Pilot Environmental Justice Project: Correlating Soil Metals Concentrations and Soil Health with Socioeconomic Factors in a Fredericksburg, Virginia, Soil Survey

Melanie Szulczewski, Anna Velardi, Faith Jones, and Audrey Turner
with Lily Hoffman and Natalie Anderson
Dept Earth and Environmental Sciences, University of Mary Washington, Fredericksburg VA

Background

Environmental injustice is when poor or marginalized communities are negatively impacted by hazardous waste, resource extraction, and land use that they don't benefit from. Legacy pollution of heavy metals may exist in soils in a way that disproportionately affects areas with certain socioeconomic factors. Human exposures to excess lead in soils, for example, can occur from ingesting the contaminated soils, particles on clothes and shoes, and gardening which can lead to damage to the brain and nervous system, development, especially in children (CDC, 2022). Arsenic is a known carcinogen and can be deposited from past use of chemicals and fossil fuels (Chirenje et al. 2003). Copper is necessary for both plants and animals for enzyme function, however absorption of excess copper can lead to chronic Cu poisoning. It is often correlated with organic matter, carbonates, clays, pH, and Mn-Fe hydroxides (Kabata-Pendias and Szteke 2015). Other metals, including micronutrients, have similar health concerns. The research question driving this pilot project was to look for correlations between soil health factors and socioeconomic factors in the soils of the City of Fredericksburg, Virginia, with a total population of 28,757.

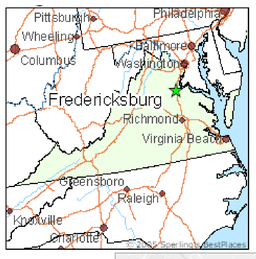
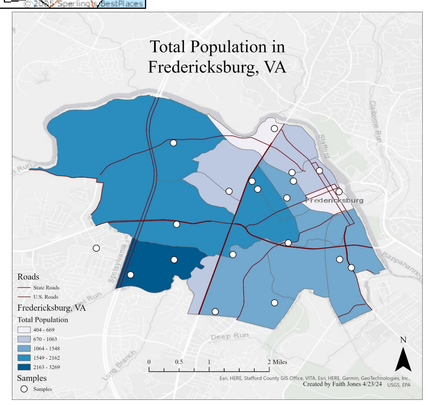


Figure 1a. Map showing the location of the City of Fredericksburg (green star) in Virginia.
Figure 1b. Map of first 20 study site locations within 2020 census block borders. Blue color corresponds with population density.



Materials and Methods

Study sites: Twenty study sites from residential areas were selected in the City of Fredericksburg VA, based on the 20 census block groups delineated by the 2020 US Census, as shown in the map in Figure 1. Census block groups are the smallest geographical area with published census data. A composite soil sample was collected at each site by sampling the top 10 cm of soil with a soil probe. Soil samples were air-dried and screened through a 2-mm sieve, and the <2-mm fraction was retained for analysis.

Laboratory methods: Soil pH was obtained in deionized water with a 1:1 ratio. Texture was determined with the hydrometer method. Loss-On-Ignition (LOI) method (Nelson and Sommers 1996) was used to determine organic matter content. Total metal concentrations were determined by acid digestion, adapted from EPA Method 3050B (1996). Bioavailable/exchangeable metals were extracted with AB-DTPA (adapted from Soltanpour et al. 1996). Solutions were analyzed for metals with an inductively coupled plasma-atomic emission spectrometer (ICP-AES).

Data analysis: ArcGIS, Excel and SPSS were used to analyze the data and look for initial correlations.

Table 1. Soil characteristics from 20 sites in the City of Fredericksburg, Virginia (see Figure 1b).

Site ID	Soil pH	Soil Organic Matter %	Sand Content %	Silt Content %	Clay Content %
1	6.05	2.63	82.61	12.42	4.67
2	5.06	6.74	80.03	9.98	9.98
3	5.87	7.12	67.61	7.48	24.92
4	4.53	4.60	72.85	12.34	14.81
5	5.98	3.65	67.56	7.49	24.95
6	4.92	5.91	70.15	9.95	19.90
7	5.57	7.65	65.03	7.49	27.47
8	6.43	6.60	80.04	9.98	9.98
9	5.53	3.31	75.02	12.49	12.49
10	6.82	4.59	80.00	15.00	5.00
11	5.91	7.30	55.02	22.49	22.49
12	6.35	3.69	52.55	29.97	17.48
13	6.53	5.30	60.69	22.11	17.20
14	5.84	2.34	80.04	7.49	12.48
15	6.31	5.94	77.56	2.49	19.95
16	5.74	6.01	65.01	7.50	27.50
17	6.09	4.35	80.16	4.96	14.88
18	6.71	8.22	77.82	2.46	19.72
19	5.66	6.31	55.64	9.86	34.50
20	6.00	4.89	60.00	15.00	25.00

Table 2. Summary of total metal concentrations in the soils from the 20 sites.

	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
	mg kg-1										
Range	7600-21,200	0.3-18.4	0-0.45	2.3-9.1	19-46	4-31	6800-20,400	90-730	7-20	5-102	20-175
Mean	11,400	2.5	0.11	4.8	28	13	12,800	260	11	42	59
Median	10,600	1.6	0.07	4.6	27	13	11,000	190	10	37	46

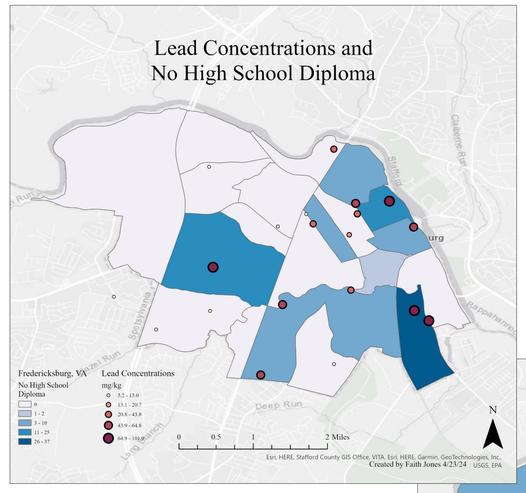


Figure 2a. This ArcGIS map overlays ranges of soil lead concentration with the percentage of people in that census block without a high school diploma.

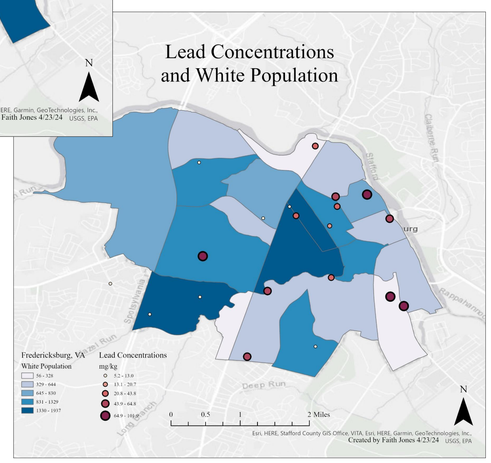


Figure 2b. This ArcGIS map overlays ranges of soil lead concentration with the percentage of people in that census block who are white.

Results and Discussion

- Soil pH values ranged from 4.53 to 6.82 and soil organic matter ranged from 2.3 to 8.2%, showing wide ranges (Table 1). Correlations xxxx
- As was detected in all samples, ranging up to 18.4 mg kg^{-1} at Site 2 (Table 2); 16 of the 20 sites had average As levels above the US EPA screening level for residential soil of 0.68 mg kg^{-1} (EPA 2024).
- Total Pb levels ranged up to 102 mg kg^{-1} at Site 16, well below the new EPA residential soil cleanup level of 200 mg kg^{-1} (EPA 2024).
- Total Al, Fe, Cu, and Zn concentrations had large ranges but were all within the typical range in uncontaminated soils, as seen in Table 2 (McLean and Bledsoe 1992). Total Cu was significantly correlated with organic matter content and pH as expected.
- Preliminary findings point to correlations between soil metal concentrations and socioeconomic factors.
  - Lower levels of education were strongly correlated with higher soil concentrations of both total Pb and Zn (Figure 2a).
  - Higher white resident populations were inversely correlated with total concentrations of Pb, Zn, and Mn (Figure 2b).
  - Higher bioavailable Pb concentrations were correlated with greater populations on public assistance.
- Further sampling and analysis are ongoing after finding these initial correlations in this pilot study.

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