# Correlation between the Rates and Mortality of Ischemic Heart Disease and Magnesium Concentrations in Ohio Drinking Water

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Submitted in Partial Fulfillment of the Requirements

for the Degree of

Masters of Science

in the

Environmental Studies Program

YOUNGSTOWN STATE UNIVERSITY

August, 2016

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## ABSTRACT

This study investigates the possible correlation between ischemic heart disease and magnesium concentrations in Ohio drinking water using linear regression analysis. Three correlation analyses were made in this study: (1) magnesium concentrations vs. heart disease rates, (2) magnesium concentrations vs. heart disease mortality rates, and (3) magnesium concentrations vs. heart disease mortality rates in people age 35 and above. Magnesium concentrations in drinking water were obtained from 69 of the 88 Ohio counties. The magnesium concentrations vary from 10 to 70 mg/l. To investigate the effects of the different magnesium concentration levels on heart disease and mortality, the concentrations were divided into four groups: 10-19 mg/l, 20-29 mg/l, 30-39 mg/l, and greater than 40 mg/l. In correlations (1) and (3), linear regression was applied to each magnesium concentration group and to all four groups combined as one group. In correlation (2), linear regression was applied to the four magnesium groups. Microsoft Excel was used to run the regression analysis. Results of the three correlations yielded a negative correlation between ischemic heart disease (rates and mortality) and magnesium concentrations in drinking water. This supports the hypothesis that magnesium may help to protect against death from heart disease. The three correlations yielded low correlation coefficients ranging from 0.33 to 0.50, indicating that factors other than magnesium concentrations may affect heart disease rates and mortality (e.g., high blood pressure, high cholesterol, genetic factors, etc.). The highest magnesium concentrations in Ohio drinking water are found in the northwestern part of the state where dolomite outcrops are present.

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# CHAPTER 1: Introduction

According to the Center for Disease Control (CDC), the leading cause of death in the United States is heart disease (CDC, 2012) and Ohio is ranked by the Department of Health as the 14th state in the nation among the 50 states. 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. The high prevalence of heart disease has led to continuous effort to identify and reduce the potential risks associated with it (CDC, 2012). More than 1 out of 4 deaths in Ohio are due to heart disease. In 2006, the number of Ohioans who died from heart disease was 27,886 which were 26.1% of total deaths in Ohio (CDC, 2009). According to the 2007 Behavioral Risk Factor Surveillance System (CDC, 2007), adults in Ohio have the following risk factors for heart disease and stroke: 28.4% had high blood pressure, 39.6% had high blood cholesterol, 9.5% had diabetes, 23.1% were current smokers, 63.5% were overweight or obese (Body Mass Index greater than or equal to 25.0), 50.0% reported no exercise in the prior 30 days and 79.2% ate fruit and vegetables less than 5 times a week. Because of the high prevalence of death in Ohio by heart disease, there has been raised concerns about the cause of these deaths and if they are being caused by the quality of the drinking water. There have also been other schools of opinion questioning if the deaths can be due to other environmental factors such as behavioral characteristics like smoking and bad eating habits. Therefore efforts are being made to determine the causes.

Water hardness is caused by the presence of divalent ions, primarily magnesium and calcium. A major hypothesis has emerged from recent studies that low concentrations of magnesium and calcium in drinking water are the main cause of death in relation to heart

disease (Axelsson et al. 1996). Magnesium, which is an enzyme activator, is necessary for the transport of sodium and potassium across cell membranes and it is also essential for neuromuscular excitability and cell permeability (Axelsson et al, 1996). The term hardness is used to describe water that cannot lather well with soap and causes a scum in the bath tub and also leaves hard, crusty deposits in tea kettles and coffee pots (Davies, 2011). Water hardness can be removed by removing the ions that cause it. This is termed as water softening. Softening can be achieved by ion exchange, reverse osmosis or lime-soda processes. Generally, the majority of treatment systems that use softening are those utilizing groundwater sources (Davies, 2011). About 55% of Ohio residents obtain their drinking water from surface-water and 45% from groundwater sources (Brown and Coltman, 1990). In general, raw groundwater undergoes less of a water treatment before it is distributed to customers and has higher content of magnesium and calcium than surface –water due its contact with minerals in its geologic environment. Generally speaking, the concentration of magnesium and calcium remain reasonably constant for long periods of time and is a quite stable characteristic of municipality's water supply.

### 1.1 Study Objectives

The objectives of this study is to find a possible correlation between (i) magnesium concentrations vs. heart disease rates (ii) magnesium concentrations vs. heart disease mortality rates (iii) magnesium concentrations vs. heart disease mortality rates in people age 35 and above using linear regression analysis. Linear regression was conducted using Microsoft Excel.

## 1.2 Study Area

Initially, seventeen Ohio counties were chosen to be studied but upon careful consideration it was found that the number of counties was not enough to come to a conclusion regarding the correlation between death from heart disease and magnesium concentrations in drinking water. The initial counties were chosen based on their drinking water source, their population and the availability of reported magnesium concentrations in their yearly consumer reports. Therefore, to increase the accuracy of the results, the study area was increased to 69 counties with a total population of 9,095,454. This population constitutes 78.4% of the Ohio state population. 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 and Coltman, 1990).

# CHAPTER 2: Literature Review

## 2.1 General Studies

Many studies have shown that magnesium protects against death from ischemic heart disease (Axelsson et al, 1996). There has been an inverse relation between the concentration of magnesium in water and death from cardiovascular disease. Generally, lower magnesium concentrations have been found in persons who suddenly died from heart disease as compared to other diseases. Studies conducted in Sweden, Finland, Germany and Africa has all shown inverse correlation between magnesium in their drinking water and heart disease mortality (Axelsson et al, 1996). Our daily intake of magnesium is mainly through food. In drinking water, magnesium occurs as a hydrated ion which is readily absorbed into our body system than from food (Axelsson et al, 1996). In our modern day or current world, the intake of magnesium is much lower than the recommended dietary intake which is 6mg/kg/day. When food is cooked in magnesium rich water, there tend to be a loss of it (Axelsson et al, 1996). The absorption of magnesium is also inhibited by several other nutrients such as sugar, proteins, phosphates and calcium. Magnesium concentration in water has many related health benefits. Some studies conducted by Marier and Neri (1986), concluded that 6mg/l of magnesium consumed has the tendency to decrease death from heart disease by 10%. According to Axelsson et al (1996), it has been hypothesized that there are higher death rates that are related to heart disease when magnesium levels are low due to an increased vasoconstriction (narrowing of the blood vessels that results from contraction of the muscular walls of the vessels). Recent epidemiological studies have shown that there are no known harmful effects if magnesium is consumed in larger quantities but deficiency

of it are known to cause some diseases (WHO, 2005). Death from heart disease in general might not just be caused by certain elements alone such as magnesium but from elements and behavioral factors and lifestyles such as diet, cigarette smoking, lack of exercise and a family history of heart disease.

Leading a healthy lifestyle (avoiding tobacco use, being physically active, and eating well) greatly reduces a person's risk for developing chronic diseases (CDC, 2007). Ecological based studies of magnesium in drinking water and heart disease has also been done. The results indicated low correlation coefficient between the magnesium concentrations and heart disease rate which is the case for this study. Some studies carried out in the United States, England and Wales showed an inverse correlation between death rates from hypertensive and arteriosclerotic heart disease (hardening and narrowing of the arteries to block blood flow to the heart) and calcium and magnesium levels in drinking water (Axelsson et al, 1996). Other investigations in the United States and Canada showed inverse but statistically non-significant correlations between magnesium concentrations in water and heart disease mortality (Axelsson et al, 1996). In summary, many studies have shown that magnesium in drinking water protects against heart disease but some studies contradict this finding.

**2.2 Studies in the United States and Canada**

In the United States of America, magnesium present in our diet is very low. Because of its low occurrence, one of the major concerns is its association with cardiovascular complications such as hypertension, ischemic heart disease and acute myocardial infarction (Bloom and Peric-Golia, 1999). Bloom and Peric-Golia searched for evidence of myocyte (muscle cell) calcification in hearts of patients found to have acute

myocardial infarction at autopsy in Salt Lake City, a region with a low myocardial infarction death rate, and Washington, DC, a region with a high myocardial infarction death rate. The basis of this difference is unknown, but it may be related to the fact that the Salt Lake City drinking water contains a higher level of magnesium, which is known to protect against soft tissue calcification, than that of Washington, DC. This finding is consistent with the apparent protection that dietary magnesium exerts against myocardial infarction death (Bloom and Peric-Golia, 1999).

### 2.3 Studies in European Countries

In Europe, a vast number of studies have been done on the role water hardness plays in ischemic heart disease. Water constituents like magnesium and calcium were found to have negative correlation with ischemic heart disease in Germany (Nebrand et al, 1992). In Finland, research was done for men within the ages of 30-64 years who have been first diagnosed with myocardial infarction (Ong, 2003). It was realized that low intake of magnesium in drinking water or dietary magnesium has an influence in a person attaining atherosclerosis(narrowing of the blood arteries) which eventually lead to myocardial infarction and death from ischemic heart disease (Ong, 2003). To examine whether higher concentrations of magnesium in drinking water supplies are associated with lower mortality from acute myocardial infarction, a geographical study using 13,794 census enumeration districts was conducted in North England. It was suggested that there was no evidence of an association between magnesium concentrations in drinking water supplies and mortality from acute myocardial infarction. The main finding of this study does not support the hypothesis that magnesium is the key water factor in relation to mortality from heart disease (Ong, 2003). In another case study conducted in southern Sweden,

investigations were done on the levels of magnesium and calcium in drinking water and death from acute myocardial infarction among women (Nerbrand et al 1992). The study population encompassed 16 municipalities in southern Sweden. Cases were women who had died from acute myocardial infarction between the ages of 50 and 69 years during 1982-1993. The results suggest that magnesium and calcium in drinking water are important protective factors for death from acute myocardial infarction among women (Nerbrand et al 1992).

In 2008, a study of well water was done in Finland about their magnesium levels and whether it has a direct relationship with heart disease mortality (Kousa et al., 2008). Finland has groundwater quality ranging from very soft to soft (that is little or no magnesium in groundwater). It was observed that any 1mg/l of magnesium concentration in the groundwater tends to decrease the chance of a person acquiring heart disease by 2% (Kousa et al., 2008). There are also a few studies that contradict these findings. One study used an average of magnesium values instead of actual values from the water treatment plants and the results did not tally with what other studies confirmed (Yang, 1993). There have been some clinical trials done using magnesium injection into the body. Very high doses of up to 2,200 mg of intravenous magnesium have been proposed to improve survival immediately after myocardial infarction(sudden deprivation of blood to the heart muscles)(Axelsson et al, 1996). It is not clear how relevant any findings from such high doses would be to the prevention of death from heart disease by lower doses (Axelsson et al, 1996).

Two Swedish studies demonstrated a relation between water hardness and mortality from arteriosclerotic heart disease, but no relation to magnesium. Both studies had important

shortfalls. The average values rather than the actual mineral levels of individual waterworks were analyzed, magnesium concentrations were measured years after the disease study period, and areas in which the water composition had changed were not excluded. In South Wales, a cross-sectional study was done (Axelsson et al, 1996) using tap water to establish the effect of magnesium and calcium, but instead there was no association between the minerals and death from heart disease.

### 2.4 Studies in Asian Countries

A number of studies that were conducted in some Asian countries have determined a negative correlation between trace elements in drinking water and coronary and heart disease mortality (Ong, 2003). In the northern part of India, a study was conducted on 20 random streets to determine if higher amounts of magnesium are associated with coronary heart disease. It was determined that magnesium rather has an inverse correlation with coronary heart disease (Ong, 2003). Therefore, lower intake of magnesium tends to bring about higher risk of getting and dying from coronary heart disease. Between 1981and1990, data on water hardness was collected in Taiwan to determine the ecological correlation between deaths from coronary heart disease and water hardness (Ong, 2003). The same group of researchers further examined specifically whether calcium and magnesium in drinking water are protective against cerebrovascular disease (limited blood flow to some affected parts of the brain) and the general finding suggests that there was a significant protective effect of magnesium intake from drinking water on the risk of cerebrovascular disease (Ong, 2003). Deficiency of magnesium can cause an increase in contractibility of the muscles in the arteries and abundance of it might harmonize the smooth muscle contractibility (Perry and Perry, 1985). A random

survey conducted in North India suggests that the intake of magnesium has a negative association with hypertension (Yang, 1993). Hypertension is a disorder whose origin is associated with coronary heart disease (Perry and Perry, 1985)

### 2.5 Studies in South Africa

In Africa, there have been a few studies done on drinking water and minerals (Ong, 2003). The mortality rates for acute myocardial infarction and ischemic heart disease (IHD) of white males and females in South Africa were noted to be much higher than those in the USA, Australia, England and Wales when individuals in the 15- to 64-year age group are considered (Ong, 2003). Twelve (12) South African districts were assessed for death caused by ischemic heart disease using magnesium in drinking water. The research was done using the white population. It showed a negative correlation between the two variables. There has also been a sudden increase in deaths from ischemic heart disease in parts of South Africa where there was lack of magnesium in drinking water and soil (Yang, 1993).

## CHAPTER 3: Research Data

### 3.1 Heart Disease Rate and Magnesium Concentration

Sixty-nine Ohio counties were investigated in the study. Not all of the Water Treatment Plants (WTPs) in each county were investigated. The WTPs were chosen based on their available water quality data, the consistency in their water source and quality over the years, and also the availability of data on magnesium. Below is a summary of the counties, their WTPs, source of water supply, heart disease rate per 100,000 of the population and their various magnesium concentrations.

Vinton County

Vinton County has a heart disease rate of 217.4. Its water is obtained from the Vinton County Water Company. Its primary source of water is surface-water and the treated water has a magnesium concentration of 15.5 mg/l.

Highland County

Groundwater is the main source of drinking water for this county. Highland County WTP, Hillsboro City WTP and New Vienna Village WTP were used. The county has a heart disease rate of 220.2 and a magnesium concentration of 34.8 mg/l.

Perry County

About 90% of the population relies on surface-water for their drinking water (Consumer Confidence Report, 2010). New Lexington WTP is the only plant used in this county. The Village of New Lexington uses surface-water, which requires extensive treatment

prior to using it for drinking (Consumer Confidence Report, 2010). The county has a heart disease rate of 214.1 and a magnesium concentration of 36 mg/l.

Medina County

The county's main source of drinking water is surface-water. The plants used were Medina County WTP, Medina City PWS and Medina County PWS. Since July 2002, Medina has purchased water that is supplied from the City of Avon Lake Water Treatment Plant on the shore of Lake Erie (Consumer Confidence Report, 2013). The county has a heart disease rate of 170.4 and magnesium concentration of 18.69 mg/l.

Brown County

The county's population is predominately rural and about 80% depends on groundwater for their water supply (Grims, Ricker and Brown, 2000). The plant used is Brown County Rural water Association. The county has a heart disease rate of 206.1 and magnesium concentration of 12.8 mg/l.

Carroll County

In Carroll County, almost all the population relies solely on groundwater for their drinking water supply. The largest water systems in the county are the Village of Carrollton and Mohawk Utilities. All public water systems in Carroll County rely on groundwater (Boon, Brown and Hogan, 2000). The county has a heart disease rate of 217.5 and magnesium concentration 14.8 mg/l.

Clinton County

The county has a heart disease rate of 179.6 and magnesium concentration of 17.04 mg/l. Magnesium concentrations were obtained from Dublin Village PWS and Wilmington City PWS. The two PWSs depend solely on groundwater for their water supply.

Crawford County

The county's largest public water system is the City of Bucyrus WTP, which uses surface-water from the Sandusky River for its supply. It is the only WTP selected due to its data availability. The county's heart disease rate is 197.2 while the magnesium concentration is 44 mg/l.

Erie County

Surface-water is the major source of water for the county's population. Erie County Perkins District PWS and Erie County Margarita PWS are the plants that have data on magnesium concentrations. The two PWSs obtain their raw water from Lake Erie. The county recorded a heart disease rate of 170.1 and a magnesium concentration of 26.44 mg/l.

Delaware County

The county has a mixture of rural and urban population. Delaware City PWS and Delaware County Water Inc. are the plants used in this study. The magnesium concentration is 47.5 mg/l and heart disease rate is 162.

Guernsey County

The county has a heart disease rate of 210.8. Byesville WTP is used in this study because it is the only plant that has magnesium concentration data. Magnesium concentration is 16.4 mg/l.

Hocking County

The heart disease rate for Hocking County is 191.1. City of Logan WTP is the plant selected. Its source of water supply is groundwater. The magnesium concentration is 18.9 mg/l.

Holmes County

The heart disease rate for Holmes County is 200.2. Berlin Water WTP and Millersburg Village PWS were the plants selected. Both have groundwater as their water source. Berlin Water WTP's magnesium concentration is 24 mg/l while that of Millersburg Village PWS is 22.5 mg/l. The average magnesium concentration of the two WTPs is 23.3 mg/l.

Huron County

The heart disease rate of Huron County is 202.3. Norwalk City PWS, Bellevue City PWS and Monroe City PWS are the plants that have magnesium concentration data available. Surface-water is the main source of water supply for the three plants. The average magnesium concentration of the three plants is 31.4mg/l.

Knox County

The heart disease rate for Knox County is 225.7. Groundwater is the main source of drinking water in the county. The plants used include Knox County WTP, Danville Village PWS and Mount Vernon City PWS. Their magnesium concentrations are 54.7 mg/l, 11.4 mg/l and 17.5 mg/l, respectively. The average magnesium concentration of the three plants is 27.9 mg/l.

Lake County

The county has two water treatment divisions: the East District and the West District. Each district is served by a water treatment plant. Both plants take water from Lake Erie. The East District Treatment Plant has a magnesium concentration of 26.8 mg/l and the West District Treatment Plant has 32 mg/l. The average concentration of the two plants is 29.4 mg/l. The county's heart disease rate is 185.5.

Lucas County

The major source of drinking water in Lucas County is surface-water from Lake Erie. Two plants have magnesium data available, Toledo PWS and Perrysburg City PWS. Their magnesium concentrations are 23.67 mg/l and 36.3 mg/l. The average concentration of the two plants is 30.0 mg/l. The county recorded a heart disease rate of 228.

Marion County

The plant that has magnesium data available is Aqua Ohio Marion WTP. Water is drawn from Lake Erie. The plant has a magnesium concentration of 12 mg/l. The county recorded a heart disease rate of 213.7.

Meigs County

Groundwater is the county's major source of drinking water. Middleport Village PWS and Pomeroy Village PWS have magnesium data available. Their magnesium concentrations are 17.1 mg/l and 21mg/l, respectively. Their average magnesium concentration is 19.1 mg/l. The county's heart disease rate is 298.2.

Monroe County

This county has a recorded heart disease rate of 254.4. Monroe City PWS uses surface-water. The plant has a recorded magnesium concentration of 27.8 mg/l.

Butler County

The county has a heart disease rate of 173.3. Fairfield WTP is the only plant that has data on magnesium concentration. The plant has a magnesium concentration of 25.77 mg/l.

Champaign County

Champaign County's heart disease rate is 190.9. The source of water for the county is mainly groundwater. Magnesium concentration of 39.9 mg/l is recorded at the City of Urbana WTP.

Columbiana County

Columbiana County has a heart disease rate of 194.3. Groundwater provides drinking water for 65% of the total population in Columbiana. Two WTPs are used in Columbiana: Columbiana City WTP and East Palestine WTP. Both have groundwater as their primary source of water. Columbiana City and East Palestine have magnesium concentrations of 26 mg/l and 54 mg/l, respectively, with an average of 40.0mg/l.

Cuyahoga County

This county reported a heart disease rate of 203.9. The main source of drinking water is surface-water from Lake Erie. The WTP with magnesium data is Cleveland Division of Water. Its magnesium concentration is 35.8 mg/l.

Defiance County

The county's main source of water is groundwater. The county has 150.3 as its heart disease rate. Hicksville WTP is chosen based on magnesium data availability. The Hicksville WTP has a magnesium concentration of 48.1 mg/l.

Miami County

The county has a heart disease rate of 189.1. The City of Troy WTP is chosen based on data availability. The City of Troy obtains its public drinking water from groundwater. The plant has a magnesium concentration of 19.4 mg/l.

Stark County

Two plants are selected based on data availability: Canton WTP and North Canton WTP with magnesium concentrations of 24.8 mg/l and 29.2 mg/l, respectively. The county's main source of water is groundwater. Stark County has a heart disease rate of 171.2. The two WTPs have an average magnesium concentration of 26.8 mg/l.

Morrow County

Cardington Village WTP is the chosen plant. Its main source of water is groundwater. The county has a heart disease rate of 183.3 and the WTP has a magnesium concentration of 51 mg/l.

Paulding County

The county has a heart disease rate of 127.5. Its water supply comes from both ground and surface-water. Paulding Village WTP and Hicksville Village WTP are the two selected plants. They have magnesium concentrations of 27 mg/l and 22 mg/l, respectively with an average of 24.5 mg/l.

Pickaway County

Groundwater is the county's main source of drinking water. Ashville Village WTP and Earnhat Hill Water District are the selected plants. Ashville Village WTP has a magnesium concentration of 28.6 mg/l and Earnhat Water District has 50.1 mg/l. The average magnesium concentration is 39.4 mg/l. The county heart disease rate is 174.9.

Pike County

The main source of water supply for this county is groundwater. The county's heart disease rate is 219.8. Pike Water Inc. is the selected plant. The plant has a magnesium concentration of 19 mg/l.

Preble County

The Lakengreen Water Authority (LWA) provides water service to a community developed around Lakengreen Lake. The LWA obtains its drinking water from groundwater. It has a magnesium concentration of 30.3 mg/l and the county has a heart disease rate of 228.2.

Richland County

Richland County has a heart disease rate of 188.5. Mansfield City PWS is the selected plant, which has a magnesium concentration of 16 mg/l. Its main source of water is surface-water from the Clear Fork Reservoir.

Scioto County

In Scioto County, the WTP chosen is Scioto City WTP. It has a magnesium concentration of 12.9 mg/l. Its main source of water supply is surface-water. The county has a heart disease rate of 273.6.

Seneca County

Magnesium concentration is obtained from the county's largest water supply system, Aqua Ohio-Tiffin WTP, which has a magnesium concentration of 36 mg/l. The WTP uses surface-water from the Sandusky River. The county has a heart disease rate of 200.1

Shelby County

Botkins WTP and Jackson WTP are the selected plants. Both utilize groundwater. Botkins WTP has a magnesium concentration of 47 mg/l while Jackson WTP has 27.8mg/l. Their average magnesium concentration is 37.4 mg/l. The county has a heart disease rate of 180.1.

Union county

Marysville City PWS is the county's largest water treatment plant. It uses both surface and groundwater. The plant's magnesium concentration is 23.6 mg/l. The county has a heart disease rate of 118.8.

Van Wert

The county has a heart disease rate of 190.7. Van Wert WTP has a magnesium concentration of 40 mg/l. The plant's main source of water is surface-water.

Washington County

The selected plant is Marrieta WTP, which uses groundwater. The WTP has a magnesium concentration of 25 mg/l and the county has a heart disease rate of 155.4.

Wayne County

Wayne County's heart disease rate is 190.4. Wooster City PWS and Orville City PWS are the selected plants with magnesium concentrations of 23.8 mg/l and 21 mg/l, respectively and an average of 22.4 mg/l. Both treatment plants use groundwater.

Williams County

The selected plant is Montpelier Village PWS. It has a magnesium concentration of 32 mg/l. The county has a heart disease rate of 158.7.

Wood County

Pemberville Village PWS is the only plant that has data on magnesium. Its primary source of water is groundwater. The treated water has a magnesium concentration of 40 mg/l. The county has a heart disease rate of 214.3.

Wyandot County

The selected plant is Upper Sandusky WTP, which uses surface-water. The WTP has a magnesium concentration of 15 mg/l. The county has a heart disease rate of 187.9.

Auglaize County

The selected plant is Wapakoneta City PWS, which uses groundwater. The plant has a magnesium concentration of 42.4 mg/l. The county has a heart disease rate of 174.8.

Henry County

The selected plant is the City of Napoleon, which uses surface-water. The plant has a magnesium concentration of 52 mg/l. Henry County has a heart disease rate of 206.7.

Lawrence County

The Hecla Water Association System is the selected plant. It uses groundwater with a magnesium concentration of 9 mg/l. The county has a heart disease rate of 225.5.

Greene County

The selected plant is the Xenia WTP, which uses groundwater. The plant has a magnesium concentration of 32.5 mg/l. The county has a heart disease rate of 171.6.

Trumbull County

The county has a heart disease rate of 213.6 and is served by the City of Warren WTP. The primary source of water is surface-water. The treated water has a magnesium concentration of 5.6 mg/l.

Allen County

Allen County has a heart disease rate 211.9. Lima WTP is the selected plant in this county. Its primary source of water is surface-water. Lima WTP has a magnesium concentration of 14.5 mg/l.

Tuscarawas County

The county has a heart disease rate of 205.2. The WTPs selected are New Philadelphia and City of Dover with magnesium concentrations of 14 mg/l and 17 mg/l, respectively. Their average magnesium concentration is 15.5 mg/l. Both plants use groundwater as their primary source of water.

Ashland County

Ashland County has a heart disease rate of 205.2. Ashland City WTP is the selected plant. Its primary source of water is groundwater. The WTP has a magnesium concentration of 13 mg/l.

Ashtabula County

Two WTPs are selected in Ashtabula County, Ashtabula County WTP and Aqua Ohio WTP. Their magnesium concentrations are 7.5 mg/l and 9 mg/l, respectively. Their average magnesium concentration is 8.3 mg/l. Both WTPs use surface-water from Lake Erie. The county has a heart disease rate of 205.2.

Athens County

Athens County has a heart disease rate of 232.4. The county's largest public water system is the City of Athens WTP, which uses groundwater. The treated water has a magnesium concentration of 67 mg/l.Belmont County

The county's largest public water system is Belmont County Sanitary Sewer District, which uses groundwater for its primary supply and surface-water as a secondary

source. The county has a heart disease rate of 261. The plant has a magnesium concentration of 14.9 mg/l.

Clermont County

Clermont County has a heart disease rate of 161.3. The county's largest public water system is the Clermont County Water System, which uses surface-water and groundwater. Its main source of water is the Ohio River. The treated water has a magnesium concentration of 7.8 mg/l.

Coshocton County

The county's largest public water system is the Coshocton county PWS, which uses groundwater. It has a magnesium concentration of 20.6 mg/l. The county has a heart disease rate of 157.7.

Fayette County

Fayette County has a heart disease rate of 296. City of Washington Courthouse WTP is the selected plant. The treated water has a magnesium concentration of 46 mg/l.

Hardin County

Kenton City WTP is the selected plant. The county has a heart disease rate of 269.5. Kenton City is the county’s largest WTP with a magnesium concentration of 44 mg/l.

Licking County

Licking county has a heart disease rate of 160.9. Southwest Licking Water Company is the selected plant. The treated water has a magnesium concentration of 7 mg/l.

Mercer County

The heart disease rate of Mercer County is 255.6. Celina City WTP is the selected plant. The plant's primary source of water is surface-water. The treated water has a magnesium concentration of 56 mg/l.

Summit County

The heart disease rate of Summit County is 172.3. Akron Water Treatment Plant, the largest public water supplier in Summit County, is the selected plant. It uses surface-water. The WTP has a magnesium concentration of 8.74 mg/l.

Hamilton County

Hamilton County has a heart disease rate of 169.1. 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. The treated water has a magnesium concentration of 32.4 mg/l.

Mahoning County

The county has a heart disease rate of 203.6. The selected plant is the Mahoning Valley Sanitary District (MVSD). This is the largest supplier of drinking water in the county. The plant's magnesium concentration is 5.6 mg/l.

Montgomery County

Montgomery County has a heart disease rate of 175.5. The selected plant is the City of Dayton WTP, which uses groundwater. The treated water has a magnesium concentration of 10 mg/l.

Ottawa

This county has a heart disease rate of 170.7. Ottawa County Regional WTP is the selected plant. Its primary source of water is surface-water. The plant has a magnesium concentration of 16 mg/l.

Jackson County

The selected plants are Jackson City WTP, Jackson County WTP, North Wellston WTP and Village of Oak Hill Water System with magnesium concentrations of 18.7 mg/l,

15.4 mg/l, 7 mg/l and 7.5 mg/l, respectively. The average magnesium concentration is 12.2 mg/l. The county has a heart disease rate of 326.2.

Franklin County

Franklin County has a heart disease rate of 181. Huber Ridge WTP, City of Westerville WTP and Worthington Hill WTP are the plants selected with magnesium concentrations of 11 mg/l, 13.8 mg/l and 13 mg/l, respectively. The average magnesium concentration is 12.6 mg/l.

Adams County

The county's main source of drinking water is groundwater. Village of Manchester, Village of West Union Water System and Adams County Regional Water District WTPs are used for this research. Their magnesium concentrations are 12.3 mg/l, 16.5 mg/l and 17.5 mg/l, respectively. The three WTPs have a magnesium concentration average of 15.4 mg/l. The county has a heart disease rate of 237.

Darke County

Groundwater is the main source of water for this county. Ansonia WTP and Greenville City Public Water System are the plants used with magnesium concentrations of 40 mg/l and 41 mg/l, respectively with an average of 40.5 mg/l. The county has a heart disease rate of 188.4.

Ross County

The county's main source of drinking water is groundwater. City of Chillicothe Water System and Ross County Water Co. Inc. are the WTPs used. The WTPs has magnesium concentrations of 24 mg/l and 27 mg/l, respectively with an average of 25.5 mg/l. The county has a heart disease rate of 198.

### 3.2 Drinking Water Data

Most of the drinking water data was obtained from consumer confidence reports. Public water systems are required to give out these reports yearly. Data that was not found in the reports was collected directly from the public water treatment plants. Other missing information was obtained from the Ohio EPA. In locations where private wells served as

the main source of drinking water, data was ignored because private wells are not monitored by any regulatory agency such as the EPA. Table 3.1 shows the water treatment plants, their water sources and their magnesium concentrations.

**Table 3.1 Water Treatment Plants, Their Water Source And Magnesium Concentration.**

GW = Groundwater  SW = Surface Water

| **WTP** | **Source** | **Magnesium Conc. (mg/l)** |
|---|---|---|
| Adams County Regional Water District | GW | 17.5 |
| Ansonia WTP | GW | 40 |
| Aqua Ohio Lake Water PWS | GW | 23 |
| Aqua Ohio Marion WTP | SW | 12 |
| Aqua Ohio-Tiffin | SW | 36 |
| Ashville Village PWS | GW | 28.6 |
| Bellevue City PWS | SW | 16 |
| Berlin Water Co. | GW | 24 |
| Botkins Village PWS | GW | 47 |
| Brown Co. Rural Water | GW | 12.8 |
| Bucyrus City WTP | SW | 44 |
| Byesville WTP | GW | 16.4 |
| Canton WTP | GW | 24.8 |
| Cardington Village PWS | GW | 51 |
| City of Chillicothe Water System | GW | 24 |
| City of Logan WTP | GW | 18.9 |

| | | |
|---|---|---|
| City of Troy WTP | GW | 19.4 |
| City of Urbana WTP | GW | 39.6 |
| Cleveland Division of Water | SW | 35.9 |
| Columbiana City WTP | GW | 26 |
| Convoy Village WTP | SW | 69.6 |
| Danville Village PWS | GW | 11.4 |
| Delaware City PWS | SW | 46 |
| Delaware Co. Water Company | SW | 49.6 |
| Dublin Village PWS | GW | 22.8 |
| Earnhat Hill Water District | GW | 50.1 |
| East Palestine WTP | GW | 54.7 |
| Elyria WTP | GW | 19.7 |
| Erie Co. Margarita PWS | SW | 21.5 |
| Erie Co. Perkins District PWS | SW | 28 |
| Fairfield WTP | GW | 25.8 |
| Findlay WTP | SW | 35.3 |
| Fremont City Waterworks | SW | 34.6 |
| Greenville City PWS | SW | 41 |
| Harrison City PWS | GW | 28 |
| Hicksville WTP | GW | 48.1 |
| Highland County WTP | GW | 37.6 |
| Hillsboro City WTP | SW | 23 |
| Jackson Center PWS | GW | 27.8 |
| Jefferson County Water & Sewer District | GW | 22.2 |
| Jefferson Regional Water Authority | GW | 24.7 |
| Knox County WTP | GW | 54.7 |

| | | |
|---|---|---|
| Lake Co. East Water Sub-District | SW | 26.8 |
| Lake Co. West Sub-District | SW | 32 |
| Lakengreen Water Authority | GW | 30.3 |
| Madison Water District | SW | 20.5 |
| Mansfield City PWS | SW | 16 |
| Middleport Village PWS | GW | 17.1 |
| Millersburg Village PWS | GW | 22.5 |
| Mohawk PWS | GW | 16 |
| Monroe City PWS | SW | 36.4 |
| Monroe City PWS | SW | 27.8 |
| Mount Vernon City PWS | GW | 17.5 |
| New Lexington WTP | SW | 36 |
| New Vienna Village WTP | GW | 33.9 |
| North Canton WTP | GW | 29.2 |
| Norwalk City PWS | SW | 36 |
| Orville City PWS | GW | 21 |
| Pemberville Village PWS | GW | 40.4 |
| Perrysburg City PWS | SW | 36.3 |
| Pike Water Inc. Plant | GW | 18.6 |
| Pomeroy Village PWS | GW | 24 |
| Ross county Water Co. Inc. PWS | GW | 27 |
| Rural Lorain Water Authority | SW | 35 |
| Scioto City WTP | SW | 12.9 |
| Toledo PWS | SW | 23.7 |
| Upper Sandusky WTP | SW | 15 |
| Van Wert WTP | SW | 38 |
| Village of Carrolton WTP | GW | 14 |

| | | |
|---|---|---|
| Village of Manchester WTP | GW | 12.3 |
| Village of West Union Water System | GW | 16.5 |
| Vinton County Water Co. | SW | 15.5 |
| West Salem Village PWS | SW | 9.6 |
| Wilmington City PWS | GW | 15.7 |
| Wooster City PWS | GW | 23.8 |

### 3.3 Mortality Data

Ischemic heart disease mortality rate for Ohio counties were obtained from the Ohio Department of Health and the Center for Disease Control. Both sources of data were obtained from their respective websites. To determine the actual number of people killed by heart disease, the heart disease mortality (HDM) rate for the county was divided by a hundred thousand and the result was multiplied by the population served by each WTP. There was no specification on the type of heart disease that killed people. Figure 3.1 shows heart disease mortality rates per 100,000 of the populations in Ohio. Table 3.2 presents the treatment plants, their heart disease rate and mortality.

**Table 3.2: Heart Disease Rate (HDR) and Heart Disease Mortality Rate (HDM) of the WTPs.**

| WTP | HDR | HDM |
|---|---|---|
| Adams County Regional Water District | 237 | 43 |
| Ansonia WTP | 188.4 | 21 |
| Aqua Ohio Lake Water PWS | 219.8 | 3 |
| Aqua Ohio Marion WTP | 213.7 | 90 |
| Aqua Ohio-Tiffin | 200.1 | 36 |
| Ashville Village PWS | 174.9 | 7 |
| Bellevue City PWS | 202.3 | 17 |
| Berlin Water Company | 200.2 | 5 |
| Botkins Village PWS | 180.1 | 2 |
| Brown Co. Rural Water | 206.1 | 47 |
| Bucyrus City WTP | 197.2 | 26 |
| Byesville WTP | 210 | 9 |
| Canton WTP | 171.2 | 48 |
| Cardington Village PWS | 183.3 | 4 |
| City of Chillicothe Water System | 198 | 43 |
| City of Logan WTP | 191.1 | 15 |
| City of Troy WTP | 189.1 | 47 |
| City of Urbana WTP | 190.9 | 22 |
| Cleveland Division of Water | 203.9 | 856 |
| Columbiana City WTP | 194.3 | 12 |
| Convoy Village WTP | 190.7 | 2 |
| Danville Village PWS | 202.3 | 3 |
| Delaware City PWS | 162 | 57 |

| | | |
|---|---|---|
| Delaware Co. Water Company | 162 | 42 |
| Dublin Village PWS | 179.6 | 5 |
| Earnhat Hill Water District | 174.9 | 18 |
| East Palestine WTP | 194.3 | 10 |
| Elyria WTP | 159.9 | 109 |
| Erie Co. Margarita PWS | 170.1 | 14 |
| Erie Co. Perkins District PWS | 170.1 | 44 |
| Fairfield WTP | 173.3 | 73 |
| Findlay WTP | 204.5 | 82 |
| Fremont City Waterworks | 182.7 | 36 |
| Greenville City PWS | 188.4 | 25 |
| Harrison City PWS | 211.9 | 21 |
| Hicksville WTP | 150.3 | 5 |
| Highland County WTP | 220.2 | 66 |
| Hillsboro City WTP | 220.2 | 15 |
| Jackson Center PWS | 180.1 | 3 |
| Jefferson County Water & Sewer District | 275.2 | 60 |
| Jefferson Regional Water Authority | 275.2 | 10 |
| Knox Co. WTP | 225.7 | 20 |
| Lake Co. East Water Sub-District | 185.5 | 61 |
| Lake Co. West Sub-District | 185.5 | 110 |
| Lakengreen Water Authority | 228.2 | 7 |
| Madison Water District | 188.5 | 4 |
| Mansfield City PWS | 219.8 | 96 |
| Middleport Village PWS | 298.2 | 9 |
| Millersburg Village PWS | 200.2 | 7 |

| | | |
|---|---|---|
| Mohawk PWS | 217.5 | 6 |
| Monroe City PWS | 254.4 | 21 |
| Monroe City PWS | 254.4 | 25 |
| Mount Vernon City PWS | 225.7 | 40 |
| New Lexington WTP | 214.1 | 33 |
| New Vienna Village WTP | 220.2 | 3 |
| North Canton WTP | 171.2 | 43 |
| Norwalk City PWS | 202.3 | 33 |
| Orville City PWS | 190.4 | 18 |
| Pemberville Village PWS | 214.3 | 3 |
| Perrysburg City PWS | 228 | 59 |
| Pike Water Inc. Plant | 219.8 | 40 |
| Pomeroy Village PWS | 298.2 | 9 |
| Ross County Water Co. Inc. PWS | 198 | 65 |
| Rural Lorain Water Authority | 159.9 | 103 |
| Scioto City WTP | 273.6 | 24 |
| Toledo PWS | 228 | 440 |
| Upper Sandusky WTP | 187.9 | 12 |
| Van Wert WTP | 190.7 | 20 |
| Village of Carrollton WTP | 217.5 | 8 |
| Village of Manchester WTP | 237 | 2 |
| Village of West Union Water System | 237 | 8 |
| Vinton County Water Co. | 217.4 | 3 |
| West Salem Village PWS | 190.4 | 3 |
| Wilmington City PWS | 179.6 | 21 |
| Wooster City PWS | 190.4 | 51 |

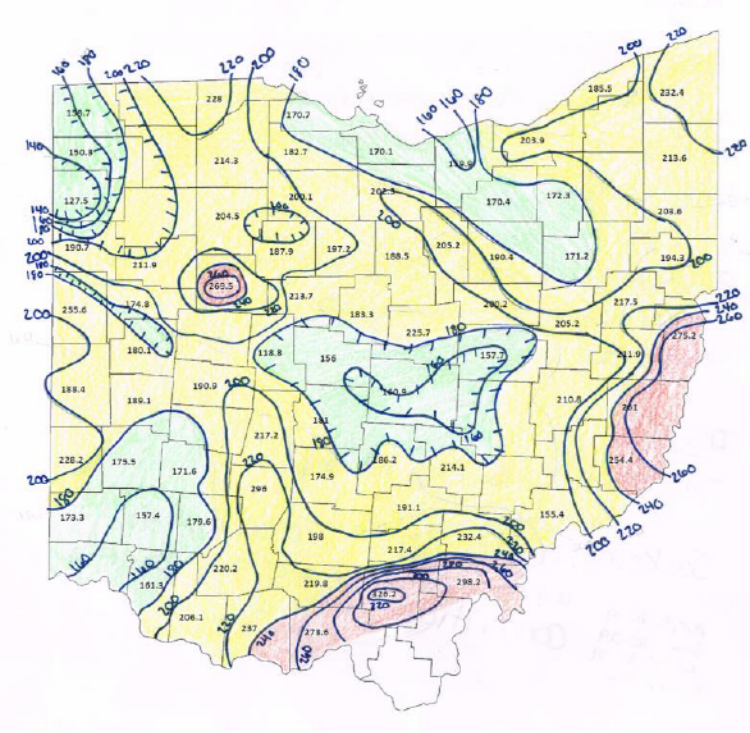


**Figure 3.1: Heart Disease Mortality Rates per 100,000 of the Population in Ohio [from Center for Disease Control (2007)]**

### 3.4 Limitations of the Magnesium Concentration Data

- There seem to be slight changes in the magnesium concentrations obtained from the semi- annual reports of the WTPs.
- Many WTPs in the investigated counties do not have data on magnesium concentration. This is because magnesium is not a major a constituent that is tested for. This has limited the number of WTPs that are used in the study.
- Some townships and cities that are served by more than one water treatment plant with different magnesium concentrations are eliminated from the study.
- Migration of the population to and from the counties is another problem. This might result in an incorrect number of the population served by the water treatment plants.

# CHAPTER 4: Linear Regression Analysis

## 4.1 Introduction

Three correlations are conducted in this study using linear regression analysis:

(1) magnesium concentrations vs. heart disease rates

(2) magnesium concentrations vs. heart disease mortality rates

(3) magnesium concentrations vs. heart disease mortality rates in people age 35 and above

Microsoft Excel was used to run the regression analysis.

## 4.2 Regression Equation

The regression equation takes the form:

$$Y = mX + b$$

where: X is the independent variable = concentration of magnesium in drinking water (mg/l)

m = slope of the regression line

b = intercept of the regression line

The definitions of parameters X, m, and b are the same for the three correlations. The definition of parameter Y for each correlation is given below:

<u>the first correlation</u>:

Y is the dependent variable = heart disease rate

the second correlation:

Y is the dependent variable = heart disease mortality rate

the third correlation:

Y is the dependent variable = heart disease mortality rates in people age 35 and above

### 4.3 Magnesium Concentrations

The magnesium concentrations for the WTPs were in the range 10 mg/l to 70 mg/l. In order to investigate the effects of the different magnesium concentrations on ischemic heart disease, the magnesium concentrations of all 69 investigated counties were divided into four groups as follows: 10-19 mg/l, 20-29 mg/l, 30-39 mg/l and greater or equal to 40 mg/l. Linear regression was run for each concentration group and for all four groups combined in one group. This was done to determine if all groups would yield a negative correlation. Figure 4.1 shows magnesium concentration in drinking water by county in Ohio. Figure 4.1 shows that magnesium concentrations in Ohio drinking water are high in the northwestern part of the state because high-purity dolomite outcrops [greater than 95% $CaMg(CO_3)_2$] occur in that region (Figure 4.2). Table 4.1 summarizes magnesium concentrations and heart disease mortality rates for people age 35 and above at each WTP.

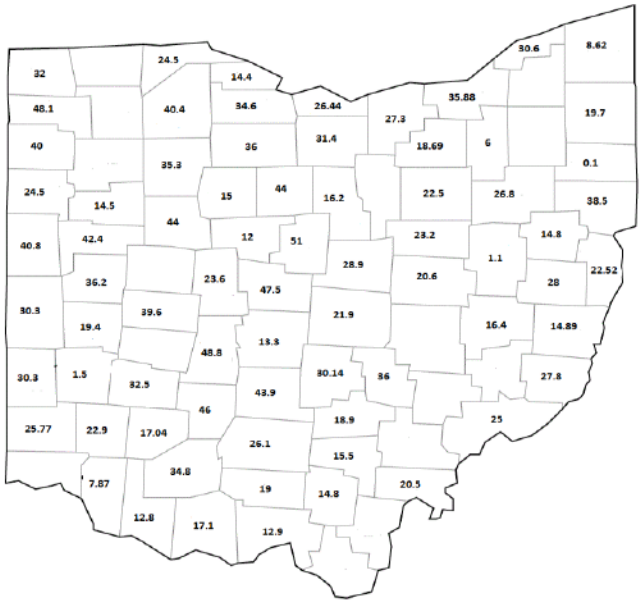



**Figure 4.1: Map of Magnesium Concentrations in the Drinking Water of Ohio Counties**

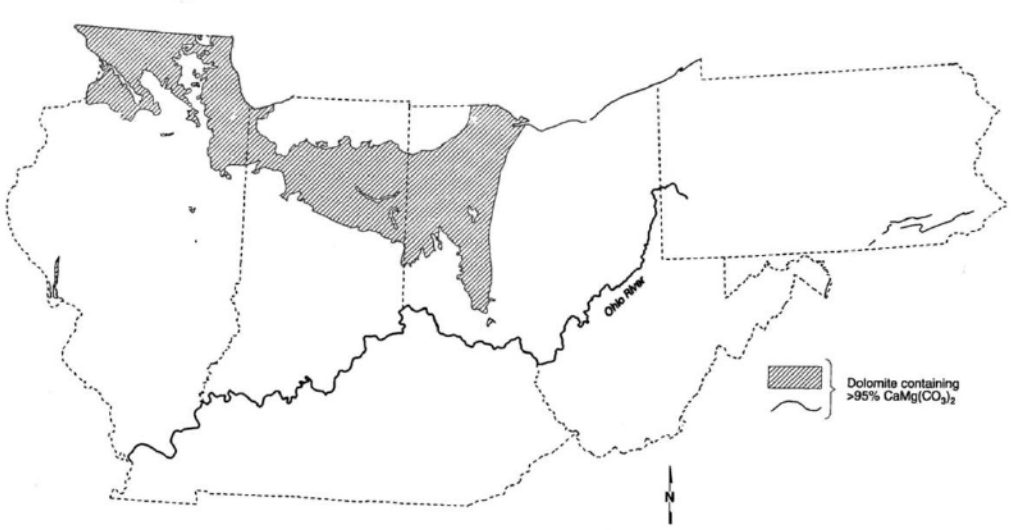



**Figure 4.2: Map of Dolomite in Ohio, Indiana and Illinois [from: Stith et al (1997)**

**Table 4.1: Water treatment plants with their magnesium concentrations and age adjusted heart disease mortality rates.**

| WTP | Magnesium Conc. (mg/l) | HDR above 35 |
|---|---|---|
| Adams County Regional Water District | 18 | 223 |
| Ansonia WTP | 40 | 197 |
| Aqua Ohio Lake Water PWS | 23 | 229 |
| Aqua Ohio Marion WTP | 12 | 203 |
| Aqua Ohio-tiffin | 36 | 238 |
| Ashville Village PWS | 29 | 188 |
| Bellevue City PWS | 16 | 193 |
| Berlin Water Co. | 24 | 203 |
| Botkins Village PWS | 47 | 183 |
| Brown Co. Rural Water | 13 | 203 |
| Bucyrus City WTP | 44 | 191 |
| Byesville WTP | 16 | 214 |
| Canton WTP | 24 | 173 |
| Cardington Village PWS | 51 | 182 |
| City of Chillicothe Water System | 24 | 231 |
| City of Logan WTP | 19 | 195 |
| City of Troy WTP | 19 | 176 |
| City of Urbana WTP | 40 | 187 |
| Cleveland Division of Water | 36 | 214 |
| Columbiana City WTP | 26 | 201 |
| Convoy Village WTP | 70 | 191 |
| Danville Village PWS | 11 | 223 |
| Delaware City PWS | 46 | 154 |

| | | |
|---|---|---|
| Delaware Co. Water Company | 50 | 154 |
| Dublin Village PWS | 23 | 197 |
| Earnhat Hill Water District | 50 | 188 |
| East Palestine WTP | 55 | 201 |
| Elyria WTP | 20 | 175 |
| Erie Co. Margarita PWS | 22 | 165 |
| Erie Co. Perkins District PWS | 28 | 165 |
| Fairfield WTP | 26 | 177 |
| Findlay WTP | 35 | 195 |
| Fremont City Waterworks | 35 | 175 |
| Greenville City PWS | 41 | 197 |
| Harrison City PWS | 28 | 273 |
| Hicksville WTP | 48 | 163 |
| Highland County WTP | 28 | 235 |
| Hillsboro City WTP | 23 | 235 |
| Jackson Center PWS | 28 | 183 |
| Jefferson County Water & Sewer District | 22 | 299 |
| Jefferson Regional Water Authority | 25 | 299 |
| Knox Co. WTP | 55 | 223 |
| Lake Co. East Water Sub-District | 27 | 185 |
| Lake Co. West Sub-District | 32 | 185 |
| Lakengreen Water Authority | 30 | 210 |
| Madison Water District | 21 | 210 |
| Mansfield City PWS | 16 | 210 |
| Middleport Village PWS | 17 | 277 |
| Millersburg Village PWS | 23 | 203 |

| | | |
|---|---|---|
| Mohawk PWS | 16 | 224 |
| Monroe City PWS | 28 | 289 |
| Monroe City PWS | 36 | 193 |
| Mount Vernon City PWS | 18 | 223 |
| New Lexington WTP | 36 | 217 |
| New Vienna Village WTP | 34 | 235 |
| North Canton WTP | 29 | 173 |
| Norwalk City PWS | 36 | 193 |
| Orville City PWS | 21 | 190 |
| Pemberville Village PWS | 40 | 214 |
| Perrysburg City PWS | 36 | 210 |
| Pike Water Inc Plant | 19 | 229 |
| Pomeroy Village PWS | 24 | 277 |
| Ross County Water Co. Inc PWS | 27 | 231 |
| Rural Lorain Water Authority | 35 | 175 |
| Scioto City WTP | 13 | 280 |
| Toledo PWS | 24 | 210 |
| Upper Sandusky WTP | 15 | 188 |
| Van Wert WTP | 38 | 191 |
| Village of Carrolton WTP | 14 | 224 |
| Village of Manchester WTP | 12 | 223 |
| Village of West Union Water System | 17 | 223 |
| Vinton County Water Co. | 16 | 217 |
| West Salem Village PWS | 10 | 190 |
| Wilmington City PWS | 16 | 197 |
| Wooster City PWS | 24 | 190 |

# CHAPTER 5: Results and Discussion

## 5.1 The First Correlation: Magnesium Concentrations vs. HDR

The initial analysis involved correlation between the magnesium concentrations and HDR of their respective counties. The average magnesium concentration of all the WTPs in a particular county was correlated with the HDR in that county. The following correlations were done:

(i) all the magnesium concentrations (as one group) were correlated with the HDR of their respective counties.

(ii) the magnesium concentrations were divided into four groups (mentioned earlier) and each group was correlated with their corresponding HDR.

(i) Correlation of all magnesium concentrations (as one group) with HDR:

A negative slope resulted. This shows that magnesium do protect against death from ischemic heart disease. The correlation of magnesium concentrations and heart disease rates (HDR) appears to consist of two distinct populations (Figures 5.1 and 5.2) rather than one homogeneous population. The two populations have different magnesium concentrations and heart disease rates. The first population has magnesium concentrations less than 35 mg/l, and heart disease rates ranging from 160-218 with an average of 189. The second population is characterized by magnesium concentrations greater than 35 mg/l, and heart disease rates from 150-214 with an average of 182. Linear regression was run for each population. The results clearly show inverse relations (negative slopes) between magnesium and heart disease rate. The first population yielded

a correlation coefficient of 0.50 and the second population gave a value of 0.68. Therefore, the results support high correlation coefficient when the heart disease rate is low and the magnesium concentration is high as indicated by the second population.

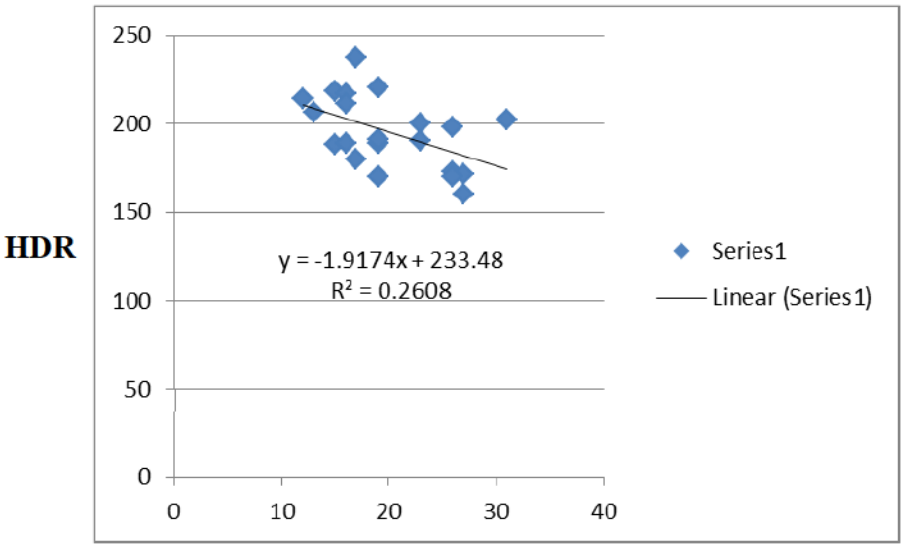



**Figure 5.1: Regression Relationship of Mg Concentration and HDR for Population 1**

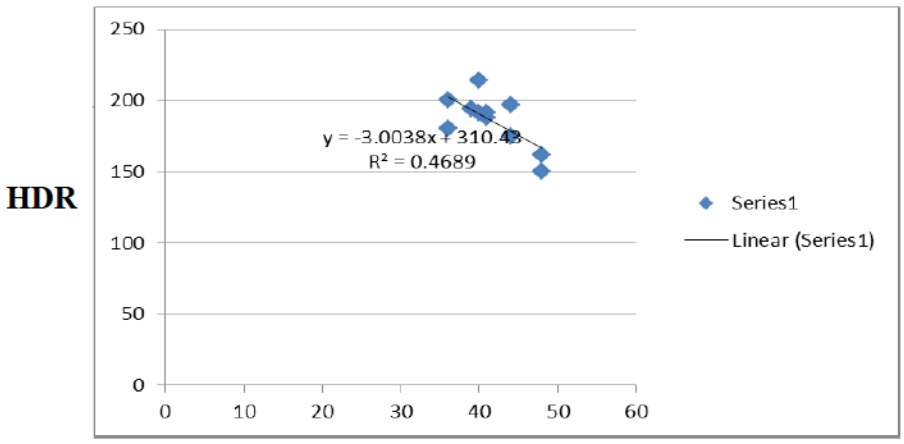


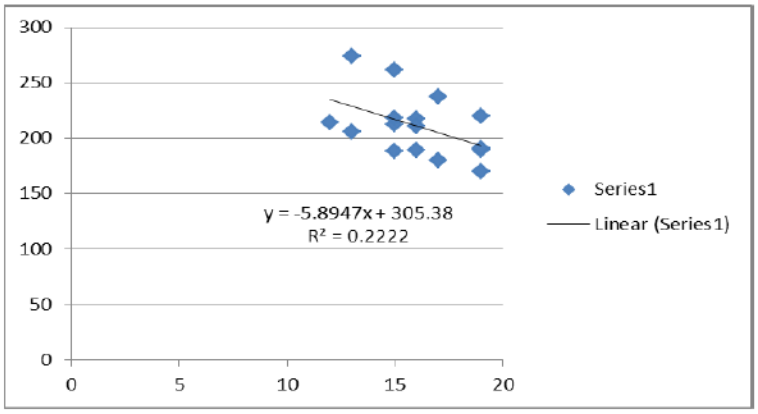

**Figure 5.2: Regression Relationship of Mg Concentration and HDR for Population 2**

(ii) Correlations of the four magnesium concentration groups with HDR:

The magnesium concentrations were divided into four groups (as mentioned earlier) and each group was correlated with their corresponding HDR. This was done to determine if each of the four groups would result in a negative correlation as shown by analysis (i), where all magnesium concentrations were treated as one group. All four groups resulted in negative slopes, which mean that the four different magnesium concentrations do protect against ischemic heart disease. The correlation coefficient values of the four groups are shown in Table 5.1. Figures 5.3-5.6 show the regression relationships of the four magnesium groups.

**Table 5.1: Correlation Coefficients of the Four Mg Concentration Groups and HDR**

| Magnesium Concentration (mg/l) | Correlation Coefficient |
|---|---|
| 10-19 | 0.47 |
| 20-29 | 0.40 |
| 30-39 | 0.33 |
| ≥40 | 0.37 |




**HDR**

**Mg Concentration (mg/l)**

**Figure 5.3: Regression Relationship of Mg Concentrations 10-19 mg/l**

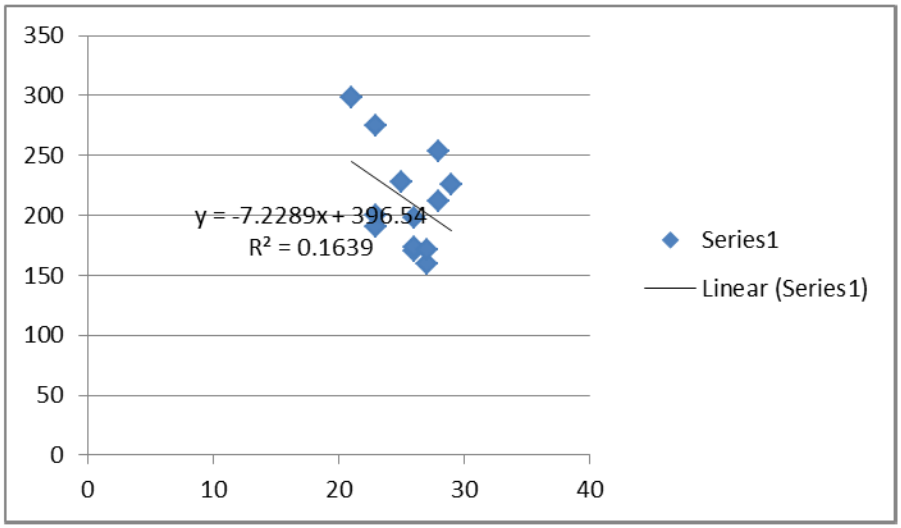



**Figure 5.4: Regression Relationship of Mg Concentration 20-29 mg/l**

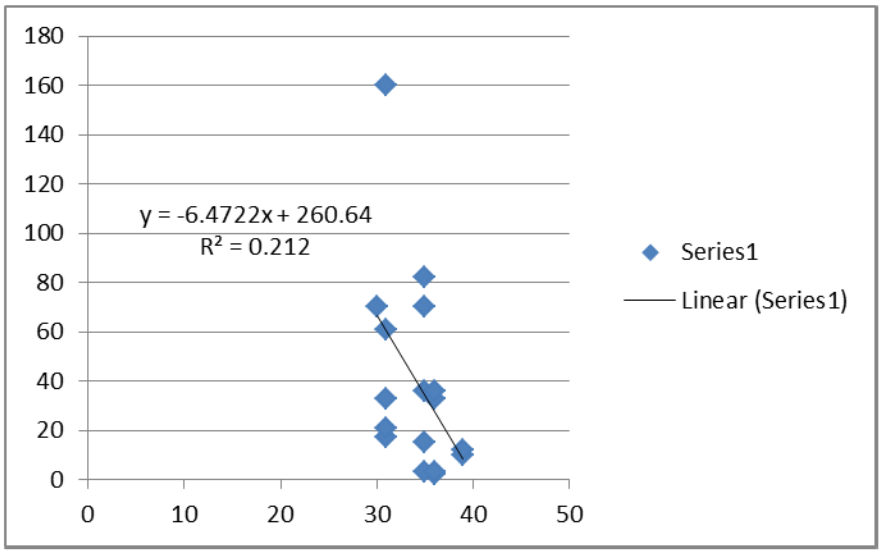



**Figure 5.5: Regression Relationship of Mg Concentration 30-39 mg/l**

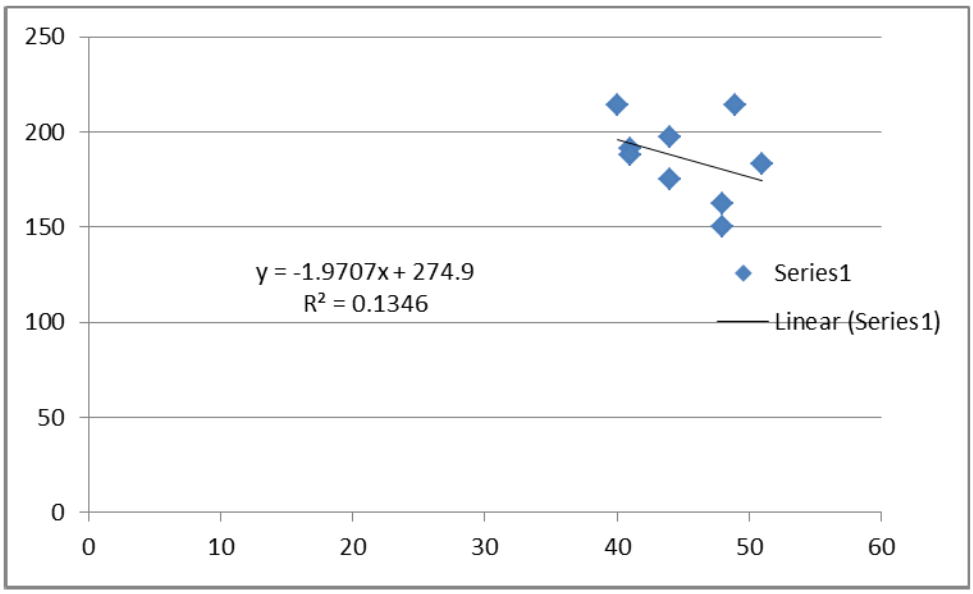



**Figure 5.6: Regression Relationship of Mg Concentration ≥ 40mg/l**

## 5.2 The Second Correlation: Magnesium Concentrations vs. the Actual Number of People Killed by Heart Disease

A second approach was taken to see if magnesium truly protects against death from heart disease. In this analysis, the actual number of people killed by heart disease was determined for each WTP and correlated with their respective magnesium concentrations. The actual number of people killed by heart disease for each WTP was found by taking the mortality rate for each county, dividing it by a hundred thousand and multiplying the result by the population served by the WTP. The same procedure of section 5.2(ii) was followed, i.e., magnesium concentrations were divided into four groups. All groups

yielded negative slopes except for the concentration group 10-19 mg/l. It yielded a positive slope. This indicates that low magnesium concentrations (10-19 mg/l) do not affect heart disease mortality rates (HDM). The obtained correlation coefficients are summarized in Table 5.2. Figures 5.7-5.10 show the regression relationships of the four magnesium groups.

**Table 5.2: Correlation Coefficients of Mg Concentration and Actual Number of People Killed**

| Magnesium Concentration (mg/l) | Correlation Coefficient |
|---|---|
| 10-19 | 0.58 |
| 20-29 | 0.37 |
| 30-39 | 0.44 |
| ≥40 | 0.36 |

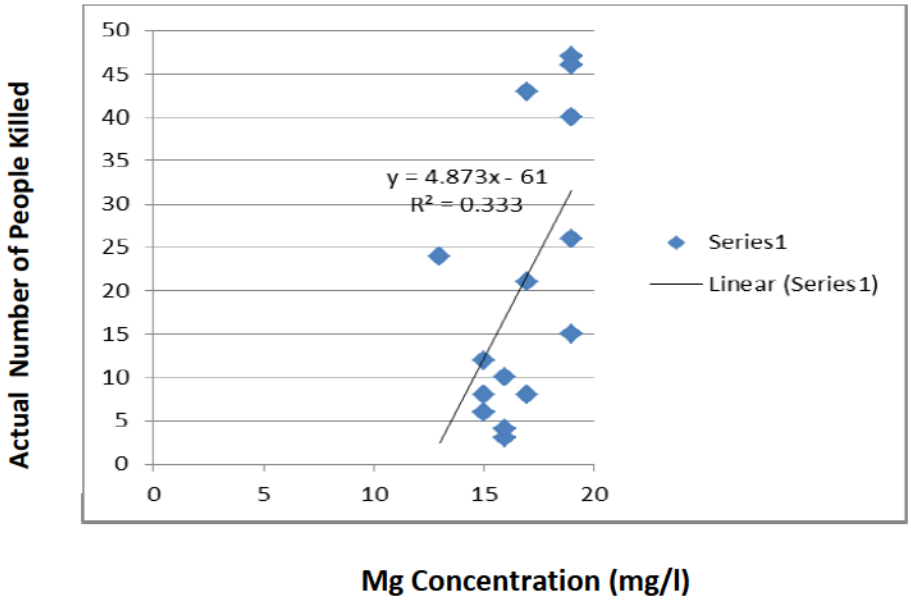



**Figure 5.7: Regression Relationship of Magnesium Concentration 10-19 mg/l**

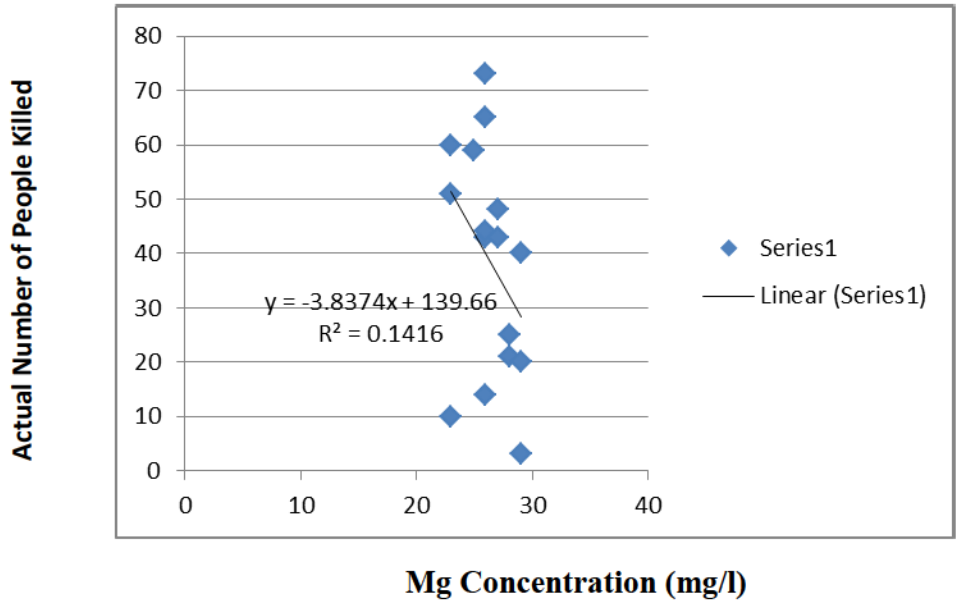



**Figure 5.8: Regression Relationship of Mg Concentration 20-29 mg/l**

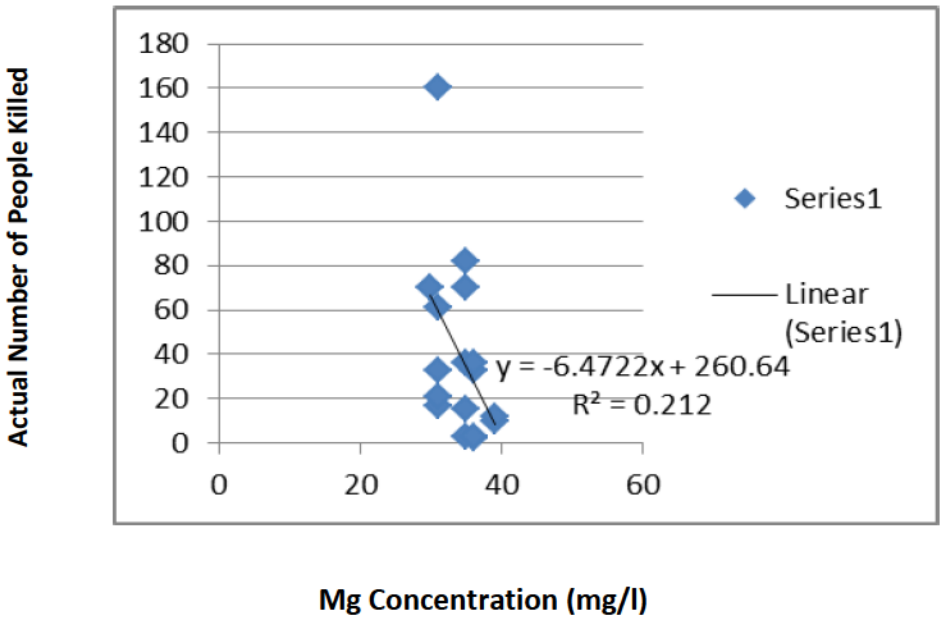



**Figure 5.9: Regression Relationship of Mg Concentration 30-39 mg/l**

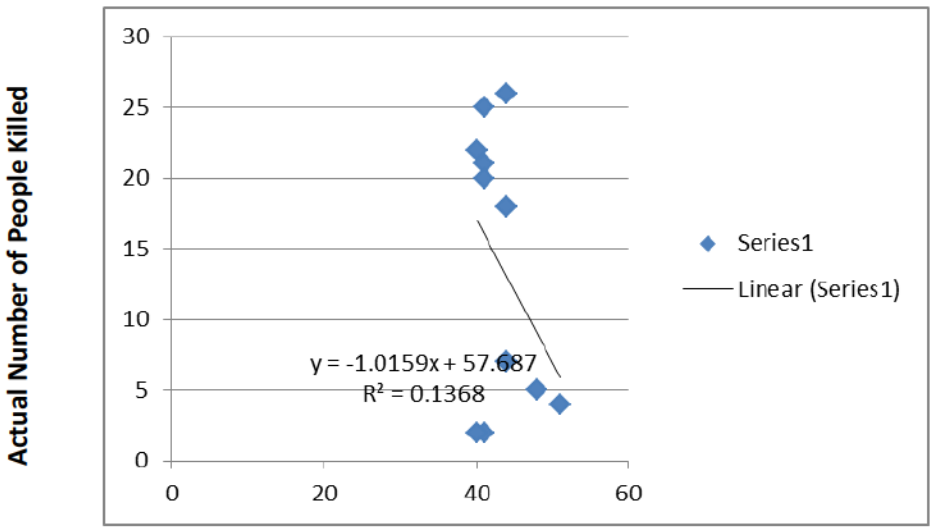



**Figure 5.10: Regression Relationship of Mg Concentration ≥40 mg/l**

### 5.3 The Third Correlation: Magnesium Concentrations vs. Heart Disease Mortality Rates in people Age 35 and above

The third approach correlates heart disease mortality rates in people 35 years or older with magnesium concentrations. The age 35 and above is chosen because most people die from ischemic heart disease at this age. The same procedure of sections 5.1 and 5.2 was followed, i.e., magnesium concentrations were divided into four groups and correlated with their corresponding age-adjusted heart disease mortality rates (Figures 5.11-5.14). Also, all the magnesium concentrations were combined as one group and correlated with their corresponding age-adjusted heart disease mortality rates (Figure 5.15). The five magnesium concentration groups yielded a negative correlation, thus confirming the results of sections 5.1 and 5.2. The correlation coefficients of this analysis are summarized in Table 5.3.

**Table 5.3: Correlation Coefficients of Magnesium Concentration and Heart Disease Mortality in People Age 35 or above**

| Magnesium Concentration (mg/l) | Correlation Coefficient |
|---|---|
| 10-19 | 0.44 |
| 20-29 | 0.79 |
| 30-39 | 0.44 |
| ≥40 | 0.34 |
| All magnesium concentrations | 0.46 |

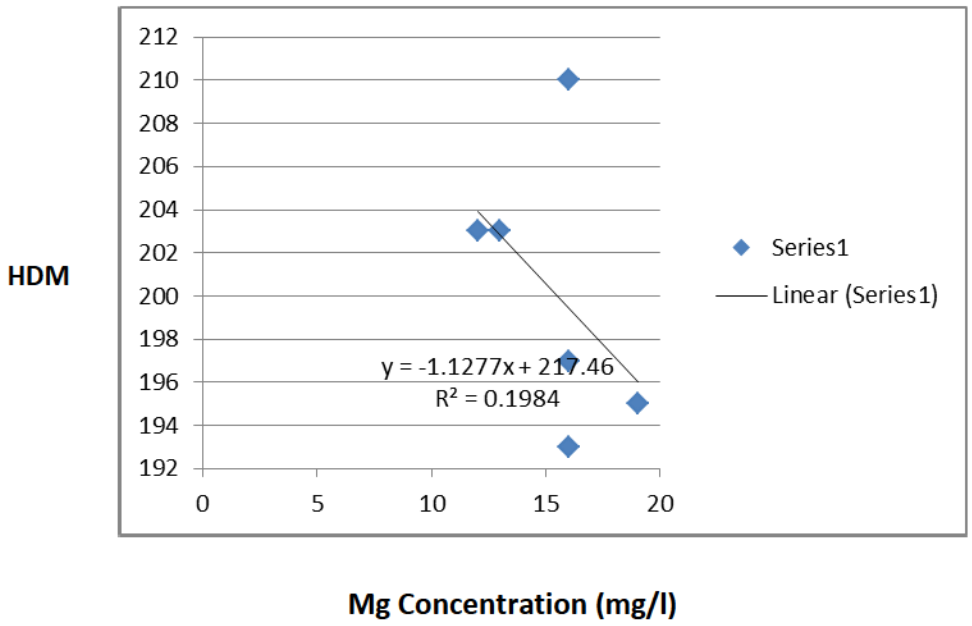



**Figure 5.11: Regression Relationship for Mg Concentration 10-19 mg/l**

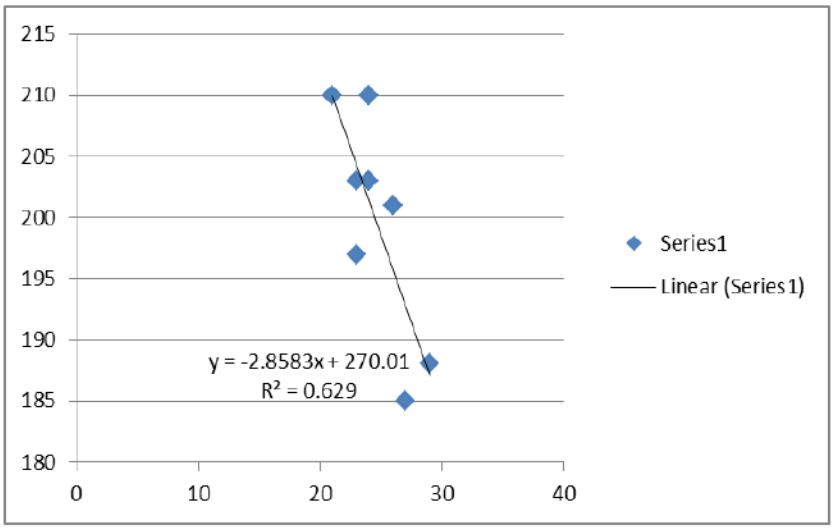



**Figure 5.12: Regression Relationship for Mg Concentration 20-29 mg/l**

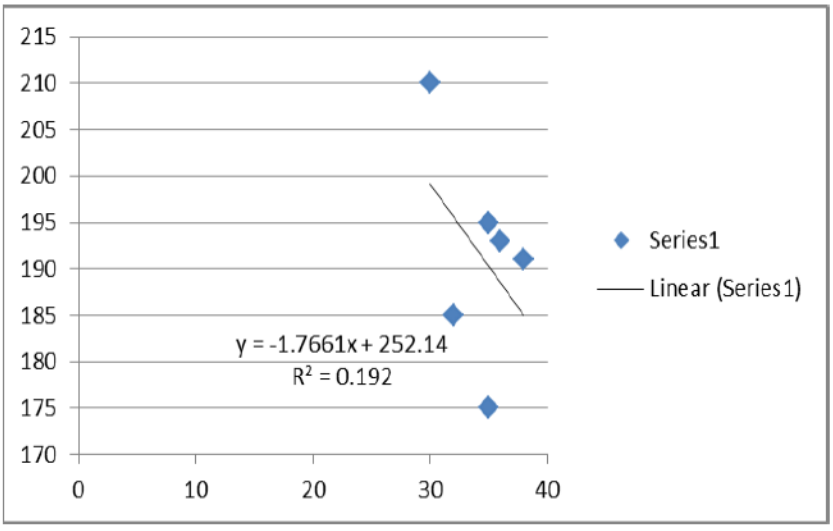



**Figure 5.13: Regression Relationship for Mg Concentration 30-39 mg/l**

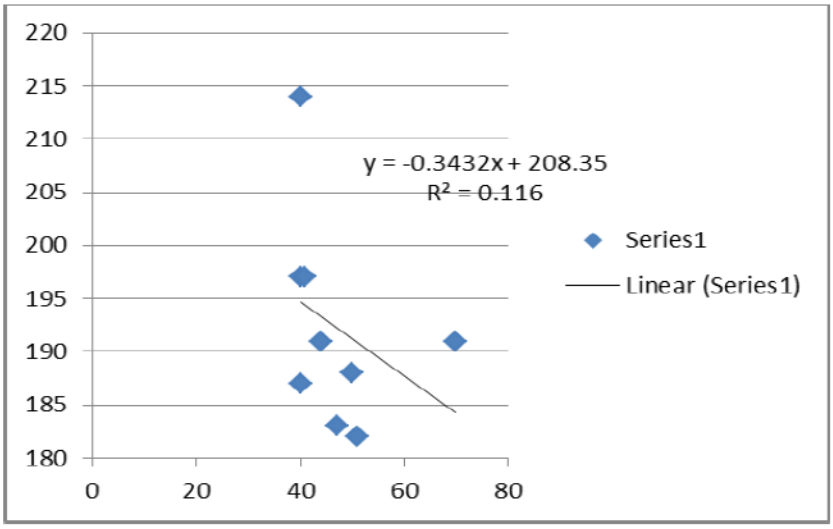



**Figure 5.14: Regression Relationship for Mg Concentration $\geq 40$ mg/l**

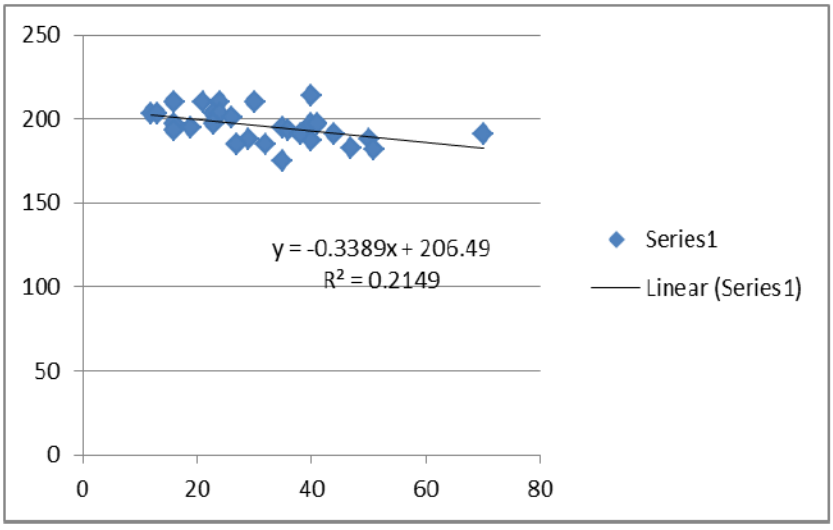



**Figure 5.15: Regression Relationship for All Magnesium Concentrations**

# CHAPTER 6: Conclusions and Recommendations

## 6.1 Conclusions

- This study investigates the correlation between ischemic heart disease rates and mortality with magnesium concentrations in Ohio drinking water using linear regression analysis. Magnesium concentrations in drinking water were obtained from 69 of the 88 Ohio counties. The magnesium concentrations vary from 10 to 70 mg/l. To investigate the effects of the different magnesium concentrations on heart disease and mortality, the concentrations were divided into four groups: 10-19 mg/l, 20-29 mg/l, 30-39 mg/l, and greater than 40 mg/l.

- Three correlation analyses were made:

  (1) magnesium concentrations vs. heart disease rates

  (2) magnesium concentrations vs. heart disease mortality rates

  (3) magnesium concentrations vs. heart disease mortality rates in people age 35 and above

In analyses (1) and (3), linear regression was applied to each magnesium concentration group and to all four groups combined as one group. In analysis (2), linear regression was applied to the four magnesium groups. Microsoft Excel was used to run the regression analysis.

- Results of the three analyses yielded a negative correlation between ischemic heart disease (rates and mortality) and magnesium concentrations in drinking water. This

supports the hypothesis that magnesium may help to protect against death from heart disease. The three analyses yielded low correlation coefficients (0.33 – 0.50), indicating that factors other than magnesium concentrations may affect heart disease rates and mortality (e.g., high blood pressure, high cholesterol, genetic factors, etc.).

- The best correlation obtained from the third analysis (for ages thirty-five years and older) was for magnesium concentrations of 20-29 mg/l. This indicates that high magnesium concentrations are not required for the protection from heart disease and its mortality.

- The distribution of magnesium concentrations in Ohio drinking water was compared to the distribution of dolomite in Ohio counties. The comparison shows that magnesium concentrations in drinking water are high where dolomite is present in the counties located at the northwestern part of Ohio.

### 6.2 Recommendations for Further Studies

- This research can be extended to include five states surrounding Ohio. Results of the proposed regional-scale study can be compared to the results of this study.

- A study similar to this one involving calcium (and not water hardness) can be conducted to determine if there is a relationship between calcium concentrations in Ohio drinking water and death from ischemic heart disease. Previous studies conducted in this Department using water hardness in Ohio drinking water yielded weak positive correlations and in some cases no correlations at all, whereas magnesium results of this study yielded negative correlations with low correlation coefficients.

- This type of study can benefit from being conducted under a more controlled environment. In 2003, a study conducted in northern India collected data from twenty

  random streets (Ong, 2003). Although weak inverse correlations were obtained between magnesium in drinking water and heart disease, a more in-depth study involving collection of data from a specific region could have yielded a strong negative correlation.

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