BIOACCESSIBILITY OF METALS IN TORONTO CITY PARKS

By

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We accept this thesis as conforming to the required standard

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Abstract

The purpose of this work was to estimate metals bioaccessibility in soil samples from 15 city parks in Toronto, Ontario, Canada. Total metals concentrations were analyzed to identify contaminants that exceeded the Canadian Council of Ministers of the Environment (CCME) guidelines for residential/parkland use. Arsenic, barium, cadmium, cobalt, copper, lead, nickel and zinc were of particular interest as they have been known to have major effects on human health. Metal concentrations were below the CCME guidelines except for lead at three of the parks. Lead, copper and cadmium bioaccessibility in the soil samples as determined by an in-vitro physiologically based extraction test (PBET) were relatively high. Based on linear regression analyses there were no significant relationships between total metals and soil properties such as pH and total organic carbon (TOC). Generally there was negative correlation between metal bioaccessibility and TOC and positive correlation between bioaccessibility and soil pH.

Table of Contents

List of Figures

List of Tables

List of Appendices

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1 Introduction

The world's population is increasingly becoming urbanized. According to the United Nations World Urbanization Prospect Revision 2009, 80 % of Canadians live in urban areas and this figure will increase to 88 % by the year 2050 (United Nations [U.N.], 2009). With increased urbanization, comes a need for recreational spaces within city limits but consequently a variety of environmental problems including toxic metals pollution has emerged. These could be as a result of increased vehicle use around these spaces, disposal of household and industrial solid waste e.tc. It is therefore, necessary to understand the risks associated with potential contaminants in urban green spaces.

Toronto is the largest city in Canada with a population of 2.7 million and the capital of Ontario with close to 8,000 hectares of public parklands representing 1,500 parks (Patterson, 2010). These parks are located in various areas of the city including several in downtown. Because of their proximity to high volumes of traffic and other human activities, studies have shown that urban parks can be a source of contamination to users especially children who are estimated to ingest between 39-270 mg of soil per day (Ljuan, Oomen, Duits, Selinus, & Berglund, 2007) depending on their behaviour.

Studies of the geochemistry of urban soils have been carried out in a few major cities, for example Stockholm, Sweden (Linde, 2005); Havana city, Cuba (Rizo Castillo, López, & Merlo, 2011); and Montreal, Canada (Marr & Fyles, 1999). These studies showed higher levels of some metals depending on the jurisdiction. City parks studied in Beijing, China (Chen, Zheng, Lei, Huang, Wu, Chen, Fan et al., 2005) and in the European cities Seville and Torino (Madrid, Biasioli, & Ajmone-Marsan, 2002) also indicated higher levels of lead (Pb), copper (Cu) and zinc (Zn) which were attributed to anthropogenic sources. Toronto is a major metropolitan city that is likely to be in similar geochemical status but studies are yet to be conducted as such, this study was initiated in an attempt to fill this knowledge gap.

The principal objective for this study was to develop an understanding of the state of a few Toronto city parks by providing an indication of total metals concentrations and their bioaccessibility and not a complete assessment of the parks. To achieve this objective, total metals concentration in the soil samples were determined by inductively couple plasma spectroscopy. This was followed by the use of an in vitro extraction procedure based on United States Environmental Protection Agency (USEPA) methodology (USEPA, 2007a; 2012) to estimate the bioaccessibility of selected metals (As, Ba, Cd, Co, Cu, Pb, Ni and Zn) which form the bulk of regulated metals in the Canadian Council of Ministers of the Environment (CCME) environmental quality guidelines for residential/parkland (R/P) land use. The study also determined if soil pH and total organic carbon had influence on metal bioaccessibility.

2 Literature Review

2.1 Sources of Metals Input to Soils

Metals can accumulate in soils naturally due to weathering of rock minerals or through anthropogenic sources. The impact of anthropogenic activities on metal contamination in soil has been shown in several surveys (Meuser, 2010; Wong & Thornton, 2006). For example, proximity to industrial activities such as factories, scrap metal yards, wastelands and repair garages was found to increase the level of Pb in adjacent garden soils and house dusts (Thums, Farago & Thornton, 2008).

2.1.1 Mineral Weathering

Mineral weathering of rocks is the primary source of naturally occurring background metals in soils. The mobility and availability of these metals are then dependent on a variety of chemical reactions, the binding mechanisms for metal elements, and forms of their occurrence in soils (Kabata-Pendias, & Mukherjee, 2007). For example sorption is influenced by the species' charge (i.e., cation, anion or neutral). Because most soils are negatively charged (USEPA, 2007b) there is a greater chance for cations to be sorbed than the anions. Soil pH is also important in that hydrogen ion competes with metal cations for adsorption sites, such that adsorption of metal cations is low in acid systems but increases with increasing pH and thus metal containing minerals are more soluble in acidic conditions (USEPA, 2007b).

2.1.2 Anthropogenic Sources

Human activities play a great role in the introduction of metals into the environment and Ross (1994) reported five categories of these anthropogenic sources:

1. Metalliferous mining and smelting (e.g., As, Cd, Hg, Ni, Pb, Zn)
2. Industry (e.g., Co, Cr, Cd, Hg)
3. Atmospheric deposition (e.g., As, Cd, Cu, Sn, Hg, V, Pb)
4. Agriculture (e.g., As, Cd, Mn, Pb, Mo, Fe)
5. Waste disposal on land (e.g., Cd, Cr, Cu, Hg, Mn, Pb, Zn)

Although parks are presently excluded from the aforementioned activities, metal mobility and consequent contamination of parks is aided by aerial deposition of dust and vehicle emissions as well as acid rain which decreases pH and metal dissolution. However, parks that are located on or close to previous industrial sites may have residual contamination due to the persistence of metals in soils. One such example is Cherry Beach Park which is located on Toronto's Port Land industrial area which was developed by landfilling a marsh (Boyle, 1989).

Once soils are contaminated through a variety of sources, the metal pollution becomes a long term issue. Bowen (1979) estimated the residence time of Cd in soil to be 75-380 years and As, Cu, Ni, Pb, Se and Zn to be in the range of 1000-3000 years (as cited in Alloway, 1995).

2.2 Effects of Metals to Humans and the Environment

The exposure to metals in urban soils can occur through three main pathways (a) direct oral ingestion (b) inhalation of suspended particles emitted from soil and (c) dermal absorption of heavy metals in particles adhered to skin (Luo, Ding, Xu, Wang, Li, & Yu, 2012).

The adverse effects of metals on human health especially children has been widely explored. For example, beryllium can cause dermatologic, respiratory, and malignant diseases (Mamtani, Stern, Dawood & Cheema, 2011). Also, Lidsky and Schneider (2005) suggested a link between autisms and lead poisoning in children. Similarly, Thums, Farago & Thornton (2008) reported that Precoproporphyrin, a specific indicator of heavy-metal toxicity, was elevated in autistic disorders. Excess of manganese has been linked to effects on adult brain and reduction in intellectual function in children (Wasserman et al., Joseph, 2006). In another study, Canfield, Henderson, Cory-Slechta, Cox, Jusko & Lanphear (2003) demonstrated that in children, IQ was inversely and significantly associated with blood lead concentrations.

The effects of these metals to human health are as results of the inability of the body to metabolize them leading to bioaccumulation and subsequent impacts. Metals can undergo speciation changes through various processes including oxidation/reduction resulting in species with different toxicities (e.g., oxidation of chromium III compounds which are non-carcinogenic to chromium VI compounds which are carcinogenic (Wardenbach, 2006)). A summary of metals and their target organs are listed in Table 1. These studies are indicative of the potential hazards of metal contaminants in soils to human health and require appropriate testing to assess their bioaccessibility once ingested

Table 1 *Target organs of a few metals, adapted from Wardenbach (2006)*

Target Organ	Metals										
	As	Be	Pb	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni
Liver	x									x	
Respiratory tract	x	x		x	x	x					x
Blood	x		x				x				
Nerves			x					x	x		
Kidney	x		x	x				x		x	
Skin	x	x				x					x
Reproduction			x								
Heart					x						

2.3 Metal Bioaccessibility and Bioavailability in Relation to Human Health

Increasing studies have shown that not all ingested metal concentrations are available for uptake (Luo, Yu, & Li, 2012). Hence, there is a greater emphasis in trying to find the concentrations that are actually available for uptake. Bioavailability is defined by Ruby et al. (1999) as the "fraction of an administered dose that reaches the central (blood) compartment from the gastrointestinal tract" and the uptake into the circulation system from ingested soil is determined by the interactions of physical, chemical and/or biological processes (Richardson, Bright & Dodd, 2006). Bioaccessibility is a closely related term which refers to the fraction of contaminant that is dissolved in the digestive fluids and assumed to be available for absorption and bioavailable (Ruby et al., 1999).

Metal bioavailability can be determined by in vivo laboratory assays using animals such as rabbits, rats or swine. The animals are dosed with the contaminated substrate following which body tissue samples are analysed to determine absorption (Ruby, Davis, Link, Schoof, Chancy, Freeman, & Bergstromo, 1993). Due to the cost, ethical issues and time constraints involved in in vivo testing, in vitro digestion model have been developed using simulated human stomach and intestinal tract fluids (Ruby, Davis, Schoof, Eberle & Sellstone, 1996; USEPA, 2007a). In these models commonly referred to as physiologically based extraction tests (PBET), soil samples are subjected to extraction at controlled temperature and pH, with the addition of enzymes and organic acids at different stages to simulate residence in gastric and small intestines. The fraction of a metal that dissolves during the stomach and small-intestinal incubations represents the fraction that is bioaccessible (i.e., available for absorption) (USEPA, 2007a). If a correlation between in vitro bioaccessibility and in vivo bioavailability results can be demonstrated, then in vitro results can be used as a reasonable surrogate for bioavailability. Various models that correlate in vitro bioaccessibility extraction data with bioavailability data from animal testing have been developed for lead (Drexler and Brattin 2007; Ruby et al. 1999; USEPA 2007a). The USEPA protocol was used to determine metal bioaccessibility in this study (USEPA, 2007a; 2012), For the purposes of determining human health risks, bioaccessibility and bioavailability data is a more precise alternative to default characterization of risks based on total metal concentrations in soils particularly for site specific assessments. These may reduce clean-up targets and associated costs, and put to use lands that would otherwise be considered contaminated.

The use of bioaccessibility data to assess human health risks is becoming common among government agencies such as Health Canada which is engaged in its own research and has provided funding to other scientists with regards to bioavailability of contaminants (Health Canada, 2005).

2.4 Effect of Soil Properties on Metal bioaccessibility and Bioavailability

Properties of soil such as organic carbon, pH and mineral constituents have influence on the bioavailability of contaminants bound to the soil (Cave, Wragg, Denys, Jondreville, & Feidt, (2011). Of these properties, pH is the most important in controlling ions in the soil (Selinus & Alloway, 2005). Soil pH has been demonstrated to increase the bioavailability of anions and vice versa. For example Bradham, Dayton, Basta, Schroder, Payton, & Lanno, (2006) demonstrated the existence of a negative correlation between mortality and pH for earthworms exposed to lead indicating Pb was more bioavailable in acidic conditions. In another study, Tang, Zhu, Shan, McLaren & Duan, (2007) demonstrated that bioaccessibility of arsenic increased with pH. Soil pH also affects the solubility of organic carbon which in turn affects bioavailability (Cave et al, 2011).

The contributions of organic carbon in controlling bioaccessibility of contaminants in soil have been described by Selinus et al, 2005 and can be summarized as follows:

- Influence the adsorption of cations to negatively charged sites.
- Affect the mobility and protection of some metal ions from adsorption through the formation of soluble complexes.
- In the retention of many elements in the higher molecular weight, solid forms of humus by chelation.

2.5 Metals in the Urban Environment

Numerous studies have been conducted to assess metals in urban parks and play grounds (Ljung et al., 2007; Chen et al., 2005; Madrid et al., 2007; Madrid, Díaz-Barrientos & Madrid, 2002). The approach taken by these researchers differ largely by the way they conducted the assessment in that some were based on soil samples analyzed for total metals as is the case with Chen et al. (2002) and Madrid et al. (2002). Others such as Madrid et al. (2008) and Ljung et al. (2007) used bioavailability studies to estimate risks to human and environmental health. Considering the ambiguity of using measurements of total metal content alone to assess human health risks, recent studies appear to trend towards using bioaccessibility and bioavailability studies and is the method of choice in this project.

Ljung et al, (2007) assessed bioaccessibility of metals in 25 urban playgrounds and parks including those with close proximity to major roads and others in natural lands without visible human activity in Uppsala, Sweden frequented by school children. However, the results were not compared to specific regulatory guidelines to determine if there were any exceedances. The samples were collected from 1-10 cm depths and extracted using in vitro digestion. The extracts were then analysed for As, Cd, Cr, Ni, Pb and Zn using ICP-OAS. Their study also investigated effect of particle size, mass and pH on bioaccessibility. The study found bioaccessibility had no direct correlation with particle size, amount of soil ingested or the metal type. The results also found bioaccessibility was influenced by pH in that increased pH decreased the mobility of cations and conversely for anions.

In another study by Luo et al. (2012) 40 urban park samples in Xiamen Island in China (a city comparable to Toronto, Canada in population) were collected and analysed for both total metals and bioaccessibility. Based on totals metals, the results for some sites posed health risk (Luo et al., 2012) but were within guidelines even when compared to the Canadian environmental quality guidelines such as the CCME residential/parkland standards and bioaccessibility was even lower.

3 Methodology

3.1 Sampling Locations

Fifteen city parks were selected within the boundaries of the city of Toronto with a geographical distribution across the city. Sampling locations are shown in Figure 1 and coordinates are provided in Appendix A.

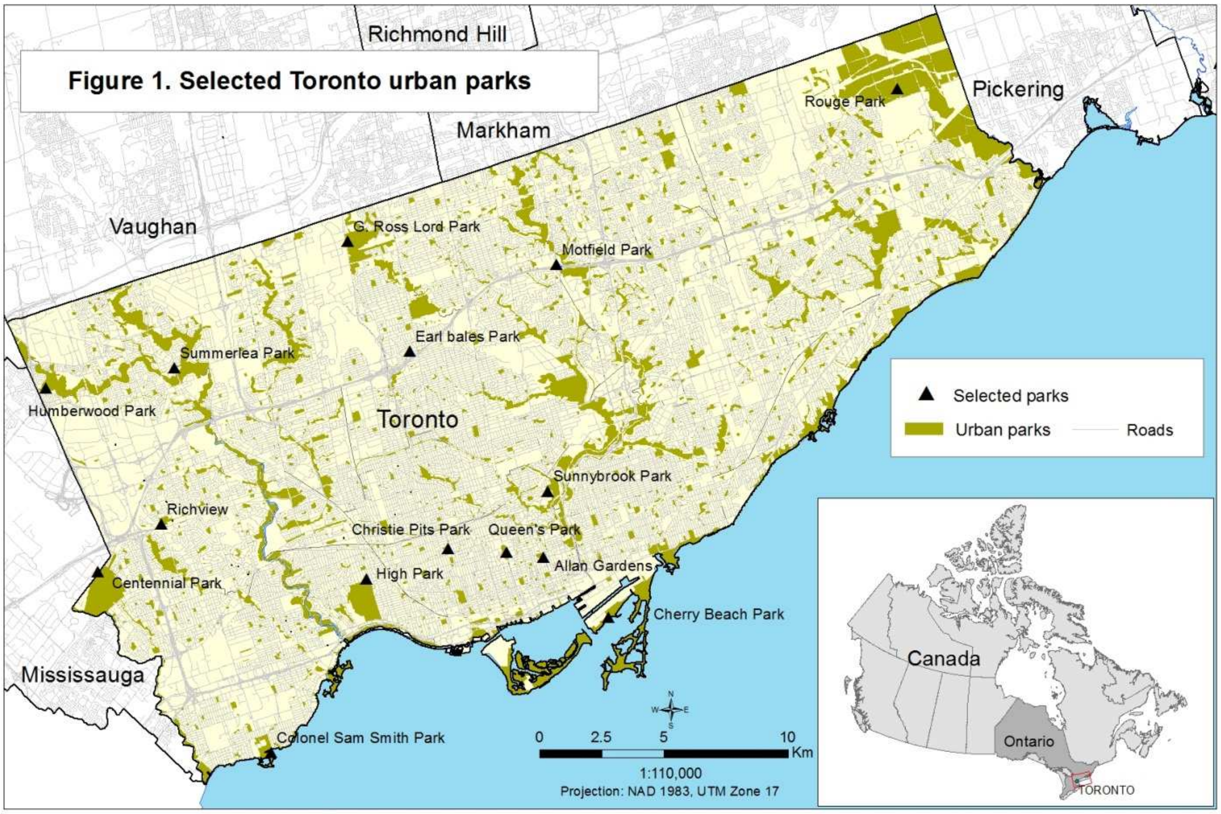

Figure 1: Selected Toronto city parks *(Contains public sector datasets made available under the City of Toronto's Open Data Licence v2.0)*

Surface soil samples were collected November 8th and 9th, 2011 at locations of the parks that were easily accessible to users. Samples were taken from the 0-5 cm depths due to the potential exposure to soil metal contamination associated with the top soil (Madrid et al., 2008). Approximately 1 kg of the soil sample was collected at each site using a plastic trowel and placed into two Ziploc® bags and labelled as ONTO-01 to ONTO-15 in the order they were collected. After each use, the trowel was cleaned with laboratory detergent and distilled water to prevent cross contamination and clean disposable nitrile gloves were worn at each sampling site. All the samples were shipped to the laboratory at Royal Roads University.

3.2 Sample Preparation

The two Ziploc® bags of samples for each location were homogenized in a stainless steel bowl and air dried at room temperature. The dried sample was sieved to <250 µm using USA Standard Testing Sieve ASTM E11 series and a Meinzer II Sieve Shaker. The sieved samples were placed into two separate 250 ml glass jars. One set of jars was shipped to Maxxam Analytics while the other was retained at the laboratory at RRU. Detailed laboratory sample preparation data is given in Appendix B. Samples from two locations (ONTO-6 and ONTO-14) were prepared in duplicates and labelled ONTO-16 and ONTO-17, respectively.

3.3 Soils Metals Analysis

The soil samples were analyzed for total metals by Maxxam Analytics in Edmonton, Alberta, using ICP-OES and ICP-MS methods (EPA 200.7 and EPA 200.8 respectively). Soil digestion was done using a nitric-hydrochloric acid mixture which solubilized the solid matter and removes organic material. The concentrations of total metals in the soils were reported in mg/kg. The laboratory data is presented in Appendix C.

3.4 PBET Extraction and Analysis

The air dried and sieved soil sample (1.00 ±.05 g) was weighed by difference into a 125 ml acid cleaned HPDE bottle. An aliquot of 0.4 M glycine (free base, reagent grade glycine in deionized water), adjusted to a pH of 1.50±0.05 at 37°C using trace metal grade concentrated hydrochloric acid (HCl) was added. The sealed bottles were placed into the extractor in a 37˚ ± 2˚ C water bath agitated end over end for an hour. The pH of the solution was taken at the beginning and the end to ensure it was within required range.

After the extraction was completed, the bottles were removed and extracts were drawn directly into disposable 20 ml plastic syringes with a luer slip. A 0.45µm cellulose acetate filter (25 mm diameter, Cole Palmer) was attached to the syringe and the extract was filtered into a clean 20 ml polyethylene scintillation vial. The laboratory batch extraction data are given in Appendix B. The extracts were placed in a cooler and shipped to Maxxam Analytics for total metals analysis. The concentrations of metals in the extracts are summarized in Appendix D.

3.5 Bioaccessibility Estimation

Bioaccessibility was calculated for As, Ba, Cd, Co, Cu, Pb, Ni and Zn using the formula below adapted from USEPA (2012).

$$\text{bioaccessibility, \%} = \frac{(concentration\ in\ extract, \mu\text{g/L})\ \ \text{x (vol of extract, L)}}{(concentration\ in\ soil, mg/kg) x (mass\ of\ soil\ used, g)} x100$$

3.6 Soil Properties

Soil samples were analyzed for pH and TOC. The pH of each sieved soils was determined at Royal Roads University by the slurry method by mixing the dried sample with distilled water at a ratio of 1:1. The pH of the solution was then measured using a standard pH meter. Soil samples were sent to Maxxam Analytics in Calgary, Alberta for TOC analysis using LECO method # 203-821-170 where total organic carbon is determined in dried and acidified soil sediment using a LECO CR-412 Carbon Analyzer. Sediment is combusted in an oxygen atmosphere and any carbon present is converted to CO_2. The sample gas flows into a non-dispersive infrared (NDIR) detection cell. The NDIR measures the mass of CO_2 present. The mass is converted to percent carbon based on the dry sample weight. The results of the TOC reported as percentage is attached as appendix E.

3.7 Data Analyses and Evaluation

Descriptive statistical analyses were performed using Excel (Microsoft Excel 2010). Total metals data were evaluate using the Canadian Council of Ministers of the Environment (CCME) Environmental Quality Guidelines for residential/parkland (R/P) use.

4 Results and Discussions

4.1 Total Metals

These metals - As, Ba, Cd, Co, Cu, Pb, Ni and Zn - listed in the CCME soil quality guidelines for the protection of the environment and human health because of their health risks were selected for descriptive statistics and the results are shown in Table 2. The complete list of metals analyzed in soils and PBET extracts are attached as Appendix C and D respectively. Concentration ranges in soil for As, Ba, Cd, Co, Cu, Pb, Ni and Zn were 1.7-6.7mg/kg, 28-170 mg/kg, 0.15-4.6 mg/kg, 2.2-9.3 mg/kg, 8.7-88 mg/kg, 12-690 mg/kg, 6-33 mg/kg and 31-350 mg/kg, respectively. A comparison of these concentrations with results from other cities obtained from the literature is provided in section 4.2.

Table 2: *Descriptive statistics for selected metals concentrations and CCME soil quality guidelines for residential/parkland use*

Metals	As	Ba	Cd	Co	Cu	Pb	Ni	Zn
Count	18	18	18	18	18	18	18	18
Maximum	6.7	170	4.6	9.3	88	690	33	350
Minimum	1.7	28	0.15	2.2	8.7	12	6	31
Mean	3.5	61.4	0.6	4.8	27.5	101.4	12.3	94.3
95 Percentile	6.62	136	1.63	7.09	78.6	333	25.3	188
Standard deviation	0.85	37.1	1.03	1.84	22.3	161	6.87	75.6
CCME guidelines	12	500	10	50	63	140	50	200

Note: All concentrations are expressed in mg/kg

Generally, the concentrations of metals in most of the samples collected were below the CCME guidelines for residential/parkland land use but a few exceeded the guidelines. Site ONTO-10 (G. Ross Lord Park) had 690 mg/kg of Pb which is about five times above the CCME guideline of 140 mg/kg. The park is within 600 m of two scrap metals yards to the east which could be a source of Pb (Alloway, 1995; Thums et al, 2008). The park also showed elevated Cu concentrations (88 mg/kg) which exceeded the CCME guideline (63 mg/kg)

Total Pb concentration for ONTO-15 sample (Cherry Beach Park) was found to be 270 mg/kg which is also above the guidelines. The park is located on previous Toronto Port lands industrial area which was developed by landfilling a marsh (Boyle, 1989) and the elevated Pb can be attributed to the persistence of Pb in soil. The park had Zn concentration of 350 mg/kg which was above the 200 mg/kg CCME guideline. The concentration of Pb in Queen’s Park (ONTO-06) was equivalent to the guideline of 140 mg/kg. However, duplicate analysis (ONTO-16) indicated total Pb of 150 mg/kg suggesting the site was likely above guidelines. The park is located at the city center and surrounded by highly travelled roads.

Figures 2, 3, 4, 5 and 6 for Pb, As, Cd, Zn and Cr respectively were created using total metals in soils based on the CCME threshold.

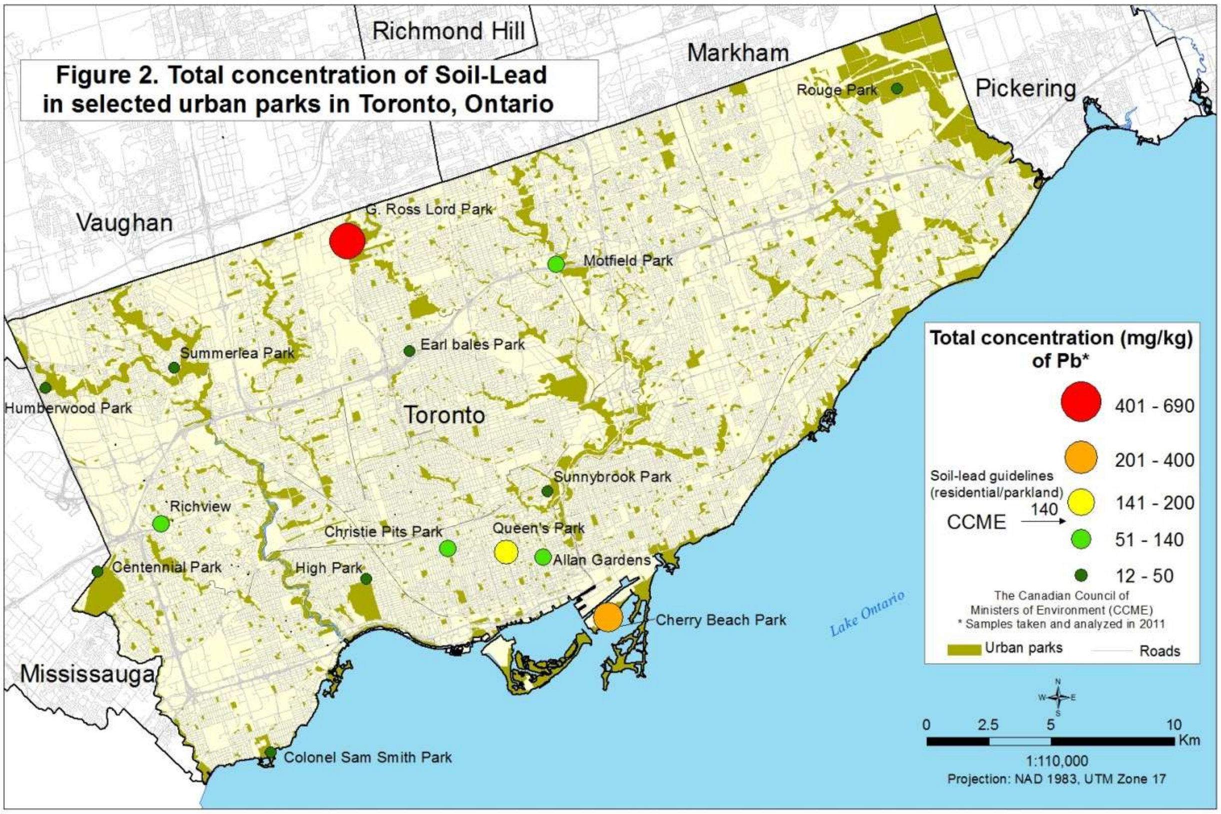

Figure 2: Total Pb in soil for selected parks. Three sites have concentrations above CCME R/P guidelines *(Contains public sector datasets made available under the City of Toronto's Open Data Licence v2.0)*

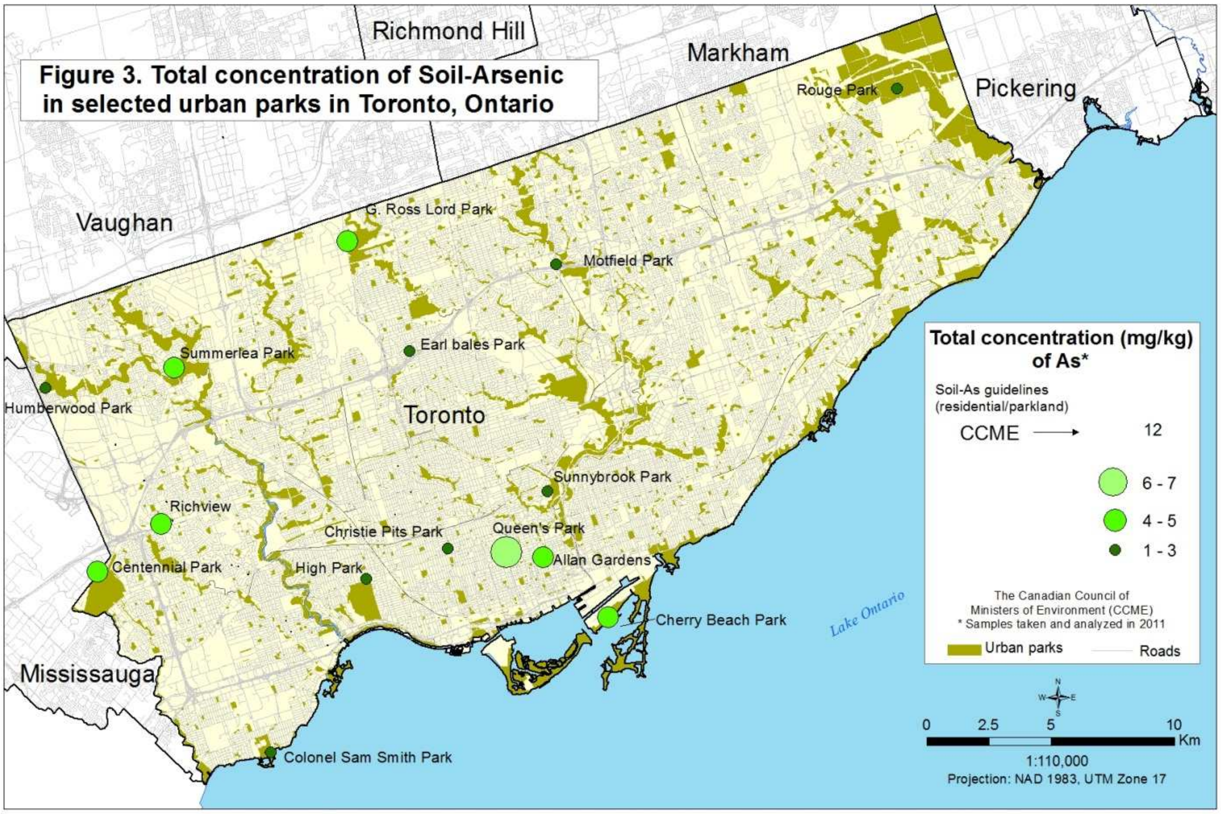

Figure 3: Total As in soil for selected parks. All selected sites are below R/P CCME guidelines

(Contains public sector datasets made available under the City of Toronto's Open Data Licence v2.0)

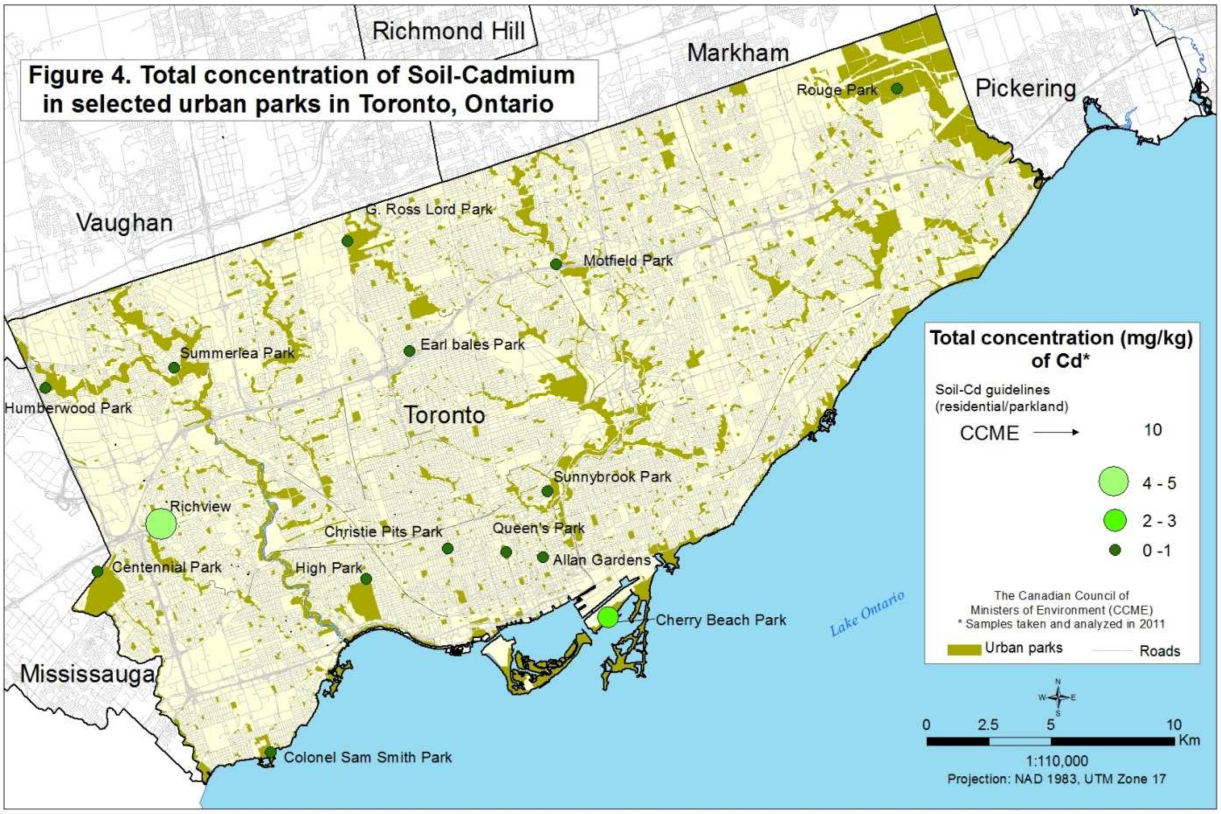

Figure 4: Total Cd in soil. All sites are below CCME R/P guidelines *(Contains public sector datasets made available under the City of Toronto's Open Data Licence v2.0)*

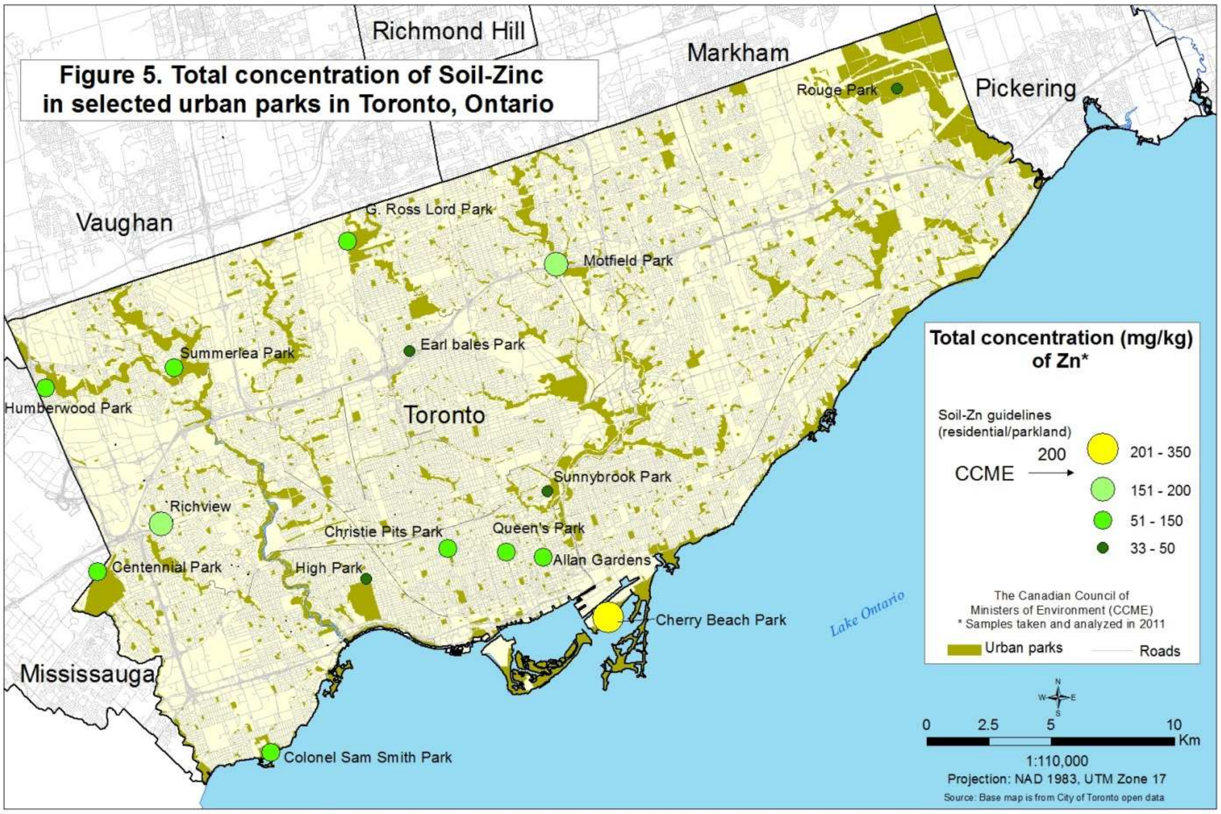

Figure 5: Total Zn in soil: Site ONTO-15 has concentration above CCME R/P guideline

(Contains public sector datasets made available under the City of Toronto's Open Data Licence v2.0)

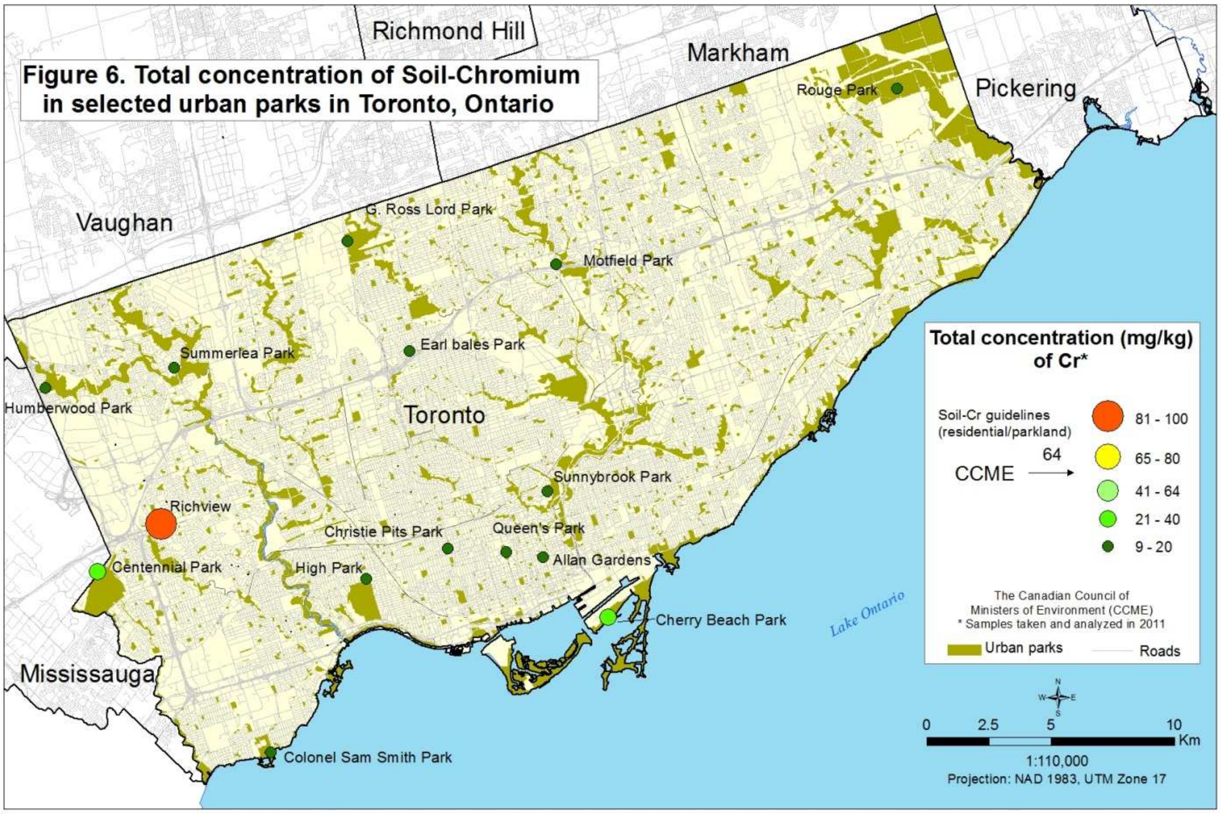

Figure 6: Total Cr in soil. Site ONTO-03 (Richview Park) has concentration above R/P CCME guidelines *(Contains public sector datasets made available under the City of Toronto's Open Data Licence v2.0)*

4.2 Comparing Toronto Parks with other Cities

The mean total metals concentrations and bioaccessibility results for Toronto were compared to similar studies done in other cities obtained from the literature. For mean total metal concentrations, the results are generally similar except for Pb in which Toronto exhibits much higher concentrations as summarized in Table 3.

Table 3: *Mean total metals (mg/kg) for selected cities*

	As	Cd	Cr	Cu	Ni	Pb	Zn
Toronto-Canada	3.5	0.57	18.7	27.5	12.3	101	94.3
Uppsala-Sweden [a]	6.7	0.31	62.4	n/a	35	43.2	n/a
Beijing-China [b]	n/a	n/a	n/a	71.2	22.2	66.2	87.6
Xiamen-China [c]	n/a	n/a	n/a	26	8.4	36	100

Sources: [a] Ljung et al, 2007; [b] Chen et al, 2005; [c] Luo et al, 2012.
Notes: n/a = not analyzed

4.3 Bioaccessibility by PBET

Bioaccessibility (%) for As, Ba, Cd, Co, Cu, Pb, Ni and Zn are provided in Appendix G: statistical summary of the data is given in Table 4. Some of the soil and PBET extract samples had concentrations below detection limit and as such bioaccessibility was not calculable. Metal bioaccessibility was variable among the samples and this was attributed largely to the differences in metal speciation. Lead and Cu indicated highest bioaccessibility values which were in line with total concentration in the soils. However, As and Cd which had significantly low concentration in soil (max. 6.7 and 4.6 mg/kg respectively) showed high bioaccessibility results. Bioaccessibility Figures 7 and 8 for Pb and As respectively are based on mean values.

Table 4: *Descriptive statistics of bioaccessibility (%) of selected metals*

Elements	As	Ba	Cd	Co	Cu	Pb	Ni	Zn
Count	15	17	17	11	17	17	10	13
Mean	41.1	39.0	75.7	28.2	65.4	75.5	18.9	43.0
Standard Deviation	9.9	31.2	8.4	7.7	15.8	10.6	7.6	14.2

Minimum	22.6	5.8	56.3	13.6	46.9	58.4	8.9	21.9
Maximum	68.7	74.9	86.1	36.0	99.6	99.3	32.3	65.0
95 Percentile	54.9	74.0	83.5	35.4	94.0	88.0	30.3	63.4

When compared with other cities, for metal bioaccessibility, Toronto appears to have higher mean bioaccessibility values than Uppsala, Sweden and Xiamen, China. However, there is a major difference in sample sizes. Whereas 17 samples were assessed for Toronto, 25, 30 and 40 samples were analyzed for Uppsala, Beijing and Xiamen, respectively and this could influence the mean values. The differences in bioaccessibility may also be attributed to differences in metal speciation between the cities. Bioaccessibility comparisons are provided in Table 5.

Table 5: *Mean metals bioaccessibility (%) for selected cities*

	Cu	Ni	Pb	Zn	As	Cd	Cr
Toronto-Canada	65.4	18.9	75.5	43	41.1	75.5	n/a
Uppsala-Sweden [a]	n/a	3.9	4.2	n/a	16.1	26.3	4.2
Xiamen-China [b]	54	26	49	39	n/a	n/a	n/a

Sources: [a] Ljung et al, 2007; [b] Luo et al, 2012.
Notes: n/a = not analyzed

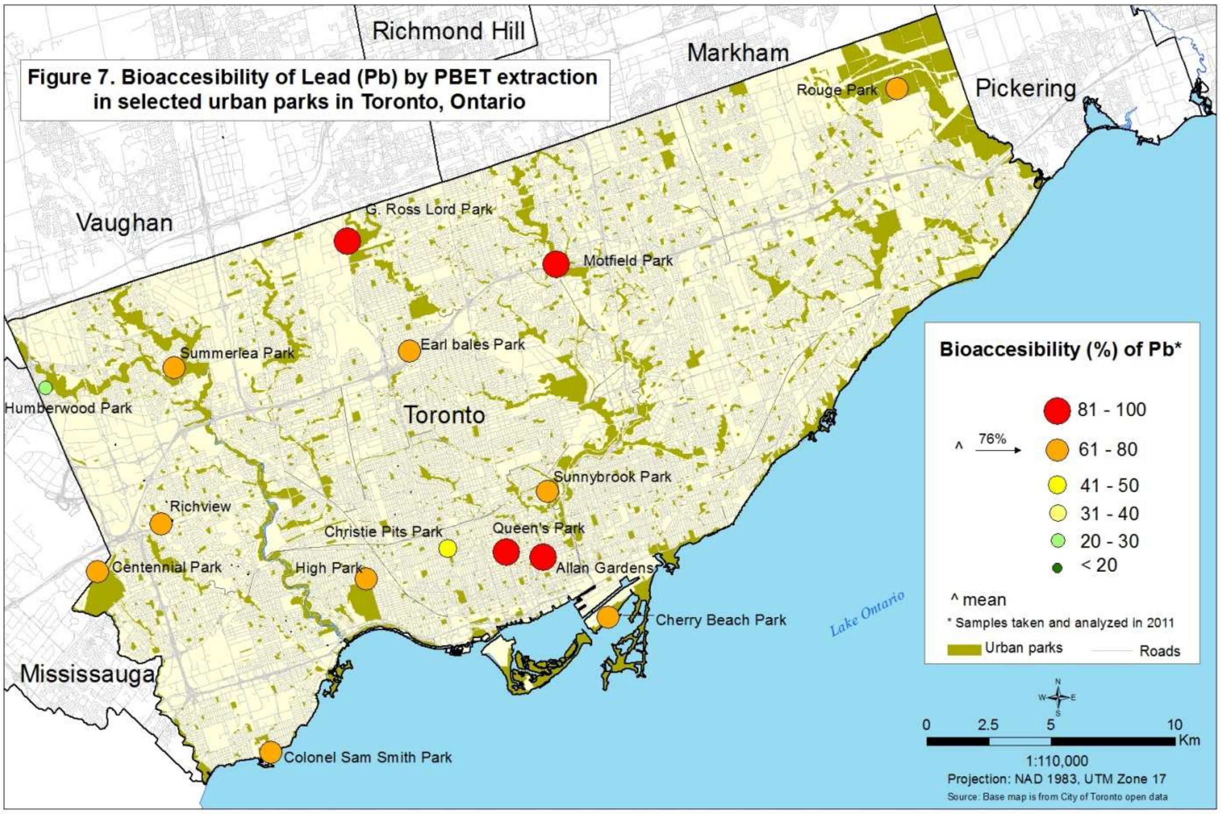

Figure 7: Bioaccessibility of Pb. Four sites are above the mean Pb bioaccessibility values

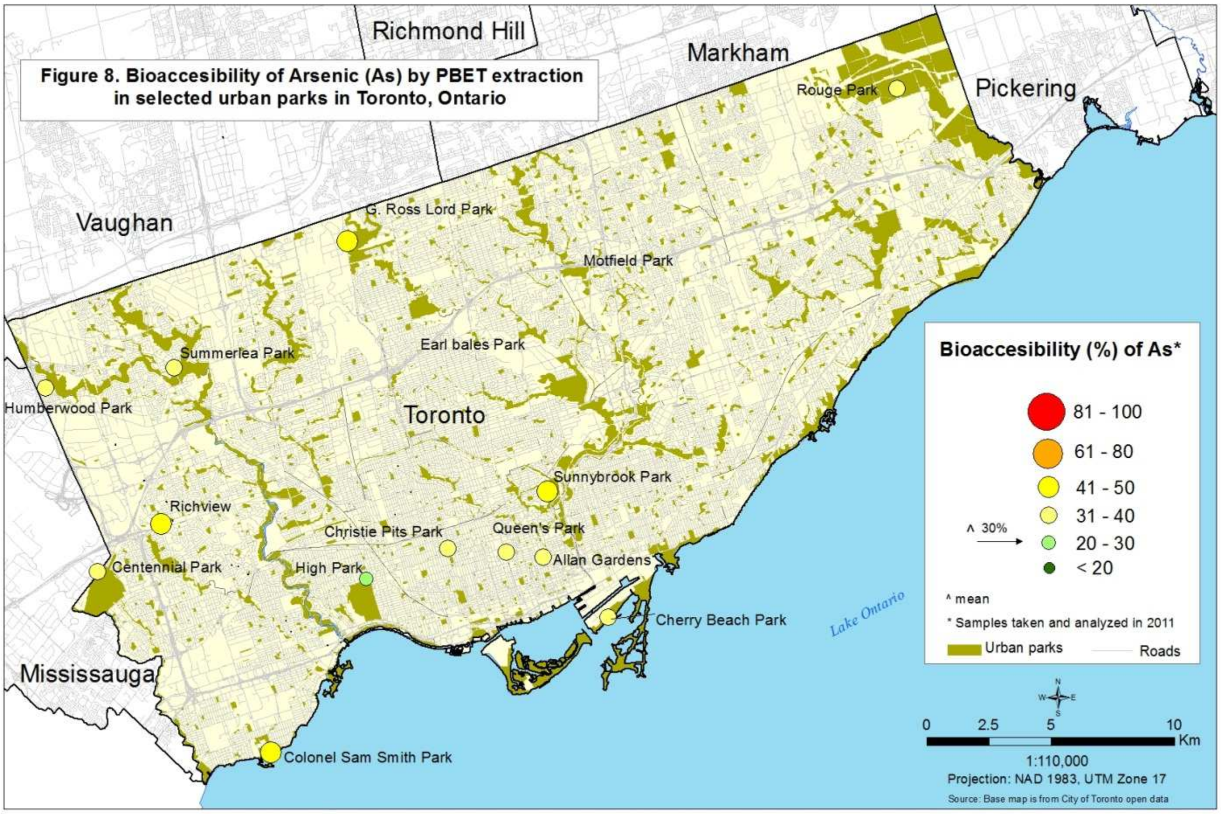

Figure 8: Bioaccessibility of As. Only one of the sites had bioaccessibility below the mean value suggesting high bioaccessibility for arsenic *(Contains public sector datasets made available under the City of Toronto's Open Data Licence v2.0)*

4.4 Effect of soil properties on bioaccessibility

A linear regression analysis was performed to determine if total organic carbon had influence on the bioaccessibility of As, Pb, Ba, Cd, Co, Cu, Fe, Mn, Ni and Zn. Total organic carbon was found to have no significant correlation with bioaccessibility. However, Ni exhibited a slightly positive correlation with R^2 =0.265. It should be noted that Ni bioaccessibility results were not calculated for seven sites because Ni concentration in the PBET extract were below detection limit. Generally there was a negative correlation trend for TOC and a positive correlation trend for pH (Appendix H). However, because of the limited number of samples (17) these correlation results may not be conclusive and more samples are required to provide better statistical significance. Correlation graphs for the effect of TOC and pH on Pb and As bioaccessibility is provided below and the complete list is provided in Appendix H.

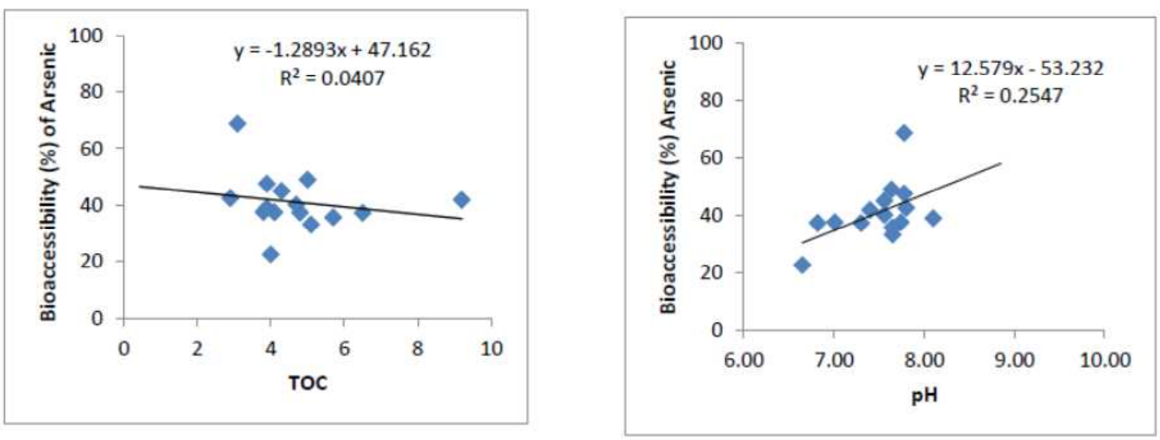

Figure 9: Relationship of arsenic with pH and TOC. No relationship observed for TOC but there is a positive correlation with pH.

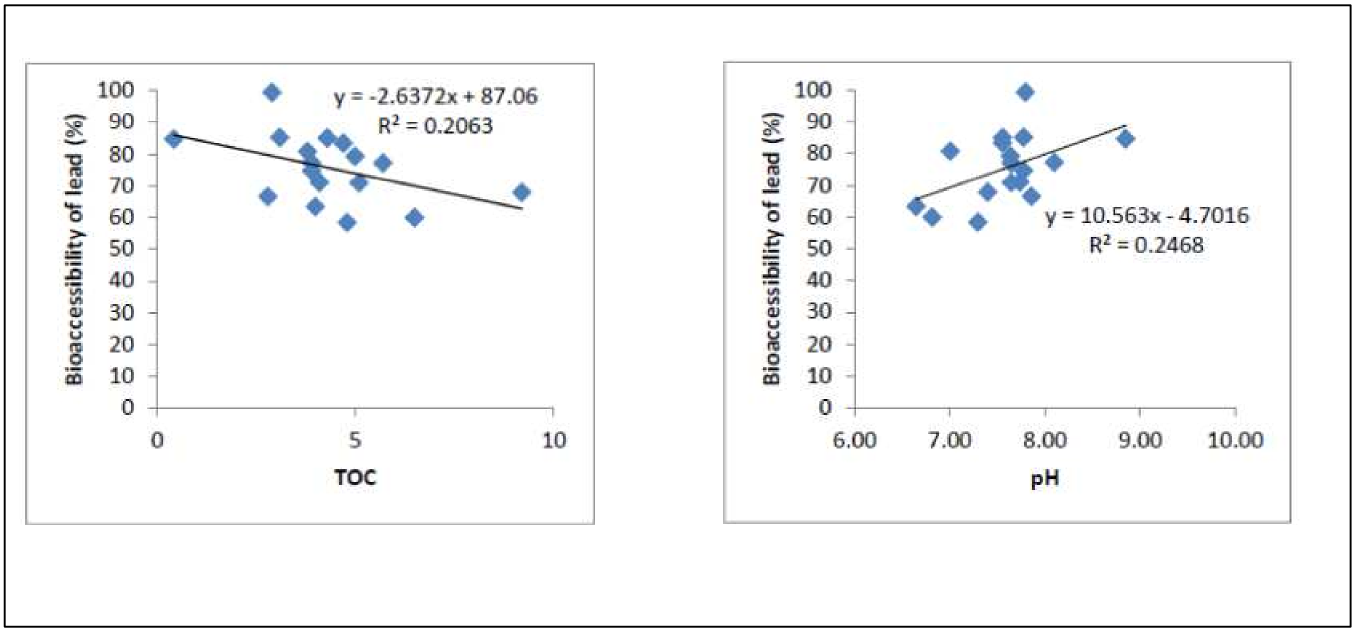

Figure 10: Relationship of Pb with pH and TOC. Lead exhibits a negative correlation with TOC and a positive for pH.

4.5 Quality assurance and quality control (QA/QC)

4.5.1 Maxxam Analytics

Maxxam adheres to requirements set by the Good Laboratory Practice (GLP), as well as Health Canada and is accredited by the Canadian Association for Environmental Analytical Laboratories (CAEAL) and has its own QA/QC program which includes laboratory blanks, spikes and duplicates. The laboratory QA/QC results as reported by Maxxam Analytics were satisfactory.

4.5.2 PBET Extraction

The QA/QC program for the PBET extraction included the analyses of a procedure blank, a standard reference material, a spiked matrix and two duplicate samples. The results of the duplicate samples are included in the tables in Appendices C and D and indicated good reproducibility overall.

The entire data for the blank and standard reference material are reported in Appendix F; a subset of the arsenic and lead data is given in Table 6. The concentrations of arsenic and lead in the procedure blanks were within the control limit (Table 6) indicating minimal interference from reagents and equipment. There are no established limits for the remaining parameters. Arsenic and lead recoveries of 92% and 111%, respectively were obtained for the National Institute of Standards and Technology (NIST) Standard Reference Material (NIST 2711, Montana Soil) (Table 6). These results were also within the laboratory acceptable control limit of ± 20 %.

Table 6: *Arsenic and lead concentrations and control limits for procedure blank and laboratory control sample*

	Procedure Blank		Standard Reference Material	
Total Metals by ICPMS	BL11-21B (µg/L)	Control limit (µg/L)	NIST 2711 (µg/L)	Recovery (%)
Arsenic (As)	<0.4	<1.0	272	92.2
(Pb)	0.5	<50	5140	111

5 Conclusions and Recommendations

The results indicated that except for three parks most soil samples were within acceptable CCME R/P guideline limits for total metals. Additional investigation is required to determine the source of the contamination especially for G. Ross Lord Park which had significant Pb content. The data also showed variable metal bioaccessibility among the samples which may be attributed largely to differences in metal speciation and further investigations in metal speciation of the soil samples are required.

For the parks that had elevated Pb above guidelines, bioaccessibility was also high (up to 99.3%). Thus Pb in these soils could be potentially bioavailable to humans following exposure through inadvertent oral ingestion, inhalation or dermal absorption. It is recommended that further sampling should be conducted to delineate the contaminated area and identify the source of contamination. To manage elevated soil lead concentrations that pose human health risk USEPA (2003) recommends that a minimum of 30 cm of clean soil should be used to cover the area to create a barrier between the contaminated soil and human contact. Alternatively the top 30 cm of contaminated soils could be excavated and back-filled with clean soil. Another treatment option that is in development involves amending the soil with phosphorus or high iron biosolids compost which has been shown to reduce the bioavailability of lead in soil by as much as 50 percent (USEPA, 2003).

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Appendix A: Sampling Sites Location

Park	ID	Location	Lat.	Long.	Sampling Date	Sampling Time
Humberwood Park	ONTO-01	43:43:33N, 79:37:13W	43.725833	79.620278	Nov-8-2011	14.11
Summerlea Park	ONTO-02	43:43:57N, 79:33:20W	43.7325	79.555556	Nov-8-2011	14.38
Richview	ONTO-03	43:40:33N, 79:33:49W	43.675833	79.563611	Nov-8-2011	15.35
Centennial Park	ONTO-04	43:39:33N, 79:35:45W	43.659167	79.595833	Nov-8-2011	15.55
Colonel Sam Smith Park	ONTO-05	43:35:33N, 79:30:38W	43.5925	79.510556	Nov-8-2011	16.41
Queen's Park	ONTO-06	43:39:48N, 79:23:29W	43.663333	79.391389	Nov-9-2011	8.32
Allan Gardens	ONTO-07	43:39:41N, 79:22:22W	43.661389	79.372778	Nov-9-2011	8.49
High Park	ONTO-08	43:39:17N, 79:27:41W	43.654722	79.461389	Nov-9-2011	9.18
Christie Pits Park	ONTO-09	43:39:55N, 79:25:14W	43.665278	79.420556	Nov-9-2011	9.47
G. Ross Lord Park	ONTO-10	43:46:38N, 79:28:4W	43.777222	79.467778	Nov-9-2011	10.27
Earl bales Park	ONTO-11	43:44:13N, 79:26:16W	43.736944	79.437778	Nov-9-2011	11.08
Rouge Park	ONTO-12	43:50:28N, 79:6:15W	43.841111	79.104167	Nov-9-2011	11.54
Motfield Park	ONTO-13	43:46:2N, 79:21:49W	43.767222	79.363611	Nov-9-2011	12.35
Sunnybrook Park	ONTO-14	43:41:7N, 79:22:12W	43.685278	79.37	Nov-9-2011	13.01
Cherry Beach Park	ONTO-15	43:38:21N, 79:20:28W	43.639167	79.341111	Nov-9-2011	13.27

Appendix B: Sample Preparation

Appendix B.1: Sample Preparation

Sample **ID**	Wet Soil Used (g)	Dry Soil (g)	Moisture (%)	Soil Used for Sieving	<um 250 m Soil (g)	< 250 μm Content (%)
ONTO-01	2011.2	1439.5	28.4	981.5	237.3	24.2
ONTO-02	2291.1	1695.3	26.0	1042.8	275.0	26.4
ONTO-03	1705.1	882.7	48.2	497.1	46.6	9.4
ONTO-04	2040.9	1332.4	34.7	839.7	146.3	17.4
ONTO-05	1737.7	1359.6	21.8	849.5	214.6	25.3
ONTO-06	1007.0	813.6	19.2	808.5	440.6	54.5
ONTO-07	1559.8	1276.7	18.1	858.9	495.9	57.7
ONTO-08	919.7	723.4	21.3	551.3	376.6	68.3
ONTO-09	1303.9	966.2	25.9	609.4	195.5	32.1
ONTO-10	909.9	776.8	14.6	773.0	158.5	20.5
ONTO-11	857.5	658.2	23.2	657.0	277.7	42.3
ONTO-12	1430.6	1093.4	23.6	575.0	193.8	33.7
ONTO-13	1893.4	1762.7	6.9	1069.2	259.9	24.3
ONTO-14	1522.1	1180.5	22.4	590.1	430.8	73.0
ONTO-15	1196.6	876.7	26.7	503.1	104.4	20.8

Appendix B.2: Physiologically Based Extraction Test (PBET) Batch Summary

EXTRACTION BATCH #1				
Date of Extraction:				9-Jan-12
Start Time:				12:33 PM
Stop Time:				1:33 PM
Initial temp of water bath (^{o}C):				36.8
Final temp of water bath (^{o}C):				37.9
Sample ID	Weight (g)	Initial pH	Final pH	Comments
ONTO-01	1.0135	1.59	1.65	
ONTO-02	1.0178	1.60	1.64	
ONTO-03	1.0324	1.59	1.62	
ONTO-04	1.0262	1.57	1.62	
ONTO-05	1.0197	1.62	1.69	
ONTO-06	1.0086	1.58	1.61	
ONTO-07	1.0299	1.56	1.57	
ONTO-08	1.0017	1.54	1.56	
PB12-01	0.0000	1.50	1.54	Procedural blank
SR12-01	0.5125	1.56	1.63	NIST 2711

EXTRACTION BATCH #2				
Date of Extraction:				9-Jan-12
Start Time:				1:40 PM
Stop Time:				2:40 PM
Initial temp of water bath (^{o}C):				37.5
Final temp of water bath (^{o}C):				38.5
Sample ID	Weight (g)	Initial pH	Final pH	Comments
ONTO-09	1.0534	1.63	1.67	
ONTO-10	1.0068	1.63	1.66	
ONTO-11	1.0027	1.56	1.57	
ONTO-12	1.0243	1.59	1.59	
ONTO-13	1.0572	1.68	1.78	
ONTO-14	1.0040	1.60	1.64	
ONTO-15	1.0089	1.65	1.70	
ONTO-16	1.0393	1.58	1.60	Duplicate of ONTO-06

ONTO-17	1.0274	1.60	1.63	Duplicate of ONTO-14
BL12-01	0.0000	1.50		Reagent blank

Appendix C: Total metals in Soil by ICP

Maxxam Job #: B202385
Report Date: 2012/01/25

ROYAL ROADS UNIVERSITY
Client Project #:
Site Location:
Sampler Initials:

ASSESSMENT ICP METALS (SOIL)

Maxxam ID				CM5503	CM5503	CM5524
Sampling Date				11/8/2011	11/8/2011	11/8/2011
	Units	**QC Batch**	**RDL**	**ONTO-01**	**ONTO-01 Lab-Dup**	**ONTO-02**
Elements						
Total Aluminum (Al)	mg/kg	5520485	10	10000	11000	8300
Total Boron (B)	mg/kg	5520485	2.0	6.2	6.0	12
Total Calcium (Ca)	mg/kg	5520485	50	27000	27000	27000
Total Iron (Fe)	mg/kg	5520485	10	17000	17000	16000
Total Lithium (Li)	mg/kg	5520485	10	15	15	17
Total Magnesium (Mg)	mg/kg	5520485	20	6700	6500	6800
Total Manganese (Mn)	mg/kg	5520485	10	530	530	470
Total Phosphorus (P)	mg/kg	5520485	20	840	800	900
Total Potassium (K)	mg/kg	5520485	25	2200	2300	1800
Total Sodium (Na)	mg/kg	5520485	50	250	260	84
Total Strontium (Sr)	mg/kg	5520485	10	44	44	45
Total Sulphur (S)	mg/kg	5520485	20	570	570	640
Total Antimony (Sb)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Arsenic (As)	mg/kg	5518436	1.0	2.9	3.1	3.4
Total Barium (Ba)	mg/kg	5518436	10	55	58	36
Total Beryllium (Be)	mg/kg	5518436	0.40	0.45	0.44	<0.40
Total Cadmium (Cd)	mg/kg	5518436	0.10	0.17	0.16	0.27
Total Chromium (Cr)	mg/kg	5518436	1.0	14	15	13
Total Cobalt (Co)	mg/kg	5518436	1.0	6.5	6.7	6.5
Total Copper (Cu)	mg/kg	5518436	5.0	18	19	21
Total Lead (Pb)	mg/kg	5518436	1.0	12	12	18
Total Molybdenum (Mo)	mg/kg	5518436	0.40	<0.40	<0.40	<0.40
Total Nickel (Ni)	mg/kg	5518436	1.0	14	14	14
Total Selenium (Se)	mg/kg	5518436	0.50	<0.50	<0.50	<0.50
Total Silver (Ag)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Thallium (Tl)	mg/kg	5518436	0.30	<0.30	<0.30	<0.30
Total Tin (Sn)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Uranium (U)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Vanadium (V)	mg/kg	5518436	1.0	23	23	19
Total Zinc (Zn)	mg/kg	5518436	10	51	51	64

RDL = Reportable Detection Limit
Lab-Dup = Laboratory
Initiated Duplicate EDL =
Estimated Detection Limit

Maxxam ID				CM5525	CM5526	CM5527
Sampling Date				11/8/2011	11/8/2011	11/8/2011
	Units	**QC Batch**	**RDL**	**ONTO-03**	**ONTO-04**	**ONTO-05**
Elements						
Total Aluminum (Al)	mg/kg	5520485	10	10000	18000	6400
Total Boron (B)	mg/kg	5520485	2.0	11	5.4	8.2
Total Calcium (Ca)	mg/kg	5520485	50	21000	12000	44000
Total Iron (Fe)	mg/kg	5520485	10	17000	25000	12000
Total Lithium (Li)	mg/kg	5520485	10	13	28	11
Total Magnesium (Mg)	mg/kg	5520485	20	3800	9400	6000
Total Manganese (Mn)	mg/kg	5520485	10	410	490	300
Total Phosphorus (P)	mg/kg	5520485	20	1800	960	1000
Total Potassium (K)	mg/kg	5520485	25	1900	2000	1500
Total Sodium (Na)	mg/kg	5520485	50	70	320	85
Total Strontium (Sr)	mg/kg	5520485	10	44	30	72
Total Sulphur (S)	mg/kg	5520485	20	900	640	580
Total Antimony (Sb)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Arsenic (As)	mg/kg	5518436	1.0	3.7	4.1	2.6
Total Barium (Ba)	mg/kg	5518436	10	95	84	44
Total Beryllium (Be)	mg/kg	5518436	0.40	0.46	0.87	<0.40
Total Cadmium (Cd)	mg/kg	5518436	0.10	4.6	0.40	0.30
Total Chromium (Cr)	mg/kg	5518436	1.0	98	25	13
Total Cobalt (Co)	mg/kg	5518436	1.0	6.5	9.3	4.6
Total Copper (Cu)	mg/kg	5518436	5.0	77	28	23
Total Lead (Pb)	mg/kg	5518436	1.0	110	33	26
Total Molybdenum (Mo)	mg/kg	5518436	0.40	0.96	0.54	<0.40
Total Nickel (Ni)	mg/kg	5518436	1.0	33	24	11
Total Selenium (Se)	mg/kg	5518436	0.50	<0.50	0.61	<0.50
Total Silver (Ag)	mg/kg	5518436	1.0	2.3	<1.0	<1.0
Total Thallium (Tl)	mg/kg	5518436	0.30	<0.30	<0.30	<0.30
Total Tin (Sn)	mg/kg	5518436	1.0	7.7	1.5	1.2
Total Uranium (U)	mg/kg	5518436	1.0	<1.0	1.0	<1.0
Total Vanadium (V)	mg/kg	5518436	1.0	22	33	17
Total Zinc (Zn)	mg/kg	5518436	10	160	120	69

RDL = Reportable Detection Limit
Lab-Dup = Laboratory Initiated Duplicate
EDL = Estimated Detection Limit

Maxxam ID				CM5528	CM5529	CM5530
Sampling Date				11/9/2011	11/9/2011	11/9/2011
	Units	**QC Batch**	**RDL**	**ONTO-06**	**ONTO-07**	**ONTO-08**
Elements						
Total Aluminum (Al)	mg/kg	5520485	10	6100	6600	6500
Total Boron (B)	mg/kg	5520485	2.0	5.9	4.1	<2.0
Total Calcium (Ca)	mg/kg	5520485	50	15000	5900	2400
Total Iron (Fe)	mg/kg	5520485	10	11000	11000	9400
Total Lithium (Li)	mg/kg	5520485	10	<10	<10	<10
Total Magnesium (Mg)	mg/kg	5520485	20	3900	2000	1000
Total Manganese (Mn)	mg/kg	5520485	10	210	220	310
Total Phosphorus (P)	mg/kg	5520485	20	1200	1200	690
Total Potassium (K)	mg/kg	5520485	25	1000	720	500
Total Sodium (Na)	mg/kg	5520485	50	95	82	<50
Total Strontium (Sr)	mg/kg	5520485	10	29	16	<10
Total Sulphur (S)	mg/kg	5520485	20	540	450	370
Total Antimony (Sb)	mg/kg	5518436	1.0	1.3	1.1	<1.0
Total Arsenic (As)	mg/kg	5518436	1.0	6.6	4.9	3.0
Total Barium (Ba)	mg/kg	5518436	10	59	44	38
Total Beryllium (Be)	mg/kg	5518436	0.40	<0.40	<0.40	<0.40
Total Cadmium (Cd)	mg/kg	5518436	0.10	0.53	0.40	0.26
Total Chromium (Cr)	mg/kg	5518436	1.0	13	12	9.5
Total Cobalt (Co)	mg/kg	5518436	1.0	3.7	3.0	2.2
Total Copper (Cu)	mg/kg	5518436	5.0	31	21	12
Total Lead (Pb)	mg/kg	5518436	1.0	140	95	41
Total Molybdenum (Mo)	mg/kg	5518436	0.40	0.47	0.42	0.47
Total Nickel (Ni)	mg/kg	5518436	1.0	10	8.3	6.0
Total Selenium (Se)	mg/kg	5518436	0.50	0.84	0.79	<0.50
Total Silver (Ag)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Thallium (Tl)	mg/kg	5518436	0.30	<0.30	<0.30	<0.30
Total Tin (Sn)	mg/kg	5518436	1.0	11	4.3	2.8
Total Uranium (U)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Vanadium (V)	mg/kg	5518436	1.0	25	23	17
Total Zinc (Zn)	mg/kg	5518436	10	110	78	45

RDL = Reportable Detection Limit
Lab-Dup = Laboratory Initiated Duplicate
EDL = Estimated Detection Limit

Maxxam ID				CM5531	CM5532	CM5533
Sampling Date				11/9/2011	11/9/2011	11/9/2011
	Units	**QC Batch**	**RDL**	**ONTO-09**	**ONTO-10**	**ONTO-11**
Elements						
Total Aluminum (Al)	mg/kg	5520485	10	6600	7600	6400
Total Boron (B)	mg/kg	5520485	2.0	6.2	9.3	2.0
Total Calcium (Ca)	mg/kg	5520485	50	35000	32000	4400
Total Iron (Fe)	mg/kg	5520485	10	12000	16000	11000
Total Lithium (Li)	mg/kg	5520485	10	<10	<10	<10
Total Magnesium (Mg)	mg/kg	5520485	20	5100	4200	1700
Total Manganese (Mn)	mg/kg	5520485	10	270	350	280
Total Phosphorus (P)	mg/kg	5520485	20	890	870	720
Total Potassium (K)	mg/kg	5520485	25	1400	1400	820
Total Sodium (Na)	mg/kg	5520485	50	120	210	<50
Total Strontium (Sr)	mg/kg	5520485	10	58	81	13
Total Sulphur (S)	mg/kg	5520485	20	510	190	400
Total Antimony (Sb)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Arsenic (As)	mg/kg	5518436	1.0	3.3	4.9	1.9
Total Barium (Ba)	mg/kg	5518436	10	51	130	38
Total Beryllium (Be)	mg/kg	5518436	0.40	<0.40	<0.40	<0.40
Total Cadmium (Cd)	mg/kg	5518436	0.10	0.27	0.20	0.29
Total Chromium (Cr)	mg/kg	5518436	1.0	13	16	16
Total Cobalt (Co)	mg/kg	5518436	1.0	4.1	4.6	3.3
Total Copper (Cu)	mg/kg	5518436	5.0	20	88	8.7
Total Lead (Pb)	mg/kg	5518436	1.0	57	690	21
Total Molybdenum (Mo)	mg/kg	5518436	0.40	<0.40	0.45	0.41
Total Nickel (Ni)	mg/kg	5518436	1.0	9.8	11	6.4
Total Selenium (Se)	mg/kg	5518436	0.50	<0.50	<0.50	<0.50
Total Silver (Ag)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Thallium (Tl)	mg/kg	5518436	0.30	<0.30	<0.30	<0.30
Total Tin (Sn)	mg/kg	5518436	1.0	4.0	2.6	<1.0
Total Uranium (U)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Vanadium (V)	mg/kg	5518436	1.0	20	24	19
Total Zinc (Zn)	mg/kg	5518436	10	72	110	35

RDL = Reportable Detection Limit
Lab-Dup = Laboratory Initiated Duplicate
EDL = Estimated Detection Limit

Maxxam ID				CM5534	CM5535	CM5536
Sampling Date				11/9/2011	11/9/2011	11/9/2011
	Units	**QC Batch**	**RDL**	**ONTO-12**	**ONTO-13**	**ONTO-14**
Elements						
Total Aluminum (Al)	mg/kg	5520485	10	11000	4500	3900
Total Boron (B)	mg/kg	5520485	2.0	4.7	2.2	5.0
Total Calcium (Ca)	mg/kg	5520485	50	14000	74000	32000
Total Iron (Fe)	mg/kg	5520485	10	15000	11000	9000
Total Lithium (Li)	mg/kg	5520485	10	<10	<10	<10
Total Magnesium (Mg)	mg/kg	5520485	20	2900	6500	6300
Total Manganese (Mn)	mg/kg	5520485	10	300	270	230
Total Phosphorus (P)	mg/kg	5520485	20	680	710	1100
Total Potassium (K)	mg/kg	5520485	25	910	940	800
Total Sodium (Na)	mg/kg	5520485	50	87	1000	120
Total Strontium (Sr)	mg/kg	5520485	10	26	110	47
Total Sulphur (S)	mg/kg	5520485	20	310	230	510
Total Antimony (Sb)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Arsenic (As)	mg/kg	5518436	1.0	2.5	1.7	2.3
Total Barium (Ba)	mg/kg	5518436	10	48	28	34
Total Beryllium (Be)	mg/kg	5518436	0.40	0.42	<0.40	<0.40
Total Cadmium (Cd)	mg/kg	5518436	0.10	0.29	0.15	0.16
Total Chromium (Cr)	mg/kg	5518436	1.0	15	11	8.8
Total Cobalt (Co)	mg/kg	5518436	1.0	5.0	4.2	2.9
Total Copper (Cu)	mg/kg	5518436	5.0	14	14	10
Total Lead (Pb)	mg/kg	5518436	1.0	24	95	16
Total Molybdenum (Mo)	mg/kg	5518436	0.40	<0.40	0.48	<0.40
Total Nickel (Ni)	mg/kg	5518436	1.0	10	9.2	6.3
Total Selenium (Se)	mg/kg	5518436	0.50	<0.50	<0.50	<0.50
Total Silver (Ag)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Thallium (Tl)	mg/kg	5518436	0.30	<0.30	<0.30	<0.30
Total Tin (Sn)	mg/kg	5518436	1.0	1.1	<1.0	<1.0
Total Uranium (U)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Vanadium (V)	mg/kg	5518436	1.0	27	17	15
Total Zinc (Zn)	mg/kg	5518436	10	49	160	33

RDL = Reportable Detection Limit
Lab-Dup = Laboratory Initiated Duplicate
EDL = Estimated Detection Limit

Maxxam ID				CM5537	CM5538	CM5539
Sampling Date				11/9/2011	11/9/2011	11/9/2011
	Units	**QC Batch**	**RDL**	**ONTO-15**	**ONTO-16**	**ONTO-17**
Elements						
Total Aluminum (Al)	mg/kg	5520485	10	11000	6600	3700
Total Boron (B)	mg/kg	5520485	2.0	15	6.8	4.5
Total Calcium (Ca)	mg/kg	5520485	50	52000	16000	32000
Total Iron (Fe)	mg/kg	5520485	10	17000	12000	8500
Total Lithium (Li)	mg/kg	5520485	10	13	<10	<10
Total Magnesium (Mg)	mg/kg	5520485	20	8900	4200	6200
Total Manganese (Mn)	mg/kg	5520485	10	350	220	220
Total Phosphorus (P)	mg/kg	5520485	20	1100	1300	1000
Total Potassium (K)	mg/kg	5520485	25	2300	1100	770
Total Sodium (Na)	mg/kg	5520485	50	240	100	110
Total Strontium (Sr)	mg/kg	5520485	10	82	31	46
Total Sulphur (S)	mg/kg	5520485	20	950	550	470
Total Antimony (Sb)	mg/kg	5518436	1.0	1.7	1.4	<1.0
Total Arsenic (As)	mg/kg	5518436	1.0	3.6	6.7	1.7
Total Barium (Ba)	mg/kg	5518436	10	170	60	33
Total Beryllium (Be)	mg/kg	5518436	0.40	0.41	<0.40	<0.40
Total Cadmium (Cd)	mg/kg	5518436	0.10	1.1	0.56	0.16
Total Chromium (Cr)	mg/kg	5518436	1.0	21	15	8.4
Total Cobalt (Co)	mg/kg	5518436	1.0	6.3	3.8	2.8
Total Copper (Cu)	mg/kg	5518436	5.0	48	32	10
Total Lead (Pb)	mg/kg	5518436	1.0	270	150	16
Total Molybdenum (Mo)	mg/kg	5518436	0.40	0.90	0.50	<0.40
Total Nickel (Ni)	mg/kg	5518436	1.0	18	11	6.1
Total Selenium (Se)	mg/kg	5518436	0.50	0.62	0.90	<0.50
Total Silver (Ag)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Thallium (Tl)	mg/kg	5518436	0.30	<0.30	<0.30	<0.30
Total Tin (Sn)	mg/kg	5518436	1.0	28	7.6	1.3
Total Uranium (U)	mg/kg	5518436	1.0	<1.0	<1.0	<1.0
Total Vanadium (V)	mg/kg	5518436	1.0	28	26	15
Total Zinc (Zn)	mg/kg	5518436	10	350	110	31

RDL = Reportable Detection Limit
Lab-Dup = Laboratory Initiated
Duplicate EDL = Estimated Detection
Limit

Appendix D: Total metals in PBET extracts

Maxxam Job #: B202385
Report Date: 2012/01/25

ROYAL ROADS UNIVERSITY
Client Project #:
Site Location: Toronto
Sampler Initials:

REGULATED METALS (CCME/AT1) - TOTAL

Maxxam ID		CM5482	CM5483	CM5484	CM5485	CM5486	CM5487
Sampling Date		1/10/2012	1/10/2012	1/10/2012	1/10/2012	1/10/2012	1/10/2012
	Units	**PB12-01**	**BL12-01**	**TOEX-01**	**TOEX-02**	**TOEX-03**	**TOEX-04**
Low Level Elements							
Total Cadmium (Cd)	ug/L	<0.050	<0.050	1.3	2.2	39	3.4
Elements							
Total Aluminum (Al)	mg/L	0.028	0.014	6.9	4.0	6.3	15 (1)
Total Antimony (Sb)	mg/L	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060	<0.0060
Total Arsenic (As)	mg/L	0.0031	0.0033	0.011	0.013	0.016	0.014
Total Barium (Ba)	mg/L	<0.010	<0.010	0.047	0.026	0.077	0.068
Total Beryllium (Be)	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Total Boron (B)	mg/L	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Total Calcium (Ca)	mg/L	<0.30	<0.30	26	26	20	14
Total Chromium (Cr)	mg/L	<0.010	<0.010	<0.010	<0.010	0.22	<0.010
Total Cobalt (Co)	mg/L	<0.0030	<0.0030	0.018	0.020	0.020	0.014
Total Copper (Cu)	mg/L	0.027	0.011	0.097	0.13	0.44	0.16
Total Iron (Fe)	mg/L	<0.060	<0.060	0.46	0.60	1.0	1.2
Total Lead (Pb)	mg/L	<0.0020	<0.0020	0.071	0.13	0.77	0.24
Total Lithium (Li)	mg/L	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Total Magnesium (Mg)	mg/L	<0.20	<0.20	2.5	2.6	0.84	4.6
Total Manganese (Mn)	mg/L	<0.0040	<0.0040	0.32	0.35	0.26	0.30
Total Molybdenum (Mo)	mg/L	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Total Nickel (Ni)	mg/L	<0.0050	<0.0050	0.017	0.022	0.11	0.022
Total Phosphorus (P)	mg/L	<0.10	<0.10	0.45	0.53	1.1	0.33
Total Potassium (K)	mg/L	<0.30	<0.30	1.1	0.62	0.58	0.42
Total Selenium (Se)	mg/L	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Total Silicon (Si)	mg/L	<0.10	<0.10	0.28	0.18	0.27	0.42
Total Silver (Ag)	mg/L	<0.0010	<0.0010	<0.0010	<0.0010	0.017	0.0012
Total Sodium (Na)	mg/L	<0.50	<0.50	0.55	<0.50	<0.50	0.61
Total Strontium (Sr)	mg/L	<0.020	<0.020	0.047	0.045	0.043	0.033
Total Sulphur (S)	mg/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Total Thallium (Tl)	mg/L	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
Total Tin (Sn)	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Total Titanium (Ti)	mg/L	0.019	0.018	0.037	0.023	0.038	0.032
Total Uranium (U)	mg/L	<0.0010	<0.0010	0.0010	<0.0010	<0.0010	0.0054
Total Vanadium (V)	mg/L	0.015	0.015	0.037	0.028	0.037	0.061
Total Zinc (Zn)	mg/L	<0.030	0.042	0.12	0.25	0.61	0.27

RDL = Reportable Detection Limit
EDL = Estimated Detection Limit
(1) Detection limits raised due to dilution to bring analyte within the calibrated range

Maxxam Job #: B202385
Report Date: 2012/01/25

Maxxam ID		CM5488	CM5489	CM5490	CM5491	CM5492	CM5493
Sampling Date		1/10/2012	1/10/2012	1/10/2012	1/10/2012	1/10/2012	1/10/2012
	Units	**TOEX-05**	**TOEX-06**	**TOEX-07**	**TOEX-08**	**TOEX-09**	**TOEX-10**
Low Level Elements							
Total Cadmium (Cd)	ug/L	2.4	4.6	2.8	1.5	1.6	1.6
Elements							
Total Aluminum (Al)	mg/L	4.6	9.4	8.1	6.2	4.5	7.9
Total Antimony (Sb)	mg/L	<0.0060	<0.0060	<0.0060	<0.0060	<0.030	<0.030
Total Arsenic (As)	mg/L	0.013	0.030	0.019	0.0068	0.013	0.021
Total Barium (Ba)	mg/L	0.031	0.044	0.033	0.022	0.27	0.98
Total Beryllium (Be)	mg/L	<0.010	<0.010	<0.010	<0.010	<0.050	<0.050
Total Boron (B)	mg/L	<0.020	<0.020	<0.020	<0.020	<0.20	<0.20
Total Calcium (Ca)	mg/L	45	15	5.1	1.6	310	310
Total Chromium (Cr)	mg/L	<0.010	0.011	<0.010	<0.010	<0.050	<0.050
Total Cobalt (Co)	mg/L	0.012	0.013	0.0095	0.0030	<0.015	0.016
Total Copper (Cu)	mg/L	0.11	0.21	0.14	0.063	0.099	0.82
Total Iron (Fe)	mg/L	0.66	0.54	0.42	0.22	3.5	4.5
Total Lead (Pb)	mg/L	0.21	1.2	0.79	0.26	0.36	6.9
Total Lithium (Li)	mg/L	<0.020	<0.020	<0.020	<0.020	<0.20	<0.20
Total Magnesium (Mg)	mg/L	3.0	2.2	0.59	<0.20	21	16
Total Manganese (Mn)	mg/L	0.21	0.15	0.14	0.11	1.4	2.1
Total Molybdenum (Mo)	mg/L	<0.0020	<0.0020	<0.0020	<0.0020	<0.010	<0.010
Total Nickel (Ni)	mg/L	0.018	0.028	0.019	0.0069	<0.025	<0.025
Total Phosphorus (P)	mg/L	0.67	0.84	0.66	0.22	4.1	6.0
Total Potassium (K)	mg/L	0.72	0.58	0.36	0.33	5.9	7.0
Total Selenium (Se)	mg/L	<0.0020	<0.0020	<0.0020	<0.0020	<0.010	<0.010
Total Silicon (Si)	mg/L	0.19	0.36	0.22	<0.10	2.0	5.1
Total Silver (Ag)	mg/L	<0.0010	0.0023	0.0016	<0.0010	<0.0050	<0.0050
Total Sodium (Na)	mg/L	<0.50	<0.50	<0.50	<0.50	6.4	7.3
Total Strontium (Sr)	mg/L	0.082	0.028	<0.020	<0.020	0.52	0.85
Total Sulphur (S)	mg/L	<0.20	<0.20	<0.20	<0.20	<2.0	<2.0
Total Thallium (Tl)	mg/L	<0.0020	<0.0020	<0.0020	<0.0020	<0.010	<0.010
Total Tin (Sn)	mg/L	<0.010	<0.010	<0.010	<0.010	<0.050	<0.050
Total Titanium (Ti)	mg/L	0.032	0.051	0.046	0.036	<0.050	0.057
Total Uranium (U)	mg/L	0.0011	0.0010	<0.0010	<0.0010	<0.0050	<0.0050
Total Vanadium (V)	mg/L	0.032	0.065	0.051	0.023	<0.050	<0.050
Total Zinc (Zn)	mg/L	0.33	0.57	0.31	0.13	0.27	0.62

Maxxam Job #: B202385
Report Date: 2012/01/25

Maxxam ID		CM5494	CM5495	CM5496	CM5497	CM5498	CM5499
Sampling Date		1/10/2012	1/10/2012	1/10/2012	1/10/2012	1/10/2012	1/10/2012
	Units	**TOEX-11**	**TOEX-12**	**TOEX-13**	**TOEX-14**	**TOEX-15**	**TOEX-16**
Low Level Elements							
Total Cadmium (Cd)	ug/L	2.3	2.3	1.2	1.1	8.9	4.7
Elements							
Total Aluminum (Al)	mg/L	6.1	11	3.7	2.8	11	11
Total Antimony (Sb)	mg/L	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Total Arsenic (As)	mg/L	<0.010	0.010	<0.010	0.011	0.013	0.028
Total Barium (Ba)	mg/L	0.26	0.34	0.19	0.23	1.2	0.42
Total Beryllium (Be)	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Total Boron (B)	mg/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Total Calcium (Ca)	mg/L	37	120	720	280	470	140
Total Chromium (Cr)	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Total Cobalt (Co)	mg/L	<0.015	0.017	0.016	<0.015	<0.015	<0.015
Total Copper (Cu)	mg/L	0.059	0.088	0.11	0.10	0.27	0.22
Total Iron (Fe)	mg/L	2.4	5.5	8.0	8.9	5.5	5.7
Total Lead (Pb)	mg/L	0.14	0.19	0.85	0.12	2.1	1.3
Total Lithium (Li)	mg/L	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Total Magnesium (Mg)	mg/L	2.9	4.5	40	37	43	21
Total Manganese (Mn)	mg/L	1.3	2.2	2.0	1.4	2.2	1.5
Total Molybdenum (Mo)	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Total Nickel (Ni)	mg/L	<0.025	<0.025	<0.025	<0.025	0.034	0.028
Total Phosphorus (P)	mg/L	3.6	4.0	5.3	6.2	5.9	8.2
Total Potassium (K)	mg/L	6.3	4.0	4.4	4.2	9.3	6.1
Total Selenium (Se)	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Total Silicon (Si)	mg/L	1.2	3.9	3.5	1.7	5.1	3.7
Total Silver (Ag)	mg/L	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Total Sodium (Na)	mg/L	5.9	5.5	14	<5.0	<5.0	<5.0
Total Strontium (Sr)	mg/L	<0.20	0.23	1.2	0.44	0.80	0.27
Total Sulphur (S)	mg/L	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Total Thallium (Tl)	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Total Tin (Sn)	mg/L	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Total Titanium (Ti)	mg/L	<0.050	<0.050	0.050	<0.050	<0.050	<0.050
Total Uranium (U)	mg/L	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Total Vanadium (V)	mg/L	<0.050	<0.050	<0.050	<0.050	0.053	0.072
Total Zinc (Zn)	mg/L	<0.15	<0.15	1.1	<0.15	2.2	0.62

Maxxam Job #: B202385
Report Date: 2012/01/25

Maxxam ID		CM5500	CM5501
Sampling Date		1/10/2012	1/10/2012
	Units	**TOEX-17**	**SR12-01**
Low Level Elements			
Total Cadmium (Cd)	ug/L	1.3	390
Elements			
Total Aluminum (Al)	mg/L	3.1	15
Total Antimony (Sb)	mg/L	<0.030	<0.030
Total Arsenic (As)	mg/L	0.012	0.60
Total Barium (Ba)	mg/L	0.25	1.5
Total Beryllium (Be)	mg/L	<0.050	<0.050
Total Boron (B)	mg/L	<0.20	<0.20
Total Calcium (Ca)	mg/L	300	200
Total Chromium (Cr)	mg/L	<0.050	<0.050
Total Cobalt (Co)	mg/L	<0.015	0.038
Total Copper (Cu)	mg/L	0.094	0.57
Total Iron (Fe)	mg/L	9.6	8.7
Total Lead (Pb)	mg/L	0.14	10
Total Lithium (Li)	mg/L	<0.20	<0.20
Total Magnesium (Mg)	mg/L	41	17
Total Manganese (Mn)	mg/L	1.6	3.6
Total Molybdenum (Mo)	mg/L	<0.010	<0.010
Total Nickel (Ni)	mg/L	<0.025	0.041
Total Phosphorus (P)	mg/L	6.7	6.0
Total Potassium (K)	mg/L	4.0	14
Total Selenium (Se)	mg/L	<0.010	<0.010
Total Silicon (Si)	mg/L	1.8	9.2
Total Silver (Ag)	mg/L	<0.0050	0.026
Total Sodium (Na)	mg/L	<5.0	<5.0
Total Strontium (Sr)	mg/L	0.47	0.35
Total Sulphur (S)	mg/L	<2.0	<2.0
Total Thallium (Tl)	mg/L	<0.010	<0.010
Total Tin (Sn)	mg/L	<0.050	<0.050
Total Titanium (Ti)	mg/L	<0.050	<0.050
Total Uranium (U)	mg/L	<0.0050	<0.0050
Total Vanadium (V)	mg/L	<0.050	0.066
Total Zinc (Zn)	mg/L	<0.15	1.2

Appendix E: TOC and pH results

Park Name	Sample #	pH	TOC
Humberwood Park	ONTO-01	7.83	4.8
Summerlea Park	ONTO-02	7.74	4.1
Richview	ONTO-03	7.40	9.2
Centennial Park	ONTO-04	7.65	5.1
Colonel Sam Smith Park	ONTO-05	7.64	5.0
Queen's Park	ONTO-06	7.56	4.3
Allan Gardens	ONTO-07	7.01	3.8
High Park	ONTO-08	6.65	4.0
Christie Pits Park	ONTO-09	6.82	6.5
G. Ross Lord Park	ONTO-10	7.80	2.9
Earl Bales Park	ONTO-11	7.86	2.8
Rouge Park	ONTO-12	8.10	3.9
Motfield Park	ONTO-13	8.85	0.42
Sunnybrook Park	ONTO-14	7.78	3.9
Cherry Beach Park	ONTO-15	7.65	5.7
Queen's Park	ONTO-16	7.56	4.7
Sunnybrook Park	ONTO-17	3.10	3.1

Appendix F: Blanks and standard reference results

Total Metals by ICPMS	BL11-21B (µg/L)	Control limit (µg/L)	SR11-21B (µg/L)	Recovery (%)
Total Aluminum (Al)	<10		8540	
Total Antimony (Sb)	<0.5		9.0	
Total Arsenic (As)	<0.4	<1.0	272	92.2
Total Barium (Ba)	<1		684	
Total Beryllium (Be)	<0.2		2.1	
Total Bismuth (Bi)	<1		4	
Total Boron (B)	<100		<100	
Total Cadmium (Cd)	<0.1		210	
Total Chromium (Cr)	<2		6	
Total Cobalt (Co)	<0.5		17.2	
Total Copper (Cu)	14		256	
Total Iron (Fe)	<20		4230	
Total Lead (Pb)	0.5	<50	5140	111
Total Lithium (Li)	<10		<10	
Total Manganese (Mn)	<1		1810	
Total Mercury (Hg)	<0.2		0.94	
Total Molybdenum (Mo)	<1		<1	
Total Nickel (Ni)	2		19	
Total Selenium (Se)	<0.8		1.2	
Total Silicon (Si)	<2000		4450	
Total Silver (Ag)	<0.1		14.5	
Total Strontium (Sr)	<1		177	
Total Thallium (Tl)	<0.05		7.93	
Total Tin (Sn)	<5		<5	
Total Titanium (Ti)	<10		12	
Total Uranium (U)	<0.1		1.0	
Total Vanadium (V)	<5		22	
Total Zinc (Zn)	10		567	
Total Zirconium (Zr)	<2		2	
Total Calcium (Ca)	<1		107	
Total Magnesium (Mg)	<1		9	
Total Potassium (K)	<1		6	
Total Sodium (Na)	<1		<1	
Total Sulphur (S)	<60		<60	

Appendix G: Bioaccessibility of Selected Contaminants

Arsenic Bioaccessibility

Sample ID	Weight used for extraction (g)	Arsenic in soil (mg/kg)	Arsenic in extract (mg/L)	Arsenic Bioaccessibility (%)
ONTO-01	1.0135	2.9	0.011	**37.4**
ONTO-02	1.0178	3.4	0.013	**37.6**
ONTO-03	1.0324	3.7	0.016	**41.9**
ONTO-04	1.0262	4.1	0.014	**33.3**
ONTO-05	1.0197	2.6	0.013	**49.0**
ONTO-06	1.0086	6.6	0.030	**45.1**
ONTO-07	1.0299	4.9	0.019	**37.6**
ONTO-08	1.0017	3.0	0.0068	**22.6**
ONTO-09	1.0534	3.3	0.013	**37.4**
ONTO-10	1.0068	4.9	0.021	**42.6**
ONTO-11	1.0027	1.9	<0.010	**NC**
ONTO-12	1.0243	2.5	0.010	**39.1**
ONTO-13	1.0572	1.7	<0.010	**NC**
ONTO-14	1.0040	2.3	0.011	**47.6**
ONTO-15	1.0089	3.6	0.013	**35.8**
ONTO-16	1.0393	6.7	0.028	**40.2**
ONTO-17	1.0274	1.7	0.012	**68.7**

NC = Not calculated since concentration in extract was below detection

Barium Bioaccessibility

Sample ID	Weight used for extraction (g)	Barium in soil (mg/kg)	Barium in extract (ug/L)	Barium Bioaccessibility (%)
ONTO-01	1.0135	55	0.047	**8.4**
ONTO-02	1.0178	36	0.026	**7.1**
ONTO-03	1.0324	95	0.077	**7.9**
ONTO-04	1.0262	84	0.068	**7.9**
ONTO-05	1.0197	44	0.031	**6.9**
ONTO-06	1.0086	59	0.044	**7.4**
ONTO-07	1.0299	44	0.033	**7.3**
ONTO-08	1.0017	38	0.022	**5.8**
ONTO-09	1.0534	51	0.27	**50.3**
ONTO-10	1.0068	130	0.98	**74.9**
ONTO-11	1.0027	38	0.26	**68.2**
ONTO-12	1.0243	48	0.34	**69.2**
ONTO-13	1.0572	28	0.19	**64.2**
ONTO-14	1.0040	34	0.23	**67.4**
ONTO-15	1.0089	170	1.2	**70.0**

ONTO-16	1.0393	60	0.42	**67.4**
ONTO-17	1.0274	33	0.25	**73.7**

Cadmium Bioaccessibility

Sample ID	**Weight used for extraction (g)**	**Cadmium in soil (mg/kg)**	**Cadmium in extract (ug/L)**	**Cadmium Bioaccessibility (%)**
ONTO-01	1.0135	0.17	1.3	**75.5**
ONTO-02	1.0178	0.27	2.2	**80.1**
ONTO-03	1.0324	4.6	39	**82.1**
ONTO-04	1.0262	0.40	3.4	**82.8**
ONTO-05	1.0197	0.30	2.4	**78.5**
ONTO-06	1.0086	0.53	4.6	**86.1**
ONTO-07	1.0299	0.40	2.8	**68.0**
ONTO-08	1.0017	0.26	1.5	**57.6**
ONTO-09	1.0534	0.27	1.6	**56.3**
ONTO-10	1.0068	0.20	1.6	**79.5**
ONTO-11	1.0027	0.29	2.3	**79.1**
ONTO-12	1.0243	0.29	2.3	**77.4**
ONTO-13	1.0572	0.15	1.2	**75.7**
ONTO-14	1.0040	0.16	1.1	**68.5**
ONTO-15	1.0089	1.1	8.9	**80.2**
ONTO-16	1.0393	0.56	4.7	**80.8**
ONTO-17	1.0274	0.16	1.3	**79.1**

Cobalt Bioaccessibility

Sample ID	Weight used for extraction (g)	Cobalt in soil (mg/kg)	Cobalt in extract (mg/L)	Cobalt Bioaccessibility (%)
ONTO-01	1.0135	6.5	0.018	**27.3**
ONTO-02	1.0178	6.5	0.020	**30.2**
ONTO-03	1.0324	6.5	0.020	**29.8**
ONTO-04	1.0262	9.3	0.014	**14.7**
ONTO-05	1.0197	4.6	0.012	**25.6**
ONTO-06	1.0086	3.7	0.013	**34.8**
ONTO-07	1.0299	3.0	0.0095	**30.7**
ONTO-08	1.0017	2.2	0.0030	**13.6**
ONTO-09	1.0534	4.1	<0.015	**NC**
ONTO-10	1.0068	4.6	0.016	**34.5**
ONTO-11	1.0027	3.3	<0.015	**NC**
ONTO-12	1.0243	5.0	0.017	**33.2**
ONTO-13	1.0572	4.2	0.016	**36.0**
ONTO-14	1.0040	2.9	<0.015	**NC**
ONTO-15	1.0089	6.3	<0.015	**NC**
ONTO-16	1.0393	3.8	<0.015	**NC**
ONTO-17	1.0274	2.8	<0.015	**NC**

NC = Not calculated since concentration in extract was below detection

Copper Bioaccessibility

Sample ID	Weight used for extraction (g)	Copper in soil (mg/kg)	Copper in extract (mg/L)	Copper Bioaccessibility (%)
ONTO-01	1.0135	18	0.097	**53.2**
ONTO-02	1.0178	21	0.13	**60.8**
ONTO-03	1.0324	77	0.44	**55.3**
ONTO-04	1.0262	28	0.16	**55.7**
ONTO-05	1.0197	23	0.11	**46.9**
ONTO-06	1.0086	31	0.21	**67.2**
ONTO-07	1.0299	21	0.14	**64.7**
ONTO-08	1.0017	12	0.063	**52.4**
ONTO-09	1.0534	20	0.099	**47.0**
ONTO-10	1.0068	88	0.82	**92.6**
ONTO-11	1.0027	8.7	0.059	**67.6**
ONTO-12	1.0243	14	0.088	**61.4**
ONTO-13	1.0572	14	0.11	**74.3**
ONTO-14	1.0040	10	0.10	**99.6**
ONTO-15	1.0089	48	0.27	**55.8**
ONTO-16	1.0393	32	0.22	**66.2**
ONTO-17	1.0274	10	0.094	**91.5**

Lead Bioaccessibility

Sample ID	Weight used for extraction (g)	Lead in soil (mg/kg)	Lead in extract (mg/L)	Lead Bioaccessibility (%)
ONTO-01	1.0135	12	0.071	**58.4**
ONTO-02	1.0178	18	0.13	**71.0**
ONTO-03	1.0324	110	0.77	**67.8**
ONTO-04	1.0262	33	0.24	**70.9**
ONTO-05	1.0197	26	0.21	**79.2**
ONTO-06	1.0086	140	1.2	**85.0**
ONTO-07	1.0299	95	0.79	**80.7**
ONTO-08	1.0017	41	0.26	**63.3**
ONTO-09	1.0534	57	0.36	**60.0**
ONTO-10	1.0068	690	6.9	**99.3**
ONTO-11	1.0027	21	0.14	**66.5**
ONTO-12	1.0243	24	0.19	**77.3**
ONTO-13	1.0572	95	0.85	**84.6**
ONTO-14	1.0040	16	0.12	**74.7**
ONTO-15	1.0089	270	2.1	**77.1**
ONTO-16	1.0393	150	1.3	**83.4**
ONTO-17	1.0274	16	0.14	**85.2**

Iron Bioaccessibility

Sample ID	Weight used for extraction (g)	Iron in soil (mg/kg)	Iron in extract (mg/L)	Iron Bioaccessibility (%)
ONTO-01	1.0135	17000	0.46	**0.3**
ONTO-02	1.0178	16000	0.60	**0.4**
ONTO-03	1.0324	17000	1.0	**0.6**
ONTO-04	1.0262	25000	1.2	**0.5**
ONTO-05	1.0197	12000	0.66	**0.5**
ONTO-06	1.0086	11000	0.54	**0.5**
ONTO-07	1.0299	11000	0.42	**0.4**
ONTO-08	1.0017	9400	0.22	**0.2**
ONTO-09	1.0534	12000	3.5	**2.8**
ONTO-10	1.0068	16000	4.5	**2.8**
ONTO-11	1.0027	11000	2.4	**2.2**
ONTO-12	1.0243	15000	5.5	**3.6**
ONTO-13	1.0572	11000	8.0	**6.9**

ONTO-14	1.0040	9000	8.9	**9.8**
ONTO-15	1.0089	17000	5.5	**3.2**
ONTO-16	1.0393	12000	5.7	**4.6**
ONTO-17	1.0274	8500	9.6	**11.0**

Manganese Bioaccessibility

Sample ID	Weight used for extraction (g)	Manganese in soil (mg/kg)	Manganese in extract (mg/L)	Manganese Bioaccessibility (%)
ONTO-01	1.0135	530	0.32	**6.0**
ONTO-02	1.0178	470	0.35	**7.3**
ONTO-03	1.0324	410	0.26	**6.1**
ONTO-04	1.0262	490	0.30	**6.0**
ONTO-05	1.0197	300	0.21	**6.9**
ONTO-06	1.0086	210	0.15	**7.1**
ONTO-07	1.0299	220	0.14	**6.2**
ONTO-08	1.0017	310	0.11	**3.5**
ONTO-09	1.0534	270	1.4	**49.2**
ONTO-10	1.0068	350	2.1	**59.6**
ONTO-11	1.0027	280	1.3	**46.3**
ONTO-12	1.0243	300	2.2	**71.6**
ONTO-13	1.0572	270	2.0	**70.1**
ONTO-14	1.0040	230	1.4	**60.6**
ONTO-15	1.0089	350	2.2	**62.3**
ONTO-16	1.0393	220	1.5	**65.6**
ONTO-17	1.0274	220	1.6	**70.8**

Nickel Bioaccessibility

Sample ID	Weight used for extraction (g)	Nickel in soil (mg/kg)	Nickel in extract (mg/L)	Nickel Bioaccessibility (%)
ONTO-01	1.0135	14	0.017	**12.0**
ONTO-02	1.0178	14	0.022	**15.4**

ONTO-03	1.0324	33	0.11	**32.3**
ONTO-04	1.0262	24	0.022	**8.9**
ONTO-05	1.0197	11	0.018	**16.0**
ONTO-06	1.0086	10	0.028	**27.8**
ONTO-07	1.0299	8.3	0.019	**22.2**
ONTO-08	1.0017	6.0	0.0069	**11.5**
ONTO-09	1.0534	9.8	<0.025	**NC**
ONTO-10	1.0068	11	<0.025	**NC**
ONTO-11	1.0027	6.4	<0.025	**NC**
ONTO-12	1.0243	10	<0.025	**NC**
ONTO-13	1.0572	9.2	<0.025	**NC**
ONTO-14	1.0040	6.3	<0.025	**NC**
ONTO-15	1.0089	18	0.034	**18.7**
ONTO-16	1.0393	11	0.028	**24.5**
ONTO-17	1.0274	6.1	<0.025	**NC**

NC = Not calculated since concentration in extract was below detection

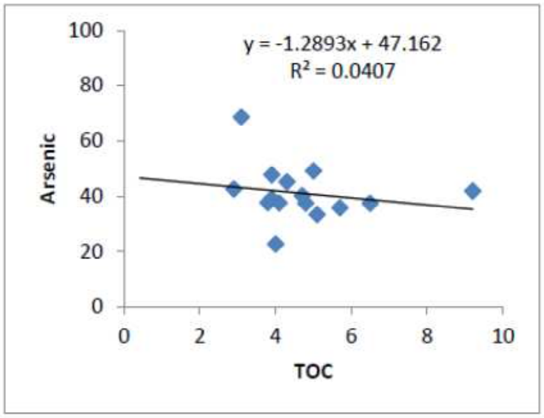
Zinc Bioaccessibility

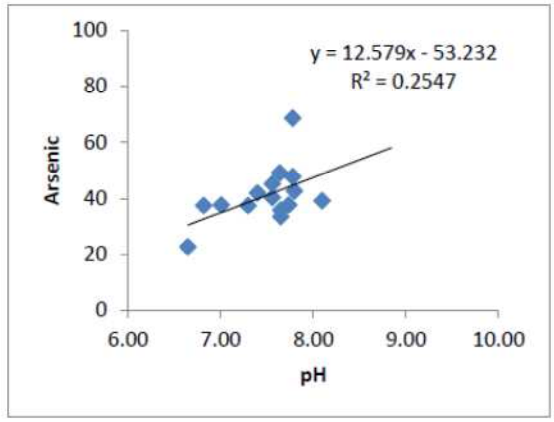
Sample ID	Weight used for extraction (g)	Zinc in soil (mg/kg)	Zinc in extract (mg/L)	Zinc Bioaccessibility (%)
ONTO-01	1.0135	51	0.12	**23.2**
ONTO-02	1.0178	64	0.25	**38.4**
ONTO-03	1.0324	160	0.61	**36.9**
ONTO-04	1.0262	120	0.27	**21.9**
ONTO-05	1.0197	69	0.33	**46.9**
ONTO-06	1.0086	110	0.57	**51.4**
ONTO-07	1.0299	78	0.31	**38.6**
ONTO-08	1.0017	45	0.13	**28.8**
ONTO-09	1.0534	72	0.27	**35.6**
ONTO-10	1.0068	110	0.62	**56.0**
ONTO-11	1.0027	35	<0.15	**NC**
ONTO-12	1.0243	49	<0.15	**NC**
ONTO-13	1.0572	160	1.1	**65.0**
ONTO-14	1.0040	33	<0.15	**NC**
ONTO-15	1.0089	350	2.2	**62.3**
ONTO-16	1.0393	110	0.62	**54.2**
ONTO-17	1.0274	31	<0.15	**NC**

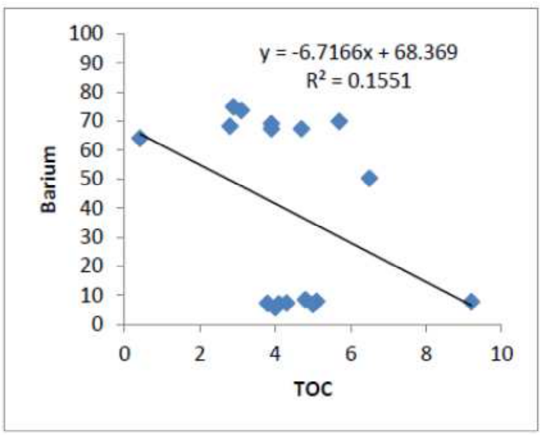
NC = Not calculated since concentration in extract was below detection

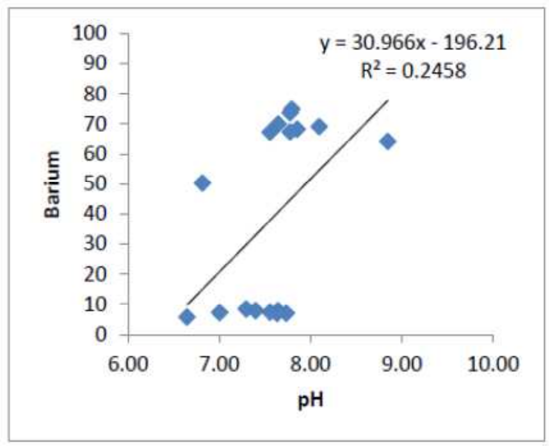
Appendix H: Effect of TOC and pH on bioaccessibility

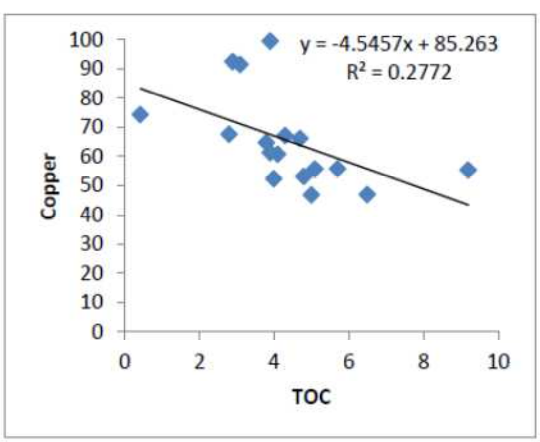
Effect of TOC and pH on bioaccessibility of selected contaminants of concern

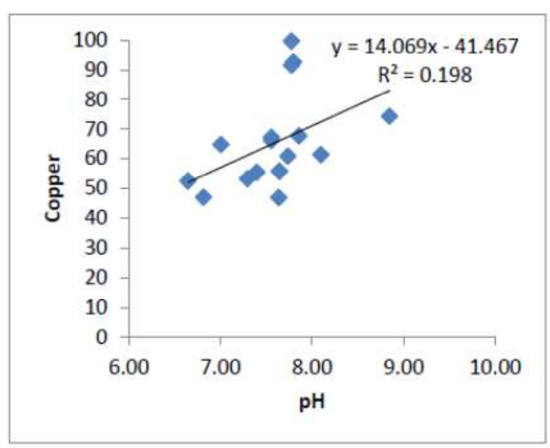


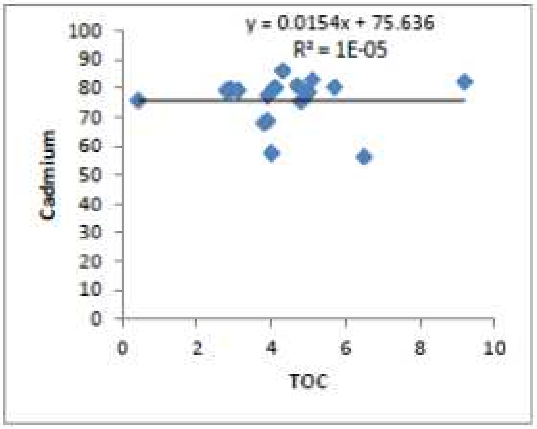


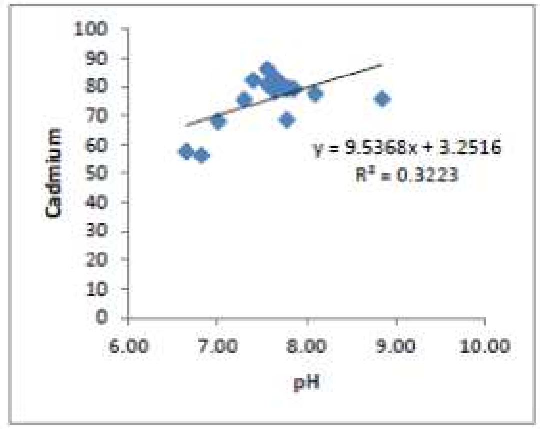


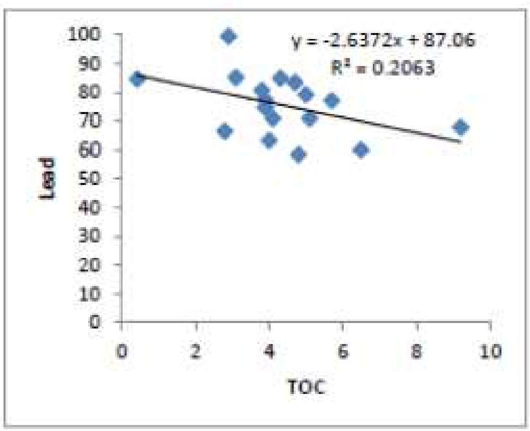


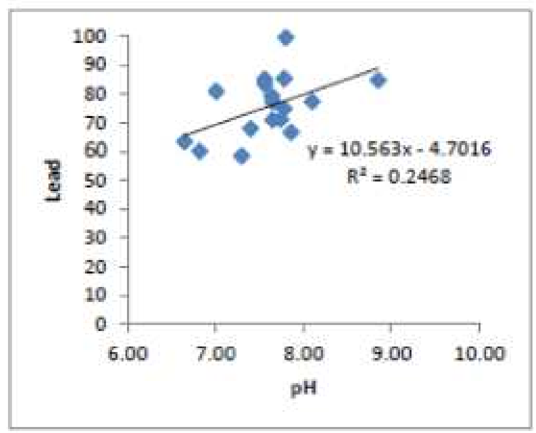


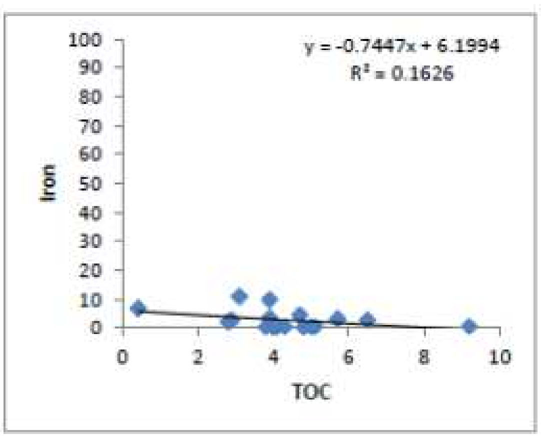


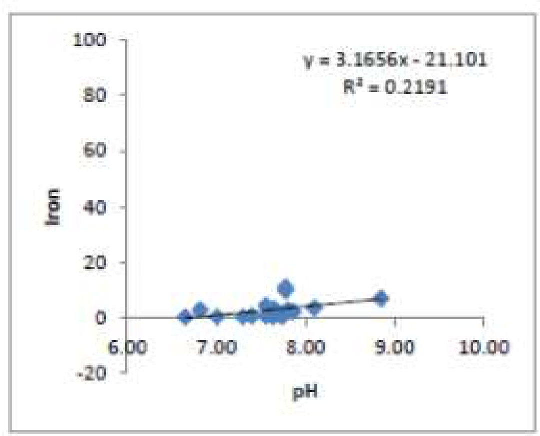

y = 0.0154x + 75.636
R² = 1E-05
Cadmium
TOC

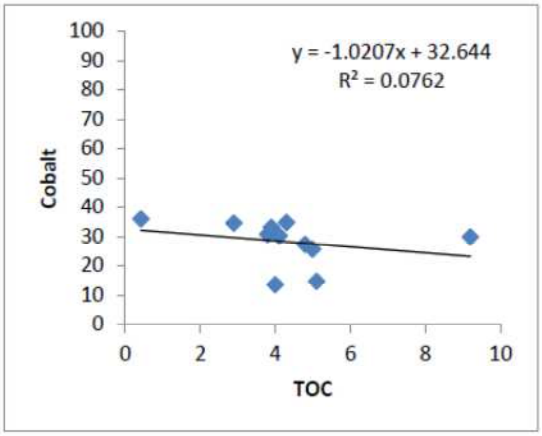

y = 9.5368x + 3.2516
R² = 0.3223
Cadmium
pH

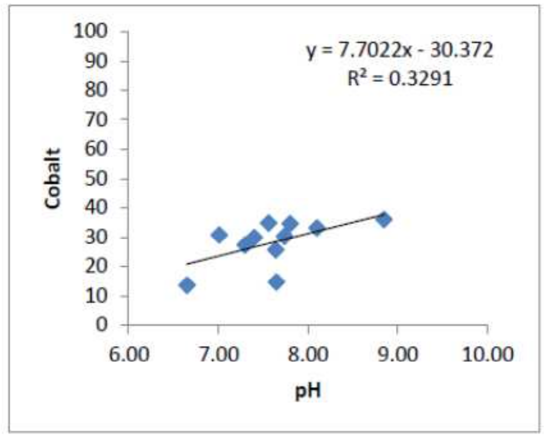

y = -2.6372x + 87.06
R² = 0.2063
Lead
TOC

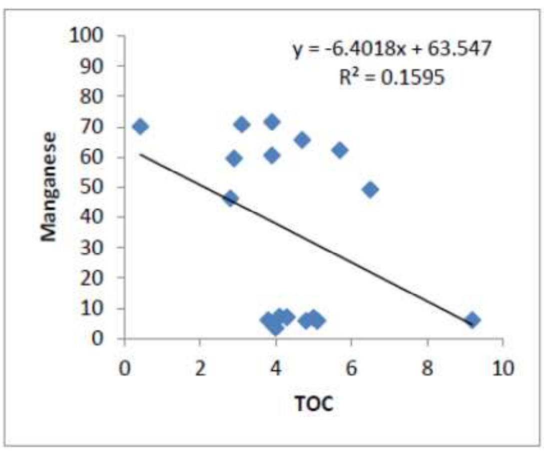

y = 10.563x - 4.7016
R² = 0.2468
Lead
pH

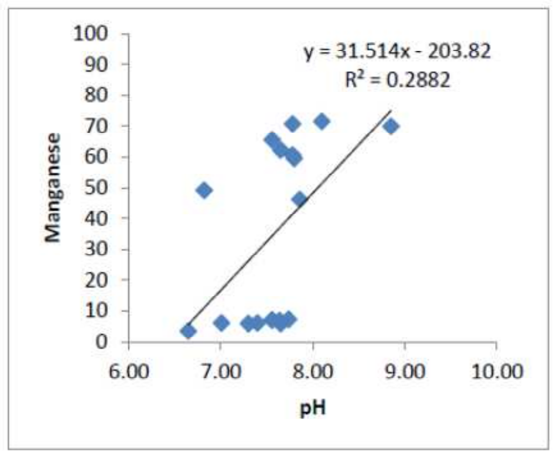

y = -0.7447x + 6.1994
R² = 0.1626
Iron
TOC


y = 3.1656x - 21.101
R² = 0.2191
Iron
pH


y = -1.0207x + 32.644
R² = 0.0762
Cobalt
TOC
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10


y = 7.7022x - 30.372
R² = 0.3291
Cobalt
pH
0
10
20
30
40
50
60
70
80
90
100
6.00
7.00
8.00
9.00
10.00


y = -6.4018x + 63.547
R² = 0.1595
Manganese
TOC
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10


y = 31.514x - 203.82
R² = 0.2882
Manganese
pH
0
10
20
30
40
50
60
70
80
90
100
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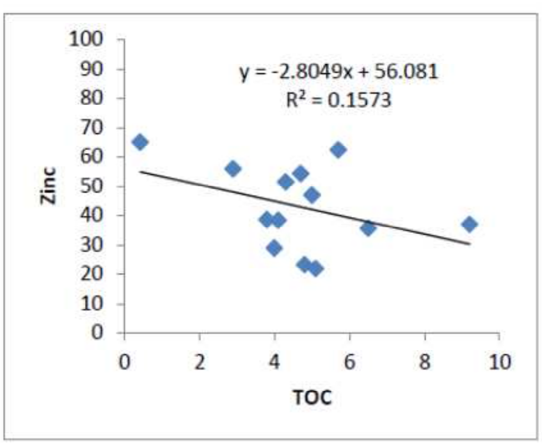
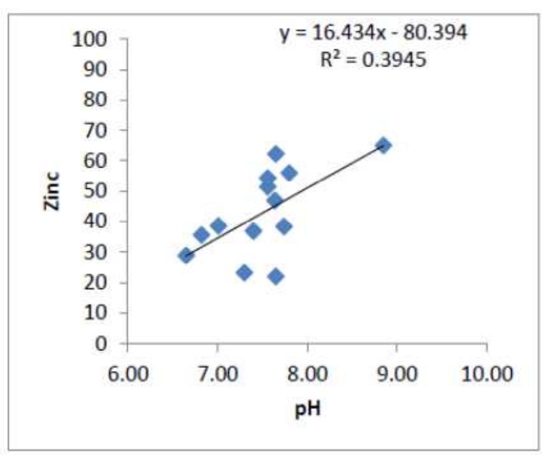
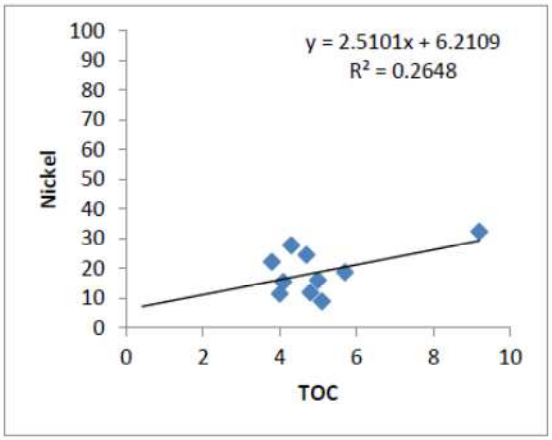
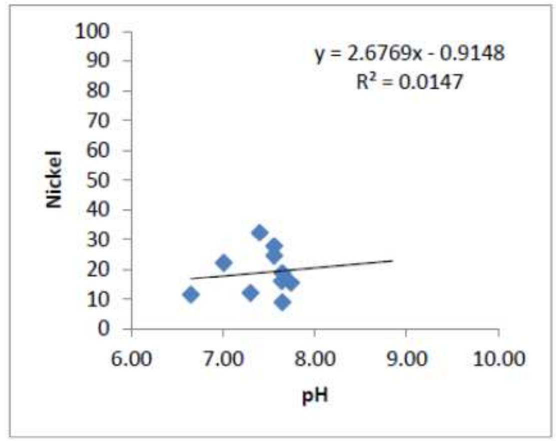
7.00
8.00
9.00
10.00


y = -2.8049x + 56.081
R² = 0.1573
Zinc
TOC
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10


y = 16.434x - 80.394
R² = 0.3945
Zinc
pH
0
10
20
30
40
50
60
70
80
90
100
6.00
7.00
8.00
9.00
10.00


y = 2.5101x + 6.2109
R^2 = 0.2648
Nickel
TOC
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10


y = 2.6769x - 0.9148
R^2 = 0.0147
Nickel
pH
100
90
80
70
60
50
40
30
20
10
0
6.00
7.00
8.00
9.00
10.00