Statistical Analysis: Metal Concentrations in Soil

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Objective

The Site Remediation and Waste Management Program (SRWMP) collected soil samples from 2016 to 2017 to characterize the polycyclic aromatic hydrocarbon (PAH) and metal concentrations in New Jersey. Previously, the SRWMP and the Division of Science and Research (DSR) produced a report detailing the results of the PAH analyses. Now, the main objective of this report is to statistically analyze and interpret the metal concentrations in soil at various sites across New Jersey. Another goal is to assess potential relationships between metal concentrations and other parameters including depth of sample, county, population density, distance to nearest known contaminated site, and forested versus open areas.

Statistical Methods

From 2016 to 2017, surface (0 to 6 inches) and subsurface (18-24 inches) field samples were collected to measure the concentrations of 22 metals throughout New Jersey (see Table 1 for a list of the metals). These 22 metals are the current inorganic compounds designated for analysis as contained in the Target Analyte List of the EPA Contract Laboratory Program Statement of Work for Inorganic Superfund Methods (EPA 2016). Surface and subsurface samples were collected at 148 individual sites (*n* = 296). Municipalities with population densities higher than 2,000 individuals per square mile were selected for sampling. Thus, all 21 counties in New Jersey were evaluated to varying degrees. At 21 of these 148 individual sites (i.e., one site in each county), multiple samples were collected at both depths. The initial experimental design stated that one triplicate sample would be collected in each of New Jersey's 21 counties, and this was completed with the exception that a quadruplicate sample was inadvertently collected in Middlesex county. At locations where multiple samples were collected, the three or four samples were averaged prior to statistical analysis (separately for each depth). If one of these multiple values was censored (i.e., non-detect), one half of the detection limit value was utilized to calculate the average, and the sample was considered not censored in the subsequent analyses. The subsequent analyses utilized Kaplan-Meier methods (described below) to account for censored values.

The database (*n* = 148 locations X 22 metals X 2 depths = 6,512 total data points) contained many metal measurements with one or more laboratory data qualifiers including (personal communication with Joseph Sanguiliano):

U: The analyte was analyzed for, but it was not detected (*n* = 794).

J: The analyte was detected, but the result was an estimated concentration that was interpolated from calibration curves. This qualifier may also be applied for reported values between the method reporting limit (MRL) and the method detection limit (MDL; n = 1,822).

N: The spike recovery was outside of the limits of 75 – 125 (n = 516).

E: The reported value was estimated because of the presence of interference based on serial dilution analysis (n = 474).

***:** Duplicate analysis was not within control limits (n = 40).

NA: No laboratory qualifier (n = 3,219).

Instead of assuming a constant value (such as the detection limit, half of the detection limit, or zero) for the *U*-qualified values, the metal measurements with *U*-qualifiers were included in the analysis as less than the reported MDL, instead of as a number. All other qualified measurements were treated as quantified real numbers.

Summary statistics, including mean, standard deviation (SD), standard error (SE), and percentiles, were calculated for each of the 22 metals using the Kaplan-Meier[1] method to allow inclusion of the left-censored values (i.e., values below detection). Although parametric summary statistics (mean, SD, and SE) were calculated, the data distributions were non-normally distributed because of the overabundance of low and censored measurements. Instead of a normal distribution, the metal concentrations followed a left-censored, skewed distribution. Therefore, nonparametric summary statistics (i.e., percentiles such as medians and quartiles) were more valid to describe the distribution of the data than parametric measures. Furthermore, the summary statistics for each metal were calculated separately for surface and subsurface samples.

To determine whether the concentrations of metals in background soil varied as a function of various parameters (distance to contaminated site, population density, depth, and forest/open), a multiple regression model was fit by using a maximum likelihood estimation (MLE) approach. This method was selected to allow for data below the MDL to be included in statistical analyses instead of substituting with arbitrary values.

To determine whether metal concentration varied based on county, a Wilcoxon rank test was implemented with a Peto-Prentice weighting method. For each type of metal, the Wilcoxon test was utilized to determine whether the distributions of metal concentrations for each county were identical or not. When a significant result was detected by the Wilcoxon test, pairwise, post-hoc Wilcoxon tests were performed to determine which counties had significantly higher concentrations of metals.

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[1] The Kaplan-Meier method is a non-parametric statistic that can be utilized to estimate summary statistics (e.g., means) with censored data by fitting the censored data to a survival curve.

All statistical analyses were performed in program R (3.6.1), and the statistical models were fit using the NADA package (Lee 2015) which allowed for the inclusion of the left-censored data (*U*-qualified values). Statistical significance was assumed when $p \leq 0.05$.

Results and Discussion

Overall, the medians of the individual metals ranged from 0.05 to 14,400 mg/kg of metal in soil (Table 1; Fig. 1). At the 95th percentile, no metal exceeded the residential or the non-residential remediation standard (Table 1). At the 99th percentile, lead and vanadium exceeded the residential remediation standard. However, no metals exceeded the non-residential remediation standard at the 99th percentile.

In addition, metals at each site were summarized by sample depth (Table 2). When comparing medians between surface and subsurface samples, the concentrations were higher in the surface samples than in the subsurface samples for 13 metals (antimony, arsenic, barium, cadmium, calcium, copper, lead, manganese, potassium, selenium, sodium, vanadium, and zinc). For seven metals (aluminum, beryllium, chromium, cobalt, iron, magnesium, and nickel), the concentrations were higher in the subsurface than in the surface samples. This relationship could not be determined for the remaining two metals (silver and thallium) because there were too many censored values to estimate the median using this technique. At the 95th percentile, arsenic in surface samples exceeded the residential and the non-residential remediation standards. Lead in subsurface samples exceeded the residential standard at the 99th percentile, whereas vanadium in both surface and subsurface samples exceeded the residential standard at the 99th percentile.

According to the left-censored multiple regressions, the following trends were statistically significant for most metals. The results from the left-censored multiple regression analyses showed that most metal concentrations ($n = 19$) were significantly higher in areas located closer to known contaminated sites (Table 3; p-values < 0.015). However, the estimated coefficients were all close to zero, suggesting a limited relationship between predictor variable (distance to contaminated site) and response variable (metal concentration). Furthermore, contaminant concentration was slightly higher when population density was higher (p-values < 0.035) for most metals ($n = 14$). Concentrations of cadmium and potassium were higher in open areas than in forested areas (p-values < 0.021). However, differences in medians were not identified in other metals between open and forested areas. Finally, for nine metals (antimony, arsenic, cadmium, calcium, copper, lead, selenium, silver, and zinc), concentrations were significantly higher when sampled at the surface compared to the subsurface (p-values < 0.004), which confirmed assumptions generated from the summary statistics (Table 2).

Many metal concentrations varied significantly between counties (Wilcoxon tests; p-values < 0.05), and pairwise comparisons indicated where the significant differences existed (Wilcoxon tests; Tables 4 & 5). The median concentration for each metal in each county is displayed in Table 6. Overall, metal concentrations were highest in Hudson, Somerset, and Sussex counties based on the three highest median concentrations in the various counties (Table 6; Fig. 2). Some of these differences in metal concentrations between counties may be due to physiographic, geologic, or demographic factors. For instance, background metal concentrations are typically higher in urban areas because of the dense human population and substantial industrial activity (Sanders 2003). Also, soils in the coastal plain region of New Jersey have decreased affinity for metal accumulation because of higher sand content, lower organic carbon content, and lower pH values than other regions of the State.

Previously, in 1993, soil samples were collected and analyzed for 15 metals (antimony, arsenic, beryllium, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium, and zinc) by the Site Remediation Program and the DSR (NJDEP 1993). The metal concentrations assessed in 1993 were also evaluated in this study, except for mercury. The sample size (*n* = 80) was smaller in the previous study, and only arithmetic means were calculated. The 1993 study selected sites in rural areas, agricultural areas, and golf courses whereas this study selected sites based on population density. Although these results should not be directly compared because of differences in experimental design, the results are presented in Table 7.

Three additional studies were performed from 1996 to 2003 to determine background levels of metals in New Jersey soils (Sanders 2003). During these assessments, soil samples (*n* = 248) were taken in five different regions (urban Piedmont, urban Coastal Plain, rural Valley and Ridge, rural Highlands, and rural Coastal Plain). As with the 1993 study, the current results should not be directly compared to the previous results because of differences in experimental design. However, the results are presented in Table 8 for consideration considering these caveats.

Conclusions

- When samples were analyzed regardless of depth, no metal exceeded the residential or the non-residential remediation standard at the 95th percentile.
    - Two metals (lead and vanadium) exceeded the residential remediation standard at the 99th percentile.
    - No metal exceeded the non-residential remediation standard at the 99th percentile.
- When samples were analyzed separately based on depth (surface or subsurface), only one metal (arsenic) exceeded the residential and the non-residential remediation standards at the 95th percentile.
    - Lead in subsurface samples exceeded the residential standard at the 99th percentile.
    - Vanadium in both surface and subsurface samples exceeded the residential standard at the 99th percentile.
- Metal concentrations were higher in surface samples than subsurface samples for 13 metals. However, concentrations were higher in subsurface samples than surface samples for seven of the metals.
- Concentrations of many metals were higher in the areas with high population density and/or close to known contaminated sites.
- Many metal concentrations varied significantly by county with metal concentrations being highest in Hudson, Somerset, and Sussex counties. Refer to Table 6 for the median concentrations of each metal in each county.

Figures

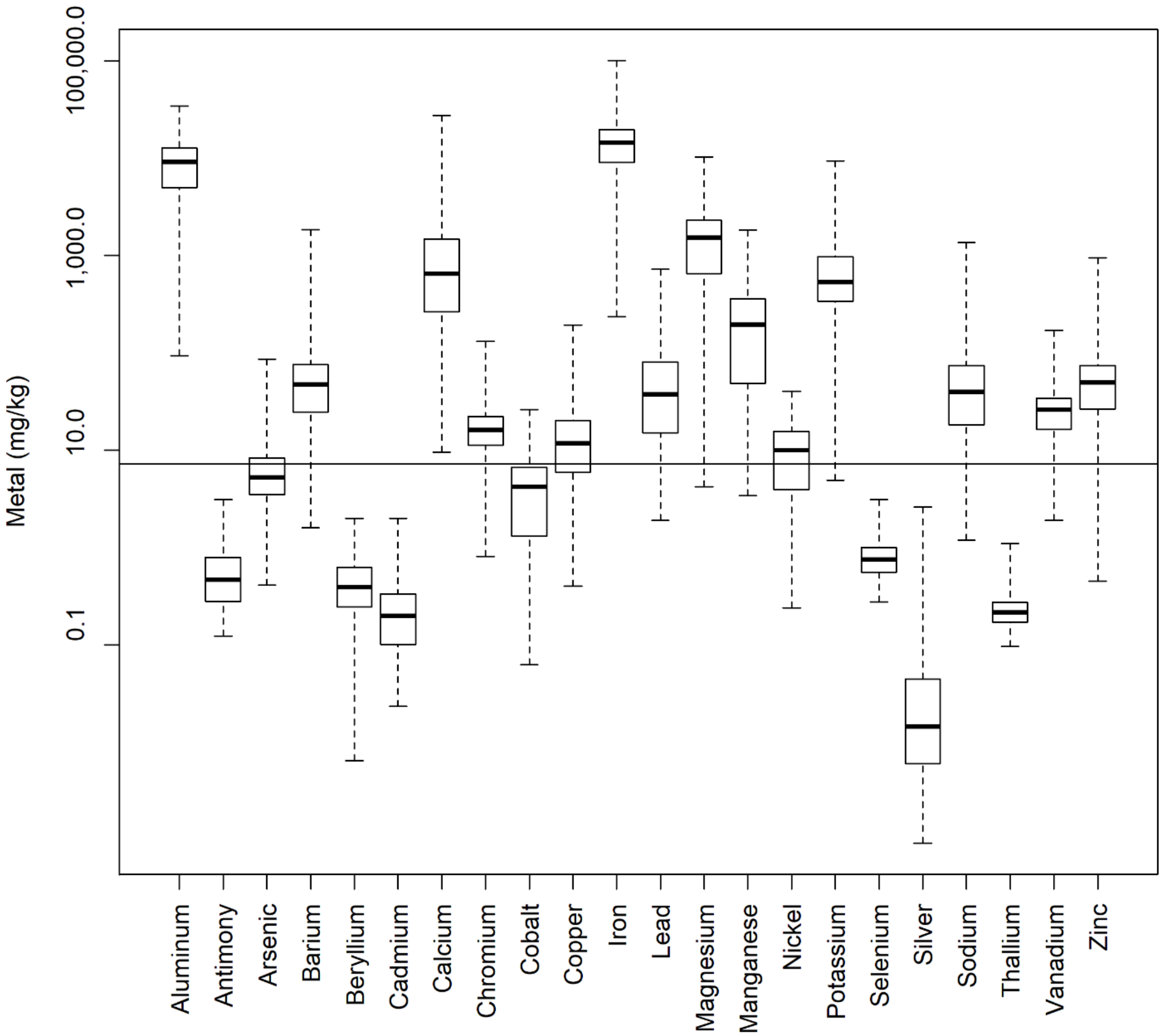


Fig. 1. Summary percentiles of metal concentrations. The horizontal line represents the maximum censored value (*U*-qualified values). Box plot: box, 25th-75th percentiles; center line, median; whiskers, minimum & maximum. The *y*-axis is displayed in the log scale.

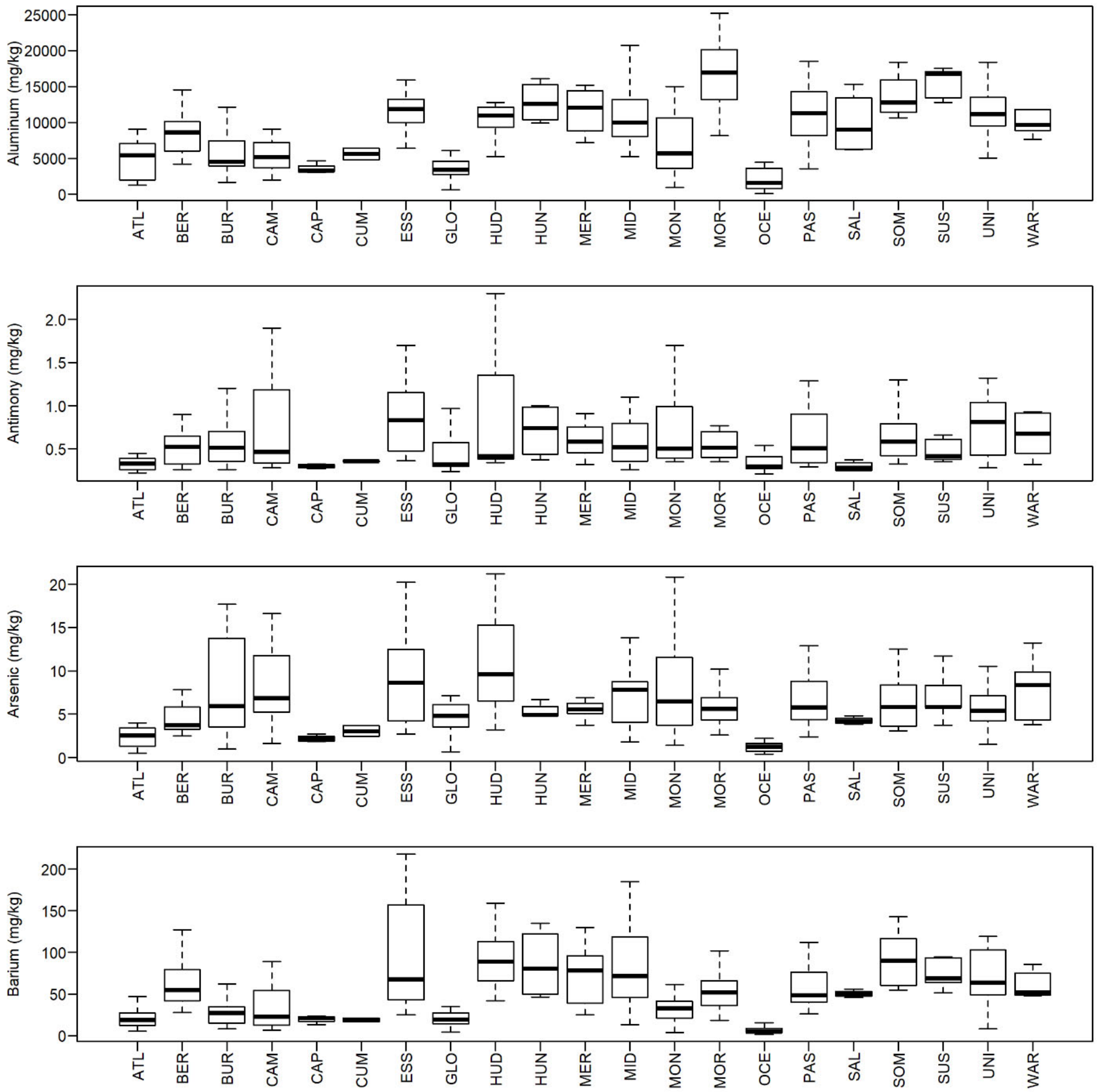


Fig. 2. Boxplots of metal concentrations by county. Figure continued on the next five pages. Note: scale is truncated. See Table 4 for county abbreviations.

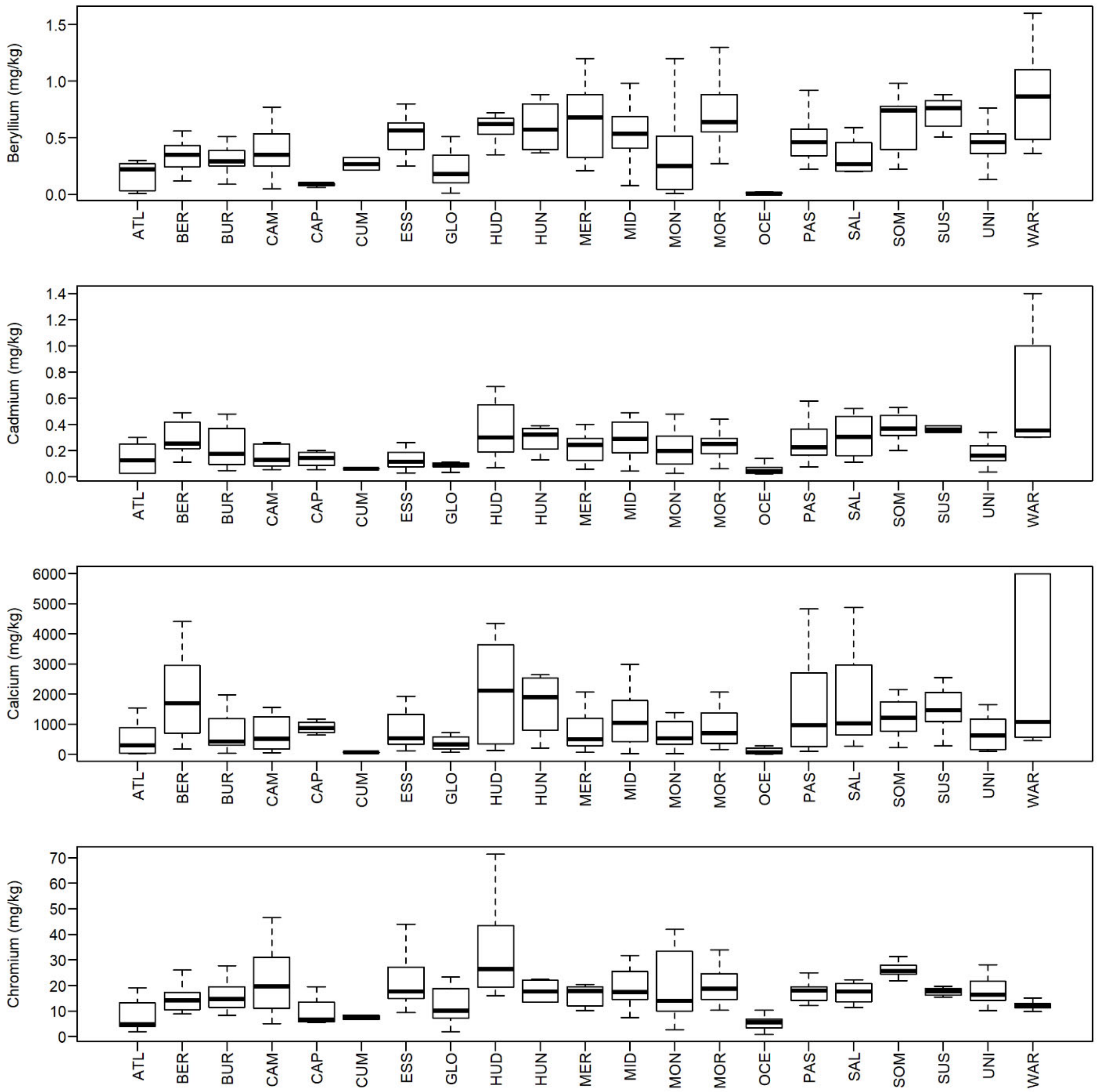

Beryllium (mg/kg)
Cadmium (mg/kg)
Calcium (mg/kg)
Chromium (mg/kg)
ATL BER BUR CAM CAP CUM ESS GLO HUD HUN MER MID MON MOR OCE PAS SAL SOM SUS UNI WAR

Fig. 2. Cont.

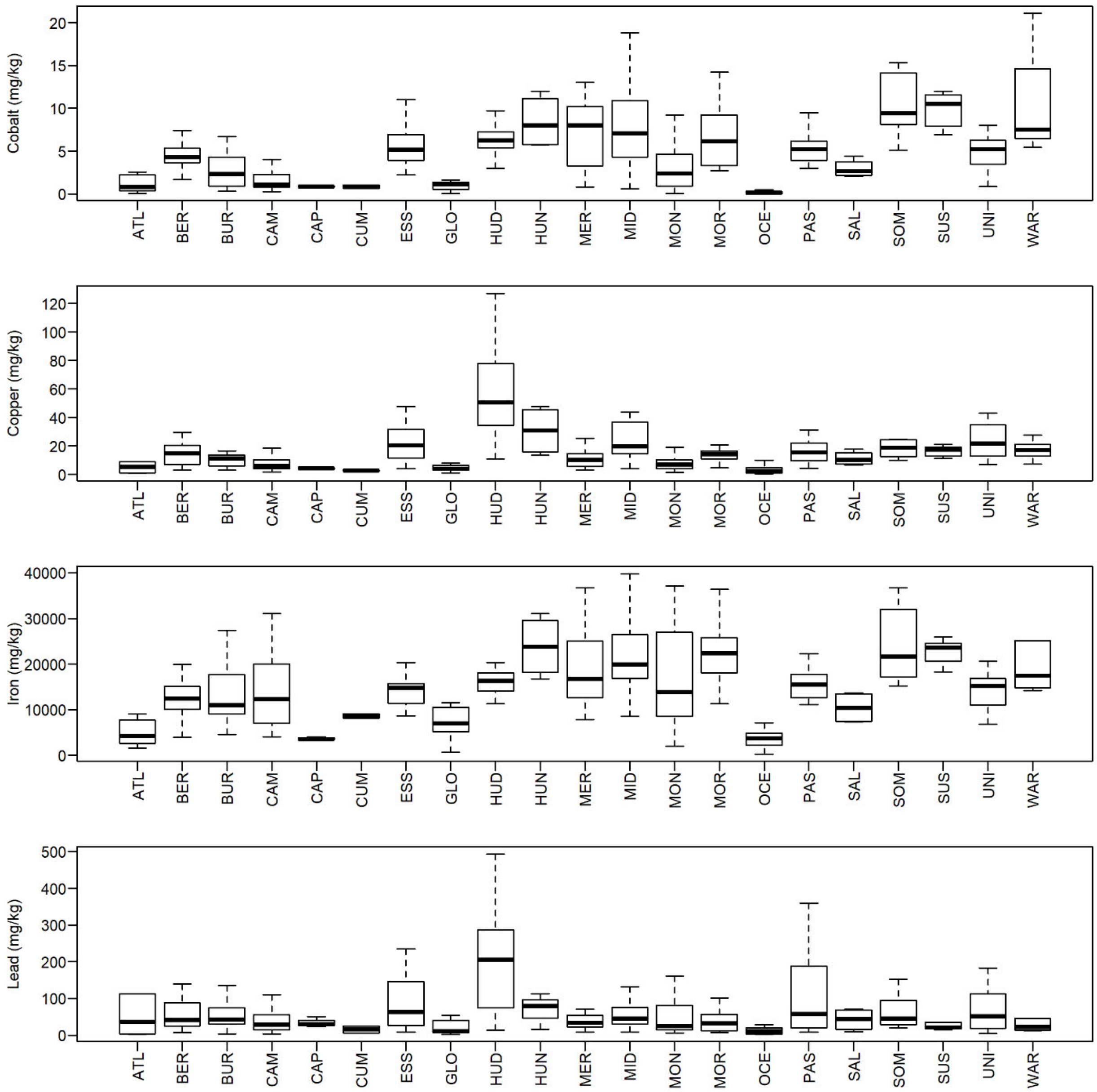
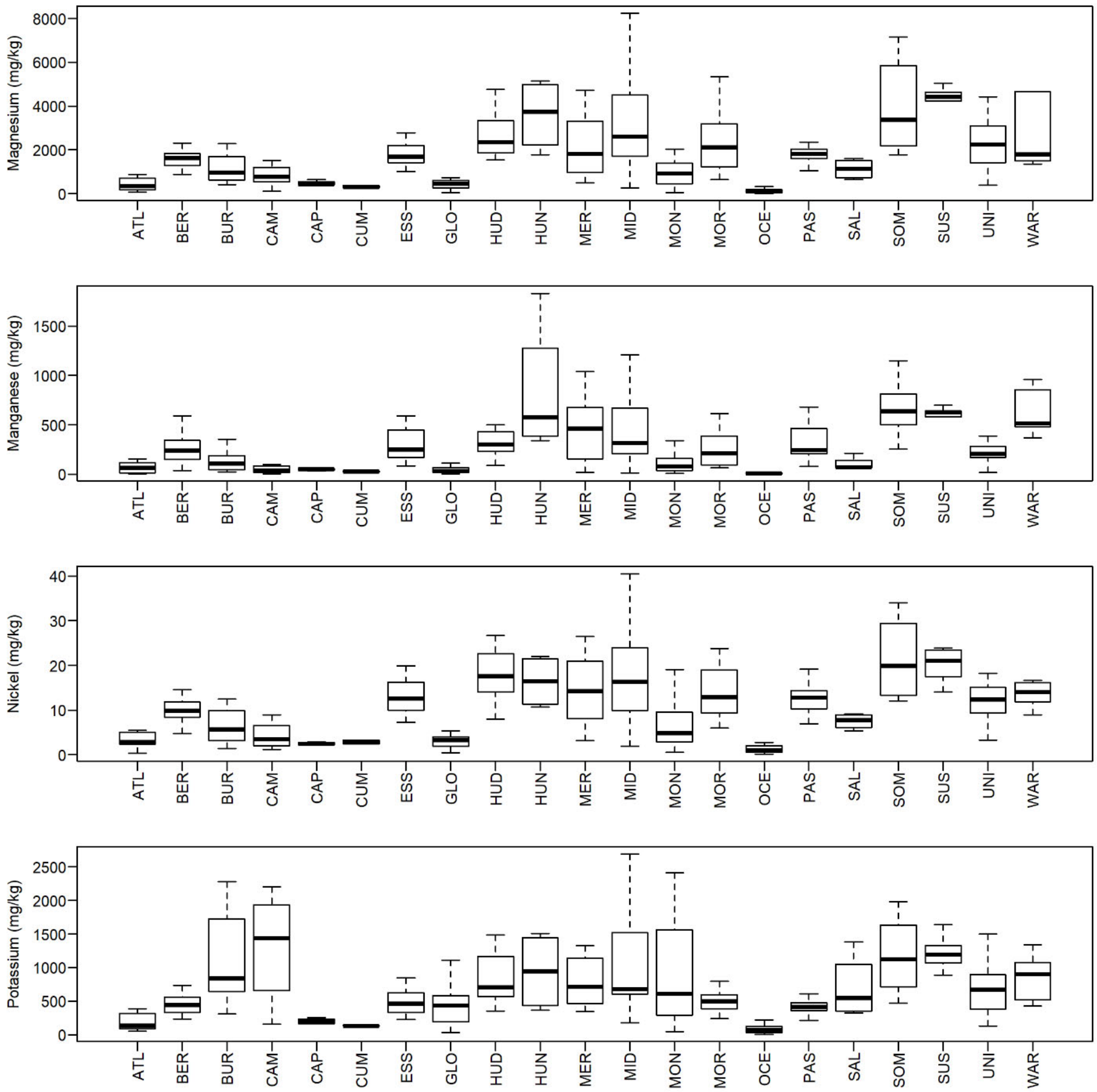

Cobalt (mg/kg)
Copper (mg/kg)
Iron (mg/kg)
Lead (mg/kg)
ATL
BER
BUR
CAM
CAP
CUM
ESS
GLO
HUD
HUN
MER
MID
MON
MOR
OCE
PAS
SAL
SOM
SUS
UNI
WAR

Fig. 2. Cont.


Magnesium (mg/kg)
0
2000
4000
6000
8000
Manganese (mg/kg)
0
500
1000
1500
Nickel (mg/kg)
0
10
20
30
40
Potassium (mg/kg)
0
500
1000
1500
2000
2500
ATL
BER
BUR
CAM
CAP
CUM
ESS
GLO
HUD
HUN
MER
MID
MON
MOR
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PAS
SAL
SOM
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WAR

Fig. 2. Cont.

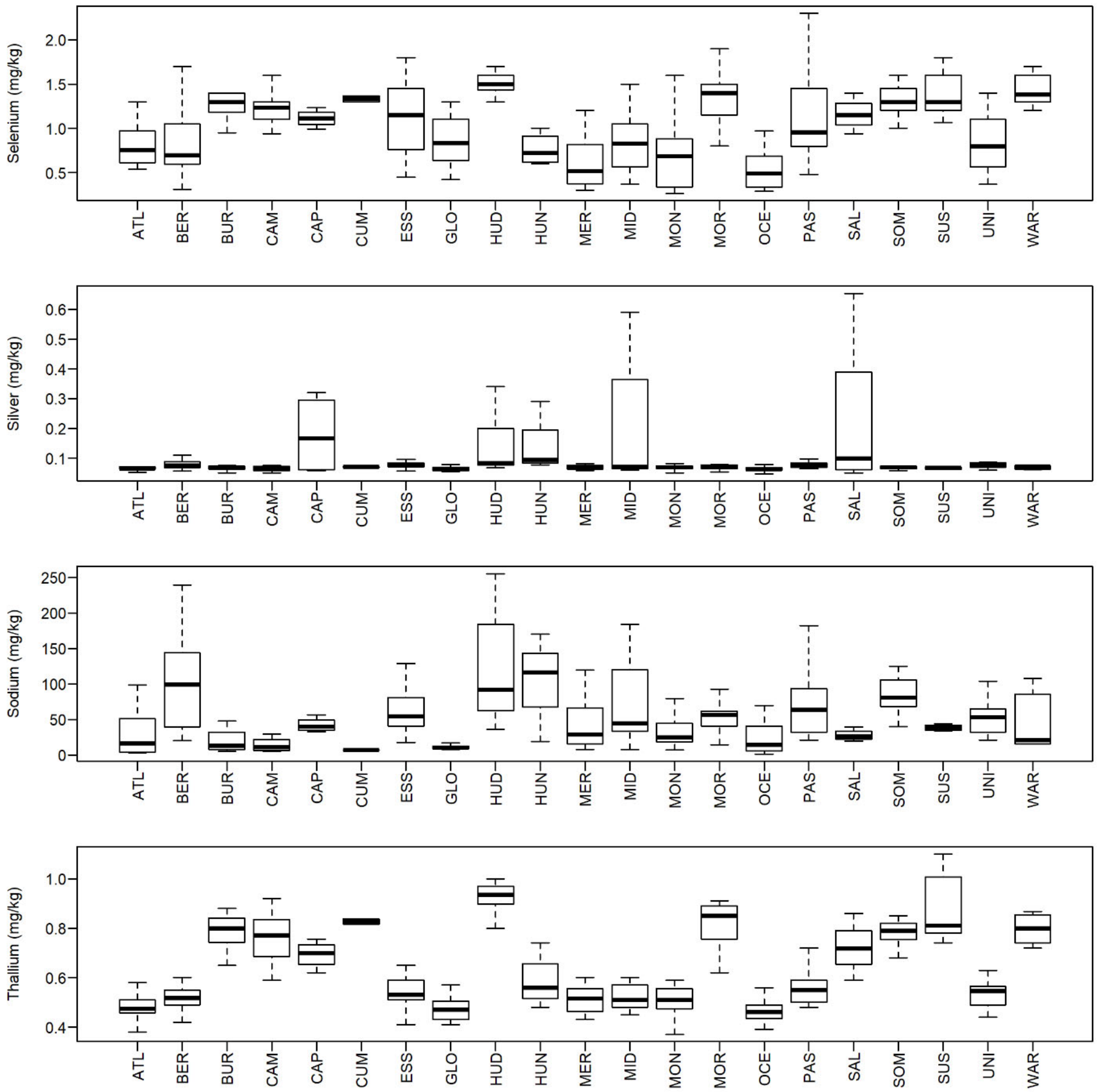
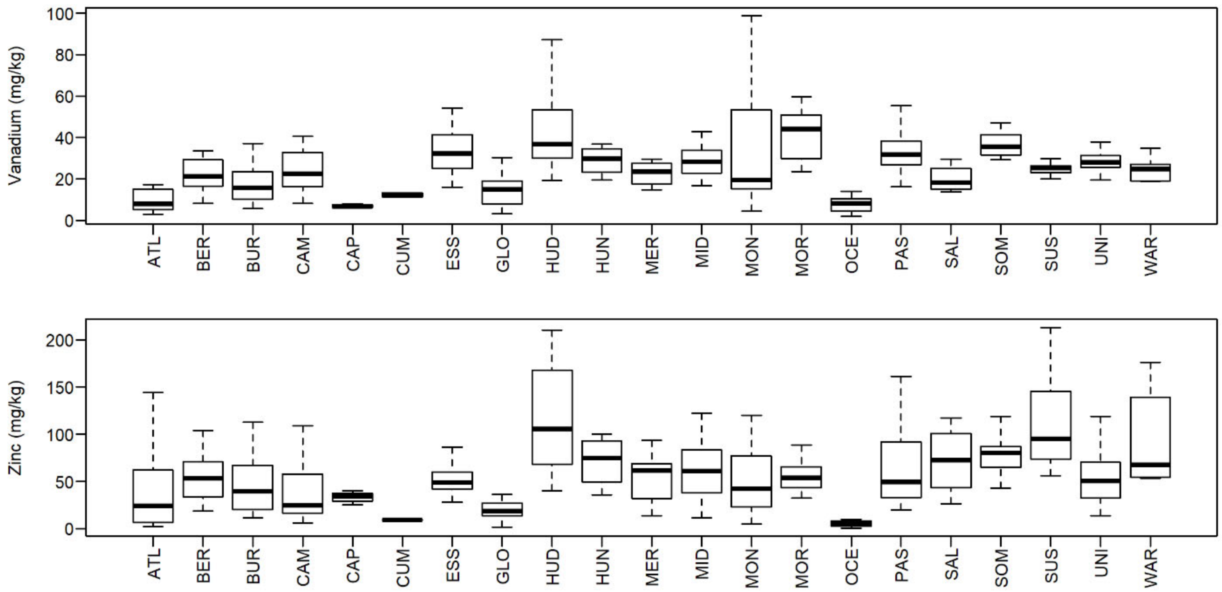

Selenium (mg/kg)
Silver (mg/kg)
Sodium (mg/kg)
Thallium (mg/kg)
ATL BER BUR CAM CAP CUM ESS GLO HUD HUN MER MID MON MOR OCE PAS SAL SOM SUS UNI WAR

Fig. 2. Cont.


Vanadium (mg/kg)
100
80
60
40
20
0
ATL
BER
BUR
CAM
CAP
CUM
ESS
GLO
HUD
HUN
MER
MID
MON
MOR
OCE
PAS
SAL
SOM
SUS
UNI
WAR
Zinc (mg/kg)
200
150
100
50
0
ATL
BER
BUR
CAM
CAP
CUM
ESS
GLO
HUD
HUN
MER
MID
MON
MOR
OCE
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SAL
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WAR

Fig. 2. Cont.

Tables

Table 1. The following 22 metals were selected based on the EPA's Target Analyte List (EPA 2016). Summary statistics for metals (mg/kg) including mean, standard deviation (SD), standard error (SE), and percentiles (50 = median). The NJDEP soil remediation standards are also included (NJDEP 2017); starred values (*) exceed the residential and/or the non-residential remediation standards. In some cases, statistics could not be estimated because there were too many censored values (--). Table continued on next page.

Metal	*n*	Mean	SD	SE	Min	25	50	75	90	95	99	Max	Residential Remediation Standard	Non-Residential Remediation Standard
Aluminum	296	9,250	5,270	300	90	4,950	9,100	12,600	16,200	18,300	23,800	34,200	78,000	NA
Antimony	296	0.62	0.46	0.03	0.21	0.28	0.47	0.79	1.20	1.70	2.30	3.10	31	450
Arsenic	296	7.1	7.4	0.4	0.4	3.5	5.3	8.3	14.4	17.7	34.4	86.3	19	19
Barium	296	62.8	115.3	6.7	1.6	24.5	47.2	75.4	114.0	140.0	218.0	1,850.0	16,000	59,000
Beryllium	296	0.46	0.33	0.02	0.01	0.24	0.39	0.63	0.86	1.00	1.60	2.00	16	140
Cadmium	296	0.26	0.24	0.01	0.02	0.10	0.20	0.33	0.48	0.69	1.40	2.00	78	78
Calcium	296	1,320	2,540	140	0	260	640	1,470	2,740	4,330	17,400	27,400	NA	NA
Chromium	296	19.6	16.5	1.0	0.8	11.3	16.2	22.1	33.9	44.0	121.0	132.0	NA	NA
Cobalt	296	4.8	4.0	0.2	0.0	1.3	4.2	6.6	9.9	12.3	18.8	26.2	1,600	590
Copper	296	18.2	21.5	1.3	0.4	5.9	11.7	20.3	41.2	66.1	104.0	193.0	3,100	45,000
Iron	296	15,860	11,740	680	230	9,040	14,400	19,500	26,400	32,700	69,600	101,000	NA	NA
Lead	296	69.7	92.5	5.4	1.9	15.1	37.3	80.5	163.0	273.0	461.0 *	727.7 *	400	800
Magnesium	296	1,810	1,630	90	0	650	1,530	2,300	3,720	5,030	8,240	10,290	NA	NA
Manganese	296	269	304	18	3	48	193	358	643	836	1,800	1,830	11,000	5,900
Nickel	296	10.6	7.6	0.4	0.2	3.9	10.0	15.6	20.3	23.9	33.7	40.5	1,600	23,000
Potassium	296	770	830	40	0	330	530	950	1,560	2,050	3,970	9,370	NA	NA
Selenium	296	0.8	0.5	0.0	0.3	0.5	0.8	1.0	1.4	1.6	2.2	3.1	390	5,700
Silver	296	0.10	0.22	0.01	0.05	0.05	0.05	0.05	0.18	0.34	1.30	2.60	390	5,700
Sodium	296	62.9	97.9	5.7	1.2	18.0	39.7	74.0	136.0	198.0	325.0	1,360.0	NA	NA

Metal	*n*	Mean	SD	SE	Min	25	50	75	90	95	99	Max	Residential Remediation Standard	Non-Residential Remediation Standard
Thallium	296	0.74	0.02	--	0.34	--	--	--	--	--	0.76	1.10	NA	NA
Vanadium	296	27.9	20.8	1.2	1.9	16.3	26.2	34.0	46.5	54.7	165.0 *	170.0 *	78	1,100
Zinc	296	63.6	86.0	5.0	0.5	26.4	49.4	73.5	117.3	149.0	402.0	945.0	23,000	110,000

Table 2. Summary statistics for metals (mg/kg) at different depths including mean, standard deviation (SD), standard error (SE), and percentiles (50 = median). Soil remediation standards are also included (NJDEP 2017); starred values (*) exceed the residential and/or the non-residential remediation standard. In some cases, statistics could not be estimated because there were too many censored values (--). Table continued on the next page.

Metal	Depth	*n*	Mean	SD	SE	Min	25	50	75	90	95	99	Max	Residential Remediation Standard	Non-Residential Remediation Standard
Aluminum	Surface	148	8,630	4,560	370	180	4,600	8,230	11,900	14,360	16,200	20,400	25,200	78,000	NA
	Subsurface	148	9,880	5,850	480	90	5,230	9,510	13,500	18,200	18,700	23,800	34,200		
Antimony	Surface	148	0.76	0.51	0.04	0.23	0.38	0.61	0.98	1.50	1.70	2.60	3.10	31	450
	Subsurface	148	0.49	0.35	0.03	0.21	0.24	0.40	0.55	0.89	1.10	1.90	1.90		
Arsenic	Surface	148	8.3	8.8	0.7	0.4	4.1	6.1	9.3	15.6	20.2 *	35.6 *	86.3 *	19	19
	Subsurface	148	5.9	5.5	0.5	0.4	3.1	4.3	6.8	11.9	16.6	31.3 *	34.3 *		
Barium	Surface	148	56.0	53.6	4.4	2.3	24.0	47.2	70.1	109.0	130.0	168.0	530.0	16,000	59,000
	Subsurface	148	69.7	154.0	12.7	1.6	24.5	47.2	83.6	122.0	159.0	218.0	1,850.0		
Beryllium	Surface	148	0.42	0.30	0.02	0.01	0.24	0.37	0.56	0.76	0.93	1.30	2.00	16	140
	Subsurface	148	0.49	0.35	0.03	0.01	0.24	0.46	0.68	0.92	1.20	1.60	1.70		
Cadmium	Surface	148	0.29	0.26	0.02	0.02	0.12	0.24	0.36	0.53	0.79	1.40	1.80	78	78
	Subsurface	148	0.22	0.22	0.02	0.03	0.09	0.17	0.28	0.44	0.52	1.00	2.00		
Calcium	Surface	148	1,520	2,880	230	20	350	950	1,680	2,880	4,310	19,490	27,400	NA	NA
	Subsurface	148	1,120	2,140	170	0	170	410	1,220	2,650	4,340	15,300	17,400		
Chromium	Surface	148	18.6	13.6	1.1	1.2	11.8	15.9	21.5	30.7	42.2	71.4	125.0	NA	NA
	Subsurface	148	20.6	19.0	1.6	0.8	10.9	16.4	23.3	35.0	46.6	121.0	132.0		
Cobalt	Surface	148	4.3	3.6	0.3	0.0	1.3	3.6	6.1	8.8	9.9	14.6	26.2	1,600	590
	Subsurface	148	5.2	4.3	0.4	0.0	1.3	4.6	7.4	12.0	13.0	18.8	21.1		
Copper	Surface	148	22.3	24.5	2.0	0.8	8.5	16.0	24.1	47.6	72.6	104.0	193.0	3,100	45,000
	Subsurface	148	14.2	17.2	1.4	0.4	4.2	9.4	16.4	31.1	49.5	85.5	127.0		

Metal	Depth	*n*	Mean	SD	SE	Min	25	50	75	90	95	99	Max	Residential Remediation Standard	Non-Residential Remediation Standard
Iron	Surface	148	14,540	8,690	710	230	9,150	13,600	18,100	23,800	27,900	42,800	68,600	NA	NA
	Subsurface	148	17,190	14,050	1,150	270	8,780	15,200	21,100	29,700	36,400	88,800	101,000		
Lead	Surface	148	93.8	84.7	7.0	4.8	35.5	61.3	121.0	233.0	278.0	360.0	461.0 *	400	800
	Subsurface	148	45.5	93.9	7.7	1.9	9.1	17.7	37.6	80.8	139.0	493.0 *	727.7 *		
Magnesium	Surface	148	1,660	1,390	110	10	640	1,460	2,190	3,300	3,910	6,060	10,290	NA	NA
	Subsurface	148	1,970	1,830	150	0	650	1,570	2,360	4,660	5,440	8,240	10,100		
Manganese	Surface	148	260.0	280.6	23.1	4.4	51.4	207.0	350.0	614.0	702.0	1,800.0	1,820.0	11,000	5,900
	Subsurface	148	277.1	325.9	26.8	3.4	38.7	179.0	360.0	775.0	959.0	1,430.0	1,830.0		
Nickel	Surface	148	10.5	7.1	0.6	0.2	3.8	9.8	15.0	19.9	22.4	30.2	34.0	1,600	23,000
	Subsurface	148	10.8	8.1	0.7	0.2	4.0	10.0	15.6	22.5	25.8	33.7	40.5		
Potassium	Surface	148	720	590	40	20	350	540	930	1,530	1,830	3,700	3,930	NA	NA
	Subsurface	148	810	1,010	80	0	310	520	1,000	1,830	2,280	4,250	9,370		
Selenium	Surface	148	0.9	0.5	0.0	0.3	0.6	0.9	1.2	1.6	1.8	2.2	3.1	390	5,700
	Subsurface	148	0.8	0.4	0.0	0.3	0.5	0.7	0.9	1.4	1.5	1.7	2.3		
Silver	Surface	148	0.15	0.29	0.02	0.05	--	--	0.08	0.34	0.59	1.50	2.60	390	5,700
	Subsurface	148	0.06	0.09	0.01	0.05	--	--	--	0.05	0.12	0.42	0.98		
Sodium	Surface	148	61.1	59.8	4.9	3.4	21.7	43.0	70.3	125.0	198.0	295.0	325.0	NA	NA
	Subsurface	148	64.8	125.1	10.3	1.2	12.4	34.3	80.0	143.0	186.0	443.0	1,360.0		
Thallium	Surface	148	--	--	--	0.39	--	--	--	--	--	--	1.10	NA	NA
	Subsurface	148	0.74	0.03	0.00	0.34	--	--	--	--	--	0.81	1.10		
Vanadium	Surface	148	28.8	19.4	1.6	2.6	16.6	26.5	35.9	47.5	54.0	101.0 *	169.0 *	78	1,100
	Subsurface	148	27.0	22.1	1.8	1.9	15.7	23.5	31.9	42.4	58.2	165.0 *	170.0 *		
Zinc	Surface	148	72.7	88.6	7.3	1.5	32.4	57.3	86.4	122.0	170.0	402.0	903.0	23,000	110,000
	Subsurface	148	54.5	82.7	6.8	0.5	19.3	41.2	66.0	98.3	143.9	186.0	945.0		

Table 3. Results from multiple regression models fit with a Maximum Likelihood Estimation (MLE) approach for each metal. The table includes type of metal, sample size (*n*), number of censored values, parameter, coefficient, standard error (SE), *Z*-value, *p*-value, and whether the relationship between Metal and Parameter was statistically significant (designated by *). When the *p*-value was less than 0.05, the relationship between Metal and Parameter was statistically significant. A positive coefficient suggested an increasing relationship between variables, whereas a negative coefficient suggests a decreasing relationship. Table continued on next two pages.

Metal	*n*	Censored	Parameter	Coefficient	SE	*Z*-value	*p*-value	Sig
Aluminum	296	0	Intercept	9.06	0.12	77.04	0.000	*
			Distance	0.00	0.00	-2.44	0.015	*
			Open Area	-0.06	0.10	-0.57	0.570	
			Density	0.00	0.00	1.69	0.091	
			Shallow	-0.08	0.09	-0.85	0.395	
Antimony	296	79	Intercept	-0.73	0.10	-7.17	0.000	*
			Distance	0.00	0.00	-4.06	0.000	*
			Open Area	0.14	0.08	1.73	0.083	
			Density	0.00	0.00	-0.85	0.393	
			Shallow	0.48	0.08	6.09	0.000	*
Arsenic	296	1	Intercept	1.57	0.11	13.89	0.000	*
			Distance	0.00	0.00	-3.81	0.000	*
			Open Area	0.16	0.09	1.72	0.085	
			Density	0.00	0.00	2.66	0.008	*
			Shallow	0.35	0.09	4.00	0.000	*
Barium	296	0	Intercept	3.75	0.14	27.29	0.000	*
			Distance	0.00	0.00	-3.56	0.000	*
			Open Area	0.21	0.11	1.82	0.069	
			Density	0.00	0.00	3.57	0.000	*
			Shallow	-0.01	0.11	-0.09	0.929	
Beryllium	296	19	Intercept	-1.06	0.20	-5.38	0.000	*
			Distance	0.00	0.00	-2.72	0.007	*
			Open Area	0.11	0.16	0.66	0.508	
			Density	0.00	0.00	1.81	0.071	
			Shallow	-0.08	0.15	-0.52	0.606	
Cadmium	296	22	Intercept	-1.80	0.13	-13.66	0.000	*
			Distance	0.00	0.00	-3.70	0.000	*
			Open Area	0.28	0.11	2.53	0.011	*
			Density	0.00	0.00	2.43	0.015	*
			Shallow	0.30	0.10	2.94	0.003	*

Metal	*n*	Censored	Parameter	Coefficient	SE	*Z*-value	*P*-value	Sig
Calcium	296	1	Intercept	6.03	0.19	31.07	0.000	*
			Distance	0.00	0.00	-2.76	0.006	*
			Open Area	0.31	0.16	1.92	0.055	
			Density	0.00	0.00	3.64	0.000	*
			Shallow	0.59	0.15	3.95	0.000	*
Chromium	296	0	Intercept	2.85	0.10	27.87	0.000	*
			Distance	0.00	0.00	-3.63	0.000	*
			Open Area	0.12	0.08	1.43	0.152	
			Density	0.00	0.00	2.11	0.035	*
			Shallow	-0.01	0.08	-0.17	0.867	
Cobalt	296	11	Intercept	1.18	0.20	5.82	0.000	*
			Distance	0.00	0.00	-3.02	0.003	*
			Open Area	0.08	0.17	0.50	0.617	
			Density	0.00	0.00	2.47	0.014	*
			Shallow	-0.05	0.16	-0.31	0.756	
Copper	296	0	Intercept	2.28	0.14	16.69	0.000	*
			Distance	0.00	0.00	-4.82	0.000	*
			Open Area	0.09	0.11	0.83	0.405	
			Density	0.00	0.00	4.52	0.000	*
			Shallow	0.55	0.11	5.23	0.000	*
Iron	296	0	Intercept	9.62	0.12	82.70	0.000	*
			Distance	0.00	0.00	-3.65	0.000	*
			Open Area	0.13	0.10	1.37	0.170	
			Density	0.00	0.00	0.99	0.323	
			Shallow	-0.07	0.09	-0.76	0.447	
Lead	296	0	Intercept	3.16	0.14	22.58	0.000	*
			Distance	0.00	0.00	-5.56	0.000	*
			Open Area	0.22	0.12	1.93	0.053	
			Density	0.00	0.00	4.55	0.000	*
			Shallow	1.18	0.11	10.93	0.000	*
Magnesium	296	0	Intercept	7.11	0.17	41.97	0.000	*
			Distance	0.00	0.00	-2.57	0.010	*
			Open Area	0.05	0.14	0.37	0.711	
			Density	0.00	0.00	3.04	0.002	*
			Shallow	-0.01	0.13	-0.09	0.927	
Manganese	296	0	Intercept	4.78	0.21	23.33	0.000	*
			Distance	0.00	0.00	-1.51	0.130	
			Open Area	0.02	0.17	0.14	0.893	
			Density	0.00	0.00	3.06	0.002	*
			Shallow	0.10	0.16	0.65	0.519	

Metal	*n*	Censored	Parameter	Coefficient	SE	*Z*-value	*P*-value	Sig
Nickel	296	1	Intercept	2.07	0.15	14.15	0.000	*
			Distance	0.00	0.00	-3.27	0.001	*
			Open Area	0.06	0.12	0.54	0.593	
			Density	0.00	0.00	3.34	0.001	*
			Shallow	0.03	0.11	0.29	0.769	
Potassium	296	0	Intercept	6.26	0.15	43.02	0.000	*
			Distance	0.00	0.00	-2.91	0.004	*
			Open Area	0.28	0.12	2.31	0.021	*
			Density	0.00	0.00	1.93	0.054	
			Shallow	0.08	0.11	0.73	0.466	
Selenium	296	114	Intercept	-0.40	0.09	-4.35	0.000	*
			Distance	0.00	0.00	0.10	0.923	
			Open Area	-0.03	0.07	-0.37	0.708	
			Density	0.00	0.00	0.31	0.759	
			Shallow	0.19	0.07	2.88	0.004	*
Silver	296	243	Intercept	-4.70	0.51	-9.19	0.000	*
			Distance	0.00	0.00	-3.02	0.003	*
			Open Area	0.05	0.35	0.13	0.895	
			Density	0.00	0.00	1.41	0.157	
			Shallow	1.58	0.37	4.27	0.000	*
Sodium	296	11	Intercept	3.54	0.16	22.91	0.000	*
			Distance	0.00	0.00	-3.80	0.000	*
			Open Area	0.10	0.13	0.77	0.440	
			Density	0.00	0.00	4.38	0.000	*
			Shallow	0.22	0.12	1.83	0.068	
Thallium	296	292	Intercept	-3.49	3.93	-0.89	0.375	
			Distance	0.00	0.00	0.55	0.584	
			Open Area	0.81	1.03	0.79	0.430	
			Density	0.00	0.00	0.47	0.638	
			Shallow	-26.70	0.00	NA	NA	NA
Vanadium	296	0	Intercept	3.11	0.10	30.99	0.000	*
			Distance	0.00	0.00	-3.10	0.002	*
			Open Area	0.07	0.08	0.90	0.370	
			Density	0.00	0.00	2.84	0.005	*
			Shallow	0.12	0.08	1.49	0.138	
Zinc	296	0	Intercept	3.67	0.14	25.55	0.000	*
			Distance	0.00	0.00	-4.78	0.000	*
			Open Area	0.20	0.12	1.71	0.087	
			Density	0.00	0.00	3.51	0.000	*
			Shallow	0.37	0.11	3.37	0.001	*

Table 4. Abbreviations for counties in New Jersey.

County	Abbreviation
Atlantic	ATL
Bergen	BER
Burlington	BUR
Camden	CAM
Cape May	CAP
Cumberland	CUM
Essex	ESS
Gloucester	GLO
Hudson	HUD
Hunterdon	HUN
Mercer	MER
Middlesex	MID
Monmouth	MON
Morris	MOR
Ocean	OCE
Passaic	PAS
Salem	SAL
Somerset	SOM
Sussex	SUS
Union	UNI
Warren	WAR

Table 5. Significant *p*-values from Wilcoxon tests of metal concentrations by county (see Table 4 for abbreviations). When a *p*-value is displayed, one of the two counties has significantly higher metal concentrations than the other county being compared.

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
Aluminum	BER	0.009																			
	BUR		0.001																		
	CAM		0.002																		
	CAP		0.009																		
	CUM					0.021															
	ESS	0.000	0.000	0.000	0.000	0.006															
	GLO		0.000	0.022	0.007		0.001	0.000													
	HUD	0.000	0.023	0.000	0.000	0.006			0.000												
	HUN	0.000	0.003	0.000	0.000	0.011			0.000												
	MER	0.000	0.005	0.000	0.000	0.007			0.000												
	MID	0.001		0.000	0.000	0.006			0.000												
	MON							0.001	0.015	0.012	0.007	0.001	0.009								
	MOR	0.000	0.000	0.000	0.000	0.006		0.002	0.000	0.000		0.002	0.000	0.000							
	OCE	0.001	0.000	0.000	0.000	0.044	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.001	0.033	0.000	0.000	0.007			0.000					0.002	0.001	0.000					
	SAL	0.020		0.016	0.043	0.011			0.000						0.049	0.000					
	SOM	0.000	0.000	0.000	0.000	0.006			0.000	0.007			0.006	0.000	0.036	0.000					
	SUS	0.000	0.000	0.000	0.000	0.009		0.008	0.000	0.000		0.010	0.000	0.000		0.000	0.010	0.034	0.035		
	UNI	0.000	0.007	0.000	0.000	0.006			0.000					0.002	0.000	0.000			0.046	0.000	
	WAR	0.000		0.000	0.000	0.009			0.000						0.017	0.000				0.043	
Antimony	BER	0.024																			
	BUR	0.005																			
	CAM	0.028																			
	CAP			0.024	0.029																
	CUM																				
	ESS	0.000	0.009	0.033		0.008															

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	GLO							0.002													
	HUD																				
	HUN	0.002				0.011															
	MER	0.001				0.012			0.036												
	MID	0.009				0.013			0.046												
	MON	0.007				0.011			0.028												
	MOR	0.009				0.032		0.030													
	OCE		0.011	0.002	0.008			0.000			0.001	0.000	0.001	0.001	0.002						
	PAS	0.031														0.009					
	SAL			0.016	0.026			0.008			0.011	0.012	0.016	0.012	0.032						
	SOM	0.004				0.021			0.047							0.000		0.021			
	SUS	0.024				0.009										0.010		0.010			
	UNI	0.002	0.023			0.017			0.010							0.000		0.018			
	WAR	0.001				0.010			0.040							0.000		0.010			
	BER	0.005																			
	BUR	0.002																			
Arsenic	CAM	0.001	0.018																		
	CAP		0.007	0.046	0.025																
	CUM																				
	ESS	0.000	0.009			0.006															
	GLO	0.003			0.029	0.021		0.048													
	HUD	0.000	0.000			0.006			0.001												
	HUN	0.000				0.012															
	MER	0.000	0.039			0.006				0.007											
	MID	0.000	0.016			0.014			0.049												
	MON	0.002				0.039															
	MOR	0.000	0.041			0.007				0.003											
	OCE	0.029	0.000	0.000	0.000	0.015	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.000				0.007				0.021						0.000					

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	SAL	0.001				0.011				0.046	0.032	0.043				0.000					
	SOM	0.001				0.006				0.019						0.000					
	SUS	0.000	0.031			0.009										0.000					
	UNI	0.000				0.016				0.002						0.000					
	WAR	0.000	0.012			0.009										0.000					
	BER	0.001																			
	BUR		0.000																		
Barium	CAM		0.001																		
	CAP		0.006																		
	CUM																				
	ESS	0.000		0.000	0.000	0.006															
	GLO		0.000					0.000													
	HUD	0.000	0.006	0.000	0.000	0.006			0.000												
	HUN	0.002		0.000	0.005	0.011			0.000												
	MER	0.001		0.000	0.000	0.007			0.000												
	MID	0.001		0.000	0.000	0.020			0.000												
	MON		0.000					0.000	0.014	0.000	0.000	0.001	0.000								
	MOR	0.003		0.000	0.006	0.011			0.000	0.001				0.006							
	OCE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.001		0.000	0.001	0.006			0.000	0.010				0.000		0.000					
	SAL	0.011		0.005		0.011			0.000					0.003		0.000					
	SOM	0.000	0.003	0.000	0.000	0.007			0.000					0.000	0.001	0.000	0.018	0.013			
	SUS	0.000		0.000	0.000	0.009			0.000					0.000	0.041	0.000		0.018			
	UNI	0.001		0.000	0.001	0.024			0.000					0.001		0.000					
	WAR	0.001		0.000	0.017	0.009			0.000					0.000		0.000			0.015		
	BER	0.006																			
	BUR	0.016																			
Beryllium	CAM	0.005																			
	CAP		0.006	0.009	0.027																

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	CUM					0.021															
	ESS	0.000	0.000	0.001	0.020	0.006															
	GLO		0.029	0.036	0.030			0.000													
	HUD	0.000	0.000	0.002	0.011	0.005			0.000												
	HUN	0.000	0.011	0.012	0.045	0.011			0.000												
	MER	0.000	0.007	0.016		0.007			0.000												
	MID	0.000	0.005	0.007	0.038	0.012			0.000												
	MON							0.011		0.010		0.043	0.026								
	MOR	0.000	0.000	0.000	0.001	0.006			0.000					0.003							
	OCE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.000	0.018	0.013		0.006			0.000	0.034				0.043	0.004	0.000					
	SAL					0.011									0.022	0.000					
	SOM	0.000	0.001	0.003	0.011	0.006			0.000					0.028		0.000		0.043			
	SUS	0.000	0.000	0.000	0.001	0.009		0.022	0.000	0.045				0.013		0.000	0.003	0.018			
	UNI	0.000	0.022	0.019		0.006			0.000	0.015				0.049	0.001	0.000			0.034	0.000	
	WAR	0.000	0.000	0.001	0.001	0.009			0.000					0.019		0.000	0.011	0.034			0.006
	BER	0.018																			
	BUR																				
Cadmium	CAM		0.006																		
	CAP		0.027																		
	CUM		0.049																		
	ESS		0.000																		
	GLO		0.000	0.008																	
	HUD	0.010		0.018	0.003	0.039		0.000	0.000												
	HUN	0.019						0.002	0.000												
	MER							0.014	0.000												
	MID	0.018			0.040			0.001	0.000												
	MON		0.042						0.013	0.015											
	MOR							0.004	0.000	0.047											

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	OCE		0.000	0.000	0.000	0.001		0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.040			0.032			0.001	0.000							0.000					
	SAL							0.032	0.000							0.000					
	SOM	0.001		0.006	0.002	0.008		0.000	0.000			0.003		0.002	0.001	0.000	0.021				
	SUS	0.000			0.017	0.009		0.000	0.000			0.005		0.014	0.002	0.000					
	UNI		0.005					0.043	0.000	0.003			0.036			0.000			0.000	0.001	
	WAR	0.000	0.021	0.007	0.001	0.009		0.000	0.000			0.001		0.001	0.000	0.000	0.022				0.000
	BER	0.007																			
	BUR		0.010																		
Calcium	CAM		0.007																		
	CAP																				
	CUM																				
	ESS		0.018																		
	GLO		0.000			0.000		0.023													
	HUD	0.004		0.013	0.005			0.049	0.001												
	HUN	0.034			0.050				0.011												
	MER		0.019							0.021											
	MID								0.009	0.034											
	MON		0.019						0.026	0.022											
	MOR		0.023						0.001	0.041											
	OCE		0.000	0.000	0.000	0.000		0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.034							0.017							0.000					
	SAL								0.004							0.000					
	SOM	0.014		0.022	0.019			0.040	0.000					0.026		0.000					
	SUS	0.011		0.030	0.025				0.000					0.036		0.000					
	UNI		0.011							0.006	0.037					0.000			0.019	0.024	
	WAR	0.048							0.002							0.000					
	BER	0.013																			
	BUR	0.009																			

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
Chromium	CAM	0.003																			
	CAP																				
	CUM																				
	ESS	0.001	0.018																		
	GLO				0.039			0.014													
	HUD	0.000	0.000	0.000	0.031	0.016		0.003	0.000												
	HUN	0.005																			
	MER	0.014								0.001											
	MID	0.001	0.032						0.021	0.004											
	MON	0.020								0.011											
	MOR	0.001	0.012			0.037			0.009	0.007											
	OCE		0.000	0.000	0.000			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.001	0.039						0.025	0.000						0.000					
	SAL	0.011														0.000					
	SOM	0.000	0.000	0.000		0.010		0.017	0.000		0.019	0.000	0.011		0.007	0.000	0.000	0.019			
	SUS	0.001	0.046							0.021						0.000			0.003		
	UNI	0.001	0.045						0.027	0.001						0.000			0.000		
	WAR							0.008		0.001	0.016		0.019		0.013	0.000	0.006		0.001	0.001	0.010
	BER	0.000																			
	BUR	0.027	0.012																		
Cobalt	CAM		0.000																		
	CAP		0.006																		
	CUM		0.049																		
	ESS	0.000		0.001	0.000	0.006															
	GLO		0.000	0.018				0.000													
	HUD	0.000	0.000	0.000	0.000	0.006			0.000												
	HUN	0.000	0.000	0.000	0.000	0.011		0.031	0.000												
	MER	0.000	0.046	0.001	0.000	0.019			0.000												
	MID	0.000	0.007	0.000	0.000	0.023			0.000												

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	MON		0.020					0.002	0.023	0.000	0.000	0.003	0.001								
	MOR	0.000	0.038	0.000	0.000	0.006			0.000					0.001							
	OCE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.000		0.001	0.000	0.006			0.000	0.028	0.011			0.003		0.000					
	SAL	0.016			0.018	0.011		0.030	0.000	0.009	0.011					0.000	0.038				
	SOM	0.000	0.000	0.000	0.000	0.007		0.000	0.000	0.000			0.028	0.000	0.003	0.000	0.000	0.007			
	SUS	0.000	0.000	0.000	0.000	0.009		0.000	0.000	0.000				0.000	0.019	0.000	0.000	0.009			
	UNI	0.000		0.006	0.000	0.008			0.000	0.024	0.023			0.014		0.000			0.000	0.000	
	WAR	0.000	0.000	0.000	0.000	0.009		0.007	0.000					0.000		0.000	0.001	0.009			0.001
	BER	0.030																			
	BUR																				
Copper	CAM		0.016																		
	CAP		0.016																		
	CUM																				
	ESS	0.003		0.004	0.000	0.011															
	GLO		0.000	0.001	0.023			0.000													
	HUD	0.000	0.000	0.000	0.000	0.006		0.000	0.000												
	HUN	0.005	0.037	0.000	0.000	0.011			0.000												
	MER					0.034		0.013	0.000	0.000	0.003										
	MID	0.002	0.031	0.000	0.000	0.011			0.000	0.006		0.004									
	MON		0.006					0.000	0.028	0.000	0.000		0.000								
	MOR	0.013		0.021	0.002	0.007	0.050		0.000	0.000	0.014		0.004	0.000							
	OCE		0.000	0.000	0.000			0.000	0.024	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.017		0.033	0.002	0.013			0.000	0.000				0.000		0.000					
	SAL					0.011			0.000	0.011	0.033					0.000					
	SOM	0.002		0.002	0.000	0.007			0.000	0.009		0.013		0.000	0.036	0.000					
	SUS	0.032		0.003	0.003	0.009			0.000	0.008		0.030		0.000		0.000					
	UNI	0.002		0.000	0.000	0.006			0.000	0.000		0.004		0.000	0.016	0.000					
	WAR	0.047		0.009	0.010	0.009			0.000	0.009		0.040		0.000		0.000					

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	BER	0.000																			
	BUR	0.000																			
Iron	CAM	0.002																			
	CAP		0.007	0.006	0.006																
	CUM					0.021															
	ESS	0.000				0.006															
	GLO		0.002	0.004	0.011	0.027		0.000													
	HUD	0.000	0.001	0.027		0.006			0.000												
	HUN	0.000	0.000	0.008	0.015	0.011		0.000	0.000	0.002											
	MER	0.000	0.020			0.007			0.000												
	MID	0.000	0.000	0.006	0.008	0.006		0.002	0.000	0.005											
	MON	0.001				0.013			0.007												
	MOR	0.000	0.000	0.000	0.001	0.006		0.000	0.000	0.000											
	OCE		0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.000	0.016	0.044		0.006			0.000		0.002		0.009		0.000	0.000					
	SAL	0.020				0.011				0.019	0.011		0.020		0.009	0.000					
	SOM	0.000	0.000	0.001	0.001	0.007		0.000	0.000	0.000						0.000	0.000	0.007			
	SUS	0.000	0.000	0.004	0.004	0.009		0.000	0.000	0.000						0.000	0.000	0.009			
	UNI	0.000				0.006			0.000		0.000		0.003		0.000	0.000			0.000	0.000	
	WAR	0.000	0.001	0.022	0.027	0.009		0.031	0.000							0.000		0.009			
	BER																				
	BUR																				
Lead	CAM																				
	CAP																				
	CUM																				
	ESS				0.031																
	GLO		0.003	0.006				0.001													
	HUD		0.001	0.001	0.000			0.018	0.000												
	HUN								0.001												

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	MER								0.030	0.001	0.040										
	MID								0.002	0.001											
	MON								0.014	0.000											
	MOR								0.017	0.000											
	OCE		0.000	0.001	0.011	0.005		0.000		0.000	0.001	0.002	0.000	0.003	0.007						
	PAS				0.049				0.003							0.000					
	SAL															0.031					
	SOM								0.002	0.017						0.000					
	SUS									0.011						0.022					
	UNI								0.006	0.001						0.001					
	WAR									0.014						0.040					
	BER	0.000																			
	BUR	0.001	0.004																		
Magnesium	CAM	0.043	0.000																		
	CAP		0.006	0.039																	
	CUM																				
	ESS	0.000		0.001	0.000	0.006															
	GLO		0.000	0.000	0.004			0.000													
	HUD	0.000	0.000	0.000	0.000	0.006		0.003	0.000												
	HUN	0.000	0.000	0.000	0.000	0.011		0.002	0.000												
	MER	0.000		0.022	0.002	0.010			0.000												
	MID	0.000	0.007	0.001	0.000	0.033		0.031	0.000												
	MON	0.036	0.000					0.000	0.012	0.000	0.000	0.004	0.000								
	MOR	0.000		0.001	0.000	0.006			0.000					0.000							
	OCE	0.002	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.000		0.000	0.000	0.006			0.000	0.001	0.002		0.009	0.000		0.000					
	SAL	0.011				0.011			0.000	0.007	0.011					0.000	0.039				
	SOM	0.000	0.000	0.000	0.000	0.007		0.000	0.000			0.012		0.000	0.008	0.000	0.000	0.007			
	SUS	0.000	0.000	0.000	0.000	0.009		0.000	0.000	0.006		0.001		0.000	0.000	0.000	0.000	0.009			

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	UNI	0.000	0.022	0.000	0.000	0.011			0.000					0.000		0.000			0.022	0.000	
	WAR	0.000		0.003	0.000	0.009			0.000					0.000		0.000					
	BER	0.001																			
	BUR		0.003																		
Manganese	CAM		0.000	0.006																	
	CAP		0.013																		
	CUM																				
	ESS	0.000		0.001	0.000	0.006															
	GLO		0.000	0.001				0.000													
	HUD	0.000		0.000	0.000	0.006			0.000												
	HUN	0.000	0.002	0.000	0.000	0.011		0.008	0.000	0.016											
	MER	0.004		0.003	0.000	0.034			0.000												
	MID	0.001		0.003	0.000	0.046			0.000												
	MON		0.000					0.000	0.029	0.000	0.000	0.001	0.000								
	MOR	0.006		0.011	0.000	0.006			0.000		0.005			0.001							
	OCE	0.001	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.000		0.000	0.000	0.006			0.000		0.011			0.000		0.000					
	SAL					0.011		0.016	0.023	0.013	0.011				0.045	0.000	0.016				
	SOM	0.000	0.000	0.000	0.000	0.007		0.000	0.000	0.000			0.023	0.000	0.000	0.000	0.000	0.007			
	SUS	0.000	0.000	0.000	0.000	0.009		0.000	0.000	0.000				0.000	0.000	0.000	0.002	0.009			
	UNI	0.001		0.028	0.000	0.039			0.000	0.007	0.000		0.033	0.001		0.000			0.000	0.000	
	WAR	0.000	0.000	0.000	0.000	0.009		0.002	0.000	0.000				0.000	0.001	0.000	0.002	0.009			0.000
	BER	0.000																			
	BUR	0.043	0.003																		
Nickel	CAM		0.000																		
	CAP		0.006																		
	CUM		0.049																		
	ESS	0.000	0.009	0.000	0.000	0.006															
	GLO		0.000	0.009				0.000													

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	HUD	0.000	0.000	0.000	0.000	0.006		0.003	0.000												
	HUN	0.000	0.007	0.000	0.000	0.011			0.000												
	MER	0.000		0.002	0.000	0.007			0.000												
	MID	0.000	0.003	0.000	0.000	0.013			0.000												
	MON		0.010					0.000	0.049	0.000	0.001	0.005	0.001								
	MOR	0.000	0.018	0.000	0.000	0.006			0.000	0.017				0.000							
	OCE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.000	0.014	0.000	0.000	0.006			0.000	0.001				0.001		0.000					
	SAL	0.000			0.012	0.011		0.028	0.000	0.009	0.011				0.046	0.000	0.019				
	SOM	0.000	0.000	0.000	0.000	0.007		0.001	0.000			0.047		0.000	0.005	0.000	0.000	0.007			
	SUS	0.000	0.000	0.000	0.000	0.009		0.000	0.000					0.000	0.004	0.000	0.000	0.009			
	UNI	0.000		0.000	0.000	0.006			0.000	0.000			0.047	0.007		0.000			0.000	0.000	
	WAR	0.000	0.002	0.000	0.000	0.009			0.000					0.009		0.000		0.018		0.011	
	BER	0.001																			
	BUR	0.000	0.000																		
Potassium	CAM	0.000	0.001																		
	CAP		0.011	0.006	0.028																
	CUM																				
	ESS	0.001		0.000	0.001	0.007															
	GLO	0.011		0.001	0.001																
	HUD	0.000	0.000			0.006		0.000	0.001												
	HUN	0.001				0.011															
	MER	0.000	0.005			0.007		0.008	0.014												
	MID	0.000	0.001			0.013		0.001	0.001												
	MON	0.007																			
	MOR	0.000		0.001	0.003	0.007				0.001			0.002								
	OCE	0.012	0.000	0.000	0.000	0.008		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.000		0.000	0.000	0.009				0.000	0.046	0.001	0.000			0.000					
	SAL	0.002				0.011										0.000					

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	SOM	0.000	0.000			0.007		0.000	0.000						0.000	0.000	0.000				
	SUS	0.000	0.000			0.009		0.000	0.000	0.050		0.022			0.000	0.000	0.000				
	UNI	0.000	0.020		0.019	0.013		0.019	0.050							0.000	0.006		0.014	0.001	
	WAR	0.000	0.001			0.009		0.003	0.014						0.015	0.000	0.000				
	BER																				
	BUR																				
Selenium	CAM																				
	CAP																				
	CUM																				
	ESS	0.038	0.010	0.007	0.002																
	GLO							0.026													
	HUD																				
	HUN																				
	MER	0.040	0.037					0.001	0.030												
	MID											0.034									
	MON							0.000	0.046				0.030								
	MOR											0.034		0.029							
	OCE	0.003	0.004					0.000	0.001				0.001		0.001						
	PAS		0.027	0.020	0.007				0.045			0.001		0.000		0.000					
	SAL																				
	SOM															0.002					
	SUS											0.025		0.043		0.000					
	UNI							0.019								0.003	0.026				
	WAR				0.047											0.007					
	BER																				
	BUR		0.008																		
Silver	CAM																				
	CAP			0.001	0.042																
	CUM																				

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	ESS			0.018																	
	GLO		0.017			0.002		0.035													
	HUD	0.045		0.001	0.017				0.003												
	HUN	0.014		0.000	0.010				0.000												
	MER		0.039			0.009				0.009	0.001										
	MID			0.002	0.022				0.005			0.016									
	MON		0.009			0.001		0.020		0.001	0.000		0.002								
	MOR					0.033				0.017	0.005		0.041								
	OCE		0.041			0.020				0.005	0.001		0.008								
	PAS		0.048			0.020				0.006	0.001		0.013								
	SAL			0.001	0.042				0.002			0.009		0.001		0.010	0.020				
	SOM										0.044										
	SUS			0.046					0.014		0.017										
	UNI			0.016					0.031					0.019							
	WAR																				
	BER	0.003																			
	BUR		0.000																		
Sodium	CAM		0.000																		
	CAP			0.034	0.000																
	CUM																				
	ESS	0.015		0.000	0.000																
	GLO		0.000			0.000		0.000													
	HUD	0.001		0.000	0.000	0.016		0.006	0.000												
	HUN	0.010		0.008	0.000				0.000												
	MER		0.020	0.046	0.002				0.000	0.002											
	MID	0.034		0.001	0.000				0.000	0.040											
	MON		0.000	0.050	0.001			0.001	0.000	0.000	0.010		0.003								
	MOR	0.028		0.000	0.000				0.000	0.001				0.009							
	OCE		0.000					0.000		0.000	0.004		0.001		0.002						

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	PAS	0.019		0.000	0.000				0.000	0.018				0.001		0.000					
	SAL		0.039		0.005			0.039	0.000	0.007											
	SOM	0.002		0.000	0.000	0.025			0.000			0.010		0.000	0.006	0.000		0.007			
	SUS			0.027	0.000				0.000	0.002						0.040			0.005		
	UNI	0.035		0.000	0.000				0.000	0.001				0.003		0.001			0.004		
	WAR		0.037		0.021				0.000	0.031											
	BER																				
	BUR																				
Thallium	CAM																				
	CAP																				
	CUM																				
	ESS																				
	GLO																				
	HUD																				
	HUN																				
	MER																				
	MID																				
	MON																				
	MOR																				
	OCE																				
	PAS																				
	SAL																				
	SOM																				
	SUS																				
	UNI																				
	WAR																				
	BER	0.000																			
	BUR	0.016																			
Vanadium	CAM	0.001																			

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	CAP		0.006	0.013	0.006																
	CUM					0.021															
	ESS	0.000	0.002	0.000	0.016	0.006															
	GLO		0.008		0.010			0.000													
	HUD	0.000	0.000	0.000	0.001	0.006			0.000												
	HUN	0.000		0.025		0.011			0.000												
	MER	0.000				0.006		0.003	0.011	0.000											
	MID	0.000	0.035	0.001		0.006			0.000	0.007		0.037									
	MON	0.005				0.020				0.036											
	MOR	0.000	0.000	0.000	0.000	0.006			0.000			0.000	0.001	0.033							
	OCE		0.000	0.000	0.000		0.014	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS	0.000	0.002	0.000	0.023	0.006			0.000			0.003			0.033	0.000					
	SAL	0.010				0.011		0.039		0.020					0.016	0.000	0.033				
	SOM	0.000	0.000	0.000	0.000	0.007			0.000			0.000	0.002			0.000		0.010			
	SUS	0.000		0.041		0.009			0.001	0.014					0.007	0.000			0.001		
	UNI	0.000	0.043	0.001		0.006			0.000	0.005		0.019			0.001	0.000			0.000		
	WAR	0.000		0.041		0.009			0.005	0.022					0.009	0.000			0.005		
	BER																				
	BUR																				
Zinc	CAM		0.009																		
	CAP																				
	CUM																				
	ESS				0.010																
	GLO		0.000	0.007		0.001		0.000													
	HUD	0.003	0.001	0.000	0.000	0.007		0.000	0.000												
	HUN				0.034	0.033			0.000												
	MER								0.000	0.002											
	MID				0.023				0.000	0.001											
	MON								0.003	0.000											

Metal	County	ATL	BER	BUR	CAM	CAP	CUM	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI
	MOR				0.007	0.023			0.000	0.000											
	OCE	0.004	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
	PAS				0.007				0.000	0.003						0.000					
	SAL								0.000							0.000					
	SOM	0.018	0.008	0.005	0.000	0.007		0.001	0.000			0.018		0.016	0.002	0.000	0.048				
	SUS	0.007	0.006	0.003	0.000	0.009		0.000	0.000			0.005	0.014	0.003	0.000	0.000	0.030				
	UNI				0.047				0.000	0.000						0.000			0.008	0.001	
	WAR	0.048		0.027	0.002	0.009		0.008	0.000					0.032	0.032	0.000					0.032

Table 6. Median metal concentration (mg/kg) in each of New Jersey's counties. For each metal (i.e., row of the table), the highest three (or four in the case of a tie) median values are highlighted in light gray. The median metal concentrations tended to be highest in Hudson, Somerset, and Sussex counties. See Table 4 for county abbreviations. Note: Median concentrations could not be estimated in Cumberland county because of small sample size (*n* = 2).

Metal	ATL	BER	BUR	CAM	CAP	ESS	GLO	HUD	HUN	MER	MID	MON	MOR	OCE	PAS	SAL	SOM	SUS	UNI	WAR
Sample Size (*n*)	10	20	20	20	4	20	16	20	4	12	20	20	20	20	20	4	12	6	20	6
Aluminum	5,100.0	8,400.0	4,500.0	5,160.0	3,250.0	11,800.0	3,320.0	10,700.0	10,800.0	10,400.0	9,600.0	5,680.0	15,666.7	1,560.0	10,400.0	6,363.3	12,133.3	16,700.0	10,800.0	9,400.0
Antimony	0.2	0.5	0.5	0.4	NA	0.8	0.3	NA	0.5	0.6	0.4	0.4	0.5	0.3	0.5	0.2	0.6	0.4	0.8	0.6
Arsenic	2.5	3.7	5.8	6.3	2.0	7.6	4.7	8.3	4.8	5.4	7.8	5.9	5.5	1.2	5.5	4.0	4.9	5.8	5.3	7.6
Barium	18.5	53.3	25.7	22.6	21.2	63.0	18.9	86.7	52.7	68.6	70.0	30.5	50.1	4.9	47.7	49.6	88.2	64.6	60.6	50.2
Beryllium	0.2	0.3	0.3	0.3	0.1	0.6	0.2	0.6	0.4	0.6	0.5	0.3	0.6	NA	0.5	0.2	0.7	0.7	0.5	0.8
Cadmium	0.0	0.3	0.2	0.1	0.1	0.1	0.1	0.3	0.3	0.2	0.3	0.2	0.3	0.0	0.2	0.2	0.4	0.4	0.2	0.3
Calcium	133.0	1,230.0	410.0	434.0	790.0	476.0	316.0	1,980.0	1,390.3	359.0	938.0	509.0	653.0	68.8	951.0	1,003.0	1,140.0	1,180.0	507.0	619.0
Chromium	4.2	14.1	14.6	18.6	5.9	17.0	9.8	25.4	13.7	17.0	16.9	13.3	17.2	5.1	17.9	15.8	25.6	17.2	16.1	11.4
Cobalt	0.8	4.2	2.2	1.1	0.8	4.8	1.1	6.1	5.8	7.2	6.8	1.6	6.1	0.1	5.1	2.3	9.0	9.7	5.0	6.6
Copper	3.2	12.2	11.1	5.5	4.3	20.3	3.9	50.2	18.4	9.6	19.2	6.8	14.0	2.2	14.9	7.7	16.1	17.3	19.6	16.7
Iron	4,000.0	12,300.0	10,900.0	12,000.0	3,466.7	14,600.0	6,760.0	16,300.0	19,733.3	15,400.0	19,500.0	11,900.0	22,000.0	3,620.0	15,100.0	7,473.3	21,600.0	22,800.0	15,200.0	15,966.7
Lead	20.0	35.6	40.7	24.3	30.2	61.3	10.1	180.0	77.9	29.2	42.9	20.0	18.8	9.6	54.9	21.8	41.9	19.5	47.4	15.1
Magnesium	350.0	1,610.0	951.0	740.0	423.0	1,680.0	454.0	2,330.0	2,693.3	1,530.0	2,590.0	924.0	2,110.0	137.0	1,810.0	821.7	3,050.0	4,270.0	2,200.0	1,510.0
Manganese	54.0	229.0	95.2	36.9	48.1	246.0	30.9	289.0	429.0	350.0	312.0	59.0	211.0	8.2	234.0	68.3	572.0	623.7	207.0	509.0
Nickel	2.8	9.7	5.1	3.5	2.3	12.3	3.2	17.6	12.1	12.7	16.0	4.7	12.9	1.0	12.8	6.9	18.4	18.7	11.2	13.7
Potassium	128.0	416.0	818.0	1,430.0	169.0	431.0	404.0	690.0	509.0	556.0	665.0	445.0	485.7	69.0	415.0	379.7	996.0	1,120.0	661.0	745.0
Selenium	0.7	0.7	NA	NA	NA	1.1	0.8	NA	0.6	0.5	0.8	0.5	1.0	0.5	1.0	NA	1.0	1.1	0.8	NA
Silver	NA	NA	NA	NA	NA	NA	NA	NA	0.1	NA	NA	NA	NA	NA	NA	NA	NA	0.1	0.0	NA
Sodium	13.9	93.8	12.3	10.0	37.1	52.2	10.5	91.2	116.0	23.2	41.5	24.2	55.8	11.9	61.4	24.2	74.4	37.5	49.7	20.3
Thallium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium	7.2	21.2	15.3	21.4	6.6	31.7	12.9	35.5	27.2	23.4	28.3	19.3	43.5	7.9	31.3	16.4	34.8	24.1	27.7	22.6
Zinc	13.8	52.0	34.6	23.2	33.0	48.7	18.4	103.0	63.7	58.1	57.1	41.1	51.6	3.8	42.7	60.5	79.0	78.7	49.1	66.0

Table 7. Arithmetic mean metal concentration (mg/kg) in 1993 (NJDEP 1993) and 2017.

Metal	1993 Mean Concentration	2017 Mean Concentration
Antimony	0.03	0.62
Arsenic	4.46	7.14
Beryllium	0.93	0.46
Cadmium	0.37	0.26
Chromium	12.3	19.60
Copper	17.2	18.25
Lead	58.4	69.69
Manganese	261	268.56
Nickel	10.3	10.64
Selenium	0.07	0.85
Silver	0.14	0.10
Thallium	0.07	0.74
Vanadium	17.6	27.92
Zinc	73.4	63.56

Table 8. Median metal concentrations (mg/kg) from Sanders 2003 and the current study, 2017.

	Urban - Sanders 2003		Rural - Sanders 2003			2017
Metal	**Piedmont**	**Coastal Plain**	**Ridge and Valley**	**Highlands**	**Coastal Plain**	
Aluminum	10,500	6,800	15,300	16,800	1,375	9,100
Antimony	--	--	--	--	--	0.47
Arsenic	5.2	5.2	4.9	4.8	1.15	5.3
Barium	80.6	28.3	60.2	69.6	7.25	47.2
Beryllium	0.51	--	--	0.73	--	0.39
Cadmium	--	--	--	--	--	0.20
Calcium	1,425	995	--	1,160	76.4	640
Chromium	18.5	11.8	14.3	17.7	2.9	16.2
Cobalt	6.3	--	7.3	6.8	0.37	4.2
Copper	29.5	9.3	17.2	16	4.2	11.7
Iron	14,600	8,830	14,800	18,700	1,795	14,400
Lead	111	37.6	31.6	26.6	17.5	37.3
Magnesium	2,190	673	2,600	2,340	79.65	1,530
Manganese	311	62.4	470	407	11.65	193
Nickel	12.4	--	15.7	11.6	0.84	10.0
Potassium	693	--	961	955	76	530
Selenium	0.41	--	--	--	--	0.8
Silver	--	--	--	--	--	0.05
Sodium	90.1	--	--	--	54.65	39.7
Thallium	--	--	--	--	--	--
Vanadium	29.6	16	20.7	32.3	7.8	26.2
Zinc	75.3	39.9	75.8	69.7	6.7	49.4

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