of the variance in heart disease mortality can be explained by the change in total water hardness. The adjusted R^2 value reported in Table 6.6 was -0.048. This slight negative correlation found in WTPs under 150 mg/l could warrant future investigation into studies where the total water hardness of the study consists of a range of water hardness that includes softer water.

Table 6.5: Selected WTP with Total Hardness of 150mg/l or less

Water Treatment Plant	**H_2O hardness mg/l**	**HDR***
Akron WTP	121	201.94
Alliance WTP	150	253.73
Cincinnati Bolton WTP	147	87.70
Cincinnati Miller WTP	137	194.99
Cleveland Division of Water	120	275.29
Columbiana WTP	114	266.19
Columbus: Dublin Rd WTP	122	189.07
Columbus: Hap Cremean WTP	108	159.12
Columbus: Parsons Avenue WTP	123	155.24
Fairfield WTP	132	197.16
Hudson City WTP	135	111.41
Lancaster WTP	135	280.18
Little Walnut Water System	119	109.82
MVSD	94	203.23
New Philadelphia WTP	117	316.60
North Canton WTP	150	360.44
Shalersville Water System	150	219.83
Troy WTP	125	198.92
Tussing Road Water System	131	70.60
Warren	93	256.21
Westerville WTP	144	121.75

HDR * = Heart Disease Rate per 100,000(total population),

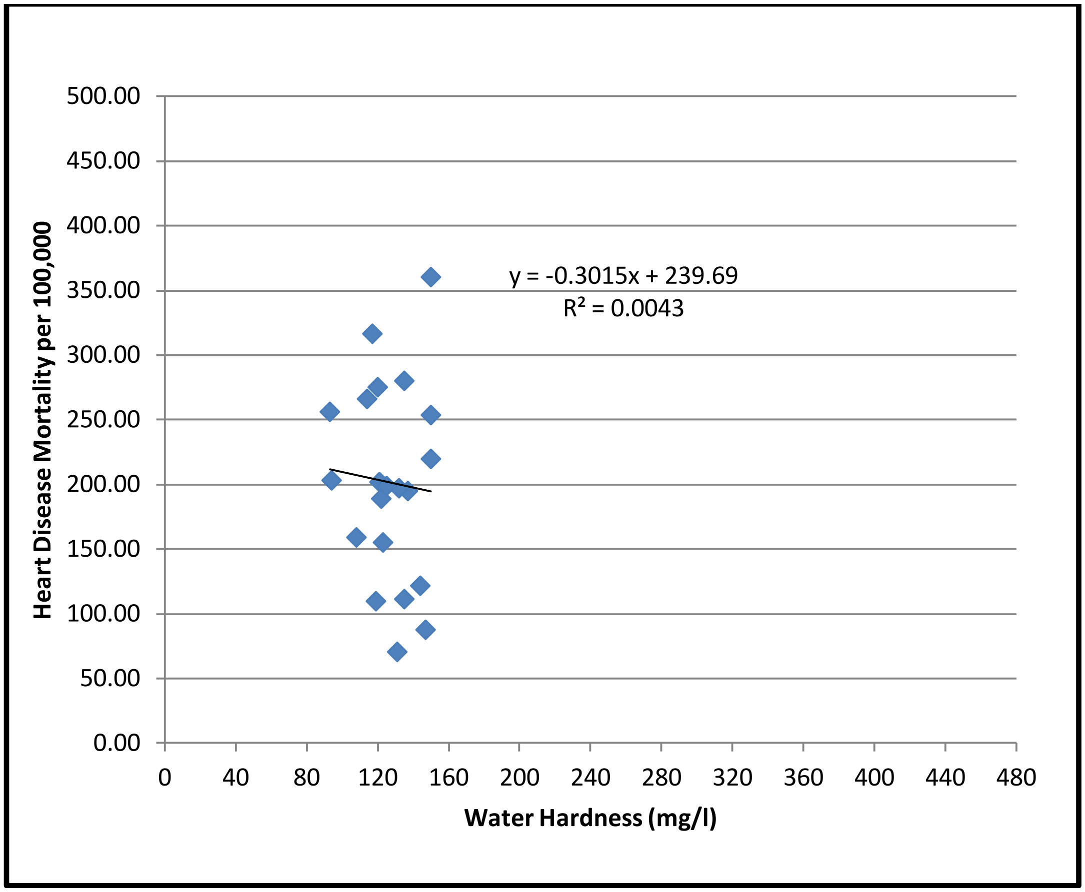

Figure 6.1: Selected WTP (≤ 150 mg/l) versus total population

Table 6.6: Statistical results of linear regression of total harness vs. total population HD mortality rates of selected WTPs (<150 mg/l)

	Selected WTP
Intercept	239.687
Slope	-0.301
STEYX[a]	78.475
CORREL[b]	-0.066
RSQ[c]	0.004
RSQ[c] **adjusted**	-0.048
p-value	0.777

[a]STEYX = standard error of the predicted y value for each x in a regression, [b]CORREL= correlation
[c]RSQ= R squared

Another possible cause that could confound the results in this study is the lack of information on the daily lifestyle habits of the subjects in the study area. Many factors such as weight, genetics, diet, stress and daily activity all play a role in heart disease. A

2003 study done in Sweden attempted to include some of these factors in their study. 207 individuals that lived in two areas characterized by different heart disease mortality rates and water hardness answered a questionnaire about their health, social and living conditions and diet. Water samples were also taken from each household and analyzed for calcium and magnesium. They found positive correlation between the calcium content in the water and systolic blood pressure and a negative correlation with s-cholestrol and s-LDL-cholesterol. No correlation was found with the magnesium content. A regression analysis indicated that calcium in water could be a factor of cardiovascular disease but from their results it was not possible to make a definite conclusion and it was indicated that further research was needed (Agréus, Nebrand, Lenner, Nyber, & Svardsudd, 2003).

7.0 Conclusion

This study investigating the total hardness of 31 water treatment plants encompassing 2,657,785 individuals in 86 cities and townships, with moderate to high total hardness and the heart disease mortality of the customer population did not show a negative correlation supporting the protective value of hard water against heart disease. The investigation resulted in a weak positive correlation between the two indicating that increasing water hardness is slightly associated with an increase in heart disease mortality. Further investigation into the study area showed that between certain water hardness levels a negative correlation can occur. However because of the weak associations found, no definite relationships could be defined out of this study.

Instead this study formulates the need for further research to be done perhaps taking into consideration different types of cardiac disease and the effect that individual elements, such as calcium and magnesium, have on heart disease. It is also important to keep in mind that there are numerous factors that are contributors to cardiovascular disease. These factors could have a confounding effect on the results and contribute to the variations in heart disease mortality found in the study.

8.0 Recommendation for Further Studies

As has been done in past studies around the world, such as Scotland (Smith, & Crombie, 1987) and Australia (Meyers, 1975), this study took a broad look at the connection between water hardness and heart disease mortality. Results were obtained from the data analyzed, but a greater understanding of the complicated relationship between heart health and the mineral content of water in the same area could benefit from additional investigations. One such study, introduced in the discussion to examine the possible beneficial threshold of hard water, would be to examine WTPs with a wider range of hardness to include soft water. Other possible studies could examine the individual minerals that affect the hardness of water as well as breakdown heart disease mortality into more specifics categories such as mortality from acute myocardial infarction and the complications from high blood pressure. Some studies have found correlation when investigating the effects that magnesium and calcium have separately on heart disease (Kousa et al., 2008; Elwood et al., 1977; Agréus et al., 2003).

A study by Rubenowitz, Axelsson, and Rylander in 2000 examined the role of calcium and magnesium in drinking water and the link to acute myocardial infarction morbidity and mortality. A link was not found with calcium, but data suggested that increased magnesium consumption is linked to a decrease in death from acute myocardial infarction but does not decrease the development of heart disease. This is due to the fact that magnesium helps to control the electrical impulses of the cardiac muscle (Rubenowitz et al., 2000). With this in mind different results could be obtained using the same study area in Ohio but using acute myocardial infarction as the dependent variable as opposed to total heart disease mortality.

Other evidence suggests that the ratio of the two elements plays an important role. Many individuals in developed countries do not get the recommended intake of magnesium and at the same time may increase their calcium consumption which throws off the recommended ratio of 1:2 for magnesium to calcium (Durlach, 1989). Further studies on the area investigated in this research could examine the ratio of calcium and magnesium in the drinking water and determine if a correlation exists between different ratios and the heart disease mortality rate.

The relationship between water hardness and heart disease could also benefit from a study that is done on a smaller number of individuals under a more controlled environment. A previous 1996 study by Rubenowitz, Axelsson, and Rylander, in Sweden examined magnesium and acute myocardial on such a population. In the study area, 854 men that had died from acute myocardial infarction were used as the experimental group and 989 men who had died from cancer were used as the control group. Both groups, selected from across 17 municipalities, had died in the same time period and were between the ages of 50 and 69 years of age. The subjects were divided up according to the magnesium and calcium levels in their drinking water. Data suggested that magnesium consumption had a protective role against acute myocardial infarction but calcium had no such relation (Rubenowitz et al., 1996).

As in many past studies, another conclusion that can be made at the end of this study is that the mineral content of drinking water is a topic that needs further in-depth investigation. This study showed that negative correlations are not always found when total water hardness is compared to heart disease mortality. What was not ruled out is that negative correlations do not exist. As was established in past studies, negative correlation can be found in investigations using more specific components of hard water, particularly magnesium. This in conjunction with examining different types of heart disease seems to hold the most promise. Such a multifaceted issue as heart disease has many contributing factors, and the potential to find more significant and specific relationships between drinking water hardness and cardiovascular health remains.

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Appendix: Complete Statistical Results from Microsoft Excel Data Analysis, 2010.

SUMMARY OUTPUT: TOTAL POPULATION

Regression Statistics	
Multiple R	0.427
R Square	0.183
Adjusted R Square	0.154
Standard Error	77.739
Observations	31

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	39132.379	39132.379	6.475	0.017
Residual	29	175255.327	6043.287		
Total	30	214387.707			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	160.205	28.887	5.546	5.57177E-06	101.124	219.286
X Variable 1	0.358	0.141	2.545	0.017	0.070	0.645

SUMMARY OUTPUT: AGE ADJUSTED

Regression Statistics	
Multiple R	0.439
R Square	0.193
Adjusted R Square	0.165
Standard Error	139.601
Observations	31

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	135000.954	135000.954	6.927	0.013
Residual	29	565164.548	19488.433		
Total	30	700165.502			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	305.650	51.875	5.892	2.14264E-06	199.554	411.746
X Variable 1	0.665	0.252	2.632	0.013	0.148	1.181

SUMMARY OUTPUT Moderately Hard 60-120 mg/l

Regression Statistics	
Multiple R	0.046
R Square	0.002
Adjusted R Square	-0.197
Standard Error	79.480
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	66.832	66.832	0.011	0.922
Residual	5	31585.617	6317.123		
Total	6	31652.450			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	194.881	310.215	0.628	0.557	-602.552	992.315
X Variable 1	0.291	2.825	0.103	0.922	-6.972	7.553

SUMMARY OUTPUT Hard 121-180 mg/l

Regression Statistics	
Multiple R	0.407
R Square	0.166
Adjusted R Square	0.110
Standard Error	74.765
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	16650.402	16650.402	2.979	0.105
Residual	15	83846.208	5589.747		
Total	16	100496.610			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-154.431	207.931	-0.743	0.469	-597.626	288.764
X Variable 1	2.565	1.486	1.726	0.105	-0.603	5.734

SUMMARY OUTPUT Very Hard 181mg/l or greater

Regression Statistics	
Multiple R	0.624
R Square	0.389
Adjusted R Square	0.267
Standard Error	83.303
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	22095.070	22095.070	3.184	0.134
Residual	5	34696.711	6939.342		
Total	6	56791.782			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	14.494	149.160	0.097	0.926	-368.934	397.921
X Variable 1	0.746	0.418	1.784	0.134	-0.329	1.820

SUMMARY OUTPUT: SELECTED WTPs

Regression Statistics	
Multiple R	0.066
R Square	0.004
Adjusted R Square	-0.048
Standard Error	78.475
Observations	21

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	510.192	510.192	0.083	0.777
Residual	19	117007.089	6158.268		
Total	20	117517.281			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	239.687	134.112	1.787	0.090	-41.012	520.386
X Variable 1	-0.301	1.047	-0.288	0.777	-2.494	1.891