BIOACCESSIBILITY OF METALS IN CITY PARK SOILS – CITY OF EDMONTON

By

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We accept this thesis as conforming
to the required standard

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Abstract

Urban parks are widely used by Canadians for various leisure and sporting activities with children being the most exposed to any contaminants that may occur in the soils at playgrounds. Thus, a good understanding of soil ingestion and bioaccessibility has implications for the environmental management of urban parks. To this effect, this thesis focuses on heavy metals bioaccessibility in urban landscapes using the City of Edmonton as a case study. Total metal concentrations in soil samples collected from 12 city parks were all below the Canadian Council of Ministers of the Environment soil quality guidelines for residential/parkland use except for copper in two samples and zinc in one sample. Based on the total metals concentrations and the bioaccessibility data obtained the potential risks associated with the ingestion of heavy metal contaminants in soils at the playgrounds, especially the most toxic ones such as arsenic, cadmium, and lead were deemed low.

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Introduction

Background

Certain metals (e.g., iron and manganese) form an essential part of human physiology and as such are important to our lives, though the presence, use and intake of some of the heavy metals (e.g., arsenic, lead, cadmium and mercury) do have negative impacts on environmental and human health. A review article by Mamtani, Stern, Dawood, and Cheema (2011) on "Metals and Disease: A Global Primary Health Care Perspective" discussed the consequences of metals in the environment by examining the relationship between metal exposures and their adverse health effects. A key issue discussed in this article was the health effects of heavy metals exposure from both industrial and non-industrial sources (Mamtani et al., 2011). Some of these effects include carcinogenic properties and toxicological effects in human organ systems as such examining metals exposure in the environment is vital to the protection of environmental and human health. This thesis will focus on heavy metals exposure in urban landscapes using the City of Edmonton as a case study and in relation to results from other cities across Canada.

The most sensitive individuals, who also have the highest exposure rates to soils in parks, are children. "The amount ingested varies with the child's behavior and daily ingestion rates have been calculated to be between 39 and 270 mg/day" (Ljung, Oomen, Duits, Selinus, & Berglund, 2007). Children are most likely to participate in outdoor activities during the warmer seasons as part of their leisure time. A pathway of contaminant exposure for children would be 'hand to mouth' contact during play time in and around soils at park grounds. This method of entry is relatively dependent on soil adsorption rates to the skin and is a function of the soil particle size (Madrid, Biasioli, & Ajmone-Marsan 2008). Other avenues of metals pollutants entry into the body system include inhalation, and dermal contact. To this effect an understanding of the bioavailability of metals in soils in city parks is critical to developing guidelines to minimize such risks.

Bioavailability is “the fraction of an ingested dose that crosses the gastrointestinal epithelium and becomes available for distribution to internal target tissues and organs” (United States Environmental Protection Agency (USEPA), 2007). The risk associated with metal exposure is generally assessed using the soil quality guidelines such as the Canadian Council of Minister of the Environment (CCME) soil quality guidelines for the protection of Environmental and human health (CCME, 2012). The guidelines are based on total metal concentrations that conservatively assume 100% bioavailability for most metals. Studies to date suggest metal bioavailability is dependent on various physical and chemical characteristics of the soil including organic carbon content, particle size, pH (National Research Council, 2002). It is therefore pertinent to have some measure of bioavailability for a more realistic estimate of the risk associated with ingestion or absorption of contaminated soils. Bioaccessibility is the measure of the solubility of the metal at the point of entry into a human body system (USEPA, 2007). Bioaccessibility is considered a reasonable surrogate measurement for bioavailability given that solubilization in the gastrointestinal tract is a critical step in the absorption process. This is especially the case if solubility is the major determinant of absorption at the portal of entry (USEPA, 2007).

Since 2008, there has been an increasing effort to assess trace metals concentrations and the associated environmental and human health risk in city parks across the world (e.g., Toronto (Dakane, 2011), Sevilla & Torino (Madrid et al., 2008), Fredericton and Saint John, New Brunswick (Dupuis, 2013). These studies have included the use of bioaccessibility and bioavailability assays to estimate the health risks posed to humans via ingestion, inhalation or dermal contact. For example Madrid et al., (2008) studied the bioavailability and bioaccessibility of metals in fine particles in urban parks soils of two European cities (Sevilla & Torino) using an ethylene diamine tetraacetic acid (EDTA) extraction method and a simplified bioaccessibility extraction test (SBET). These studies indicated the importance of bioaccessibility estimates for a more realistic understanding of the risk association with heavy metals in an urban setting. Thus, the focus of this research has management implications for the human health risk assessment of metal contaminants at urban parks and playgrounds and especially for the health and safety of the most vulnerable members of society, children, who play more frequently in these urban parks.

Objective, Research Questions and Approach

The main objective of this thesis is to assess the bioaccessibility of trace metals in selected Edmonton city parks as part of a Canada-wide study on metals bioaccessibility. As such this thesis has the following research questions:

1) What are the concentrations and bioaccessibility of heavy metals in soils at selected Edmonton city parks?

2) How does the data influence the management of potential risk associated with heavy metal contaminants?

3) Are heavy metal concentrations and bioaccessibility in the selected Edmonton city parks soils comparable to data for other Canadian urban centers i.e., Toronto, St. John and Fredericton?

To achieve the objective outlined above 17 soil samples were collected from 12 parks in Edmonton. Total metals concentrations in the soils were determined and a physiologically based extraction tests (PBET) was used to assess the bioaccessibility of selected metals including aluminum (Al), arsenic (As), barium (Ba), cadmium (Cd), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni) and zinc (Zn) in the soil samples. The methodology was based on approaches used in past related studies at other Canadian urban centers (Royal Roads University, 2010; Dakane, 2012; Dupuis 2013) for consistency and to allow for comparison.

Literature Review

Metals in the Urban Environment

Metals in urban soils are considered potential toxic elements because they are persistent in the soil environment and can negatively impact human health when found in high concentrations (Madrid et al., 2008). These concentrations can accumulate in soil through both anthropogenic and natural sources. Given the potential for accumulation and persistence in the soil environment, it is very critical to understand how metals in urban park soils could potentially impact human health. In Canada, the risk associated with metal exposure is generally assessed using the soil quality guidelines such as the Canadian Council of Minister of the Environment (CCME) soil quality guidelines for the protection of Environmental and human health (CCME, 2012). The guidelines are based on total metal concentrations that conservatively assume 100% bioavailability for most metals.

Madrid et al. (2008) studied metals in test samples from parks in the cities of Torino and Sevilla, Italy, that represented locations near medium to high metal contaminated land areas of each city. They found that the finer soil particles in the Torino samples showed metal enrichment for copper, zinc and to a lesser extent lead whereas the Sevilla samples showed metal enrichment for all the metals studied for the whole soil (Madrid et al., 2008). The Torino samples showed, in general, higher metal content especially in the case of chromium and nickel, with contents 10 to 20 fold greater than in Sevilla. Their work also found that metals availability was higher in the clay fractions (<2 microns i.e., finer particles) than in other fractions or whole soils in both Torino and Sevilla which lead to their major finding that availability was especially due to the clay fraction.

There are several key metals of concern in the urban environment, many of which will be discussed during the course of this paper. One of such is arsenic (As), a known human carcinogen. According to the Agency for Toxic Substances and Disease Registry

(ATSDR), arsenic is a toxic substance and a known human carcinogen (ATSDR, 2014a). It is a naturally occurring element which can combine with carbon and hydrogen in plants or animals to form organic arsenic compounds or combine with oxygen, chlorine and sulphur to form inorganic arsenic compounds (ATSDR, 2014a). Speciation of arsenic into organic and inorganic states has management implications for bioavailability and remediation protocols. Essentially, different clean-up techniques are required for arsenic remediation depending on the contaminant species present.

Other carcinogenic metallic elements of concern discussed in this thesis include lead (Pb), cadmium (Cd), and Nickel (Ni). In addition to As, exposure to these metals have detrimental health effects to humans. Typically, the toxicological and adverse health effects from exposure to As, Pb, Cd and Ni occur at various organ systems in the human body: affected organ systems for As, Pb, Cd, Ni and other metals are listed in Table 1.

Sources of Metal Input to Soils

Total metals deposition from the atmosphere is a major source of metals into soils in the urban environment. Metals from industrial waste, biosolids, compost, agricultural soil, amongst others can be introduced into the atmosphere. Once airborne, these particulates find their way into soil through wet and dry deposition. According to a study Nicholson, Smith, Alloway, Carlton-Smith, and Chambers (2006) in England and Wales the rate of deposition of metals particulates from the atmosphere into soils varies depending on its proximity to point sources of pollution. Biosolids and composts also contain residues of heavy metals (Nicholson et al., 2006) resulting in the incorporation of metals into soils when they are used as soil amendments.

Metals Toxicology and Risk Assessment

Exposure to toxic heavy metals remains a cause for concern for human and environmental health. Flora (2009) articulates the toxic effects of metals which can be lethal at certain doses; for example “lead, arsenic and cadmium generally interfere with a number of body functions such as the haematopioetic system, central nervous system (CNS), liver and kidneys”. Other studies further indicate the toxicity and human health risks associated with varying doses of certain metallic elements. Lead, arsenic and cadmium remain amongst the most toxic elements. Grass, Rensing and Rensing (2011) cite some examples of metals and their chemical toxicity in human cells (e.g., excess chromate can have negative effects on human cells through oxidative stress and disease which occur through sulfate deprivation). Likewise, other metals have varying modes of toxicity in human systems. “Despite many years of treatment we are still far from an effective treatment of chronic heavy metal poisoning” (Flora, 2009).

The toxicity of arsenic species in humans presents an example of the detrimental effects of heavy metals on humans. Inorganic arsenic species are known carcinogens and also portray other toxicological effects in humans including reproductive, gastrointestinal, and cardiovascular impairment. Rao (2009) further elucidates on the potential toxic and carcinogenic effects of arsenic species by stating “the toxicities and side effects of arsenic compounds are well known” and include impaired fetal growth or even fetal loss. Chronic or acute arsenic exposure doses can cause various kinds of cancers in the lungs, bladder, skin, renal or prostate gland (Rao, 2009). Furthermore, diabetes, gastrointestinal complications, cardiac arrhythmias and even death has also been reported in test animals during toxicity assessment tests (Rao, 2009).

Apart from arsenic, other metals species show severe toxic effects at elevated concentrations. Das (2009) discuss in generality the harmful effects of heavy metals on humans. This study shows that heavy metals, when found in high concentrations, tend to bioaccumulate in human tissue because many of the elements are neither degradable nor destroyed in the body at such concentrations (Das, 2009). As such heavy metals in high concentrations pose a risk to the human health and can cause severe effects ranging from irritability, tremors, autoimmune diseases, chronic infections and cancer.

Below is a summary table of key metals of interest and their toxicological effects.

Table 1

Metals of Interest and their Toxicological Effects

Compound	Carcinogenic Properties	Affected organ systems in humans	Speciation
Arsenic (As)	Known Human Carcinogen	Skin, Digestive, liver, Nervous System, Respiratory system (from nose to lungs)	Combines with oxygen, chlorine and sulphur to form inorganic arsenic compounds. Also, arsenic found in animals and plants combines with carbon and hydrogen to form organic arsenic compounds.
Lead (Pb)	Poisonous metal, also reasonably anticipated	Affects also all organ systems in the body	N/A

	to be a human carcinogen	including cardiovascular, neurological, haematological and reproductive systems.	
Cadmium (Cd)	Known human Carcinogen	Cardiovascular (heart & blood vessels), Gastrointestinal (Digestive), Neurological (Nervous), Reproductive and Respiratory systems	Cadmium is usually found as a mineral combined with other elements such as oxygen, chlorine or sulphur.
Copper (Cu)	N/A	Excess concentrations affects Gastrointestinal (Digestive), Haematological (Blood forming) & Hepatic (liver) systems	N/A
Zinc (Zn)	N/A	Excess concentrations affects Gastrointestinal (Digestive), Haematological (Blood forming) & Respiratory systems	Zinc combines with other elements to form zinc compounds i.e. zinc chloride, zinc oxide, zinc sulphate and zinc sulphide.
Nickel (Ni)	Known human carcinogen	Affects Cardiovascular (heart & blood vessels), Dermal, Respiratory and immune systems in the human body	Nickel combines with other metals, such as iron, copper, chromium & zinc to form alloys.

Source: ATSDR, 2014a.

Methodology

The methodology for this research was similar to the approach used to assess metal bioaccessibility in Toronto, Ontario (Dakane, 2012) and in Fredericton and Saint John, New Brunswick (Dupuis, 2013). This will allow for a comparison of the data across these Canadian urban locations.

Sampling Locations

Twelve city parks in Edmonton earmarked to cover the city-wide region were selected for this study. The parks were chosen from the Northwest, Northeast, Central, Southwest and Southeast areas of Edmonton. The sampling locations are summarized in Table 2 and shown in Figure 1. Detailed information for the sampling locations are given in Appendix 1.

Table 2

Edmonton City Parks Sampling Locations

Sample ID	Location
EDM-01	Capilano Community Park - 10810 54 Street
EDM-02	Gold Bar Park - 4620 105 Avenue
EDM-03	Capilano Park - 56 st and 109a Avenue
EDM-04	Millcreek Ravine Park - 8323 95A Street
EDM-05	Whitemud Park - 13204 Fox drive
EDM-06	Whitemud Park - 13204 Fox Drive #2
EDM-07	Whitemud Park - 13204 Fox Drive #2 Duplicate
EDM-08	Callingwood Park - 17740 69 Avenue
EDM-09	Glenora Park - 10410 136 Street
EDM-10	Central McDougall Park - 109 av and 107 Street
EDM-10 Dup	Field duplicate sample
EDM-11	Rundle Park - 2909 - 113 Avenue
EDM-12	Rundle Park - 2909 - 113 Avenue #2
EDM-13	Rundle Park - 2909 - 113 Avenue #2 Duplicate
EDM-14	Belvedere Park - 13223 60 Street
EDM-15	Belle River Park - 15904 84 street
EDM-16	Beaumaris Park - 10210 155 Avenue
EDM-16 Dup	Field duplicate sample
EDM-17	Orval Allen Park - 15910 127 Street

Sample Collection

One soil sample was collected from each park from an area with high potential for human soil contact such as near a playground structure or picnic area. Samples were collected on November 9 – 10, 2013 from the top 0 – 5 cm since this is the layer humans are most exposed to during activities in the park and likely to provide human exposure risk estimates. Each sample was taken with a small high density polyethylene (HDPE) trowel after a bigger shovel had been used to loosen the frozen soil. Gloves were worn at all times during sampling. The scoop and shovel were decontaminated after each sample location by washing with Sparkleen™ followed by rinsing with deionized – inorganic free water obtained from the Maxxam Analytics, Edmonton. Samples were placed into plastic bags provided by the laboratory. The samples were placed in a cooler and shipped to the School of Environment and Sustainability laboratory at Royal Roads University (RRU). The GPS coordinates for each site were recorded for mapping purposes and are given in Appendix I. Soil characteristics and site observations were also noted and are presented in Appendix I.

Sample Preparation

Each sample was homogenized and air dried at room temperature. The dried sample was sieved to <250 µm using a sieve shaker and testing sieve (US standard ASTM E11 series). The sieved samples were stored in 75 mL HDPE vials. A portion of each sample was subsequently placed into a small Ziploc bag and shipped to ACME Analytical Laboratories Ltd. (ACME Labs), Vancouver, BC, for total metal analysis. The remaining samples were analyzed at RRU. Sample preparation details are given in Appendix II.

Soil pH

The soil pH was determined using a standard pH meter (Denver Instrument UB-10) and probe (pH/ATC electrode #300728). A 10 g portion of soil from each sample was placed into a 50 ml beaker and 20 ml of water was added and stirred. The solution was then allowed to settle for about 1 hour before measuring the pH reading using the probe. The soil pH results are given in Appendix III.

Loss-On-Ignition (LOI)

The loss-on-ignition was measured using a methodology developed by Heiri, Lotter and Lemcke (2001). Samples were analyzed in triplicate for this procedure and were analyzed in two sequential phases to estimate the organic carbon and carbonate content of the soils. Approximately 1g of the sample was weighed directly into a crucible and placed in a pre-heated oven at 105 degrees Celsius overnight. The next day the samples were removed, cooled to room temperature in a desiccator then reweighed. The re-weighed samples were then re-heated in a pre-heated oven (550 degrees Celsius) for four hours. The cooling and re-weighing process followed after the four full hours. The new weighed samples were once more re-heated in a pre-heated oven (now 950 degrees Celsius) for two hours. After two hours, the final weights of the samples were taken after cooling to room temperature. The difference in weight after 550 ^{O}C represented organic carbon while the difference in weight after 950 ^{O}C indicated carbonate content. Full LOI results are given in Appendix IV.

Total Metals Analysis

Total metals analysis of the park soil samples was completed at Acme Labs in Vancouver, BC, using ICP-OES and ICP-MS methods after aqua regia digestion. The concentrations of total metals in the soils were reported in mg/kg. The laboratory data is provided in Appendix V.

Physiologically Based Extraction Test (PBET)

Metal bioaccessibility was assessed using an in vitro physiologically based extraction test (PBET) based on USEPA methodology (USEPA, 2011). Sieved soil samples (1.00 g) were weighed into 125 ml acid cleaned HPDE bottles and 100 mL of extraction fluid (0.4M glycine adjusted to a pH of 1.50 ±0.05 at 37 degrees Celsius using trace metal grade concentrated Hydrochloric acid) was added to each bottle. The sealed 125 ml HPDE bottles were placed into an extraction rotator in a 37 ±2 degrees Celsius water bath. The extracts were then agitated in the rotator for an hour. The pH of each solution was measured prior to extraction and after rotation to ensure it was within the required range (1.5 ± 0.5 pH units). Once completed, each extract was filtered into a 20 ml polyethylene vial using a plastic syringe through a 0.45 micron cellulose acetate filter. The laboratory batch extraction data is shown in Appendix VI.

The extracts were shipped to Maxxam Analytic, Burnaby, BC, for metals analysis by ICPMS with an Agilent Model 7500ce Collision Cell ICPMS based on US EPA Method 200.8. Metal concentrations in the extract were reported in µg/L.

Bioaccessibility was calculated for Al, As, Ba, Cd, Co, Fe, Pb, Mn, Ni, and Zn using the formula below;

$$\text{Bioaccessibility, \%} = \frac{\text{(concentration in extract, mg/L) x (Vol of extract, L)}}{\text{(concentration in soil, mg/kg) x (mass of soil used, kg)}} \text{ x 100}$$

Detailed results for selected metal bioaccessibility are given in Appendix VI.

Quality Assurance/Quality Control (QA/QC) Program:

For quality control, two duplicate samples were obtained from two randomly selected parks. The quality control for the PBET extraction also included a procedure blank, two duplicates, and a standard reference material (NIST 2710).

Data Analysis

Test results were compiled in an Excel 2010 spreadsheet for statistical analysis. The total metal concentrations were evaluated by comparing them against the Canadian Council of Ministries of the Environment (CCME) soil quality guidelines for residential parkland use (CCME, 2012).

Results

Total Metals

Descriptive statistical analysis were performed for selected total metals in the soil samples including As, Ba, Cd, Co, Fe, Pb, Mn, Ni, and Zn. A summary of these results is given in Table 3: the entire laboratory report is attached in Appendix V. Apart from Cu in EDM-03 and EDM-08 and Zn in EDM-08, the concentrations of the metals in the soil samples were all below the CCME soil quality guidelines for the protection of the Environment and Human health for residential/parkland use.

Table 3

Concentrations and Descriptive Summary Statistics for Selected Metals in Edmonton Park Soil Samples

	Metal Concentration (mg/kg)									
Sample ID	As	Ba	Cd	Co	Cr	Cu	Fe	Ni	Pb	Zn
EDM-01	4.5	139	0.26	5.4	12.6	15.3	1240	16.2	11.7	55.3
EDM-02	5.6	485	0.28	6.5	12.7	22.2	1260	17.0	11.4	82.5
EDM-03	3.2	203	0.76	5.6	23.3	**75.7**	1170	19.9	29.5	178
EDM-04	7.4	249	0.55	8.8	17.3	48.9	2080	33.4	23.6	169.4
EDM-05	4.3	122	0.23	5.9	14.4	24.6	1160	14.9	15.7	84.8
EDM-06	4.0	164	0.41	5.5	6.8	14.4	940	14.7	17.7	170
EDM-07	4.1	172	0.33	5.6	5.5	11.0	820	12.2	15.7	135

EDM-08	4.6	258	0.76	4.4	48.7	**93.9**	1180	20.8	13.8	**237**
EDM-09	4.7	54.9	0.12	3.4	7.7	7.62	900	9.4	3.65	28.6
EDM-10	4.5	187	0.36	7.2	14.2	21.6	1410	19.4	23.2	74.8
EDM-11	6.4	225	0.53	8.1	21.1	28.4	1670	25.8	36.9	111
EDM-12	5.6	159	0.33	7.1	17.3	21.7	2130	21.4	37.0	88.5
EDM-13	5.4	165	0.34	7.4	17.1	23.8	2040	21.7	36.9	95.4
EDM-14	4.8	97.6	0.2	3.8	11.5	14.8	930	11.7	15.8	57.5
EDM-15	6.7	85.2	0.12	4.3	6.4	7.98	1210	11.4	4.35	29.8
EDM-16	5.5	247	0.21	6.7	12.5	19.5	1410	18.3	8.75	45.7
EDM-17	5.8	162	0.29	8.9	18.9	27.9	1960	25.6	17.3	88.5
Mean	*5.1*	*187*	*0.36*	*6.2*	*15.8*	*28.2*	*1383*	*18.5*	*19.0*	*102*
Std Dev	*1.1*	*96*	*0.19*	*1.7*	*9.9*	*23.6*	*436*	*6.2*	*10.7*	*58*
Median	*4.8*	*165*	*0.33*	*5.9*	*14.2*	*21.7*	*1240*	*18.3*	*15.8*	*89*
Minimum	*3.2*	*55*	*0.12*	*3.4*	*5.5*	*7.6*	*820*	*9.4*	*3.7*	*29*
Maximum	*7.4*	*485*	*0.76*	*8.9*	*48.7*	*93.9*	*2130*	*33.4*	*37.0*	*237*
95 Percentile	*6.8*	*303*	*0.76*	*8.8*	*28.4*	*79.4*	*2090*	*27.3*	*36.9*	*190*
CCME R/P	*12*	*500*	*10*	*50*	*64*	*63*	*N/A*	*50*	*140*	*200*

Notes: Values in bold exceed the CCME soil quality guideline for residential/parkland use.
Std Dev = standard deviation

The mean concentrations of some metals parameters were comparable to results for other cities previously studied in Canada (i.e., Toronto (Dakane, 2012), St. John and Fredericton (Dupuis, 2013)), while others were vastly different. For example, the mean concentration of As in Edmonton was 5.1 mg/kg while that in Toronto was found to be 3.5 mg/kg. In vast contrast, the mean concentration of Pb in Toronto was 101.4 mg/kg while Edmonton was a magnitude lower as 19.0 mg/kg signifying an elevated presence of Pb in Toronto city parks. A summary comparison of mean metal concentrations amongst Canadian cities (Edmonton, Toronto, and Urban New Brunswick) is listed in Table 4.

Table 4

Summary Comparison of Mean Concentrations of Metals amongst Canadian Cities (Edmonton, Toronto, and Urban New Brunswick)

Mean (mg/kg)	As	Ba	Cd	Co	Cu	Ni	Pb	Zn
Edmonton	5.1	187	0.36	6.2	28.2	18.5	19	102
Toronto	3.5	61.4	0.6	4.8	27.5	101.4	12.3	94.3
St. John	8.87	58.8	0.27	9.3	31.8	20.2	46.1	95.5
Fredericton	10.4	109	0.19	10.8	23.1	31.6	35.4	78.6

Soil pH and Loss-On-Ignition (LOI)

Soil pH and Loss-on-ignition (LOI) analysis and data was collected for each sample point (Table 5) in order to assess and analyze the relationship of both factors to soil metals bioaccessibility. A linear regression analysis was performed for this purpose and details discussed in the discussion section under the heading ‘Relationship of soil pH, LOI and Metals Bioaccessibility’. Soil pH values ranged from 6.13 – 8.13 and were within the CCME soil quality guidelines (CCME, 2012) while the LOI data indicated variable organic matter content in the soil samples.

Table 5

Summary Table of the Soil pH and LOI

Sample ID	LOI (%) after 550C	pH
EDM-01	8.44	7.69
EDM-02	7.29	7.32
EDM-03	39.47	6.27
EDM-04	10.81	8.13
EDM-05	27.82	6.82
EDM-06	19.65	7.38
EDM-07	18.7	7.39
EDM-08	43.89	7.35
EDM-09	1.24	8.07
EDM-10	19.07	7.5
EDM-11	25.45	6.13
EDM-12	22.88	6.33
EDM-13	24.05	6.17
EDM-14	21.24	7.19
EDM-15	1.65	7.91
EDM-16	4.78	7.68
EDM-17	12.71	7.83

Bioaccessibility

A summary of the results for metal bioaccessibility data is presented in Table 6. The parameters that had greater than 50% bioaccessibility and possess the highest bioaccessibility are Ba (average of 68.3%), Cd (average of 86.6%), and Pb (59.5% average). This infers that these metals (Ba, Cd, and Pb) are more available for uptake into the body system via ingestion from exposure to park soils.

Table 6

Metal Bioaccessibility and Descriptive Statistics for Edmonton Park Soil Samples

	Metal Bioaccessibility (%)								
Sample ID	As	Ba	Cd	Co	Cu	Fe	Pb	Ni	Zn
EDM-01	20.5	71.3	74.9	49.7	24.3	6.5	58.0	38.0	40.8
EDM-02	32.3	46.5	80.7	22.3	21.2	2.6	49.5	22.1	56.4
EDM-03	19.7	70.5	82.3	37.6	10.2	7.1	51.8	37.3	67.8
EDM-04	35.1	77.5	83.2	43.9	42.9	7.6	63.6	25.1	73.3
EDM-05	10.1	76.8	89.8	24.9	22.4	3.4	60.3	28.7	72.6
EDM-06	10.1	70.4	89.5	44.6	8.9	4.6	66.0	35.6	79.6
EDM-07	11.9	68.1	108.2	43.4	9.1	4.9	73.7	45.4	96.2
EDM-08	32.9	86.5	127.9	35.9	31.6	2.5	54.4	31.4	84.4
EDM-09	15.8	59.2	70.2	23.0	11.5	3.2	46.7	18.0	25.7
EDM-10	20.2	78.9	99.4	41.1	12.5	3.5	58.7	36.1	39.9
EDM-11	12.1	76.7	80.1	33.7	7.3	2.7	56.3	31.9	37.8
EDM-12	12.4	71.3	84.7	19.9	7.4	5.2	46.3	32.5	35.3
EDM-13	15.5	73.4	84.3	21.4	16.9	5.6	55.0	34.1	40.4
EDM-14	13.4	77.7	105.2	37.1	6.0	3.0	75.6	37.6	52.1
EDM-15	5.3	38.9	56.9	14.3	56.3	2.6	119.0	19.9	50.5
EDM-16	26.3	53.2	80.6	21.1	8.0	3.0	42.3	21.7	23.1
EDM-17	23.7	68.9	88.4	36.8	6.4	3.7	50.2	31.3	21.0

EDM-10 Dup	20.9	81.7	93.9	38.9	5.3	3.5	62.2	35.2	37.6
EDM-16 Dup	24.9	50.2	65.1	19.4	7.4	2.8	40.4	21.6	23.5
Mean	*19.1*	*68.3*	*86.6*	*32.1*	*16.6*	*4.1*	*59.5*	*30.7*	*50.4*
Std Dev	*8.5*	*12.8*	*16.1*	*10.7*	*13.9*	*1.6*	*17.3*	*7.5*	*22.7*
Median	*19.7*	*71.3*	*84.3*	*35.9*	*10.2*	*3.5*	*56.3*	*31.9*	*40.8*
Minimum	*5.3*	*38.9*	*56.9*	*14.3*	*5.3*	*2.5*	*40.4*	*18.0*	*21.0*
Maximum	*35.1*	*86.5*	*127.9*	*49.7*	*56.3*	*7.6*	*119.0*	*45.4*	*96.2*
95 Percentile	*33.1*	*82.2*	*110.1*	*45.1*	*44.3*	*7.1*	*79.9*	*38.7*	*85.5*

Notes: Std Dev = standard deviation

Quality Assurance Quality Control (QA/QC)

Total metals analysis. Soil samples were analyzed at ACME Labs for total metals. ACME Labs is accredited for total metals analysis under ISO 17025:2005 with the Standard Council of Canada (ACME Labs, 2014). The QA/QC included the analysis of two standard reference materials (STD DS10 and STD OREAS45EA) and a spike blank (BLK). The results obtained were within the control limits and are included in the Appendix V.

PBET Extraction. The QA/QC protocols for the PBET extraction included the analysis of a procedure blank, a standard reference material (NIST 2710), and two duplicate samples chosen at random. The results of the duplicate samples, standard reference material and blank are provided in the Appendix VII. Metal concentrations in the blanks and reference materials were within the control limit (Appendix VII-1). Data obtained for the duplicate sample (Appendix VII-2) indicated fair to good reproducibility for the analytes.

Discussion

A simple physiologically based extraction (PBET) method was used in this thesis for the extraction of metal elements from the sample media for bioaccessibility estimations. This extraction method was selectively chosen based on its common use in similar studies in other cities both outside and within Canada. One of such studies conducted using the PBET extraction method defined the test as “an in vitro test system for predicting the bioavailability of metals from a solid matrix and incorporates gastrointestinal tract parameters representative of a human” (Ruby et al., 1996, pg. 1). Another study conducted by Sailelli, Urquhart, Davidson, and Hursthouse (2010) also used PBET as the preferred extraction method for calculating bioaccessibility. The study by Sailelli et al. (2010) went a step further by conducting and comparing bioaccessibility calculations for two different widely known extraction methods: the PBET extraction method and the BCR sequential (three phase) extraction method. They tested 20 urban soils from Glasgow, UK and used both extraction methods and compared the results to pseudototal (aqua regia soluble) analyte concentrations for all metallic elements. Their correlation analysis found that PBET was generally more effective at providing a better indication of human bioaccessibility than the BCR sequential extraction method. Other studies on the BCR sequential extraction method found that it worked well for some metal parameters and not so much for others. For example, Fernandez, Jimenez, Lallena and Aguilar (2004) used the BCR method for two polluted sites and found it to work reasonably well for only three metal parameters (Cd, As, & Pb).

Arsenic

Arsenic is a contaminant of great concern and ranked Number 1 on the ATSDR 2013 Substance Priority List (ATSDR, 2014b) indicating this element is of greatest concern amongst the metals parameters studied. Bioaccessibility values for arsenic ranged from 5.3 to 35.1 % with the lowest percent occurring at Belle River Park and the highest percentage at Millcreek Ravine Park (EDM-04). The Millcreek Ravine Park was also found to have the highest total arsenic concentration of 7.4 mg/kg which was below the CCME soil quality guideline for residential/parkland use of 12 mg/kg (CCME, 2012). In comparison with other cities (i.e., Toronto (Dakane, 2012) and Urban New Brunswick (Dupuis, 2013)), the Edmonton city parks had relatively low arsenic concentrations with no exceedances. The city of Toronto also had relatively low arsenic concentrations with no CCME guidelines exceedances while for Saint John and Fredericton (Urban New Brunswick) there were seven sampling points that exceeded the CCME guidelines. It is important to note that the sample points with exceedances each had relatively low arsenic bioaccessibility (all below <20% bioaccessibility) indicating minimal risk from soil ingestion. This highlights the importance of understanding the bioaccessibility and bioavailability of metals in soils for liability management of sites.

Barium

Total barium concentrations in the soil samples were all below the CCME soil quality guideline for residential/parkland use of 500 mg/kg indicating minimal concern for this study. Similar results were noted in other cities (Dakane, 2012; Dupuis, 2013). Barium is also not considered a metal of high concern according to the ranking on the

ATSDR list of toxic substances for 2013 which places it at Number 131 (ATSDR, 2014b).

Cadmium

Cadmium is highly ranked (at 7th) amongst the ASTDR priority list of hazardous substances for 2013 (ASTDR, 2014b). The concentrations of total Ca in the soil samples were quite low ranging from 0.12 to 0.76 mg/kg which were well below the CCME soil quality guidelines for residential/parkland use (10 mg/kg). Even though Cd was found to be generally bioaccessible across the study sites (56.9% to 100%), the potential impact from soil ingestion at the playgrounds was deemed minimal due to the low total Cd concentrations detected in the soil samples.

Chromium

Total chromium in the soil samples ranged from 5.5 to 48.7 mg/kg which were all below the CCME Canadian Environmental Quality Guidelines for residential/parkland use (Table 3): the CCME guideline for Chromium is 64 mg/kg. Furthermore, Cr concentrations in all but three of the PBET extracts were below detection (<8.0 µg/L). Chromium was therefore considered a metal of minimal concern in this study.

Cobalt

Cobalt concentrations were generally much lower than the CCME guideline of 50 mg/kg, ranging from 3.4 mg/kg to 8.9 mg/kg. The bioaccessibility for Co amongst the study sites were found to be variable ranging from 5.5 % to 48.7%. The potential impact of Co in the park soils was therefore considered minimal.

Copper

The bioaccessibility of Cu in the Edmonton park soils ranged from 6% to 43%.The lowest bioaccessibility was found at sample point EDM-14 (Belvedere Park) which was mainly fine sand and the highest occurred at sample point EDM-04 (Millcreek Ravine) which was a mixture of sand and organic matter. For the total metals results, sample point EDM-08 (Callingwood park – located South West of Edmonton) had the highest Cu concentration (93.08 mg/kg) which exceeded the CCME Soil Quality guidelines for residential/parkland use (63 mg/kg); this sample had a bioaccessibility of 31.6 % indicating the risk associated with ingestion is moderate. In comparison with the data from Saint John and Fredericton (Dupuis, 2013), Cu concentrations in Edmonton were generally higher; the highest data point for St. John and Fredericton was just below the CCME guidelines at 62.66 mg/kg. Copper concentrations in the Edmonton soil samples were comparable to the data obtained for Toronto (Dakane2012). .

Lead

Lead bioaccessibility values for the Edmonton parks soil samples ranged from and 42.3 – 100 % while total Pb concentrations ranged from 3.65 mg/kg to 37.03 mg/kg. The highest concentration was detected in Sample EDM-12 which was collected from Rundle Park, a former landfill/garbage dump. The highest concentration was still below the CCME guideline of 140 mg/kg for Pb. A second sample collected from a different location in the vast Rundle Park (EDM-11) had a total Pb concentration of 36.91 mg/kg. The relatively elevated Pb concentrations compared to other Edmonton parks may be due to its former use as a landfill. Although Pb is the second element on the ATSDR 2013

Substance Priority List (ATSDR, 2014b), the concentrations found in Edmonton Park soils which were well below the CCME guidelines, coupled with the low to moderate bioaccessibility suggested there are no major concerns from soil ingestion at Edmonton playgrounds.

Other cities studied in Canada (i.e., Toronto, Saint John and Fredericton) had sample points with Pb values exceeding the Canadian soil quality guidelines (Dakane, 2012; Dupuis 2013). In Toronto, one of the sample points taken at G. Ross Lord Park had a significantly high Pb concentration of 690 mg/kg which was over five times the CCME soil quality guideline (140 mg/kg). The study's author noted that this park was located within 600 m of two scrap metals yards (Dakane, 2012).

Nickel

For total metals results, sample point EDM-04 (Mill Creek Ravine Park) had the highest Ni concentration (33.4 mg/kg) which was below the CCME soil quality guidelines for residential/parkland areas (50 mg/kg). Bioaccessibility of Ni in the Edmonton city park ranged from 18 – 45%. The data therefore suggested minimal soil ingestion concerns for Ni.

Zinc

The bioaccessibility of Zn ranged from 21% to 96.2% in the Edmonton park soil samples. This dispersion was similar to the range distribution in the Torino & Sevilla studies by Madrid et al. (2008). The highest bioaccessibility was found in the sample collected for the forested area of the Whitemud Park. For total Zn in soils, one sample

(EDM-08, 237 mg/kg) had concentrations that exceeded the CCME Soil quality guidelines for Zn (200 mg/kg). This sample also had an exceedance for Cu and is located on the South West part of Edmonton (Callingwood Park). Zinc bioaccessibility was relatively high (84.4%) for EDM-08 indicating some potential concerns with soil exposure and ingestion.

In comparison to the data from New Brunswick conducted by Dupuis (2013) Zn concentrations in soils were generally higher in Edmonton with no sample point exceeding guidelines in Saint John and Fredericton parks while in Toronto (Dakane, 2012) a number of parks exceeded guidelines with highest result at 350 mg/kg.

There are several possible pathways for the introduction of Zn in city parks. One notable source is via wood and paint chips from park benches. Zinc is sometimes used as a preservative in wood and paints (ATSDR, 2014a). This may attribute to the high mass of Zn in the park soils as compared to other metals constituents.

Relationship between Soil pH, LOI and Metal Bioaccessibility

Loss-on-ignition relates to the organic matter content in a soil. As such it has a potential to affect metal bioaccessibility depending on the chemical form of the metals present (metal speciation). The soil pH may also affect bioavailability depending on the pH of the soil as it influences the adsorption of the metals to the soils particles. Nederlof , Van Riemsdijk and De Haan’s work on the “effect of pH on the bioavailability of metals in soils” supports this observation. Their work showed that metal binding to soils increased with increasing pH (Nederlof et al., 1993). A linear regression analysis was therefore performed to investigate the relationship between metal bioaccessibility and soil pH and LOI.

The regression analysis showed a negative, positive or no correlation trend for LOI and pH depending on the metal. Details of the linear graphs and equations are given in Appendix VIII. LOI was found to have no significant correlation to metals bioaccessibility with different metals responding differently to LOI while pH did typically show a positive relationship to metals bioaccessibility with copper and arsenic showing the highest positive response. It is important to note that the findings are limited due to data size and will require further sampling and analysis to derive definite relationships between pH or LOI and metals bioaccessibility.

Conclusions and Recommendations

Conclusion

Total metal concentrations in soil samples collected from 12 Edmonton city parks were all below the CCME soil quality guidelines for residential/parkland use except for Cu in two samples (EDM-03 and EDM-08) and Zn in one sample (EDM-08). Based on the total metals concentrations and the bioaccessibility data the potential risks associated with the ingestion of heavy metal contaminants in soils at the playgrounds, especially the most toxic ones such as As, Cd and Pb, are considered low.

Comparison of the Edmonton data with other cities shows some consistency in values for certain metals. For example, high concentrations of Zn were noted in soils across all Canadian cities mentioned in the three related thesis –Toronto (Dakane, 2012), Urban New Brunswick (Dupuis, 2013) and Edmonton (this study). Lead in particular was generally higher in Toronto and Saint John compared to Edmonton and Fredericton. The elevated concentrations in Toronto were attributed to proximity of the parks to high traffic corridors and scrap metal processing industries (Dakane, 2012).

Management Implications of Research

Data and findings from this research could contribute to developing a framework for further studies in Canada aimed at completing a national picture of elemental bioaccessibility in urban parks in Canada. This study along with similar projects conducted in various cities in Canada could provide the baseline data and information necessary to assist researchers, policy makers and industry alike to use bioaccessibility data for adjusting default values that are based on 100% bioavailability for metals risk assessment in urban landscapes and residential parkland. The results could also be used by the City of Edmonton for the risk assessments and maintenance of city parks including the mitigation of environmental and human health risks associated with heavy metals that may be found during the risk assessment.

Recommendations

Further sampling and analysis is recommended to determine the extent and source of Zn and Cu concentrations that exceeded the CCME soil quality guidelines for residential/parkland use. Studies at more cities across Canada are also recommended to complete an urban soils profile for metals bioaccessibility. The selection of the parks should include areas with different surrounding land use (industrial, commercial, residential, urban corridors, climate, park usage, and soil types. Additional investigations into the relationships between LOI and pH of the soils and metals bioaccessibility are also recommended. More sampling and analysis followed by regression analysis of results is needed to develop models that can be used for the management of metal contaminants in the urban environment.

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Appendix I: Sampling Locations and descriptions

Appendix I-1: Sample Locations and Sampling Time

Sample point	Sample ID	Sampling Date	Sampling Time	GPS Coordinates
Capilano Community Park - 10810 54 st	EDM - 01	2013/11/09	9:45	N53 33.339 W113 25.335
Gold Bar Park - 4620 105 ave	EDM - 02	2013/11/09	10:10	N53 33.423 W113 24.416
Capilano Park - 56 st and 109a avenue	EDM - 03	2013/11/09	10:30	N53 33.546 W113 25.225
Millcreek Ravine Park - 8323 95A Street	EDM - 04	2013/11/09	12:00	N53 30.912 W113 28.418
Whitemud Park - 13204 Fox drive	EDM - 05	2013/11/09	12:55	N53 28.867 W113 33.180
Whitemud Park - 13204 Fox drive #2	EDM - 06	2013/11/09	13:10	N53 28.517 W113 33.373
Whitemud Park - 13204 Fox drive #2 Duplicate	EDM - 07	2013/11/09	13:10	N53 28.517 W113 33.373
Callingwood Park - 17740 69 Avenue	EDM - 08	2013/11/09	14:25	N58 30.443 W113 37.280
Glenora Park - 10410 136 Street	EDM - 09	2013/11/09	15:01	N53 32.794 W113 33.423
Central McDougall Park - 109 av and 107 Street	EDM - 10	2013/11/09	15:30	N53 33.308 W113 30.237
Rundle Park - 2909 - 113 Ave	EDM - 11	2013/11/10	12:15	N53 33.566 W113 23.105
Rundle Park - 2909 - 113 Ave #2	EDM - 12	2013/11/10	12:32	N53 34.043 W113 22.851
Rundle Park - 2909 - 113 Ave #2 Duplicate	EDM - 13	2013/11/10	12:32	N53 34.043 W113 22.851
Belvedere Park - 13223 60 Street	EDM - 14	2013/11/10	13:05	N53 35.643 W113 26.125
Belle River Park - 15904 84 street	EDM - 15	2013/11/10	13:25	N53 37.178 W113 28.245
Beaumaris Park - 10210 155 Ave	EDM - 16	2013/11/10	13:45	N53 37.038 W113 29.889

Orval Allen Park - 15910 127 Street	EDM - 17	2013/11/10	14:30	N53 37.225 W113 32.277

Appendix I-2: Descriptions of Sample Locations and Observations:

Capilano Community Park (EDM-01): 10810 54 Street, Edmonton, AB.

This sample point is located in the south east of the citySample matrix was a mixture of mainly sand and some organic matter. Sample point located near park playground structure.

Gold Bar Park (EDM 02): 4620 105 avenue, Edmonton AB.

This park is also located in the southeast corner of Edmonton. Summer activities occurring in the park area includes picnics, barbecues, walks, biking etc. Winter activities include skiing, bobsledding etc. This park is located just beside the Gold bar waste water treatment facility owned by EPCOR (a utilities and waste water management corporation). The sample was mainly composed of clayey material taken close by a barbecue and picnic spot near the parking lot of the park.

Capilano Park (EDM-03): Intersection of 56 st and 109 a Avenue, Edmonton, AB.

This sample point is located in the south east of Edmonton, downhill from the Gold bar waste water treatment plant located nearby 4620 105 avenue, Edmonton. The sample was taken just below the snow slide in the park open area. We observed a number of kids playing around the snow slide during sampling.

Millcreek Ravine Park (EDM-04): 8323 95A Street, Edmonton, AB.

This sample point is located in the South East of Edmonton. Sample matrix was a mixture of sand and organic matter. The sampling point was located near a barbecue and picnic spot just uphill from the ravine.

Whitemud Park (EDM-5): 13204 Fox drive, Edmonton AB.

This sample point is located in the Southwest of Edmonton by a major express road that runs from the west to east of the city. The first sample point (EDM-5) was taken at the entrance of the park close by the busy Whitemud express road. Sample consists of mostly organic material with some sand.

Whitemud Park (EDM-6 & EDM-7 duplicate): 13204 Fox drive, Edmonton AB.

This Sample point was taken deeper into the large park in the forested area along a walking path and play space. This sample consists of mostly organic material with some sand. Sample point was a 10 mins walk into the forested area from the park entrance, located in the park ravine area; soil was not yet frozen likely due to the forest cover in the area.

Callingwood Park (EDM-8): 17740 69 Avenue, Edmonton AB.

This sample was taken in the southwest area of Edmonton. Sample was taken at the barbecue /picnic area adjacent to the kid's playground. It consists of mainly organic material.

Glenora Park (EDM-09): 10410 136 Street, Edmonton AB.

This sample point is located in the Northwest Edmonton. The sample was taken from playground sand in the kid's play area. Sample is entirely play sand. Playground sand is atypical of soil sample types usually taken for this project.

Central McDougall Park (EDM-10): Intersection of 109av & 107 Street, Edmonton AB.

This sample point is located in downtown Edmonton. It consists of mainly organic material taken from grass area by the playground area. The sample location was located in a highly dense residential neighborhood in central Edmonton.

Rundle Park A (EDM-11) - 2909 – 113 Ave, Edmonton AB.

This Sample point is located in the Northeast of Edmonton from Rundle Park. Rundle Park is one of the largest parks in the City and was a former landfill area. It will be interesting to see the metal analytes concentrations from this sample point. This particular sample was taken besides the chairs located near a Barbecue/picnic area by the family center structure. The sample consists of mostly organic material.

Rundle Park B (EDM-12 & EDM-13 as duplicate) - 2909 – 113 Ave, Edmonton AB.

This sample point was taken near the Rundle park Golf course by a resting chair. As mentioned earlier, Rundle Park is located in the north east corner of Edmonton. Furthermore, it’s located downhill from major oil refineries. This sample was also taken as a duplicate for QA/QC purposes. Rundle Park used to be a former dump area (major landfill) located in the north eastern corner of Edmonton and close by a number of major oil refineries which are just adjacent from the park (Edmonton City Parks, 2014).

Belvedere Park (EDM-14) – 13223 60 Street, Edmonton AB.

This sample was mainly organic material taken from the park lawn area near the kids playground in Belvedere park. Belvedere park is located in the northeast area of Edmonton. This park is located in a highly dense residential area.

Belle River park (EDM-15) – 15904 84 street, Edmonton, AB.

This sample point is located in the Northeast of the city of Edmonton; Belle River Park is situated just across from Belle River in North Edmonton. This sample was purely a sandy sample taken from the play sand area in the kids’ playground. This sample point is located in a largely residential neighborhood.

Beaumaris Park (EDM-16): 10210 155 Ave, Edmonton AB.

Sample was taken from top of the hill (snow slide) by the bench and is located in the northwest of Edmonton. Sample consists of fill material and underlying clay.

Orval Allen Park (EDM-17):15910 127 Street, Edmonton AB.

This sample point is located in the Northwest corner of Edmonton. The sample consists of mainly clay and organic matter and was sampled nearby the benches close to the main field of the park.

Appendix II: Laboratory Sample Preparation

Sample ID	Wet Soil Used (g)	Dry Soil (g)	Moisture (%)	<um 250 m Soil (g)	< 250 µm Content (%)
EDM-01	430.6	316.7	26.5	83.6	39.2
EDM-02	696.2	574.8	17.4	102.0	24.3
EDM-03	611.0	437.3	28.4	46.7	15.7
EDM-04	342.8	212.8	37.9	56.6	37.4
EDM-05	887.7	633.5	28.6	65.9	18.7
EDM-06	503.0	400.1	20.5	99.1	34.8
EDM-07	572.1	469.0	18.0	114.4	37.0
EDM-08	507.7	353.2	30.4	48.4	18.8
EDM-09	668.6	643.4	3.8	48.4	10.4
EDM-10	452.4	364.1	19.5	75.0	25.9
EDM-11	379.5	267.5	29.5	39.5	18.1
EDM-12	453.5	392.7	13.4	73.5	27.7
EDM-13	518.0	442.8	14.5	63.4	21.1
EDM-14	589.1	500.1	15.1	64.7	18.4
EDM-15	1018.1	1009.2	0.9	11.4	1.9
EDM-16	675.7	594.8	12.0	124.6	30.1
EDM-17	474.3	401.4	15.4	47.1	17.2

Appendix III: Detailed Soil pH Data

Sample ID	Weight of Soil Used (g)	Deionized Water Used (ml)	pH	Comment
EDM-01	10.00	20	7.69	Decanted
EDM-02	10.07	20	7.32	Decanted
EDM-03	10.02	30	6.27	Centrifuged
EDM-04	10.03	20	8.13	Decanted
EDM-05	10.00	20	6.82	Centrifuged
EDM-06	10.03	20	7.38	Centrifuged
EDM-07	10.06	20	7.39	Decanted
EDM-08	10.00	30	7.35	Centrifuged
EDM-09	10.04	20	8.07	Centrifuged
EDM-10	10.00	20	7.5	Decanted
EDM-11	10.02	20	6.13	Centrifuged
EDM-12	10.02	20	6.33	Centrifuged
EDM-13	10.05	20	6.17	Centrifuged
EDM-14	10.04	20	7.19	Centrifuged
EDM-15	10.04	20	7.91	Decanted
EDM-16	10.05	20	7.68	Decanted
EDM-17	10.01	20	7.83	Decanted

Appendix IV: Detailed Loss-on-Ignition (LOI) Data

Sample ID	Mass lost after 105C (g)	Mass lost after 550C (g)	Mass lost after 950C (g)	LOI 105 (%)	LOI 550 (%)	LOI 950 (%)
EDM-1	0.0204	0.0855	0.0108	1.99	8.34	1.05
EDM-1	0.0212	0.0852	0.0109	2.10	8.44	1.08
EDM-1	0.0212	0.0841	0.0110	2.07	8.22	1.07
EDM-2	0.0207	0.0747	0.0077	2.05	7.40	0.76
EDM-2	0.0200	0.0737	0.0072	1.98	7.29	0.71
EDM-2	0.0213	0.0740	0.0082	2.09	7.25	0.80
EDM-3	0.0752	0.4018	0.0128	7.42	39.62	1.26
EDM-3	0.0725	0.3906	0.0119	7.33	39.47	1.20
EDM-3	0.0756	0.4027	0.0108	7.53	40.13	1.08
EDM-4	0.0325	0.1135	0.0238	3.21	11.20	2.35
EDM-4	0.0322	0.1095	0.0244	3.18	10.81	2.41
EDM-4	0.0348	0.1098	0.0239	3.42	10.80	2.35
EDM-5	0.0673	0.2760	0.0100	6.54	26.84	0.97
EDM-5	0.0697	0.2886	0.0104	6.72	27.82	1.00
EDM-5	0.0625	0.2745	0.0100	6.21	27.29	0.99
EDM-6	0.0373	0.1955	0.0145	3.63	19.04	1.41
EDM-6	0.0376	0.1996	0.0137	3.70	19.65	1.35
EDM-6	0.0275	0.1958	0.0129	2.72	19.36	1.28
EDM-7	0.0407	0.1957	0.0140	3.95	19.00	1.36
EDM-7	0.0391	0.1904	0.0137	3.84	18.70	1.35
EDM-7	0.0396	0.1937	0.0140	3.85	18.85	1.36
EDM-8	0.0694	0.4536	0.0395	6.74	44.02	3.83
EDM-8	0.0689	0.4447	0.0390	6.80	43.89	3.85
EDM-8	0.0698	0.4510	0.0400	6.91	44.65	3.96
EDM-9	0.0030	0.0138	0.0157	0.29	1.35	1.53
EDM-9	0.0032	0.0126	0.0136	0.31	1.24	1.34
EDM-9	0.0031	0.0121	0.0146	0.31	1.20	1.45
EDM-10	0.0434	0.1908	0.0171	4.19	18.44	1.65
EDM-10	0.0425	0.1940	0.0168	4.18	19.07	1.65
EDM-10	0.0413	0.1880	0.0169	4.09	18.61	1.67

Appendix IV: Detailed Loss-on-Ignition (LOI) Data Continued

Sample ID	Mass lost after 105C (g)	Mass lost after 550C (g)	Mass lost after 950C (g)	LOI 105 (%)	LOI 550 (%)	LOI 950 (%)
EDM-11	0.0506	0.2578	0.0181	5.01	25.51	1.79
EDM-11	0.0502	0.2575	0.0186	4.96	25.45	1.84
EDM-11	0.0532	0.2704	0.0196	4.98	25.31	1.83
EDM-12	0.0404	0.2290	0.0159	3.95	22.37	1.55
EDM-12	0.0412	0.2353	spilled	4.01	22.88	spilled
EDM-12	0.0395	0.2225	0.0146	3.86	21.72	1.43
EDM-13	0.0426	0.2432	0.0145	4.16	23.76	1.42
EDM-13	0.0428	0.2493	0.0150	4.13	24.05	1.45
EDM-13	0.0407	0.2390	0.0145	3.99	23.43	1.42
EDM-14	0.0298	0.2119	0.0097	2.94	20.89	0.96
EDM-14	0.0298	0.2144	0.0086	2.95	21.24	0.85
EDM-14	0.0299	0.2225	0.0089	2.87	21.39	0.86
EDM-15	0.0032	0.0180	0.0075	0.31	1.73	0.72
EDM-15	0.0028	0.0168	0.0060	0.27	1.65	0.59
EDM-15	0.0027	0.0163	0.0061	0.26	1.60	0.60
EDM-16	0.0129	0.0485	0.0106	1.28	4.81	1.05
EDM-16	0.0122	0.0485	0.0105	1.20	4.78	1.03
EDM-16	0.0136	0.0494	0.0109	1.32	4.80	1.06
EDM-17	0.0391	0.1325	0.0178	3.77	12.77	1.72
EDM-17	0.0385	0.1300	0.0177	3.76	12.71	1.73
EDM-17	0.0382	0.1295	0.0169	3.81	12.91	1.68

Appendix V: ACME Laboratory Report for Total Metals in Soils

ACME ANALYTICAL LABORATORIES LTD. Final Report
Client: Royal Roads University
File Created: 23-Dec-13
Job Number: VAN13005260

Method	1F	1F	1F	1F	1F	1F	1F	1F
Analyte	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn
Unit	PPM	PPM	PPM	PPM	PPB	PPM	PPM	PPM
MDL	0.01	0.01	0.01	0.1	2	0.1	0.1	1
EDM-01	0.63	15.29	11.73	55.3	85	16.2	5.4	334
EDM-02	0.79	22.24	11.43	82.5	121	17	6.5	413
EDM-03	1.54	75.74	29.47	178.6	1687	19.9	5.6	331
EDM-04	0.9	48.92	23.56	169.4	201	33.4	8.8	487
EDM-05	0.75	24.57	15.7	84.8	190	14.9	5.9	332
EDM-06	0.39	14.37	17.69	170.1	62	14.7	5.5	325
EDM-07	0.29	11.03	15.7	135.8	49	12.2	5.6	282
EDM-08	2.58	93.86	13.82	236.5	185	20.8	4.4	456
EDM-09	0.3	7.62	3.65	28.6	29	9.4	3.4	255
EDM-10	0.63	21.63	23.17	74.8	92	19.4	7.2	403
EDM-11	1.52	28.38	36.91	111.4	127	25.8	8.1	475
EDM-12	1.43	21.73	37.03	88.5	111	21.4	7.1	517
EDM-13	1.19	23.76	36.92	95.4	81	21.7	7.4	537
EDM-14	0.57	14.82	15.76	57.5	59	11.7	3.8	219
EDM-15	0.7	7.98	4.35	29.8	36	11.4	4.3	269
EDM-16	0.63	19.46	8.75	45.7	52	18.3	6.7	333
EDM-17	0.61	27.92	17.32	88.5	102	25.6	8.9	402
Reference Materials								
STD DS10	14.18	156.41	154.43	363.4	1722	75.6	13	880
STD OREAS45EA	1.39	648.97	14.37	30.1	256	357	49.8	407
BLK	<0.01	<0.01	<0.01	<0.1	4	<0.1	<0.1	<1

Appendix V: ACME Laboratory Report for Total Metals in Soils - Continued

ACME ANALYTICAL LABORATORIES LTD.

Client:	Royal Roads University							
File Created:	23-Dec-13							
Job Number:	VAN13005260							
Method	1F	1F	1F	1F	1F	1F	1F	1F
Analyte	Fe	As	U	Au	Th	Sr	Cd	Sb
Unit	%	PPM	PPM	PPB	PPM	PPM	PPM	PPM
MDL	0.01	0.1	0.05	0.2	0.1	0.5	0.01	0.02
EDM-01	1.24	4.5	0.83	0.7	1.7	24.1	0.26	0.39
EDM-02	1.26	5.6	1.43	1.8	2.3	65.9	0.28	0.48
EDM-03	1.17	3.2	2.06	52.1	1	84.5	0.76	0.69
EDM-04	2.08	7.4	1.13	<0.2	3.2	103.4	0.55	0.52
EDM-05	1.16	4.3	0.76	2.8	1.5	31.3	0.23	0.35
EDM-06	0.94	4	0.72	0.9	1	72.5	0.41	0.23
EDM-07	0.82	4.1	0.69	<0.2	0.9	58.3	0.33	0.2
EDM-08	1.18	4.6	1.81	5.2	0.6	239.7	0.76	2.02
EDM-09	0.9	4.7	0.52	1.6	2.1	21.1	0.12	0.17
EDM-10	1.41	4.5	1.24	3.8	1.7	57.6	0.36	0.31
EDM-11	1.67	6.4	1.83	7.5	1.6	50.5	0.53	0.47
EDM-12	2.13	5.6	1.46	0.7	1.6	47.7	0.33	0.33
EDM-13	2.04	5.4	1.5	0.6	1.6	48.4	0.34	0.31
EDM-14	0.93	4.8	0.83	0.9	1.3	25.5	0.2	0.26
EDM-15	1.21	6.7	0.36	0.4	1.3	8.7	0.12	0.2
EDM-16	1.41	5.5	1.21	0.9	2.7	61.6	0.21	0.27
EDM-17	1.96	5.8	2.01	0.2	3	76.9	0.29	0.19
Reference Materials								
STD DS10	2.69	44.1	2.58	61.2	7.4	64.4	2.52	8.6
STD OREAS45EA	22.92	8.3	1.81	49	10.4	3.7	0.03	0.24
BLK	<0.01	0.3	<0.05	<0.2	<0.1	<0.5	<0.01	<0.02

Appendix V: ACME Laboratory Report for Total Metals in Soils - Continued

ACME ANALYTICAL LABORATORIES LTD.

Client:	Royal Roads University							
File Created:	23-Dec-13							
Job Number:	VAN13005260							
Method	1F	1F	1F	1F	1F	1F	1F	1F
Analyte	Bi	V	Ca	P	La	Cr	Mg	Ba
Unit	PPM	PPM	%	%	PPM	PPM	%	PPM
MDL	0.02	2	0.01	0.001	0.5	0.5	0.01	0.5
EDM-01	0.11	16	0.74	0.066	12.4	12.6	0.3	139.5
EDM-02	0.2	22	0.55	0.068	19	12.7	0.18	485.2
EDM-03	1.82	17	1.36	0.362	12.8	23.3	0.33	203.9
EDM-04	0.16	24	1.79	0.085	16.8	17.3	0.44	249.7
EDM-05	0.12	15	0.7	0.105	9.9	14.4	0.27	122.9
EDM-06	0.07	10	1.26	0.08	9.7	6.8	0.2	164.5
EDM-07	0.07	9	1.02	0.064	9.5	5.5	0.17	172.8
EDM-08	0.17	13	4.01	0.233	9.5	48.7	0.33	258
EDM-09	0.02	11	0.96	0.038	9.8	7.7	0.23	54.9
EDM-10	0.18	21	1.1	0.091	11.5	14.2	0.4	187.1
EDM-11	0.16	23	1.16	0.148	19.2	21.1	0.4	225.6
EDM-12	0.13	25	0.78	0.168	14.6	17.3	0.28	159.8
EDM-13	0.13	24	0.75	0.166	14.9	17.1	0.29	165.3
EDM-14	0.07	13	0.54	0.097	9.5	11.5	0.2	97.6
EDM-15	<0.02	10	0.22	0.04	7.2	6.4	0.14	85.2
EDM-16	0.14	23	0.7	0.053	15.1	12.5	0.31	247.1
EDM-17	0.2	29	1.03	0.076	15.2	18.9	0.46	162.7
Reference Materials								
STD DS10	12.62	42	1.04	0.072	15.5	51.9	0.76	369.3
STD OREAS45EA	0.26	286	0.04	0.026	6.7	734.1	0.1	143.8
BLK	<0.02	<2	<0.01	<0.001	<0.5	<0.5	<0.01	<0.5

Appendix V: ACME Laboratory Report for Total Metals in Soils - Continued

ACME ANALYTICAL LABORATORIES LTD.								
Client:	Royal Roads University							
File Created:	23-Dec-13							
Job Number:	VAN13005260							
Method	1F	1F	1F	1F	1F	1F	1F	1F
Analyte	Ti	B	Al	Na	K	W	Sc	Tl
Unit	%	PPM	%	%	%	PPM	PPM	PPM
MDL	0.001	20	0.01	0.001	0.01	0.05	0.1	0.02
EDM-01	0.005	<20	0.6	0.005	0.13	0.22	1.5	0.08
EDM-02	0.009	<20	0.75	0.053	0.15	0.24	2.4	0.11
EDM-03	0.005	<20	0.7	0.024	0.31	1.84	1.3	0.11
EDM-04	0.005	<20	0.91	0.036	0.28	0.37	2.7	0.1
EDM-05	0.004	<20	0.48	0.007	0.22	0.42	1.6	0.12
EDM-06	0.004	<20	0.38	0.005	0.1	0.31	1.2	0.08
EDM-07	0.003	<20	0.34	0.005	0.09	0.18	1	0.08
EDM-08	0.006	44	0.67	0.045	0.32	0.55	1	0.06
EDM-09	0.009	<20	0.31	0.004	0.04	0.08	1.1	0.06
EDM-10	0.005	<20	0.89	0.019	0.23	0.11	1.9	0.1
EDM-11	0.004	<20	0.87	0.012	0.26	0.66	2.4	0.13
EDM-12	0.005	<20	0.98	0.004	0.19	0.27	2.1	0.1
EDM-13	0.005	<20	0.95	0.004	0.2	0.27	1.9	0.1
EDM-14	0.004	<20	0.46	0.002	0.16	0.25	0.9	0.07
EDM-15	0.015	<20	0.25	0.004	0.06	0.08	1.1	0.14
EDM-16	0.007	<20	0.84	0.045	0.16	0.06	2.6	0.14
EDM-17	0.004	<20	1.27	0.006	0.26	0.07	3.4	0.13
Reference Materials								
STD DS10	0.07	<20	0.98	0.064	0.33	2.68	2.5	5
STD OREAS45EA	0.089	<20	2.85	0.021	0.05	<0.05	72.6	<0.02
BLK	<0.001	<20	<0.01	<0.001	<0.01	<0.05	<0.1	<0.02

Appendix V: ACME Laboratory Report for Total Metals in Soils - Continued

ACME ANALYTICAL LABORATORIES LTD.

Client:	Royal Roads University				
File Created:	23-Dec-13				
Job Number:	VAN13005260				
Method	1F	1F	1F	1F	1F
Analyte	S	Hg	Se	Te	Ga
Unit	%	PPB	PPM	PPM	PPM
MDL	0.02	5	0.1	0.02	0.1
EDM-01	0.04	53	0.2	0.02	1.7
EDM-02	0.04	24	0.2	0.03	2.7
EDM-03	0.23	333	0.7	0.05	2
EDM-04	0.04	33	0.2	<0.02	2.9
EDM-05	0.1	43	0.4	<0.02	1.8
EDM-06	0.06	81	0.1	<0.02	1.3
EDM-07	0.05	47	<0.1	<0.02	1.3
EDM-08	0.21	30	<0.1	0.06	1.9
EDM-09	<0.02	7	<0.1	<0.02	1.1
EDM-10	0.15	53	0.4	<0.02	2.6
EDM-11	0.11	62	0.3	0.06	2.9
EDM-12	0.11	100	0.6	<0.02	3
EDM-13	0.1	107	0.2	<0.02	3.1
EDM-14	0.09	50	0.3	<0.02	1.4
EDM-15	<0.02	47	<0.1	0.06	1
EDM-16	0.03	27	0.2	0.05	2.7
EDM-17	0.06	23	0.4	0.02	3.8
Reference Materials					
STD DS10	0.28	267	2.1	4.64	4
STD OREAS45EA	0.04	12	0.7	0.04	11.4
BLK	<0.02	<5	<0.1	<0.02	<0.1

Appendix VI: Detailed Bioaccessibility Data

Arsenic Bioaccessibility

Sample ID	Weight used for extraction (g)	Arsenic in soil (mg/kg)	Arsenic in extract (ug/L)	Arsenic Bioaccessibility (%)
EDM-01	1.0060	4.5	9.3	**20.5**
EDM-02	1.0052	5.6	18.2	**32.3**
EDM-03	1.0163	3.2	6.4	**19.7**
EDM-04	1.0073	7.4	26.2	**35.1**
EDM-05	1.0122	4.3	4.4	**10.1**
EDM-06	1.0188	4.0	4.1	**10.1**
EDM-07	1.0029	4.1	4.9	**11.9**
EDM-08	1.0124	4.6	15.3	**32.9**
EDM-09	1.0085	4.7	7.5	**15.8**
EDM-10	1.0364	4.5	9.4	**20.2**
EDM-11	1.0340	6.4	8.0	**12.1**
EDM-12	1.0266	5.6	7.1	**12.4**
EDM-13	1.0052	5.4	8.4	**15.5**
EDM-14	1.0076	4.8	6.5	**13.4**
EDM-15	1.0100	6.7	3.6	**5.3**
EDM-16	1.0041	5.5	14.5	**26.3**
EDM-17	1.0257	5.8	14.1	**23.7**
EDM-10 Dup	1.0208	4.5	9.6	**20.9**
EDM-16 Dup	1.0166	5.5	13.9	**24.9**

Barium Bioaccessibility

Sample ID	Weight used for extraction (g)	Barium in soil (mg/kg)	Ba in extract (ug/L)	Barium Bioaccessibility (%)
EDM-01	1.0060	139.5	1000	**71.3**
EDM-02	1.0052	485.2	2270	**46.5**
EDM-03	1.0163	203.9	1460	**70.5**
EDM-04	1.0073	249.7	1950	**77.5**
EDM-05	1.0122	122.9	955	**76.8**
EDM-06	1.0188	164.5	1180	**70.4**
EDM-07	1.0029	172.8	1180	**68.1**
EDM-08	1.0124	258	2260	**86.5**
EDM-09	1.0085	54.9	328	**59.2**
EDM-10	1.0364	187.1	1530	**78.9**
EDM-11	1.0340	225.6	1790	**76.7**
EDM-12	1.0266	159.8	1170	**71.3**
EDM-13	1.0052	165.3	1220	**73.4**
EDM-14	1.0076	97.6	764	**77.7**
EDM-15	1.0100	85.2	335	**38.9**
EDM-16	1.0041	247.1	1320	**53.2**
EDM-17	1.0257	162.7	1150	**68.9**
EDM-10 Dup	1.0208	187.1	1560	**81.7**

EDM-16 Dup	1.0166	247.1	1260	**50.2**

Cadmium Bioaccessibility

Sample ID	Weight used for extraction (g)	Cadmium in soil (mg/kg)	Cadmium in extract (ug/L)	Cadmium Bioaccessibility (%)
EDM-01	1.0060	0.26	1.96	**74.9**
EDM-02	1.0052	0.28	2.27	**80.7**
EDM-03	1.0163	0.76	6.36	**82.3**
EDM-04	1.0073	0.55	4.61	**83.2**
EDM-05	1.0122	0.23	2.09	**89.8**
EDM-06	1.0188	0.41	3.74	**89.5**
EDM-07	1.0029	0.33	3.58	**108.2**
EDM-08	1.0124	0.76	9.84	**127.9**
EDM-09	1.0085	0.12	0.85	**70.2**
EDM-10	1.0364	0.36	3.71	**99.4**
EDM-11	1.0340	0.53	4.39	**80.1**
EDM-12	1.0266	0.33	2.87	**84.7**
EDM-13	1.0052	0.34	2.88	**84.3**
EDM-14	1.0076	0.2	2.12	**105.2**
EDM-15	1.0100	0.12	0.69	**56.9**
EDM-16	1.0041	0.21	1.70	**80.6**
EDM-17	1.0257	0.29	2.63	**88.4**
EDM-10 Dup	1.0208	0.36	3.45	**93.9**
EDM-16 Dup	1.0166	0.21	1.39	**65.1**

Cobalt Bioaccessibility

Sample ID	Weight used for extraction (g)	Cobalt in soil (mg/kg)	Cobalt in extract (ug/L)	Cobalt Bioaccessibility (%)
EDM-01	1.0060	5.4	27.0	**49.7**
EDM-02	1.0052	6.5	14.6	**22.3**
EDM-03	1.0163	5.6	21.4	**37.6**
EDM-04	1.0073	8.8	38.9	**43.9**
EDM-05	1.0122	5.9	14.9	**24.9**
EDM-06	1.0188	5.5	25.0	**44.6**
EDM-07	1.0029	5.6	24.4	**43.4**
EDM-08	1.0124	4.4	16.0	**35.9**
EDM-09	1.0085	3.4	7.9	**23.0**
EDM-10	1.0364	7.2	30.7	**41.1**
EDM-11	1.0340	8.1	28.2	**33.7**
EDM-12	1.0266	7.1	14.5	**19.9**
EDM-13	1.0052	7.4	15.9	**21.4**
EDM-14	1.0076	3.8	14.2	**37.1**
EDM-15	1.0100	4.3	6.2	**14.3**
EDM-16	1.0041	6.7	14.2	**21.1**

EDM-17	1.0257	8.9	33.6	**36.8**
EDM-10 Dup	1.0208	7.2	28.6	**38.9**
EDM-16 Dup	1.0166	6.7	13.2	**19.4**

Copper Bioaccessibility

Sample ID	**Weight used for extraction (g)**	**Copper in soil (mg/kg)**	**Copper in extract (ug/L)**	**Copper Bioaccessibility (%)**
EDM-01	1.0060	15.29	37.4	**24.3**
EDM-02	1.0052	22.24	47.4	**21.2**
EDM-03	1.0163	75.74	78.6	**10.2**
EDM-04	1.0073	48.92	211.6	**42.9**
EDM-05	1.0122	24.57	55.6	**22.4**
EDM-06	1.0188	14.37	13.1	**8.9**
EDM-07	1.0029	11.03	10.1	**9.1**
EDM-08	1.0124	93.86	300.6	**31.6**
EDM-09	1.0085	7.62	8.8	**11.5**
EDM-10	1.0364	21.63	28	**12.5**
EDM-11	1.0340	28.38	21.3	**7.3**
EDM-12	1.0266	21.73	16.5	**7.4**
EDM-13	1.0052	23.76	40.3	**16.9**
EDM-14	1.0076	14.82	8.9	**6.0**
EDM-15	1.0100	7.98	45.4	**56.3**
EDM-16	1.0041	19.46	15.6	**8.0**
EDM-17	1.0257	27.92	18.3	**6.4**
EDM-10 Dup	1.0208	21.63	11.7	**5.3**
EDM-16 Dup	1.0166	19.46	14.7	**7.4**

Iron Bioaccessibility

Sample ID	**Weight used for extraction (g)**	**Iron in soil (mg/kg)**	**Iron in extract (ug/L)**	**Iron Bioaccessibility (%)**
EDM-01	1.0060	12400	8110	**6.5**
EDM-02	1.0052	12600	3320	**2.6**
EDM-03	1.0163	11700	8420	**7.1**
EDM-04	1.0073	20800	16000	**7.6**
EDM-05	1.0122	11600	4020	**3.4**
EDM-06	1.0188	9400	4370	**4.6**
EDM-07	1.0029	8200	4000	**4.9**
EDM-08	1.0124	11800	2930	**2.5**
EDM-09	1.0085	9000	2940	**3.2**
EDM-10	1.0364	14100	5130	**3.5**
EDM-11	1.0340	16700	4640	**2.7**
EDM-12	1.0266	21300	11400	**5.2**
EDM-13	1.0052	20400	11400	**5.6**
EDM-14	1.0076	9300	2830	**3.0**
EDM-15	1.0100	12100	3190	**2.6**
EDM-16	1.0041	14100	4180	**3.0**

EDM-17	1.0257	19600	7530	**3.7**
EDM-10 Dup	1.0208	14100	5040	**3.5**
EDM-16 Dup	1.0166	14100	4030	**2.8**

Lead Bioaccessibility

Sample ID	Weight used for extraction (g)	Lead in soil (mg/kg)	Lead in extract (ug/L)	Lead Bioaccessibility (%)
EDM-01	1.0060	11.73	68.5	**58.0**
EDM-02	1.0052	11.43	56.9	**49.5**
EDM-03	1.0163	29.47	155	**51.8**
EDM-04	1.0073	23.56	151	**63.6**
EDM-05	1.0122	15.7	95.8	**60.3**
EDM-06	1.0188	17.69	119	**66.0**
EDM-07	1.0029	15.7	116	**73.7**
EDM-08	1.0124	13.82	76.1	**54.4**
EDM-09	1.0085	3.65	17.2	**46.7**
EDM-10	1.0364	23.17	141	**58.7**
EDM-11	1.0340	36.91	215	**56.3**
EDM-12	1.0266	37.03	176	**46.3**
EDM-13	1.0052	36.92	204	**55.0**
EDM-14	1.0076	15.76	120	**75.6**
EDM-15	1.0100	4.35	52.3	**119.0**
EDM-16	1.0041	8.75	37.2	**42.3**
EDM-17	1.0257	17.32	89.1	**50.2**
EDM-10 Dup	1.0208	23.17	147	**62.2**
EDM-16 Dup	1.0166	8.75	35.9	**40.4**

Manganese Bioaccessibility

Sample ID	Weight used for extraction (g)	Manganese in soil (mg/kg)	Manganese in extract (ug/L)	Manganese Bioaccessibility (%)
EDM-01	1.0060	334	2130	**63.4**
EDM-02	1.0052	413	1360	**32.8**
EDM-03	1.0163	331	1960	**58.3**
EDM-04	1.0073	487	3160	**64.4**
EDM-05	1.0122	332	1830	**54.5**
EDM-06	1.0188	325	1880	**56.8**
EDM-07	1.0029	282	1880	**66.5**
EDM-08	1.0124	456	3430	**74.3**
EDM-09	1.0085	255	1050	**40.8**
EDM-10	1.0364	403	2770	**66.3**
EDM-11	1.0340	475	2310	**47.0**

EDM-12	1.0266	517	1570	**29.6**
EDM-13	1.0052	537	1810	**33.5**
EDM-14	1.0076	219	895	**40.6**
EDM-15	1.0100	269	688	**25.3**
EDM-16	1.0041	333	1100	**32.9**
EDM-17	1.0257	402	2120	**51.4**
EDM-10 Dup	1.0208	403	2570	**62.5**
EDM-16 Dup	1.0166	333	1050	**31.0**

Nickel Bioaccessibility

Sample ID	Weight used for extraction (g)	Nickel in soil (mg/kg)	Nickel in extract (ug/L)	Nickel Bioaccessibility (%)
EDM-01	1.0060	16.2	61.9	**38.0**
EDM-02	1.0052	17	37.7	**22.1**
EDM-03	1.0163	19.9	75.4	**37.3**
EDM-04	1.0073	33.4	84.6	**25.1**
EDM-05	1.0122	14.9	43.3	**28.7**
EDM-06	1.0188	14.7	53.3	**35.6**
EDM-07	1.0029	12.2	55.6	**45.4**
EDM-08	1.0124	20.8	66.2	**31.4**
EDM-09	1.0085	9.4	17.1	**18.0**
EDM-10	1.0364	19.4	72.6	**36.1**
EDM-11	1.0340	25.8	85.1	**31.9**
EDM-12	1.0266	21.4	71.5	**32.5**
EDM-13	1.0052	21.7	74.4	**34.1**
EDM-14	1.0076	11.7	44.3	**37.6**
EDM-15	1.0100	11.4	22.9	**19.9**
EDM-16	1.0041	18.3	39.8	**21.7**
EDM-17	1.0257	25.6	82.3	**31.3**
EDM-10 Dup	1.0208	19.4	69.8	**35.2**
EDM-16 Dup	1.0166	18.3	40.2	**21.6**

Zinc Bioaccessibility

Sample ID	Weight used for extraction (g)	Zinc in soil (mg/kg)	Zinc in extract (mg/L)	Zinc Bioaccessibility (%)
EDM-01	1.0060	55.3	227	**40.8**
EDM-02	1.0052	82.5	468	**56.4**
EDM-03	1.0163	178.6	1230	**67.8**
EDM-04	1.0073	169.4	1250	**73.3**
EDM-05	1.0122	84.8	623	**72.6**
EDM-06	1.0188	170.1	1380	**79.6**
EDM-07	1.0029	135.8	1310	**96.2**
EDM-08	1.0124	236.5	2020	**84.4**
EDM-09	1.0085	28.6	74	**25.7**
EDM-10	1.0364	74.8	309	**39.9**
EDM-11	1.0340	111.4	435	**37.8**
EDM-12	1.0266	88.5	321	**35.3**
EDM-13	1.0052	95.4	387	**40.4**
EDM-14	1.0076	57.5	302	**52.1**
EDM-15	1.0100	29.8	152	**50.5**
EDM-16	1.0041	45.7	106	**23.1**

EDM-17	1.0257	88.5	191	**21.0**
EDM-10 Dup	1.0208	74.8	287	**37.6**
EDM-16 Dup	1.0166	45.7	109	**23.5**

Appendix VII: QA/QC Data

VII-1: Metal Concentrations and Control Limits for Blank and Control Sample NIST 2710

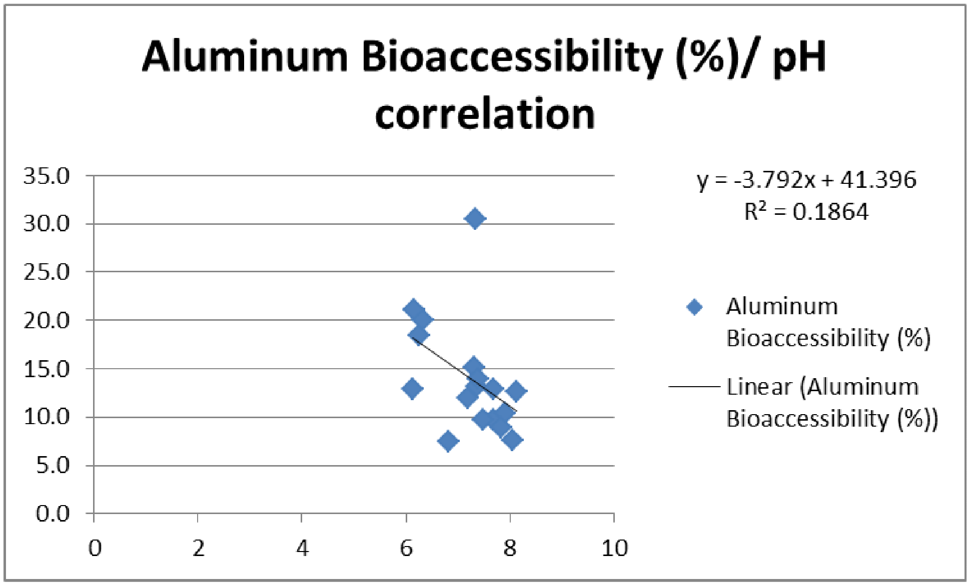
	Concentration in Extracts (µg/L)			
Total Metals	BL13-15	Control Limits	SR13-15	Control Limits
Aluminum (Al)	148		16100	
Antimony (Sb)	<2.0		17.6	
Arsenic (As)	<1.6	<10	579	590 ±90
Barium (Ba)	<4.0		1340	
Cadmium (Cd)	<0.40		385	
Chromium (Cr)	<8.0		9.1	
Cobalt (Co)	<2.0		35.1	
Copper (Cu)	49.4		539	
Iron (Fe)	<80		8450	
Lead (Pb)	1.10	<50	10500	9220 ±1490
Manganese (Mn)	4.5		3470	
Nickel (Ni)	<4.0		42.2	
Selenium (Se)	<3.2		<3.2	
Zinc (Zn)	<40		1170	

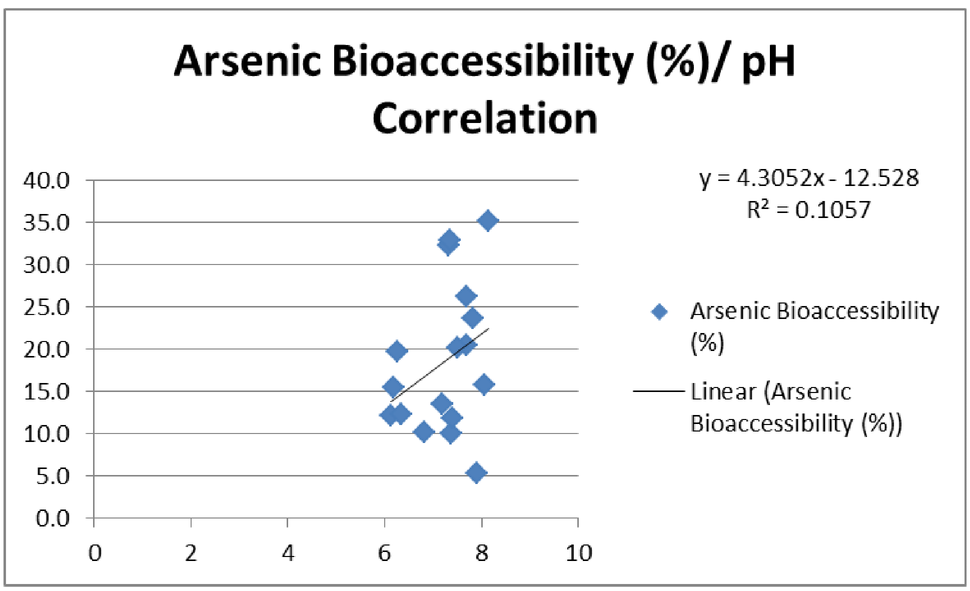
VII-2: Mean and Relative Percent Difference (RPD) for Metal Bioaccessibility in Duplicate Samples

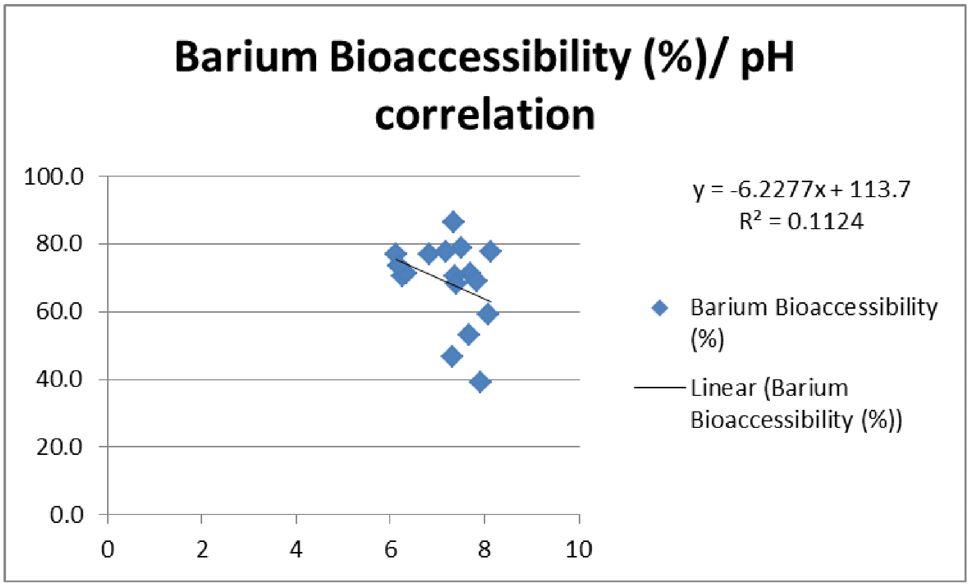
	Metal Bioaccessibility (%)							
	EDM-10	EDM10 Duplicate	Mean	RPD*	EDM-16	EDM-16 Duplicate	Mean	RPD*
As	20.2	20.9	20.5	3.6	26.3	24.9	25.6	5.5
Ba	78.9	81.7	80.3	3.5	53.2	50.2	51.7	5.9
Cd	99.4	93.9	96.7	5.7	80.6	65.1	72.9	21.3
Co	41.1	38.9	40.0	5.6	21.1	19.4	20.2	8.5
Cu	34.3	26.7	30.5	24.9	33.3	32.4	32.9	2.7
Fe	3.5	3.5	3.5	0.3	3.0	2.8	2.9	4.9
Pb	58.7	62.2	60.4	5.7	42.3	40.4	41.3	4.8
Mn	66.3	62.5	64.4	6.0	32.9	31.0	32.0	5.9
Ni	36.1	35.2	35.7	2.4	21.7	21.6	21.6	0.2
Zi	39.9	37.6	38.7	5.9	23.1	23.5	23.3	1.6

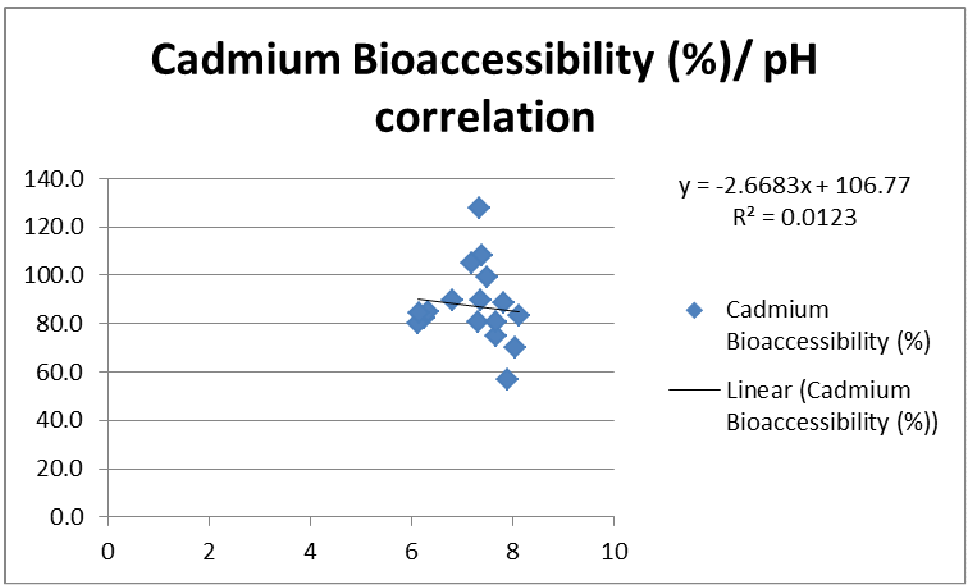
Appendix VIII: Linear Regression Plots for Relation between Metal Bioaccessibility, pH and Loss on Ignition (LOI)

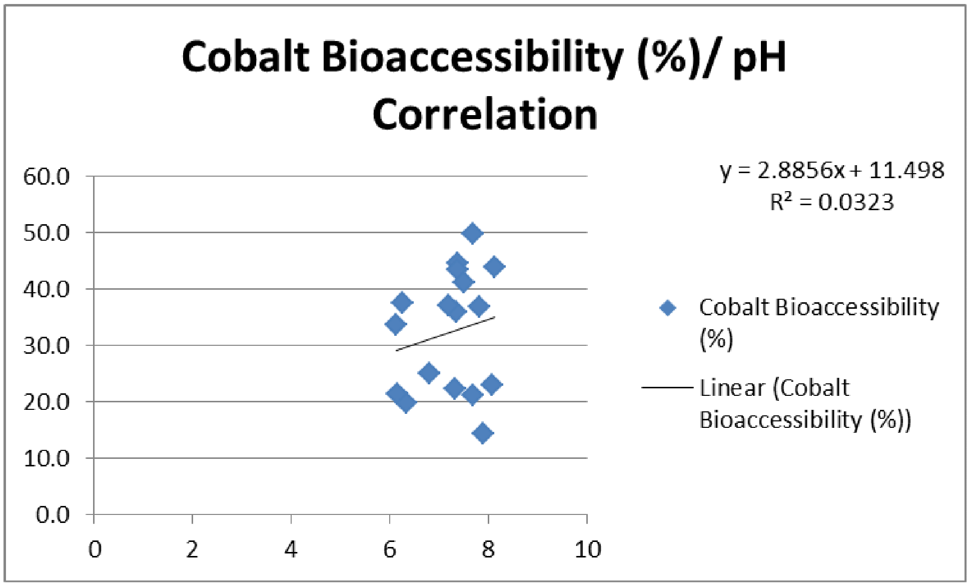
VIII-1: Linear Regression Curves for Metals bioaccessibility and pH

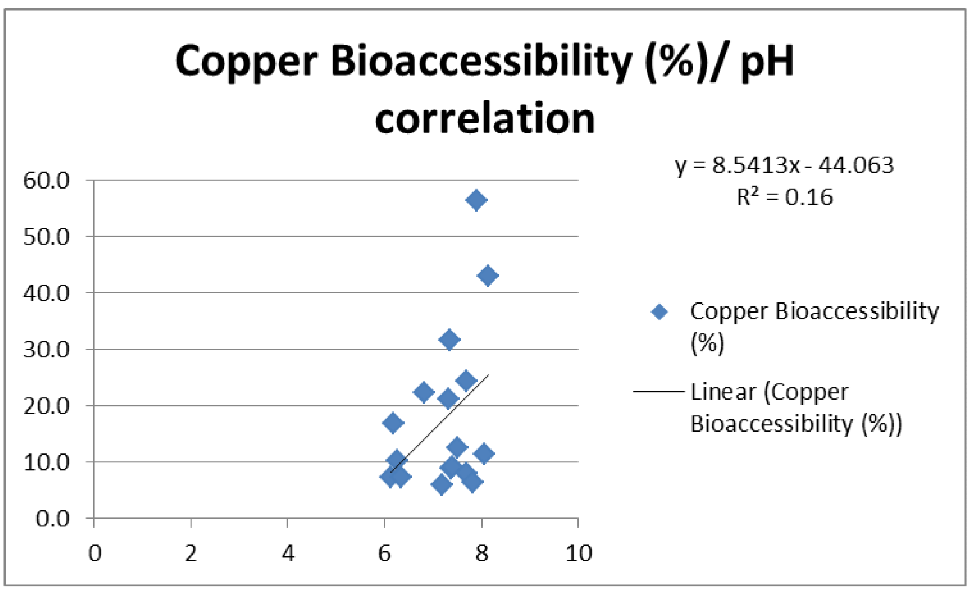


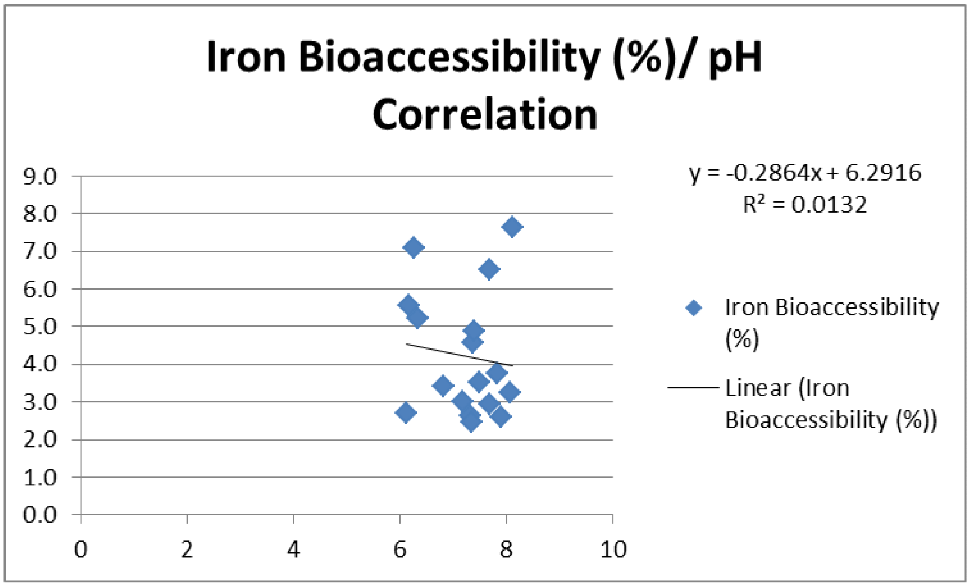


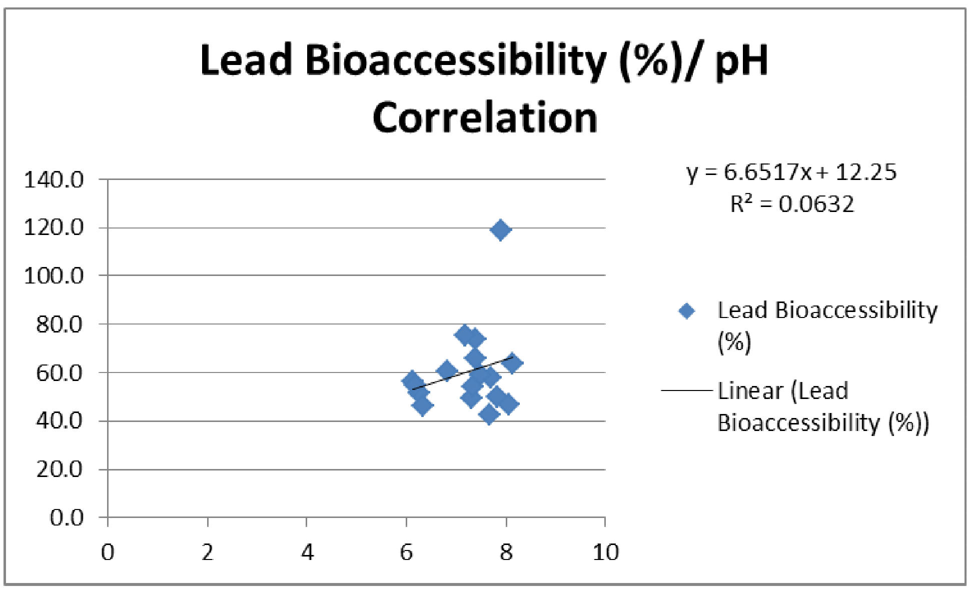

Barium Bioaccessibility (%)/ pH correlation
100.0
80.0
60.0
40.0
20.0
0.0
0
2
4
6
8
10
y = -6.2277x + 113.7
R² = 0.1124
Barium Bioaccessibility (%)
Linear (Barium Bioaccessibility (%))

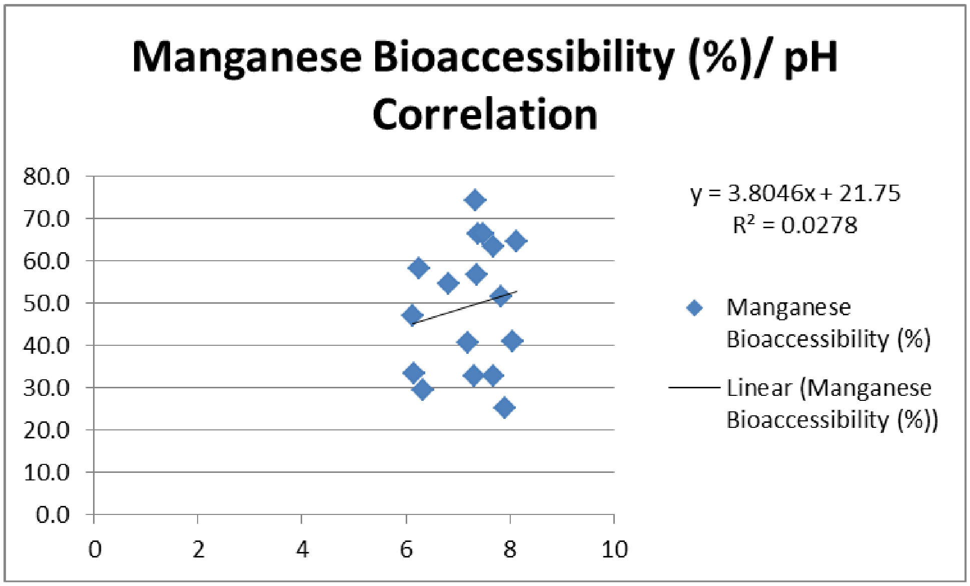

Cadmium Bioaccessibility (%)/ pH correlation
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
2
4
6
8
10
y = -2.6683x + 106.77
R² = 0.0123
Cadmium Bioaccessibility (%)
Linear (Cadmium Bioaccessibility (%))

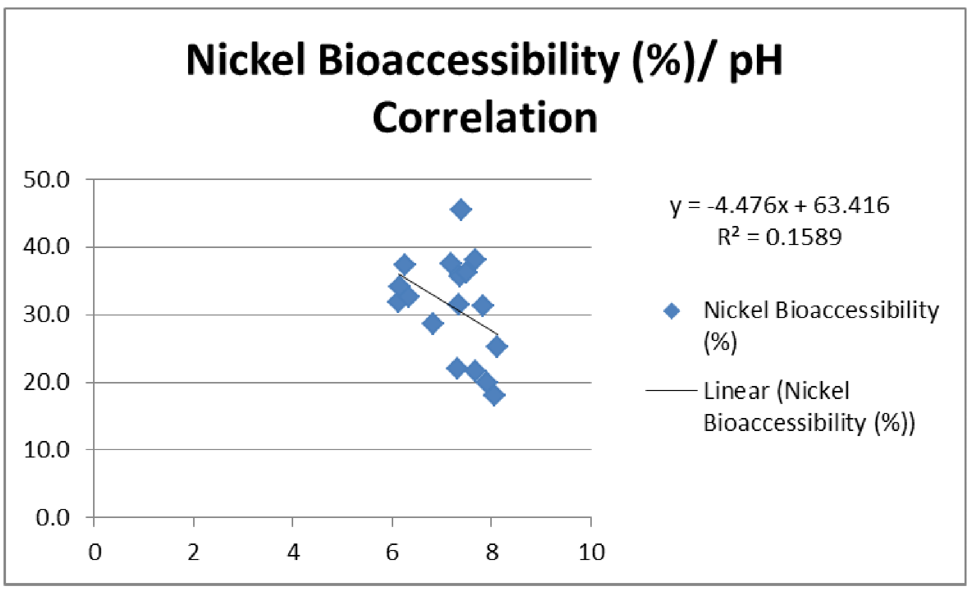

Cobalt Bioaccessibility (%)/ pH Correlation
y = 2.8856x + 11.498
R² = 0.0323
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
2
4
6
8
10
Cobalt Bioaccessibility (%)
Linear (Cobalt Bioaccessibility (%))

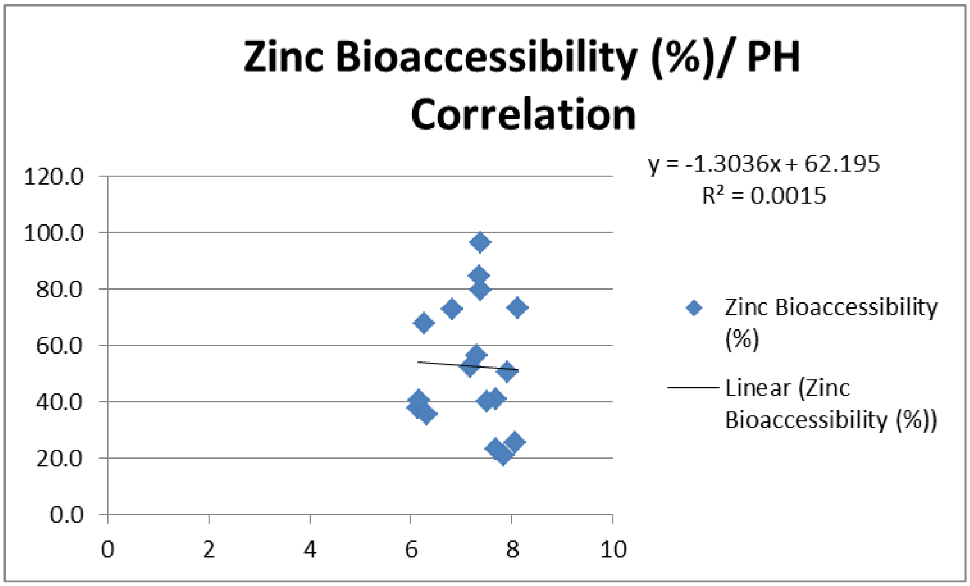

Copper Bioaccessibility (%)/ pH correlation
y = 8.5413x - 44.063
R² = 0.16
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
2
4
6
8
10
Copper Bioaccessibility (%)
Linear (Copper Bioaccessibility (%))


Iron Bioaccessibility (%)/ pH Correlation
y = -0.2864x + 6.2916
R² = 0.0132
Iron Bioaccessibility (%)
Linear (Iron Bioaccessibility (%))
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
2
4
6
8
10

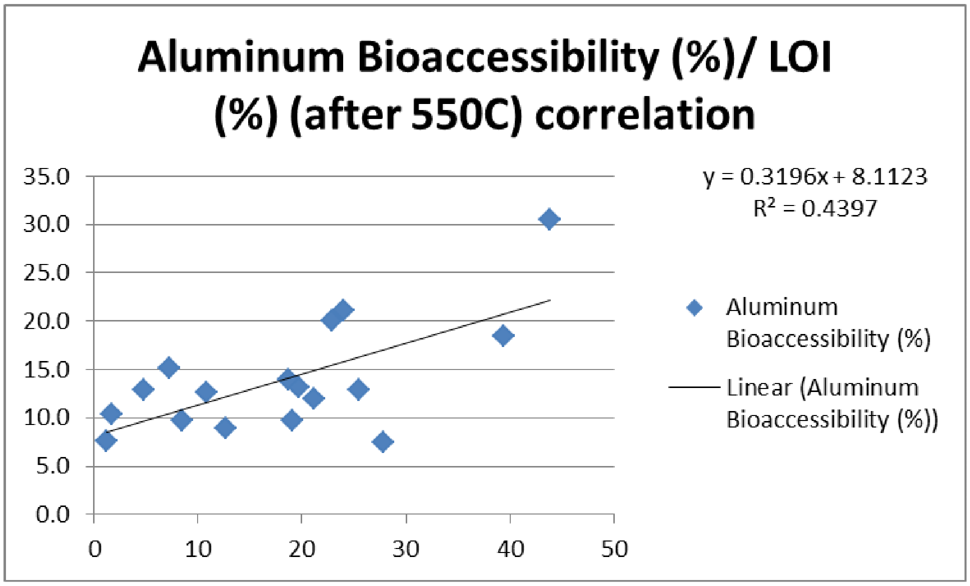

Lead Bioaccessibility (%)/ pH Correlation
y = 6.6517x + 12.25
R² = 0.0632
Lead Bioaccessibility (%)
Linear (Lead Bioaccessibility (%))
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
2
4
6
8
10

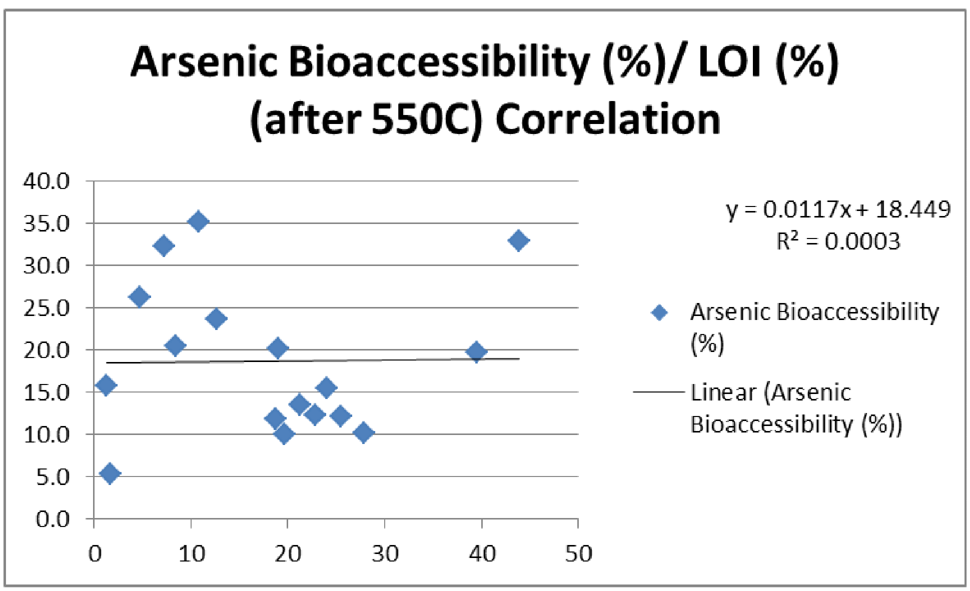

Manganese Bioaccessibility (%)/ pH Correlation
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
2
4
6
8
10
y = 3.8046x + 21.75
R² = 0.0278
Manganese Bioaccessibility (%)
Linear (Manganese Bioaccessibility (%))

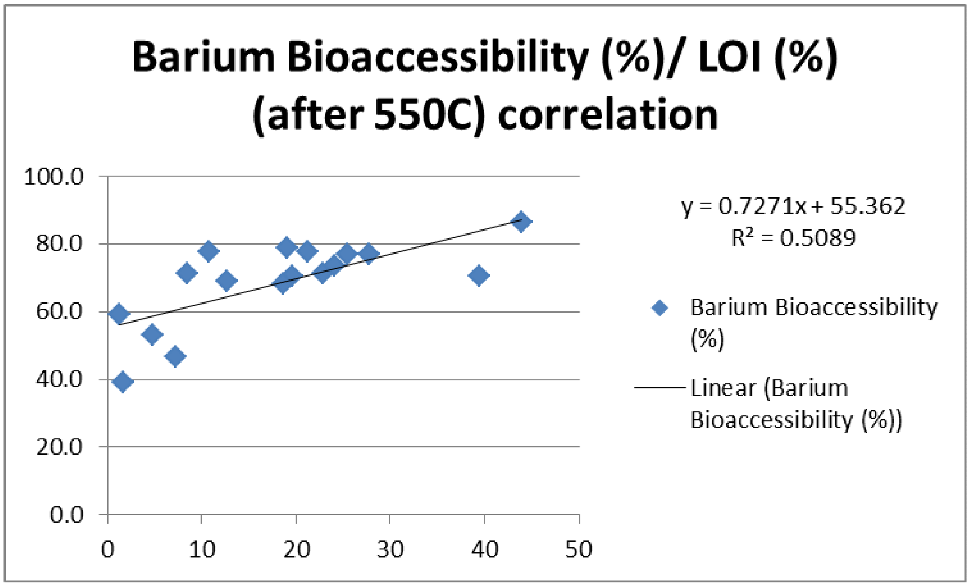

Nickel Bioaccessibility (%)/ pH Correlation
50.0
40.0
30.0
20.0
10.0
0.0
0
2
4
6
8
10
y = -4.476x + 63.416
R² = 0.1589
Nickel Bioaccessibility (%)
Linear (Nickel Bioaccessibility (%))

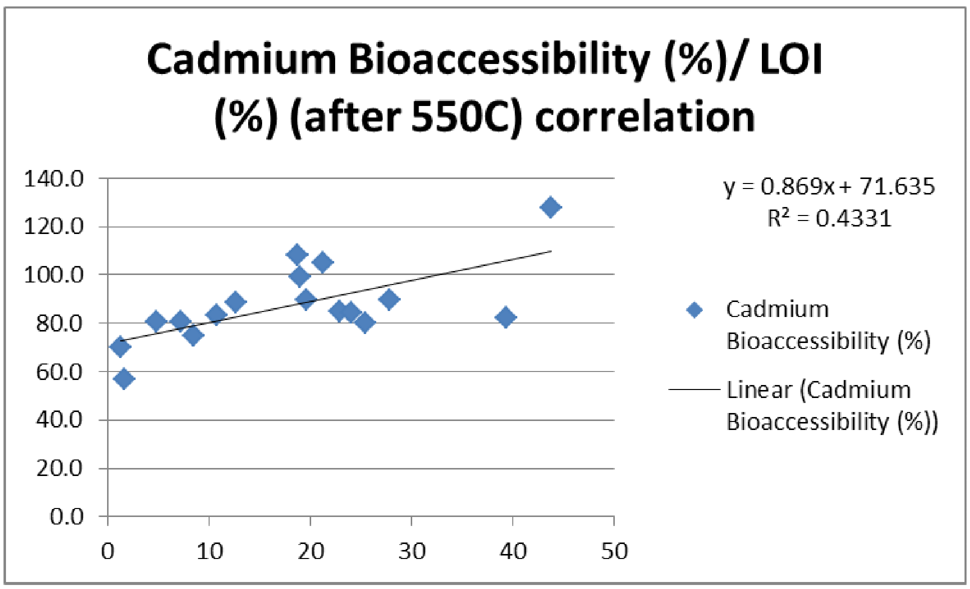

Zinc Bioaccessibility (%)/ PH Correlation
y = -1.3036x + 62.195
R² = 0.0015
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
2
4
6
8
10
Zinc Bioaccessibility (%)
Linear (Zinc Bioaccessibility (%))

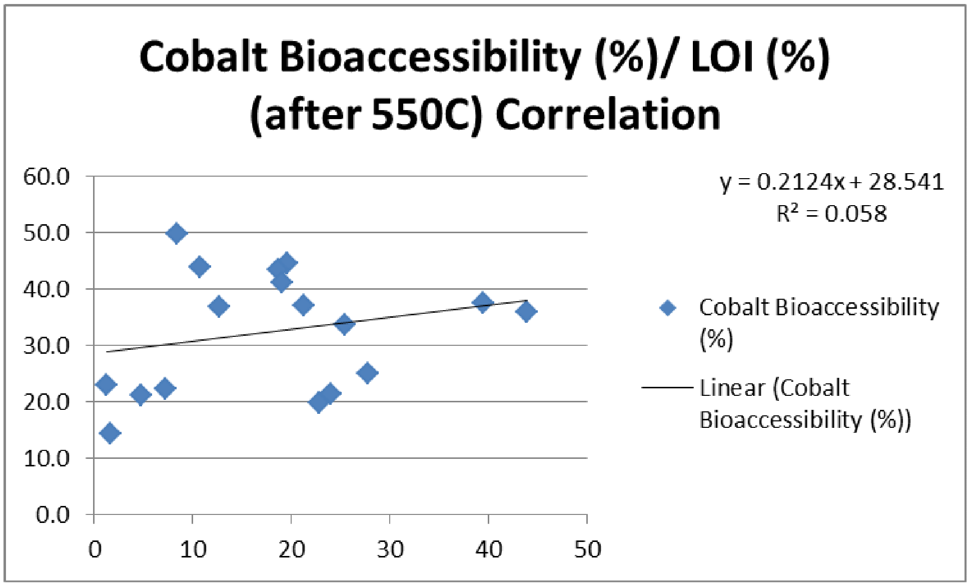
VIII-2: Linear Regression Curves for Metals bioaccessibility and LOI (after 550C) Correlation

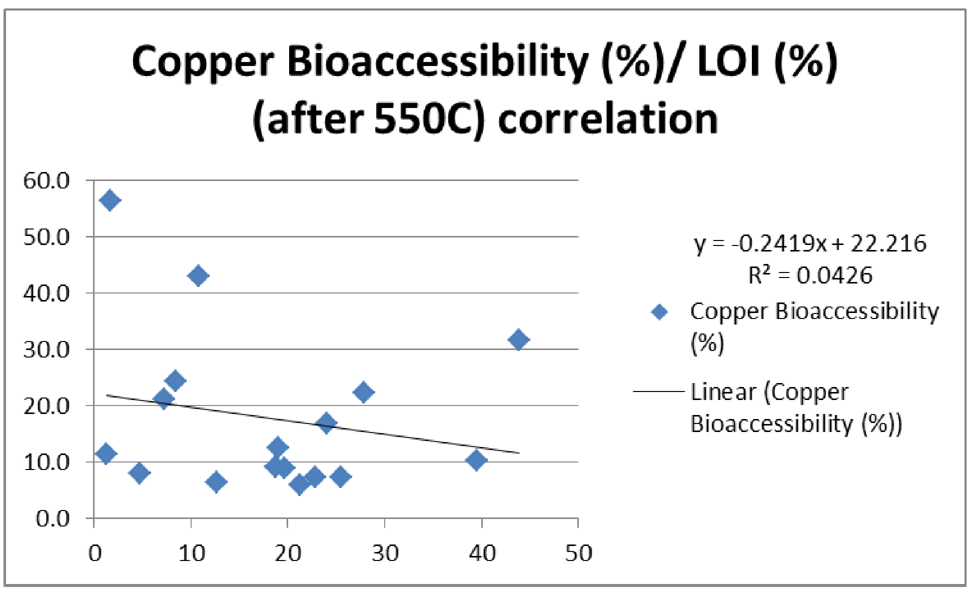


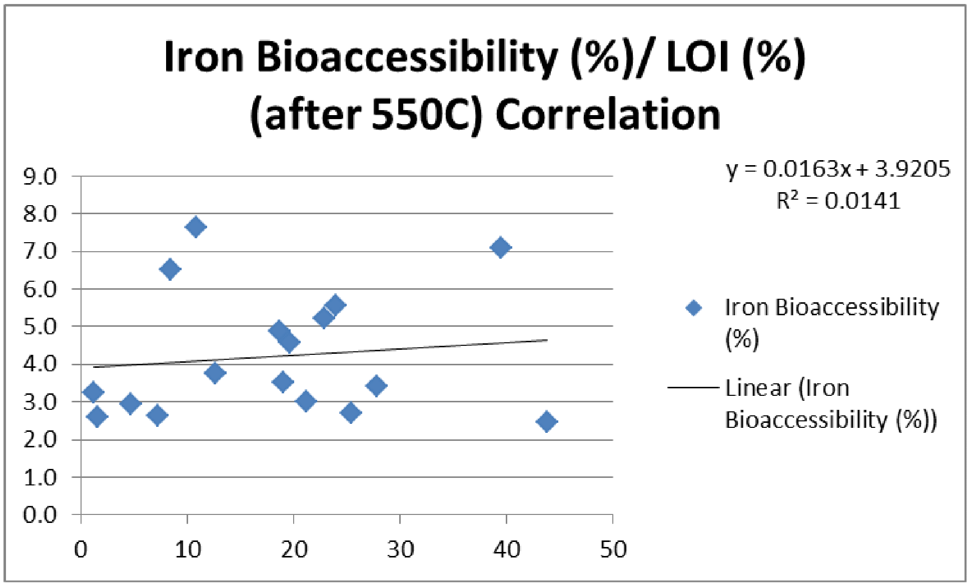


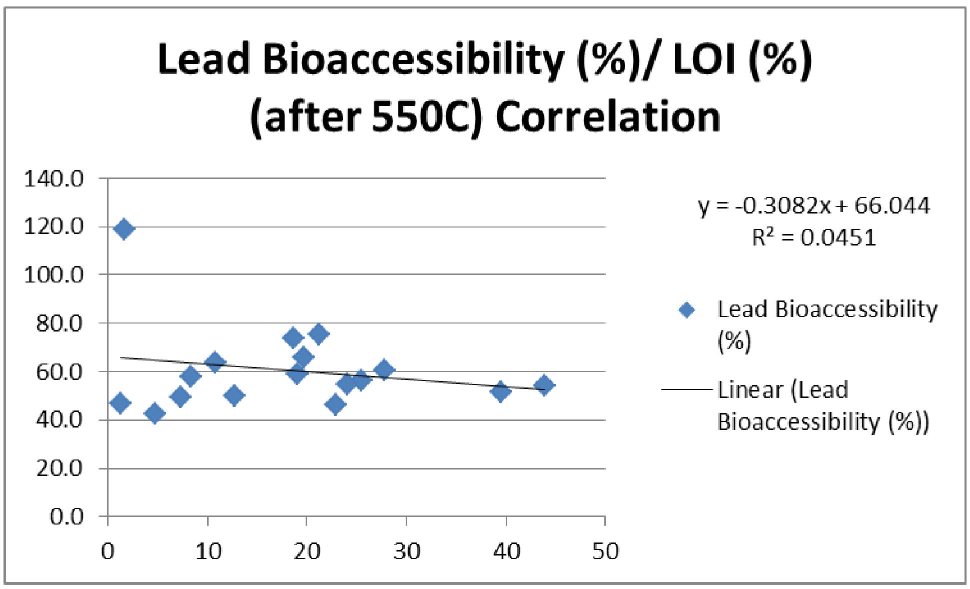

Barium Bioaccessibility (%)/ LOI (%) (after 550C) correlation
100.0
80.0
60.0
40.0
20.0
0.0
0
10
20
30
40
50
y = 0.7271x + 55.362
R² = 0.5089
Barium Bioaccessibility (%)
Linear (Barium Bioaccessibility (%))

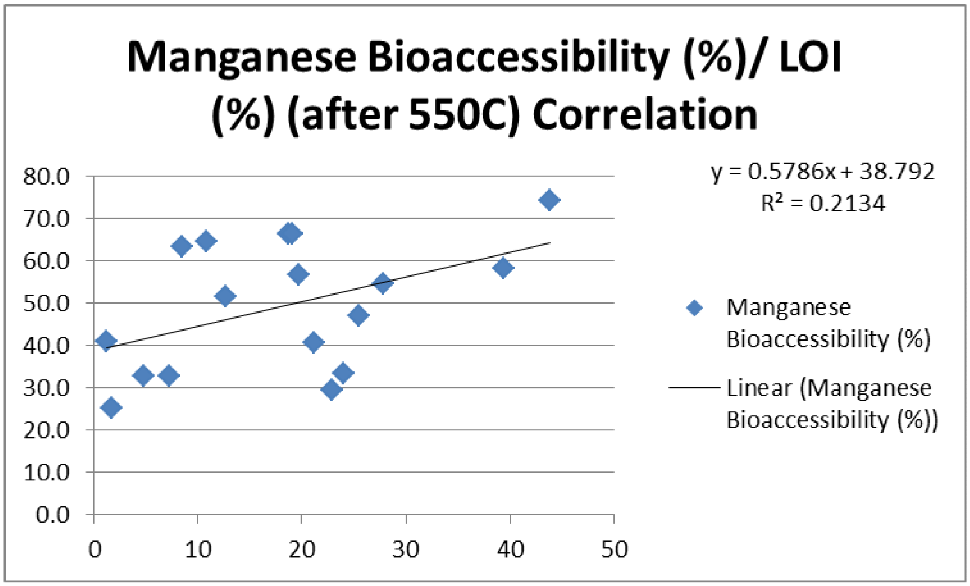

Cadmium Bioaccessibility (%)/ LOI (%) (after 550C) correlation
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
10
20
30
40
50
y = 0.869x + 71.635
R² = 0.4331
Cadmium Bioaccessibility (%)
Linear (Cadmium Bioaccessibility (%))

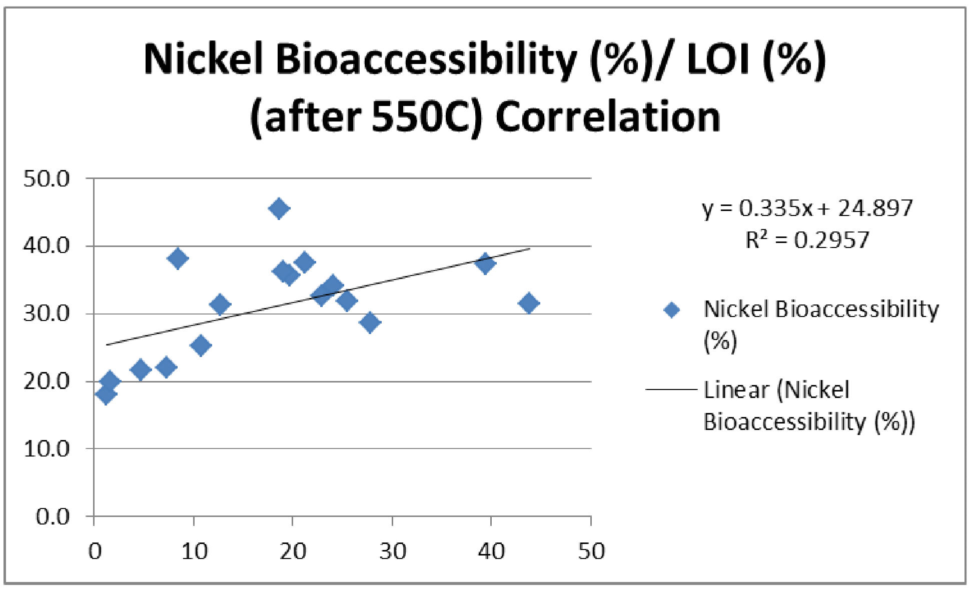

Cobalt Bioaccessibility (%)/ LOI (%) (after 550C) Correlation
y = 0.2124x + 28.541
R² = 0.058
Cobalt Bioaccessibility (%)
Linear (Cobalt Bioaccessibility (%))
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50

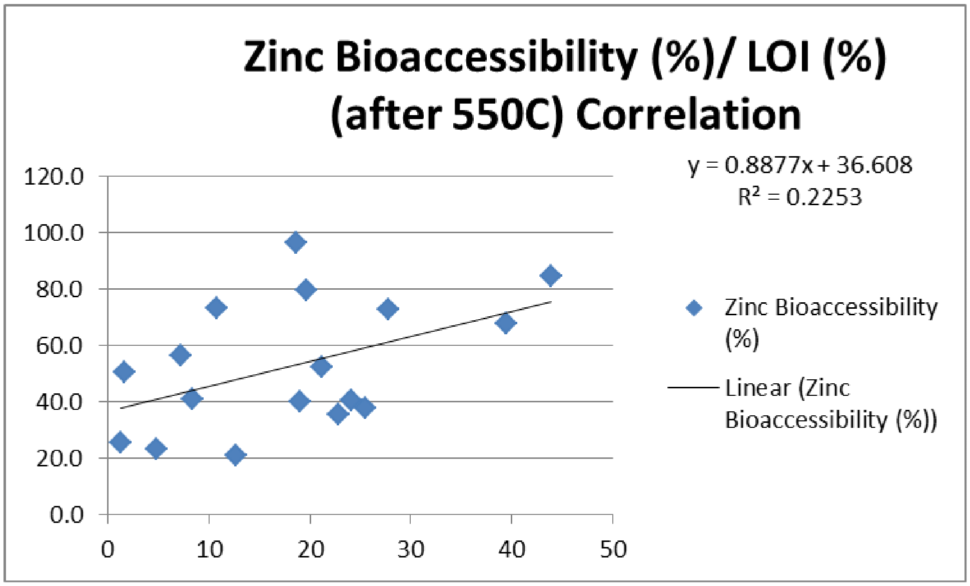

Copper Bioaccessibility (%)/ LOI (%) (after 550C) correlation
y = -0.2419x + 22.216
R² = 0.0426
Copper Bioaccessibility (%)
Linear (Copper Bioaccessibility (%))
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50


Iron Bioaccessibility (%)/ LOI (%) (after 550C) Correlation
y = 0.0163x + 3.9205
R² = 0.0141
Iron Bioaccessibility (%)
Linear (Iron Bioaccessibility (%))
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
10
20
30
40
50


Lead Bioaccessibility (%)/ LOI (%) (after 550C) Correlation
y = -0.3082x + 66.044
R² = 0.0451
Lead Bioaccessibility (%)
Linear (Lead Bioaccessibility (%))
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
10
20
30
40
50


Manganese Bioaccessibility (%)/ LOI (%) (after 550C) Correlation
y = 0.5786x + 38.792
R² = 0.2134
Manganese Bioaccessibility (%)
Linear (Manganese Bioaccessibility (%))
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50


Nickel Bioaccessibility (%)/ LOI (%) (after 550C) Correlation
y = 0.335x + 24.897
R² = 0.2957
Nickel Bioaccessibility (%)
Linear (Nickel Bioaccessibility (%))
50.0
40.0
30.0
20.0
10.0
0.0
0
10
20
30
40
50


Zinc Bioaccessibility (%)/ LOI (%) (after 550C) Correlation
y = 0.8877x + 36.608
R² = 0.2253
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
10
20
30
40
50
Zinc Bioaccessibility (%)
Linear (Zinc Bioaccessibility (%))