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Drinking Water Contamination in the United States and Why It Matters For Infant Health

By Matthew Harding

While drinking water quality has long been associated with the outbreak of various diseases and human mortality, research has focused almost exclusively on developing countries and has emphasized the huge benefits of providing basic sanitation infrastructure (Olmstead 2010). More recently, a series of *New York Times* articles highlighted the extent to which violations in established drinking water standards are also relatively common in the United States and pointed out that their number has increased significantly over the last decade (Duhigg 2009).

The impact of different drinking water violations in the United States is poorly understood and while most Americans are very concerned about drinking tap water while traveling abroad, few are aware of the potential health costs of being exposed to drinking water contaminants while staying at home. Many of the hazards to human health, such as an increased likelihood of certain cancers from exposure to water contaminants, are difficult to quantify separately from the myriad other exposures to toxic contaminants over a lifetime. Since the enforcement of regulations related to drinking water standards is expensive and the benefits in the United States have not been precisely quantified, we see less enforcement activity than we would expect under the existing legal framework. The *New York Times* found that less than 3 percent of all violations resulted in significant fines or punishment and the popular perception is that regulators are not doing enough to enforce laws and are falling short of stated policy goals. This appears to be confirmed by a memorandum released by the former administrator of the Environmental Protection

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About The Author

Matthew Harding is an Assistant Professor of Economics at Stanford University and a SIEPR Faculty Fellow. Prior to joining the Stanford faculty, he received a PhD in Economics from MIT and an MPhil from Oxford University. He is an applied econometrician specializing in the analysis of Big Data. His research covers many areas related to health, nutrition, energy and the environment.

Agency (EPA) in 2009, which states that "water in the United States is not meeting public health and environmental goals" and "the level of enforcement activity is unacceptably low."

In this brief we document the extent and nature of drinking water violations in the United States, explain the hazards of accidental exposure to contaminants, and measure the health impact of in utero exposure to drinking water contaminants on infant health at birth. We also show that while avoidance behavior, e.g., buying bottled water, is significant, it is also insufficient to completely offset the negative health impact on the population. In practice we observe a spectrum of enforcement activities and show that even informal enforcement can be an effective tool for addressing violations in the supply of drinking water in the United States.

How Contaminated is the Drinking Water?

The U.S. population consumes drinking water from a public water system (PWS), which is defined as an entity that provides piped water to at least 25 people for at least 60 days each year. The majority of the population receives drinking water from one of more than 50,000 community water systems that provide drinking water year-round. More than 100,000 other water systems are also recorded as providing water for part of the year, such as campgrounds or schools with their own water supply. While the drinking water in the United States is safe compared with that in developing countries, a wide variety of water contaminants are still found in U.S. drinking water, both naturally occurring and man-made, that have serious effects on human health. Contamination can happen for a variety of reasons. Bacterial contamination usually results from human or animal waste. Chemical contamination results from industrial discharges or runoff from fertilizer and herbicide usage. Lead and copper contamination occurs as a result of household plumbing erosion. Radionuclides contamination is usually a result of the decay of natural or man-made radiation-emitting mineral deposits.

In order to understand the extent of the contamination of the drinking water supply in the United States, we filed several Freedom of Information Act requests with the EPA and received detailed information on violations at the PWS level between 2001 and 2006. Each violation records the date of occurrence as well as the precise nature of the violation. Since the EPA monitors more than 90 different contaminants, we use the EPA designations to group them as follows: Total Coliforms (TCR), Nitrates, Lead/Copper, Volatile Organic Compounds (VOC), Synthetic Organic Compounds (SOC),

Table 1
National drinking water violations over the period 2001-2006.

	All counties	Big counties (N=521)					
	Total	Total	Mean	SD	25th	75th	Max
TCR (Any)	248014	99735	191.43	285.97	20	238	2216
TCR Acute	6337	2606	5.00	10.74	0	5	113
Nitrates	5476	2323	4.46	22.03	0	2	320
Lead/Copper	18643	8012	15.38	25.58	1	19	289
VOC	436	236	0.45	2.33	0	0	34
SOC	183	97	0.19	1.36	0	0	19
Radionuclides	5677	2857	5.48	26.09	0	0	261
Arsenic	1537	705	1.35	4.47	0	0	43

Radionuclides, and Arsenic. Since we are primarily interested in violations that may have an impact on fetal health, we restrict our attention to violations where the maximum allowable amount of a specific contaminant was exceeded and exclude other types of violations, such as missing a reporting deadline, that are not directly linked to human health outcomes.

For TCR violations we further distinguish between acute and other forms. A violation is deemed acute if in addition to testing total coliform positive, one of the samples is also E. coli or fecal coliform positive.

In Table 1 we report the number of violations by category over the sampling period. Since more than 80 percent of the U.S. population lives in counties with more than 100,000 inhabitants, we also report summary statistics for large counties over the same period. Thus, we observe an average of 191 violations over this period for a large county. The distribution is highly skewed with some counties experiencing no violations over this period and others experiencing a very significant number. In Figure 1 and Figure 2 we plot the density of acute TCR violations and radionuclides violations by county (darker areas correspond to counties with a higher number of violations). While we observe a broad geographic dispersion, violations appear to be more heavily concentrated in the South and South East, raising potential environmental justice issues.

Figure 1
County Level Total Coliform Bacterial Contamination

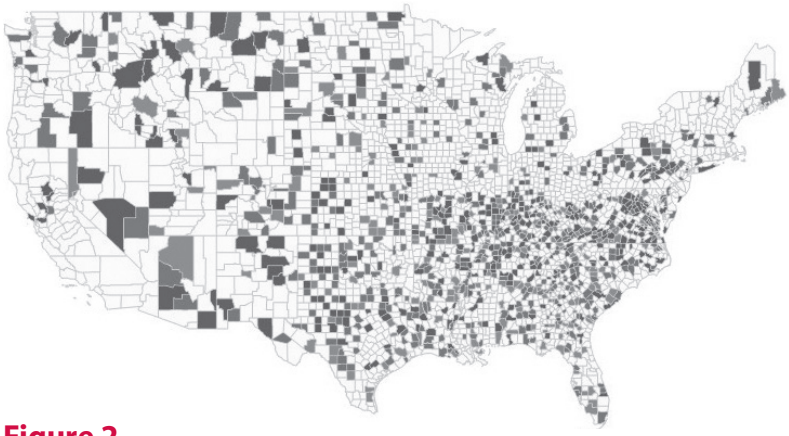
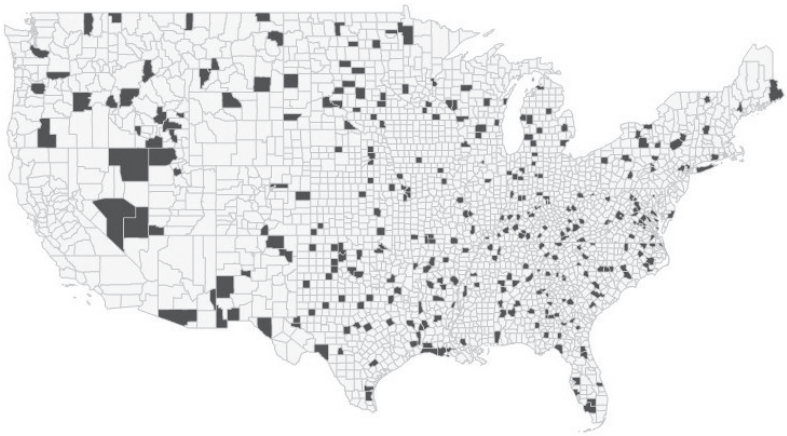


Figure 2
County Level Contamination With Radionuclides



What are the Hazards of Drinking Water Contaminants for Infant Health?

The biological mechanisms of in utero exposure to contaminants impacting infant health at birth are extensively documented by scientists, especially for some of the most frequent (and dangerous) contaminants. Coliform bacteria include a variety of genera including E. coli, and babies are more susceptible to these bacteria as they have a suppressed immune system and thus are more likely to get a severe disease. Studies show that E. coli causes mortality rates as high as 40 percent. The second most frequent form of water contamination comes from nitrates and nitrites resulting from a variety of sources, such as excessive fertilizer use, animal waste, erosion of natural deposits, and sewage. It has been well

established that nitrates cause methemoglobinemia, more commonly known as blue baby syndrome, a condition whereby nitrates consumed by the mother cross the placenta to the fetus, leading to severe lack of oxygen in the blood. Among organic compounds many have been shown to cause fetal development retardation, birth defects, and low birth weight. Tetrachloroethylane affects the development of the nervous system and is also associated with low birth weight; benzene and toluene cause both weight and skeletal development retardation; carbon tetrachloride exposure causes a significant decrease in fetal birth weight and length. Arsenic has been shown to decrease birth weight and substantially increase the risk of stillbirth. Mercury also crosses the placenta to the fetus and leads to neurological damage, such as convulsions and uncontrollable muscle movement. Mothers exposed to mercury were nine times more likely to have a baby with neural tube defects.

Regulating Drinking Water Contaminants

The Safe Drinking Water Act (SDWA) was enacted in 1974 and granted the EPA the authority to establish regulations for drinking water in order to protect human health. This includes enforcing a number of thresholds, known as maximum contaminant levels, or MCL, for which violations are triggered. Monitoring is central and separate rules are established for the monitoring of more than 90 different contaminants. Broadly, the process requires PWSs to collect samples at regular time intervals throughout the month.

The SDWA mandates that PWSs notify customers of drinking water violations. From the time a violation is detected the PWS has 24 hours, 30 days, or 1 year to provide notification, depending on the type and severity of contamination as well as the implied health hazard. The EPA uses a tiered system to determine the timing of the required notification. Tier 1 violations require notification within 24 hours and are triggered primarily by contamination with fecal coliform bacteria or E. coli as well as by exceeding the MCL for nitrate/nitrite. Tier 2 violations consist of all other MCL violations not covered by the Tier 1 notification requirements. Additionally, PWSs must mail an annual "consumer confidence report" that records the violations in all tiers. Tier 3 violations consist mostly of violations in the sampling, monitoring, and reporting requirements and are included in the annual report.

The EPA's regulations are legally enforceable and the EPA itself and states may take actions against water systems that are not meeting safety standards. The SDWA provides for a variety legal actions that can be taken in federal district court against PWSs found in violation of the SDWA and that can impose substantial financial penalties of up to $27,500 per day of violation. At the same time, the EPA has a number of informal enforcement methods available. A common approach involves issuing a "Notice of Violation (NOV)" to the state and to the PWS informing them about the lack of compliance with existing regulations and threatening further action if appropriate actions are not taken within 30 days. The EPA states that "the NOV is a very effective tool in getting water systems back into compliance with the SDWA because systems receiving an NOV often contact the state to learn what needs to done to respond to the action. This begins a dialog between the system and the state which frequently leads to compliance without further formal actions or penalties." In our data we observe that 12 percent of the violations resulted in at least one NOV being issued. While less than 1 percent resulted in legal action, we observe more than 60 different types of informal enforcement actions being conducted by the EPA in dealing with violations.

The Impact of Drinking Water Violations on Infant Health At Birth

In order to measure the effect of drinking water violations on infant health, in Harding (2013) we restrict our attention to in utero exposure to water contaminants and measure its effect on health at birth. We use two crucial infant health outcomes at birth, ones that medical science indicates are

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particularly sensitive to drinking water contaminants, low birth weight and low APGAR score. The APGAR score ranges from 0 to 10 and is calculated 1 minute after birth. It measures five health criteria: appearance, pulse, grimace, activity, respiration. APGAR scores below 6 are considered low and generally indicate the need for additional medical attention. We look at all live births in large U.S. counties over the period 2002-2006. In our sample less than 1.5 percent of births are recorded as having had a low APGAR score and low birth weight was observed for 7.7 percent of births.

Our main empirical strategy is to estimate the impact of exposure to drinking water contaminants during pregnancy on the number of births with low APGAR and low birth weight in a given county–month, while controlling for other health risks, parental characteristics (including the percent of births that were male, twins, not in a hospital, that received no prenatal care, where the mother smoked, the mother was black, the mother was not married, the mother did not attend college, and the percent of births where the father was black) and county and time fixed effects.

The regression estimates indicate that the number of births with a low APGAR score is significantly higher after Acute TCR, Nitrates, SOC, and Radionuclides violations. Low birth weight is significantly more likely to be observed after exposure to SOC and Radionuclides violations. It is also notable that births with a low APGAR score and also low birth weight are more likely after Tier 1 violations were experienced during pregnancy.

Since Tier 1 violations require immediate 24 hour notification, the degree to which they impact infant health is puzzling. If households are notified of the violation, should we not observe evasive actions, such as buying bottled water? In order to investigate this we use a unique large scanner data set that captures all the bottled water sales for a large part of the country over the same sampling period. When we regress bottled water sales on indicators of the different violations, we measure a 35 percent increase in sales in areas where Acute TCR violations were recorded. We do not observe any consumer response to any other type of violation. This indicates that at least some individuals take evasive actions following the disclosure of drinking water violations. However, bottled water is expensive and while most people appear to understand the risks posed by bacterial contaminants, they fail to appreciate the health hazards posed by less salient contaminants such as synthetic organic chemicals.

Additional econometric models reveal that while the negative impacts of exposure to drinking water contaminants are somewhat smaller in areas where mothers are more educated or benefit from prenatal care, neither of these factors totally negates the danger of in utero exposure to drinking water contaminants. Once exposure to a similar set of violations has occurred, even in areas where more than 95 percent of women benefit from prenatal care compared with areas where prenatal care is much lower, we see only a minute reduction in the number of births with low APGAR scores or low birth weight. This indicates that once a woman has been exposed to these contaminants, medical professionals do not have the ability to detect and/or treat the already inflicted damage to the fetus.

We do, however, find that enforcement of existing regulations does mitigate the negative health impact. Violations where informal enforcement actions are taken do not lead to the same negative health impacts on infants at birth as violations where no enforcement action is taken. This indicates that the duration of exposure is crucial and that even simple informal enforcement actions may reduce the duration of exposure, lead to improved notification, and ultimately to superior infant health outcomes at birth.

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