Examination of Soil Metals Concentrations and Soil Health Factors at the Census Block Level in Fredericksburg, Virginia

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Background

Legacy pollution of metals and poor soil health may exist in soils in a way that disproportionately affects areas with certain socioeconomic factors. Human exposure to excess lead in soils can occur from ingestion, particles on clothes and shoes, and gardening, which can lead to damage to the brain and nervous system or developmental delays, especially in children (CDC, 2022). Arsenic, a known carcinogen, can accumulate in soils from past use of chemicals and fossil fuels (Chirenje et al. 2003). Copper, necessary for enzyme function in both plants and animals, can lead to chromic copper poisoning. Other metals have similar health concerns and correlations. Metals occurring in soil in more mobile forms, such as the exchangeable or bioavailable fraction (often correlated to clay or organic matter content) have a greater potential for biological uptake and human health effects. This project analyzed soils in the City of Fredericksburg, Virginia, with a population of 28,757 for metals and soil health factors, including phosphatase activity, then compared the results with socioeconomic data from the 2020 US Census.

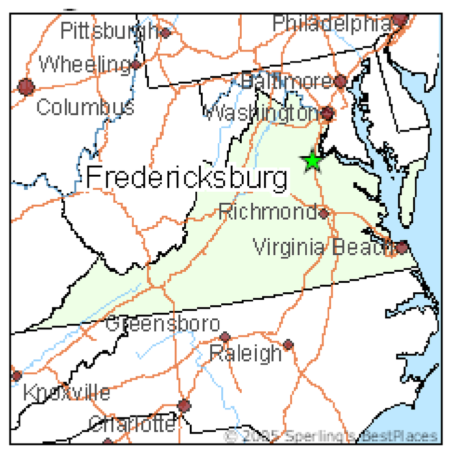
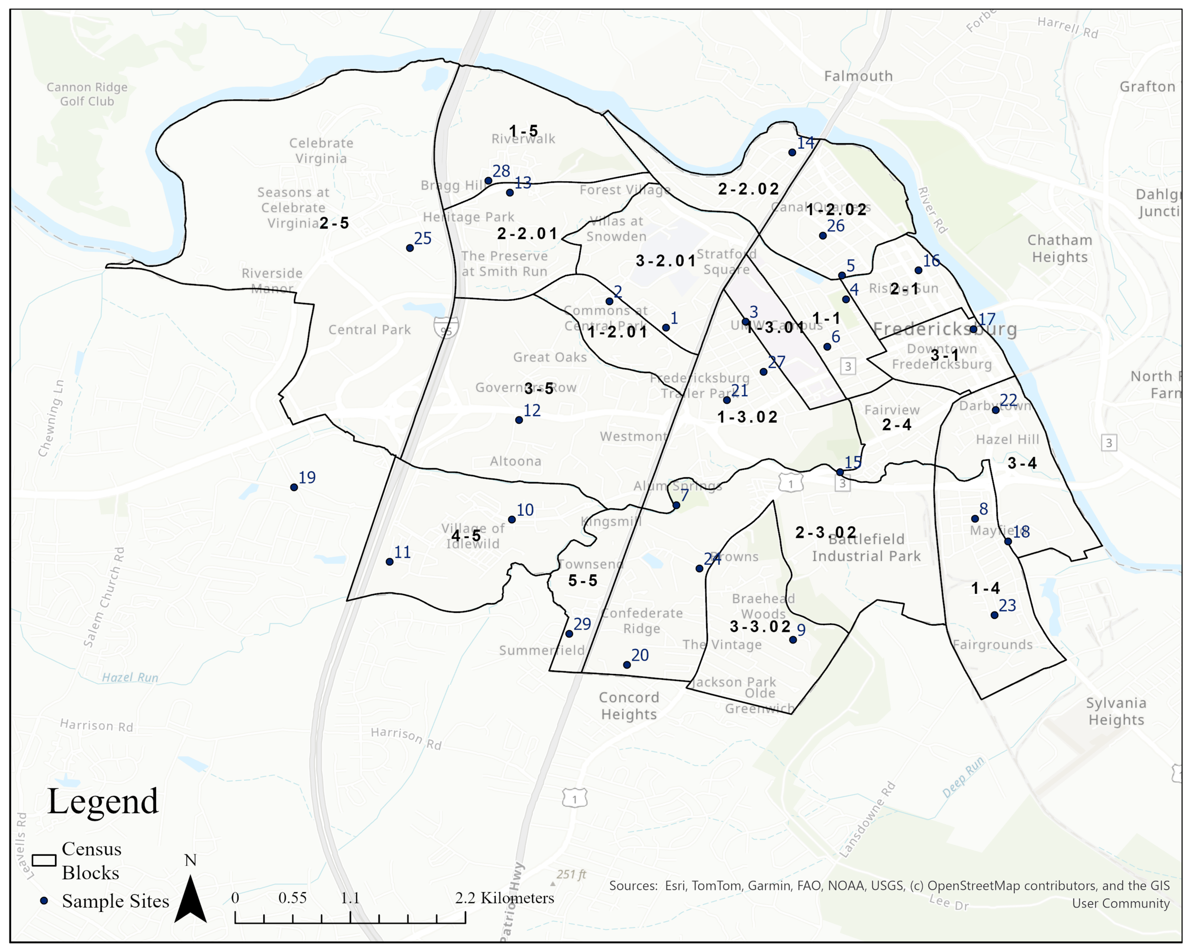


Figure 1a. Map showing the location of the City of Fredericksburg (green star) in Virginia.

Figure 1b. Map of 29 study site locations (blue numbers), 28 within 2020 census block-tract city borders (black numbers and outlines).



Materials and Methods

Study sites: Twenty-nine study sites from residential areas were randomly selected within the 20 census block and tracts delineated by the 2020 US Census in the City of Fredericksburg VA, as shown in the map in Figure 1. Census blocks and their tracts 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. The <2-mm fraction was retained for analysis.

Lab methods: Soil pH was obtained in water in a 1:1 ratio. Texture was determined by the hydrometer method. Loss-On-Ignition (LOI) (Nelson and Sommers 1996) determined organic matter content. Total metal concentrations were extracted by acid digestion (adapted from EPA Method 3050B 1996) and bioavailable/exchangeable metals with AB-DTPA (adapted from Soltanpour et al. 1996). An inductively coupled plasma-atomic emission spectrometer (ICP-AES) was used to analyze solutions for metals. Enzyme activity was determined with acid phosphatase (Acosta-Martinez et al. 2018).

Data analysis: ArcGIS, Excel, and SPSS.

Table 1. Soil characteristics from the 29 sites in residential areas in the City of Fredericksburg VA.

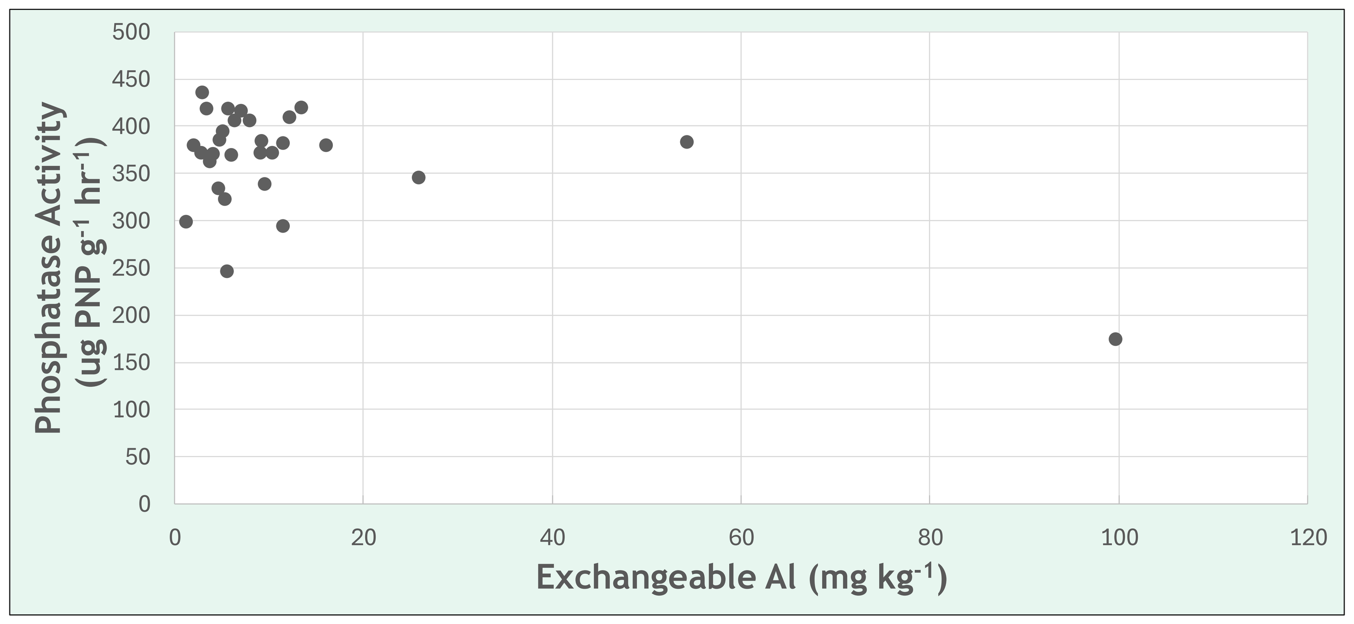
	Mean	Median	Range
Soil pH	5.86 ± 0.5	5.90	4.51 - 6.83
Organic matter %	6 ± 2	6	1 - 11
Clay %	13 ± 8	10	2 - 37
Phosphatase Activity	360 ± 60	380	170 - 480

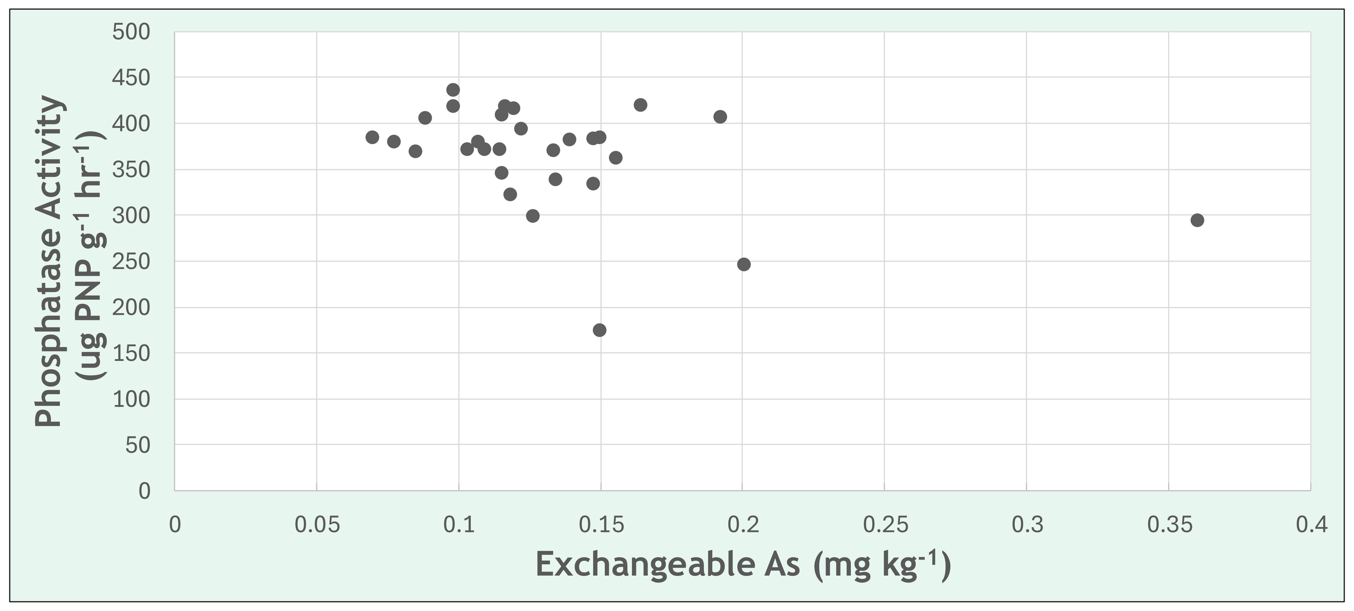
Table 2. Summary of mean, median, and range of total metal concentrations in the soils from the 29 Fredericksburg VA sites.

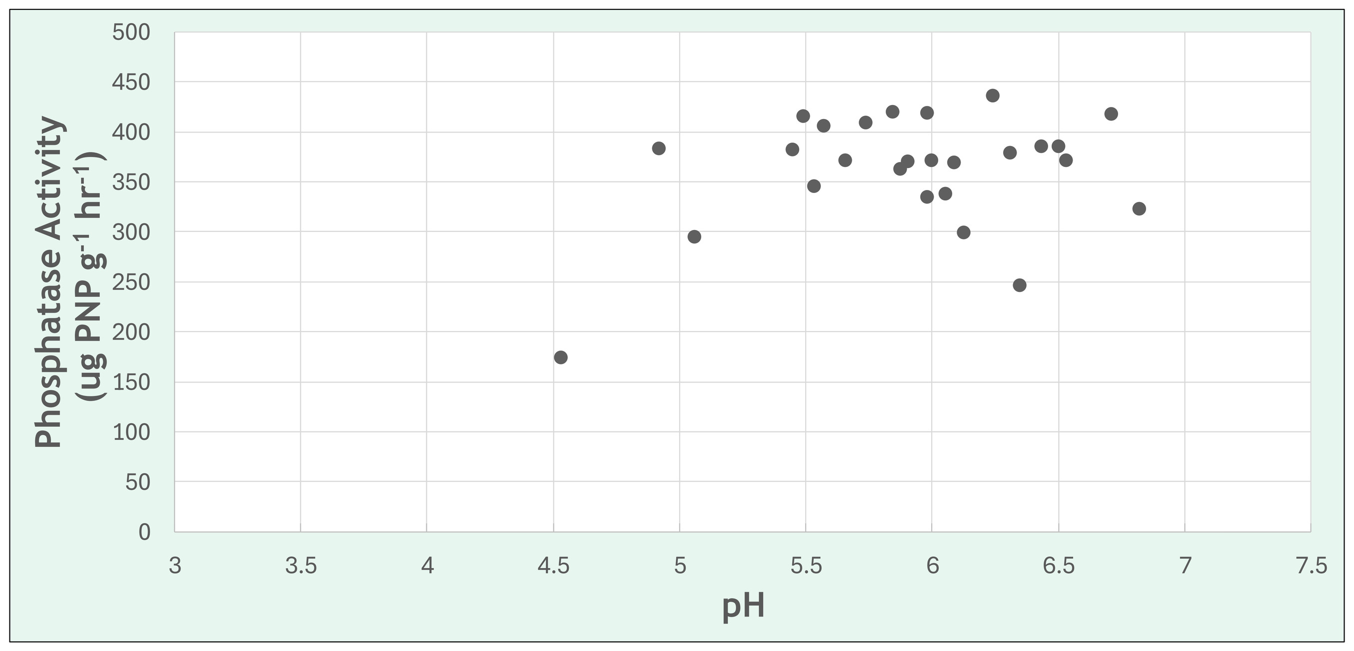
Metal	Mean Total Conc. (mg kg^{-1})	Median (mg kg^{-1})	Range (mg kg^{-1})
Al	11,000 ± 4000	9700	3000 - 22,000
As	2 ± 2	1.4	0.5 - 20
Cd	0.1 ± 0.1	0.08	bdl - 0.5
Cr	30 ± 30	27	17 - 260
Cu	12 ± 6	11	4 - 33
Fe	13,000 ± 4000	13,000	6500 - 24,000
Mn	200 ± 200	170	30 - 700
Ni	12 ± 4	10	8 - 22
Pb	40 ± 30	35	5 - 140
Zn	60 ± 40	40	20 - 170

Results and Discussion of Soil Analysis

- Soil pH ranged from 4.51 to 6.83 and soil organic matter ranged from 1 to 11%, showing wide ranges, as did soil texture (Table 1).
- As was detected in all samples, ranging up to 20 mg kg^{-1} at Site 2 (Table 2); 26 of the 29 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 140 mg kg^{-1} at Site 12, below the new EPA residential soil cleanup level of 200 mg kg^{-1} (EPA 2024) but above the California play area limit of 80 mg kg^{-1}.
- Bioavailable As and Pb were strongly correlated with Total As and Pb, a concerning result in these residential soils.
- Total Al and Fe concentrations had large ranges but were all within the typical range in uncontaminated soils, as seen in Table 2 (McLean and Bledsoe 1992). They were strongly correlated with each other (P<0.01) and Total Fe was also correlated with Total Pb, Mn, Zn, Cu, Cr, and Ni.







Figures 2a, 2b, and 2c. Soil phosphatase activity was significantly negatively correlated with Exchangeable Al and As and positively correlated with pH.

Results and Discussion of Socioeconomic Connections

- Initial analysis indicate some correlations between soil quality and socioeconomic factors. The percentage of white people in a census tract (range 4 – 93%) was negatively correlated to
  - Bioavailable Cd (r= -0.360, P <0.01)
  - Bioavailable Mn (r= -0.306, P <0.01)
  - Bioavailable Pb (r= -0.341, P <0.01)
  - and Bioavailable Zn (r= -0.446, P <0.01),
  - yet positively correlated to Bioavail Al (r=0.315, P <0.01)
- This seems to indicate an environmental justice issue since the higher the white population percentage, the lower the levels of potentially harmful bioavailable metals.
- Further census data calculations are needed to look for other socioeconomic relationships to soil quality factors.

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