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Article

Correlation of socioeconomic status and lead concentration in tap water in Missouri

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SUMMARY

Lead exposure can have devastating health consequences. This effect is especially detrimental to the developing brain of children. Tap water is the most common source of lead in our diet. There is evidence that lower socioeconomic populations are at higher risk of exposure to tap water with a higher concentration of contaminants. We hypothesized that lead concentration is higher in the tap water of communities with lower per capita income and lower median household income. Using publicly available data from the annual water quality reports, we analyzed the 90th percentile lead levels for municipalities in the state of Missouri. Our results demonstrated that cities in the highest per capita income quartile had significantly lower 90th percentile lead levels than those in the lowest per capita income quartile (2.62±0.28 ppb vs. 4.74±0.83 ppb). Similarly, the highest median household income cities had significantly lower 90th percentile lead levels than those in the lowest median household income quartile (2.44±0.29 ppb vs. 4.62±0.88 ppb). In view of the long-lasting and irreversible health consequences of lead exposure, these findings have important implications when it comes to allocation of resources for mitigating effects of lead on health of populations.

INTRODUCTION

The presence of organic and non-organic contaminants in drinking water and their adverse health effects have been the subject of multiple previous investigations. Schullehner *et al*. demonstrated that elevated concentration of manganese in drinking water is associated with increased incidence of attention-deficit hyperactivity disorder (1). Ahmed and colleagues have detected high levels of cadmium and chromium in the municipal water in Malaysia (2). Exposure to these highly soluble minerals have been associated with increased risk of many cancers including lung, kidney, and gastrointestinal cancers (2). However, no other contaminant has been the subject of greater investigation than lead (3-5).

Lead is a potent neurotoxin whose effect is particularly devastating to the developing brain of children. Studies have demonstrated that children can absorb 40% to 50% of an oral dose of water-soluble lead (6). Adults, in comparison, absorb only 3% to 10% of the dose (6). As such, lead poisoning has long been a major public health issue, particularly for developing children and pregnant women. This risk is especially high for infants drinking reconstituted formula (7). Since the effects of lead are irreversible, the only effective remedy is prevention (8). In 2017, a study by Roberts *et al*. estimated that 1.2 million children between the ages of 12 months and 5 years had elevated blood lead levels (9). Even more concerning, only 50% of these cases were reported to the CDC.

The Safe Drinking Water Act of 1974 established safety limits for 88 contaminants, including lead, and mandated public reporting of maximum contaminant levels (MCLs) (10). With federal regulation requiring the removal of lead from gasoline and paint, the incidence of lead poisoning has decreased (7). However, drinking water remains a major source of lead intake, especially for those in lower socioeconomic levels (11). Degrading, older pipes in the municipal water system release lead depending on the water source and the type of water treatment and disinfectants used (11). A recent reminder of municipal water as a source of lead is the city of Flint, Michigan, which in 2014, in an attempt to save money, switched its water source from Lake Huron to Flint River. This change resulted in a significant increase in the lead content of the tap water, causing in a dramatic rise in the incidence of lead poisoning in the children of Flint (12). The long-term impact on the intellectual ability of the children will not be known for years. Since over 60% of the Flint residents are African American, and 40% have incomes below the poverty line, this incident renewed a national discussion about environmental justice (12).

Low-income communities are disproportionately exposed to drinking water contaminants (13). We hypothesized that this trend also applies to lead and that lead concentration is higher in the tap water of communities with lower per capita income and lower median household income in Missouri. Our findings demonstrated that of the studied cities in Missouri, those with lower socioeconomic status had significantly higher concentrations of lead in the drinking water.

RESULTS

We analyzed the relationship between socioeconomic status and lead levels in public tap water in the state of Missouri. The socioeconomic indices of a community as measured by the per capita income and median household income were obtained from the US Census Bureau (14). Our data indicates that there is an inverse relationship between per capita income levels and concentration of lead in tap water (**Figure 1**, ANOVA p = 0.011). The 90th percentile lead levels and the standard errors are presented in **Table 1**. The difference in the lead levels of the 1st Quartile (4.74 ± 0.83 ppb) and 3rd Quartile (2.18 ± 0.45 ppb) was statistically significant (p = 0.02), as was the difference between the 1st Quartile and the 4th Quartile (2.62 ± 0.28 ppb, p = 0.03). The difference between the 1st and 2nd quartiles and 3rd and 4th quartiles were not statistically significant with a p values of 0.89 and 0.34,

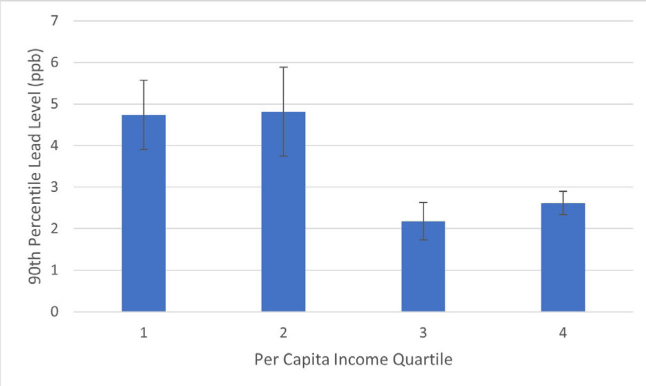

Figure 1: 90th Percentile Lead Levels vs. Per Capita Income. The difference in the lead levels is statistically significant between the 1st and the 3rd Quartile and 1st and the 4th Quartile. The 1st quartile group had the lowest income, and the 4th quartile group had the highest income. The error bars reflect standard error.

respectively.

As with per capita income, there is an inverse relationship between median household Income and concentration of lead in tap water (**Figure 2**, ANOVA p = 0.014). The 90th percentile lead levels and the standard errors are presented in **Table 2**. The 1st Quartile income group have significantly higher lead levels (4.62 ± 0.88 ppb) compared to those in the 4th Quartile (2.44 ± 0.29 ppb, p = 0.03). The difference between the 1st and 2nd quartiles, 1st and 3rd quartiles and 2nd and 3rd quartiles were not statistically significant with a p values of 0.64, 0.43 and 0.24, respectively.

DISCUSSION

Lead poisoning remains a significant public health issue (15). The toxic effects of lead, especially on the developing brains of children, is irreversible (16). Drinking water remains the primary source of lead exposure for most of the world population (11). We hypothesized that lead concentration is higher in the tap water of communities with lower per capita income and lower median household income in Missouri.

We used per capita income and median household income as our matrices of socioeconomic status because they are both readily available from public sources and are often used in populations studies. Furthermore, these values do generally correlate well with each other. However, for our investigation, the median household income is probably the better index. Per capita income is a useful tool for comparing large groups (such as countries), but it is easily skewed by households that have significantly above or below the average income for the dataset. On the other hand, median household income is a more robust measure of the distribution of wealth and poverty in a particular area. Since our data came from a limited population (those residing in the state of Missouri), median household income was a more appropriate index for our analysis.

Quartile	90th Percentile Lead Level (ppb)	Standard Error
1	4.74	0.83
2	4.81	1.07
3	2.18	0.45
4	2.62	0.28

Table 1: Per Capita Income Quartiles.

We used 90% lead levels in our analysis because that is how the individual public districts report their data. Reporting of average lead levels is not mandated by the regulatory authorities, and as such, is not readily available from public sources.

Our data supported our hypothesis and indicated that, in the state of Missouri, communities with lower median household incomes and lower per capita incomes had significantly higher lead levels in their tap water.

Our data does not differentiate between where the lead came from. However, previous studies have looked at possible sources of lead in drinking water (11). The common sources of lead in drinking water are municipal water transmission pipes, water pipes in buildings, and plumbing fixtures (12). Corrosion caused by a chemical reaction between water and the old pipes results in leaching of lead and other heavy metals into the water supply (12). Other factors such as acidity/alkalinity of water, the temperature of the water, the amount of time the water spends in the pipes, and the presence or absence of specialized coating inside the pipe can affect the level of dissolved lead (16).

Whatever the sources, poorer communities in Missouri have significantly higher levels of lead in the water coming out of their tap than their more affluent neighbors.

Further studies can look at this issue on a national level and look for solutions, such as better funding for replacing corroded pipes and fixtures that contain lead or adding a protective coating to existing pipes to improve water quality in low-income communities.

MATERIALS AND METHODS

We analyzed the relationship between socioeconomic status and lead levels in public tap water in the state of Missouri. The socioeconomic indices of a community as measured by the per capita income and median household income were obtained from the US Census Bureau (14). The

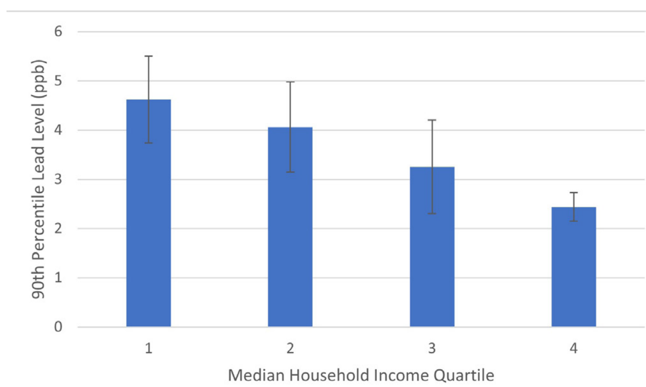

Figure 2: 90th Percentile Lead Levels vs. Median Household Income. The difference in the lead levels is statistically significant between the 1st and the 3rd Quartile and 1st and the 4th quartile. Quartiles: 1st quartile group had the lowest income, and the 4th quartile group had the highest income. The error bars reflect standard error.

Quartile	90th Percentile Lead Level (ppb)	Standard Error
1	4.62	0.88
2	4.06	0.92
3	3.25	0.95
4	2.44	0.29

Table 2: Median Household Income Quartile

Missouri Department of Natural Resources provides data on all the public water supply districts (PWSD) in the state, along with the number of people each PWSD serves (17). We limited the data collection to those water districts that supplied more than 10,000 people, which reduced our data set to 84 PWSDs. The water lead data was obtained from the EPA (18) and the individual localities' annual Consumer Confidence Reports (CCRs) (19). We divided the data into quartiles based on per capita income or median household income (per capita income ranges: 1st quartile $0-$16137, 2nd quartile $16138-$30453, 3rd quartile $30453-$43378, 4th quartile >$43378; median household income ranges: 1st quartile $0-$27314, 2nd quartile $27315-$55643, 3rd quartile $55644-$72454, 4th quartile >$72454). Approximately equal number of PWSDs fell into each quartile. An analysis of variance (ANOVA) test and a Tukey post-hoc analysis was used to examine the data. All statistical analysis was performed using the GraphPad software (Graphpad.com). We analyzed the data for the relationship of per capita income quartile, median household income quartile, and the 90th percentile lead levels.

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