

Memo

Date: August 18, 2008
To: Alan Hair From: Elliot Sigal
cc:
Re: Supplemental Dust Study

Supplemental Dust Study – Preliminary Results

We are in receipt of the preliminary results from the supplemental vacuum dust study of carpeted areas in residential properties. Initial testing of vacuum dust and associated wipe samples from hardwood floors and window sills was completed in 2007. The supplemental study of vacuum dust was necessary due to problems with the initial vacuum study that resulted in an insufficient volume of material being collected in the 2007 study. Due to the low volume of material collected, the original study was unable to obtain the detection limits necessary for risk assessment purposes.

Results from the supplemental study indicate that lead dust vacuum results from two of 38 residential properties sampled were exceptionally high. The two samples were taken from homes in Manitoba. Lead concentrations on dust wipe samples taken from hardwood floors and window sills inside both of these houses in 2007 were low (less than available guidelines) and co-located yard soil was also low (228 ppm) at one of the houses, with no yard soil sample having been taken at the other property. It is doubtful that the extreme levels found in the vacuum samples are connected to the facility, based on the fingerprint of the metals within the samples. These two samples are considered statistical outliers and are referred to as such. Beyond these two samples, both lead and arsenic vacuum dust results appear elevated for about half of the homes tested, albeit, there are no criteria to compare to dust results. Floor and windowsill wipe results for all homes fell within acceptable ranges for lead (there are no guidelines for other metals).

At this point, we have some concerns related to the accuracy of the 2008 vacuum dust results. As pointed out below, some of the trends noted with these data raise some serious doubt as to the validity of these results. Jacques Whitford and Bodycote (the lab where the material was analyzed) have completed their QA/QC process and both feel that the results are reflective of the dust samples provided. Bodycote is a CAEAL (Canadian Association for Environmental Analytical Laboratories) accredited lab and they met all of their QA/QC tolerances (reproducibility and comparison to certified reference material); however, we are still awaiting information from Bodycote regarding other available QA/QC data to further evaluate data quality. We have made arrangements for the 2008 samples to be sent to Testmark Laboratories in Sudbury for further analysis. We have used Testmark on previous studies for dust analysis, and they have a protocol developed for this type of analysis. It

appears as if there might be enough material remaining for Testmark to conduct analysis on most, if not all of the samples. These results should be available within a week or two, and would provide an indication of whether the Bodycote results are reproducible. We have also sent splits from 5 or 6 of the larger vacuum dust samples to Dr. John Drexler at the University of Colorado for speciation analysis. This analysis may be able to provide some insight into the source of the lead (and/or other metals) in the samples.

At this point, we feel that there are three questions that must be considered:

- 1) what do we have?
- 2) what does it mean?
- 3) what are we going to do about it?

The following is a summary of our findings, details are provided below:

Summary of 'What do we have':

- We have two dust samples (out of 38) which appear to be outliers from the remaining data, and are distinguished by very high lead and tin concentrations (elevated tin levels have not been found in previous sampling programs);
- The remaining 36 dust samples generally have maximum metal values that are similar to those reported in an urban community, which does not have a point source emitter, with the exception of some of the metals associated with the facility (e.g., copper, zinc, etc.);
- Dust wipe samples from hardwood floors and window sills taken in 2007 from these same properties do not suggest any concerns related to lead exposures (guidelines are not available for other metals);
- An expected relationship between co-located outdoor soils and indoor dusts is not evident in the data, which suggests the possibility of other source(s);
- The expected geographical distribution of results is not present;
- While Quality Assurance of the data has been approved by the laboratory, there are still some outstanding Quality Assurance questions that we feel need to be answered. The tin data within laboratory duplicates have poor repeatability, which suggests that tin results should be treated with some degree of caution; and,
- The samples are being re-analyzed by another laboratory facility to confirm repeatability of results (supplementary Quality Assurance standards are also being run by this lab, to enhance the data quality assessment), and some samples have also been submitted to a geochemistry laboratory for speciation analysis.

Summary of ‘What does it mean’:

The interpretation of these results is unclear for the following reasons:

- some of the data remains in question and further analysis is underway;
- the hard surface floor and windowsill data taken from the same properties were all within acceptable ranges for lead;
- the HVS3 vacuum used in the study is specially designed to collect deeply embedded material;
- since no regulatory benchmarks exist for dust, this data will require thorough evaluation in the HHRA; and,
- based on comparisons to urban house dust characterized in Ottawa, the samples collected in the Flin Flon study appear to be similar to those reported in Ottawa for many of the metals.

Summary of ‘What are we going to do about it’:

- Notification;
- Additional analysis;
- Speciality speciation; and,
- Re-sampling in some homes.

1) What do we have?

The preliminary results from the supplemental vacuum dust study have indicated some potentially elevated levels of lead and other metals in house dust of homes in the Flin Flon area (see Table 1). No regulatory benchmarks or criteria for vacuum dust exist; these data were collected for input into the human health risk assessment. Wipe samples of other surfaces within these homes, collected as part of the original 2007 dust study, were all within acceptable ranges for lead. Also of note, results for schools and daycares were on the low end of the range and are not considered elevated.

Closer examination of these data has highlighted several issues, as detailed below:

- Soil to dust relationships:

The purpose of the vacuum dust study was to investigate the relationship between outdoor soil and indoor dust. In locations such as Flin Flon, where metals levels are elevated in soil due to an anthropogenic source, it is hypothesized that there is a statistically significant relationship between outdoor soil and indoor dust indicating that soil is having some influence on indoor dust concentrations. This type of relationship is expected in areas with elevated soil concentrations. With the exception of mercury, this relationship is not observed for any of the chemicals of concern. Both linear and non-linear (log-log) correlations were estimated for all co-located soil and dust samples, and these relationships were not significant, indicating a poor correlation. In other words, there was no relationship between outdoor soil and indoor dust observed. The lack of this relationship was unexpected and is difficult to explain.

Of particular note are the elevated tin levels in the dust. Tin levels are not elevated in soils in the Flin Flon area and elevated dust levels are difficult to explain.

The correlation curves are provided in Appendix A.

- Geographical Distribution of Results

As indicated above, examination of the results of the supplementary dust study reveal a lack of correlation between dust and soil concentrations in the Flin Flon area. As such, the geographical distribution of dust concentrations is contrary to the geographical distribution of soil concentrations. That is, dust concentration patterns, primarily for lead and arsenic, are not similar to those observed with soil and do not decrease in relation to the HBMS facility, as would be expected. Concentrations tend to be lower in the west Flin Flon area and elevated in west Creighton and east Flin Flon.

Table 1. Metals in Flin Flon Area Indoor Dust

Laboratory Lot Ref. #	Laboratory Sample #	Sample ID	Sample Date	Analytical Results (mg/kg)																											
				Aluminum	Antimony	Arsenic	Barium	Beryllium	Bismuth	Cadmium	Chromium	Calcium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese	Mercury	Molybdenum	Nickel	Phosphorus	Selenium	Silicon	Silver	Strontium	Thallium	Tin	Titanium	Vanadium	Zinc
1	2773454	AA-DS-1	6/23/08	8590	2.2	36.2	162	0.2	3.1	11.79	57.8	41600	12.3	1397	16800	152	14000	235	-	3	30.1	900	2.8	1090	2.1	425	0.16	5	496	28.6	1764
2	2773606	AG-DS-1	6/23/08	7530	7.1	47.0	200	<0.5	8.0	35.09	85.7	56300	14.0	3297	23100	943	9400	250	-	10	131.8	1700	5.2	1600	30.0	130	<0.20	583	445	23.0	2894
3	2773607	BD-DS-1	6/23/08	3190	2.4	29.0	100	<0.1	22.3	8.43	43.8	65900	7.9	1097	13500	568	8200	142	-	6	63.2	1900	2.4	860	5.8	69	0.09	294	177	11.0	2294
4	2773608	AS-DS-1	6/23/08	9910	1.4	52.1	174	0.3	3.0	16.09	49.9	52200	17.3	2377	22700	166	29100	294	2.40	4	19.9	910	5.0	1320	2.5	45	0.22	9	658	35.0	2544
5	2773609	A-DS-1	6/23/08	5110	4.8	102.0	87	0.1	3.3	19.19	57.4	68400	18.8	3517	22100	231	23000	206	10.10	5	37.0	1360	8.6	1420	4.3	93	0.23	346	309	17.8	3644
6	2773610	F-DS-1	6/23/08	4060	2.5	31.5	125	<0.1	2.9	14.19	46.0	16500	8.2	2057	9290	124	6300	107	1.97	26	18.7	830	3.1	860	4.5	27	0.12	13	223	11.5	1374
7	2773611	Q-DS-1	6/23/08	8070	3.6	36.7	206	0.2	2.1	14.89	62.2	25400	13.2	1557	17400	284	10200	213	5.40	34	45.6	1540	4.2	1200	4.1	50	0.16	16	432	20.4	3884
45	2773649	QZ-DS-1*	6/23/08	7670	4.4	36.3	204	0.2	1.5	14.59	60.4	24100	13.0	1507	16900	504	9900	205	-	31	44.6	1540	3.8	1160	3.8	50	0.16	166	420	19.7	3594
8	2773612	O-DS-1	6/23/08	8080	9.5	56.3	257	<0.2	<1.0	27.59	76.4	40300	11.0	2197	17500	722	12000	230	-	6	89.8	1000	5.1	4230	4.1	200	0.10	353	345	16.0	4294
9	2773613	X-DS-1	6/23/08	6850	2.9	52.9	276	0.1	24.0	25.59	46.5	33300	17.1	3307	16200	306	5200	228	16.00	4	51.5	970	9.4	800	2.8	139	0.15	20	462	20.8	3424
10	2773614	AH-DS-1	6/24/08	10900	4.0	54.7	260	0.2	2.7	12.59	60.2	80600	12.5	2337	16900	171	10600	192	7.20	3	24.4	1090	6.2	1650	2.4	76	0.17	26	560	27.5	2334
11	2773615	K-DS-1	6/24/08	6460	3.1	97.1	277	0.2	2.3	20.49	44.2	34200	18.3	4817	23600	331	10900	223	7.70	6	24.1	810	9.6	1250	6.3	149	0.26	32	311	15.8	4624
12	2773616	BC-DS-1	6/24/08	6160	12.0	78.4	170	<0.6	<3.0	23.19	63.9	28000	15.0	2797	18800	1179	7300	180	-	<6	44.8	1600	10.0	2200	6.7	68	<0.30	773	362	17.0	3314
13	2773617	W-DS-1	6/24/08	9810	6.0	31.0	340	<0.8	<4.0	11.59	68.0	34000	9.4	1857	14400	919	12000	170	-	<8	27.8	1300	3.0	4000	4.0	79	<0.40	616	347	15.0	2364
14	2773618	BB-DS-1	6/24/08	13100	4.6	38.1	293	0.2	3.0	13.49	82.9	58000	17.5	1497	26900	163	16600	330	2.85	5	199.8	1400	3.6	1500	30.8	77	0.18	30	787	44.7	2324
15	2773619	E-DS-1	6/24/08	5940	3.2	78.3	205	<0.1	3.6	23.29	36.3	19600	17.8	5507	23600	585	10600	183	-	8	14.7	1360	15.9	830	5.4	40	0.27	174	379	20.6	4974
16	2773620	L-DS-1	6/24/08	8460	16.0	71.2	409	0.2	3.3	26.49	62.8	29000	14.0	2887	23400	399	12500	392	8.10	11	30.6	1190	7.8	1170	10.0	52	0.28	26	540	26.3	3604
17	2773621	Y-DS-1	6/24/08	7980	2.9	79.4	314	0.2	3.9	20.99	47.4	40500	20.7	5607	25400	210	14500	307	13.30	7	18.8	1620	11.1	1880	4.0	92	0.24	24	608	26.8	4894
46	2773650	YZ-DS-1*	6/24/08	7610	2.9	83.9	305	0.2	3.2	21.09	43.7	38600	21.1	5707	25100	226	15000	299	11.90	7	19.9	1620	11.1	1500	4.0	90	0.24	28	466	25.1	4224
18	2773622	AC-DS-1	6/24/08	7700	45.0	86.0	220	<1.0	<7.0	24.69	61.0	38000	23.0	4727	23700	11399	10000	170	-	<10	34.8	1000	10.0	5800	18.0	80	<0.70	7896	341	16.0	4434
19	2773623	AL-DS-1	6/24/08	8970	6.5	50.7	225	0.2	28.3	9.23	54.7	31700	11.5	1357	18100	279	15700	226	-	4	30.6	880	3.4	1020	2.2	44	0.14	125	446	21.2	1664
20	2773624	AW-DS-1	6/24/08	7980	1.6	55.8	161	0.2	9.6	9.35	51.5	26600	11.8	1187	18200	96	10700	197	1.65	2	15.8	1810	4.0	1130	1.6	47	0.16	14	410	24.1	1804
21	2773625	AB-DS-1	6/25/08	9180	2.2	50.3	207	0.2	1.4	10.99	48.3	28000	12.5	1237	18700	128	12200	219	1.52	4	22.2	1810	3.2	1230	1.7	42	0.19	16	550	29.0	5344
22	2773626	C-DS-1	6/25/08	8300	54.0	56.0	300	<5.0	<30.0	28.39	110.0	30000	20.0	4997	23000	34399	10000	<500	-	<50	71.8	3000	<20.0	9000	40.0	70	<3.00	20996	646	30.0	6674
23	2773627	U-DS-1	6/25/08	8600	3.6	51.1	224	0.2	5.1	14.69	92.9	31800	13.7	1907	15000	185	11200	199	1.90	4	27.6	2290	2.9	1740	2.2	78	0.15	45	438	20.0	2534
24	2773628	R-DS-1	6/25/08	7140	9.8	73.0	244	<0.2	3.5	28.19	45.3	24700	15.0	4317	20600	1289	12000	210	-	6	22.4	1800	5.4	1600	9.3	48	0.20	656	462	22.0	3954
25	2773629	AR-DS-1	6/25/08	8130	14.0	38.9	408	0.5	<2.0	16.49	116.0	80500	13.0	1667	16100	2199	23000	250	-	4	23.8	2000	3.8	2200	3.8	549	0.20	996	398	17.0	2154
26	2773630	AT-DS-1	6/25/08	17600	1.0	27.5	220	0.4	2.1	11.79	109.0	30400	17.8	1087	28200	129	19200	402	2.04	4	55.6	1490	2.8	1950	1.6	82	0.28	7	1180	59.0	1724
27	2773631	N-DS-1	6/25/08	9930	1.6	22.9	213	0.3	1.7	12.59	56.6	28900	11.4	1177	17200	119	11600	232	1.79	4	35.4	1470	2.3	940	3.1	47	0.15	12	632	31.3	2734
28	2773632	D-DS-1	6/25/08	6460	12.0	66.9	270	<0.3	5.4	49.79	53.0	34600	15.0	3177	18200	1829	12000	190	-	4	20.3	1700	9.2	2800	4.8	67	0.20	1196	370	18.0	4014
29	2773633	T-DS-1	6/25/08	7270	7.9	83.3	170	<0.5	8.8	16.39	90.2	44000	12.0	1677	17400	997	19000	190	-	<5	72.1	1400	4.0	2800	5.2	150	<0.20	627	340	16.0	1984
30	2773634	AN-DS-1	6/25/08	8010	2.7	38.7	412	0.2	1.4	16.19	104.0	35200	19.8	1897	22300	314	12000	323	-	56	34.2	1070	3.6	1850	1.8	178	0.16	110	452	40.0	2034
31	2773635	AO-DS-1	6/25/08	4570	4.4	85.7	358	<0.1	2.2	24.59	35.4	23100	21.8	7517	25000	304	12000	204	35.00	9	24.1	840	16.0	1090	5.5	48	0.24	19	296	17.1	6014
32	2773636	AJ-DS-1	6/26/08	10200	3.7	65.7	349	0.3	4.2	19.99	63.6	31800	17.1	4257	22900	346	12000	244	9.93	7	49.9	1420	8.7	1150	4.4	53	0.22	53	617	31.9	4984
47	2773651	AJZ-DS-1*	6/26/08	9690	4.7	64.0	331	0.3	4.6	19.79	60.6	30800	17.4	4077	22300	855	11500	238	-	6	47.1	1310	9.1	1000	5.3	51	0.22	396	590	30.8	4974
33	2773637	P-DS-1	6/26/08	9000	5.6	53.3	938	0.2	3.7	19.79	65.0	32900	14.6	4657	20300	833	13000	208	-	6	45.3	1000	5.8	2140	4.7	62	0.17	486	495	22.0	3384
34	2773638	AD-DS-1	6/26/08	6810	4.6	187.0	219	0.1	2.1	15.99	56.9	60100	23.9	2477	32100	306	28400	261	5.10	10	43.7	4580	7.8	1500	3.2	1040	0.36	70	395	20.4	3244
35	2773639	J-DS-1	6/26/08	5800	14.0	60.0	200	<0.9	5.0	16.39	54.0	36000	14.0	2807	17300	1969	14000	160	-	<9	25.8	1200	5.0	4600	11.0	230	<0.40	1586	369	16.0	3334
36	2773640	AK-DS-1	6/26/08	6050	4.9	56.0	204	0.2	3.5	10.79	39.7	25800	11.4	1377	15100	455	9200	145	-	4	17.7	1000	5.6	960	2.7	56	0.17	214	293	14.4	1864
37	2773641	S-DS-1	6/26/08	9020	7.2	41.7	257	0.2	2.3	12.89	41.9	22800	8.7	997	14000	1059	7600	180	-	4	40.2	1960	2.6	1600	2.9	72	0.10	370	404	18.9	1324
38	2773642	AY-DS-1	6/26/08	7920	4.0	84.6	146	0.2	2.6	29.99	46.6	20200	16.6	3517	24100	340	8600	237	26.00	7	25.5	980	13.3	1140	3.5	47	0.34	20	449	27.4	5054
Laboratory Detection Limits				20	0.2	0.2	1	0.1	0.5	0.01	0.5	200	0.1	1	100	0.1	100	10	0.01	1	0.5	30	0.3	50	0.1	1	0.05	1	0.5	0.1	1

- Chemical to chemical interrelationships/concentration trends:

Also of interest is a comparison of the interrelationships between chemicals in soil versus those in dust. A simplistic method of looking at these trends is to look at the correlation between various elements, to look for common trends. As shown in Appendix B, these trends are very different for soil as compared to dust. In soil, arsenic, copper and zinc all correlate extremely well with lead, while in dust none of these elements correlate with lead. Conversely, lead correlates extremely well with tin in dust, but not at all in soil. This correlation between lead and tin is unexpected given the constituents of smelter emissions and tailings, and is likely indicative of a sampling error, an analytical error or a source unrelated to the smelter.

A principal components analysis is a more statistically robust method for looking at these types of trends. Principal components analysis (PCA) is used for two objectives: (1) reducing the number of variables comprising a dataset while retaining the variability in the data, and (2) identifying patterns in the data, and classifying them according to how much information they account for. The objective of this analysis was to investigate relationships between metal (and related elements) concentrations in paired soil and dust samples collected from residential lots within the study area. The detailed methods and results of the PCA are included in Appendix C.

Six principal components were identified and considered, accounting for approximately 90% of the total variance in the dataset. Additional components did not significantly increase the percentage of the variation accounted for by the model. The first component explains the highest proportion of the variation (39%), and is strongly correlated with 10 of the 24 original variables, including: lead, silver, copper, cadmium, zinc, antimony, arsenic and cobalt in soil, as well as, to a lesser extent, selenium in soil. The second component explains 18% of the variation in the original dataset, and is strongly correlated with lead, tin and antimony concentration in dust. The third through sixth components all relate to intercorrelations within the dust. Each component reflects a correlation trend in the original data. However, the exact cause of the trend may not be easily explained. Generally, the principal components in this analysis split the variables of the dataset by media. That is to say that most of the components appear to be governed by either concentrations in soil, or concentrations in dust. This suggests a lack of correlation between the two (i.e., we cannot accurately predict metals concentrations in dust from known concentrations in soil, nor vice versa). It is possible that two or more components are associated with a common source. Manifestation of such a source in soil and dust concentrations may be multidimensional, and related to other factors governing concentrations in soil and dust.

- Matrix Interference:

Examination of the supplementary dust data reveals elevated detection limits for a number of elements in the two samples with extremely elevated lead and tin levels. These elevated detection limits suggest that some type of matrix interference was occurring in these samples and as such, these results are suspect.

- Comparison to other locations:

Other than the two extremely elevated samples, the lead results for Flin Flon are generally not outside of range reported for an urban area without a point source. Table 2 provides a comparison of the Flin Flon dataset (both with the two high samples included, and without those samples) with typically house dust levels characterized by Rasmussen et al. (2001) from the Ottawa area (no point source industry present). Arithmetic mean, 90th%ile and maximum concentration metrics are presented for comparison purposes. Average and 90th%ile dust metal concentrations are higher than those reported for the Ottawa area for many of the elements, including arsenic, cadmium, copper, lead, silver, tin and zinc. Maximum levels in Flin Flon are similar to those in the Ottawa area when the 2 high samples are removed from the dataset, albeit some of the metals associated with the facility (such as copper and zinc, for example) are higher. Two important differences in the datasets are critical to note:

- The Rasmussen data was generated using a total acid digestion (with hydrofluoric acid) which tends to liberate all metals from the soil particles. Typically, in environmental studies of metals, an available digest is conducted (involving nitric acid, such as method US EPA 3050B), which is the approach used in the Flin Flon dataset. The comparison of total digest to available digest is complicated by the fact that some metals (particularly aluminum and iron) will be present in higher concentrations when a total digest is applied to a given sample. Other metals, such as lead and arsenic, for example, are not influenced as strongly by the differences in acid strength.
- The Rasmussen data was generated based on a sieve size of 100 – 250 μm , whereas the Flin Flon data was generated based on sieving the dust to 63 μm . The smaller sieve size used in the Flin Flon study is the standard size (as per ASTM protocols) for dust studies. Comparisons of samples using different sieve sizes is complicated by the fact that metal concentrations tend to increase on smaller particles, due to surface area differences. Therefore, one would expect that a 63 μm sample would have higher metals loadings than a 100 – 250 μm sample. Finer size fractions generally have higher element concentrations values than coarser fractions (Duggan and Inskip, 1985; Gulson et al, 1995; cited in Rasmussen et al, 2001).

Based on these considerations, Table 2 suggests that the Flin Flon dataset is higher than typical house dust, but this comparison is complicated by a potential bias related to digest applied (which would bias the Ottawa data high) and sieve size (which would bias the Ottawa concentrations low, when compared to those reported in the Flin Flon dataset). Examination of the maximum metals concentrations measured suggested that while the Flin Flon data set are higher than many of the concentrations measured in Ottawa area, the metals concentrations are similar, especially considering that the Flin Flon data would be expected to exhibit higher concentrations based on sieve size alone (finer sieve used). The metals with the most marked differences between the datasets are lead and tin, which are orders of magnitude higher when the two elevated samples are considered ($n = 38$), but concentrations of lead fall within the range measured in the Ottawa area for all other samples ($N = 36$) suggesting that the measured concentrations of lead within the town of Flin Flon are similar to those seen elsewhere (with the exception of the two particularly elevated samples).

Table 2 Comparison of Arithmetic Mean, 90th percentile and Maximum Dust Concentrations in Flin Flon Area to Concentrations reported in Urban House Dust (Rasmussen et al., 2001)

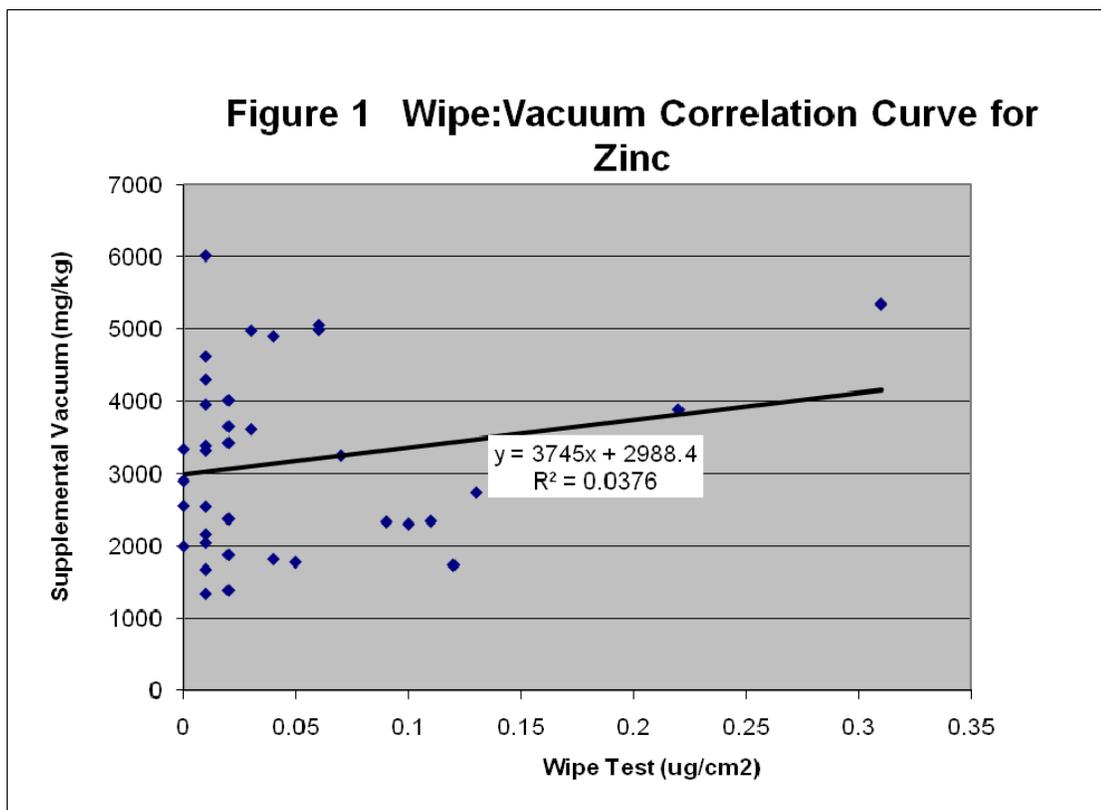
Element	Arithmetic Mean Dust Concentration (mg/kg)			90 th Percentile Dust Concentration (mg/kg)			Maximum Dust Concentration (mg/kg)		
	Rasmussen et al. (2001) Dataset (n=48)	Flin Flon Dataset		Rasmussen et al. (2001) Dataset (n=48)	Flin Flon Dataset		Rasmussen et al. (2001) Dataset (n=48)	Flin Flon Dataset	
		All Data (n=38)	Samples with two lead outliers removed (n=36)		All Data (n=38)	Samples with two lead outliers removed (n=36)		All Data (n=38)	Samples with two lead outliers removed (n=36)
Aluminum	25948	8022.11	8023.33	40160	10011	10065	51100	17600	17600
Antimony	7.28	7.86	5.54	12.50	14	12	57.41	54	16
Arsenic	7.3	60.71	60.14	12.8	85.79	85.15	79.5	187	187
Barium	492	257.89	257.78	682	373	383	1480	938	938
Beryllium	0.56	0.41	0.27	0.81	0.66	0.5	1.00	5	0.9
Bismuth	1.67	5.98	5.29	3.78	13.41	9.2	8.62	30	28.3
Cadmium	6.46	19.07	18.65	15.30	28.26	27.9	34.94	49.8	49.8
Chromium	86.7	62.82	61.56	157.3	96.23	91.55	330.3	116	116
Calcium	48760	37918.42	38136.11	65300	61840	63000	117200	80600	80600
Cobalt	8.92	14.99	14.63	12.05	20.21	19.3	22.67	23.9	23.9
Copper	206.08	2795.79	2680.83	381.76	4874	4740	601.47	7520	7520
Iron	14135	19976.05	19788.61	19120	25120	25200	40350	32100	32100
Lead	405.56	1749.07	574.02	969.37	1872	1235	3225.66	34400	2200
Magnesium	9826	13047.37	13216.67	12895	20340	21100	23250	29100	29100
Manganese	269.3	232.34	226.64	365.8	325.1	315	423.5	500	402
Molybdenum	3.16	9.61	8.47	3.78	15.5	10.5	28.64	56	56
Nickel	62.9	51.61	51.00	103.4	81.09	76.85	243.3	209	209
Phosphorus	1380	1478.42	1449.44	1761	1972	1930	3600	4580	4580
Selenium	1.2	6.64	6.18	2.0	11.76	10.55	6.8	20	16
Silicon	-	2002.63	1702.78	-	4069	2800	-	9000	4600
Silver	2.05	6.92	5.69	4.46	13.1	9.65	9.33	40	30.8

Table 2 Comparison of Arithmetic Mean, 90th percentile and Maximum Dust Concentrations in Flin Flon Area to Concentrations reported in Urban House Dust (Rasmussen et al., 2001)

Element	Arithmetic Mean Dust Concentration (mg/kg)			90 th Percentile Dust Concentration (mg/kg)			Maximum Dust Concentration (mg/kg)		
	Rasmussen et al. (2001) Dataset (n=48)	Flin Flon Dataset		Rasmussen et al. (2001) Dataset (n=48)	Flin Flon Dataset		Rasmussen et al. (2001) Dataset (n=48)	Flin Flon Dataset	
		All Data (n=38)	Samples with two lead outliers removed (n=36)		All Data (n=38)	Samples with two lead outliers removed (n=36)		All Data (n=38)	Samples with two lead outliers removed (n=36)
Strontium	255	128.97	131.97	369	209	215	410	1040	1040
Thallium	0.14	0.30	0.21	0.20	0.372	0.32	0.24	3	0.4
Tin	54.84	1026.47	280.72	111.12	1060	718.5	595.02	21000	1590
Titanium	-	458.53	456.58	-	636.2	624.5	-	1180	1180
Vanadium	24.8	23.41	23.43	35.5	32.83	33.45	43.6	59	59
Zinc	716.9	3290.26	3164.17	1226.0	5011	4985	1840.0	6680	6020
Mercury	3.633	8.42	8.42	6.565	18	18	37.099	35	35

- Dust to wipe relationships:

The original (2007) dust study included wipe sampling in addition to vacuum sampling. One would expect to find a correlation between wipe and vacuum samples on a location-by-location basis. Wipe results are skewed by levels below the analytical detection limit for the majority of elements; however, zinc is an example of an element where this comparison can be considered. As indicated in Figure 1, the hypothesized correlation between wipe and supplemental vacuum results is non-existent.



- QA/QC concerns:

Examination of the analytical data generated for the supplemental dust study reveal several QA/QC concerns issues related to the data. Bodycote, in Winnipeg, the lab where the material was analyzed, have completed their QA/QC check and feel that the results are acceptable according to their CAEAL accredited standards (i.e., they met all of their QA/QC tolerances related to reproducibility and comparison to certified reference material). However, some outstanding issues remain regarding these data and we are still awaiting information from Bodycote regarding other available QA/QC data to further evaluate data quality. These issues/questions include:

- Use of a non-validated analytical test method (Bodycote has indicated that the method is validated for soil but not validated for dust)
- Use of a certified reference material (CRM) soil standard (SS-2) rather than a CRM dust standard (this should not create a concern, as the SS-2 standard was subjected to the same analytical protocol as the dust samples)
- Inconsistency between Bodycote's reported CRM standards and the SS-2 Certificate of Analysis
- Poor data reproducibility for tin within the laboratory duplicates submitted for analysis by JWL (all other metals were within acceptable ranges), as detailed below:

Laboratory Duplicate Quality Assurance Check

As part of the JWL supplementary dust study, 3 samples were split in the field, and sent to the laboratory for analysis as duplicates. The duplicate samples are identified in Table 3 with a "z" letter coding. Similar to metals in soil, dust metal levels would be expected to have some degree of variability within a given sample (heterogeneous material). While no specific Data Quality Objectives were identified as part of the supplemental dust study, the application of Data Quality Objectives established by the US EPA for metals in soils and sediments were considered to represent a reasonable surrogate for evaluation of the within-laboratory duplicates (Standard Operation Procedure, US EPA Region 2, Sept. 2006). Calculation of the Relative Percent Difference (RPD) between the various metals detected within the duplicate samples, and comparisons to accepted ranges was undertaken for the current dataset as a data quality assurance check. Accepted ranges cited by US EPA (2006) are:

- a) if any RPD is $> 35\%$ and $< 120\%$ then the sample is flagged with a 'J' as an estimate
- b) if any RPD is $> 120\%$ then the sample is reject and flagged with an 'R'
- c) if samples are < 5 times the MDL (method detection limit), an absolute difference, rather than a relative percent difference, is calculated. If result is $> 2 * \text{MDL}$ (method detection limit) and $< 4 * \text{MDL}$ then the sample is flagged with a 'J' as an estimate
- d) if any absolute difference is $> 4 * \text{MDL}$ then the sample is reject and flagged with an 'R'

All metals/metalloids for the three duplicates met US EPA guidance for repeatability, with the following exceptions:

- For sample AJ-DS-1 and its lab duplicate AJZ-DS-1, two of the parameters had an RPD value over the US EPA (2006) guidance. Lead had an RPD of 84.62% and tin had an RPD of 150.11%. The lead value would be acceptable for use in decision making (as an estimate value), whereas the tin value would not be considered acceptable for decision making.
- For sample Q-DS-1 and its lab duplicate QZ-DS-1, two of the parameters had an RPD value over the US EPA (2006) standard. Lead had an RPD of 55.72% and tin had an RPD of 157.89%. Again, the lead value is still acceptable for decision-making, whereas as the tin value would not be considered acceptable for decision-making (RPD of tin is $\geq 120\%$).

These results show very good to acceptable agreement for all metals/metalloids within the three duplicate analyses, with the exception of tin, wherein two out of the three duplicate analyses showed poor reproducibility. Based on the outcomes of these comparisons, the metals analyses are considered acceptable and reasonable, but the tin results in all samples should be considered suspect, and treated with caution.

Table 3 Relative Percent Difference Quality Assurance Calculations for Duplicate Dust Samples (JWL, 2008)

	Sample Description	Q-DS-1	QZ-DS-1			Y-DS-1	YZ-DS-1			AJ-DS-1	AJZ-DS-1		
Parameter Name	Detection Limit	Result (mg/kg)	Result (mg/kg)	RPD (%)	Abs Calc	Result (mg/kg)	Result (mg/kg)	RPD (%)	Abs Calc	Result (mg/kg)	Result (mg/kg)	RPD	Abs Calc
Aluminum	20	8070	7670	5.08		7980	7610	4.75		10200	9690	5.13	
Antimony	0.2	3.6	4.4	-20.00		2.9	2.9	0.00		3.7	4.7	-23.81	
Arsenic	0.2	36.7	36.3	1.10		79.4	83.9	-5.51		65.7	64	2.62	
Barium	1	206	204	0.98		314	305	2.91		349	331	5.29	
Beryllium	0.1	0.2	0.2		0	0.2	0.2		0	0.3	0.3		0
Bismuth	0.5	2.1	1.5		0.6	3.9	3.2	19.72		4.2	4.6	-9.09	
Cadmium	0.01	14.9	14.6	2.03		21	21.1	-0.48		20	19.8	1.01	
Chromium	0.5	62.2	60.4	2.94		47.4	43.7	8.12		63.6	60.6	4.83	
Calcium	200	25400	24100	5.25		40500	38600	4.80		31800	30800	3.19	
Cobalt	0.1	13.2	13	1.53		20.7	21.1	-1.91		17.1	17.4	-1.74	
Copper	1	1560	1510	3.26		5610	5710	-1.77		4260	4080	4.32	
Iron	100	17400	16900	2.92		25400	25100	1.19		22900	22300	2.65	
Lead	0.1	285	505	-55.70		211	227	-7.31		347	856	-84.62	
Magnesium	100	10200	9900	2.99		14500	15000	-3.39		12000	11500	4.26	
Manganese	10	213	205	3.83		307	299	2.64		244	238	2.49	
Molybdenum	1	34	31	9.23		7	7	0.00		7	6	15.38	
Nickel	0.5	54.8	53.8	1.84		28	29.1	-3.85		59.1	56.3	4.85	
Phosphorus	30	1540	1540	0.00		1620	1620	0.00		1420	1310	8.06	
Selenium	0.3	4.2	3.8	10.00		11.1	11.1	0.00		8.7	9.1	-4.49	
Silicon	50	1200	1160	3.39		1880	1500	22.49		1150	1000	13.95	
Silver	0.1	4.1	3.8	7.59		4	4	0.00		4.4	5.3	-18.56	
Strontium	1	50	50	0.00		92	90	2.20		53	51	3.85	
Thallium	0.05	0.16	0.16		0	0.24	0.24		0	0.22	0.22		0
Tin	1	20	170	-157.89		28	32	-13.33		57	400	-150.11	
Titanium	0.5	432	420	2.82		608	466	26.44		617	590	4.47	
Vanadium	0.1	20.4	19.7	3.49		26.8	25.1	6.55		31.9	30.8	3.51	
Zinc	1	3890	3600	7.74		4900	4230	14.68		4990	4980	0.20	
Mercury	0.01	5.4				13.3	11.9	11.11		9.93			

Note:

Abs = absolute difference calculation

RPD = relative percent difference calculation

If the RPD was above 35% and below 120 % then the cell was shaded in purple; RPD >120% is highlighted in green.

If the absolute value is greater than 2*MDL and below 4*MDL from either of the labs then the cell is shaded in purple; any above 4*MDL are highlighted in green.

Summary of 'What do we have':

- We have two dust samples (out of 38) which appear to be outliers from the remaining data, and are distinguished by very high lead and tin concentrations (elevated tin levels have not been found in previous sampling programs);
- The remaining 36 dust samples generally have maximum metal values that are similar to those reported in an urban community, which does not have a point source emitter, with the exception of some of the metals associated with the facility (e.g., copper, zinc, etc.);
- Dust wipe samples from hardwood floors and window sills taken in 2007 from these same properties do not suggest any concerns related to lead exposures (guidelines are not available for other metals);
- An expected relationship between co-located outdoor soils and indoor dusts is not evident in the data, which suggests the possibility of other source(s);
- The expected geographical distribution of results is not present;
- While Quality Assurance of the data has been approved by the laboratory, there are still some outstanding Quality Assurance questions that we feel need to be answered. The tin data within laboratory duplicates have poor repeatability, which suggests that tin results should be treated with some degree of caution; and,
- The samples are being re-analyzed by another laboratory facility to confirm repeatability of results (supplementary Quality Assurance standards are also being run by this lab, to enhance the data quality assessment), and some samples have also been submitted to a geochemistry laboratory for speciation analysis.

2) What does it mean?

The interpretation of these results is unclear for the following reasons:

- a) as discussed above, some of the data remains in question and re-analysis is underway, as well as supplementary analysis (speciation testing) of some samples, to enable a better understanding of outcomes of the current analytical laboratory work. The speciation work will hopefully assist in further evaluation of source attribution. Based on the results of the reanalysis and the speciation analysis, it may be necessary to resample some or all of the homes (see below);
- b) the hard surface floor and window sill data taken from the same properties in 2007 were all within acceptable ranges for lead (< HUD guidelines);

- c) the HVS3 vacuum used in the study is specially designed to collect deeply embedded material and therefore some of the material drawn into the sample bottle would not normally be available for exposure; the high concentrations may be related to deeply embedded small paint chips, or other sources of contamination.
- d) since no regulatory benchmarks exist for dust, this data will require thorough evaluation in the HHRA; and,
- e) Based on comparisons to urban house dust characterized in Ottawa, the maximum detected concentrations in 36 out of 38 samples in the 2008 Flin Flon study appear to be similar to those reported in Ottawa for many of the metals, albeit metals associated with the smelter are higher (which is expected due to the presence of a point source). Two of the Flin Flon samples have results which are notably higher than those seen in the Ottawa study, particularly for lead and tin.

3) What are we doing about it?

- a) Notification:
 - i. The metal of greatest interest to us, as toxicologists, in this study is lead, due to the known association with lead exposure and children's health. Although the accuracy of the results are questionable, we recommend that the two residents with the extremely high lead values be notified. The purpose of the notification would be to inform the residents of the findings, re-sample the property (interior dust and exterior soil samples) to confirm whether the results are repeatable, gather additional information about the possible sources/reasons for the high values; and, provide information about ways to reduce exposure, in the interim period until the validity of the results is established.
 - ii. Lead results for other locations do not need notification at this time in our opinion, based on the following:
 - Average and maximum lead dust levels are similar in the remaining locations to those reported in Ottawa in a study of urban house dust, which suggests that they are not atypical (despite sieve size differences in these studies, which should bias the current studies results high); and,
 - The window sill and hardwood floor data for remaining properties were below the HUD guidelines for lead, which provides some reassurance with respect to exposure levels

The lack of a reliable benchmark of comparison for dust, coupled with the comparison to dust data from other locals, leads us to make this recommendation for the two residential

properties with high lead values. The recommendation for immediate notification is somewhat arbitrary and will be re-visited once additional data becomes available.

An appropriate communication and action plan should be developed by HBMS/Intrinsic and Manitoba Health & Healthy Living in line with the actions taken for the elevated lead in soil sample in Creighton (which similarly was not consistent with HBMS operations as the source).

Notification related to other metals detected in the dust is not suggested at this time, based on comparisons to the Ottawa data, pending additional data for the various analyses currently underway, and the fact that lead is the metal of primary concern due to previously stated associated with exposure and children's health.

- b) Additional analysis is currently underway on some of the same samples, at a second lab, to confirm the results. These data will be presented in the final report along with the initial data.
- c) Speciality speciation analysis is also being commissioned to examine the form of lead (and other metals?) in the samples, in order to assist with source attribution.
- d) A second sample will be taken in these homes (through vacuum bag collection and/or repeat HSV3 sampling), as well as the exterior yards, to further clarify the results.

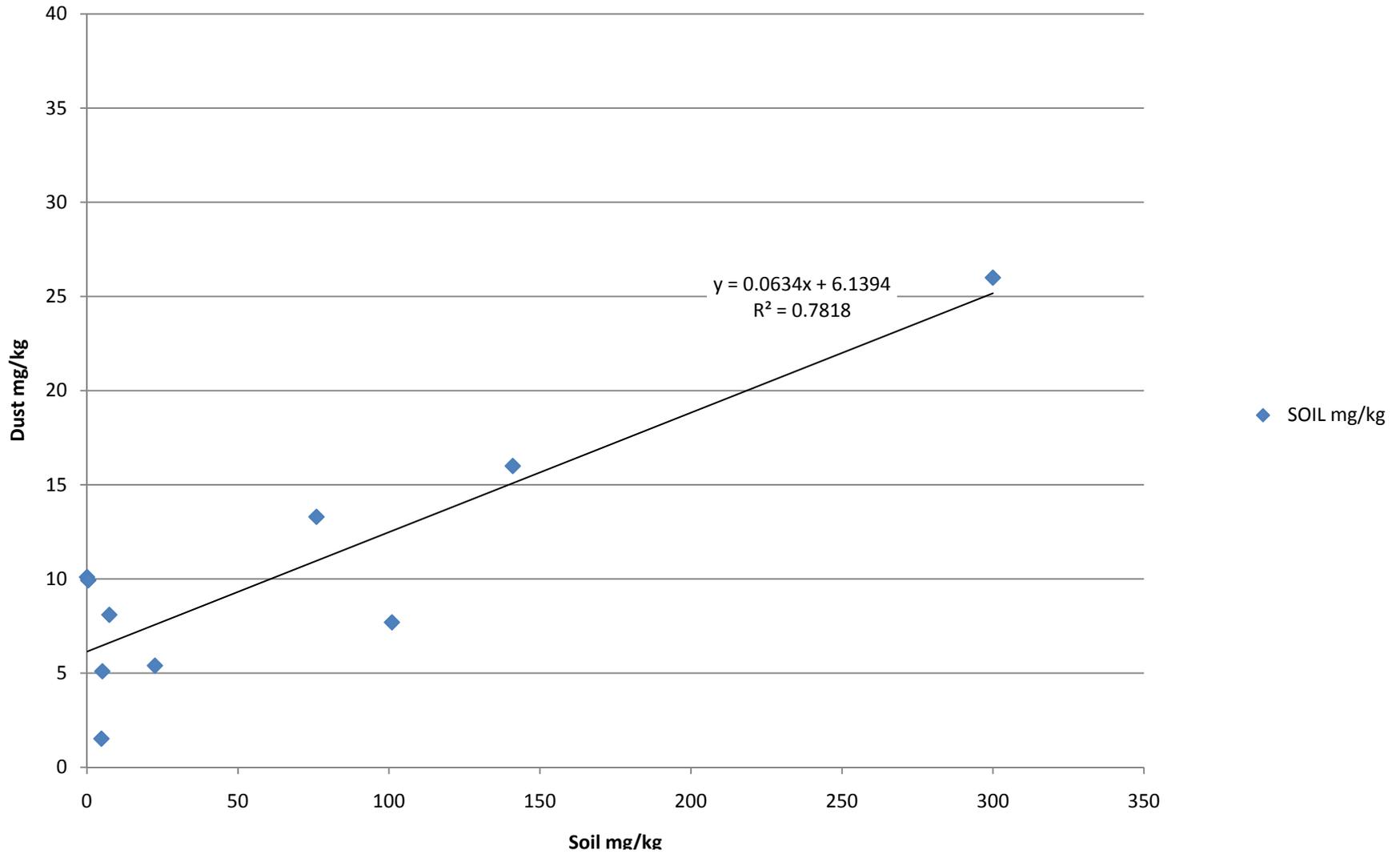
Once these additional data become available, the following will be considered in future decision making related to the dust outcomes:

- re-analysis of dust samples by Testmark
- speciation analysis by Dr. Drexler
- re-sampling and analysis of homes with elevated levels of metals in dust
- results of the HHRA for all chemicals of concern

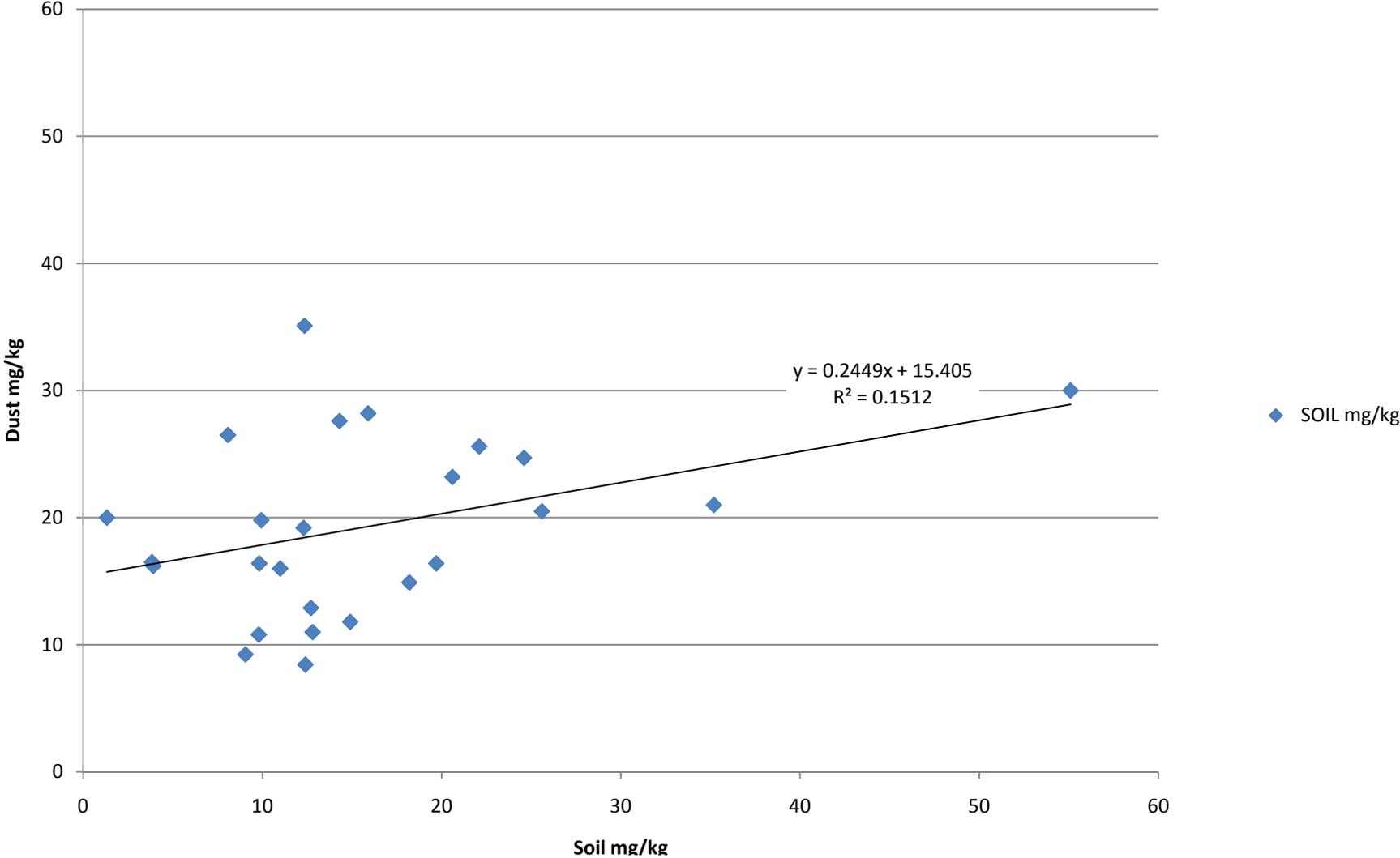
Appendix A

Soil:Dust Correlation Curves

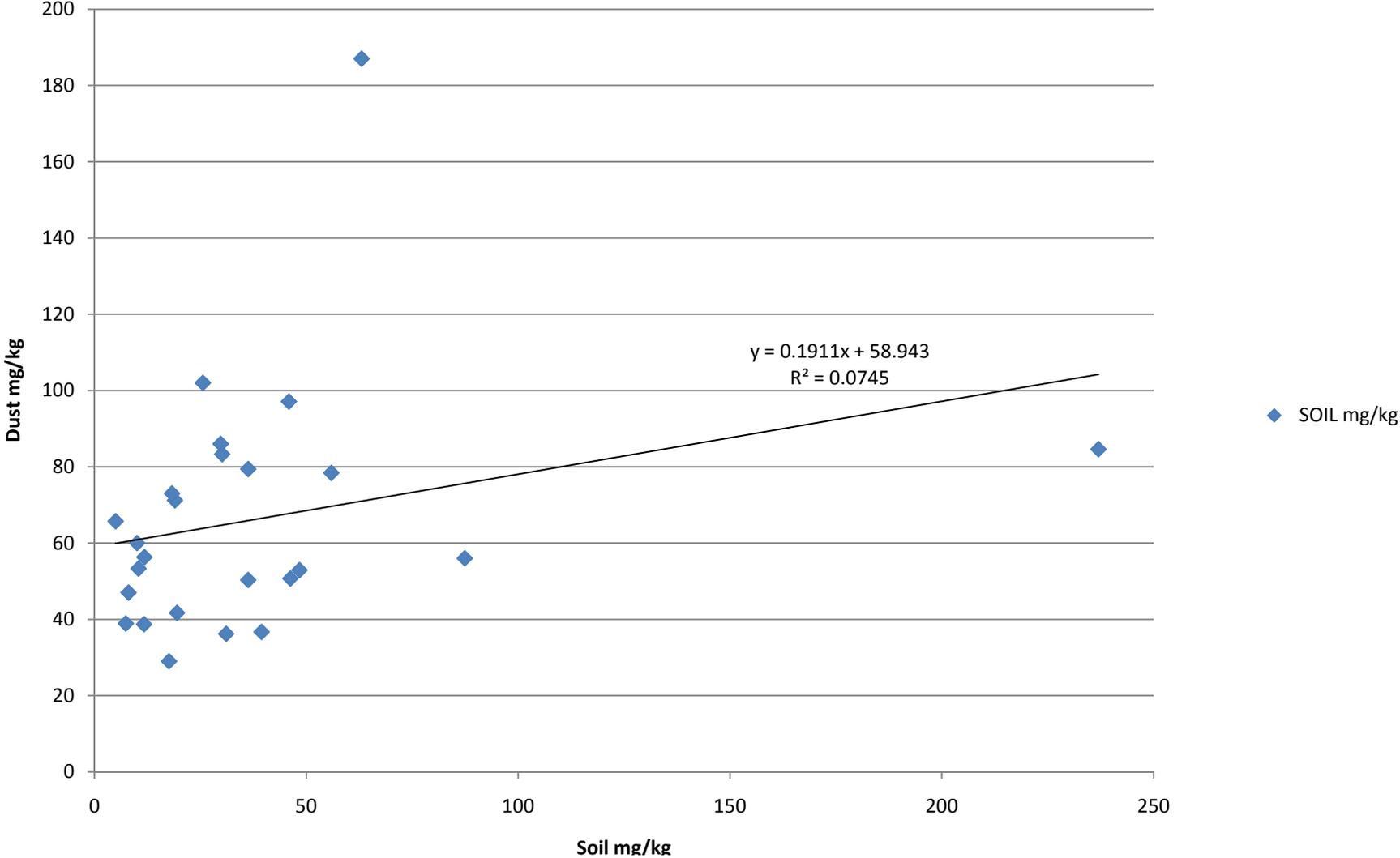
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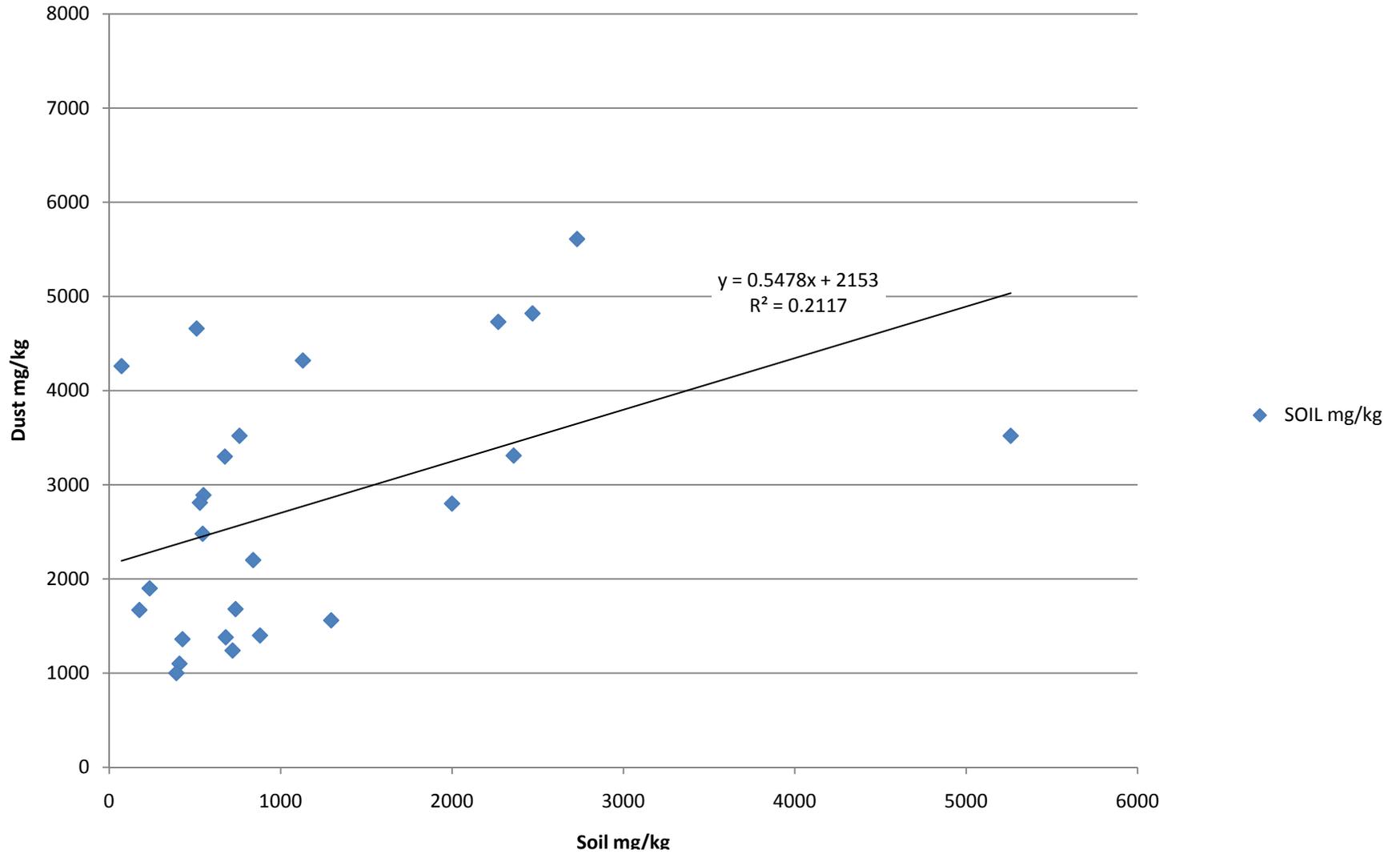
CADMIUM



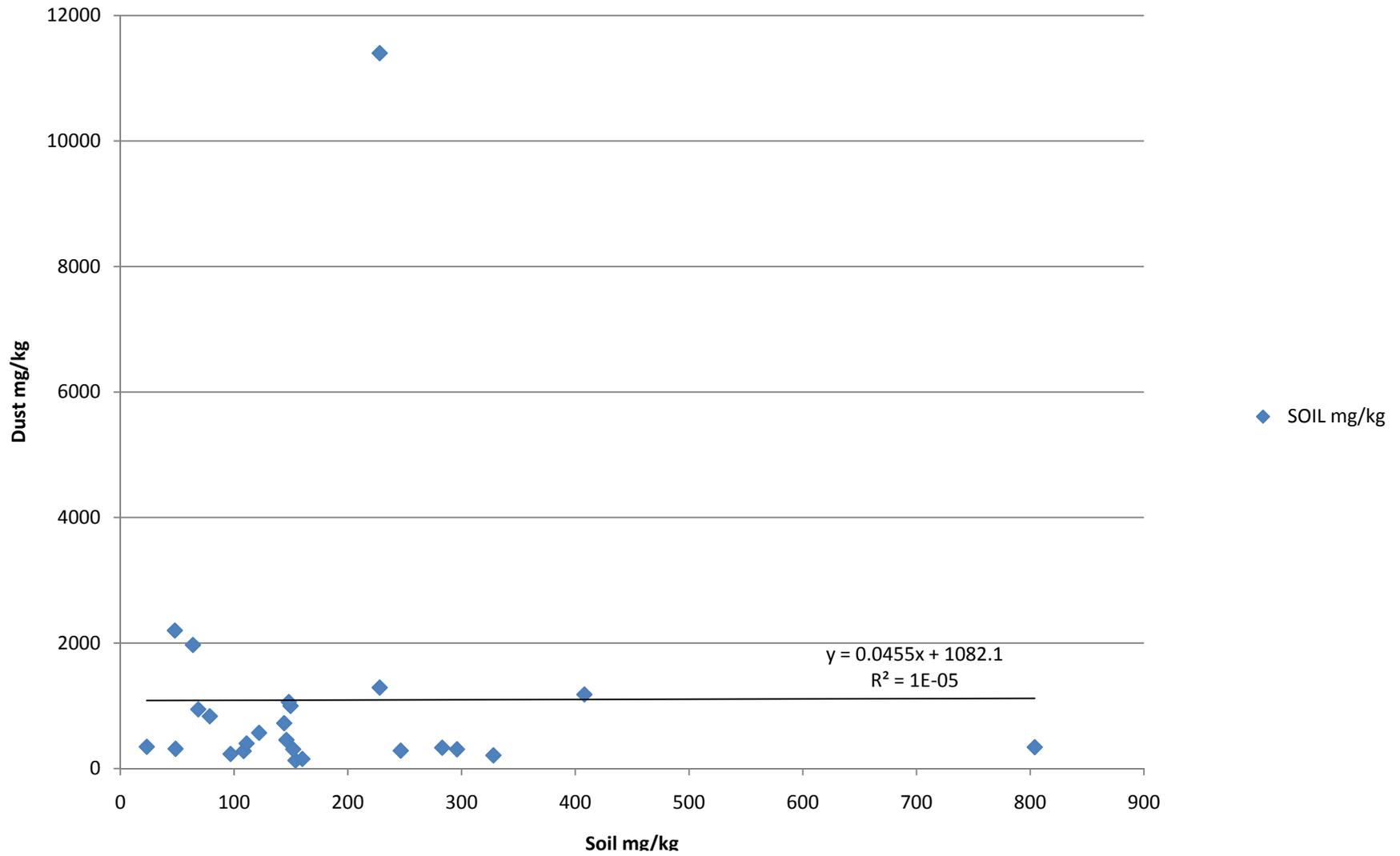
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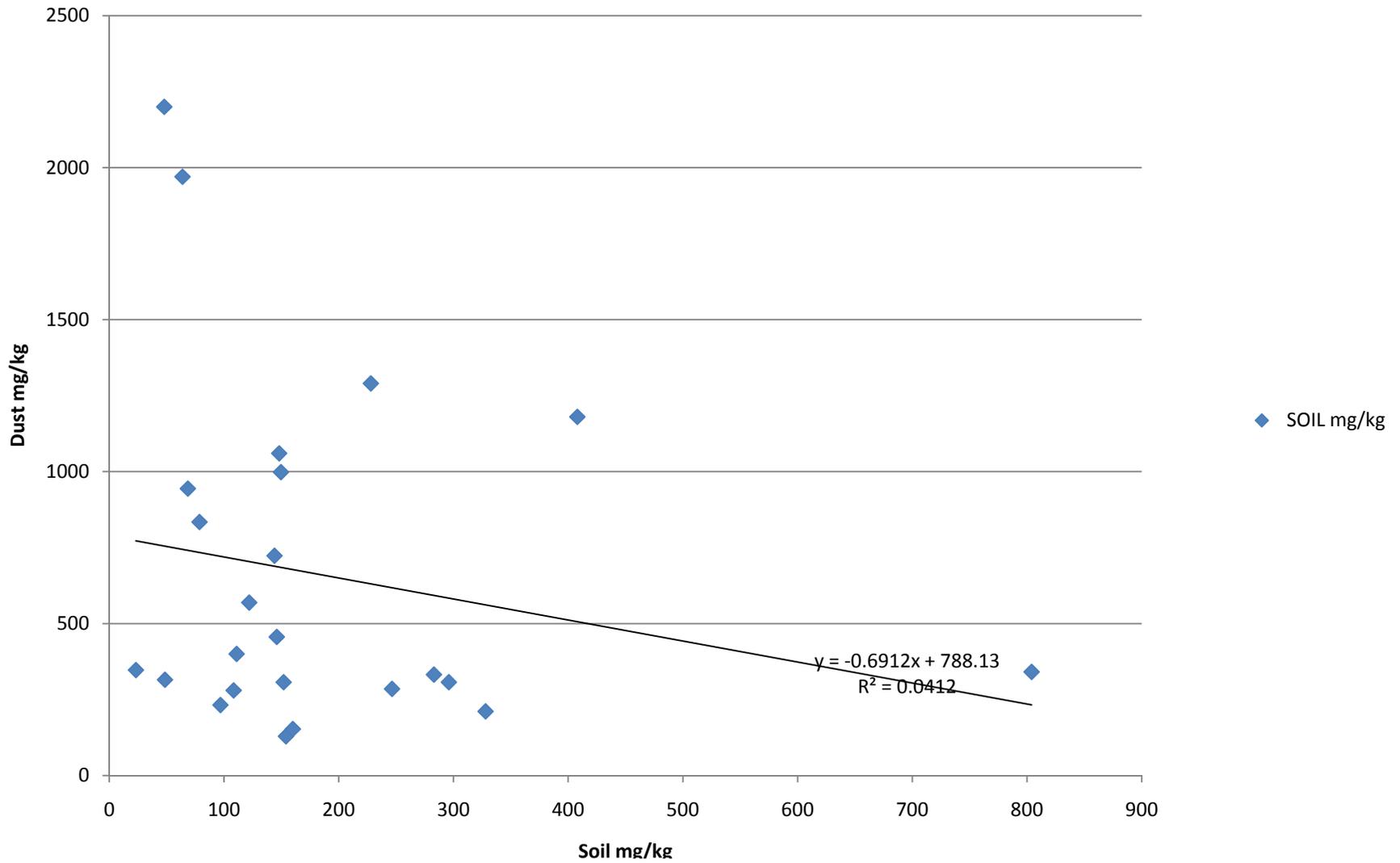
COPPER



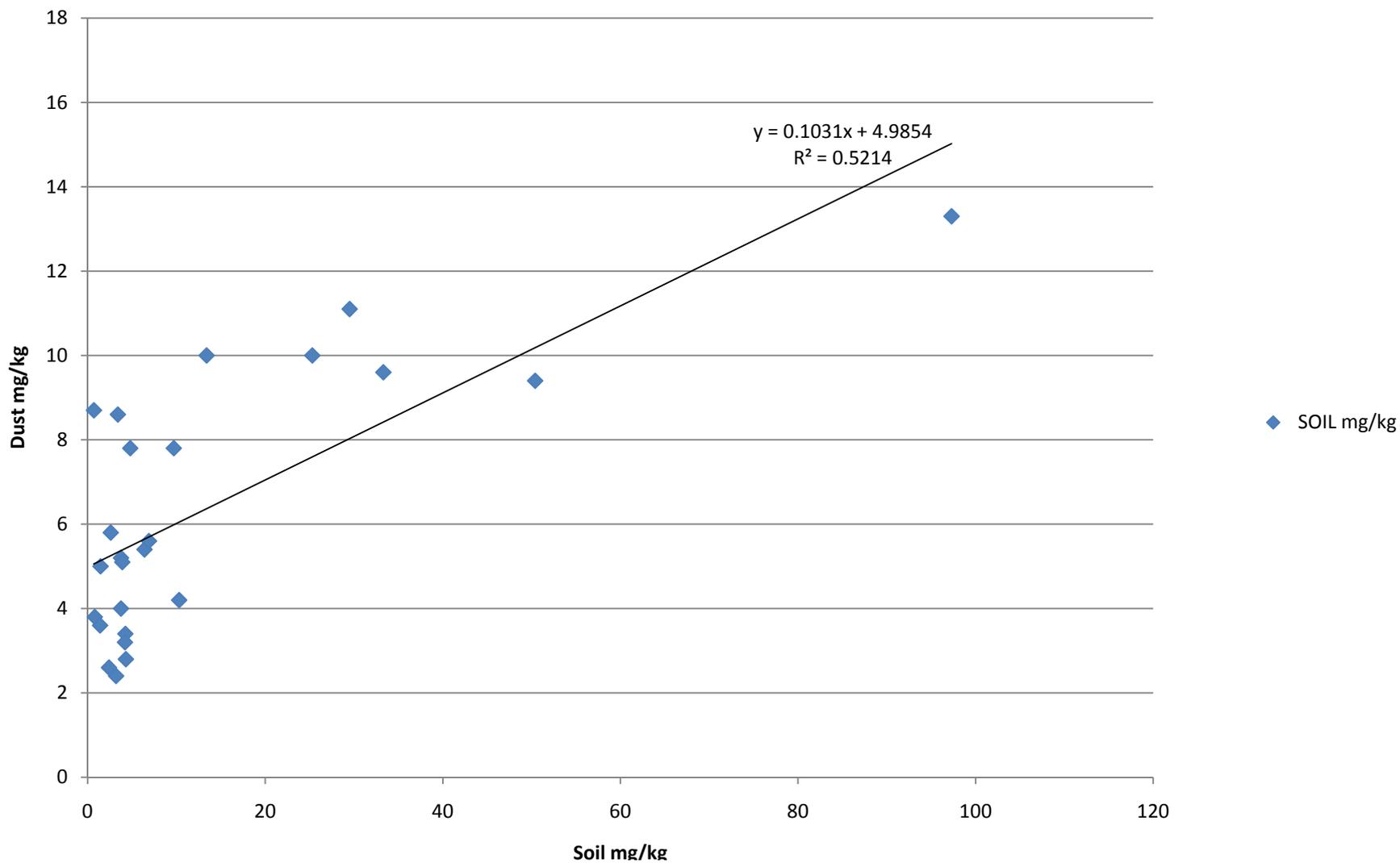
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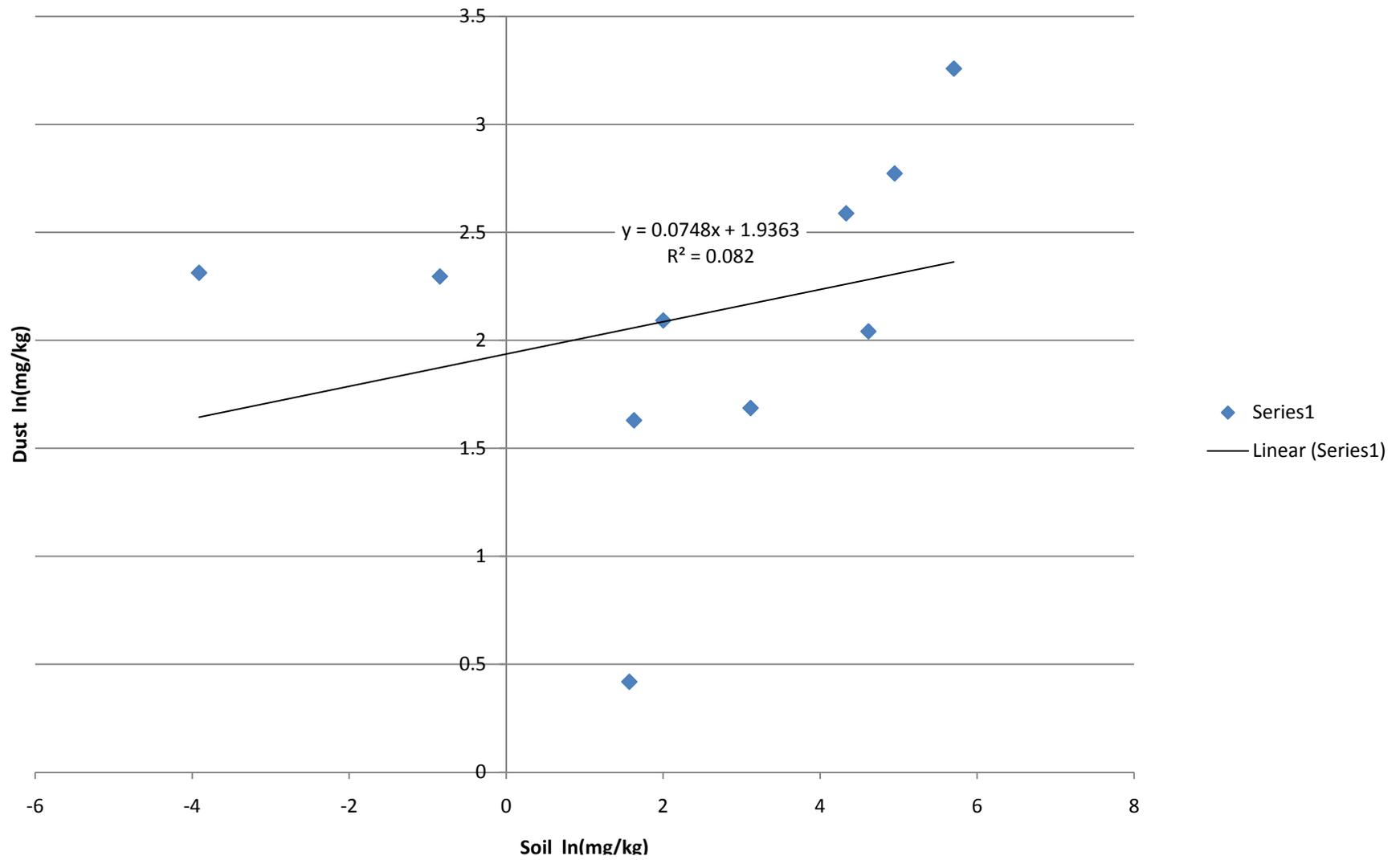
LEAD (outliers removed)



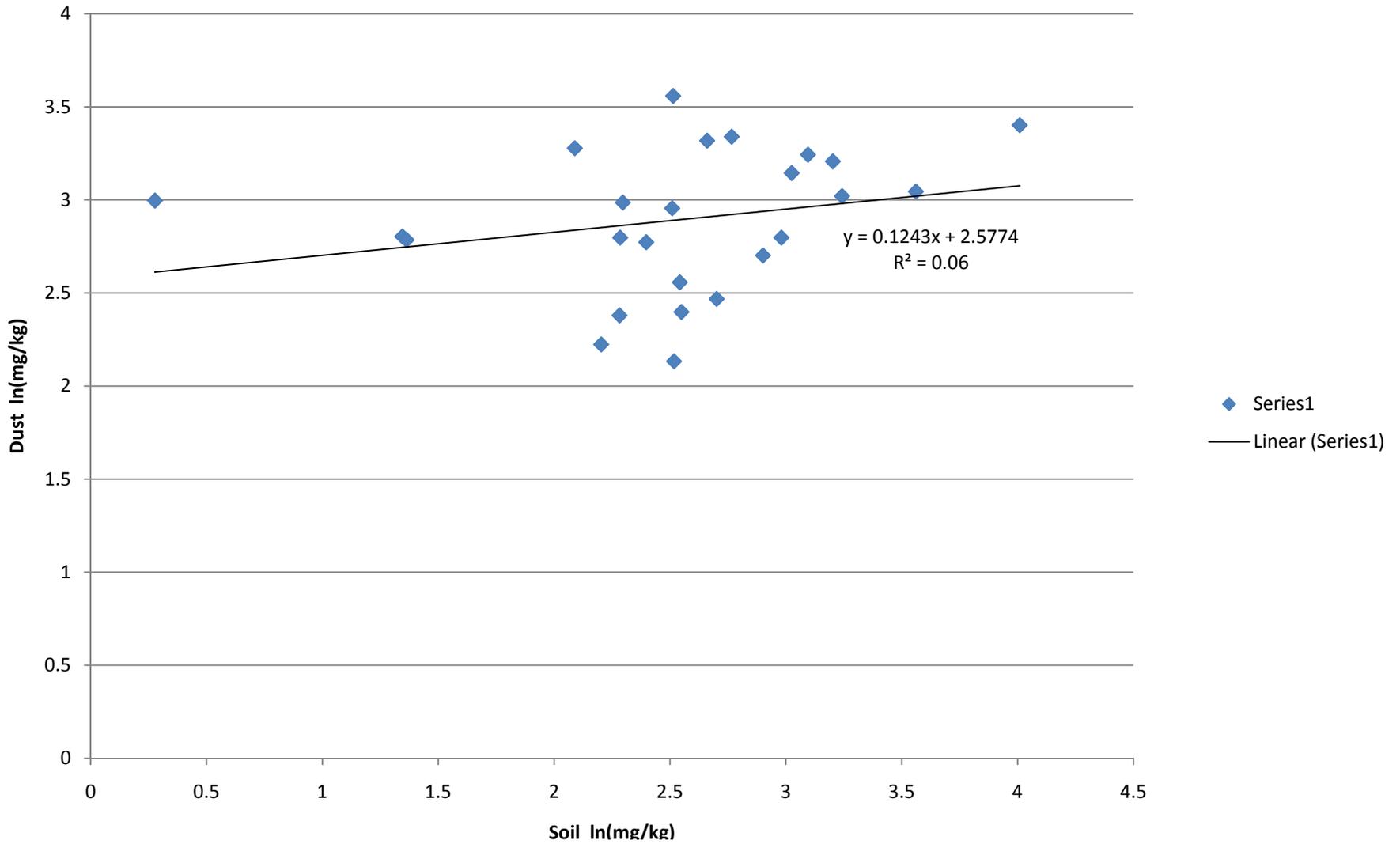
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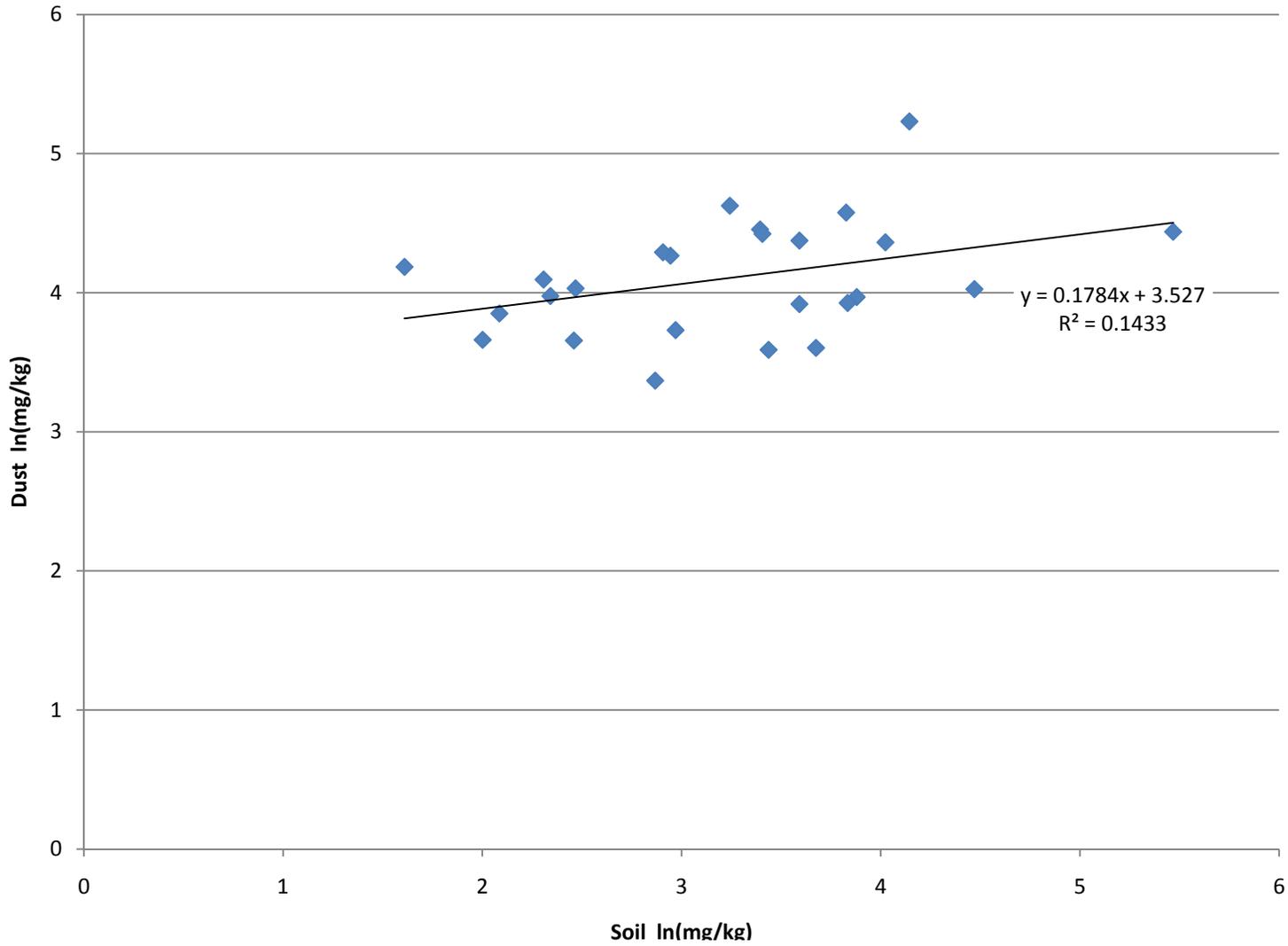
MERCURY (transformed)



CADMIUM (transformed)

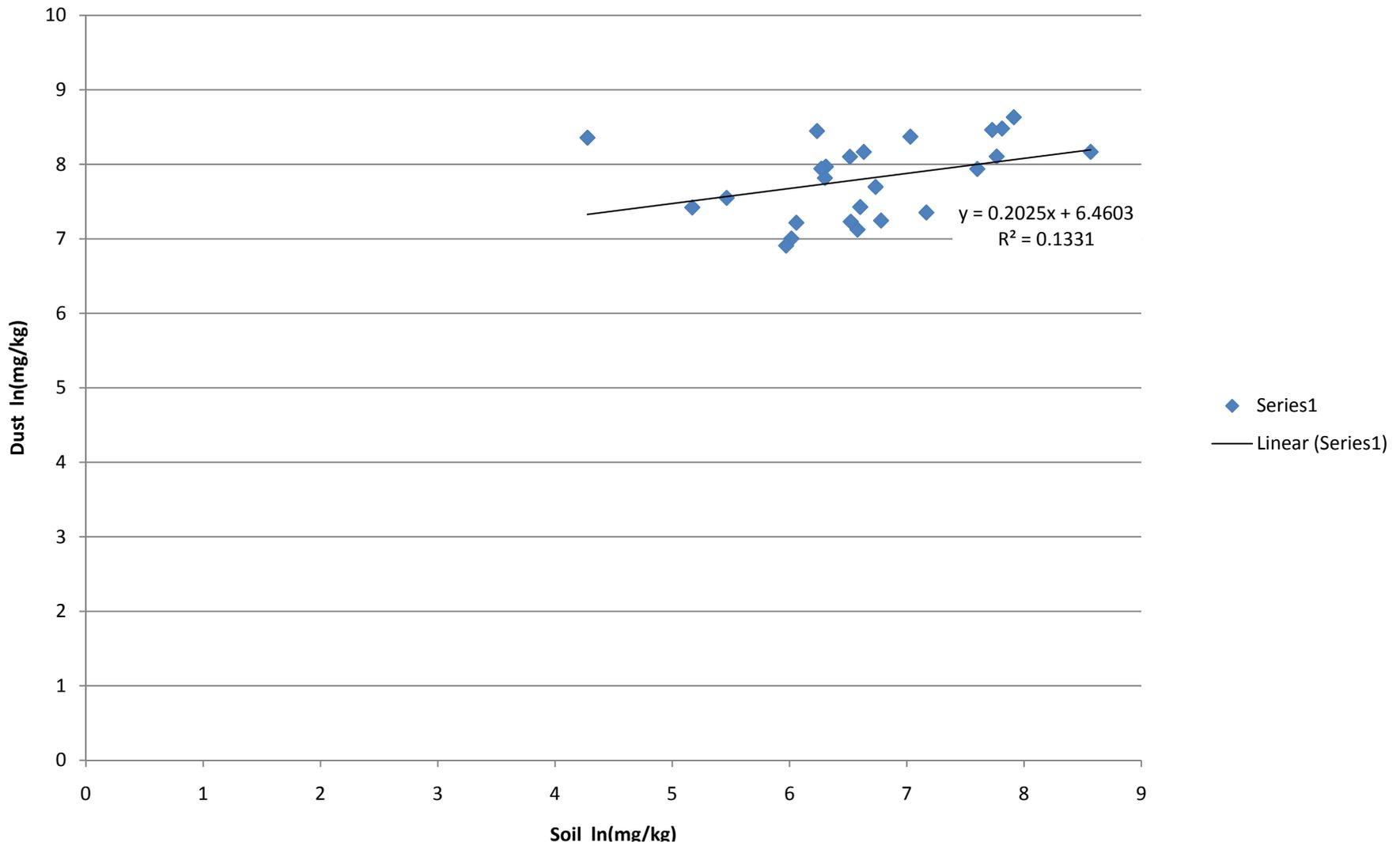


ARSENIC (transformed)

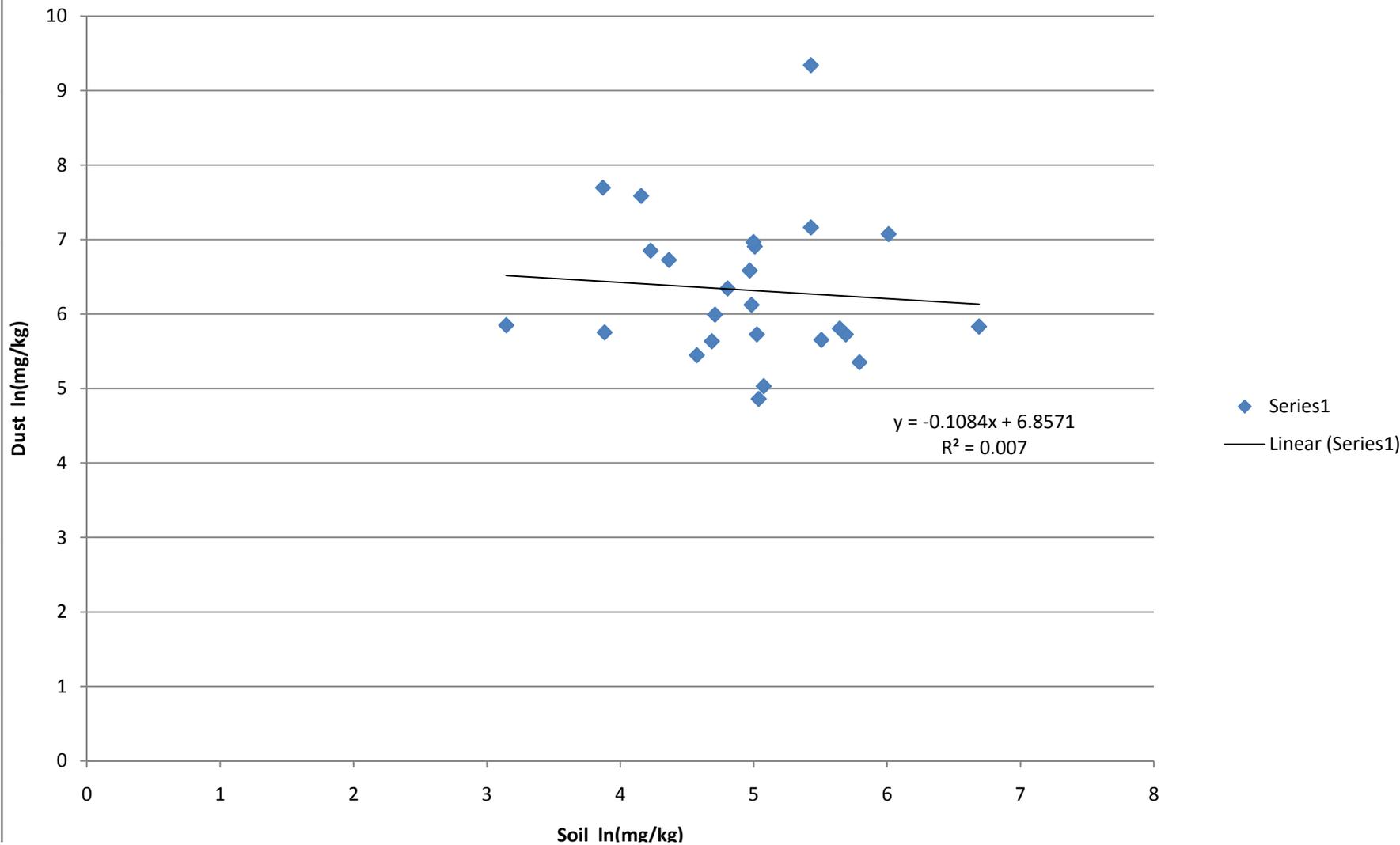


◆ Series1
— Linear (Series1)

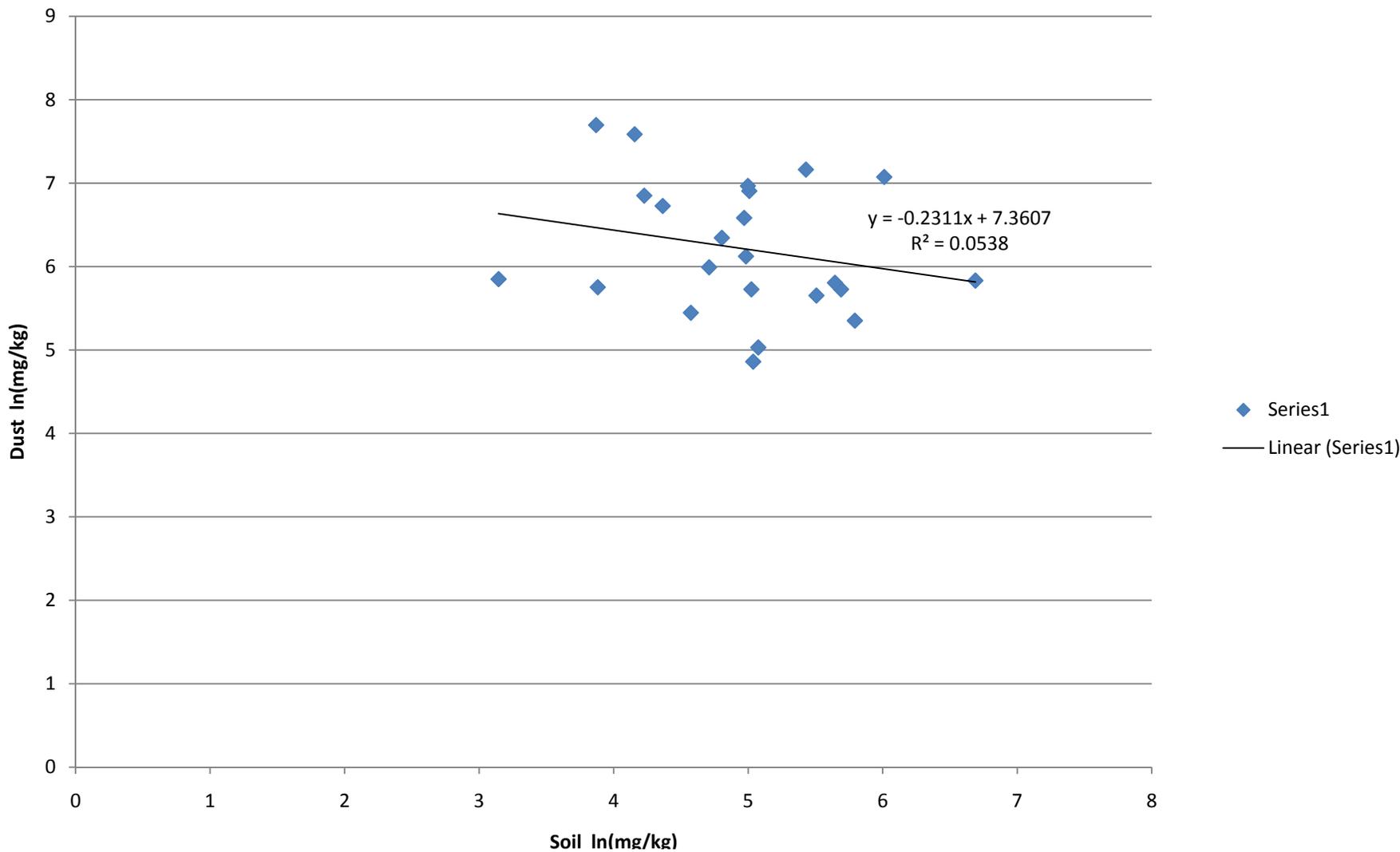
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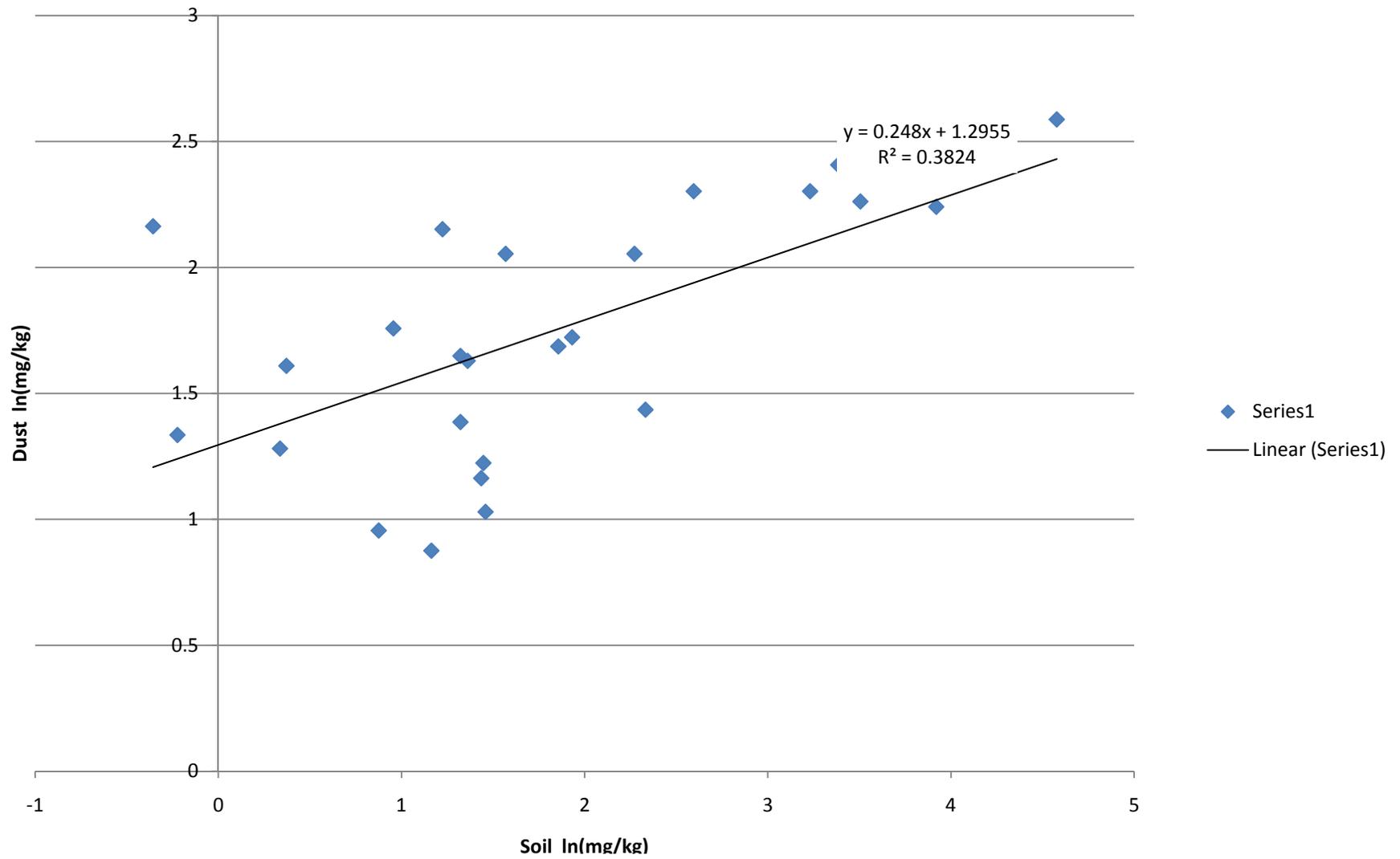
LEAD (transformed)



LEAD (transformed; some data removed)



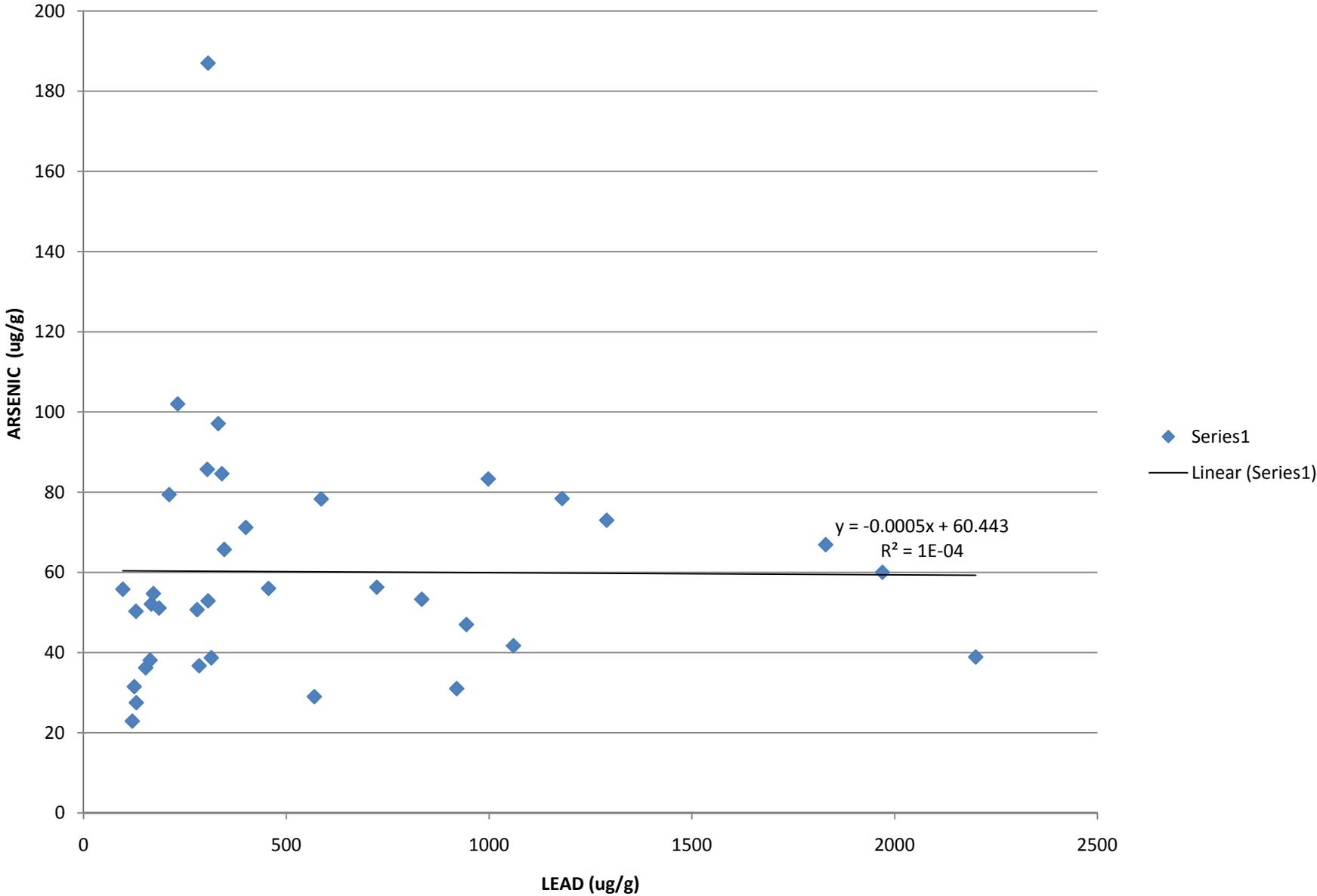
SELENIUM (transformed)



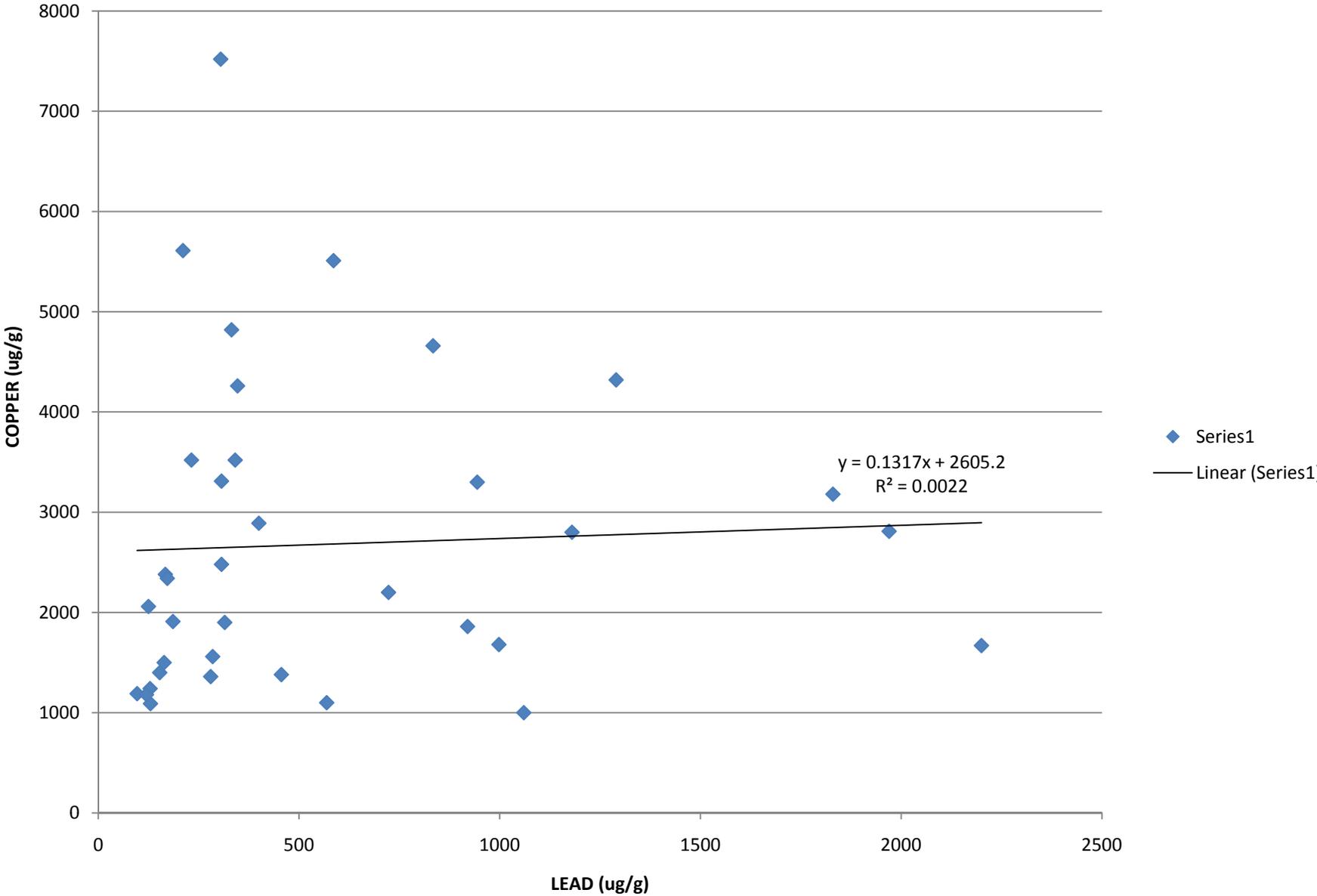
Appendix B

Chemical to Chemical Interrelationships

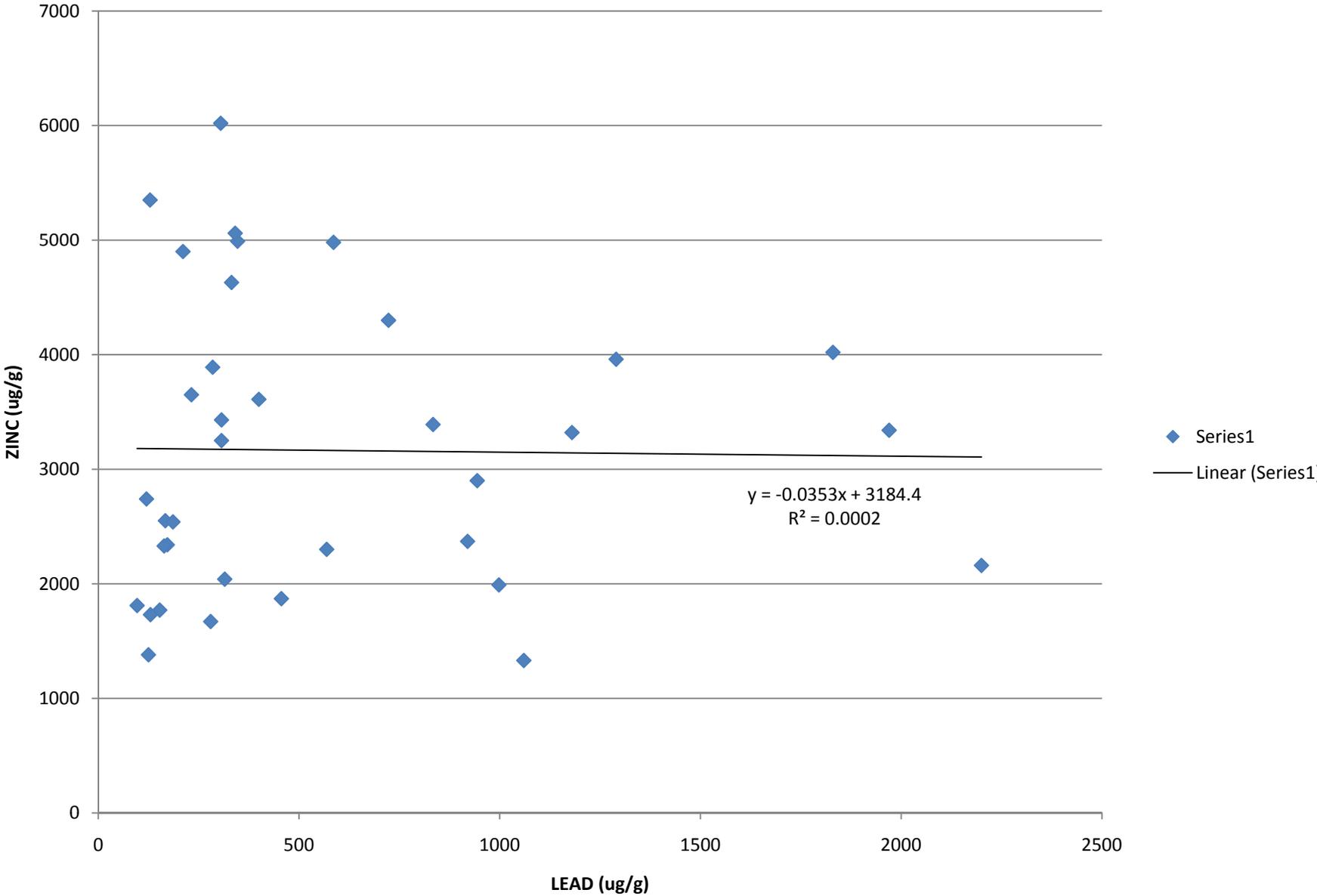
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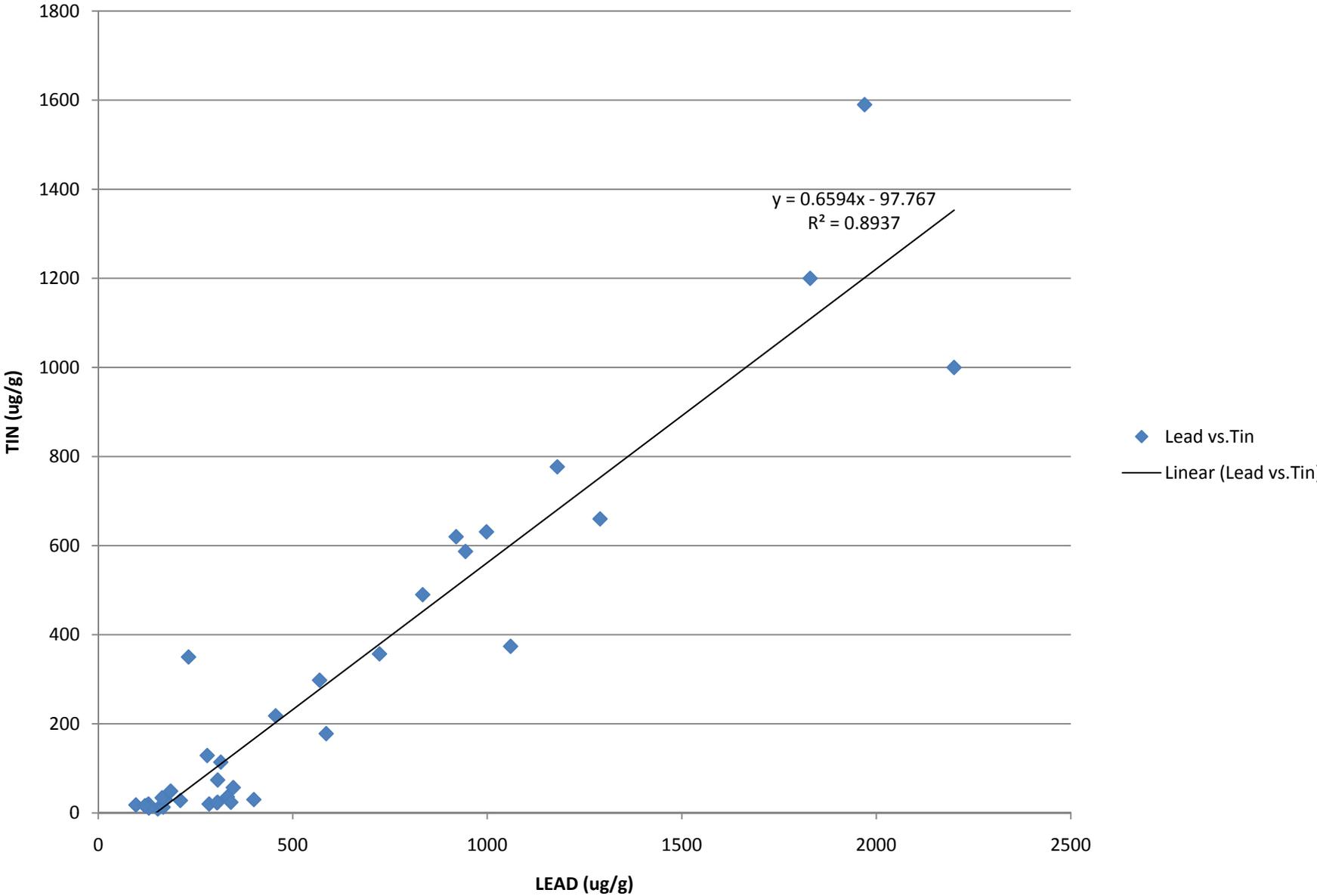
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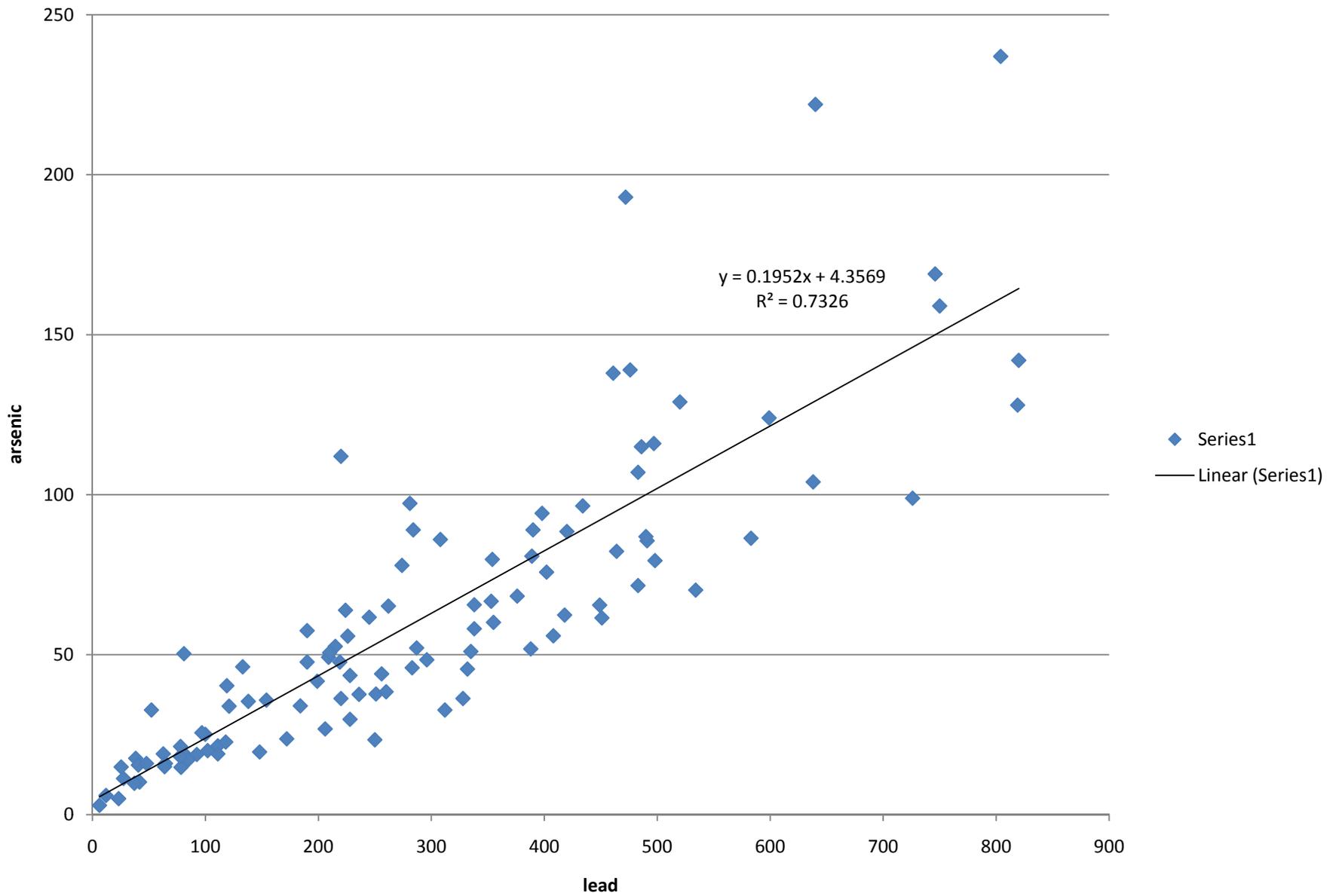
DUST



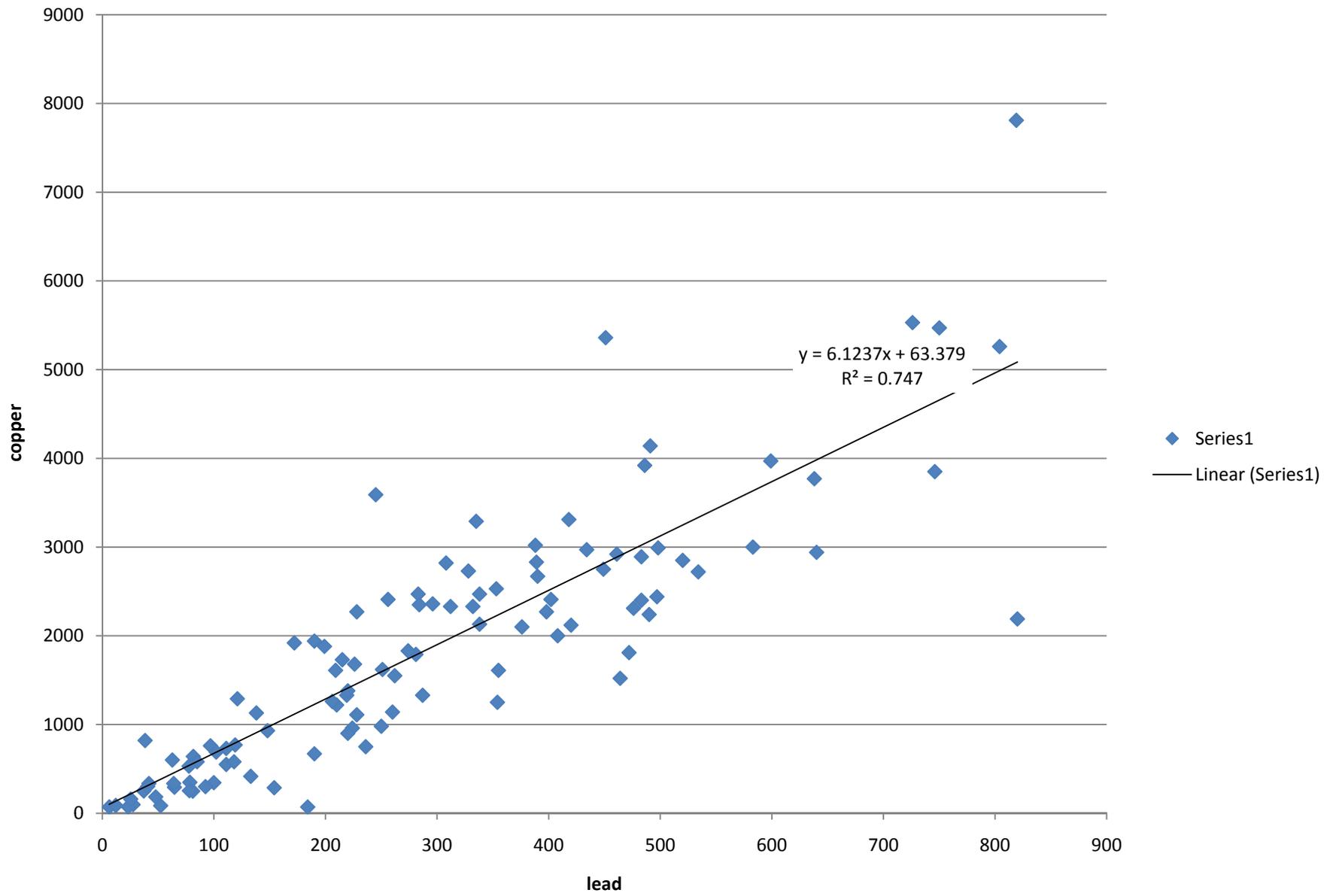
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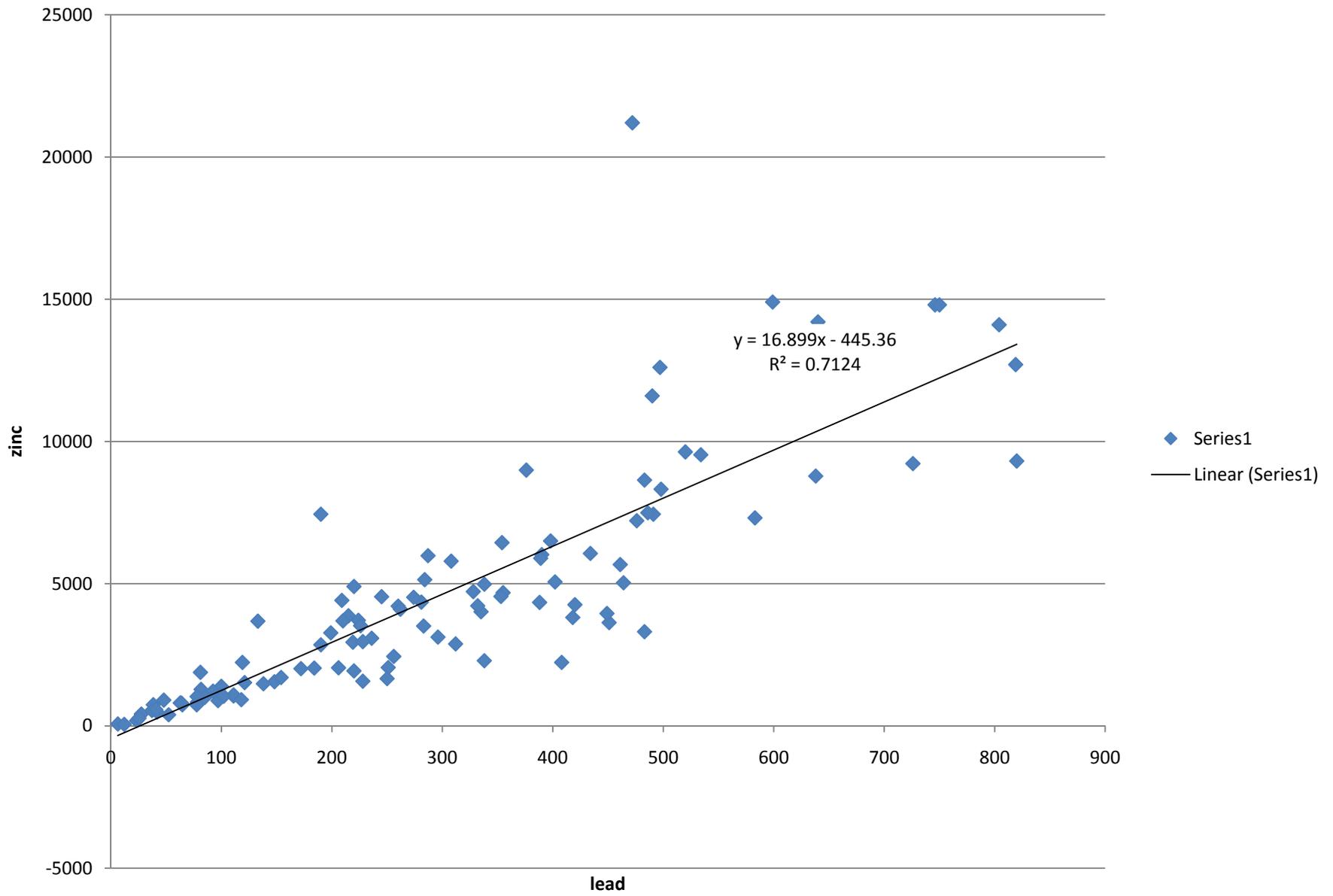
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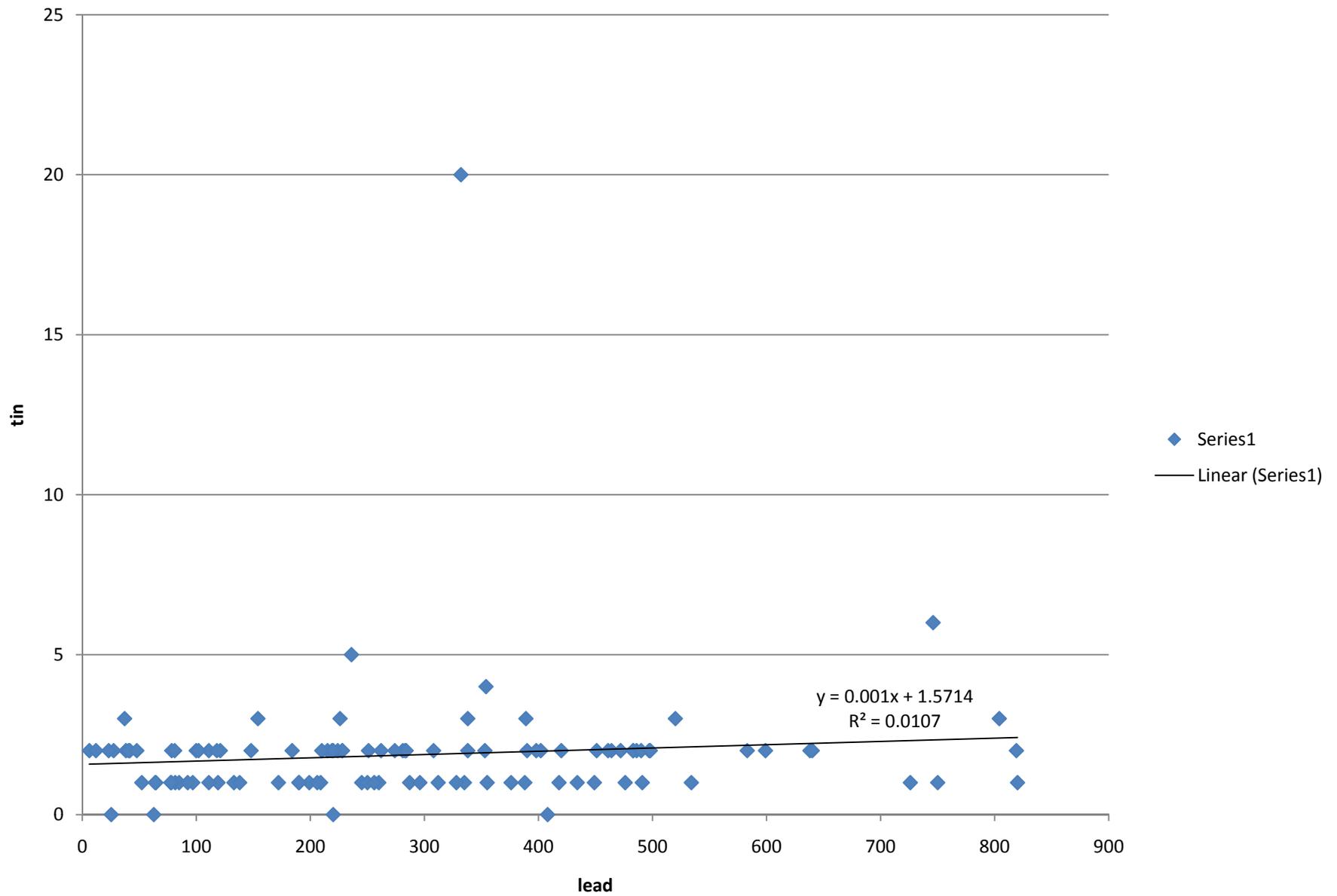
SOIL



SOIL



SOIL



Appendix C

Principal Components Analysis

APPENDIX C: Principal Components Analysis of Metal, Metalloid and Selenium Concentrations in Residential Soil and Indoor Dust Samples from Flin-Flon, Manitoba and Creighton, Saskatchewan

Introduction

A recent sampling program focusing on metals and related elements in residential soil and indoor dust in the vicinity of Flin Flon, Manitoba, has resulted in a large dataset containing numerous concentration values for various measured elements. This type of dataset is often difficult to interpret because of the many variables and the inherent correlation between some of these variables. Principal components analysis (PCA) is used for two objectives: (1) reducing the number of variables comprising a dataset while retaining the variability in the data, and (2) identifying patterns in the data, and classifying them according to how much information they account for. In PCA a reduced set of m components that accounts for most of the variance in p variables is extracted from the p variables. In other words, a set of p variables is reduced to a set of m underlying dimensions. These underlying factors are inferred from the correlations among the p variables. The objective of this analysis was to investigate relationships between metals (and related elements) concentrations in paired soil and dust samples collected from residential lots within the study area.

Methods

There were 25 residential lots in the study area where both soil and indoor dust samples were collected. In some cases, soil was sampled in front and backyards, as well as gardens and sandboxes. Data associated with gardens and sandboxes were omitted from the analyses because gardens are frequently amended with fertilizers and other additives; sandboxes are generally filled with sand imported from outside the study area. Where both back and front yards were sampled, the mean concentration of the variable was used in the PCA analysis, so that there was one soil concentration per variable per residential lot. Where concentrations were reported as an inequality (*i.e.*, less than the reported detection limit (RDL)) $\frac{1}{2}$ the RDL was used in the analysis. Seventeen common metals and related elements were measured in both soil and dust samples. However, because there were only 25 paired soil and dust samples, not all of these variables could be included in the PCA (due to insufficient degrees of freedom). Preliminary PCAs of the soil and dust data (results not included here, but available upon request from Intrinsik) were conducted. Based on these preliminary analyses and the objectives of the PCA, it was decided that all of the COPCs (with the exception of mercury, for which there was insufficient indoor dust data), as well as some other apparently associated elements would be retained in the PCA analysis of paired soil and indoor dust data. The 12 selected elements included antimony, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, selenium, silver, tin and zinc.

Paired soil and dust metal, metalloid and Se concentration data were analyzed by PCA using the PROC FACTOR procedure in SAS® software (SAS System Version 9.1, © 2001, Cary, NC,

USA). In the PCA, Varimax was used as the rotation method in the analysis following standardization of the data (Kaiser 1958). Varimax rotation is a rigid, orthogonal rotation of the original components to maximize their alignment with the original variables. Components were retained if their eigenvalues were greater or equal to one.

Results

The correlation matrix for the 24 variables in the original dataset is presented in Table C-1. Correlation coefficients range from absolute values of 0 to 0.94. Six principal components were identified and considered, accounting for approximately 90% of the total variance in the dataset. Adding more components did not significantly increase the percentage of the variation accounted for by the model. A summary of the six principal components is presented in Table C-2. The component pattern matrix yielded by Varimax rotated PCA is presented in Table C-3.

The first component explains the highest proportion of the variation (39%), and is strongly correlated with 10 of the 24 original variables, including: lead, silver, selenium, copper, cadmium, zinc, antimony, arsenic and cobalt in soil, as well as, to a lesser extent, selenium in soil. The second component explains 18% of the variation in the original dataset, and is strongly correlated with lead, tin and antimony concentration in dust. The third component explains 12% of the variation in the original dataset and is associated with nickel and chromium concentrations in soil. The fourth component (9% of variation) is positively associated with chromium and zinc concentrations in dust, and negatively associated with tin concentrations in soil. The fifth component (6% of variation) is strongly correlated with nickel, silver and cadmium concentrations in dust. Finally, arsenic and cobalt concentrations in dust are correlated through the sixth component, which explains 4% of the variation in the original dataset. The only variable that is not distinctly correlated with a single component is chromium measured in dust. This variable had only a moderate loading of 0.46 for both components 3 and 5, and a moderate to low negative loading for component 1 (-0.40).

Figures C-1 through C-5 show the results of Table C-3 in a graphical format. These figures are graphs of factor loadings. The relationships between the first component's loadings for each variable relative to the loadings for the other components are presented. Figure C-6 through C-10 display scores plots. These are essentially plots of the standardized data transformed to the six dimensions of the principal components. Again, the plots present the first component versus the other five principal components.

Table C-1. Correlation matrix for soil and dust metal, metalloid and selenium concentration variables used in the PCA

<i>Variable</i>	<i>Sb Dust</i>	<i>As Dust</i>	<i>Cd Dust</i>	<i>Cr Dust</i>	<i>Co Dust</i>	<i>Cu Dust</i>	<i>Pb Dust</i>	<i>Ni Dust</i>	<i>Se Dust</i>	<i>Ag Dust</i>	<i>Sn Dust</i>	<i>Zn Dust</i>	<i>Sb Soil</i>	<i>As Soil</i>	<i>Cd Soil</i>	<i>Cr Soil</i>	<i>Co Soil</i>	<i>Cu Soil</i>	<i>Pb Soil</i>	<i>Ni Soil</i>	<i>Se Soil</i>	<i>Ag Soil</i>	<i>Sn Soil</i>	<i>Zn Soil</i>
<i>Sb Dust</i>	1.00	0.11	0.28	0.15	0.26	0.24	0.94	-0.04	0.20	0.49	0.94	0.10	0.01	-0.14	0.03	-0.07	-0.20	0.08	-0.03	-0.18	-0.11	-0.01	-0.13	-0.15
<i>As Dust</i>	0.11	1.00	0.19	-0.17	0.69	0.37	0.08	-0.11	0.55	0.00	0.10	0.31	0.37	0.27	0.23	-0.39	0.00	0.23	0.21	-0.27	0.21	0.18	0.17	0.11
<i>Cd Dust</i>	0.28	0.19	1.00	0.14	0.35	0.62	0.19	0.41	0.59	0.60	0.18	0.48	0.37	0.16	0.39	-0.10	0.15	0.46	0.40	0.01	0.42	0.46	-0.47	0.39
<i>Cr Dust</i>	0.15	-0.17	0.14	1.00	0.04	-0.17	0.09	0.35	-0.27	0.17	0.07	-0.27	-0.41	-0.34	-0.37	0.30	-0.07	-0.35	-0.36	0.18	-0.33	-0.35	-0.34	-0.31
<i>Co Dust</i>	0.26	0.69	0.35	0.04	1.00	0.66	0.33	-0.21	0.68	0.12	0.34	0.47	0.23	0.14	0.26	-0.16	0.10	0.36	0.20	0.05	0.28	0.23	-0.08	0.14
<i>Cu Dust</i>	0.24	0.37	0.62	-0.17	0.66	1.00	0.27	-0.08	0.75	0.33	0.28	0.65	0.23	0.04	0.38	-0.21	0.01	0.46	0.27	0.00	0.33	0.35	-0.33	0.27
<i>Pb Dust</i>	0.94	0.08	0.19	0.09	0.33	0.27	1.00	-0.04	0.18	0.46	1.00	0.12	0.02	-0.10	0.10	-0.02	-0.14	0.14	0.00	-0.08	-0.06	0.02	-0.04	-0.10
<i>Ni Dust</i>	-0.04	-0.11	0.41	0.35	-0.21	-0.08	-0.04	1.00	-0.18	0.57	-0.03	-0.11	-0.18	-0.26	-0.14	0.17	-0.12	-0.20	-0.17	0.01	-0.18	-0.13	-0.28	-0.17
<i>Se Dust</i>	0.20	0.55	0.59	-0.27	0.68	0.75	0.18	-0.18	1.00	0.10	0.19	0.65	0.67	0.53	0.66	-0.29	0.32	0.76	0.66	-0.05	0.72	0.70	-0.08	0.55
<i>Ag Dust</i>	0.49	0.00	0.60	0.17	0.12	0.33	0.46	0.57	0.10	1.00	0.47	0.10	-0.04	-0.21	0.00	-0.06	-0.21	0.01	-0.07	-0.20	-0.11	-0.06	-0.34	-0.09
<i>Sn Dust</i>	0.94	0.10	0.18	0.07	0.34	0.28	1.00	-0.03	0.19	0.47	1.00	0.13	0.02	-0.11	0.10	-0.01	-0.14	0.13	-0.01	-0.08	-0.07	0.01	-0.04	-0.11
<i>Zn Dust</i>	0.10	0.31	0.48	-0.27	0.47	0.65	0.12	-0.11	0.65	0.10	0.13	1.00	0.36	0.23	0.45	-0.38	-0.03	0.52	0.41	-0.15	0.42	0.49	0.09	0.40
<i>Sb Soil</i>	0.01	0.37	0.37	-0.41	0.23	0.23	0.02	-0.18	0.67	-0.04	0.02	0.36	1.00	0.85	0.82	-0.08	0.60	0.86	0.94	0.01	0.86	0.88	0.19	0.78
<i>As Soil</i>	-0.14	0.27	0.16	-0.34	0.14	0.04	-0.10	-0.26	0.53	-0.21	-0.11	0.23	0.85	1.00	0.77	-0.03	0.77	0.78	0.86	0.23	0.86	0.80	0.40	0.84
<i>Cd Soil</i>	0.03	0.23	0.39	-0.37	0.26	0.38	0.10	-0.14	0.66	0.00	0.10	0.45	0.82	0.77	1.00	-0.01	0.65	0.96	0.94	0.26	0.88	0.93	0.09	0.89
<i>Cr Soil</i>	-0.07	-0.39	-0.10	0.30	-0.16	-0.21	-0.02	0.17	-0.29	-0.06	-0.01	-0.38	-0.08	-0.03	-0.01	1.00	0.55	-0.03	0.04	0.83	-0.07	0.04	-0.19	0.03
<i>Co Soil</i>	-0.20	0.00	0.15	-0.07	0.10	0.01	-0.14	-0.12	0.32	-0.21	-0.14	-0.03	0.60	0.77	0.65	0.55	1.00	0.67	0.73	0.74	0.70	0.69	0.06	0.75
<i>Cu Soil</i>	0.08	0.23	0.46	-0.35	0.36	0.46	0.14	-0.20	0.76	0.01	0.13	0.52	0.86	0.78	0.96	-0.03	0.67	1.00	0.95	0.25	0.94	0.97	0.05	0.89
<i>Pb Soil</i>	-0.03	0.21	0.40	-0.36	0.20	0.27	0.00	-0.17	0.66	-0.07	-0.01	0.41	0.94	0.86	0.94	0.04	0.73	0.95	1.00	0.23	0.93	0.97	0.11	0.92
<i>Ni Soil</i>	-0.18	-0.27	0.01	0.18	0.05	0.00	-0.08	0.01	-0.05	-0.20	-0.08	-0.15	0.01	0.23	0.26	0.83	0.74	0.25	0.23	1.00	0.23	0.27	-0.12	0.35
<i>Se Soil</i>	-0.11	0.21	0.42	-0.33	0.28	0.33	-0.06	-0.18	0.72	-0.11	-0.07	0.42	0.86	0.86	0.88	-0.07	0.70	0.94	0.93	0.23	1.00	0.93	0.12	0.89
<i>Ag Soil</i>	-0.01	0.18	0.46	-0.35	0.23	0.35	0.02	-0.13	0.70	-0.06	0.01	0.49	0.88	0.80	0.93	0.04	0.69	0.97	0.97	0.27	0.93	1.00	0.03	0.90
<i>Sn Soil</i>	-0.13	0.17	-0.47	-0.34	-0.08	-0.33	-0.04	-0.28	-0.08	-0.34	-0.04	0.09	0.19	0.40	0.09	-0.19	0.06	0.05	0.11	-0.12	0.12	0.03	1.00	0.06

Zn Soil	-0.15	0.11	0.39	-0.31	0.14	0.27	-0.10	-0.17	0.55	-0.09	-0.11	0.40	0.78	0.84	0.89	0.03	0.75	0.89	0.92	0.35	0.89	0.90	0.06	1.00
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<i>Principal Component</i>	<i>Eigenvalue</i>	<i>Proportion of Variation Explained</i>	<i>Cumulative Proportion of Variation Explained</i>
1	9.33	0.39	0.39
2	4.41	0.18	0.57
3	2.85	0.12	0.69
4	2.11	0.09	0.78
5	1.54	0.06	0.84
6	1.02	0.04	0.89

<i>Concentration Variable</i>	<i>PC 1</i>	<i>PC 2</i>	<i>PC 3</i>	<i>PC 4</i>	<i>PC 5</i>	<i>PC 6</i>
Pb Soil	0.98	0.00	0.04	0.08	-0.02	0.04
Ag Soil	0.96	0.01	0.05	0.20	-0.01	0.02
Se Soil	0.94	-0.08	0.02	0.14	-0.04	0.12
Cu Soil	0.94	0.12	0.03	0.25	-0.06	0.09
Cd Soil	0.93	0.09	0.03	0.17	-0.04	0.04
Zn Soil	0.93	-0.11	0.11	0.14	-0.03	-0.04
Sb Soil	0.92	0.02	-0.13	-0.04	0.01	0.18
As Soil	0.90	-0.09	0.03	-0.24	-0.13	0.18
Co Soil	0.74	-0.12	0.62	-0.12	-0.05	0.05
Se Dust	0.62	0.13	-0.16	0.50	-0.01	0.46
Pb Dust	0.00	0.99	0.00	0.07	0.03	0.07
Sn Dust	-0.01	0.99	0.00	0.07	0.03	0.08
Sb Dust	-0.04	0.96	-0.06	0.08	0.11	0.07
Ni Soil	0.23	-0.08	0.91	0.07	-0.10	-0.08
Cr Soil	0.01	0.02	0.90	-0.12	0.06	-0.20
Cr Dust	-0.40	0.07	0.46	-0.06	0.46	0.17
Cu Dust	0.22	0.19	-0.10	0.84	0.03	0.31
Zn Dust	0.38	0.06	-0.36	0.59	-0.08	0.19
Sn Soil	0.19	0.00	-0.29	-0.61	-0.42	0.17
Ni Dust	-0.13	-0.08	0.04	-0.07	0.89	-0.09
Ag Dust	-0.04	0.46	-0.15	0.20	0.73	-0.05
Cd Dust	0.38	0.13	-0.05	0.55	0.65	0.13
As Dust	0.17	0.02	-0.28	0.03	-0.01	0.88
Co Dust	0.13	0.25	0.07	0.44	-0.09	0.80

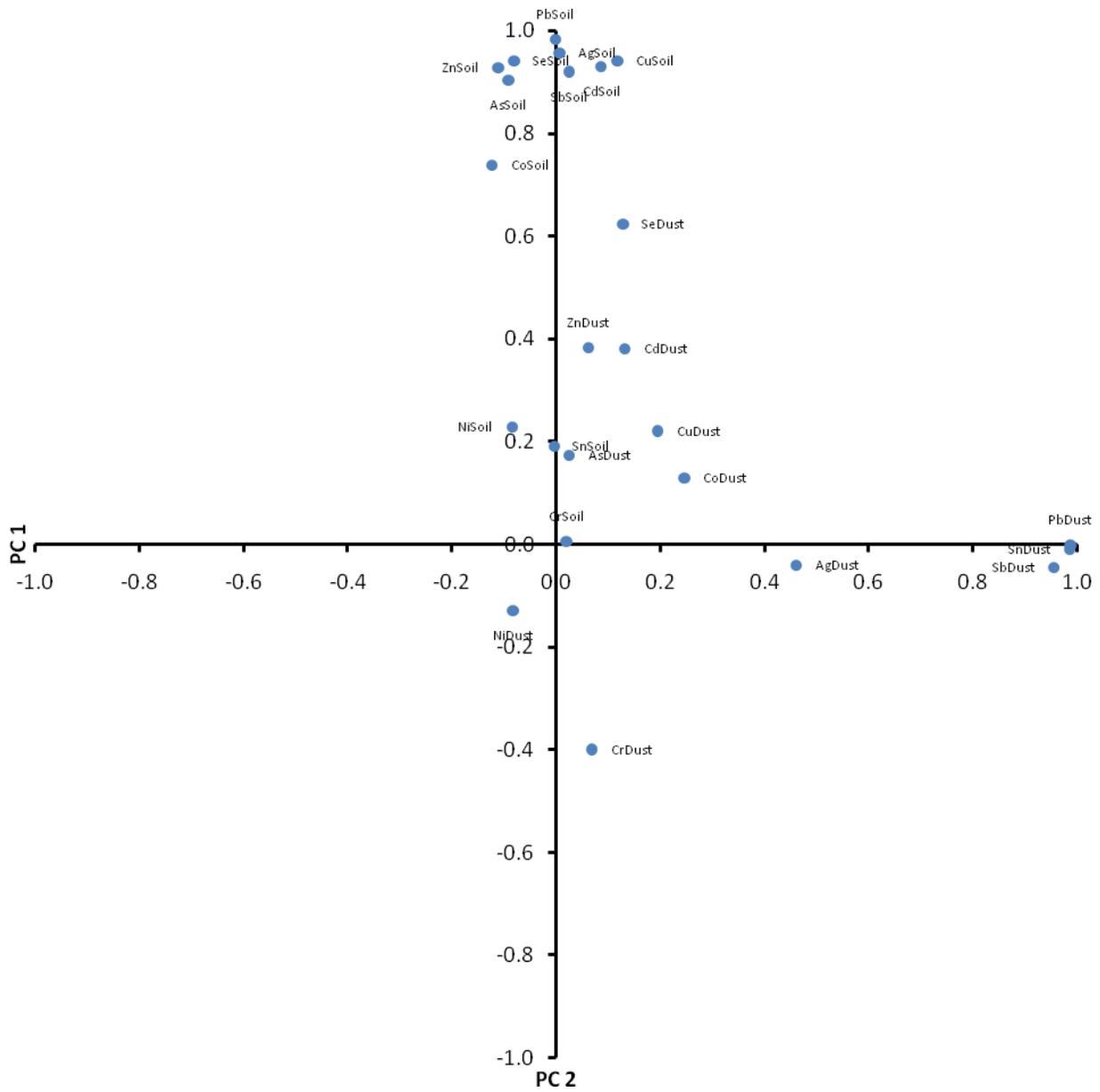


Figure C-1. Graph of factor loadings on the first (y-axis) and second (x-axis) principal components.

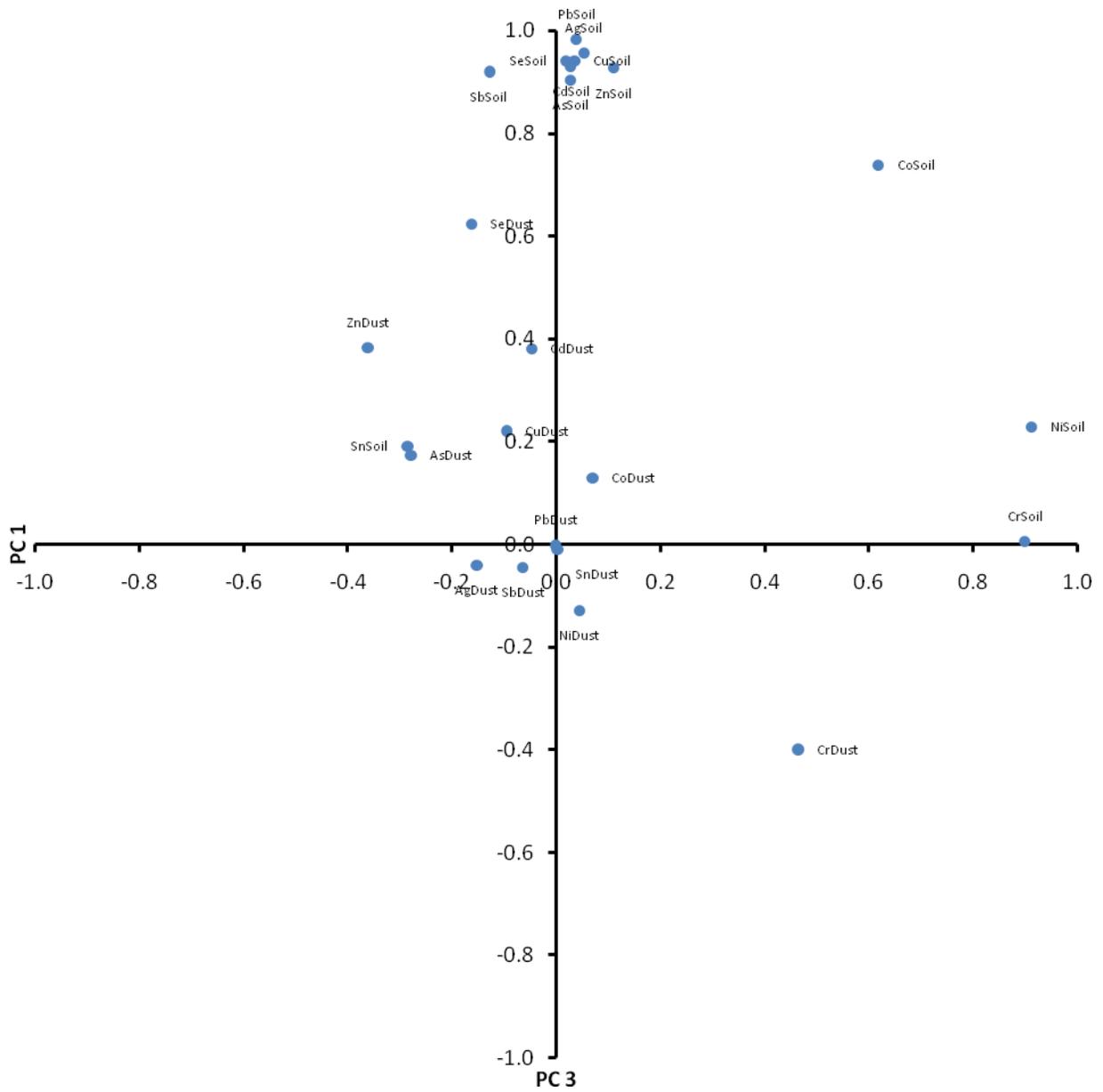


Figure C-2. Graph of factor loadings on the first (y-axis) and third (x-axis) principal components.

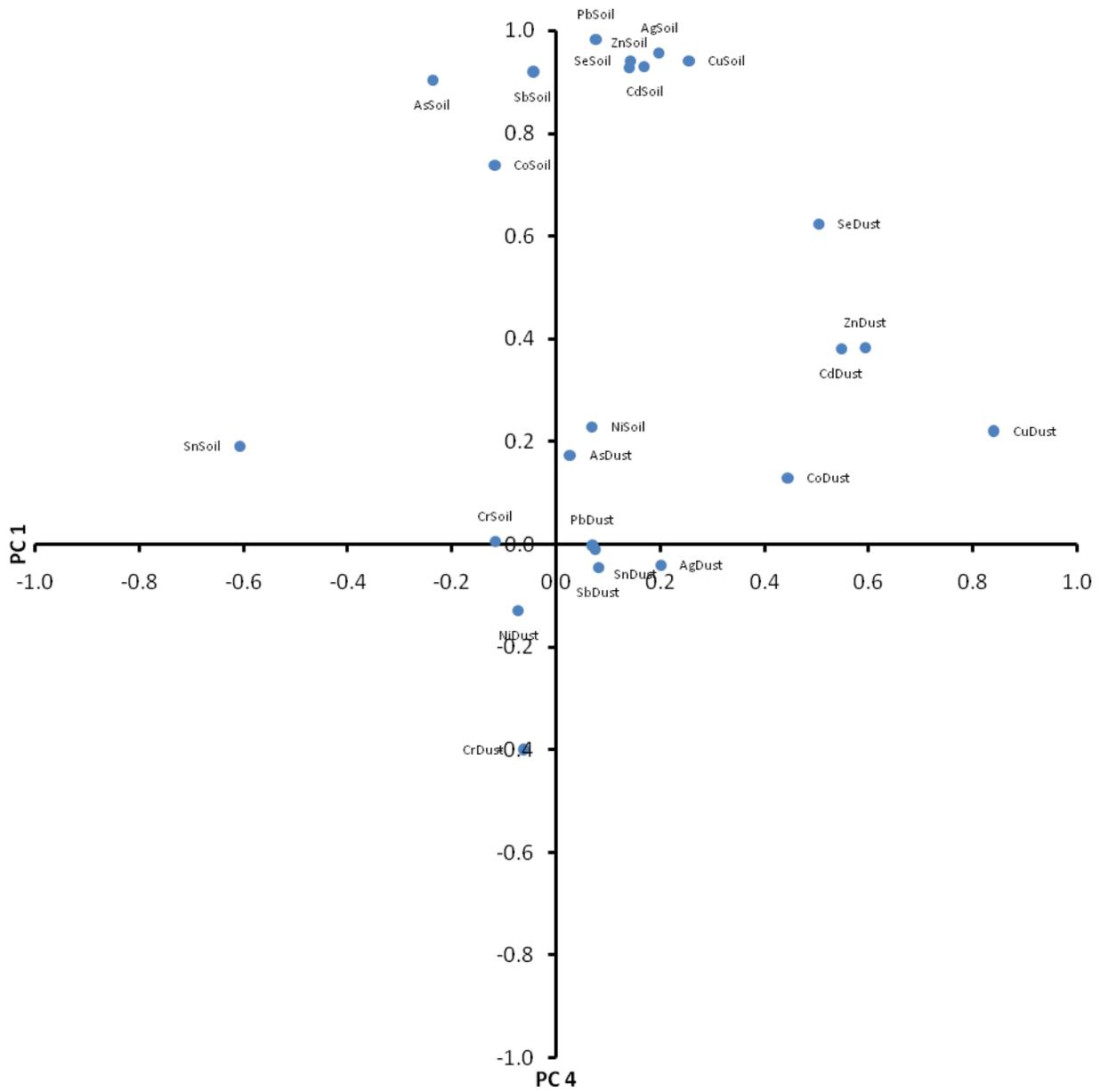


Figure C-3. Graph of factor loadings on the first (y-axis) and fourth (x-axis) principal components.

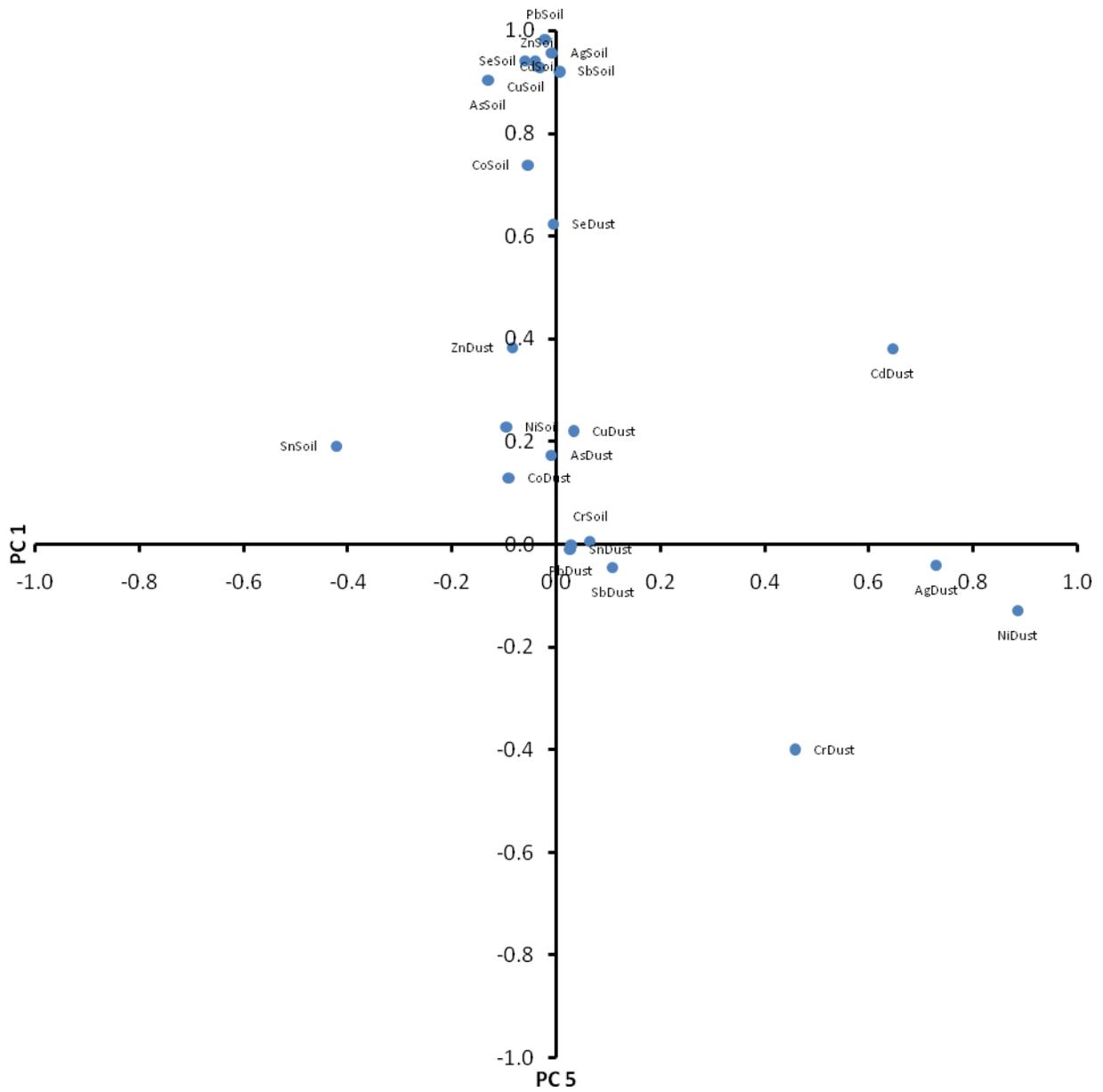


Figure C-4. Graph of factor loadings on the first (y-axis) and fifth (x-axis) principal components.

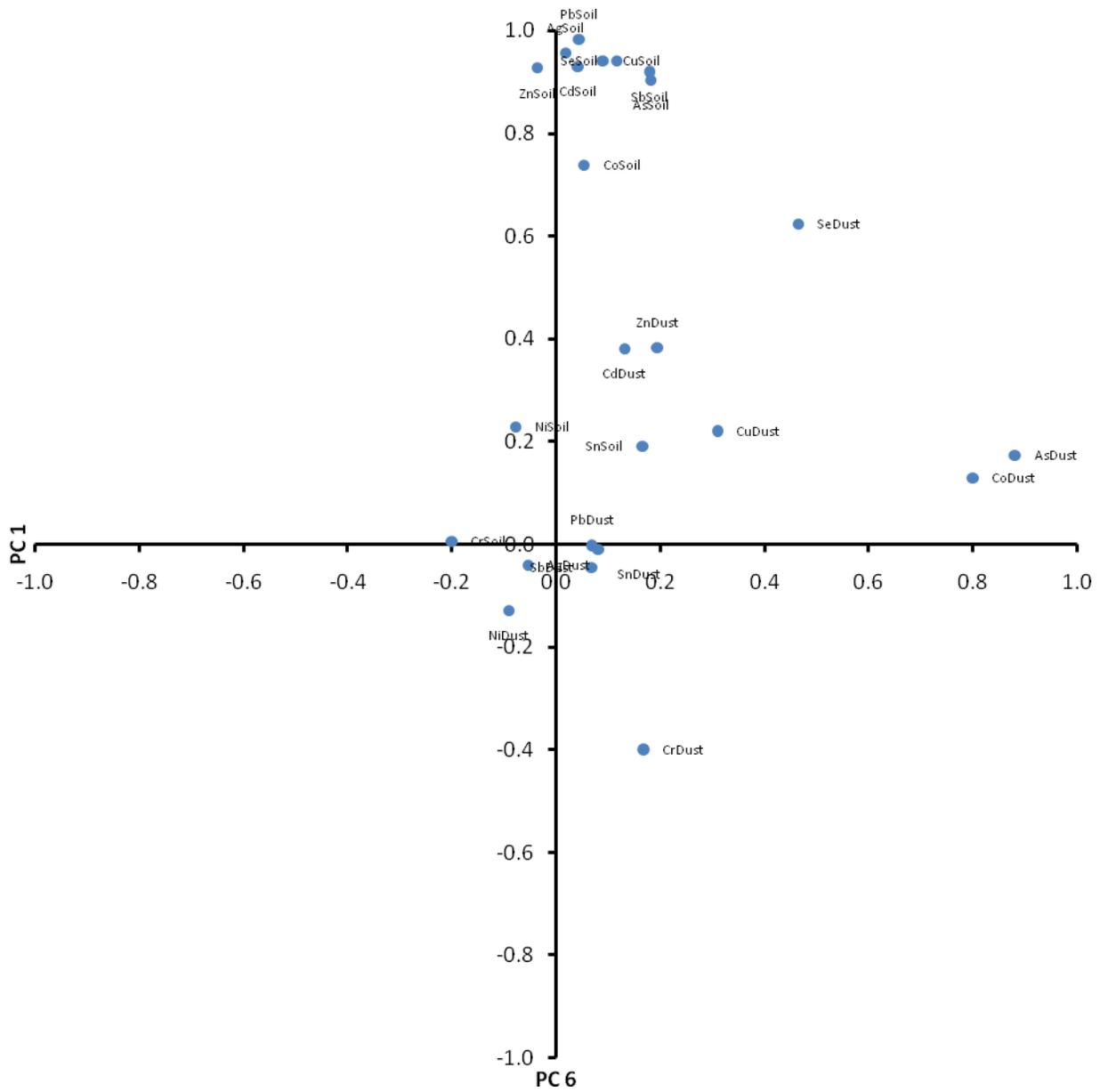


Figure C-5. Graph of factor loadings on the first (y-axis) and sixth (x-axis) principal components.

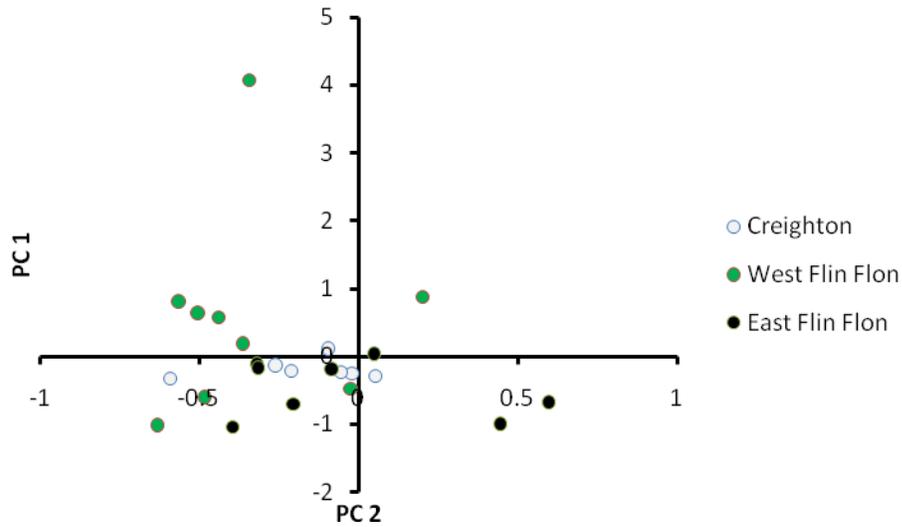


Figure C-6. Scores plot for the first (y-axis) and second (x-axis) principal components.

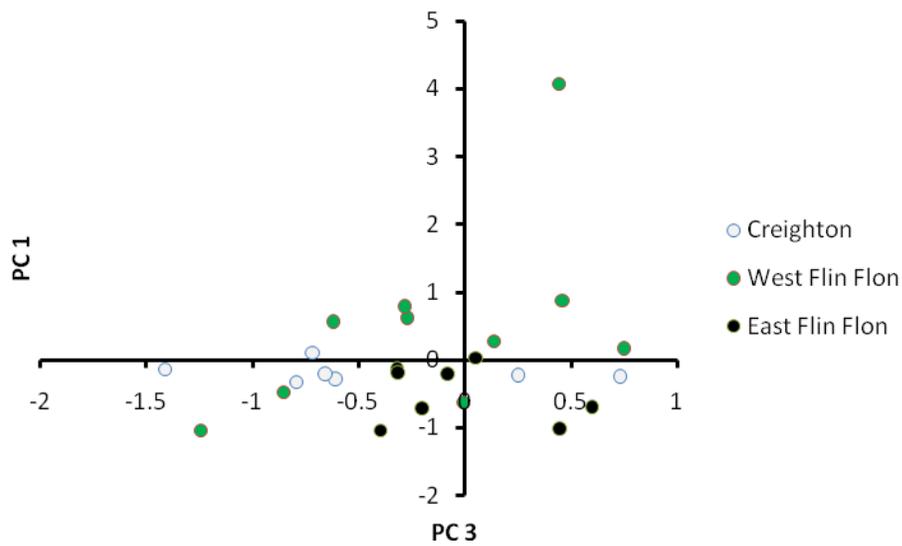


Figure C-7. Scores plot for the first (y-axis) and third (x-axis) principal components.

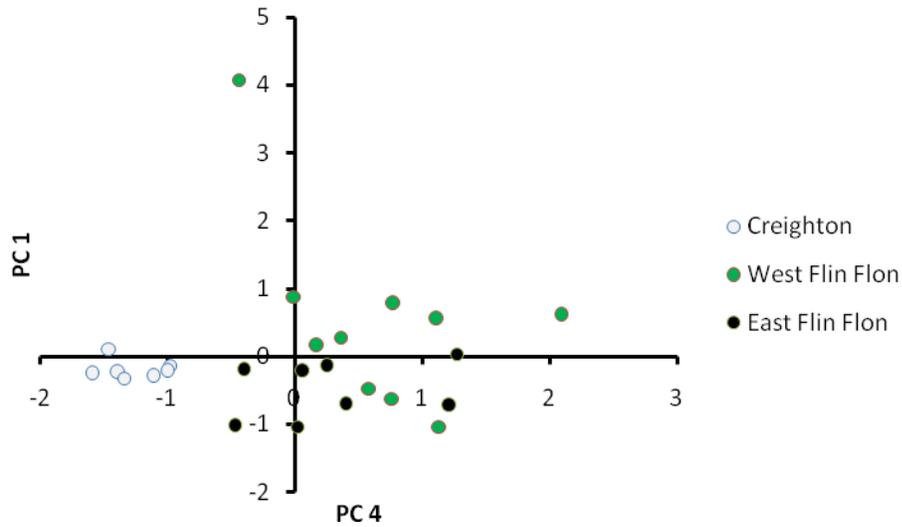


Figure C-8. Scores plot for the first (y-axis) and fourth (x-axis) principal components.

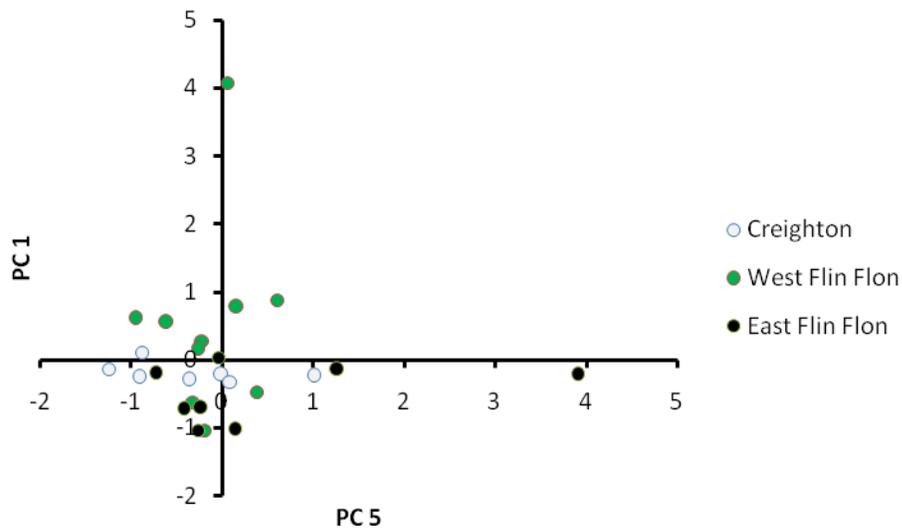


Figure C-9. Scores plot for the first (y-axis) and fifth (x-axis) principal components.

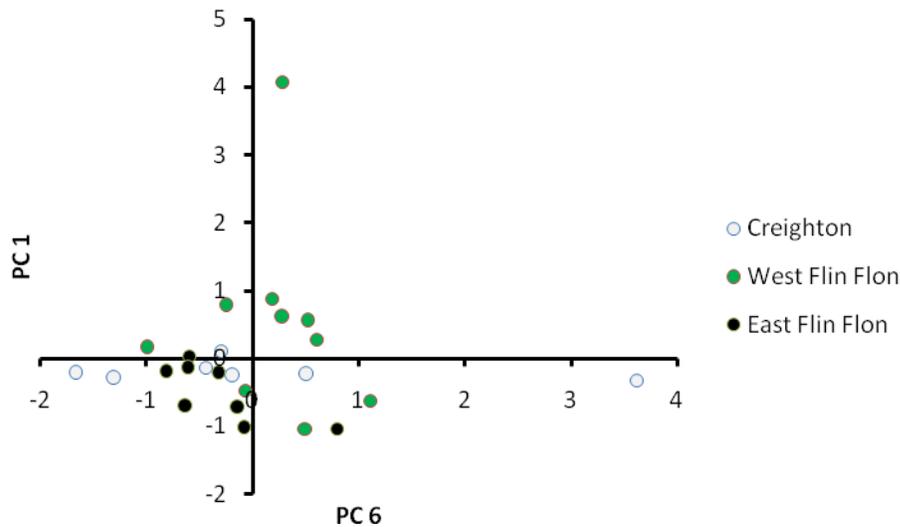


Figure C-10. Scores plot for the first (y-axis) and sixth (x-axis) principal components.

Discussion

Recall that principal components analysis (PCA) is used for two objectives: (1) reducing the number of variables comprising a dataset while retaining the variability in the data, and (2) identifying patterns in the data, and classifying them according to how much information they account for. Components 1 through 6 discussed below, account for decreasing proportions of the variation in the original data. Each component reflects a correlation trend in the original data. However, the exact cause of the trend may not be easily explained. Consider the fact that the soil is three-dimensional, and composed of minerals, organic matter, liquids, and gases. There are many processes by which specific materials are exchanged between soil and other components of the environment (Zhang et al. 2008). Indoor dust is a similarly complex medium. Thus, a principal component based on element concentrations may be explained by more than just a common source. Principal components themselves may arise through the complexities of element sources and environmental fate and behavior of elements and other unmeasured variables in the environment.

There are two main potential sources of metals (and related elements) contamination in the study area. The first is the copper-zinc smelter located in West Flin Flon. The second is the tailings area located west of the smelter. Differences in the aeolian movement and deposition of these operational wastes, could affect the dimensions of the principal components and the loadings of the associated variables. For instance, uncovered tailings would require a certain amount of wind force (speed) to achieve lift-off (this would be dependent on things like particle size, moisture content of tailing, etc.). Deposition of tailings and smelter emissions would also be a function of many variables including particle size, wind speed, direction, precipitation, etc. Such factors could add unexplained variability to the dataset that may affect variable loadings

and the breakdown of components. Historical tailings and emission data that are comparable with those gathered for the current analysis are lacking, and therefore no direct comparisons can be made between the trends observed in soil and dust metals concentrations, and those which might occur in local mine and smelting operational emissions.

Generally, the principal components in this analysis split the variables of the dataset by media. That is to say that most of the components appear to be governed by either concentrations in soil, or concentrations in dust. This suggests a lack of correlation between the two (*i.e.*, we cannot accurately predict metals concentrations in dust from known concentrations in soil, nor *vice versa*). This result has been found in similar studies (*e.g.*, Rasmussen 2004). It is possible that two or more components are associated with a common source. Manifestation of such a source in soil and dust concentrations may be multidimensional, and related to other factors governing concentrations in soil and dust. A brief description of each of the principal components of this analysis follows.

Principal Component 1

A great deal of the variation in the original dataset was attributed mostly to 9 correlated soil concentration variables, and to a lesser extent, the concentration of selenium in dust. The nine soil elements were: lead, silver, selenium, copper, cadmium, zinc, antimony, arsenic and cobalt. In the scores plots, there is an obvious outlier on the component 1 axis. This outlier is associated with a sampling location in West Flin Flon, where the variables associated with component 1 all measured high (the highest of the dataset), and in many cases, were more than an order of magnitude above the mean measured values. Generally, samples gathered in West Flin Flon comprise the upper portion of the distribution of observations for component 1, suggesting that East Flin Flon and Creighton may be less influenced by a common source of these correlated elements (*i.e.*, most of the soil metals and related elements included in the analysis). The smelter (copper-zinc) is located in West Flin Flon that has been operational since the 1930s. Higher concentrations of these metals and related elements could be due to local (possibly historical) operational emissions. These elements are commonly found together in sulphide ores, such as those refined at the Flin Flon smelter.

Principal Component 2

Eighteen percent of the variation in the data was attributed to the second principal component which was strongly correlated with lead, tin and antimony measured in dust. Figure C-6 shows the scores plot for component 1 versus component 2. Considering only the horizontal axis, it seems that scores are relatively evenly distributed for component 2 among the three communities (Creighton, East Flin Flon and West Flin Flon). This might suggest that a common source of these metals in dust may influence these communities in a similar way. These metals do occur together in some minerals (*e.g.*, franckeite and cylindrite, which can be associated with massive volcanic sulphides like the ones mined in Flin Flon) they are also used together in tin alloys, especially for soldering.

Principal Component 3

Twelve percent of the variation in the data was attributed to the third principal component which was strongly correlated with nickel and chromium measured in soil. Figure C-7 shows the scores plot for component 1 versus component 3. Considering only the horizontal axis, it seems that scores are relatively evenly distributed for component 3 among the three communities (Creighton, East Flin Flon and West Flin Flon). This might suggest that a common source of nickel and chromium in soil may influence these communities in a similar way.

Principal Component 4

Nine percent of the variation in the data was attributed to the fourth principal component which was strongly correlated with copper and zinc in dust, and negatively correlated with tin in soil. Figure C-8 shows the scores plot for component 1 versus component 4. Considering only the horizontal axis, scores in Creighton have less variability than scores in Flin Flon, and scores in Creighton are distinctly lower and always negative, whereas scores in Flin Flon are mostly positive, with some low negative scores. Considering the raw data, we note that concentrations of tin in soil are generally higher in Creighton than in Flin Flon, and zinc and copper concentrations in dust are higher in East and West Flin Flon than in Creighton. The simplest explanation may be that Flin Flon is more strongly influenced by a common source of zinc and copper in dust, while Creighton has soil that is relatively more enriched with tin.

Principal Component 5

Six percent of the variation in the data was attributed to the fifth principal component which was strongly correlated with nickel, silver and cadmium concentrations in dust. Figure C-9 shows the scores plot for component 1 versus component 5. In the scores plots, there is an obvious outlier on the component 5 (horizontal) axis. This outlier is associated with a sampling location in East Flin Flon, where the variables associated with component 5 all measured high (the highest of the dataset), and in many cases, were more than several fold above the mean measured values. Disregarding this outlier, it seems that the scores for component 5 are relatively evenly distributed among the three communities. This may suggest a common source of nickel, silver and cadmium in dust that influences the three communities in a similar way.

Principal Component 6

Four percent of the variation in the data was attributed to the sixth principal component which was strongly correlated with arsenic and cobalt concentrations in dust. Figure C-10 shows the scores plot for component 1 versus component 6. In the scores plots, there is an obvious outlier on the component 6 (horizontal) axis. This outlier is associated with a sampling location in Creighton, where the variables associated with component 6 all measured high (the highest of the dataset), and were more than two-fold above the mean measured values. Disregarding this outlier, it seems that the scores for component 6 are relatively evenly distributed among the three communities. This may suggest a common source of arsenic and cobalt in dust that influences the three communities in a similar way.

Uncertainty in the results of this analysis stem primarily from a paucity of data (*i.e.*, the component analysis was conducted on 25 samples with 24 measured concentration variables). Other sources of uncertainty include, but are not limited to errors in measurement and censored data (non-detects were set to ½ the RDL).

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