Soil contaminant concentrations at urban agricultural sites in New Orleans, Louisiana: A comparison of two analytical methods

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Abstract

Along with the many benefits of urban agriculture comes the possible exposure to contaminants not typically seen in rural soils. Through the use of standard laboratory analyses (ICP-AES and CVAAS) and a field-portable X-ray fluorescence spectrometer (XRF) calibrated for soil analysis, this study quantified contamination levels at urban agricultural sites throughout New Orleans, Louisiana. The results of the standard laboratory analyses were compared to the results from the XRF. We collected soil samples at 27 urban and suburban farm and garden sites from the Greater New Orleans area. We analyzed the soil samples for arsenic, cadmium, chromium, cobalt, copper, mercury, lead, nickel, and zinc using the XRF and standard methods. Most sites had median concentrations significantly below Louisiana's soil standards. Paired soil samples showed XRF results were significantly higher than laboratory results for all metals but copper. Only lead (ϱ=0.82, p<0.0001) and zinc (ϱ=0.78, p=0.0001) were highly correlated. Poor correlation of results between XRF and standard methods make the standard methods preferred.

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Disclaimer

The researchers have no financial interests in any companies that produce XRF products.

Introduction and Literature Review

Urban agriculture can provide numerous benefits to people and communities by improving food security and local food economies, reducing transportation costs, and revitalizing blighted neighborhoods (Brown & Jameton, 2000; Cohen, 2011; Hagey, Rice, & Flournoy, 2012; Kim, Poulsen, Margulies, Dix, Palmer, & Nachman, 2014; Mougeot, 2000; Patel, 1991; Rose, Bodor, Swalm, Rice, Farley, & Hutchinson, 2009; Smit & Nasr, 1992; Sommers & Smit, 1994). However, exposure to soil contaminants can pose a potential health hazard to those involved, and cities, having generally higher anthropogenic contamination levels, pose a greater risk. (Szynkowska, Pawlaczyk, Leśniewska, & Paryjczak, 2009). Several studies have shown that gardeners' concerns relating to possible soil contamination at urban agricultural sites can possibly prevent them from developing a site themselves (Cohen, 2011; Kaufman & Bailkey, 2000; McLaughlin, Parker, & Clarke, 1999). Kim et al. (2014) have shown that lead and other metals are the primary contaminants of concern among growers. This study specifically examines soil contamination of urban agriculture in New Orleans, Louisiana.

Cities such as New Orleans with historic and current industrial activity, high-traffic, and lead-painted houses often have higher levels of soil contamination (Brown & Jameton, 2000; Finster, Gray, & Binns, 2004; Grubinger & Ross, 2011; Laidlaw & Filippelli, 2008; Meuser, 2010; Mielke, Wang, Gonzales, Le, Quach, & Mielke, 2001; Mielke & Reagan, 1998; Wu, Edwards, He, Liu, & Kleinman, 2010). Studies examining New Orleans have shown high levels of soil contamination from metals (Mielke et al., 2001; Mielke, Wang, Gonzales, Powell, Le, & Quach, 2004; Mielke, Gonzales, Smith, & Mielke, 2000). Past lead levels in New Orleans have been found to range from non-detectable levels to 190,980 parts per million (ppm), with a median of 120.4 ppm (Mielke, Gonzales, Smith, & Mielke, 2000).

Unique to New Orleans is the sediment layer that Hurricane Katrina deposited throughout the city in 2005 (Adams et al., 2007). Arsenic and lead are prime examples of how the flood and rebuilding efforts covered, deposited, or redistributed contaminants throughout the city (Rabito, Iqbal, Perry, Arroyave, & Rice, 2012; Rotkin-Ellman, Solomon, Gonzales, Agwaramgbo, & Mielke, 2010). A study focused on arsenic concentrations sampled within 10 months after the hurricane showed that post-flood soil concentrations of arsenic increased on average by 19.7 ppm (Rotkin-Ellman, Solomon, Gonzales, Agwaramgbo, & Mielke, 2010). Information on lead contamination is mixed. In one study, lead levels in many areas were found to have decreased after the flooding due to a less-contaminated sediment layer covering up older and more contaminated layers (Natural Resources Defense Council [NRDC], 2011). Another study showed that 61.4% of residential yards sampled after the flood had at least one sample that exceeded the federal soil lead standard. The study also showed that, compared to pre-flood measurements, the median lead levels increased by 37.2 percent (Rabito et al. 2012).

Because of the potential for soil contamination, the U.S. Environmental Protection Agency (U.S. EPA) stresses the importance of testing soil before performing any urban agriculture (U.S. EPA, Office of Superfund Remediation and Technology Innovation, 2011). Kim et al. (2014) found that while many gardeners had a wide range of information on soil contamination and testing, some expressed concern that many gardeners are not aware that testing should be done prior to growing. Furthermore, for those growers that are interested in testing, there are limited testing options available in New Orleans. The Louisiana State University (LSU) Agricultural Center Extension for Orleans Parish offers soil testing through the LSU AgCenter Soil Testing and Plant Analysis Center. Sampling information and kits are available in every parish through the local agricultural extension program; however, these kits only test for soil nutrient content and pH, not for contamination (LSU AgCenter, n.d.). The Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) provide soil contamination information and screening through their soilSHOP program. However, the soilSHOP program is currently only operating in 13 states, Washington, D.C., and Puerto Rico (ATSDR, n.d.).

The purpose of this study is to quantify the levels of soil contamination at urban agricultural sites in New Orleans. Although widespread contamination in New Orleans has been documented, environmental contamination is still highly variable at both the citywide scale and at individual sites (Mielke et al., 2004; Romic & Romic, 2003). This study examines arsenic, cadmium, chromium, cobalt, copper, lead, mercury, nickel, and zinc; These substances are all soil contaminants of concern to human health (Bruker, n.d.).

We compared two analytical methods that quantify metal contamination in soil: Inductively coupled plasma-atomic emission spectrometry (ICP-AES) and an analysis using an X-ray fluorescence spectrometer (XRF). ICP-AES is one of the EPA's standard methods for metal analysis in soils. However, ICP-AES does have several drawbacks. It is relatively expensive, potentially costing hundreds of dollars per sample depending on the number of analytes, and can take days to weeks to receive results.

A newer analytical instrument that is not currently EPA-certified is the field-portable X-ray fluorescence spectrometer (XRF). Multiple companies that produce handheld XRF equipment explicitly state that lab-quality metal soil screening is an intended use (Bruker, n.d.; Olympus, n.d.; ThermoFisher Scientific, n.d.). XRF technology has been used widely and effectively in the mining industry, but its application in urban agriculture has been relatively limited (Suh, Lee, & Choi, 2016). However, according to Weindorf, Zhu, Chakraborty, Bakr, & Huang (2012) the XRF is capable of accurately quantifying some metals in soils sampled from a peri-urban agricultural setting. While the instrument is expensive due to its technical complexity, it can provide near real-time results for the analysis of several metals. Because the only costs associated with the XRF are the one-time expense of purchasing or renting the device with modest expenses for maintenance, the use of an XRF can possibly make widespread or repeat sampling over time more affordable compared to ICP-AES analysis. While, the expense of ICP-AES increases with each sample analyzed by the lab, the XRF only incurs an expensive for the purchase of the device itself. Furthermore, multiple users can share

the XRF across numerous sites. If the XRF proves to be reliable, it is expected that there will be a point where the scale of the sampling becomes large enough to justify the costs associated with renting or purchasing an XRF. This could lead to widespread use of the XRF in urban agriculture and other applications where low to moderate concentrations of contaminants are possible.

An additional aim of this study is to determine the level of correlation between lead and the other contaminants. Copper, lead, and zinc concentrations have been found to be correlated in roadside soils contaminated by heavy traffic (Yan, Zhang, Zeng, Zhang, Devkota, & Yao, 2012). Lead could be used as a proxy for other contaminants if similar correlations are found in this study. Because lead tests are often widespread and cheaper than tests for other contaminants, using lead as a proxy for other contaminants could help to reduce sampling costs.

Applied Research Methods

Site Selection
The majority of owners or managers of sites were contacted through the email listserv of Parkway Partners, a local urban agriculture group. An advertisement offering soil testing was sent to members and respondents were informed of the project's scope and sampling process. Other owners or managers were recruited directly by phone or email. Representatives from a total of 27 individual local sites responded to the email. Most of the sites were community or backyard gardens that grow produce intended primarily for personal consumption by the growers (93%, n=25). The remaining 7% (n=2) of the sites in our study were small businesses. Sites were located throughout most of the city. They were located in urban and suburban neighborhoods, including locations in Uptown, Central City, Mid-City, the Marigny, Seventh Ward, Downtown, New Orleans East, and Algiers. Some sites used raised beds while others planted in-ground.

Soil Sampling and Analyses
To determine the extent of metal contamination at urban agriculture sites in New Orleans, Louisiana,

we performed soil analyses to identify and quantify metal contaminants present in the soil. A systematic sampling plan was developed for each site. A majority of sites had the farm or garden organized in rows, and a linear sampling strategy was used for these sites. For sites using raised beds, physical soil samples were collected randomly while the XRF was used in every raised bed. Sampling was limited to areas that were currently producing food or were slated for future production.

Sample analysis consisted of two general methods, field-portable and laboratory-based. The field-portable analyses were conducted using a hand-held XRF calibrated for surface soil analyses (Innov-X Systems, INC; Woburn, MA USA; Delta Dynamic Premium XRF; Model DP-6000). The XRF provides real-time analyses of metal concentrations, and, with each sample, the XRF will report the limit of detection (LOD: the lowest possible concentration that the instrument can accurately report). Researchers were instructed by a company representative to place the device on top of a clear plastic bag on the desired sampling location (to protect the lens from contamination) and pull the trigger. Three different wavelengths were emitted for 15 seconds each, for a total of 45 seconds per sample. The XRF analyzes an area of 10 mm^2 and penetrates to a depth of 2 mm (Kalnicky & Singhvi, 2001; Olympus, n.d.). The minimum density of XRF soil analyses for each site was approximately one analysis per 300 ft^2. There were only seven samples taken at the two smallest sites, 42 samples were taken at the largest site, and an average of 22 samples were taken at each site.

Soil samples were collected from the exact location where an XRF reading was conducted to allow for correlation analyses between the two instruments used in this study. The sample was collected by removing the top 13 cm by depth and placing the soil in a 237 mL jar. Each sample was geo-coded, and the jars were then delivered to Pace Analytical Services Inc., (St. Rose, LA) using a chain-of-custody approach. Laboratory analyses consisted of the EPA 6010 method (ICP-AES) to analyze for arsenic, cadmium, chromium, cobalt, copper, lead, nickel, and zinc. Mercury was analyzed using the EPA 7471 Cold Vapor-Atomic Absorption Spectrometry (CVAAS) method.

Further use of the term "laboratory analyses" will be in reference to ICP-AES and CVAAS. Pace Analytical Services Inc., certified by the Louisiana Department of Environmental Quality (LDEQ), conducted all laboratory analyses. Sites smaller than 1,000 ft^2 only had two samples taken, while all other sites larger than this had four samples taken. The majority of the sites (23) had four soil samples taken and analyzed by Pace, while the remaining four sites only had two soil samples analyzed, generating a total of 100 paired samples.

Statistical Analyses

Statistical analyses were performed using Prism version 6.0 (GraphPad Software, La Jolla, CA). For all analyses, a p-value of 0.05 was used to determine significance. The concentration distributions were not normally distributed as determined by the D'Agostino and Pearson omnibus normality test. Spearman's correlation was used to examine the relationship between XRF analysis and ICP-AES or CVAAS, linear regression was used to determine how well the XRF predicted ICP-AES results, and the Wilcoxon matched pairs test was used to determine if the paired groups were significantly different. A correlation matrix was developed to determine if one or more metals could be used as a proxy for other contaminants to reduce overall sampling costs. Samples below the limit of detection were calculated by dividing the LOD by the square root of two.

Results

Soil Concentrations

The XRF consistently showed higher results compared to the laboratory analyses. The XRF reported a higher minimum and median concentration of all metals, and a higher maximum concentration of all metals but lead (Table 1).

The percentage of sites with a sample above the LDEQ standard varied greatly as well. The XRF reported concentrations that exceeded the LDEQ standard much more frequently than the standard laboratory methods. The XRF reported at least one concentration that exceeded the LDEQ standard for cadmium, chromium, and mercury at all 27 sites (Table 2).

Table 1. Summary Statistics of Metals Analyzed by XRF and Laboratory Analyses

Metal (LDEQ Standard ppm)	XRF (ppm)			Laboratory Analyses (ppm)		
	Median	Minimum	Maximum	Median	Minimum	Maximum
Arsenic (12.0)	4.95	1.70	231.0	3.0	0.7	61.7
Cadmium (3.9)	13.4	9.19	28.0	0.318	0.248	8.80
Chromium (23.0)	31.0	3.89	562.0	7.85	2.20	51.3
Cobalt (470)	31.1	5.66	107.0	3.10	0.629	11.0
Copper (310)	22.0	6.36	7,774	20.6	2.20	200.0
Lead (400)	57.0	2.76	6,138	38.4	1.40	9,540
Mercury (2.3)	3.25	2.19	8.49	0.062	0.009	1.80
Nickel (160)	14.9	10.6	64.0	7.50	2.55	61.1
Zinc (2,300)	129.0	5.80	10,254	91.5	17.8	7,330

Table 2. Percentage of Sites that had at Least 1 Reported Concentration Above the LDEQ Standard by Method of Analysis

Metal	Percentage of Sites with 1 Concentration Exceeding LDEQ Standard	
	XRF	Laboratory Analyses
Arsenic	59%	18%
Cadmium	**100%**	7%
Chromium	**100%**	22%
Cobalt	0%	0%
Copper	15%	0%
Lead	48%	30%
Mercury	**100%**	0%
Nickel	0%	0%
Zinc	11%	7%

Table 3. Median Concentration Differences Between XRF and Laboratory Analyses for Each Metal Analyzed

Metal	Median Concentration Difference (ppm)	Significance
Arsenic	1.6	< 0.0001
Cadmium	13.1	< 0.0001
Chromium	24.4	< 0.0001
Cobalt	28.1	< 0.0001
Copper	1.1	**0.17**
Lead	8.4	< 0.0001
Mercury	3.1	< 0.0001
Nickel	7.1	< 0.0001
Zinc	34.3	< 0.0001

T-tests and Correlation Analyses

Wilcoxan T-tests showed highly significant differences between XRF and laboratory analyses for all metals except copper. A summary of the median concentration differences can be seen in Table 3.

The XRF produced higher results for all metals and, except in the case of copper, the results were all significantly higher (Figure 1). Zinc, chromium, and cobalt had the largest differences between the two methods. Lead and zinc, while both significantly different, had the strongest correlation between methods.

To measure agreement between the two testing methodologies, two tests of correlation were run comparing paired samples for each metal: Spearman ϱ and linear regression. Correlations between the XRF and laboratory analyses were significant ($p<.05$) for all metals, albeit with varying degrees of correlation. The least correlated metal was cadmium ($\varrho=0.27$, $p=0.0058$) while lead was the most correlated metal ($\varrho=0.82$, $p<0.0001$). Zinc was also highly correlated ($\varrho=0.78$, $p<0.0001$). However, most metals showed poor to moderate correlation ($\varrho<0.6$) (Table 4).

Correlation across instruments and metals was relatively poor, and lead does not appear to be a strong candidate to be used as a proxy for any of the other contaminants other than zinc. The least correlated pair was between copper measured by the XRF and cobalt measured by ICP-AES ($\varrho=-0.003$). The highest correlation was between nickel and cobalt when both were measured by ICP-AES ($\varrho=0.89$) (Table 5).
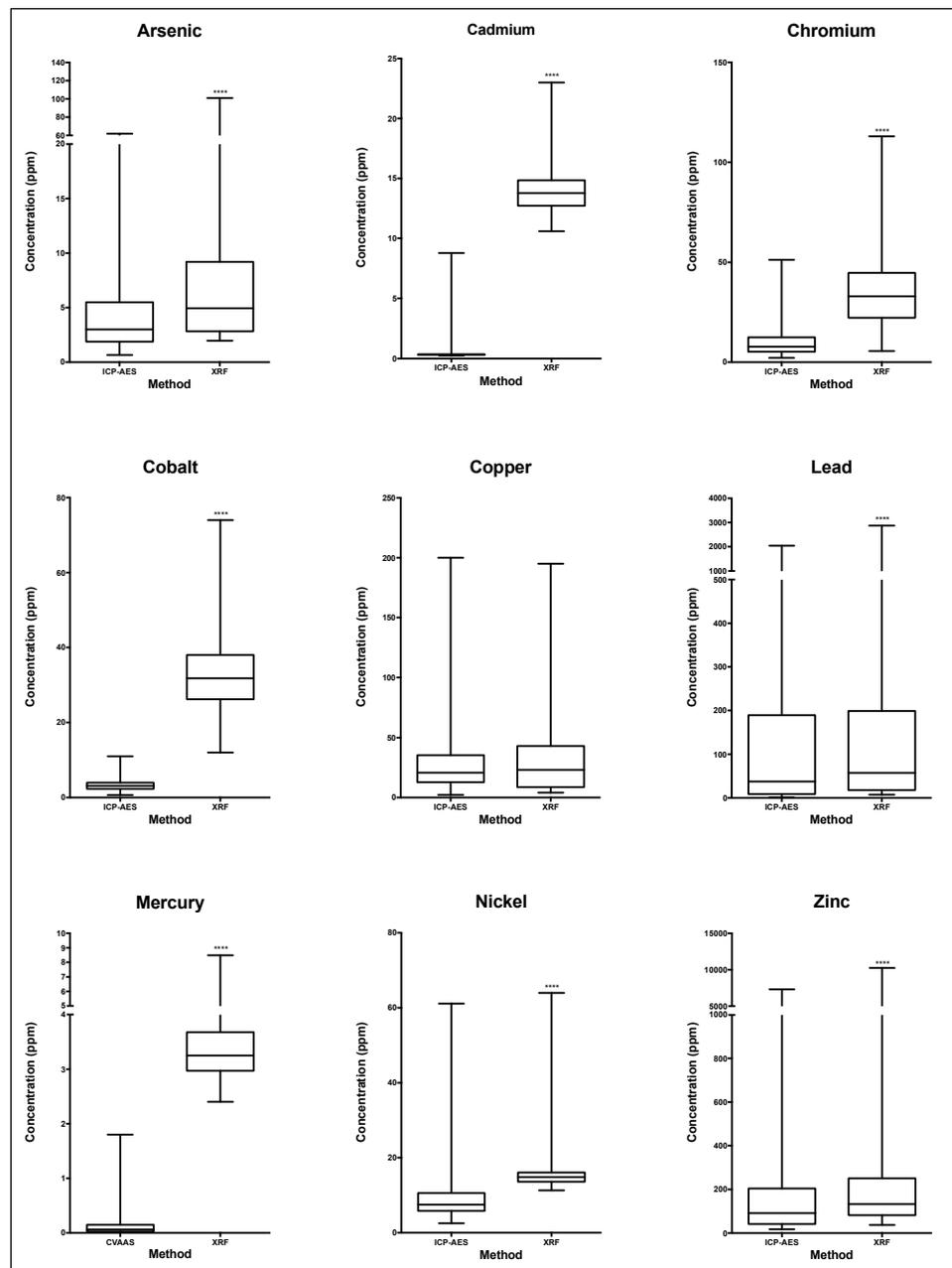
Cost Analyses

A month-long XRF rental (US$4,000 per month; metals only) is equal to 50 samples of laboratory analyses. For two and three month rentals, it would take 100 and 150 samples, respectively, of laboratory analyses to equal the rental cost. Purchase of the XRF is a possibility as well. In order for sampling costs to equal the outright purchasing price of the XRF, 438 samples would need to be analyzed. Hypothetical costs for an individual in a cooperative showed that sharing a one-month rental of the XRF between five people would cost US$800, the equivalent of 10 samples of laboratory analyses. A ten-person cooperative would require each individual to pay US$400, the equivalent of five samples of laboratory analyses. A 20-person cooperative would be required to pay US$200 for a month-long XRF rental, which would be equivalent to 2.5 samples analyzed in the laboratory.

Figure 1. Wilcoxon T-test Results for All Metals Comparing Laboratory Analyses and XRF Reported Concentrations

Asterisks indicate significant difference (****=*p*<0.0001)

Discussion

The majority of the soil had contaminant levels below their respective standards and should be considered safe for gardening and consumption. However, the results were highly variable when comparing the concentrations between methods. The XRF generally reported higher soil concentration levels for the metals in our panel than laboratory analyses. Overall the XRF reported signifi-

Table 4. Correlation and Linear Regression Results for Each Metal Between the Two Analytical Instruments

Metal	Spearman ρ	R^2	Slope
Arsenic	0.5306	0.5555	1.319 +/- 0.1192
Cadmium	0.2738	0.0582	0.3527 +/- 0.1433
Chromium	0.4019	0.2322	1.133 +/- 0.2080
Cobalt	0.5597	0.3020	3.844 +/- 0.5965
Copper	0.6628	0.4919	0.7508 +/- 0.0771
Lead	0.8237	0.7409	1.042 +/- 0.0632
Mercury	0.6160	0.2414	1.351 +/- 0.2419
Nickel	0.5317	0.0040	0.0580 +/- 0.0922
Zinc	0.7804	0.8185	1.098 +/- 0.0522

cantly higher concentrations for all metals except copper. This result is similar to that seen by Suh et al. (2016), where the XRF consistently reported higher concentrations than their validated methods. Few metals in our study showed a strong enough correlation between XRF and laboratory analyses to validate the XRF as an accurate screening field tool. Lead and zinc were the only metals that had an R^2 higher than 0.74.

These weak correlations between methods have important implications in terms of soil screening that must meet health-based and actionable regulatory standards. For example, most sites had no samples that exceeded the Louisiana Department of Environmental Quality (LDEQ) standard for all nine metals when using standard laboratory methods, whereas, in at least half of the sites, the XRF had at least one sample concentration that exceeded the LDEQ standard for four different metals. False positives when measured by the XRF could trigger further testing or unnecessary remediation efforts.

There are two primary factors likely affecting the accuracy of XRF screening: spectral effects and matrix effects. Spectral effects are caused when elements with similar spectral signatures are present in the same sample, and matrix effects can

Table 5. Spearman Correlation Coefficient Matrix Comparing Matched Sample Concentrations for Each Metal and Method of Analysis
Methods are indicated as X (XRF), I (ICP-AES), and C (CVAAS). Correlation coefficients of 0.6 or higher are **boldface**.

Method		As I	As X	Cd I	Cd X	Cr I	Cr X	Co I	Co X	Cu I	Cu X	Pb I	Pb X	Hg C	Hg X	Ni I	Ni X	Zn I
As	X	0.53																
Cd	I	0.38	0.25															
	X	0.21	0.40	0.27														
Cr	I	**0.72**	**0.62**	0.29	0.17													
	X	0.41	0.58	0.20	**0.64**	0.40												
Co	I	0.56	0.35	0.26	0.48	0.42	0.50											
	X	0.44	**0.62**	0.32	0.52	0.49	**0.61**	0.56										
Cu	I	0.53	0.48	0.42	0.08	0.58	0.20	0.16	0.34									
	X	0.31	0.42	0.21	0.00	0.44	0.05	-0.01	0.28	**0.66**								
Pb	I	0.51	0.58	0.45	0.31	0.52	0.36	0.47	0.45	0.57	0.25							
	X	0.38	**0.80**	0.35	0.40	0.53	0.52	0.38	**0.61**	0.50	0.39	**0.82**						
Hg	C	**0.60**	0.56	0.36	0.40	0.54	0.47	0.58	0.54	0.54	0.25	**0.84**	**0.70**					
	X	0.45	**0.69**	0.36	**0.74**	0.48	**0.78**	**0.63**	**0.79**	0.33	0.17	0.57	**0.69**	0.62				
Ni	**I**	0.57	0.40	0.25	0.47	0.47	0.52	**0.89**	0.58	0.16	0.00	0.56	0.48	**0.62**	**0.62**			
	X	0.31	0.52	0.22	**0.69**	0.35	**0.62**	0.58	**0.72**	0.22	0.14	0.38	0.47	0.48	**0.83**	0.53		
Zn	**I**	0.48	0.55	0.49	0.30	0.53	0.35	0.42	0.50	**0.71**	0.39	**0.80**	**0.70**	**0.68**	0.57	0.42	0.36	
	X	0.40	**0.67**	0.40	0.35	0.59	0.44	0.36	0.58	0.57	0.59	**0.65**	**0.79**	0.54	0.59	0.36	0.39	**0.78**

enhance or absorb the signal. A matrix without homogeneity can affect the accuracy of the readings as well (Schatzlein, 2015). The high LOD of the XRF is another reason for the high number of samples and sites that exceeded the LDEQ standard. For example, while ICP-AES readily detects cadmium at levels below the LDEQ standard, the LOD for the XRF was nearly four times higher than the state standard.

Further sample preparation could help improve the accuracy of the XRF. A study conducted by Hu, Huang, Weindorf, & Chen (2014) had similar XRF results to ours when sampling *in situ.* However, when they removed the sample and performed further preparation and analysis *ex situ,* they saw the accuracy of the XRF improve to levels deemed acceptable by the EPA. While performing these extra sample preparations could have improved the accuracy of the results seen in our study, it would also raise the barrier for a layperson with minimal training to perform sampling, a potential major benefit of the XRF.

Correlation analyses between metals and instruments were not accurate enough to warrant any consideration of lead as a proxy for other contaminants. Most of the highest correlated results were within the same testing method, and some of these were artifacts of the high LOD, such as the correlation between mercury and chromium concentrations using the XRF.

The cost comparison between the XRF and laboratory methods was initially conducted assuming the accuracy of the results would be similar. Had that been the case, the XRF would serve as the more cost-effective solution for sampling as the number of samples increased. Given the relatively poor accuracy of the XRF compared to standard laboratory methods, cost should not be considered as a primary variable in deciding which method to use.

The interest shown by the growers in this study to have their soil tested indicated a great need in the urban agricultural community to provide testing that goes beyond soil nutrient and pH testing. To assist growers, agricultural extension programs should expand their capabilities in three ways. First, there is a need to provide resources for growers that address proper sampling strategies.

This would allow growers to determine the range of contaminants in their soil with statistical certainty. Second, they need to expand their capability to include testing for common contaminants. Standard testing typically includes nutrients, pH, and lead. Third, educators need to provide information that explains to non-scientists what the results mean and how to minimize exposure. Kim et al. (2014) found that many growers were concerned about their ability to interpret soil contamination test results. Expansion of the CDC and ATSDR's soilSHOP program could help to provide resources to growers in underserved areas. However, the soilSHOP program only uses XRF technology for soil screening; results from our study indicate that the XRF is currently not accurate enough when used *in situ* (ATSDR, n.d.).

This study sought to quantify contamination in urban agricultural soils using XRF and to determine the accuracy of the XRF when compared to standard laboratory methods. However, there were limitations that should be addressed in future studies. First, the sampling of sites was driven by requests from producers in response to the study advertisement. This could have led to self-selection bias in the sites sampled and possibly caused us to select more heavily contaminated sites due to concerns of the producers; however, producers would likely need to have some previous knowledge of contamination for that to be a factor. Second, the different depths of sample analysis corresponding to different methods could have contributed to the difference in results. Our study did not do any further preparation of the samples when sampling using the XRF. Further sample preparation, as shown by Hu et al. (2014), could have improved our correlation results. However, this would have likely made the sample analysis more complicated than what would be done by a layperson sampling their site. Finally, while not a direct limitation of our study, soil standards are often developed from limited information and are sometimes "abstract from real environment conditions and arbitrary for site-specific conditions" (Desaules, 2012). Additional studies using toxicology and epidemiology need to be conducted to improve soil standards so that they are tied to exposure and human health outcomes.

Further studies should focus on two distinct areas. First, in the area outside of the authors' expertise, there is a need for continued advancements in XRF technology. The ideal target would be the development of field-portable units that provide reliable results that meet or exceed EPA standard methods. Second, there is a need for research to inform policy in the development of health-relevant soil contamination standards. Not all standards are based on health risk models. Development of health-risk models to better determine safe contamination levels will inform government agencies, agricultural extension programs, and individual farmers and gardeners about safe exposure levels and gardening practices.

To conclude, this study found that urban agricultural sites in New Orleans were generally safe for growing produce intended for human consumption, based on standard laboratory methods of analysis. Furthermore, unless additional sample preparation is conducted, the accuracy of the XRF needs to be improved before it should be used to detect soil contamination levels in an urban agricultural setting. If improved, the ability of the XRF to rapidly analyze a great number of samples would make it an excellent tool for analyzing the safety of urban agricultural sites.

References

Adams, C., Witt, E. C., Wang, J., Shaver, D. K., Summers, D., Filali-Meknassi, Y.,…Anderson, N. (2007). Chemical quality of depositional sediments and associated soils in New Orleans and the Louisiana peninsula following Hurricane Katrina. *Environmental Science and Technology, 41*(10), 3437–3443. https://doi.org/10.1021/es0620991

Agency for Toxic Substances and Disease Registry [ATSDR]. (n.d.). *soilSHOP Toolkit.* Latest update July 11, 2016, from https://www.atsdr.cdc.gov/soilshop/index.html

Brown, K. H., & Jameton, A. L. (2000). Public health implications of urban agriculture. *Journal of Public Health Policy, 21*(1), 20–39. https://doi.org/10.2307/3343472

Bruker. (n.d.). *Environmental soil analysis, contaminated soil testing with Bruker's S1 TITAN handheld XRF analyzer.* https://www.bruker.com/products/x-ray-diffraction-and-elemental-analysis/handheld-xrf/applications/restricted-materials/contaminated-soil-analysis.html

Cohen, N., & Robbins, P. (Eds.). (2011). *Green cities: An A-to-Z guide.* Thousand Oaks, California: SAGE Publications. https://doi.org/10.4135/9781412973816

Desaules, A. (2012). Critical evaluation of soil contamination assessment methods for trace metals. *Science of the Total Environment, 426*(1), 120–131. https://doi.org/10.1016/j.scitotenv.2012.03.035

Finster, M. E., Gray, K. A., & Binns, H. J. (2004). Lead levels of edibles grown in contaminated residential soils: A field survey. *Science of the Total Environment, 320*(2), 245–257. https://doi.org/10.1016/j.scitotenv.2003.08.009

Grubinger V., & Ross, D. (2011). *Interpreting the results of soil tests for heavy metals.* University of Vermont Extension. Retrieved from https://www.uvm.edu/vtvegandberry/factsheets/interpreting_heavy_metals_soil_tests.pdf

Hagey, A., Rice, S., & Flournoy, R. (2012). *Growing urban agriculture: Equitable strategies and policies for improving access to healthy food and revitalizing communities.* Oakland, California: PolicyLink. http://www.policylink.org/sites/default/files/URBAN_AG_FULLREPORT.PDF

Hu, W., Huang, B., Weindorf, D. C., & Chen, Y. (2014). Metals analysis of agricultural soils via portable X-ray fluorescence spectrometry. *Bulletin of Environmental Contamination and Toxicology, 92*(4), 420–426. https://doi.org/10.1007/s00128-014-1236-3

Kalnicky, D. J., & Singhvi, R. (2001). Field portable XRF analysis of environmental samples. *Journal of Hazardous Materials, 83*(1), 93–122. https://doi.org/10.1016/S0304-3894(00)00330-7

Kaufman, J. L., & Bailkey, M. (2000). *Farming inside cities: Entrepreneurial urban agriculture in the United States.* Retrieved from https://www.lincolninst.edu/publications/working-papers/farming-inside-cities

Kim, B. F., Poulsen, M. N., Margulies, J. D., Dix, K. L., Palmer, A. M., & Nachman, K. E. (2014). Urban community gardeners' knowledge and perceptions of soil contaminant risks. *PloS One, 9*(2), e87913. https://doi.org/10.1371/journal.pone.0087913

Laidlaw, M. A., & Filippelli, G. M. (2008). Resuspension of urban soils as a persistent source of lead poisoning in children: A review and new directions. *Applied Geochemistry, 23*(8), 2021–2039. https://doi.org/10.1016/j.apgeochem.2008.05.009

Louisiana State University [LSU] AgCenter. (n.d.). *Soil Testing & Plant Analysis Lab.* Retrieved April 26, 2018, from http://www.lsuagcenter.com/portals/our_offices/departments/spess/servicelabs/soil_testing_lab

McLaughlin, M. J., Parker, D., & Clarke, J. (1999). Metals and micronutrients: Food safety issues. *Field Crops Research, 60*(1), 143–163. https://doi.org/10.1016/S0378-4290(98)00137-3

Meuser, H. (2010). *Contaminated urban soils.* Dordrecht, Netherlands: Springer. https://doi.org/10.1007/978-90-481-9328-8

Mielke, H. W., Gonzales, C., Smith, M., & Mielke, P. (2000). Quantities and associations of lead, zinc, cadmium, manganese, chromium, nickel, vanadium, and copper in fresh Mississippi delta alluvium and New Orleans alluvial soils. *Science of the Total Environment, 246*(2), 249–259. https://doi.org/10.1016/S0048-9697(99)00462-3

Mielke, H. W., & Reagan, P. L. (1998). Soil is an important pathway of human lead exposure. *Environmental Health Perspectives, 106*(Suppl. 1), 217–229. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1533263/

Mielke, H. W., Wang, G., Gonzales, C., Le, B., Quach, V., & Mielke, P. (2001). PAH and metal mixtures in New Orleans soils and sediments. *Science of the Total Environment, 281*(1), 217–227. https://doi.org/10.1016/S0048-9697(01)00848-8

Mielke, H. W., Wang, G., Gonzales, C. R., Powell, E. T., Le, B., & Quach, V. N. (2004). PAHs and metals in the soils of inner-city and suburban New Orleans, Louisiana, USA. *Environmental Toxicology and Pharmacology, 18*(3), 243–247. https://doi.org/10.1016/j.etap.2003.11.011

Mougeot, L. J. (2000). *Urban agriculture: Definition, presence, potentials and risks, and policy changes* [Cities Feeding People Series, Report 31]. Ottawa: International Development Research Centre. https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/26429/117785.pdf?sequence=12

Natural Resources Defense Council [NRDC]. (2011). *Katrina's toxic legacy* [Smarter Living blog post]. Archived post retrieved from https://web.archive.org/web/20120301210644/http://www.nrdc.org/living/healthreports/katrinas-toxic-legacy.asp

Olympus. (n.d.) *How handheld XRF works as part of the reasonable testing program for regulation markets.* Olympus Corporation. Retrieved April 26, 2018, from http://www.olympus-ims.com/en/webinars/xrf-for-regulaton/

Patel, I. C. (1991). Gardening's socioeconomic impacts. *Journal of Extension, 29*(4), Article 4FEA1. https://joe.org/joe/1991winter/a1.php

Rabito, F. A., Iqbal, S., Perry, S., Arroyave, W., & Rice. J. C. (2012). Environmental lead after Hurricane Katrina: Implications for future populations. *Environmental Health Perspectives, 120*(2), 180–184. https://doi.org/10.1289/ehp.1103774

Romic, M., & Romic, D. (2003). Heavy metals distribution in agricultural topsoils in urban area. *Environmental Geology, 43*(7), 795–805. Retrieved from https://link.springer.com/article/10.1007/s00254-002-0694-9

Rose, D., Bodor, J. N., Swalm, C., Rice, J. C., Farley, T., & Hutchinson, P. (2009). *Deserts in New Orleans? Illustrations of urban food access and implications for policy.* Paper prepared for University of Michigan National Poverty Center and USDA Economic Research Service Review. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.189.2333&rep=rep1&type=pdf

Rotkin-Ellman, M., Solomon, G., Gonzales, C. R., Agwaramgbo, L., & Mielke, H. W. (2010). Arsenic contamination in New Orleans soil: Temporal changes associated with flooding. *Environmental Research, 110*(1), 19–25. https://doi.org/10.1016/j.envres.2009.09.004

Schatzlein, D. (2015). *XRF technology in the field: XRF technology for non-scientists.* Boston, Massachusetts: Author. Retrieved from https://tools.thermofisher.com/content/sfs/brochures/TS-eBook-XRF-Technology-in-the-Field.pdf

Smit, J., & Nasr, J. (1992). Urban agriculture for sustainable cities: Using wastes and idle land and water bodies as resources. *Environment and Urbanization, 4*(2), 141–152. https://doi.org/10.1177/095624789200400214

Sommers, P., & Smit, J. (1994). *Promoting urban agriculture: A strategy framework for planners in North America, Europe, and Asia* [Cities Feeding People Series Report 9]. Ottawa: International Development Research Centre. http://hdl.handle.net/10625/13680

Suh, J., Lee, H., & Choi, Y. (2016). A rapid, accurate, and efficient method to map heavy metal-contaminated soils of abandoned mine sites using converted portable XRF data and GIS. *International Journal of Environmental Research and Public Health, 13*(12), 1191. https://doi.org/10.3390/ijerph13121191

Szynkowska, M., Pawlaczyk, A., Leśniewska, E., & Paryjczak, T. (2009). Toxic metal distribution in rural and urban soil samples affected by industry and traffic. *Polish Journal of Environmental Studies, 18*(6), 1141–1150. Retrieved from https://www.pjoes.com/abstracts/2009/Vol18/No06/20.html

ThermoFisher Scientific. (n.d.). *Niton™ XLp 300 Series XRF Analyzers.* Retrieved April 26, 2018, from https://www.thermofisher.com/order/catalog/product/NITON300

U.S. Environmental Protection Agency [U.S. EPA], Office of Superfund Remediation and Technology Innovation. (2011). *Reusing potentially contaminated landscapes: Growing gardens in urban soils* [Publication No. EPA 542/F-10/011]. Washington, D.C.: Author. Retrieved from https://www.epa.gov/sites/production/files/2014-03/documents/urban_gardening_fina_fact_sheet.pdf

Weindorf, D. C., Zhu, Y., Chakraborty, S., Bakr, N., & Huang, B. (2012). Use of portable X-ray fluorescence spectrometry for environmental quality assessment of peri-urban agriculture. *Environmental Monitoring and Assessment, 184*(1), 217–227. https://doi.org/10.1007/s10661-011-1961-6

Wu, J., Edwards, R., He, X. E., Liu, Z., & Kleinman, M. (2010). Spatial analysis of bioavailable soil lead concentrations in Los Angeles, California. *Environmental Research, 110*(4), 309–317. https://doi.org/10.1016/j.envres.2010.02.004

Yan, X., Zhang, F., Zeng, C., Zhang, M., Devkota, L. P., & Yao, T. (2012). Relationship between heavy metal concentrations in soils and grasses of roadside farmland in Nepal. *International Journal of Environmental Research and Public Health, 9*(9), 3209–3226. https://doi.org/10.3390/ijerph9093209