Well Water Quality in Seven Northern PA Counties: A County-by-County Summary of US Geological Survey Data

Division of Environmental Health Epidemiology

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Executive Summary

United States Geological Survey (USGS) data on water wells in the Northern region of Pennsylvania (PA) were collected to better understand groundwater quality for private well users. A series of studies conducted from 2012 through 2017 sampled well water from Bradford (2016), Clinton (2017), Lycoming (2014), Pike (2015), Potter (2017), Sullivan (2012), and Wayne (2014) counties. Samples were analyzed for chemical contaminants and other metrics, such as well depth and total dissolved solids. In this report, the Pennsylvania Department of Health's (PA DOH) Division of Environmental Health Epidemiology further analyzed and consolidated USGS data for 24 metal and trace metal constituents found in wells by county. Most, if not all, of the included constituents are known health hazards, including arsenic, barium, and lead. The purpose of this document is to summarize well water quality issues in these seven counties to educate and inform actions by private well owners and to raise awareness of this topic among public health stakeholders.

This report includes information on minimum, maximum and median concentrations of chemicals found in wells, the percent of wells exceeding the corresponding Maximum Contaminant Level (MCL) or Secondary Maximum Contaminant Level (SMCL) (i.e., health or aesthetic-based standards for public drinking water defined by the U.S. Environmental Protection Agency [EPA]), as well as a correlation analysis to identify relationships between metals. This is an important contribution, especially given that 26% of adult Pennsylvanians rely on private wells as their primary drinking water source (PA DOH, 2022a). This data has been organized in a user-friendly way to explore chemical contaminants by county so that Pennsylvanians can better understand their well water quality. Access to the chemical makeup of wells by region allows private well owners to better select contaminants to test for and mitigate potential harmful exposures.

Analysis of the well water data shows that most wells had contaminant concentrations that are considered safe for consumption. However, this report highlights that metals may be present, even at low concentrations, in Northern PA wells (and some of these metals have known health impacts). A small percentage of wells tested exceeded regulatory limits for arsenic and barium (about one to five wells per county). Notably, lead, a metal that has neurological impacts, especially for children, was found below its MCL for public drinking water of 15 parts per billion (ppb) in all PA wells explored. However, no level of lead is considered safe. Depending upon the age of the home, lead and copper pipes may contribute to lead exposure through drinking water at the faucet. Iron concentrations exceeded EPA's SMCL (non-regulatory guidance standard based on aesthetic considerations) in at least 20% of wells (anywhere from 12-45 wells) per county. Although iron is generally not considered harmful to humans, it may alter the taste of water or stain laundry and bathroom fixtures. Similarly, manganese exceeded its SMCL in all counties, but at a lower percentage compared to iron. Given that this data is a snapshot relative to the number of wells being utilized for drinking water in PA, and only covers seven counties in one region of the state (out of 67 total counties), the PA DOH encourages well water testing and education among all well owners.

Methods

The Pennsylvania Water Science Center of the United States Geological Survey (USGS) is in the process of conducting groundwater quality studies in Northcentral and Northeastern PA in response to oil and gas development (Pennsylvania Water Science Center, 2020). To date, they have completed assessments in seven counties. For the current report, their publicly available well water data for Bradford (2016), Clinton (2017), Lycoming (2014), Pike (2015), Potter (2017), Sullivan (2012), and Wayne (2014) counties were downloaded using the dataRetrieval package (Laura DeCicco & Hirsch, 2022) and R studio (2021.9.0.351). Available concentration data were extracted for 24 metals and trace metals (measured in micrograms per liter [µg/L] or milligrams per liter [mg/L]), including Aluminum (Al), Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Boron (B), Cadmium (Cd), Calcium (Ca), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Lithium (Li), Magnesium (Mg), Manganese (Mn), Molybdenum (Mb), Nickel (Ni), Potassium (K), Selenium (Se), Silver (Ag), Sodium (Na), Strontium (Sr), and Zinc (Zn).

GraphPad Prism (9.2.0) was used to create box and whisker plots of individual metal contaminants per county and bar charts representing the percentage of wells exceeding the Maximum Contaminant Level (MCL) or Secondary Maximum Contaminant Level (SMCL) for a given contaminant. The U.S. Environmental Protection Agency (EPA) has designated MCLs and SMCLs for specific chemicals in public drinking water to limit potential acute or chronic toxicological effects that may occur upon exposure. MCLs are based on adverse health effects and are legally enforceable, while SMCLs are aesthetic-based standards used to guide public water systems' water management protocols.

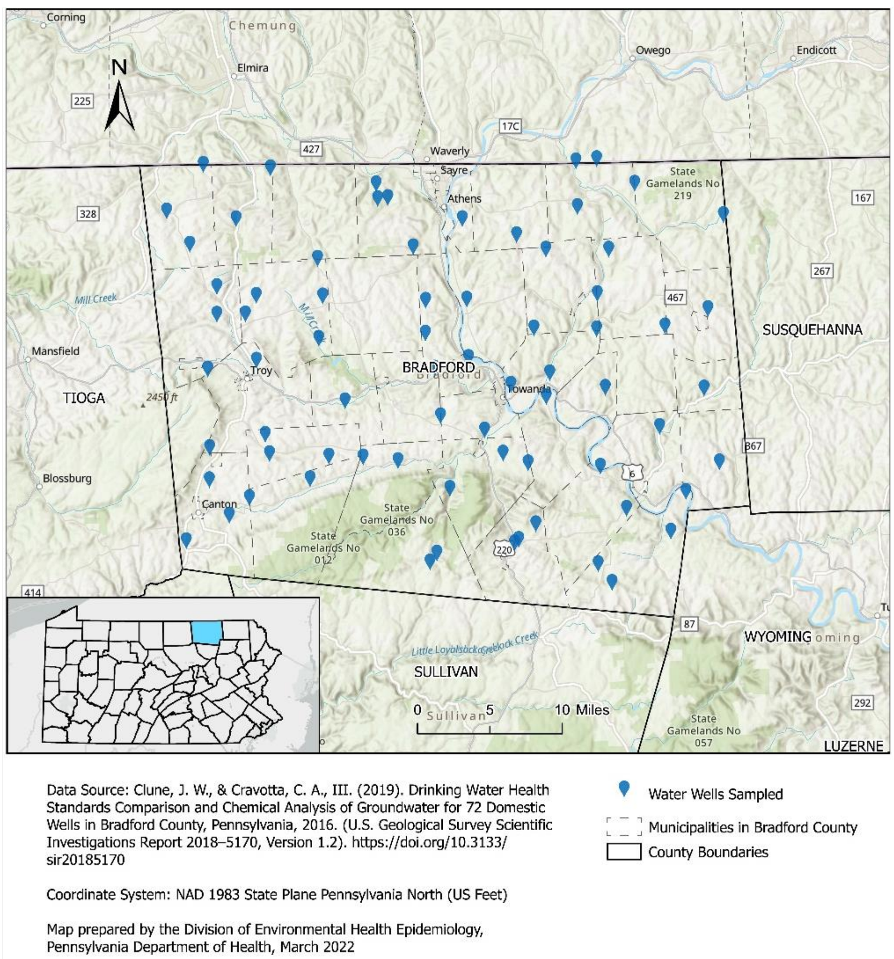
Prism was also used to conduct a non-parametric Spearman correlation analysis for the 24 contaminants tested per county to identify possible relationships between metals (Senior et al., 2017). By understanding region-specific chemical relationships in localized drinking water samples, the PA DOH may be able to better provide relevant educational material tailored to specific areas. For samples that were below the detection limit (DL), a value of (DL/2) was used for the analysis (Farnham et al., 2002). If all samples for a given metal were below the DL that metal was excluded from the analysis. A correlation matrix and heatmap were produced to identify relationships between the presence and concentration of any two chemicals (see Appendix).

The data used in this analysis was collected from past studies. Staff from the USGS collected water samples from approximately 45-80 wells per county. Wells were randomly selected, when possible, to ensure all major rock types and land uses in each county were represented and wells were not biased in terms of well water quality issues (Pennsylvania Water Science Center, 2020). Established USGS protocols were followed for well selection, sampling, laboratory, and reporting procedures. It is important to note that some study samples were collected more than 10 years ago and that changes in land usage, population, climate, and age of wells impact current trends in well water contamination. However, geological sources such as bedrock and mineral deposition, as well as anthropogenic sources, such as sustained industry, will continue to contribute to well water contamination. Additionally, variability in contaminants and concentrations across wells may not be fully captured due to the limited number of wells sampled in these studies.

Bradford County Findings

Bradford County is a rural northeastern county in Pennsylvania, bordering New York State, with a population of approximately 60,000 residents as of the 2020 Decennial Census. With a land area of about 1,147 square miles and population density of 53 people per square mile, the county has one of the lowest population densities in PA. It is home to 1,498 unconventional oil and natural gas wells (as of 5/31/2022, fourth highest among PA counties), as well as natural gas power generation and industrial waste handling (PA DOH, 2022b; Pennsylvania Department of Environmental Protection [PA DEP], 2022). The county is rich in game land, with over 54,000 acres utilized for hunting, fishing, and recreation (Outdoors Activity Possibilities in Bradford County, n.d.). The geology is primarily composed of bedrock consisting of shale, siltstone, and sandstone. The bedrock, along with overlying deposits of silt, clay, gravel and sand, are the foundations for domestic water well drilling (Clune & Cravotta, 2019). Notably, it has been estimated that more than 50% of homeowners in Bradford County rely on a private well (Clune & Cravotta, 2019).

Figure 1.1: Bradford County Water Wells Sampled by USGS, 2016



Discussed below, data are presented on 24 metal and trace metal contaminants in 72 wells sampled in Bradford County (Figure 1.1). Table 1 includes a summary of the USGS water quality samples, highlighting the number of wells that were below the detection limit, as well as the minimum, 25th percentile, median, 75th percentile, and maximum concentration detected for a given contaminant. Table

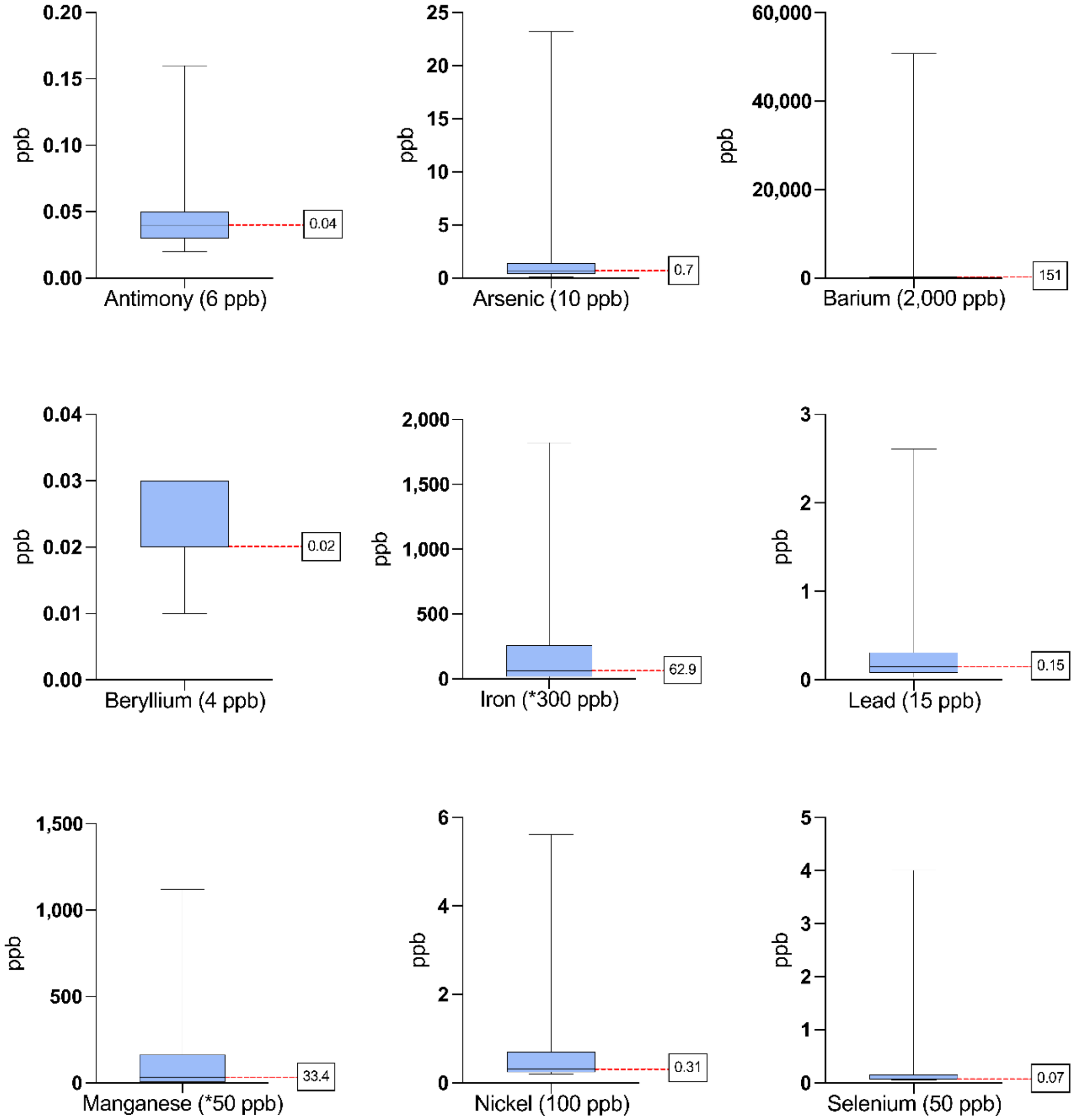
1 also provides the Maximum Contaminant Level (MCL) for a contaminant in public drinking water as designated by the U.S. EPA, or a recommended Secondary Maximum Contaminant Level [SMCL]), when applicable. Figure 1.2 presents a panel of box and whisker plots of individual contaminant data for 9 metals with MCLs or SMCLs. These plots correspond to the tabular data in Table 1. Figure 1.3 is a bar chart that depicts the percent of wells that exceeded MCLs or SMCLs.

Table 1: Summary of USGS Water Quality Samples, Bradford County, 2016 (N=72 wells)

Contaminant	# Below Detection Limit (of 72 wells sampled)	Detection Limit	Minimum Level Detected	25th Percentile	Median	75th Percentile	Maximum Level Detected	MCL or *SMCL
Aluminum	61	3	3.2	4.2	9.1	106.2	771.0	*50
Antimony	42	0.02	0.02	0.03	0.04	0.05	0.16	6
Arsenic	8	0.05	0.13	0.38	0.69	1.40	23.20	10
Barium	0	0.25	3	74	151	347	50,700	2,000
Beryllium	65	0.01	0.01	0.02	0.02	0.03	0.03	4
Boron	2	5	7	33	76	186	567	NA
Cadmium	71	0.03	0.06	0.06	0.19	0.31	0.31	5
Calcium	0	NA	380	26,450	40,500	51,300	360,000	NA
Chromium	71	0.3	0.45	0.45	0.78	1.10	1.10	100
Cobalt	56	0.03	0.04	0.06	0.06	0.09	0.75	NA
Copper	35	0.2	0.39	1.68	4.20	9.85	82.30	*1,300
Iron	27	4	4.7	17	63	259	1,820	*300
Lead	19	0.02	0.03	0.08	0.15	0.31	2.61	15
Lithium	0	NA	0.4	11.2	22.5	48.7	1,510.0	NA
Magnesium	0	NA	80	5,310	8,870	13,500	51,600	NA
Manganese	16	0.4	0.6	8.4	33.4	164.0	1,120.0	*50
Molybdenum	6	0.05	0.07	0.26	0.49	0.80	2.42	NA
Nickel	41	0.2	0.20	0.24	0.31	0.71	5.62	100
Potassium	0	NA	620	1,225	1,420	2,070	4,890	NA
Selenium	42	0.05	0.05	0.06	0.07	0.16	4.00	50
Silver	72	0.02	0.08	0.08	0.08	0.08	0.08	*100
Sodium	0	NA	2,180	11,350	19,500	57,300	897,000	NA
Strontium	0	0.8	5	287	548	1,100	46,800	NA
Zinc	24	2	2.0	3.2	6.6	15.6	981.0	*5,000

Note: All concentration data are reported in micrograms per liter (μg/L) or parts per billion (ppb). NA is used for any missing or unavailable values.

Figure 1.2: Distribution of Contaminant Concentrations Among Bradford County Wells



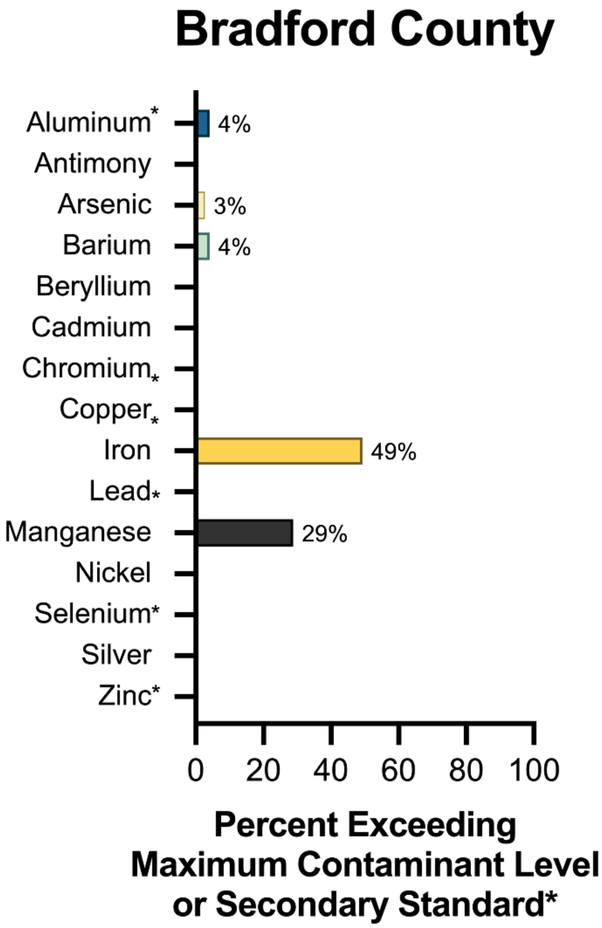
Note: N=72 wells in Bradford County. Dashed red lines indicate the median values. The value in parentheses is a contaminants MCL or *SMCL. Wells below the detection limit for a given contaminant were excluded. See Appendix for additional metal panels.

Among the 72 wells tested by USGS in Bradford County in 2016, the majority of metal contaminants were found at concentrations below designated MCLs. Specifically, two wells exceeded the MCL for arsenic and strontium, and three wells exceeded the MCL for barium. Additionally, the recommended SMCLs were exceeded in 4% of wells for aluminum, 29% for manganese, and 49% for iron (Figure 1.3).

Individuals may be exposed to multiple metal contaminants in drinking water. Bradford County wells showed statistically significant strong positive correlations greater than 0.75 between the following contaminant pairs: boron and sodium, calcium and magnesium, and lithium and sodium (see

Appendix). These relationships can be interpreted, for example, that the presence of calcium may also indicate the presence of magnesium in a water sample.

Figure 1.3: Percent of Bradford County Wells Exceeding Regulatory Standards



Note: N=72 wells in Bradford County. * Denotes metals with a secondary standard (SMCL).

Water quality data collected from Bradford County wells in 2016 shows that most wells did not exceed MCLs for toxic chemicals. However, a small percentage still exceeded MCLs for arsenic and barium, which are known to have toxicological effects in humans (ATSDR, 2007a, 2007b). Specifically, long-term exposure to arsenic has been correlated to bladder, lung, liver, and skin cancer. Short-term exposure can lead to gastrointestinal side effects, such as nausea and vomiting (ATSDR, 2007a). Four wells exceeded MCLs or SMCLs for two contaminants. Additionally, two wells exceeded MCLs or SMCLs for both 3 and 4 contaminants. Well owners in this region should be aware of potential exposure to toxic metals, as their concentrations can fluctuate based upon weather, well condition, and changes in local industrial activity. Having wells tested on a yearly basis will help ensure that unwanted exposure does not occur. Iron and manganese also exceeded secondary standards in a portion of the wells tested. Iron, which exceeded secondary standards in nearly half of the wells, may be released naturally into groundwater from rocks, or from other sources such as industrial waste or corroding metal (Water Science School, 2018).

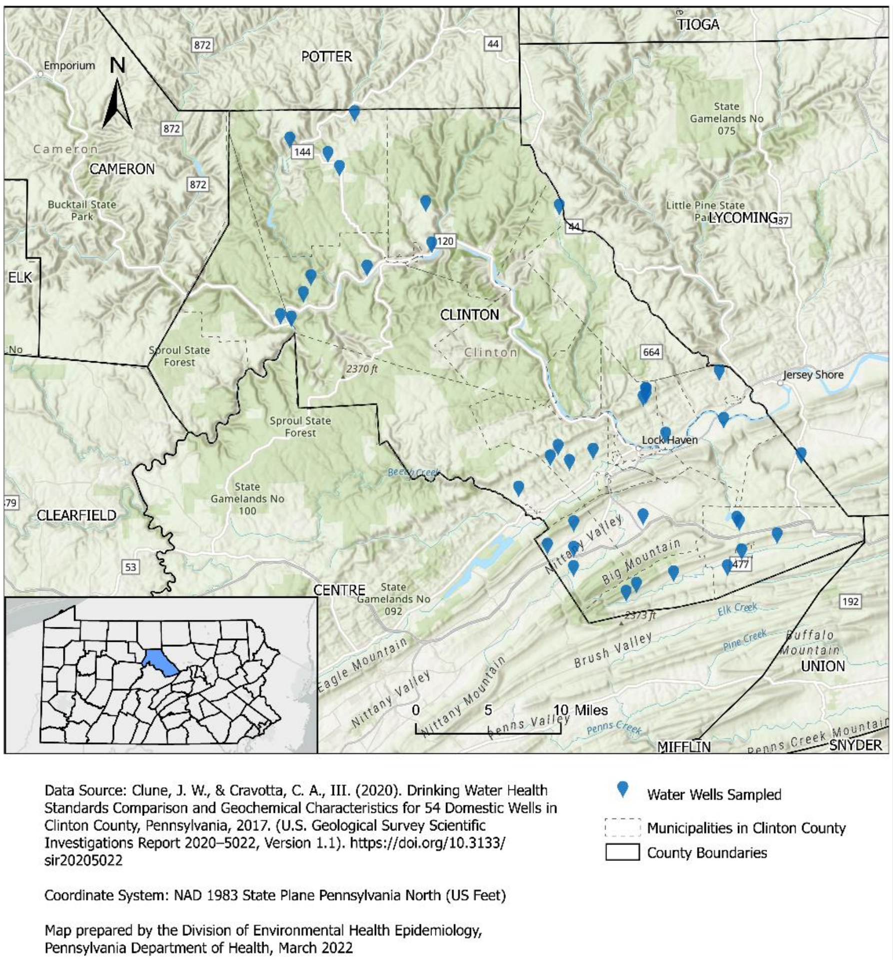
Exposure to iron in drinking water is not typically hazardous to health, however it may alter the taste of water and leave brown stains on laundered clothes. It should be noted that a rare inherited disease called hemochromatosis is associated with iron overload in a small percentage of persons. Individuals with this condition should limit their iron intake, including via drinking water, in consultation with their health care provider. Similarly, manganese can alter taste, cause scaling on plumbing, and stain laundry (Swistock et al., 2019). Exposure in drinking water is generally nontoxic, but long-term exposure to high levels of manganese may have neurological impacts (ATSDR, 2012).

In Bradford County, high levels of sodium may also indicate increased levels of lithium or boron. Additionally, a high level of calcium may also reflect a high level of magnesium. Elevated levels of magnesium and calcium will increase water hardness (mineralized water), which could result in stained fixtures and clothes, clogged plumbing, and dry skin (WHO, 2010). The best way to ensure safe drinking water for Bradford County well owners and their families is to be aware of chemical contaminants found in well water and their potential adverse health or aesthetic effects, test water quality regularly, and reach out to the PA DOH with any additional concerns.

Clinton County Findings

Clinton County is a northcentral county of Pennsylvania, bordering Lycoming, Potter, Cameron, Clearfield, and Centre Counties, with a population of approximately 37,500 residents as of the 2020 Decennial Census. With a land area of about 888 square miles and population density of 43 people per square mile, the county is among the top 10 counties for lowest population densities in the state. It is home to manufacturing companies, including commercial printing firms, and 91 unconventional oil and natural gas wells (as of 5/31/22) (PA DOH, 2022b; PA DEP, 2022). More than 60% of the county is state land and acts as a gateway to the Pennsylvania Wilds region (Clinton County Pennsylvania Visitor's Bureau, n.d.). The Appalachian Plateaus, which make up 75% of Clinton County's land area, has a geology that is primarily composed of bedrock consisting of shale, siltstone, and sandstone (Clune & Cravotta, 2020). The bedrock, along with overlying deposits of silt, clay, gravel and sand, are the foundations for domestic water well drilling (Clune & Cravotta, 2019). It has been estimated that more than 20% of homeowners in Clinton County rely on a private well (Clune & Cravotta, 2019).

Figure 2.1: Clinton County Water Wells Sampled by USGS, 2017



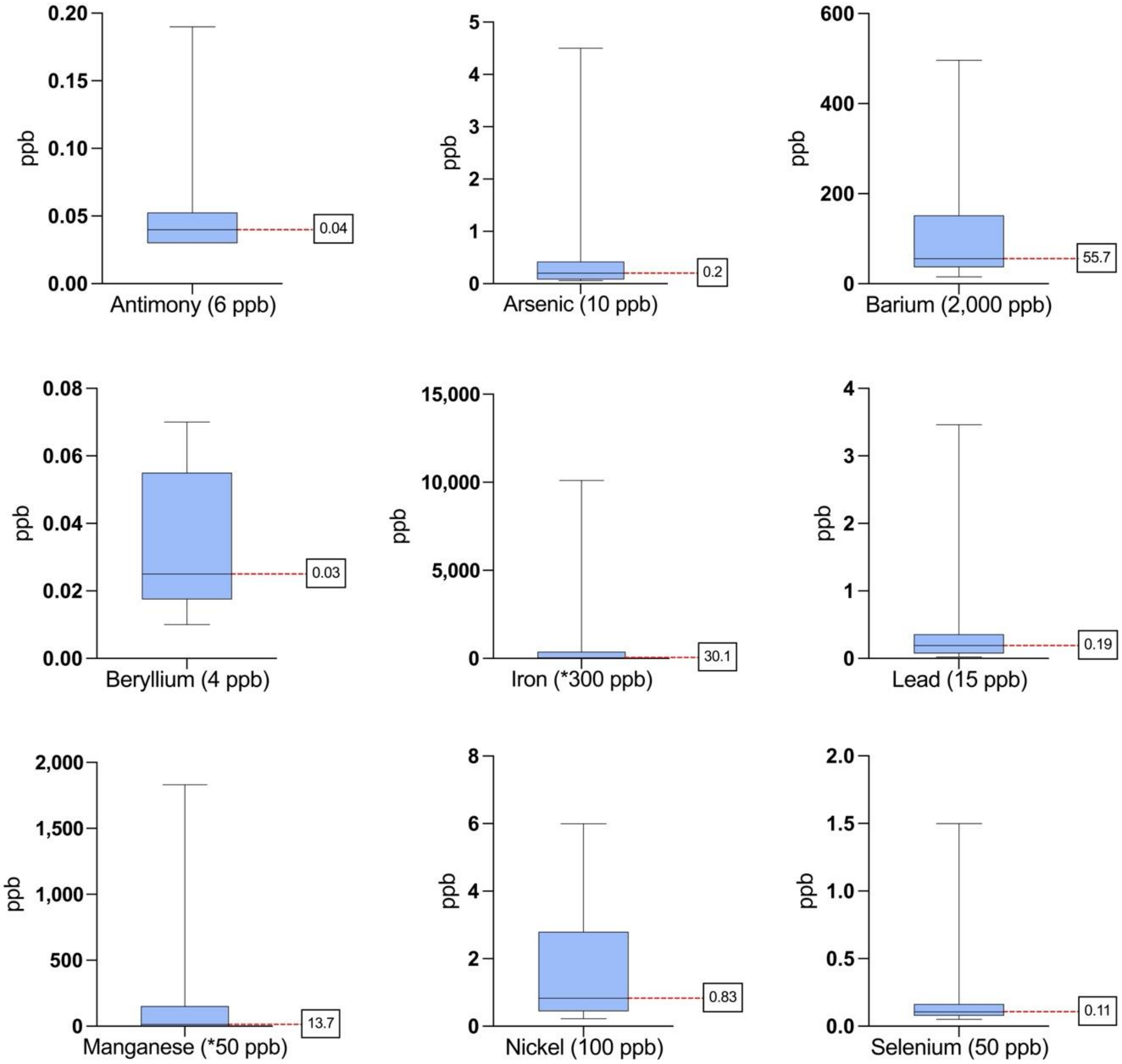
Discussed below, data are presented on 24 metal and trace metal contaminants in 38 of 54 wells sampled in Clinton County (Figure 2.1). Concentration data were not available for 16 wells. Table 2 includes a summary of the USGS water quality samples, highlighting the number of wells that were below the detection limit, as well as the minimum, 25th percentile, median, 75th percentile, and maximum concentration detected for a given contaminant. Table 2 also provides the Maximum Contaminant Level (MCL) for a contaminant in drinking water as designated by the U.S. EPA, or a recommended Secondary Maximum Contaminant Level (SMCL) when applicable. Figure 2.2 presents a panel of box and whisker plots of individual contaminant data for 9 metals with MCLs or SMCLs. These plots correspond to the tabular data in Table 2. Figure 2.3 is a bar chart that depicts the percent of wells that exceeded MCLs or SMCLs.

Table 2: Summary of USGS Water Quality Samples, Clinton County, 2017 (N=38 wells)

Contaminant	# Below Detection Limit (of 38 wells sampled)	Detection Limit	Minimum Level Detected	25th Percentile	Median	75th Percentile	Maximum Level Detected	MCL or *SMCL
Aluminum	34	3	4.1	4.2	4.6	4.9	5.0	*50
Antimony	24	0.03	0.03	0.03	0.04	0.05	0.19	6
Arsenic	6	0.05	0.06	0.08	0.20	0.42	4.50	10
Barium	0	NA	15.1	36.7	55.7	151.5	496.0	2,000
Beryllium	32	0.01	0.01	0.02	0.03	0.06	0.07	4
Boron	11	5	5	8	15	67	149	NA
Cadmium	36	0.03	0.09	0.09	0.09	0.09	0.09	5
Calcium	0	NA	3,170	13,425	29,850	60,125	140,000	NA
Chromium	37	0.5	0.51	0.51	0.51	0.51	0.51	100
Cobalt	13	0.03	0.03	0.03	0.05	0.20	7.64	NA
Copper	5	0.2	0.3	2.1	4.0	20.9	127.0	*1,300
Iron	17	5	10.8	19.7	30.1	386.5	10,100.0	*300
Lead	8	0.02	0.02	0.08	0.19	0.36	3.46	15
Lithium	0	NA	0.27	0.79	6.70	20.03	72.10	NA
Magnesium	0	NA	1,130	3,653	7,745	13,650	41,800	NA
Manganese	10	0.4	0.7	1.6	13.7	151.9	1830.0	*50
Molybdenum	10	0.05	0.06	0.15	0.21	0.54	1.35	NA
Nickel	17	0.2	0.22	0.44	0.83	2.80	6.00	100
Potassium	0	NA	540	1,023	1,305	1,590	2,590	NA
Selenium	16	0.05	0.05	0.08	0.11	0.17	1.50	50
Silver	38	1	NA	NA	NA	NA	NA	*100
Sodium	0	NA	330	1,723	8,635	21,650	67,500	NA
Strontium	0	NA	5.7	56.0	201.0	422.5	2910.0	NA
Zinc	8	2	2.1	3.9	8.6	22.2	268.0	*5,000

Note: All concentration data are reported in micrograms per liter (µg/L) or parts per billion (ppb). NA is used for any missing or unavailable values.

Figure 2.2: Distribution of Contaminant Concentrations Among Clinton County Wells

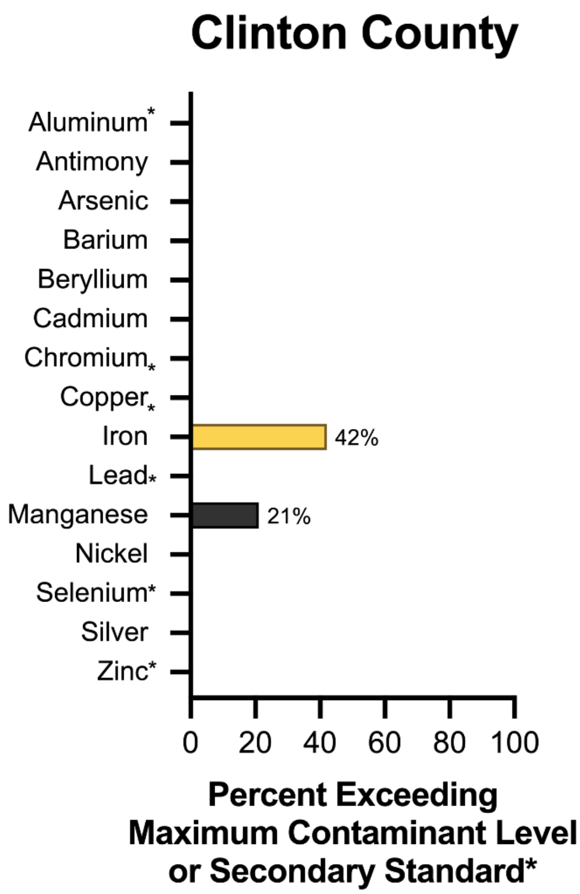


Note: N=38 wells in Clinton County. Dashed red lines indicate the median values. The value in parentheses is a contaminants MCL or *SMCL. Wells below the detection limit for a given contaminant were excluded. See Appendix for additional metal panels.

Among 38 wells tested by USGS in Clinton County in 2017, all the metal contaminants explored were found at concentrations below designated MCLs. The recommended SMCLs were exceeded in 4% of wells for aluminum, 21% for manganese, and 42% for iron (Figure 2.3).

Individuals may be exposed to multiple metal contaminants in drinking water. Clinton County wells showed statistically significant strong positive correlations greater than 0.75 between the following contaminant pairs: copper and lead, and iron and manganese (see Appendix). These relationships can be interpreted, for example, that the presence of copper may also indicate the presence of lead in a water sample.

Figure 2.3: Percent of Clinton County Wells Exceeding Regulatory Standards



Note: N=38 wells in Clinton County. * Denotes metals with a secondary standard (SMCL).

Water quality data collected from Clinton County in 2017 shows that wells did not exceed MCLs for toxic chemicals. However, well owners in this region should be aware of potential exposure to toxic metals, as their concentrations can fluctuate based upon weather, well condition, and changes in local industrial activity. Having wells tested on a yearly basis will help ensure that unwanted exposure does not occur. Additionally, the 38 wells explored here is a small sample of all Clinton County wells and may not have captured trends in the presence of toxic metals throughout the county. Iron and manganese also exceeded secondary standards in a portion of the wells tested. Three wells exceeded the SMCLs for both iron and manganese. Iron, which exceeded secondary standards in nearly half of the wells, may be released naturally into groundwater from rocks, or from other sources such as industrial waste or corroding metal (Water Science School, 2018).

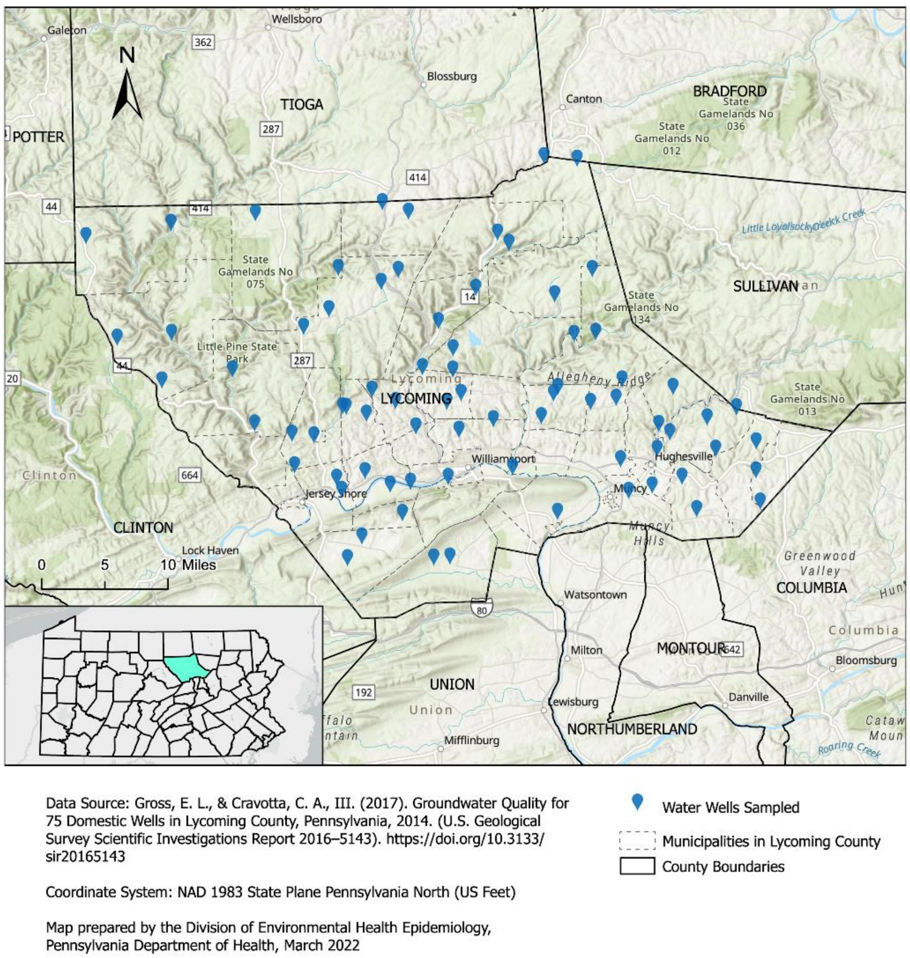
Exposure to iron in drinking water is not typically hazardous to health, however it may stain clothes and alter the taste of water. It should be noted that a rare inherited disease called hemochromatosis is associated with iron overload in a small percentage of persons. Individuals with this condition should limit their iron intake, including via drinking water, in consultation with their health care provider. Similarly, manganese can alter taste, cause scaling on plumbing, and stain laundry (Swistock et al., 2019). Exposure in drinking water is generally nontoxic, but long-term exposure to high levels may have neurological impacts (ATSDR, 2012).

In Clinton County, high levels of iron may also indicate increased levels of manganese. Additionally, a high level of copper may also reflect a high level of lead. No level of lead is safe, so it is especially important to monitor, as it can cause neurological impairment, notably in children (Ramírez Ortega et al., 2021). Depending on the age of the home, water may travel through copper and lead pipes to the faucet. This has the potential of increasing exposure concentrations compared to what was reported here. The best way to ensure safe drinking water for Clinton County well owners and their families is to be aware of chemical contaminants found in well water and their potential adverse health or aesthetic effects, test water quality regularly, and reach out to the PA DOH with any additional concerns.

Lycoming County Findings

Lycoming County is a northcentral county of Pennsylvania, bordering nine PA counties, with a population of approximately 114,000 residents as of the 2020 Decennial Census. It is home to natural gas extraction and manufacturing companies, including paving, plastics, and motor vehicles (PA DOH, 2022b). There are 992 unconventional oil and natural gas wells in the county (as of 5/31/2022, fifth highest among PA counties) (PA DEP, 2022). Lycoming is Pennsylvania's largest county in land area (approximately 1,228 square miles), much of which is heavily forested. The county's geological features consist of northern broad hillside and shallow valleys and southern deep angular valleys. The region's bedrock primarily consists of shale, siltstone, and sandstone (Gross & Cravotta, 2017). The bedrock, along with overlying deposits of silt, clay, gravel and sand, are the foundations for domestic water well drilling (Clune & Cravotta, 2019). Notably, it has been estimated that more than 40% of homeowners in Lycoming County rely on a private well (Gross & Cravotta, 2017).

Figure 3.1: Lycoming County Water Wells Sampled by USGS, 2014



Discussed below, data are presented on 24 metal and trace metal contaminants in 74 of 75 wells sampled in Lycoming County (Figure 3.1). Concentration data were not available for one well. Table 3 includes a summary of the USGS water quality samples, highlighting the number of wells that were below the detection limit, as well as the minimum, 25th percentile, median, 75th percentile, and maximum concentration detected for a given contaminant. Table 3 also provides the Maximum Contaminant Level

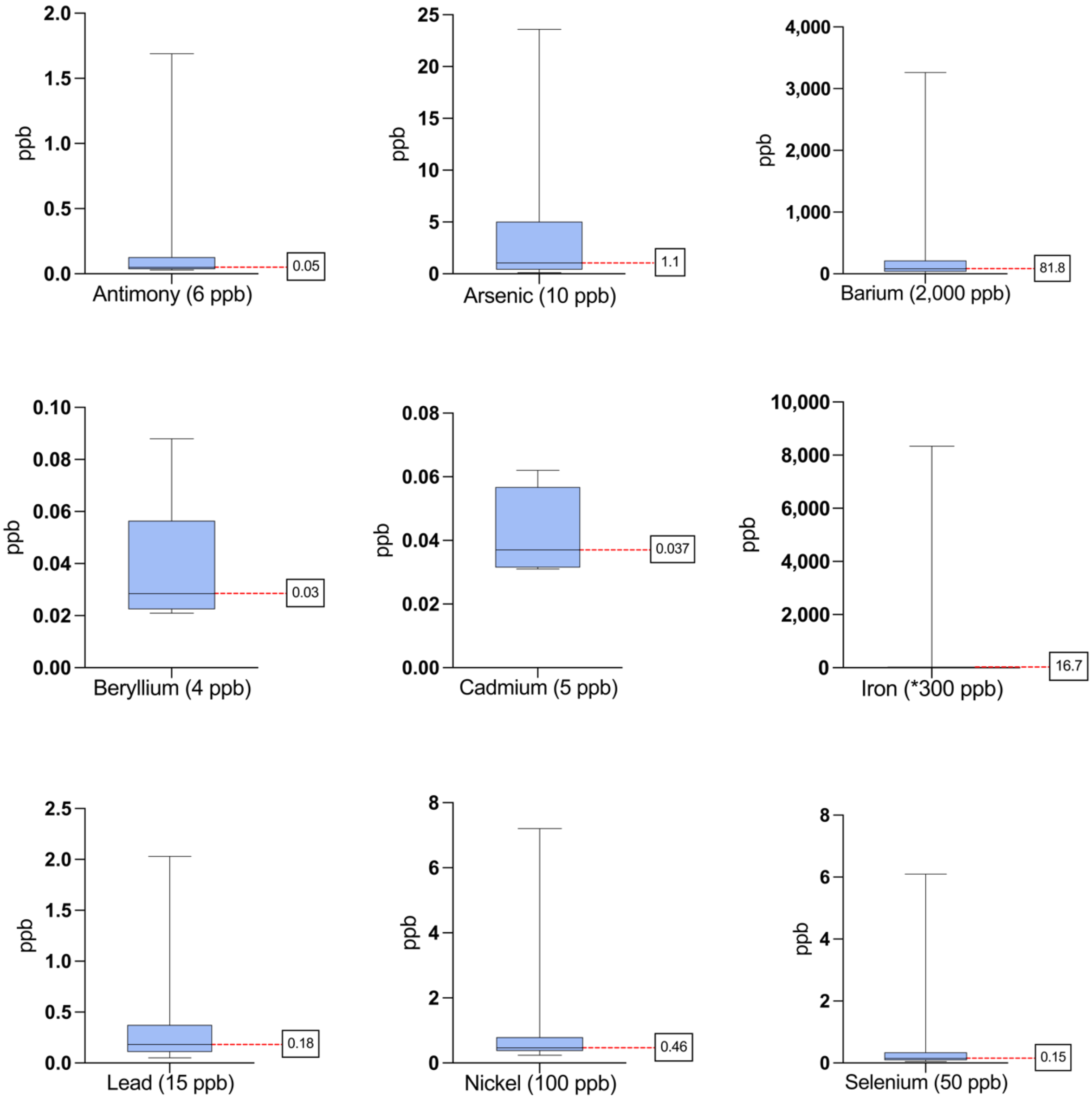
(MCL) for a contaminant in public drinking water as designated by the U.S. EPA, or a recommended Secondary Maximum Contaminant Level (SMCL), when applicable. Figure 3.2 presents a panel of box and whisker plots of individual contaminant data for 9 metals with MCLs or SMCLs. These plots correspond to the tabular data in Table 3. Figure 3.3 is a bar chart that depicts the percent of wells that exceeded MCLs or SMCLs.

Table 3: Summary of USGS Water Quality Samples, Lycoming County, 2014 (N=74 wells)

Contaminant	# Below Detection Limit (of 74 wells explored)	Detection Limit	Minimum Level Detected	25th Percentile	Median	75th Percentile	Maximum Level Detected	MCL or *SMCL
Aluminum	41	2.20	2.20	3.08	4.95	8.73	38.3	*50
Antimony	39	0.027	0.029	0.036	0.049	0.128	1.690	6
Arsenic	13	0.1	0.11	0.41	1.05	5.03	23.60	10
Barium	0	NA	1.3	35.7	81.8	215.0	3,260.0	2,000
Beryllium	69	0.02	0.021	0.023	0.029	0.057	0.088	4
Boron	7	5	5.0	9.3	24.0	67.5	561.0	NA
Cadmium	71	0.03	0.031	0.032	0.037	0.056	0.062	5
Calcium	0	NA	215	10,200	18,700	30,000	88,900	NA
Chromium	73	0.3	0.34	0.34	0.66	0.98	0.98	100
Cobalt	48	0.05	0.05	0.06	0.10	0.17	5.82	NA
Copper	22	0.8	1.1	2.2	6.1	20.0	145.0	*1,300
Iron	27	4	4.3	7.6	16.7	38.8	8,340.0	*300
Lead	17	0.04	0.05	0.11	0.18	0.37	2.03	15
Lithium	0	NA	0.4	3.5	10.7	23.4	523.0	NA
Magnesium	0	NA	45	2,010	3,800	6,760	37,300	NA
Manganese	19	0.4	0.5	1.1	5.8	36.0	1,100.0	*50
Molybdenum	11	0.05	0.05	0.18	0.49	1.66	6.52	NA
Nickel	20	0.2	0.24	0.37	0.46	0.79	7.20	100
Potassium	0	NA	220	500	740	1,040	2,980	NA
Selenium	26	0.05	0.05	0.09	0.15	0.34	6.10	50
Silver	74	0.02	0.039	0.039	0.039	0.039	0.039	*100
Sodium	0	NA	490	3,710	9,500	22,600	609,000	NA
Strontium	0	NA	4.9	76.7	232.0	720.0	3,870.0	NA
Zinc	21	2	2.1	3.2	5.9	12.7	366.0	*5,000

Note: All concentration data are reported in micrograms per liter (µg/L) or parts per billion (ppb). NA is used for any missing or unavailable values.

Figure 3.2: Distribution of Contaminant Concentrations Among Lycoming County Wells

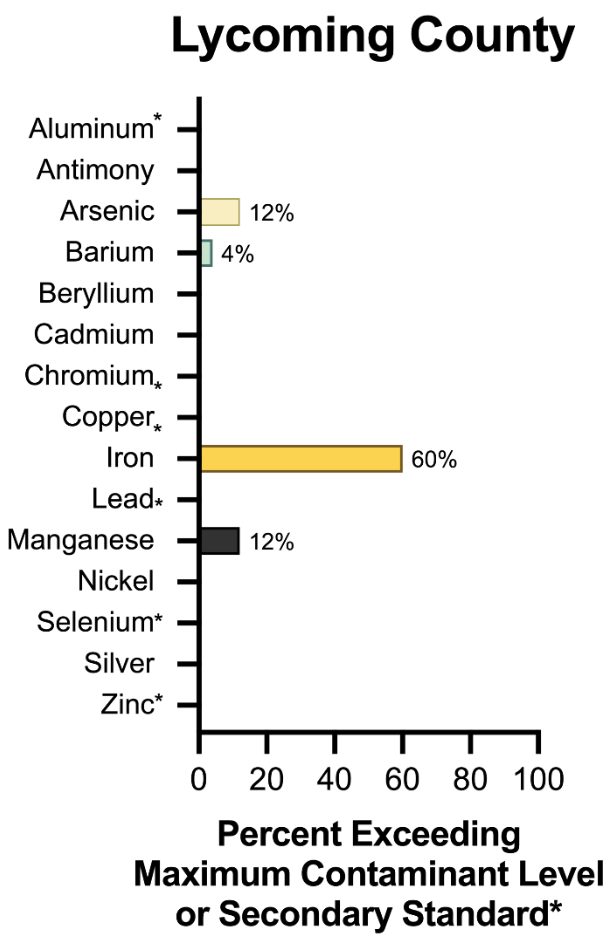


Note: N=74 wells in Lycoming County. Dashed red lines indicate the median values. The value in parentheses is a contaminants MCL or *SMCL. Wells below the detection limit for a given contaminant were excluded. See Appendix for additional metal panels.

Among the 74 wells tested by USGS in Lycoming County in 2014, the majority of metal contaminants were found at concentrations below designated MCLs. Nine wells exceeded the MCL for arsenic and three wells exceeded the MCL for barium. Additionally, the recommended SMCLs were exceeded in 12% of wells for manganese and 60% for iron (Figure 3.3).

Individuals may be exposed to multiple metal contaminants in drinking water. Lycoming County wells showed statistically significant strong positive correlations greater than 0.75 between the following pairs: boron and lithium, and boron and sodium (see Appendix). These relationships can be interpreted, for example, that the presence of boron may also indicate the presence of sodium in a water sample.

Figure 3.3: Percent of Lycoming County Wells Exceeding Regulatory Standards



Note: N=74 wells in Lycoming County. * Denotes metals with a secondary standard (SMCL).

Water quality data collected from Lycoming County wells in 2016 shows that most wells did not exceed MCLs for toxic chemicals. However, a small percentage exceeded the MCL for barium, and greater than 10% of wells tested exceeded the MCL for arsenic. These metals, especially arsenic, are known to have toxicological effects in humans (ATSDR, 2007a, 2007b). Specifically, long-term exposure to arsenic has been correlated to bladder, lung, liver, and skin cancer. Short-term exposure can lead to gastrointestinal side effects, such as nausea and vomiting (ATSDR, 2007a). Well owners in this region should be aware of potential exposure to toxic metals, as their concentrations can fluctuate based upon weather, well condition, and changes in local industrial activity. Having wells tested on a yearly basis will help ensure that unwanted exposure does not occur. Iron and manganese also exceeded secondary standards in a portion of the wells tested. Three wells exceeded the SMCLs for both iron and manganese. Iron, which exceeded secondary standards in over half of the wells, may be released naturally into groundwater from rocks, or from other sources such as industrial waste or corroding metal (Water Science School, 2018).

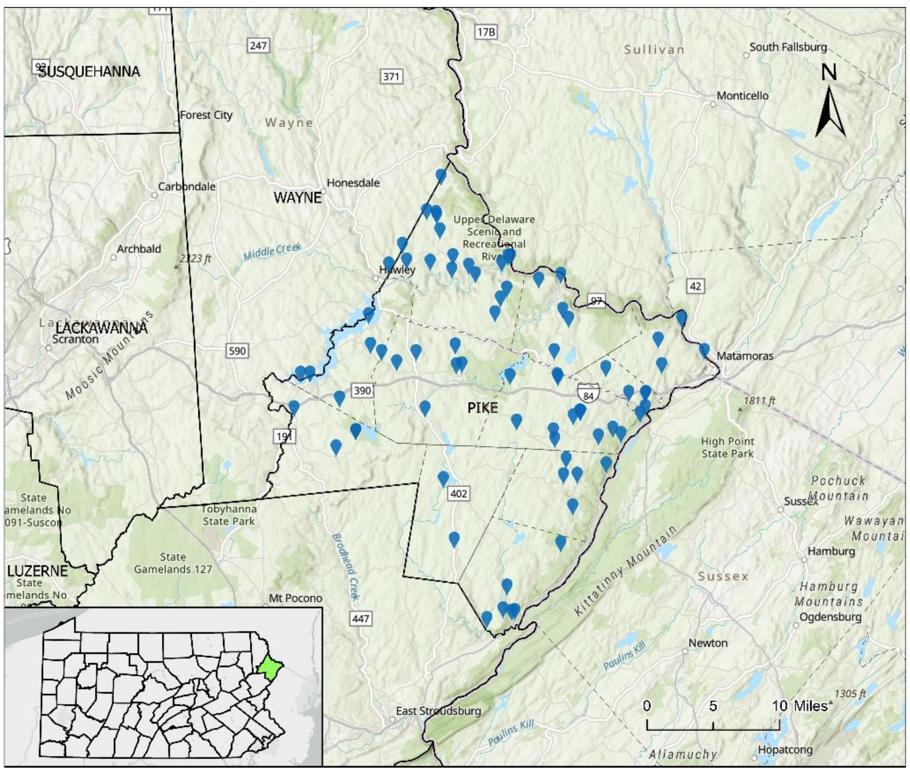
Exposure to iron in drinking water is not typically hazardous to health, however it may alter the taste of water and leave brown stains on laundered clothes. It should be noted that a rare inherited disease called hemochromatosis is associated with iron overload in a small percentage of persons. Individuals with this condition should limit their iron intake, including via drinking water, in consultation with their health care provider. Similarly, manganese can alter taste, stain laundry, and cause scaling on pluming (Swistock et al., 2019). Exposure in drinking water is generally nontoxic, but long-term exposure to high levels may have neurological impacts (ATSDR, 2012).

In Lycoming County, high levels of boron may also indicate increased levels of lithium or sodium. These metals are currently not regulated in public drinking water; however, they may still be linked to adverse health effects. For example, lithium has been associated with thyroid and kidney dysfunction (Lindsey et al., 2021). Additionally, exposure to high levels of boron over a short amount of time may negatively affect the stomach, liver, intestines, kidney or brain (ATSDR, 2010). Sodium is generally non-toxic but depending on the concentration may impact the taste of drinking water (WHO, 2015). The best way to ensure safe drinking water for Lycoming County well owners and their families is to be aware of chemical contaminants found in well water and their potential adverse health or aesthetic effects, test water quality regularly, and reach out to the PA DOH with any additional concerns.

Pike County Findings

Pike County is a northeastern county of Pennsylvania, bordering New Jersey, with a population of approximately 58,500 residents as of the 2020 Decennial Census. Pike has a land area of about 545 square miles and low population density of 107 people per square mile. It is home to the retail trade and health care industries, and industrial mineral mining, including iron (PA DOH, 2022b). With a goal of protecting its recreation and farmland, Pike County has preservation programs for its agricultural and natural environments (Pike County, PA, n.d.). The bedrock underlying Pike County consists of Marcellus Shale, with thickness that promotes its use for gas production, increasing from east to west (Senior & Cravotta, 2017). The bedrock, along with overlying glacial deposits, provides the main groundwater source for drinking water. Notably, oil and gas development has not occurred in the county due to a moratorium by the Delaware River Basin Commission.

Figure 4.1: Pike County Water Wells Sampled by U.S. Geological Survey, 2015



Data Source: Senior, L. A., & Cravotta, C. A., III. (2017). Baseline Assessment of Groundwater Quality in Pike County, Pennsylvania, 2015. (U.S. Geological Survey Scientific Investigations Report 2017–5110). https://doi.org/10.3133/sir20175110

Coordinate System: NAD 1983 State Plane Pennsylvania North (US Feet)

Map prepared by the Division of Environmental Health Epidemiology, Pennsylvania Department of Health, March 2022

Water Wells Sampled
Municipalities in Pike County
County Boundaries

Discussed below, data are presented on 24 metal and trace metal contaminants in 75 of 79 wells sampled in Pike County (Figure 4.1). Concentration data were not available for four wells. Table 4 includes a summary of the USGS water quality samples, highlighting the number of wells that were below the detection limit, as well as the minimum, 25th percentile, median, 75th percentile, and maximum concentration detected for a given contaminant. Table 4 also provides the Maximum Contaminant Level (MCL) for a contaminant in public drinking water as designated by the U.S. EPA, or a recommended

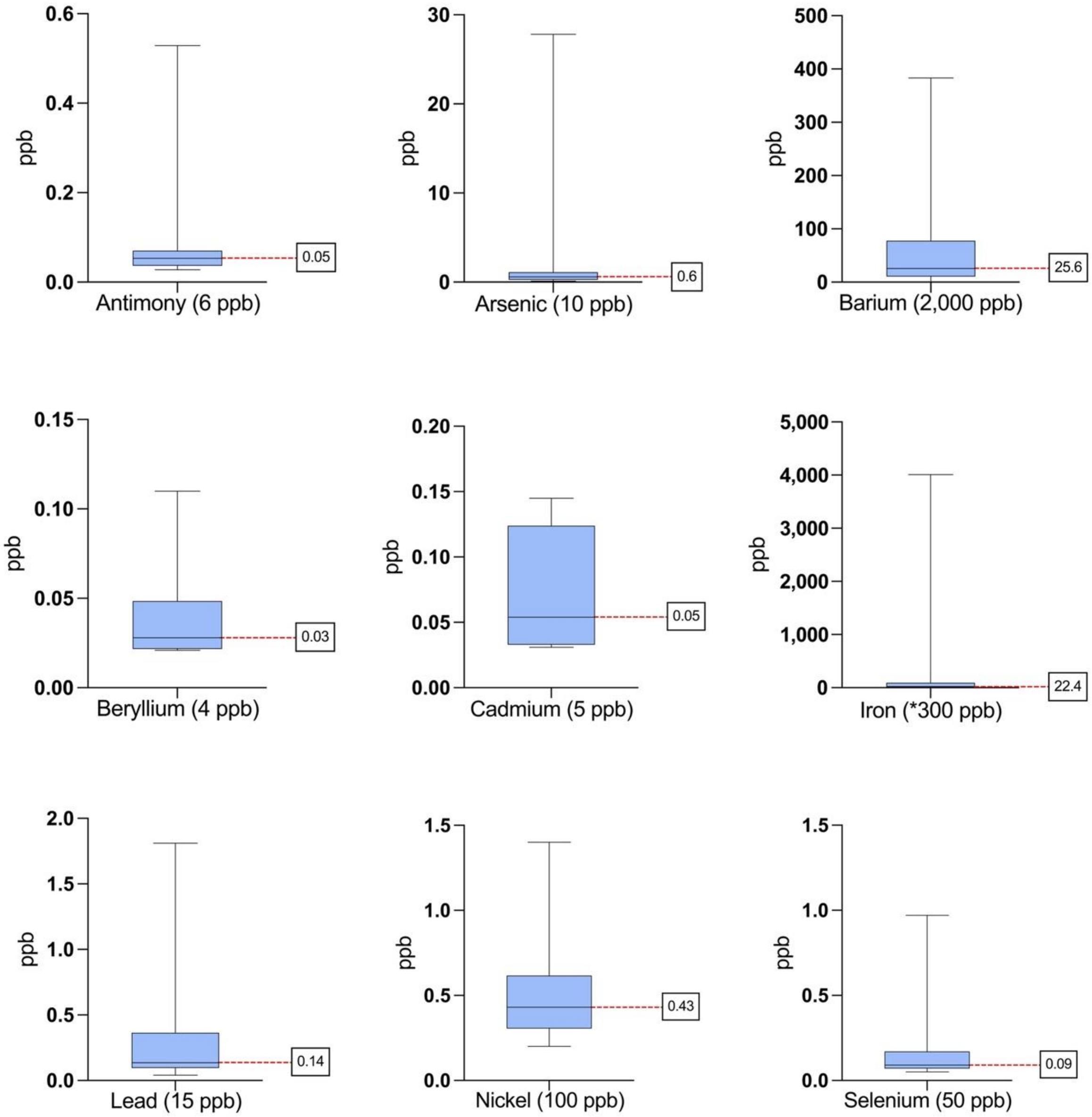
Secondary Maximum Contaminant Level (SMCL), when applicable. Figure 4.2 presents a panel of box and whisker plots of individual contaminant data for 9 metals with MCLs or SMCLs. These plots correspond to the tabular data in Table 4. Figure 4.3 is a bar chart that depicts the percent of wells that exceeded MCLs or SMCLs.

Table 4: Summary of USGS Water Quality Samples, Pike County, 2015 (N=75 wells)

Contaminant	# Below Detection Limit (of 75 wells explored)	Detection Limit	Minimum Level Detected	25th Percentile	Median	75th Percentile	Maximum Level Detected	MCL or *SMCL
Aluminum	46	3	3.1	3.7	9.2	29.5	402.0	*50
Antimony	35	0.027	0.028	0.037	0.054	0.071	0.529	6
Arsenic	11	0.1	0.12	0.27	0.59	1.10	27.80	10
Barium	0	NA	0.5	10.6	25.6	77.7	383.0	2,000
Beryllium	65	0.02	0.021	0.022	0.028	0.049	0.110	4
Boron	12	5	5	8	14	25	651	NA
Cadmium	66	0.03	0.031	0.033	0.054	0.124	0.145	5
Calcium	0	NA	4,230	10,600	17,600	25,700	103,000	NA
Chromium	75	0.3	NA	NA	NA	NA	NA	100
Cobalt	37	0.05	0.051	0.066	0.112	0.194	2.760	NA
Copper	35	0.8	0.8	1.9	3.3	8.7	61.8	*1,300
Iron	24	4	4.2	8.8	22.4	95.4	4,010.0	*300
Lead	20	0.04	0.041	0.095	0.135	0.364	1.810	15
Lithium	0	NA	1.6	4.7	10.5	24.6	1,080.0	NA
Magnesium	0	NA	810	3,380	5,330	7,290	32,200	NA
Manganese	10	0.4	0.4	3.3	14.1	99.8	963.0	*50
Molybdenum	23	0.05	0.06	0.08	0.19	0.43	1.99	NA
Nickel	45	0.2	0.20	0.31	0.43	0.62	1.40	100
Potassium	0	NA	190	430	590	790	1,770	NA
Selenium	40	0.05	0.05	0.07	0.09	0.17	0.97	50
Silver	75	NA	NA	NA	NA	NA	NA	*100
Sodium	0	NA	1,370	6,660	9,700	17,900	283,000	NA
Strontium	0	NA	10.8	62.9	238.0	513.0	3,420.0	NA
Zinc	37	2	2.0	2.9	4.8	8.3	43.6	*5,000

Note: All concentration data are reported in micrograms per liter (μg/L) or parts per billion (ppb). NA is used for any missing or unavailable values.

Figure 4.2: Distribution of Contaminant Concentrations Among Pike County Wells

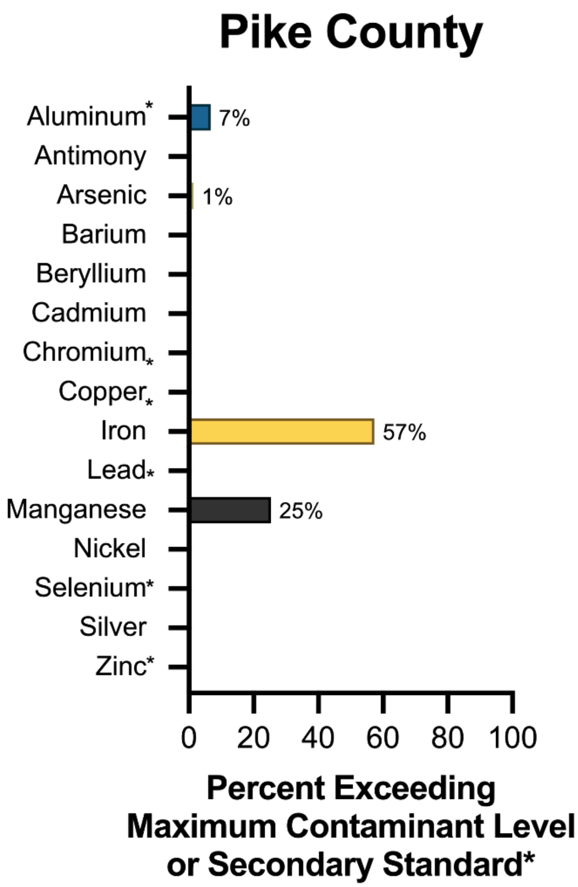


Note: N=75 wells in Pike County. Dashed red lines indicate the median values. The value in parentheses is a contaminants MCL or *SMCL. Wells below the detection limit for a given contaminant were excluded. See Appendix for additional metal panels.

Among the 75 wells tested by USGS in Pike County in 2015, most metal contaminants were found at concentrations below designated MCLs. Only one well exceeded the MCL for arsenic. Additionally, the SMCLs were exceeded in 7% of wells for aluminum, 25% for manganese, and 57% for iron (Figure 4.3).

Individuals may be exposed to multiple metal contaminants in drinking water. Pike County wells showed statistically significant strong positive correlations greater than 0.75 between the following pairs: boron and lithium, iron and manganese, and lithium and strontium (see Appendix). These relationships can be interpreted, for example, that the presence of boron may also indicate the presence of lithium in a water sample.

Figure 4.3: Percent of Pike County Wells Exceeding Regulatory Standards



Note: N=75 wells in Pike County. * Denotes metals with a secondary standard (SMCL).

Water quality data collected from Pike County wells in 2015 shows that most wells did not exceed MCLs for toxic chemicals. However, one well did exceed the MCL for arsenic, which is known to have toxicological effects in humans (ATSDR, 2007a). Specifically, long-term exposure to arsenic has been correlated to bladder, lung, liver, and skin cancer. Short-term exposure can lead to gastrointestinal side effects, such as nausea and vomiting (ATSDR, 2007a). Well owners in this region should be aware of potential exposure to toxic metals, as their concentrations can fluctuate based upon weather, well condition, and changes in local industrial activity. Having wells tested on a yearly basis will help ensure that unwanted exposure does not occur. Iron and manganese also exceeded secondary standards in a portion of the wells tested. Eight wells exceeded the SMCLs for both iron and manganese. Iron, which exceeded secondary standards in nearly half of the wells, may be released naturally into groundwater from rocks, or from other sources such as industrial waste or corroding metal (Water Science School, 2018).

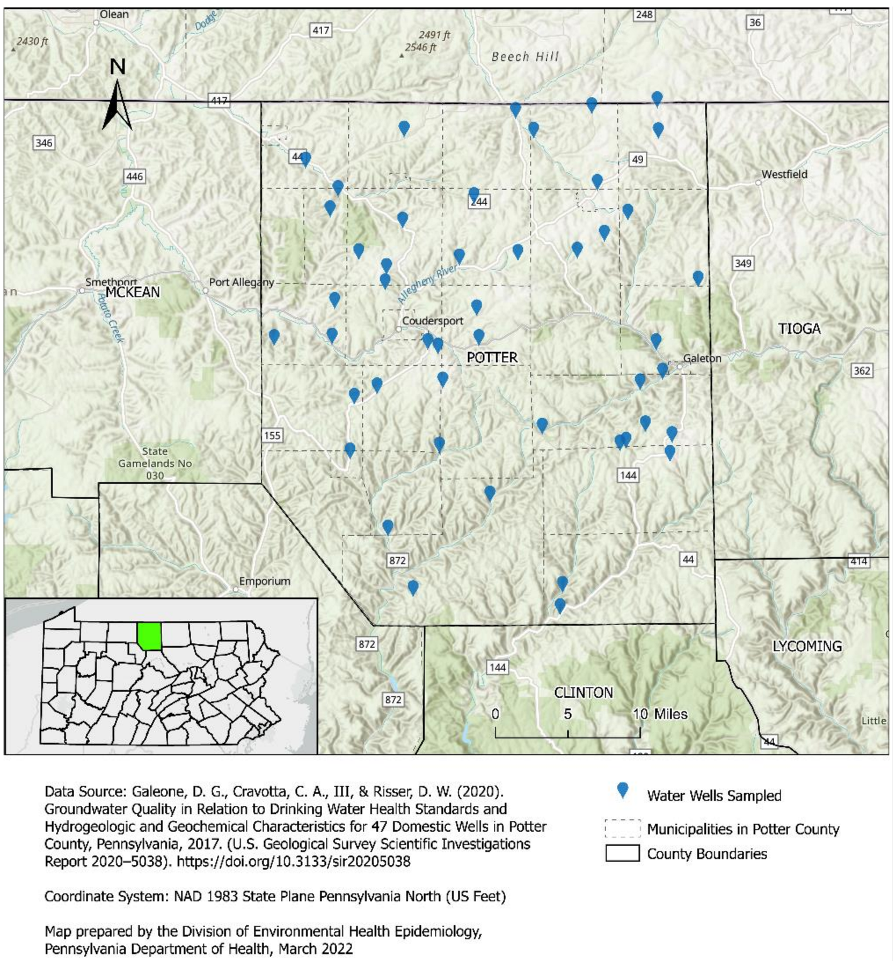
Exposure to iron in drinking water is not typically hazardous to health, however it may alter the taste of water and leave brown stains on laundered clothes. It should be noted that a rare inherited disease called hemochromatosis is associated with iron overload in a small percentage of persons. Individuals with this condition should limit their iron intake, including via drinking water, in consultation with their health care provider. Similarly, manganese can alter taste, cause scaling on plumbing, and stain laundry (Swistock et al., 2019). Exposure in drinking water is generally nontoxic, but long-term exposure to high levels may have neurological impacts (ATSDR, 2012).

In Pike County, high levels of lithium may also indicate increased levels of boron or strontium. Additionally, a high level of iron may also reflect a high level of manganese. Lithium and boron are currently unregulated in drinking water, however their levels should still be monitored as they are known to affect certain organs, such as the kidney (ATSDR, 2010; Lindsey et al., 2021). The best way to ensure safe drinking water for Pike County well owners and their families is to be aware of chemical contaminants found in well water and their potential adverse health or aesthetic effects, test water quality regularly, and reach out to the PA DOH with any additional concerns.

Potter County Findings

Potter County is a northcentral county of Pennsylvania, bordering New York State, with a population of approximately 16,400 residents as of the 2020 Decennial Census. With a land area of about 1,081 square miles and 16 people per square mile, the county has the third lowest population density in the state. It is home to manufacturing of rubber and plastics, and hazardous waste operations (PA DOH, 2022b). The county has 85 unconventional oil and natural gas wells (PA DEP, 2022). With only two percent of its land developed, most (78%) of Potter County is forested and has numerous state parks (Galeone et al., 2020) The Appalachian Plateau province within the county is primarily composed of bedrock consisting of shale, siltstone, and sandstone. Shallow bedrock along with overlying deposits of silt, clay, gravel and sand are the primary sources of groundwater for Potter County (Galeone et al., 2020). Notably, it has been estimated that more than 68% of homeowners in Potter County rely on a private well (Galeone et al., 2020).

Figure 5.1: Potter County Water Wells Sampled by USGS, 2017



Discussed below, data are presented on 24 metal and trace metal contaminants in 47 wells sampled in Potter County (Figure 5.1). Table 5 includes a summary of the USGS water quality samples, highlighting the number of wells below the detection limit, as well as the minimum, 25th percentile, median, 75th percentile, and maximum concentration detected for a given contaminant. Table 5 also provides the Maximum Contaminant Level (MCL) for a contaminant in public drinking water as designated by the

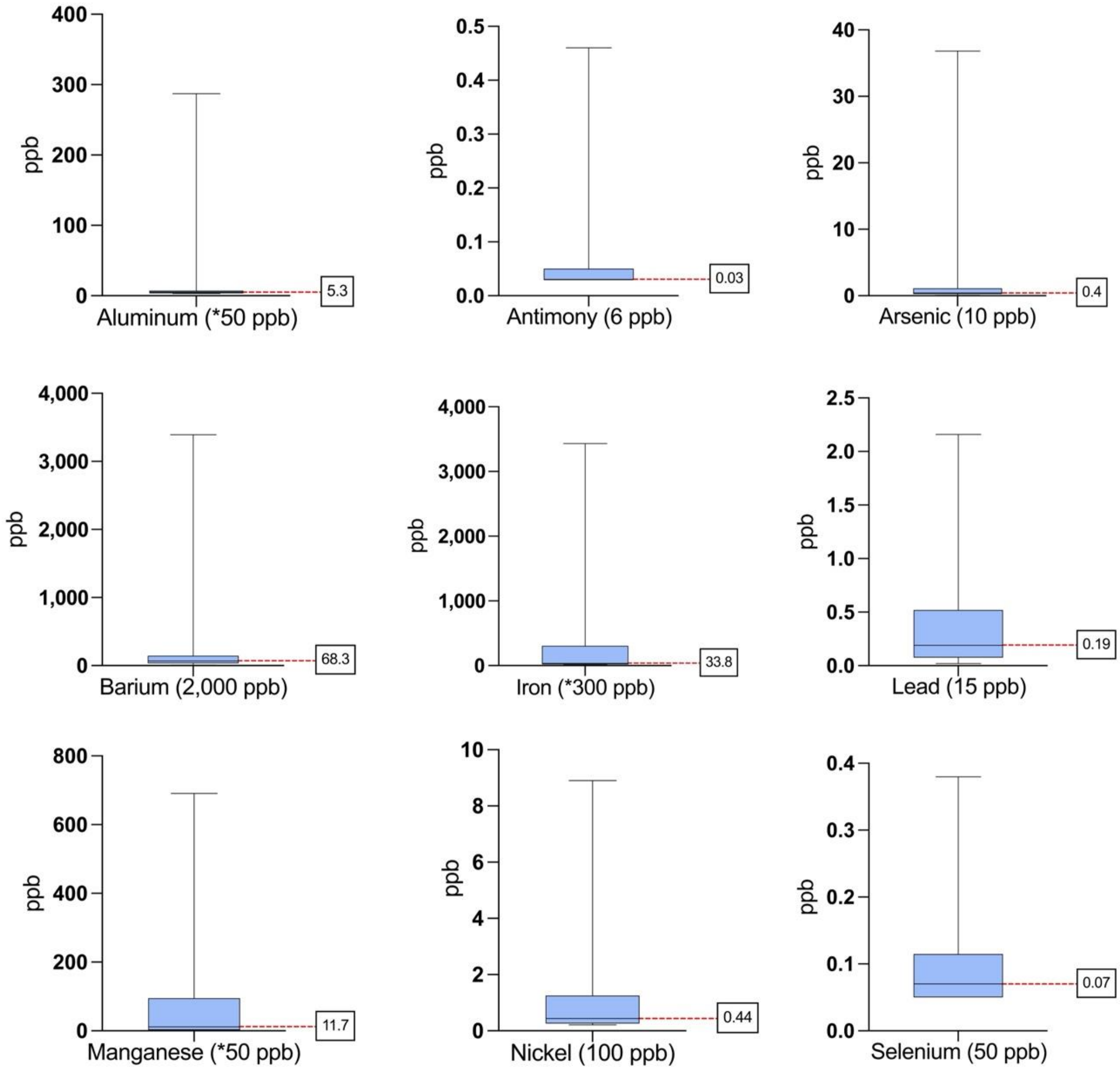
U.S. EPA, or a recommended Secondary Maximum Contaminant Level (SMCL), when applicable. Figure 5.2 presents a panel of box and whisker plots of individual contaminant data for 9 metals with MCLs or SMCLs. These plots correspond to the tabular data in Table 5. Figure 5.3 is a bar chart that depicts the percent of wells that exceeded MCLs or SMCLs.

Table 5: Summary of USGS Water Quality Samples, Potter County, 2017 (N=47 wells)

Contaminant	# Below Detection Limit (of 47 wells explored)	Detection Limit	Minimum Level Detected	25th Percentile	Median	75th Percentile	Maximum Level Detected	MCL or *SMCL
Aluminum	35	3	3.2	3.6	5.3	7.2	287.0	*50
Antimony	29	0.03	0.03	0.03	0.03	0.05	0.46	6
Arsenic	1	0.05	0.09	0.24	0.43	1.13	36.80	10
Barium	0	NA	8.9	36.2	68.3	145.0	3,390.0	2,000
Beryllium	45	0.01	0.01	0.01	0.04	0.06	0.06	4
Boron	4	5	5	8	18	64	246	NA
Cadmium	46	0.03	0.04	0.04	0.04	0.04	0.04	5
Calcium	0	NA	1,650	7,860	14,300	23,700	89,200	NA
Chromium	46	0.3	0.54	0.54	0.54	0.54	0.54	100
Cobalt	29	0.03	0.03	0.04	0.08	0.28	4.57	NA
Copper	6	0.2	0.21	2.65	6.40	18.10	66.80	*1,300
Iron	28	10	11.4	17.6	33.8	306.0	3,430.0	*300
Lead	6	0.02	0.02	0.08	0.19	0.52	2.16	15
Lithium	0	NA	0.47	2.79	8.22	27.60	86.30	NA
Magnesium	0	NA	480	2,440	4,160	7,690	23,400	NA
Manganese	11	0.4	0.4	2.0	11.7	95.2	691.0	*50
Molybdenum	13	0.05	0.05	0.12	0.29	0.53	2.29	NA
Nickel	23	0.2	0.21	0.26	0.44	1.25	8.90	100
Potassium	0	NA	650	810	1,130	1,330	4,170	NA
Selenium	26	0.05	0.05	0.05	0.07	0.12	0.38	50
Silver	47	1	NA	NA	NA	NA	NA	*100
Sodium	0	NA	500	3,060	8,200	26,000	105,000	NA
Strontium	0	NA	9.3	37.6	78.3	287.0	1,470.0	NA
Zinc	8	2	2.0	4.4	8.0	20.1	1,220.0	*5,000

Note: All concentration data are reported in micrograms per liter (µg/L) or parts per billion (ppb). NA is used for any missing or unavailable values.

Figure 5.2: Distribution of Contaminant Concentrations Among Potter County Wells

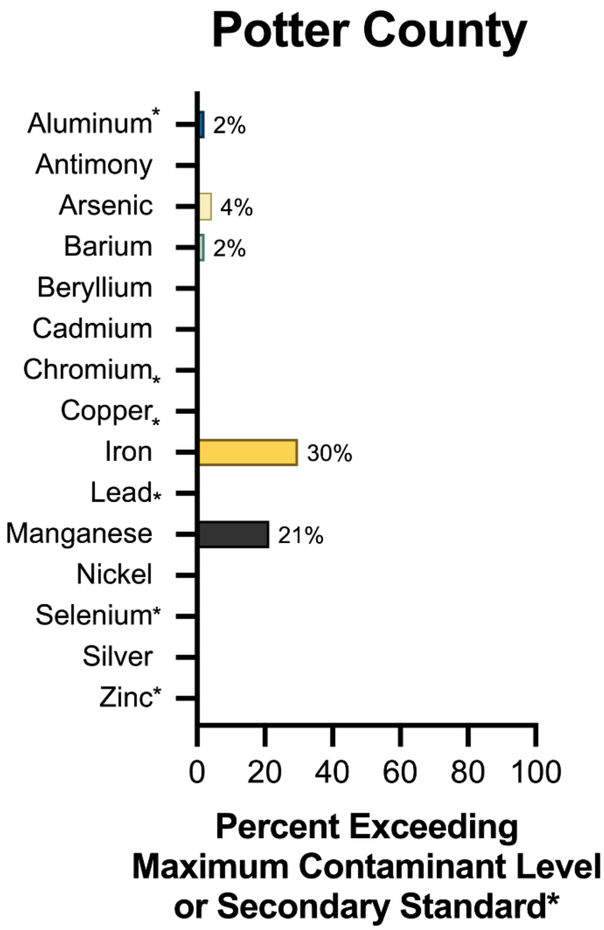


Note: N=47 wells in Potter County. Dashed red lines indicate the median values. The value in parentheses is a contaminants MCL or *SMCL. Wells below the detection limit for a given contaminant were excluded. See Appendix for additional metal panels.

Among the 47 wells tested by USGS in Potter County in 2017, most metal contaminants were found at concentrations below designated MCLs. Two wells exceeded the MCL for arsenic, and one well exceeded the MCL for barium. Additionally, the recommended SMCLs were exceeded in 2% of wells for aluminum, 21% for manganese, and 30% for iron (Figure 5.3).

Individuals may be exposed to multiple metal contaminants in drinking water. Potter County wells showed statistically significant strong positive correlations greater than 0.75 between the following pairs: boron and lithium, boron and molybdenum, boron and sodium, boron and strontium, calcium and magnesium, calcium and potassium, lithium and molybdenum, lithium and strontium, molybdenum and strontium, potassium and strontium, and sodium and strontium (see Appendix). These relationships can be interpreted, for example, that the presence of calcium may also indicate the presence of magnesium in a water sample

Figure 5.3: Percent of Potter County Wells Exceeding Regulatory Standards



Note: N=47 wells in Potter County. * Denotes metals with a secondary standard (SMCL).

Water quality data collected from Potter County wells in 2017 shows that most wells did not exceed MCLs for toxic chemicals. However, a small percentage still exceeded MCLs for arsenic and barium which are known to have toxicological effects in humans (ATSDR, 2007a, 2007b). Specifically, long-term exposure to arsenic has been correlated to bladder, lung, liver, and skin cancer. Short-term exposure can lead to gastrointestinal side effects, such as nausea and vomiting (ATSDR, 2007a). Three wells exceeded MCLs or SMCLs for two contaminants. Additionally, one well exceeded MCLs or SMCLs for three contaminants. Well owners in this region should be aware of potential exposure to toxic metals, as their concentrations can fluctuate based upon weather, well condition, and changes in local industrial activity. Having wells tested on a yearly basis will help ensure that unwanted exposure does not occur. Iron and manganese also exceeded secondary standards in a portion of the wells tested. Iron, which exceeded secondary standards in about one third of the wells, may be released from industrial waste or corroding metal, or naturally from bedrock (Water Science School, 2018).

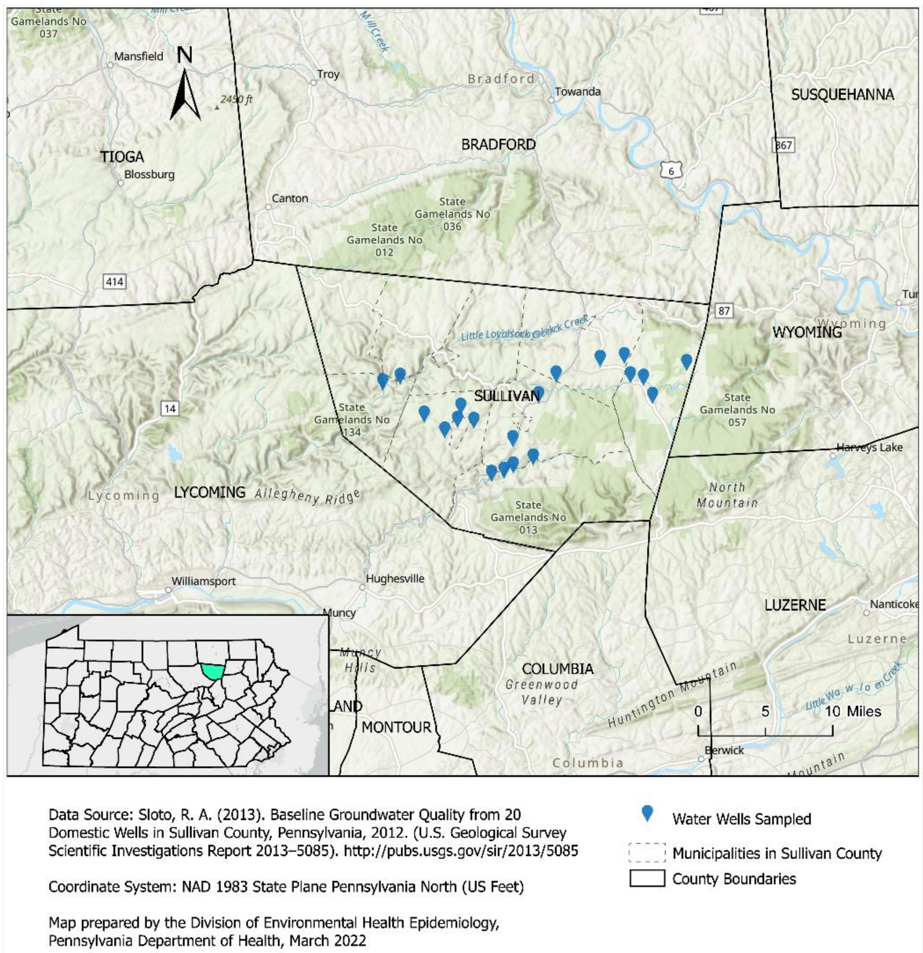
Exposure to iron in drinking water is not typically hazardous to health, however it may alter the taste of water and leave brown stains on laundered clothes. It should be noted that a rare inherited disease called hemochromatosis is associated with iron overload in a small percentage of persons. Individuals with this condition should limit their iron intake, including via drinking water, in consultation with their health care provider. Similarly, manganese can alter taste, cause scaling on plumbing, and stain laundry (Swistock et al., 2019). Exposure in drinking water is generally nontoxic, but long-term exposure to high levels may have neurological impacts (ATSDR, 2012).

In Potter County, a high level of calcium may also reflect a high level of magnesium. Elevated levels of magnesium and calcium will increase water hardness (mineralized water), which could result in stained fixtures and clothes, clogged plumbing, and dry skin (WHO, 2010). Additionally, strontium, which may not be included in a typical water quality report, had strong relationships to other contaminants that may be more commonly tested such as sodium and potassium. Among these wells, increases in sodium and potassium may indicate higher levels of strontium. The best way to ensure safe drinking water for Potter County well owners and their families is to be aware of chemical contaminants found in well water and their potential adverse health or aesthetic effects, test water quality regularly, and reach out to the PA DOH with any additional concerns.

Sullivan County Findings

Sullivan County is a northcentral county of Pennsylvania, bordering Wyoming, Bradford, Lycoming, and Columbia Counties, with a population of approximately 5,800 residents as of the 2020 Decennial Census. With a land area of about 450 square miles, the county has the second lowest population density of 13 people per square mile. It is home to timber and construction industries and has 155 unconventional oil and natural gas wells (PA DOH, 2022b; PA DEP, 2022). With more than 80% of the county forested, about half is devoted to state parks and game lands (Sloto, 2013). The majority of Sullivan County is located within the Appalachian Plateaus Physiographic Province, which is primarily composed of bedrock consisting of shale, siltstone, and sandstone (Sloto, 2013). The bedrock, along with overlying deposits of silt, clay, gravel and sand, is the foundation for domestic water well drilling (Clune & Cravotta, 2019).

Figure 6.1: Sullivan County Water Wells Sampled by USGS, 2012



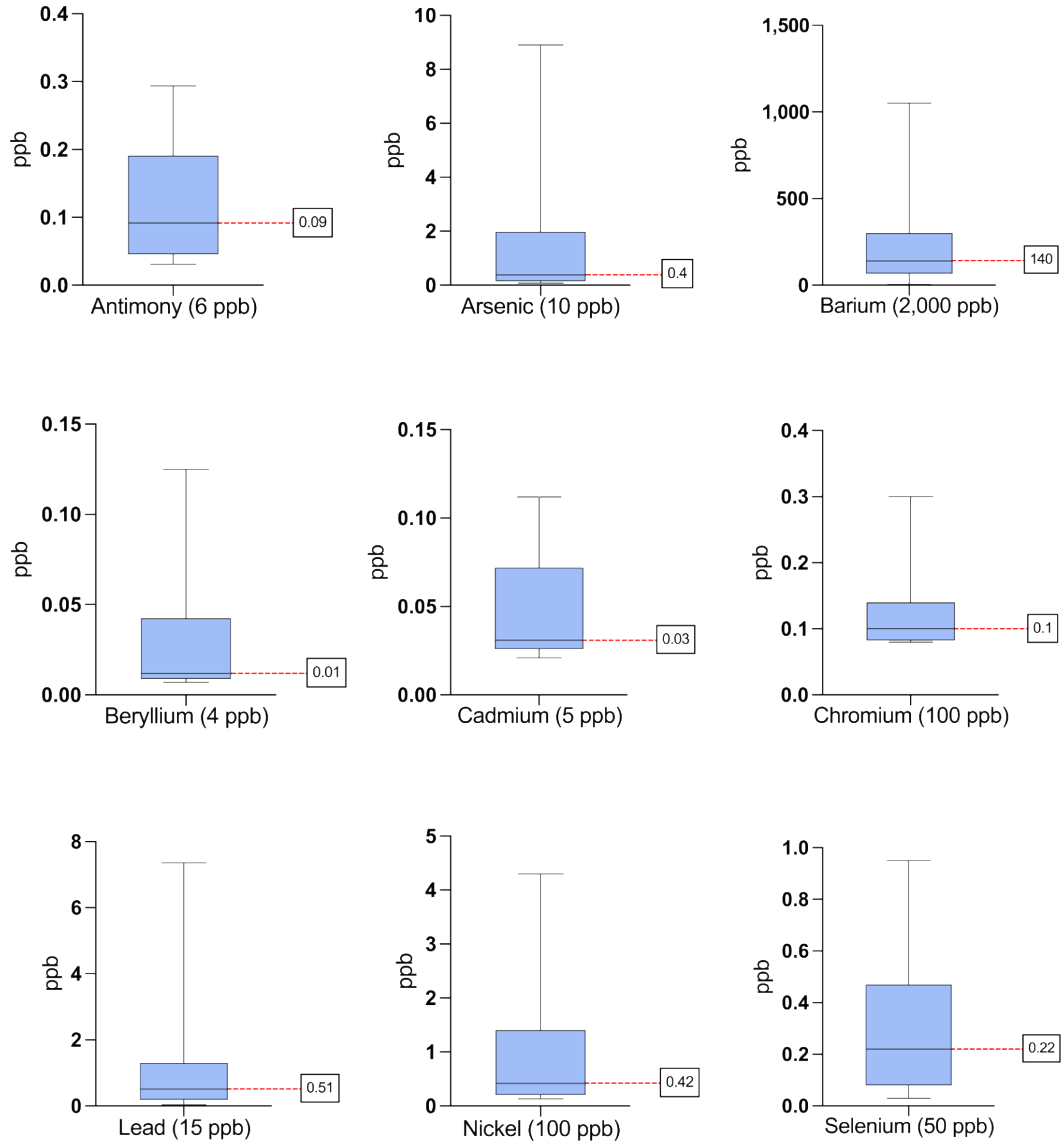
Discussed below, data are presented on 24 metal and trace metal contaminants in 20 wells sampled in Sullivan County (Figure 6.1). Table 6 includes a summary of the USGS water quality samples, highlighting the number of wells below the detection limit, as well as the minimum, 25th percentile, median, 75th percentile, and maximum concentrations detected for a given contaminant. Table 6 also provides the Maximum Contaminant Level (MCL) for a contaminant in public drinking water as designated by the U.S. EPA, or a recommended Secondary Maximum Contaminant Level (SMCL), when applicable. Figure 6.2 presents a panel of box and whisker plots of individual contaminant data for 9 metals with MCLs or SMCLs. These plots correspond to the tabular data in Table 6. Figure 6.3 is a bar chart that depicts the percent of wells that exceeded MCLs or SMCLs.

Table 6: Summary of USGS Water Quality Samples, Sullivan County, 2012 (N=20 wells)

Contaminant	# Below Detection Limit (of 20 wells explored)	Detection Limit	Minimum Level Detected	25th Percentile	Median	75th Percentile	Maximum Level Detected	MCL or *SMCL
Aluminum	12	2.2	2.4	3.7	5.7	18.4	26.3	*50
Antimony	11	0.027	0.031	0.046	0.092	0.191	0.294	6
Arsenic	2	0.03	0.08	0.16	0.38	1.98	8.90	10
Barium	0	NA	5.9	67.5	140.0	300.0	1,050.0	2,000
Beryllium	4	0.006	0.007	0.009	0.012	0.043	0.125	4
Boron	0	4	4.0	7.5	19.5	60.8	152.0	NA
Cadmium	13	0.016	0.021	0.026	0.031	0.072	0.112	5
Calcium	0	NA	2,640	15,650	25,350	29,125	41,900	NA
Chromium	12	0.07	0.08	0.08	0.10	0.14	0.30	100
Cobalt	2	0.021	0.02	0.03	0.06	0.28	8.04	NA
Copper	6	0.8	1.3	3.7	10.1	47.0	130.0	*1,300
Iron	4	3.2	4.2	6.7	21.8	465.3	6,590.0	*300
Lead	2	0.025	0.04	0.19	0.51	1.30	7.36	15
Lithium	0	NA	0.4	1.4	4.4	16.6	303.0	NA
Magnesium	0	NA	1,070	1,685	2,720	5,615	9,660	NA
Manganese	1	0.13	0.2	0.4	40.1	233.0	1,710.0	*50
Molybdenum	4	0.014	0.024	0.058	0.143	0.549	3.780	NA
Nickel	1	0.09	0.1	0.2	0.4	1.4	4.3	100
Potassium	0	NA	440	600	900	1,763	4,470	NA
Selenium	7	0.03	0.03	0.08	0.22	0.47	0.95	50
Silver	15	0.005	0.006	0.006	0.007	0.060	0.112	*100
Sodium	0	NA	420	2,405	8,075	26,300	236,000	NA
Strontium	0	NA	13.4	78.0	220.5	1,099.0	2,450.0	NA
Zinc	2	1.4	2.4	6.1	10.1	24.5	44.4	*5,000

Note: All concentration data are reported in micrograms per liter (μg/L) or parts per billion (ppb). NA is used for any missing or unavailable values.

Figure 6.2: Distribution of Contaminant Concentrations Among Sullivan County Wells

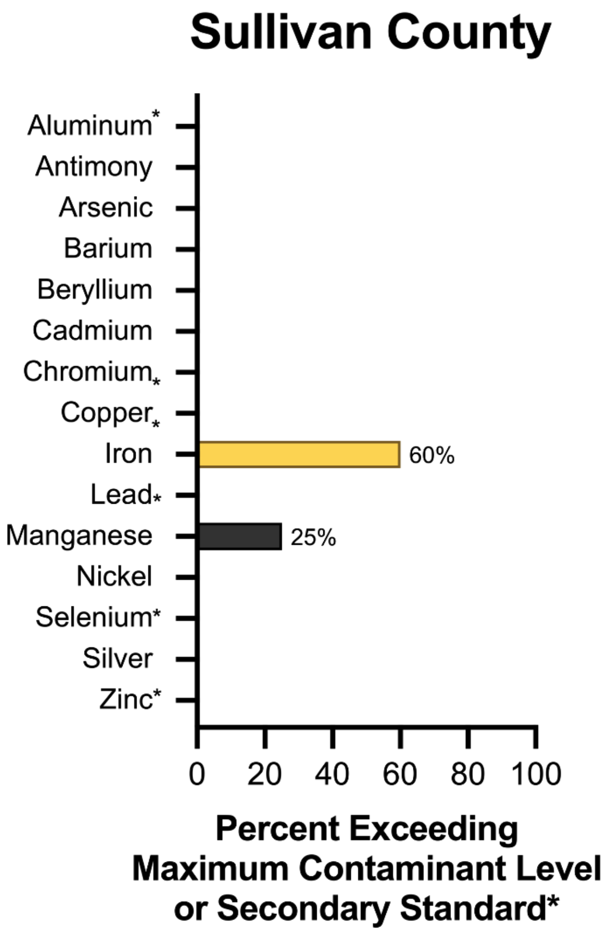


Note: N=20 wells in Sullivan County. Dashed red lines indicate the median values. The value in parentheses is a contaminants MCL or *SMCL. Wells below the detection limit for a given contaminant were excluded. See Appendix for additional metal panels.

Among the 20 wells tested by USGS in Sullivan County in 2012, all metal contaminants were found at concentrations below designated MCLs. The recommended SMCLs were exceeded in 4% of wells for aluminum, 25% for manganese, and 60% for iron (Figure 6.3).

Individuals may be exposed to multiple metal contaminants in drinking water. Sullivan County wells showed statistically significant strong positive correlations greater than 0.75 between the following pairs: arsenic and lithium, arsenic and molybdenum, barium and lithium, boron and strontium, iron and manganese, and lithium and strontium (see Appendix). These relationships can be interpreted, for example, that the presence of arsenic may also indicate the presence of lithium in a water sample.

Figure 6.3: Percent of Sullivan County Wells Exceeding Regulatory Standards



Note: N=20 wells in Sullivan County. * Denotes metals with a secondary standard (SMCL).

Water quality data collected from Sullivan County wells in 2012 shows that wells tested did not exceed MCLs for toxic chemicals. However, the sample size of 20 wells is limited, and may not capture trends for the entire county. Well owners in this region should still be aware of potential exposure to toxic metals, as their concentrations can fluctuate based upon weather, well condition, and changes in local industrial activity. Having wells tested on a yearly basis will help ensure that unwanted exposure does not occur. Iron and manganese also exceeded secondary standards in a portion of the wells tested. Three wells exceeded the SMCLs for both iron and manganese. Iron, which exceeded secondary standards in over half of the wells, may be released naturally into groundwater from rocks, or from other sources such as industrial waste or corroding metal (Water Science School, 2018).

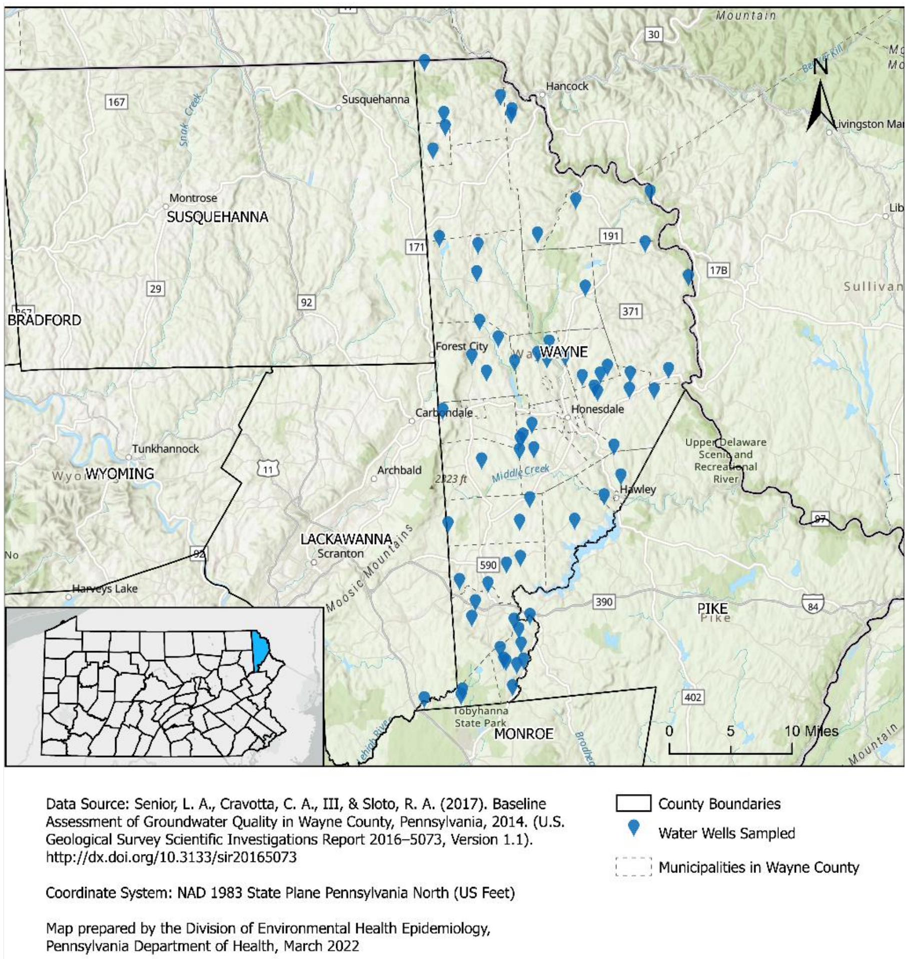
Exposure to iron in drinking water is not typically hazardous to health, however it may alter the taste of water and leave brown stains on laundered clothes. It should be noted that a rare inherited disease called hemochromatosis is associated with iron overload in a small percentage of persons. Individuals with this condition should limit their iron intake, including via drinking water, in consultation with their health care provider. Similarly, manganese can alter taste, cause scaling on plumbing, and stain laundry (Swistock et al., 2019). Exposure in drinking water is generally nontoxic, but long-term exposure to high levels may have neurological impacts (ATSDR, 2012).

In Sullivan County, high levels of lithium and molybdenum may also indicate increased levels of arsenic. This is an important relationship to be aware of, especially due to the adverse health effects associated with arsenic exposure (ATSDR, 2007a). Specifically, long-term exposure to arsenic has been correlated with bladder, lung, liver, and skin cancer. Short-term exposure can lead to gastrointestinal side effects, such as nausea and vomiting (ATSDR, 2007a). The best way to ensure safe drinking water for Sullivan County well owners and their families is to be aware of chemical contaminants found in well water and their potential adverse health or aesthetic effects, test water quality regularly, and reach out to the PA DOH with any additional concerns.

Wayne County Findings

Wayne County is a northeastern county of Pennsylvania, bordering New York State, with a population of approximately 52,800 residents as of the 2020 Decennial Census. It has a land area of about 725 square miles and corresponding low population density of 72 people per square mile. It is home to farming and lumbering industries, as well as industrial mineral mining of limestone and shale (PA DEP, 2022). Wayne County primarily consists of forests, however 22% of its land area is used for agriculture (Senior et al., 2017). Above Wayne County bedrock lies a deposit of clay, silt, and gravel, and below are Marcellus Shale and Trimmers Rock Formations. Fractured bedrock aquifers are the primary groundwater supply for private wells in Wayne County (Senior et al., 2017). Notably, oil and gas development has not occurred in the county due to a moratorium by the Delaware River Basin Commission.

Figure 7.1: Wayne County Water Wells Sampled by USGS, 2014



Discussed below, data are presented on 24 metal and trace metal contaminants in 67 of 89 wells sampled in Wayne County (Figure 7.1). Concentration data were not available for 22 wells. Table 7 includes a summary of USGS water quality samples, highlighting the number of wells below the detection limit, as well as the minimum, 25th percentile, median, 75th percentile, and maximum concentration detected for a given contaminant. Table 7 also provides the Maximum Contaminant Level (MCL) for a contaminant in public drinking water as designated by the U.S. EPA, or a recommended Secondary Maximum

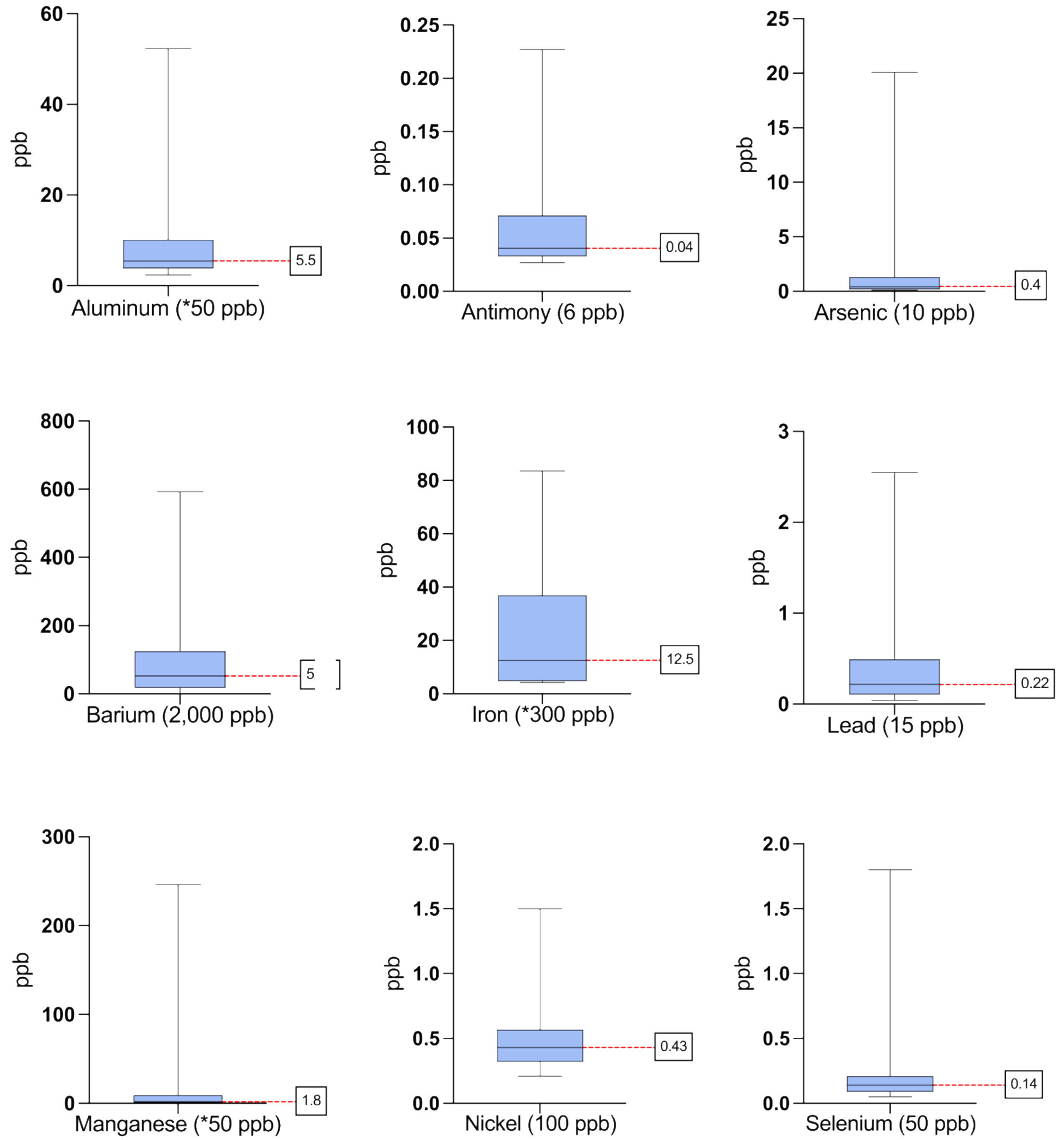
Contaminant Level (SMCL), when applicable. Figure 7.2 presents a panel of box and whisker plots of individual contaminant data for 9 metals with MCLs or SMCLs. These plots correspond to the tabular data in Table 7. Figure 7.3 is a bar chart that depicts the percent of wells that exceeded MCLs or SMCLs.

Table 7: Summary of USGS Water Quality Samples, Wayne County, 2014 (N=67 wells)

Contaminant	# Below Detection Limit (of 67 wells explored)	Detection Limit	Minimum Level Detected	25th Percentile	Median	75th Percentile	Maximum Level Detected	MCL or *SMCL
Aluminum	51	2.2	2.4	3.8	5.5	10.1	52.3	*50
Antimony	47	0.027	0.027	0.033	0.041	0.071	0.227	6
Arsenic	4	0.01	0.11	0.20	0.42	1.30	20.10	10
Barium	0	NA	1.3	17.9	52.6	125.0	592.0	2,000
Beryllium	66	0.02	0.022	0.022	0.022	0.022	0.022	4
Boron	22	5	5	8	13	28	130	NA
Cadmium	66	0.03	0.132	0.132	0.132	0.132	0.132	5
Calcium	0	NA	207	16,100	23,700	33,200	62,300	NA
Chromium	67	0.3	NA	NA	NA	NA	NA	100
Cobalt	46	0.05	0.051	0.057	0.065	0.085	0.111	NA
Copper	6	0.8	1.2	3.3	6.5	12.7	121.0	*1,300
Iron	49	4	4.2	4.75	12.5	36.9	83.5	*300
Lead	6	0.04	0.04	0.11	0.22	0.49	2.55	15
Lithium	0	NA	0.16	2.51	7.20	27.80	304.00	NA
Magnesium	0	NA	19	1,860	2,800	4,160	7,860	NA
Manganese	41	0.4	0.41	0.69	1.79	9.34	246.00	*50
Molybdenum	25	0.05	0.06	0.087	0.17	0.32	1.22	NA
Nickel	7	0.2	0.21	0.32	0.43	0.57	1.50	100
Potassium	0	NA	290	590	850	1,220	2,150	NA
Selenium	12	0.05	0.05	0.09	0.14	0.21	1.80	50
Silver	67	0.02	NA	NA	NA	NA	NA	*100
Sodium	0	NA	530	2,790	5,880	12,600	143,000	NA
Strontium	0	NA	7	48	124	577	3,040	NA
Zinc	15	2	2.0	2.6	3.8	9.8	53.0	*5,000

Note: All concentration data are reported in micrograms per liter (μg/L) or parts per billion (ppb). NA is used for any missing or unavailable values.

Figure 7.2: Distribution of Contaminant Concentrations Among Wayne County Wells

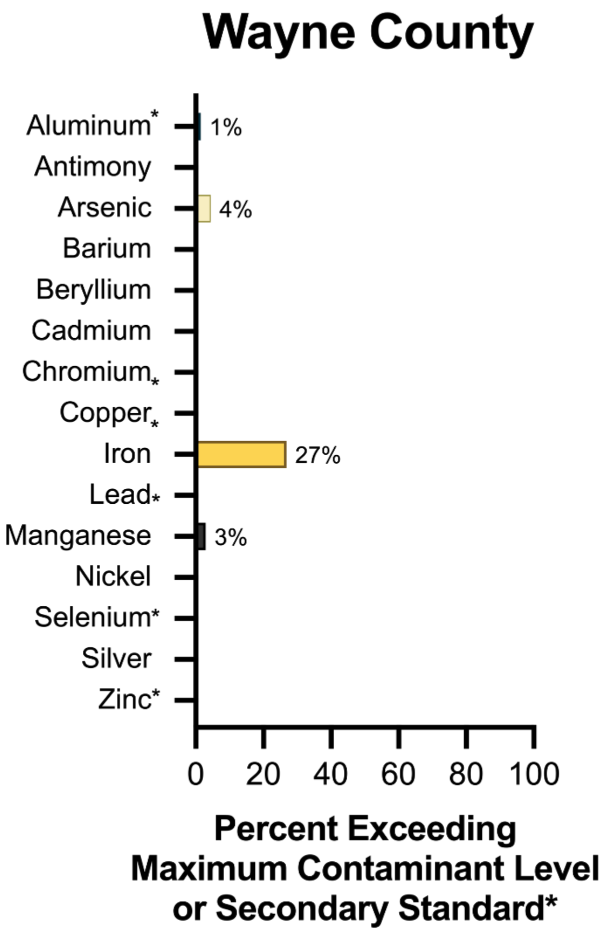


Note: N=67 wells in Wayne County. Dashed red lines indicate the median values. The value in parentheses is a contaminants MCL or *SMCL. Wells below the detection limit for a given contaminant were excluded. See Appendix for additional metal panels.

Among 67 wells tested by USGS in Wayne County in 2014 most metal contaminants were found at concentrations below designated MCLs. Specifically, three wells exceeded the MCL for arsenic. Additionally, the recommended SMCLs were exceeded in 1% of wells for aluminum, 3% for manganese, and 27% for iron (Figure 7.3).

Individuals may be exposed to multiple metal contaminants in drinking water. Wayne County wells showed statistically significant strong positive correlations greater than 0.75 between the following pairs: barium and lithium, barium and potassium, barium and strontium, boron and lithium, boron and sodium, lithium and molybdenum, lithium and potassium, lithium and sodium, lithium and strontium, molybdenum and sodium, potassium and sodium, and potassium and strontium (see Appendix). These relationships can be interpreted, for example, that the presence of barium may also indicate the presence of lithium in a water sample.

Figure 7.3: Percent of Wayne County Wells Exceeding Regulatory Standards



Note: N=67 wells in Wayne County. * Denotes metals with a secondary standard (SMCL).

Water quality data collected from Wayne County wells in 2014 shows that most wells did not exceed MCLs for toxic chemicals. However, a small percentage still exceeded MCLs for arsenic, which is known to have toxicological effects in humans (ATSDR, 2007a). Specifically, long-term exposure to arsenic has been correlated to bladder, lung, liver, and skin cancer. Short-term exposure can lead to gastrointestinal side effects, such as nausea and vomiting (ATSDR, 2007a). Well owners in this region should be aware of potential exposure to toxic metals, as their concentrations can fluctuate based upon weather, well condition, and changes in local industrial activity. Having wells tested on a yearly basis will help ensure that unwanted exposure does not occur. Iron also exceeded the secondary standard in a quarter of the wells tested. Iron may be released naturally into groundwater from rocks, or from other sources such as industrial waste or corroding metal (Water Science School, 2018).

Exposure to iron in drinking water is not typically hazardous to health, it may stain laundered clothes or alter the taste of water (Swistock et al., 2019). It should be noted that a rare inherited disease called hemochromatosis is associated with iron overload in a small percentage of persons. Individuals with this condition should limit their iron intake, including via drinking water, in consultation with their health care provider.

In Wayne County, lithium had a strong positive relationship with six of the other 23 metals tested. Lithium is not currently regulated in drinking water; however, it may still be linked to adverse health effects. For example, lithium has been associated with thyroid and kidney dysfunction (Lindsey et al., 2021). The relationship seen between potassium and sodium may indicate the use of a potassium based water softener to decrease calcium and magnesium levels (WHO, 2007). The best way to ensure safe drinking water for Wayne County well owners and their families is to be aware of chemical contaminants found in well water and their potential adverse health or aesthetic effects, test water quality regularly, and reach out to the PA DOH with any additional concerns.

Discussion

This report highlights the work of the USGS on private well water quality in PA and contributes to further knowledge on the topic. Since private water wells are not regulated in the state, there are no legal standards for well construction or water quality testing. By summarizing USGS studies in seven Northern PA counties over the last decade, this document is a useful guide for well water owners in these counties. Based on the USGS samples taken as part of these studies, most wells had contaminant concentrations that are considered safe for consumption. However, some metals were present that have known health impacts even at low concentrations. A small percentage of wells tested exceeded the regulatory limits for arsenic and barium (about one to five wells per county). Notably, wells tested in Clinton and Sullivan Counties did not exceed federal drinking water standards. In addition, wells were more likely to exceed secondary standards based on aesthetic guidelines. These contaminants, including iron and manganese, may still pose a risk to household water appliances (including toilets and pipes) and health in the long run.

In the interest of safety, and regardless of county of residence, private well owners are encouraged to regularly test their wells. The Centers for Disease Control and Prevention (CDC) recommends testing once a year for total coliform bacteria, nitrates, total dissolved solids, and pH levels (CDC, 2009). Other contaminants should be tested at least once but may require more frequent testing depending on changes in local industrial activity, well condition, or health status. Additionally, if residing in an older home (built before 1986), it may be beneficial to have faucet water tested to ensure drinking water is not being contaminated by lead or copper from pipe fixtures.

For more information about private wells and related resources, please visit:

⇒ Association of Public Health Laboratories (APHL) Private Well Sampling and Testing

⇒ CDC Private Water Systems

⇒ EPA Private Drinking Water Wells

⇒ PA DEP Private Water Wells

⇒ Penn State Extension Drinking and Residential Water

⇒ Private Well Class

⇒ Resources for Communities and People (RCAP) Solutions

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Appendix: Additional Technical Information

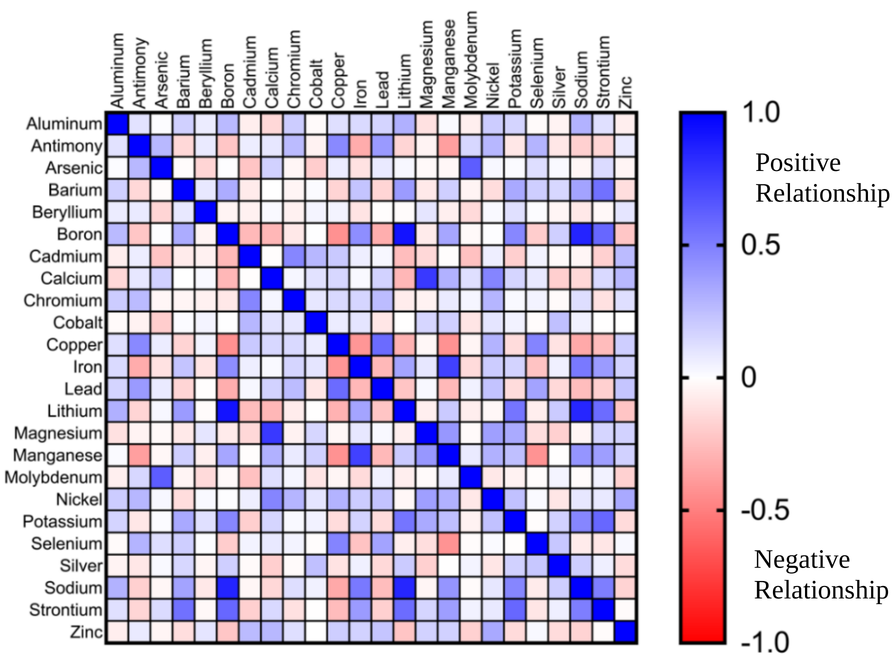
The below table and figure display the results of a nonparametric Spearman rank correlation analysis to show relationships between pairs of contaminants based upon concentrations found in Bradford County wells by USGS. The correlation matrix shows Spearman rho coefficients, in which the closer to 1.00 or -1.00, the stronger the relationship.

Table A1: Correlation Matrix of Well Water Contaminants, Bradford County

	Al	*Sb*	*As*	*Ba*	*Be*	*B*	*Cd*	*Ca*	*Cr*	*Co*	*Cu*	*Fe*	*Pb*	*Li*	*Mg*	*Mn*	*Mo*	*Ni*	*K*	*Se*	*Ag*	*Na*	*Sr*	*Zn*
Al	1.00	0.11	0.01	0.18	0.07	**0.27**	-0.07	-0.15	0.20	-0.02	0.12	0.14	0.17	**0.31**	-0.12	0.02	-0.07	0.20	0.17	-0.02	-0.05	**0.30**	0.12	-0.07
Sb		1.00	**0.28**	-0.15	0.08	-0.22	0.07	0.09	**0.26**	-0.05	**0.46**	**-0.33**	**0.40**	-0.17	-0.05	**-0.38**	0.16	**0.28**	-0.10	**0.29**	-0.10	-0.19	-0.16	0.08
As			1.00	-0.01	-0.17	0.01	-0.23	0.18	-0.04	-0.20	0.07	-0.12	0.08	0.03	-0.02	-0.03	**0.63**	0.03	0.02	0.13	0.02	-0.04	0.14	-0.04
Ba				1.00	0.09	**0.32**	-0.08	┼	-0.04	0.02	-0.17	0.23	-0.17	**0.39**	-0.09	0.19	-0.04	-0.14	**0.34**	0.19	0.16	**0.36**	**0.55**	-0.13
Be					1.00	-0.04	-0.06	0.02	-0.06	0.04	0.04	-0.11	-0.01	-0.02	0.10	-0.07	-0.15	0.02	0.12	0.01	-0.04	-0.09	-0.03	0.10
B						1.00	**-0.28**	**-0.28**	-0.09	┼	**-0.43**	**0.44**	**-0.32**	**0.92**	-0.08	**0.35**	-0.03	0.01	**0.47**	-0.20	0.18	**0.86**	**0.60**	-0.23
Cd							1.00	-0.01	**0.47**	**0.28**	0.21	0.07	0.03	**-0.26**	-0.16	-0.01	**-0.25**	0.07	-0.19	0.04	-0.02	-0.04	-0.19	**0.26**
Ca								1.00	0.03	0.11	0.16	0.02	0.18	**-0.28**	**0.77**	**0.30**	0.12	**0.48**	0.16	0.08	-0.19	-0.15	0.15	**0.28**
Cr									1.00	0.09	0.15	0.16	**0.26**	-0.08	-0.05	0.08	0.04	**0.29**	0.02	0.04	-0.02	0.13	-0.12	0.12
Co										1.00	0.07	0.10	-0.10	┼	0.16	0.18	-0.10	0.10	0.05	-0.02	**0.25**	0.05	-0.01	┼
Cu											1.00	-0.41	**0.58**	**-0.30**	-0.03	**-0.43**	-0.04	**0.30**	-0.14	**0.48**	-0.11	**-0.34**	**-0.26**	0.19
Fe												1.00	**-0.28**	**0.36**	0.09	**0.74**	-0.14	0.20	0.17	**-0.24**	0.06	**0.52**	**0.39**	0.17
Pb													1.00	**-0.23**	0.03	**-0.28**	0.05	**0.23**	-0.14	**0.36**	-0.15	**-0.26**	-0.19	0.22
Li														1.00	-0.07	0.21	-0.07	-0.03	**0.54**	-0.07	0.20	**0.85**	**0.57**	-0.23
Mg															1.00	**0.41**	-0.02	**0.38**	**0.33**	-0.13	-0.19	-0.04	0.16	0.17
Mn																1.00	0.08	**0.30**	**0.25**	**-0.42**	-0.01	**0.41**	**0.38**	0.18
Mo																	1.00	-0.09	-0.05	-0.02	0.04	-0.02	0.05	-0.18
Ni																		1.00	**0.24**	0.02	-0.10	0.09	0.08	**0.34**
K																			1.00	-0.01	0.18	**0.47**	**0.60**	-0.14
Se																				1.00	0.22	-0.08	-0.10	0.03
Ag																					1.00	0.19	0.06	-0.14
Na																						1.00	**0.50**	-0.17
Sr																							1.00	-0.02
Zn																								1.00

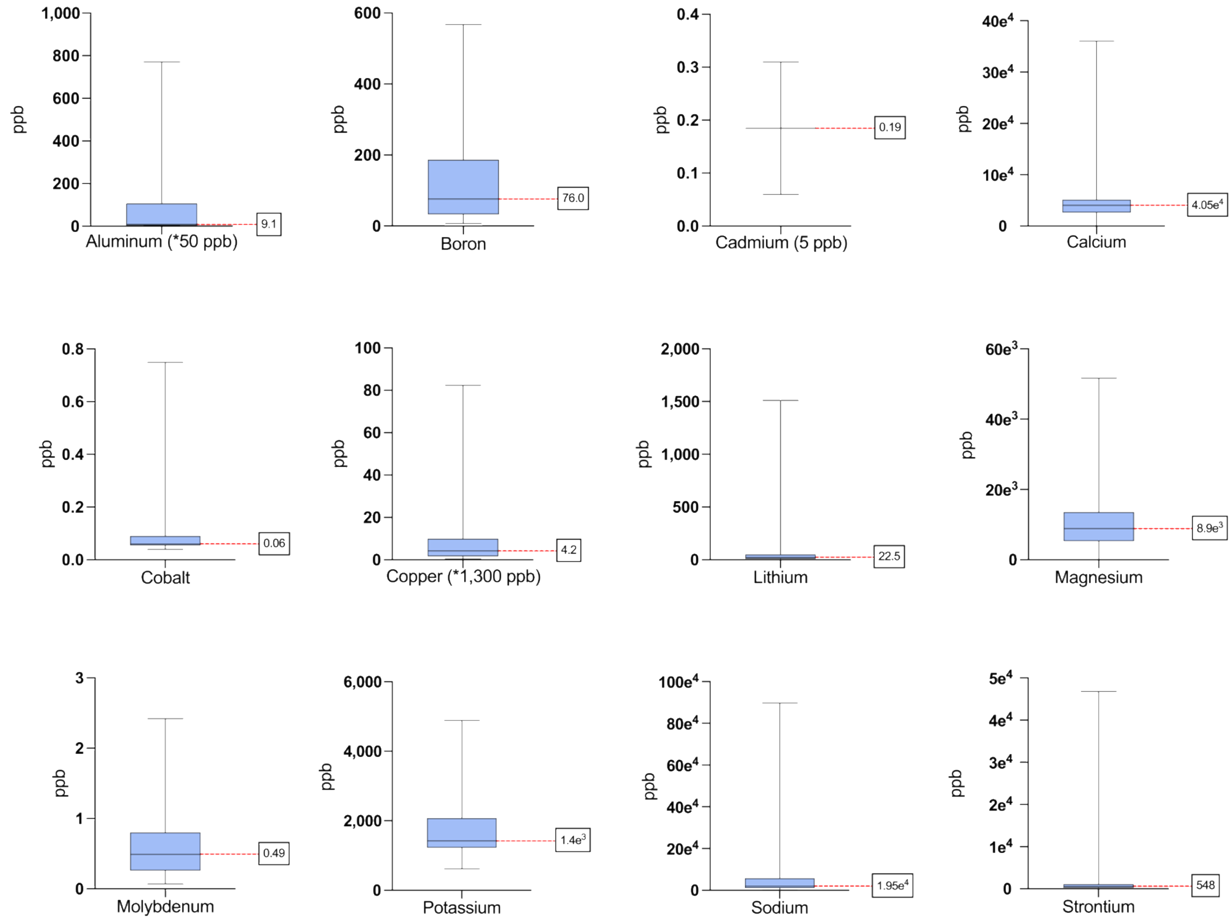
Bolded values indicate a significant correlation, *p-value* ≤ *0.05*. ┼ represents a correlation that is < 0.01.

Figure A1: Heatmap of Well Water Contaminants, Bradford County



The below figure displays a panel of box and whisker plots of individual contaminant data for additional metals found in Bradford County wells. These plots correspond to the tabular data in Table 1 in the main text.

Figure A2: Distribution of Additional Well Water Contaminants, Bradford County



Note: N=72 wells in Bradford County. Dashed red lines indicate the median values. A contaminant's corresponding MCL or *SMCL is displayed in parentheses when applicable. Data are not shown for contaminants in which minimal samples (< 3) tested above the detection limit. Wells below the detection limit for a given contaminant were excluded.

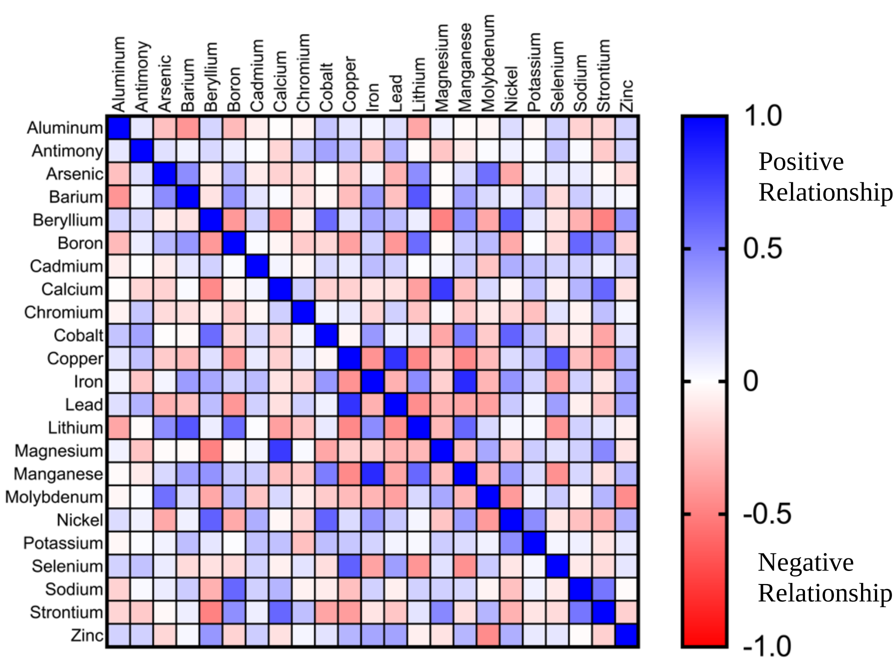
The below table and figure display the results of a nonparametric Spearman rank correlation analysis to show relationships between pairs of contaminants based upon concentrations found in Clinton County wells by USGS. The correlation matrix shows Spearman rho coefficients, in which the closer to 1.00 or -1.00, the stronger the relationship.

Table A2: Correlation Matrix of Well Water Contaminants, Clinton County

	Al	*Sb*	*As*	*Ba*	*Be*	*B*	*Cd*	*Ca*	*Cr*	*Co*	*Cu*	*Fe*	*Pb*	*Li*	*Mg*	*Mn*	*Mo*	*Ni*	*K*	*Se*	*Na*	*Sr*	*Zn*
Al	1.00	0.09	-0.25	**-0.42**	0.16	-0.27	-0.07	-0.01	-0.05	0.23	0.10	0.04	0.12	**-0.35**	0.05	-0.02	-0.04	0.14	-0.03	0.17	-0.18	-0.17	0.17
Sb		1.00	0.12	0.05	0.15	0.07	0.01	-0.16	0.22	**0.36**	0.24	-0.22	0.30	-0.02	-0.23	-0.08	0.01	0.06	0.01	0.24	0.02	-0.21	0.18
As			1.00	**0.45**	-0.08	0.28	-0.08	-0.18	-0.14	-0.01	-0.21	0.04	-0.30	**0.45**	-0.02	0.15	**0.56**	**-0.34**	0.05	0.08	0.07	-0.03	-0.16
Ba				1.00	-0.11	**0.40**	0.10	0.02	-0.13	-0.03	-0.26	**0.39**	-0.25	**0.66**	-0.02	**0.36**	0.14	0.06	0.25	-0.14	0.20	0.07	0.03
Be					1.00	**-0.40**	0.18	**-0.46**	-0.07	**0.57**	0.12	**0.34**	0.26	0.07	**-0.49**	**0.42**	**-0.34**	**0.62**	0.10	-0.12	-0.31	**-0.49**	**0.41**
B						1.00	0.02	-0.04	-0.20	-0.16	**-0.37**	0.18	**-0.41**	**0.57**	-0.02	0.20	0.26	**-0.33**	0.01	-0.15	**0.59**	**0.44**	-0.17
Cd							1.00	0.04	-0.04	0.15	0.08	0.26	0.18	0.01	0.04	0.21	-0.23	0.32	0.24	0.17	0.18	0.06	0.19
Ca								1.00	0.19	-0.18	-0.18	-0.11	-0.12	**-0.38**	**0.77**	-0.25	0.15	-0.04	0.24	-0.06	0.29	**0.59**	-0.12
Cr									1.00	0.05	0.08	-0.16	0.18	-0.23	0.02	-0.21	-0.08	-0.16	-0.25	0.11	-0.05	0.25	0.04
Co										1.00	-0.04	**0.40**	0.06	0.08	**-0.35**	**0.51**	-0.20	**0.61**	0.25	-0.13	-0.08	**-0.35**	0.11
Cu											1.00	**-0.42**	**0.80**	**-0.46**	-0.19	**-0.46**	-0.27	0.14	0.22	**0.62**	-0.25	**-0.39**	0.29
Fe												1.00	-0.31	**0.45**	-0.19	**0.83**	-0.29	**0.42**	0.17	**-0.36**	0.18	-0.11	**0.35**
Pb													1.00	**-0.44**	-0.30	**-0.35**	**-0.37**	0.21	0.04	**0.38**	-0.07	-0.22	**0.36**
Li														1.00	-0.28	**0.59**	0.15	0.04	0.02	**-0.41**	0.18	0.10	-0.07
Mg															1.00	-0.26	**0.34**	-0.23	0.20	0.12	0.18	**0.47**	-0.11
Mn																1.00	-0.29	**0.38**	0.14	**-0.43**	0.16	-0.13	0.29
Mo																	1.00	**-0.40**	0.05	0.20	-0.05	0.29	**-0.45**
Ni																		1.00	**0.44**	-0.10	-0.25	-0.30	0.31
K																			1.00	0.04	0.06	-0.11	0.08
Se																				1.00	-0.09	-0.14	0.10
Na																					1.00	**0.53**	-0.02
Sr																						1.00	-0.19
Zn																							1.00

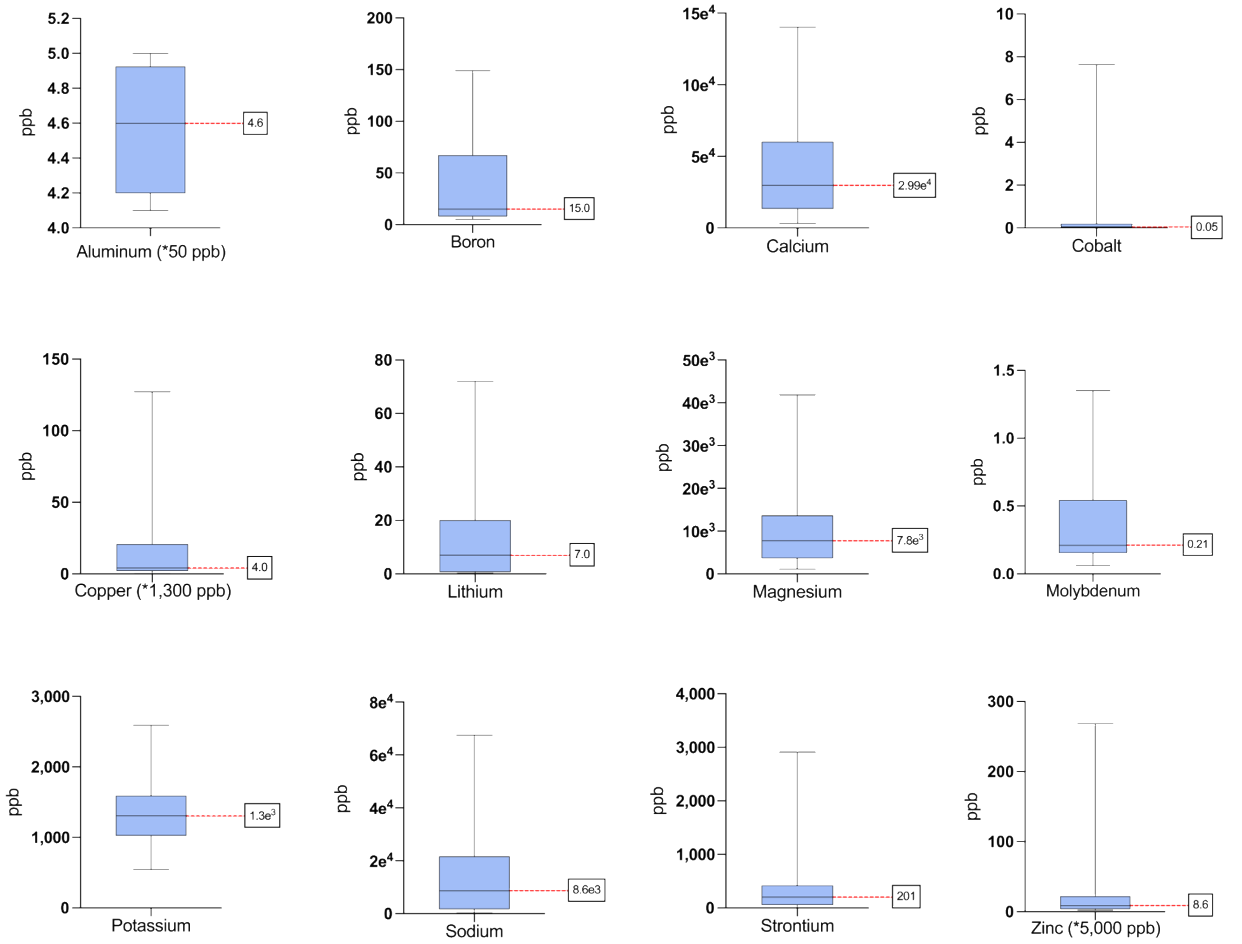
Bolded values indicate a significant correlation, *p-value* ≤ *0.05*. ┼ represents a correlation that is < 0.01.

Figure A3: Heatmap of Well Water Contaminants, Clinton County



The below figure displays a panel of box and whisker plots of individual contaminant data for additional metals found in Clinton County wells. These plots correspond to the tabular data in Table 2 in the main text.

Figure A4: Distribution of Additional Well Water Contaminants, Clinton County



Note: N=38 wells in Clinton County. Dashed red lines indicate the median values. A contaminant's corresponding MCL or *SMCL is displayed in parentheses when applicable. Data are not shown for contaminants in which minimal samples (< 3) tested above the detection limit. Wells below the detection limit for a given contaminant were excluded.

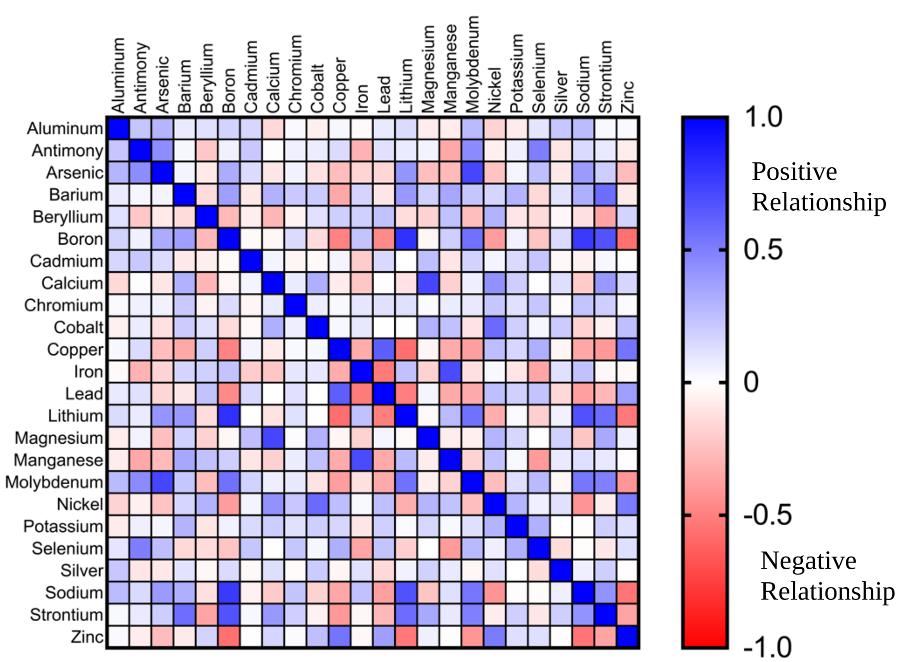
The below table and figure display the results of a nonparametric Spearman rank correlation analysis to show relationships between pairs of contaminants based upon concentrations found in Lycoming County wells by USGS. The correlation matrix shows Spearman rho coefficients, in which the closer to 1.00 or -1.00, the stronger the relationship.

Table A3: Correlation Matrix of Well Water Contaminants, Lycoming County

	Al	*Sb*	*As*	*Ba*	*Be*	*B*	*Cd*	*Ca*	*Cr*	*Co*	*Cu*	*Fe*	*Pb*	*Li*	*Mg*	*Mn*	*Mo*	*Ni*	*K*	*Se*	*Ag*	*Na*	*Sr*	*Zn*
Al	1.00	0.22	**0.29**	0.08	0.12	0.17	0.16	-0.15	0.02	-0.06	0.03	-0.03	0.08	0.14	-0.08	-0.08	**0.27**	-0.17	-0.08	0.10	0.22	**0.26**	0.03	0.02
Sb		1.00	**0.45**	0.03	-0.22	0.06	0.21	0.01	0.05	0.07	0.14	**-0.30**	0.12	0.08	0.05	**-0.34**	**0.45**	-0.06	0.06	**0.50**	-0.10	0.14	0.09	-0.07
As			1.00	0.04	-0.09	**0.32**	0.14	-0.10	0.05	-0.12	**-0.26**	-0.17	-0.16	**0.41**	**-0.25**	**-0.27**	**0.72**	**-0.24**	0.04	**0.25**	-0.09	**0.39**	0.20	**-0.27**
Ba				1.00	-0.14	**0.37**	-0.09	**0.30**	0.21	0.20	**-0.34**	0.17	-0.10	**0.40**	0.18	**0.34**	0.22	0.16	**0.30**	-0.15	0.11	**0.31**	**0.57**	-0.08
Be					1.00	**-0.28**	-0.07	**-0.29**	-0.05	0.12	0.18	0.18	**0.24**	-0.14	-0.18	**0.24**	**-0.26**	**0.30**	-0.10	-0.14	-0.03	-0.12	**-0.36**	0.17
B						1.00	-0.02	-0.04	0.14	-0.14	**-0.49**	**0.23**	**-0.46**	**0.81**	-0.04	0.19	**0.55**	**-0.39**	0.05	**-0.23**	0.14	**0.77**	**0.68**	**-0.56**
Cd							1.00	0.04	-0.04	-0.03	0.04	-0.20	0.15	+	**0.25**	-0.10	0.17	0.04	0.14	**0.23**	-0.03	-0.06	0.03	+
Ca								1.00	0.08	**0.31**	-0.08	**-0.23**	-0.01	-0.12	**0.73**	-0.19	0.06	**0.43**	0.19	+	0.13	-0.21	**0.40**	0.16
Cr									1.00	0.07	0.03	0.10	0.12	0.12	0.01	0.07	0.09	0.22	0.12	0.22	-0.02	**0.23**	0.19	0.02
Co										1.00	0.03	0.09	+	+	**0.30**	**0.24**	-0.11	**0.58**	0.19	0.03	0.20	-0.18	-0.06	**0.25**
Cu											1.00	**-0.33**	**0.63**	**-0.57**	-0.04	**-0.33**	**-0.38**	**0.26**	0.16	**0.31**	-0.04	**-0.35**	**-0.40**	**0.54**
Fe												1.00	**-0.52**	**0.24**	-0.18	**0.71**	-0.12	0.03	-0.10	**-0.35**	0.12	**0.24**	-0.03	-0.03
Pb													1.00	**-0.50**	0.04	**-0.34**	**-0.33**	**0.25**	0.18	**0.23**	-0.16	**-0.38**	**-0.28**	**0.37**
Li														1.00	-0.02	**0.26**	**0.56**	**-0.32**	0.01	-0.19	0.05	**0.68**	**0.57**	**-0.53**
Mg															1.00	-0.08	-0.07	**0.29**	0.16	+	0.18	**-0.23**	**0.34**	0.06
Mn																1.00	-0.17	**0.24**	0.02	**-0.39**	0.08	0.12	0.09	-0.01
Mo																	1.00	**-0.26**	0.12	**0.27**	-0.04	**0.54**	**0.49**	**-0.41**
Ni																		1.00	**0.29**	0.06	0.12	**-0.42**	-0.07	**0.51**
K																			1.00	**0.31**	+	-0.01	0.19	0.13
Se																				1.00	-0.13	-0.01	-0.09	0.12
Ag																					1.00	0.06	0.19	-0.01
Na																						1.00	**0.42**	**-0.54**
Sr																							1.00	**-0.36**
Zn																								1.00

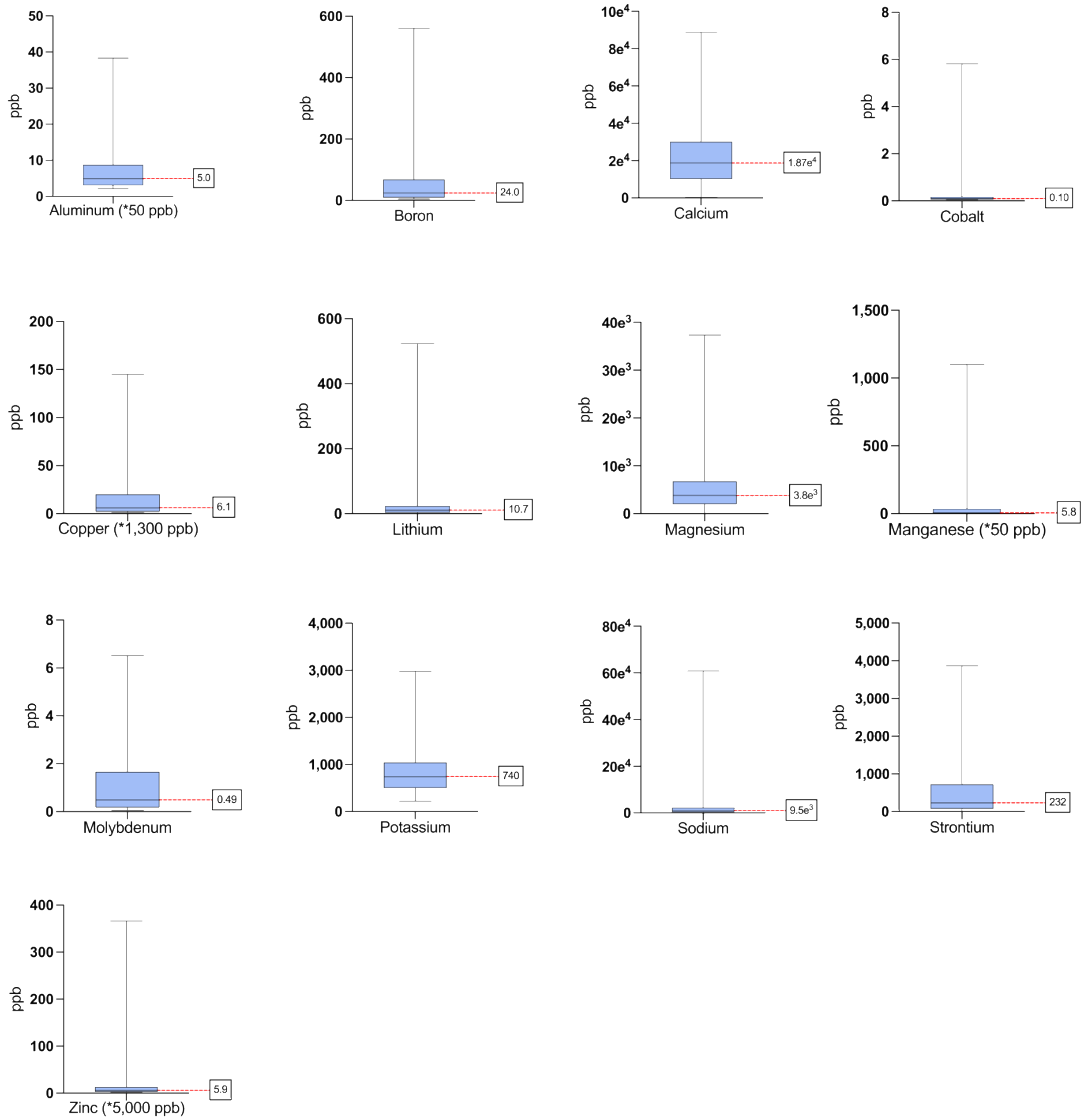
Bolded values indicate a significant correlation, *p-value* ≤ *0.05*. + represents a correlation that is < 0.01.

Figure A5: Heatmap of Well Water Contaminants, Lycoming County



The below figure displays a panel of box and whisker plots of individual contaminant data for additional metals found in Lycoming County wells. These plots correspond to the tabular data in Table 3 in the main text.

Figure A6: Distribution of Additional Well Water Contaminants, Lycoming County



Note: N=74 wells in Lycoming County. Dashed red lines indicate the median values. A contaminant's corresponding MCL or *SMCL is displayed in parentheses when applicable. Data are not shown for contaminants in which minimal samples (< 3) tested above the detection limit. Wells below the detection limit for a given contaminant were excluded.

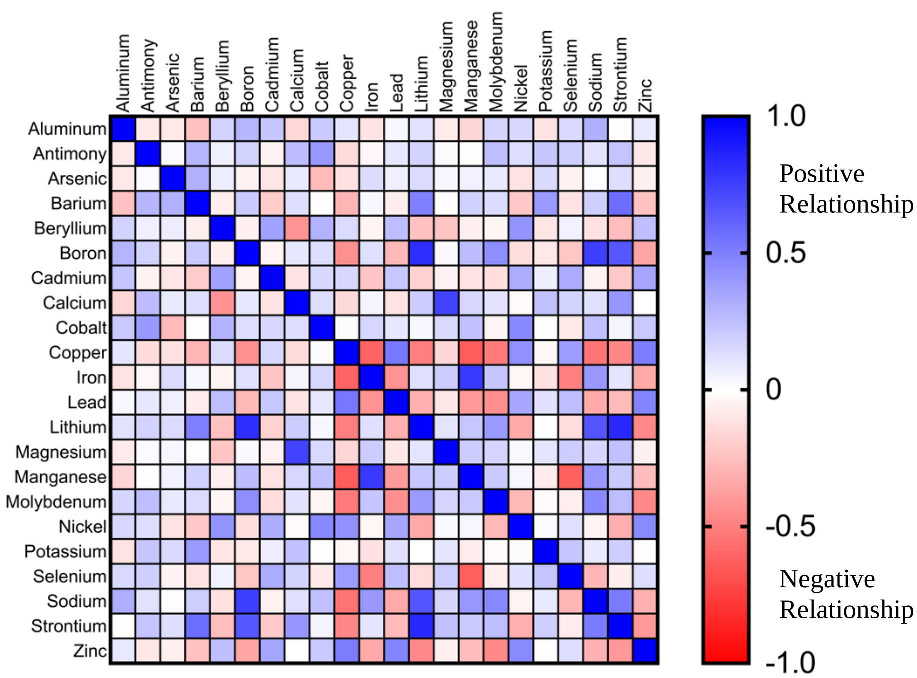
The below table and figure display the results of a nonparametric Spearman rank correlation analysis to show relationships between pairs of contaminants based upon concentrations found in Pike County wells by USGS. The correlation matrix shows Spearman rho coefficients, in which the closer to 1.00 or -1.00, the stronger the relationship.

Table A4: Correlation Matrix of Well Water Contaminants, Pike County

	Al	*Sb*	*As*	*Ba*	*Be*	*B*	*Cd*	*Ca*	*Co*	*Cu*	*Fe*	*Pb*	*Li*	*Mg*	*Mn*	*Mo*	*Ni*	*K*	*Se*	*Na*	*Sr*	*Zn*
Al	1.00	-0.09	-0.09	**-0.24**	0.17	**0.29**	0.22	-0.16	0.21	0.10	-0.12	0.03	0.11	-0.08	-0.16	0.16	0.15	-0.12	0.15	**0.31**	-0.01	0.09
Sb		1.00	0.01	**0.28**	0.06	0.17	-0.05	**0.26**	**0.40**	-0.14	-0.03	0.09	0.17	0.01	┼	**0.25**	0.13	0.22	0.19	0.11	**0.23**	-0.10
As			1.00	**0.31**	0.07	-0.05	-0.10	0.08	**-0.27**	-0.12	0.14	0.06	0.14	0.03	0.05	0.09	-0.11	0.14	-0.05	┼	0.13	-0.07
Ba				1.00	-0.07	0.21	-0.21	0.13	-0.01	**-0.29**	0.03	-0.08	**0.50**	-0.01	0.18	0.14	-0.22	**0.40**	-0.11	0.18	**0.57**	**-0.25**
Be					1.00	-0.06	**0.37**	**-0.43**	**0.30**	0.14	-0.05	**0.25**	**-0.24**	**-0.23**	-0.07	-0.04	**0.42**	-0.10	0.05	-0.12	**-0.26**	**0.25**
B						1.00	-0.05	0.09	0.13	**-0.44**	0.12	**-0.28**	**0.82**	0.02	**0.26**	**0.44**	-0.13	-0.09	-0.23	**0.75**	**0.66**	**-0.35**
Cd							1.00	-0.11	0.16	0.16	**-0.23**	0.22	-0.18	-0.06	-0.11	-0.13	**0.32**	0.07	**0.33**	-0.06	-0.21	**0.35**
Ca								1.00	0.13	-0.15	0.04	-0.12	0.20	**0.73**	0.16	0.11	-0.02	**0.24**	0.17	0.12	**0.41**	┼
Co									1.00	0.01	0.16	0.09	0.03	0.15	**0.24**	-0.05	**0.46**	-0.01	-0.09	**0.25**	0.04	0.21
Cu										1.00	**-0.61**	**0.53**	**-0.51**	-0.16	**-0.64**	**-0.52**	**0.43**	-0.04	**0.38**	**-0.55**	**-0.47**	**0.51**
Fe											1.00	**-0.43**	0.13	0.20	**0.78**	0.23	-0.04	-0.12	**-0.50**	**0.40**	0.10	**-0.34**
Pb												1.00	**-0.32**	-0.10	**-0.40**	**-0.44**	**0.35**	0.12	**0.25**	**-0.34**	**-0.27**	**0.48**
Li													1.00	0.11	0.22	**0.39**	**-0.34**	┼	-0.13	**0.67**	**0.84**	**-0.47**
Mg														1.00	0.20	0.16	0.02	0.10	0.19	0.16	**0.24**	-0.07
Mn															1.00	0.21	0.03	-0.08	**-0.62**	**0.41**	0.21	**-0.27**
Mo																1.00	**-0.28**	-0.02	-0.07	**0.46**	**0.25**	**-0.46**
Ni																	1.00	0.01	0.12	-0.05	**-0.32**	**0.46**
K																		1.00	0.23	0.08	0.19	-0.01
Se																			1.00	**-0.29**	-0.07	0.13
Na																				1.00	**0.51**	**-0.31**
Sr																					1.00	**-0.40**
Zn																						1.00

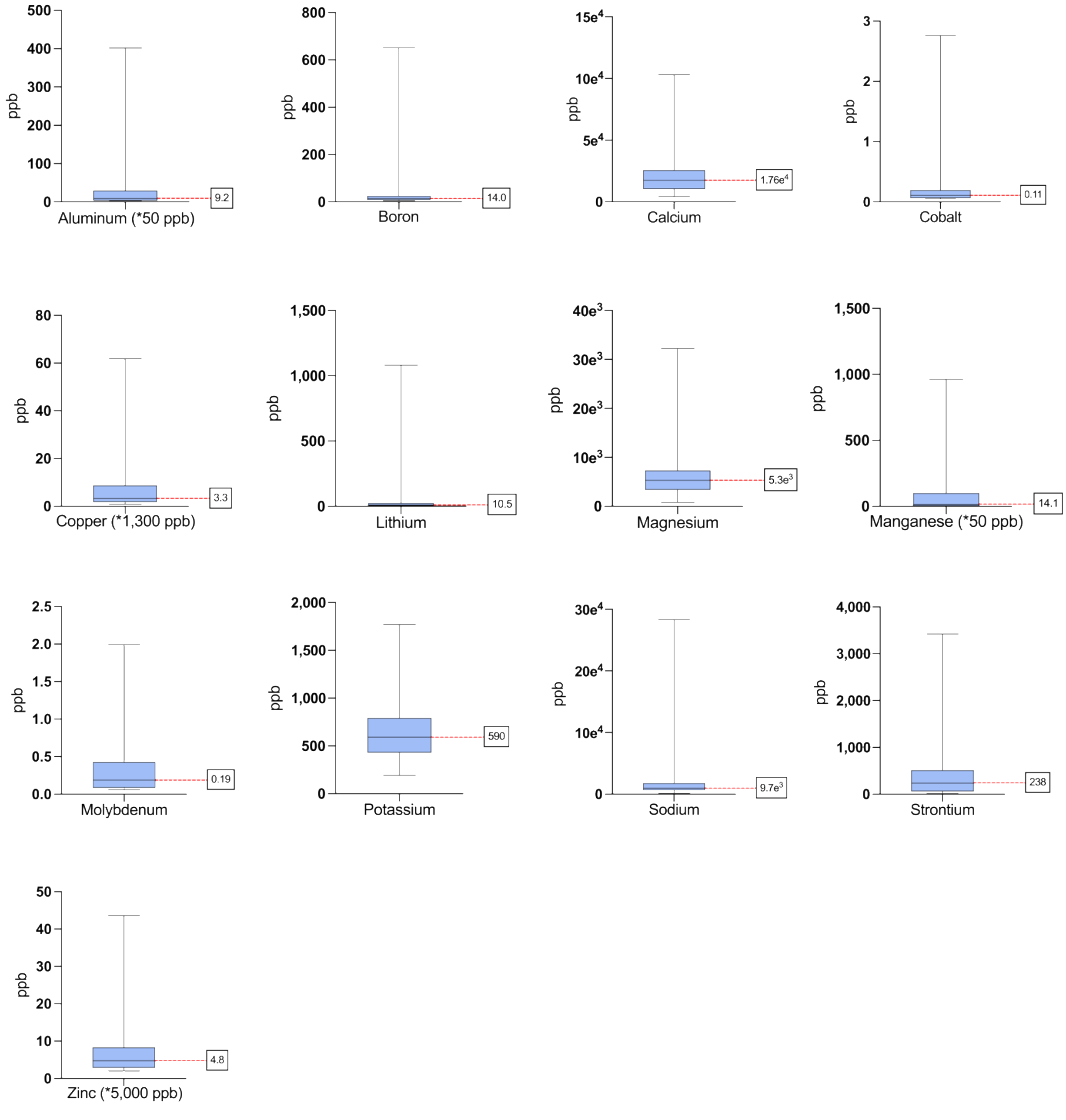
Bolded values indicate a significant correlation, *p-value* ≤ *0.05*. ┼ represents a correlation that is < 0.01.

Figure A7: Heatmap of Well Water Contaminants, Pike County



The below figure displays a panel of box and whisker plots of individual contaminant data for additional metals found in Pike County wells. These plots correspond to the tabular data in Table 4 in the main text.

Figure A8: Distribution of Additional Well Water Contaminants, Pike County



Note: N=75 wells in Pike County. Dashed red lines indicate the median values. A contaminant's corresponding MCL or *SMCL is displayed in parentheses when applicable. Data are not shown for contaminants in which minimal samples (< 3) tested above the detection limit. Wells below the detection limit for a given contaminant were excluded.

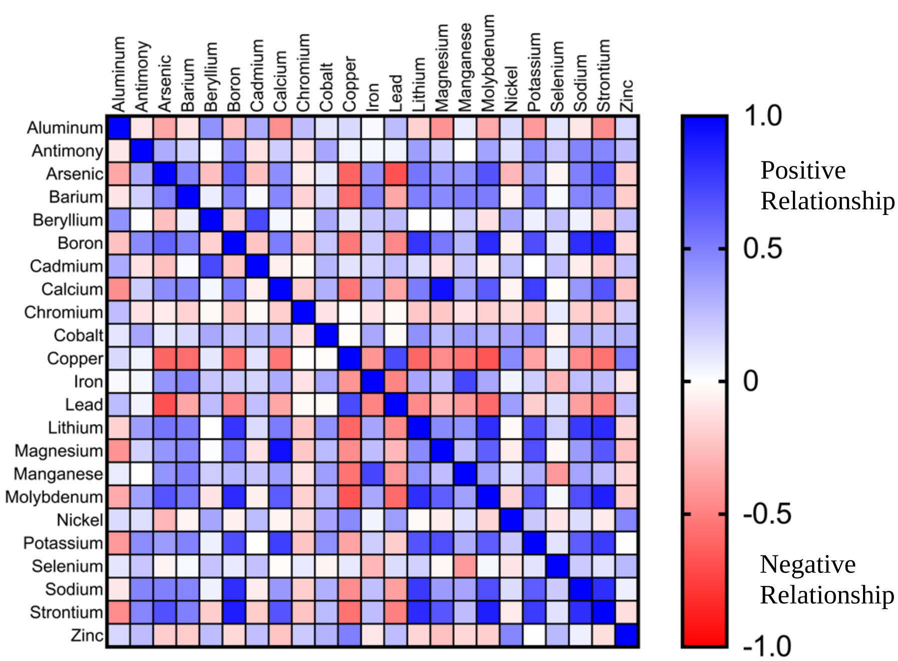
The below table and figure display the results of a nonparametric Spearman rank correlation analysis to show relationships between pairs of contaminants based upon concentrations found in Potter County wells by USGS. The correlation matrix shows Spearman rho coefficients, in which the closer to 1.00 or -1.00, the stronger the relationship.

Table A5: Correlation Matrix of Well Water Contaminants, Potter County

	Al	*Sb*	*As*	*Ba*	*Be*	*B*	*Cd*	*Ca*	*Cr*	*Co*	*Cu*	*Fe*	*Pb*	*Li*	*Mg*	*Mn*	*Mo*	*Ni*	*K*	*Se*	*Na*	*Sr*	*Zn*
Al	1.00	-0.10	**-0.35**	-0.10	**0.43**	-0.25	**0.33**	**-0.44**	0.26	0.10	0.15	0.02	0.27	-0.18	**-0.42**	0.08	**-0.33**	0.14	**-0.40**	0.10	-0.10	**-0.45**	0.16
Sb		1.00	**0.32**	0.18	0.01	**0.45**	-0.11	0.19	-0.11	**0.35**	0.05	0.04	0.05	**0.38**	0.17	┼	**0.36**	0.13	**0.45**	0.23	**0.48**	**0.48**	0.26
As			1.00	**0.49**	-0.25	**0.61**	-0.25	**0.45**	-0.08	0.09	**-0.61**	**0.41**	**-0.68**	**0.54**	**0.41**	**0.42**	**0.67**	-0.29	**0.39**	-0.04	**0.50**	**0.68**	-0.20
Ba				1.00	0.07	**0.48**	0.02	**0.47**	-0.17	0.15	**-0.57**	**0.47**	**-0.35**	**0.50**	**0.46**	**0.50**	**0.51**	-0.05	**0.48**	0.02	**0.48**	**0.50**	-0.21
Be					1.00	-0.18	**0.71**	0.04	-0.03	**0.34**	0.09	0.22	0.26	┼	0.01	0.20	-0.11	**0.35**	0.06	0.23	0.06	-0.20	0.25
B						1.00	-0.23	**0.51**	-0.23	0.22	**-0.53**	0.21	**-0.47**	**0.79**	**0.53**	0.28	**0.83**	-0.06	**0.69**	0.08	**0.82**	**0.89**	-0.16
Cd							1.00	-0.07	-0.02	0.29	0.11	0.17	0.25	0.14	-0.12	0.23	-0.06	0.27	┼	0.24	-0.08	-0.21	0.25
Ca								1.00	-0.20	**0.31**	**-0.53**	**0.32**	**-0.35**	**0.51**	**0.94**	**0.37**	**0.64**	-0.05	**0.76**	-0.01	**0.40**	**0.67**	-0.24
Cr									1.00	-0.11	-0.01	-0.12	-0.03	-0.22	-0.22	-0.12	-0.19	-0.14	-0.23	0.08	-0.20	-0.24	0.21
Co										1.00	-0.02	**0.34**	-0.02	**0.43**	0.27	**0.38**	**0.30**	**0.35**	**0.44**	-0.05	**0.31**	0.27	**0.30**
Cu											1.00	**-0.42**	**0.71**	**-0.60**	**-0.45**	**-0.55**	**-0.67**	**0.46**	**-0.36**	0.09	**-0.45**	**-0.55**	**0.50**
Fe												1.00	**-0.48**	**0.35**	0.26	**0.72**	**0.34**	0.04	0.20	-0.28	0.25	0.25	-0.10
Pb													1.00	**-0.46**	-0.28	**-0.41**	**-0.58**	**0.38**	-0.20	0.13	**-0.37**	**-0.50**	0.25
Li														1.00	**0.46**	**0.42**	**0.82**	-0.03	**0.67**	0.18	**0.77**	**0.83**	-0.16
Mg															1.00	0.26	**0.62**	-0.08	**0.69**	-0.04	**0.39**	**0.66**	-0.25
Mn																1.00	**0.37**	0.13	**0.32**	**-0.40**	**0.36**	0.26	-0.16
Mo																	1.00	-0.16	**0.64**	0.03	**0.69**	**0.88**	-0.19
Ni																		1.00	0.21	-0.10	0.14	-0.09	**0.47**
K																			1.00	0.11	**0.63**	**0.77**	-0.01
Se																				1.00	0.20	0.11	0.28
Na																					1.00	**0.82**	0.06
Sr																						1.00	-0.13
Zn																							1.00

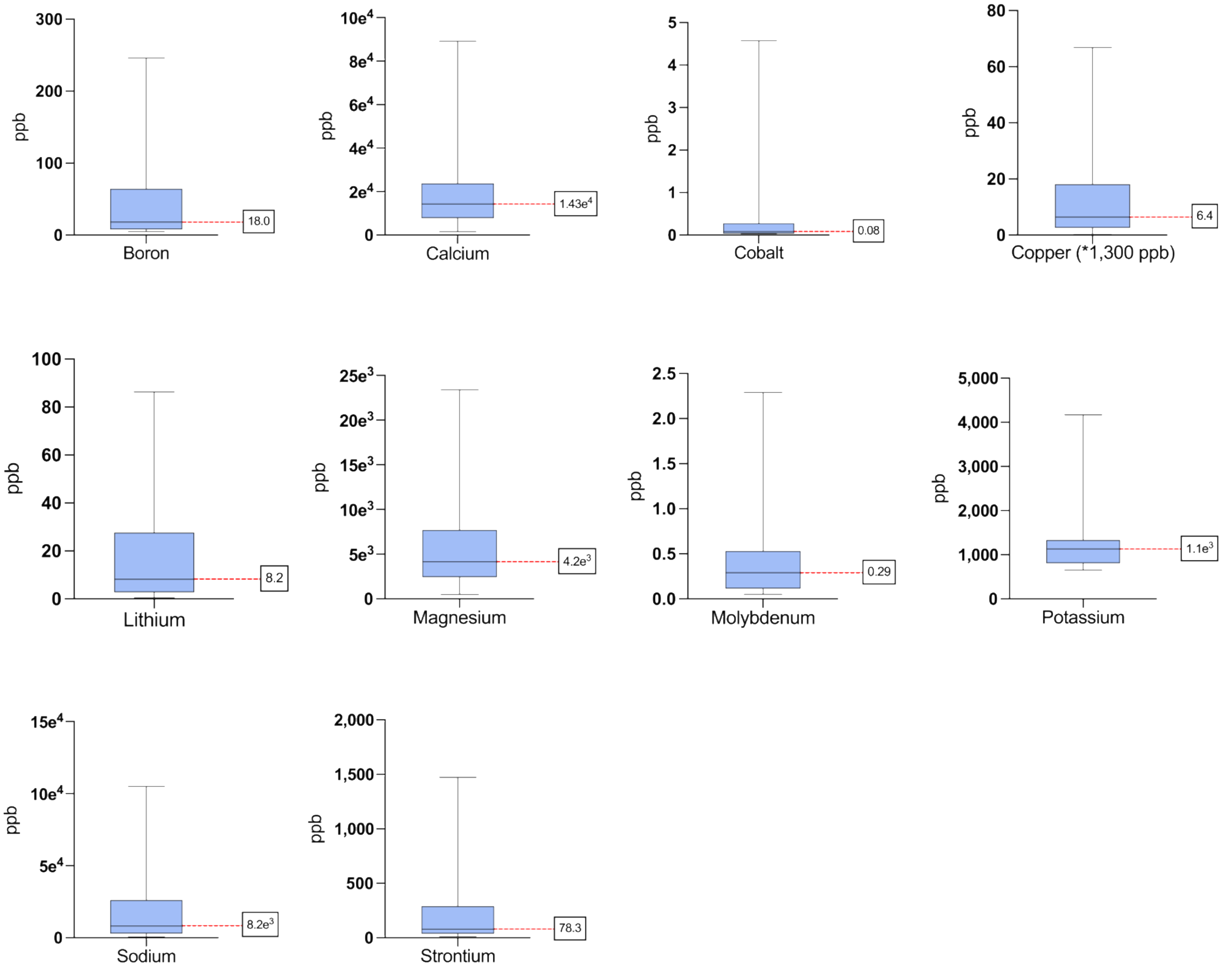
Bolded values indicate a significant correlation, *p-value* ≤ *0.05*. ┼ represents a correlation that is < 0.01.

Figure A9: Heatmap of Well Water Contaminants, Potter County



The below figure displays a panel of box and whisker plots of individual contaminant data for additional metals found in Potter County wells. These plots correspond to the tabular data in Table 5 in the main text.

Figure A10: Distribution of Additional Well Water Contaminants, Potter County



Note: N=47 wells in Potter County. Dashed red lines indicate the median values. A contaminant's corresponding MCL or *SMCL is displayed in parentheses when applicable. Data are not shown for contaminants in which minimal samples (< 3) tested above the detection limit. Wells below the detection limit for a given contaminant were excluded.

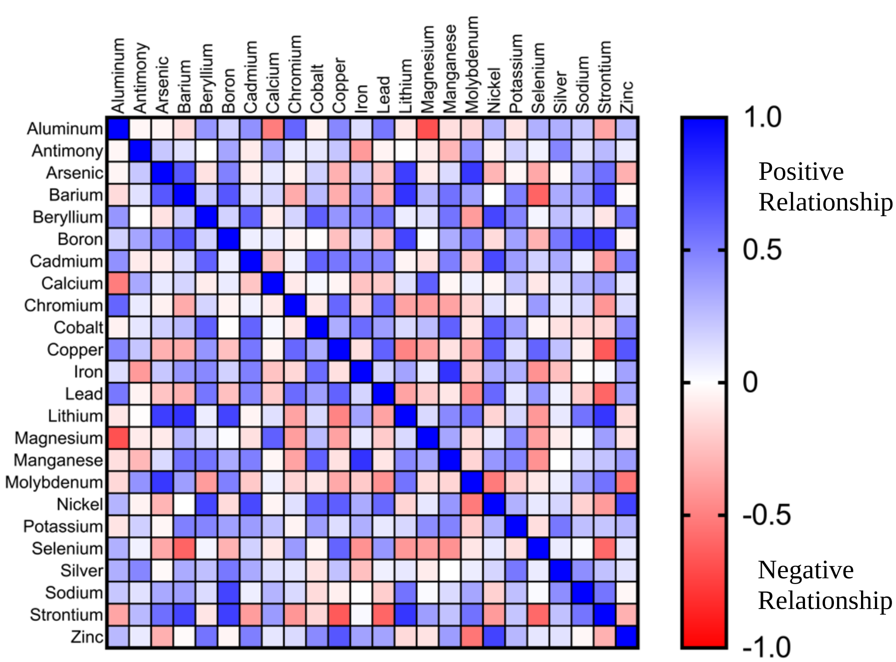
The below table and figure display the results of a nonparametric Spearman rank correlation analysis to show relationships between pairs of contaminants based upon concentrations found in Sullivan County wells by USGS. The correlation matrix shows Spearman rho coefficients, in which the closer to 1.00 or -1.00, the stronger the relationship.

Table A6: Correlation Matrix of Well Water Contaminants, Sullivan County

	Al	*Sb*	*As*	*Ba*	*Be*	*B*	*Cd*	*Ca*	*Cr*	*Co*	*Cu*	*Fe*	*Pb*	*Li*	*Mg*	*Mn*	*Mo*	*Ni*	*K*	*Se*	*Ag*	*Na*	*Sr*	*Zn*
Al	1.00	-0.04	-0.04	-0.14	0.41	0.18	0.43	**-0.51**	**0.60**	-0.06	**0.47**	0.13	**0.53**	-0.10	**-0.68**	-0.13	-0.15	0.29	-0.11	0.31	0.31	0.22	-0.36	0.27
Sb		1.00	0.22	0.12	┼	0.35	-0.08	0.34	0.08	0.10	0.22	-0.40	-0.05	-0.01	-0.08	-0.28	0.42	-0.05	0.19	0.05	**0.47**	0.12	0.27	0.08
As			1.00	**0.65**	-0.11	**0.49**	-0.08	0.09	-0.06	0.18	-0.31	0.22	-0.23	**0.76**	-0.08	0.14	**0.78**	-0.29	-0.04	-0.34	-0.03	0.34	**0.56**	-0.31
Ba				1.00	0.20	**0.66**	0.13	0.17	-0.33	0.27	-0.32	0.41	-0.30	**0.80**	0.29	**0.55**	0.38	┼	**0.50**	**-0.61**	0.33	0.38	**0.73**	-0.02
Be					1.00	0.18	**0.61**	-0.08	0.17	**0.62**	0.41	**0.46**	**0.54**	0.07	0.13	**0.54**	-0.39	**0.73**	**0.47**	0.04	0.25	0.14	-0.10	**0.54**
B						1.00	0.06	0.08	-0.05	-0.01	-0.25	0.18	-0.25	**0.73**	0.01	0.32	**0.50**	-0.14	0.37	-0.30	**0.53**	**0.73**	**0.75**	-0.04
Cd							1.00	-0.23	0.06	**0.61**	**0.53**	**0.50**	**0.48**	-0.05	-0.12	**0.50**	-0.21	**0.71**	0.39	0.18	0.33	0.06	-0.39	**0.50**
Ca								1.00	-0.09	0.03	-0.04	-0.24	-0.20	0.12	**0.62**	-0.04	0.06	-0.05	0.24	-0.09	0.13	0.29	0.39	0.09
Cr									1.00	-0.10	**0.59**	-0.16	**0.58**	-0.36	-0.38	-0.36	-0.17	0.12	-0.05	0.39	0.10	0.15	-0.41	0.14
Co										1.00	0.32	**0.58**	0.38	0.15	0.26	**0.62**	-0.10	**0.62**	0.38	-0.05	-0.11	-0.14	-0.16	**0.46**
Cu											1.00	-0.12	**0.61**	**-0.48**	-0.36	-0.12	-0.34	**0.63**	0.13	**0.61**	0.24	-0.06	**-0.65**	**0.66**
Fe												1.00	0.17	0.36	0.09	**0.80**	-0.21	0.33	0.31	-0.43	-0.25	┼	0.02	0.36
Pb													1.00	-0.36	-0.21	-0.10	-0.43	**0.59**	0.09	0.41	0.06	-0.19	**-0.60**	0.36
Li														1.00	0.15	**0.46**	**0.55**	-0.17	0.16	-0.41	0.09	**0.55**	**0.79**	-0.15
Mg															1.00	0.35	-0.14	0.09	**0.45**	-0.38	-0.08	0.02	0.38	-0.11
Mn																1.00	-0.17	0.40	**0.49**	-0.43	┼	0.14	0.24	0.38
Mo																	1.00	**-0.52**	-0.19	-0.10	0.07	0.35	**0.55**	**-0.54**
Ni																		1.00	0.31	0.09	0.16	-0.18	-0.40	**0.73**
K																			1.00	-0.13	**0.53**	0.25	0.23	0.28
Se																				1.00	0.08	0.02	**-0.59**	0.10
Ag																					1.00	0.44	0.24	0.11
Na																						1.00	**0.54**	-0.03
Sr																							1.00	-0.31
Zn																								1.00

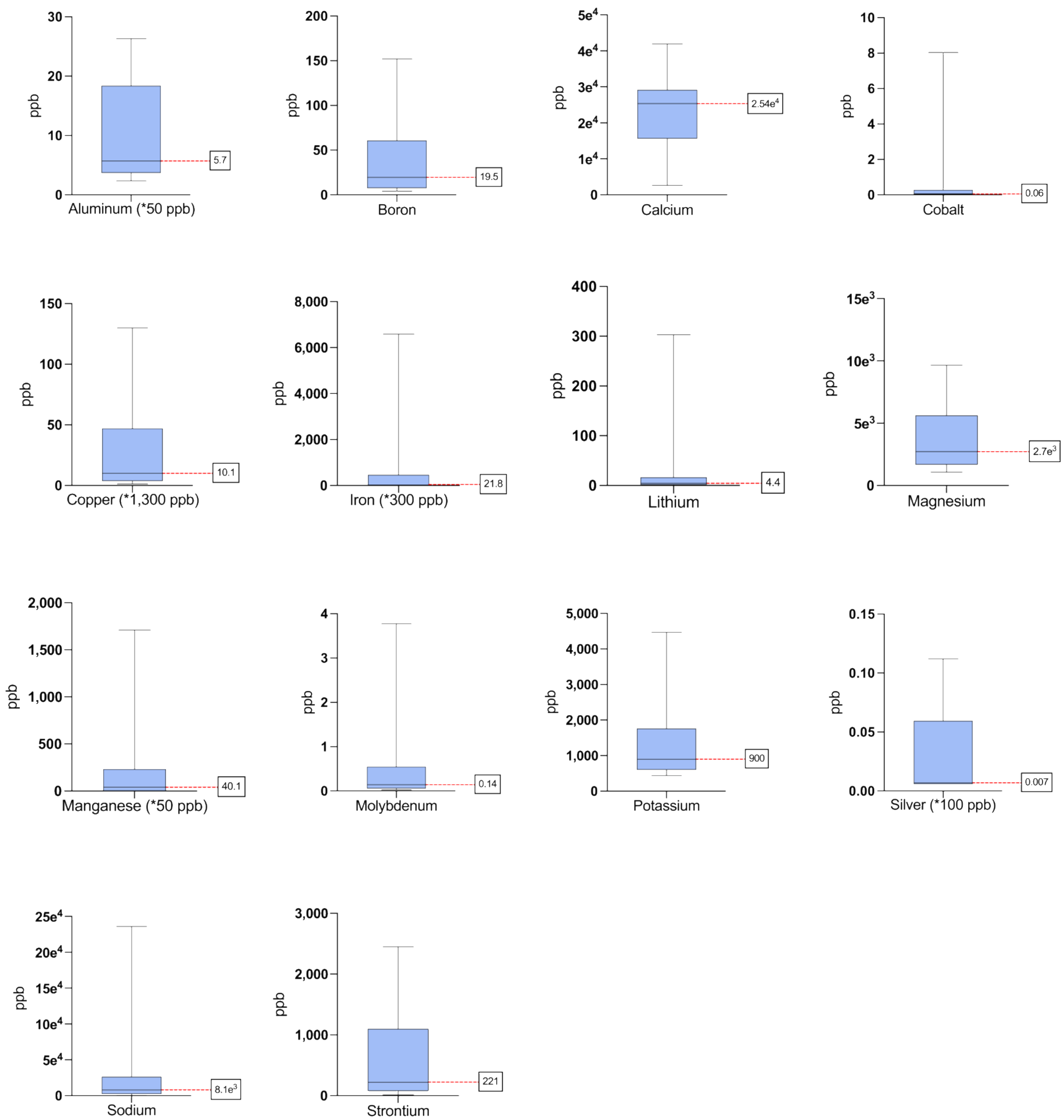
Bolded values indicate a significant correlation, *p-value* ≤ *0.05*. ┼ represents a correlation that is < 0.01.

Figure A11: Heatmap of Well Water Contaminants, Sullivan County



The below figure displays a panel of box and whisker plots of individual contaminant data for additional metals found in Sullivan County wells. These plots correspond to the tabular data in Table 6 in the main text.

Figure A12: Distribution of Additional Well Water Contaminants, Sullivan County



Note: N=20 wells in Sullivan County. Dashed red lines indicate the median values. A contaminant's corresponding MCL or *SMCL is displayed in parentheses when applicable. Data are not shown for contaminants in which minimal samples (< 3) tested above the detection limit. Wells below the detection limit for a given contaminant were excluded.

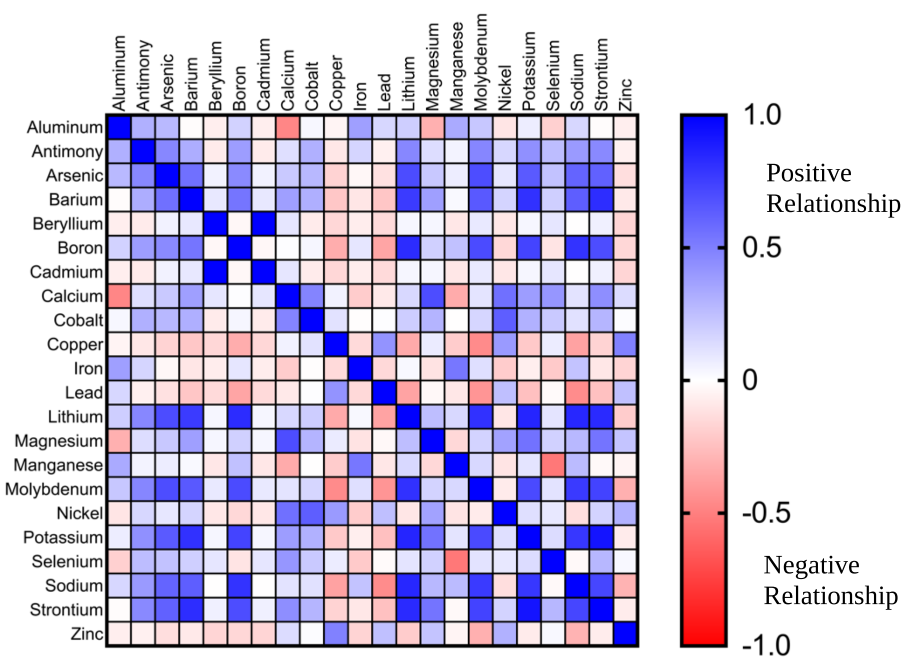
The below table and figure display the results of a nonparametric Spearman rank correlation analysis to show relationships between pairs of contaminants based upon concentrations found in Wayne County wells by USGS. The correlation matrix shows Spearman rho coefficients, in which the closer to 1.00 or -1.00, the stronger the relationship.

Table A7: Correlation Matrix of Well Water Contaminants, Wayne County

	Al	*Sb*	*As*	*Ba*	*Be*	*B*	*Cd*	*Ca*	*Co*	*Cu*	*Fe*	*Pb*	*Li*	*Mg*	*Mn*	*Mo*	*Ni*	*K*	*Se*	*Na*	*Sr*	*Zn*
Al	1.00	**0.31**	**0.27**	-0.01	-0.07	0.17	-0.07	**-0.48**	0.03	-0.05	**0.38**	0.15	0.19	**-0.31**	**0.33**	0.22	-0.10	0.07	-0.19	0.15	-0.01	-0.07
Sb		1.00	**0.47**	**0.32**	-0.08	**0.38**	-0.08	0.12	**0.31**	-0.10	0.16	-0.06	**0.47**	0.13	0.05	**0.47**	0.15	**0.43**	**0.26**	**0.39**	**0.46**	-0.06
As			1.00	**0.56**	0.05	**0.46**	0.05	0.21	**0.28**	-0.17	-0.03	-0.12	**0.70**	0.21	0.07	**0.70**	0.09	**0.65**	0.24	**0.61**	**0.62**	-0.13
Ba				1.00	0.09	**0.54**	0.09	**0.37**	**0.31**	-0.22	-0.10	-0.22	**0.77**	**0.37**	0.02	**0.65**	0.17	**0.81**	0.18	**0.63**	**0.82**	-0.09
Be					1.00	-0.03	**1.00**	0.10	-0.08	-0.16	-0.07	-0.15	0.03	0.03	-0.09	0.08	-0.10	0.03	0.10	-0.01	0.06	-0.17
B						1.00	-0.03	0.01	0.03	**-0.32**	0.09	**-0.35**	**0.83**	0.18	**0.24**	**0.70**	-0.16	**0.73**	-0.11	**0.80**	**0.70**	-0.16
Cd							1.00	0.10	-0.08	-0.16	-0.07	-0.15	0.03	0.03	-0.09	0.08	-0.10	0.03	0.10	-0.01	0.06	-0.17
Ca								1.00	**0.48**	0.05	-0.20	-0.09	0.15	**0.70**	**-0.33**	0.11	**0.56**	**0.38**	**0.41**	0.11	**0.44**	0.14
Co									1.00	0.11	-0.01	0.01	0.20	**0.29**	┼	0.16	**0.63**	**0.31**	0.21	0.12	**0.29**	0.01
Cu										1.00	-0.15	**0.42**	**-0.34**	0.08	-0.20	**-0.46**	**0.39**	-0.21	0.07	**-0.37**	-0.17	**0.49**
Fe											1.00	-0.15	0.03	-0.11	**0.53**	0.12	-0.20	-0.07	-0.21	0.23	-0.09	-0.17
Pb												1.00	**-0.36**	-0.03	-0.10	**-0.42**	**0.25**	**-0.25**	-0.02	**-0.45**	**-0.24**	**0.25**
Li													1.00	**0.25**	0.15	**0.81**	-0.10	**0.85**	0.10	**0.85**	**0.83**	-0.20
Mg														1.00	-0.16	0.17	**0.36**	**0.55**	0.18	**0.28**	**0.54**	0.23
Mn															1.00	0.15	-0.11	0.10	**-0.53**	**0.27**	-0.03	-0.05
Mo																1.00	-0.08	**0.71**	0.11	**0.77**	**0.73**	**-0.31**
Ni																	1.00	0.12	0.09	-0.13	0.17	**0.31**
K																		1.00	0.14	**0.78**	**0.92**	-0.08
Se																			1.00	-0.02	**0.28**	0.03
Na																				1.00	**0.73**	**-0.30**
Sr																					1.00	-0.08
Zn																						1.00

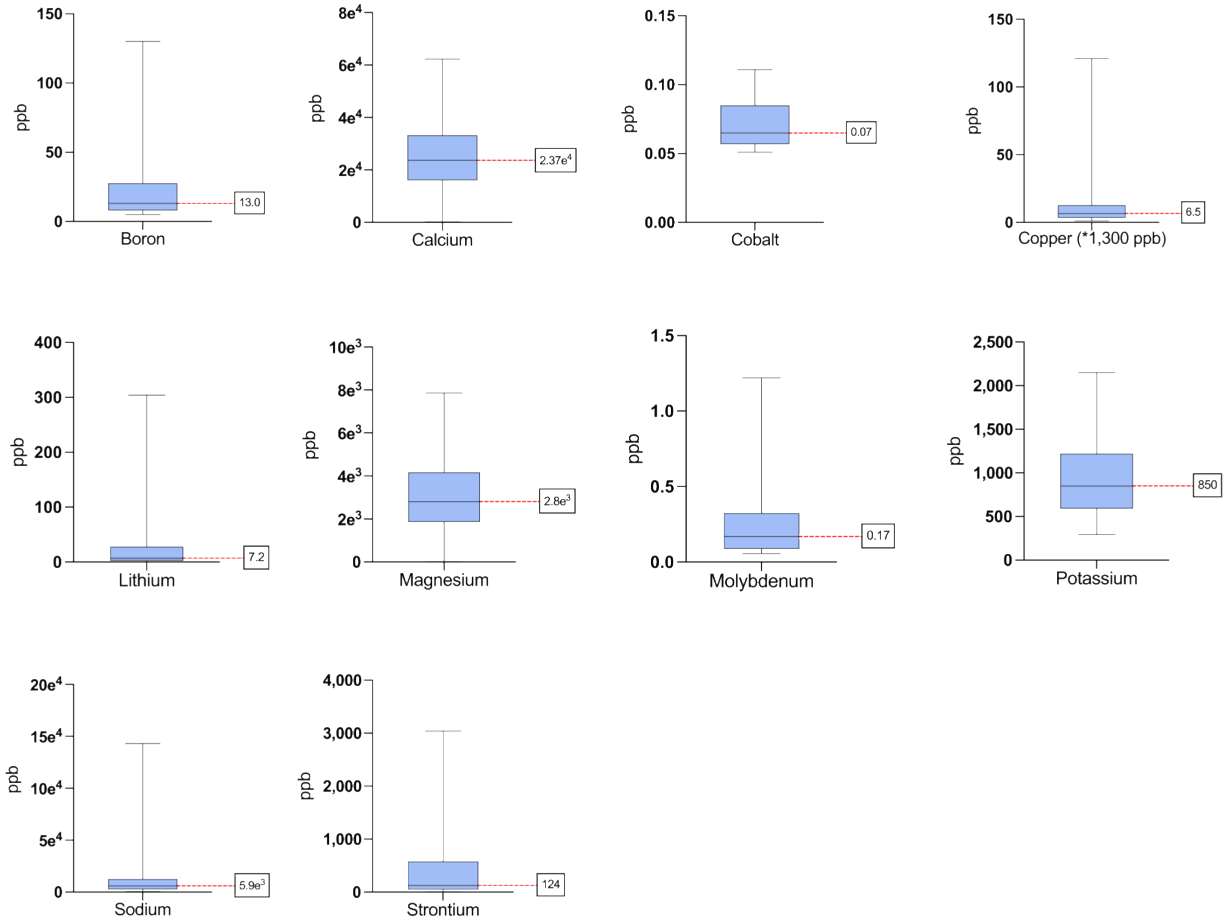
Bolded values indicate a significant correlation, *p-value* $\leq$ *0.05*. ┼ represents a correlation that is < 0.01.

Figure A13: Heatmap of Well Water Contaminants, Wayne County



The below figure displays a panel of box and whisker plots of individual contaminant data for additional metals found in Wayne County wells. These plots correspond to the tabular data in Table 7 in the main text.

Figure A14: Distribution of Additional Well Water Contaminants, Wayne County



Note: N=67 wells in Wayne County. Dashed red lines indicate the median values. A contaminant's corresponding MCL or *SMCL is displayed in parentheses when applicable. Data are not shown for contaminants in which minimal samples (< 3) tested above the detection limit. Wells below the detection limit for a given contaminant were excluded.

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