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Factors Affecting Total and Bioavailable Concentrations of Trace Metals in Surface Soils in the Kingston, Jamaica, Region

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Background

Jamaica is known to be rich in metals, with prolific aluminum mining still occurring. Naturally high levels of other metals have been detected in soils throughout the island, with various analyses since 1988 revealing very high concentrations of total Cd in many regions, elevated concentrations of As, Cu, Zn, and Cr in some types of soil, but elevated Pb levels only at specific polluted sites (e.g., Lalor et al. 1998). They found the average concentration of Cd in Jamaican soils was 20 mg kg^{-1}, varying from undetectable to over 400 mg kg^{-1} near smelters, with a world average of less than 1 mg kg^{-1}. A more recent study found influences from organic matter and pH, but with Zn as the most influential variable, inversely affecting soil Cd concentrations (Sanderson et al. 2019).

Metals occur in soil in different forms with more mobile forms, such as the exchangeable or bioavailable fraction, often correlated to the amount of clay or organic matter, having a greater potential for biological uptake and contamination of waters. One Jamaican soil study found 45-60% of total Pb to be in the bioavailable fraction at several contaminated sites (Ramikie et al. 2020), and another found bioavailable Cd to be 0.2-15% of total Cd in Central Jamaican soils (Spence et al. 2014), showing varying contamination potential. Further study of metals in soils in the capital Kingston region was deemed important due to a growing urban population and intensive, widespread urban and suburban gardening (Figure 1).

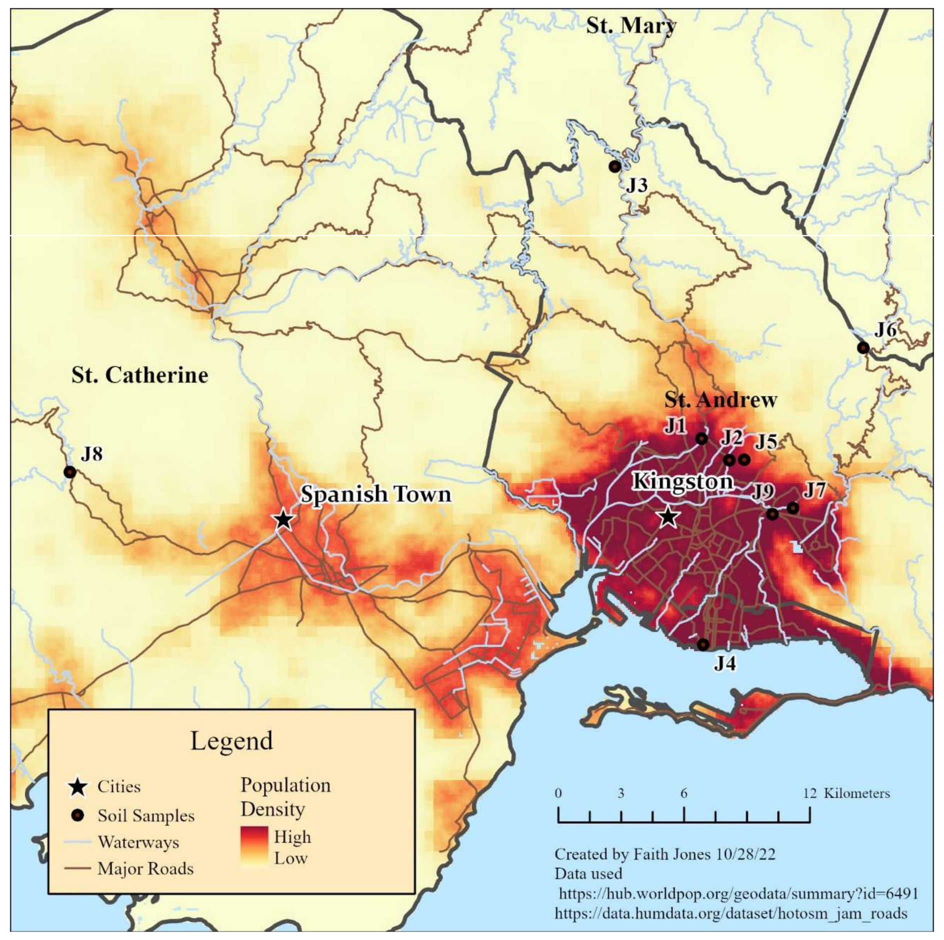


Figure 1. Map of study site locations, J1-J9, in and around Kingston, Jamaica, along with population density (in red).

Materials and Methods

Study sites: Study sites were limited to areas that were safely accessible where permission could be gained during a period of COVID-19 and crime-related lockdowns. This preliminary study focused on areas in and around the capital, Kingston, as shown in the map in Figure 1. Brief descriptions are listed in Table 1. A composite soil sample was collected at each of 9 sites by sampling the top 0-5 or 10 cm of soil with a soil probe during Summer 2022. 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 with a 1:1 ratio in deionized water. The hydrometer method was used to determine particle size in the soils. Bioavailable/exchangeable metal concentrations were extracted with AB-DTPA (adapted from Soltanpour et al. 1996). Organic matter content was determined by the Loss-On-Ignition (LOI) method (Nelson and Sommers 1996). Total metal concentrations were determined by acid digestion, adapted from EPA Method 3050B (1996). Resulting solutions were filtered and analyzed with an inductively coupled plasma-atomic emission spectrometer (ICP-AES) to obtain metal concentrations. Excel and SPSS were used to analyze the data.

Table 1. Soil characteristics from 9 samples sites in the Kingston, Jamacia, region.

Site ID	Site Description	Soil pH	Soil Organic Matter %	Clay Content %
J-1	school lawn, foot of mountains	6.44 ± 0.04	2.7 ± 0.7	7.5
J-2	suburban house banana grove	7.08 ± 0.01	5.0 ± 0.5	17
J-3	garden soil, low mountains	5.67 ± 0.02	5.8 ± 0.1	17
J-4	urban tree box near harbor	6.71 ± 0.01	8.0 ± 0.3	12
J-5	suburban lawn	7.96 ± 0.03	3.6 ± 0.7	25
J-6	Eastern mountains national park	7.14 ± 0.01	10.2 ± 0.5	10
J-7	school garden, foot of mountains	7.72 ± 0.04	3.5 ± 0.4	19
J-8	Home garden (red soil near mines)	6.62 ± 0.11	17 ± 2	15
J-9	urban lawn and flowerbed by road	8.50 ± 0.02	3.3 ± 0.3	12

Table 2. Summary of total metal concentrations found in the surface soils from the 9 sampling sites.

	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
	------------------------------mg kg-1 ------------------------------										
Range	12,000-240,000	4-21	1-24	11-36	17-525	19-84	1010-120,000	270-3900	11-160	12-69	45-170
Mean	52,000	6.6	4.2	19.7	73.4	45	29,000	1007	32	29	92
Median	18,000	4.9	1.9	17.4	30.8	45	19,000	460	18	24	82

Table 3. Summary of the bioavailable (exchangeable) metal concentrations found in the surface soils from the 9 sampling sites.

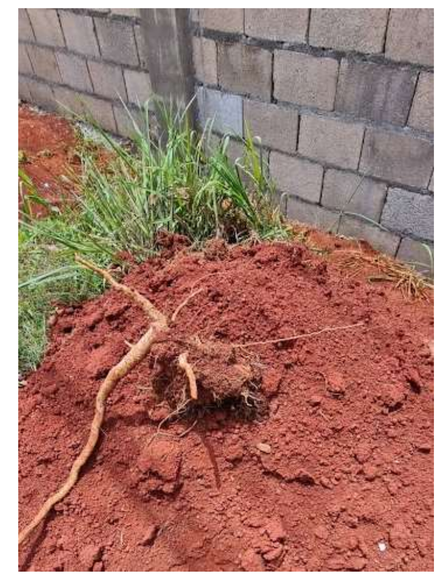
	Al_{bio}	As_{bio}	Cd_{bio}	Co_{bio}	Cr_{bio}	Cu_{bio}	Fe_{bio}	Mn_{bio}	Ni_{bio}	Pb_{bio}	Zn_{bio}
	------------------------------mg kg-1 ------------------------------										
Range	1.3-3.3	0.23-1.6	0.1-7.4	0.2-1.1	0.1-3.4	3-18	15-160	12-78	0.5-5	0.8-15	2-29
Mean	2.3	0.51	0.94	0.54	0.57	8.7	66	39	1.5	6.2	12
Median	2.6	0.32	0.12	0.41	0.22	6.6	50	3.5	0.94	4.5	7.3

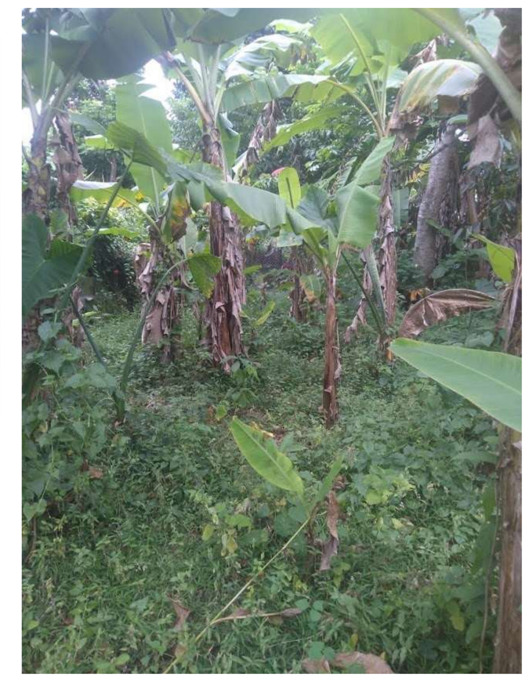
Correlation Results

- Soil pH values were negatively correlated to total Co, Cu, Mn, and Zn, as well as bioavailable As, Fe, Mn, Ni, and Se.
- Organic matter content was strongly correlated (at 0.01 level) to all the total metals except total Fe and Cu. It was also strongly correlated to bioavailable Cd, the metal of highest concern in Jamaica.
- Clay content was strongly correlated to total Cu and correlated (at the 0.05 level) with bioavailable Cr, Cu, and Mn.
- Arsenic is another metal of concern worldwide. Total As was strongly correlated to every metal except Pb and bioavailable Cd.
- Total Fe was strongly correlated with every total metal except Pb. Total Al was also strongly correlated to every metal except Cu and Pb.

Figure 2. Samples J1, J2, and J3 after drying. All soil samples were a similar color except the red J8 soil.


(a)


(b)


(c)


(d)

Figure 3. Photos from selected sample sites. (a) Site J6; (b) Site J8; (c) Site J3; (d) Site J2

Results and Discussion

- Soil pH values ranged from 5.67 to 8.50 and soil organic matter ranged from 2.7 to 17%, both showing a wide range at these sites (Table 1).
- As was detected at every site (Table 2); all sites far exceeded 0.29 mg kg^{-1}, the US EPA soil cleanup level for groundwater protection for total As. While bioavailable As ranged from 4% (J8) to 13% (J3) of total As, this bioavailable fraction was also above this limit of 0.29 mg kg^{-1} in all samples, except in J4 and J5.
- Cd was also detected at every site, with the highest levels by far in the J8 soil. The bioavailable Cd ranged from 6% (J5) to 33% (J8) of total Cd, much higher than seen in the past.
- Total Pb levels were low, similar to past studies, but with lower bioavailable fractions than seen before, ranging from 12% (J6) to 34% (J5).
- In typical uncontaminated soils, Al content ranges from 10,000 to 300,000 mg kg^{-1} with an average of 71,000 and Fe concentrations range from 7000 to 550,000 mg kg^{-1} with an average of 38,000 (McLean and Bledsoe 1992).
- Total Al concentrations here ranged from 11,700 to 150,000 mg kg^{-1}. As expected, the highest levels were found in the red soil from J8, near where Al mining occurs. Total Fe concentrations of these soils ranged from 11,400 to 47,000 mg kg^{-1}, both in the normal range.

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