Interior Health
DATA & ANALYTICS SERVICES

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Analysis of Variables Influencing Children's Blood Levels in Trail BC

PURPOSE

This analysis was completed to support the MHO Recommendation for a risk-based standard for lead remediation within the environmental management area of Teck Metals Ltd. in Trail, BC.

ACKNOWLEDGMENT

A special thanks to the following collaborators of this analysis project:

Interior Health Team

Jenna Le Noble (Consultant, Data Analytics)
Leanne Cusack (Epidemiologist)
Meghan Morris (Public Health Nurse)
Dr. Ray Copes (Consultant for IH)
Anders Erickson (Senior Human Health Risk Assessment Specialist, Ministry of Health)
Christina Yamada (Manager, Environmental Assessment)

Teck Metals Ltd. Team

Clare North
David Bell
Tara Kennedy (AtkinsRealis)
Andrea McCormick (AtkinsRealis)

Ministry of Environment Team

Jasen Nelson
Lavinia Zanini

BCCDC Team

Max Xie
Felicity Clemens

I. Introduction

The purpose of this analysis is to determine the association and impact of various environmental and socio-economic variables on child blood lead levels in the smelter community of Trail, BC.

The analysis aims to answer the following questions:

1. What is the association between soil lead concentrations with child blood lead levels?
2. What is the association between lead in ambient air (TSP) with child blood lead levels in East Trail and Shavers Bench, controlling for soil lead concentrations?
3. What is the association between pre- and post-remediation soil lead concentrations and pre- and post-remediation child blood lead levels?
4. What is the comparison between rate of change of blood lead levels in Trail to rate of change from CHMS and NHANES?
5. What is the association between dust lead levels and child blood lead levels in 2016?

II. Methods

II.1 Sampling Methods & Data Manipulation Procedures

II.1.1 Blood lead data

Child blood lead samples were obtained by Interior Health's yearly fall clinics from 2007-2023. The study includes children aged 6-36 months living in City of Trail or Rivervale (Areas 2 and 3), Warfield, Oasis, Casino or Waneta (Area 1). Within the age range of 6-36 months, children are able to have 3 yearly blood lead samples.

Blood lead data includes the following variables:

- Sample ID (identification of each unique blood sample)
- Child ID (identification of each child)
- Gender (gender of the child)
- Age (age of child at time of blood lead sample)
- BLL (blood lead level (µg/dL))
- Recieved (date of blood sample)
- Family ID (identification of family to enable linkage between properties where soil lead exposure may occur such as parental home, daycares, etc.)
- Percentage (percentage of time the child spends with associated Family ID)
- Neighborhood (the neighborhood that the child lives at during the time of their blood lead sample)
- Smoking (yes/no answer to whether anyone in the family smokes)
- Pets (yes/no answer to whether the family has pets in the home)
- Renovations (yes/no answer to whether any renovations have been done in the home)
- Home Built Pre-1976 (yes/no answer to whether the family's home was built before 1976)
- Work in lead-based industry (yes/no answer to whether anyone in the family works in the lead based industry)

A total of 203 capillary blood lead samples were removed from the blood lead dataset to include only 1695 venous samples. Capillary samples tend to demonstrate higher lead levels than venous blood lead levels due to contamination (Johnson et al. 1997). Several capillary samples that were taken during the Fall blood lead clinics had higher results than follow-up venous samples and were likely deemed to be contaminated.

For that reason, capillary method was no longer used after 2013. The data was analyzed with and without capillary samples and there was no notable difference in correlation coefficients or conclusions.

Additional blood lead testing is available for children new to the area up to 5 years old, children with previous enhanced support follow-up who are over 36 months old, and children whose parents requested testing for their child outside of the target area or age range. The results of additional testing are not included in this study.

II.1.2 Soil lead data

Soil lead levels were collected from properties in Trail by AtkinsRéalis from 2007-2023. The data includes the following variables:

- Family ID (identification of the family that lived on the property)
- Property ID (identification of each property)
- PbUCLM (95% upper confidence limit of lead in soil on the property (mg/kg))
- PbMax (maximum soil lead level in any given sample on the property (mg/kg))
- Sample date (soil sample date)
- Neighborhood (the neighborhood that the property is located within)
- Remediation extent (the type of soil remediation that was completed on the property if applicable)
- Remediation date (date of soil remediation if applicable)
- Post-rem lead (post-remediation soil lead level if applicable (mg/kg))
- Street address (property street address)
- House age (age of home in 2023)
- Move-in date (the date that the family moved into the property, if provided)
- Move-out date (the date that the family moved out of the proper, if provided and applicable)

The 95% upper confidence limit of lead in soil is used in this analysis to account for variability in the soil. Using this measure ensures 95% confidence that the level of lead in soil is at or below the upper confidence limit.

Child blood lead levels were matched to soil lead levels and property data based on Family ID. Blood lead samples that were matched to properties where the blood lead sample occurred before the property move-in date were excluded from the dataset. Further, if a child moved multiple times before their blood lead sample, the property with the move-in date closest to the date of the blood lead sample was kept.

Since children can be associated with multiple families, these samples were matched with more than one property. The percentage variable from blood lead data indicates the percentage of time a child spends with each of their associated families. Few children were associated with properties that did not have their soil tested. Thus, the total percentage of time spent at each property for these blood samples did not add up to 100%. Blood lead samples that had a total percentage of 90% or higher were kept in the dataset. Soil lead exposure was then calculated as the product of the percentage of time spent with the family and the 95% upper confidence limit of lead in soil on the family's property, summed over each blood sample's associated properties. If soil remediation occurred before the blood lead sample date, then the post-remediation soil lead level was used in the calculation. After using multiple property data to calculate soil lead exposure for each child blood lead sample, the child's family and property data with the highest percentage of time spent was then kept in the dataset. The remaining property data was excluded in the dataset to ensure that each blood lead sample was associated with only one set of property and family data. In the event of tied property percentages, the data for one property was randomly kept. A total of 1228 blood lead samples were matched to associated soil and property data.

Blood lead samples were classified as "pre-remediation" if the blood sample was taken up to 60 days after the soil remediation date on the property that the child spent majority of their time at. Additionally, blood samples were classified as "post-remediation" if the blood lead sample was taken 60 days or more after the soil remediation date. Lastly, blood samples were classified as "never-remediated" if the property that the child spent majority of their time at did not undergo any form of remediation. A total of 395 samples were classified as pre-remediation, 310 samples were classified as post-remediation and 523 samples were classified as never-remediated.

II.1.3 Lead in ambient air data

Levels of lead in total suspended particulate (TSP) were collected every two days in Butler Park, Trail from 2007 to 2023. Additionally, levels of lead in PM10 were collected every six days in Butler Park from 2007 to 2023.

PM10 is defined as inhalable particles 10 µm in diameter or less, while TSP includes all particle sizes (*Particulate Matter (PM) Basics* 2023). While neither Canada nor BC have a standard for lead in ambient Air, the US National ambient air quality standards for lead in air are set at 0.15 µg/m3 of lead in TSP as a 3-month average (*National Ambient Air Quality Standards (NAAQS) for Lead (Pb)* 2023).

Levels of lead in TSP levels were shown to be consistently higher than levels of lead in PM10 in Butler Park, Trail. Lead in TSP levels were therefore used in this analysis. Mid-August to mid-September mean TSP levels were assigned to child blood lead samples from East Trail and Shavers Bench neighborhoods based on the year of the child blood sample. A total of 306 blood lead samples were matched to lead in TSP levels.

II.1.4 Lead in dustfall data

Lead in dustfall levels were collected by AtkinsRéalis from homes in Trail in 2016. Total lead loading, in comparison to concentration of lead, is considered to be a better indicator of exposure as it is more representative of the amount of lead physically available and is less impacted by the amount of time since the last cleaning (Bevington et al. 2021). For that reason, total lead loading for the indoor dustfall container and total lead loading for outdoor dustfall container variables were used in this analysis. Blood lead samples taken in 2016 were matched with dustfall levels based on associated Family ID variable for a total sample size of 20.

II.1.5 Census data

Canadian Census Data was used to explore socio-economic variables in Trail. Census data is available on a 5-year basis (2006, 2011, 2016 and 2021) for dissemination areas (DA) in Canada. Trail dissemination areas were assigned to blood lead and soil lead data based on property street address. A total of 16 different dissemination areas were present within the Trail lead data. Census data was then matched to blood lead and soil lead data based on dissemination area and year of blood lead sample as follows:

- Blood lead samples taken in 2007-2008 were matched with 2006 census data by DA
- Blood lead samples taken in 2009-2013 were matched with 2011 census data by DA
- Blood lead samples taken in 2014-2018 were matched with 2016 census data by DA
- Blood lead samples taken in 2019-2023 were matched with 2021 census data by DA

Relationships between child blood lead levels with median household total income by DA and prevalence of low-income based on low-income measure (LIM-AT) by DA were explored. Median household total income by DA showed a more significant relationship with blood lead levels than the prevalence of low-income did. This is likely due to estimations within the low-income prevalence variable causing loss of predictive power. For that reason, median household total income by DA was used in this analysis.

II.2 Data Analysis Procedures

Both blood lead levels and soil lead levels followed log-normal distributions. To meet the assumptions of linear modelling, natural-log-transformed blood lead levels and natural log-transformed soil lead levels were used in this analysis.

Log-transforming blood lead and soil lead levels also reduced the impact of outliers. Before log-transforming blood lead levels, 49 blood lead samples out of 918 (excluding post-remediation samples) were identified as outliers with levels higher than the upper bound of 10.4 µg/dL. Many of these samples were identified as children who were included in the Enhanced Support program where there may be other potential influences on raised blood lead levels such as socio-economic status, house age, lead paint, worker carry home from parents working in lead based industries and child behaviours that increase risk of exposure (e.g. pica, mouthing, etc.). After log-transforming blood lead levels, the number of log-transformed blood lead outliers reduced to 9.

Before log-transforming soil lead levels, 55 soil lead samples out of 918 were identified as outliers with levels higher than the upper bound of 2142 mg/kg. After log-transforming soil lead levels, the number of log-transformed soil lead outliers reduced to 12.

A sensitivity analysis was performed with data that included the outliers from the log-transformed variables and data that excluded these outliers. It was found that removing outliers did not significantly change the results of the models. Since the samples were true values, outliers from log-transformed blood lead levels and log-transformed soil lead levels were kept in the data and models.

Linear mixed effects models were developed with random intercepts for Child ID to account for repeated samples from children, and random intercepts for Family ID to account for siblings and children living on the same property. Starting with a univariate baseline model (including log-transformed soil lead levels as the predictor and log-transformed blood lead levels as the outcome variable), additional predictor variables such as median household income, house age, and year of blood lead sample were added to the model in a step-wise analysis. The same process was completed for the lead in TSP subset.

A limitation of using linear models in this analysis is the requirement of a linear relationship between predictor variables with the outcome variable. Correlation matrices and scatterplots of relationships between predictor variables with log-transformed blood lead levels are included in the results section below. No predictor variables showed strong linear associations with log-transformed blood lead levels, however, some predictor variables showed moderate to strong linear relationships with log-transformed blood lead levels. The linear model results give general estimates for each predictor variable and therefore do not represent exact associations. The model results also include 95% confidence intervals and p-values for each estimate to determine significance of each predictor variable.

This study and analysis was apart of a collaboration with IH environmental health experts, the Ministry of Health, the Ministry of Environment, AtkinsRéalis and Teck Metals Ltd. The methods and results of this analysis were consistently reviewed by Human Health Risk Assessment Specialists, Risk Assessors, Toxicologists as well as Biostatisticians from BCCDC.

III. Results

1. What is the association between soil lead concentrations and child blood lead levels?

Summary Statistics

To analyze the association between soil lead levels and child blood lead levels, blood lead samples classified as post-remediation were excluded from the dataset. A separate analysis was performed on post-remediation samples to analyze the effectiveness of soil remediation on blood lead levels (see question 3). Blood lead samples classified as either never-remediated or pre-remediation were used for this part of the analysis for a total sample size of 918.

The following table summarizes the continuous variables used in the linear models.

Table 1: Summary Table of Variables

Variable	N	Mean	Geomean	Std. Dev.	Min	Pctl. 25	Pctl. 75	Max
BLL (ug/dL)	918	4.3	3.33	3.30	0.3	2.10	5.4	28.0
ln(BLL)	918	1.2	NA	0.73	-1.2	0.74	1.7	3.3
Soil Lead Exposure (mg/kg)	918	845.0	622.89	693.00	44.0	389.00	1090.0	5338.0
ln(Soil Lead Exposure)	918	6.4	6.38	0.82	3.8	6.00	7.0	8.6
Child Age (months)	918	20.0	18.17	8.60	6.0	13.00	28.0	35.0
House Age (years)	918	75.0	70.93	22.00	7.0	61.00	93.0	122.0
Median Income ($)	918	64265.0	61004.95	19718.00	15165.0	49085.00	84314.0	103000.0

Correlations

The following correlation matrix demonstrates the correlation coefficients between all continuous variables.

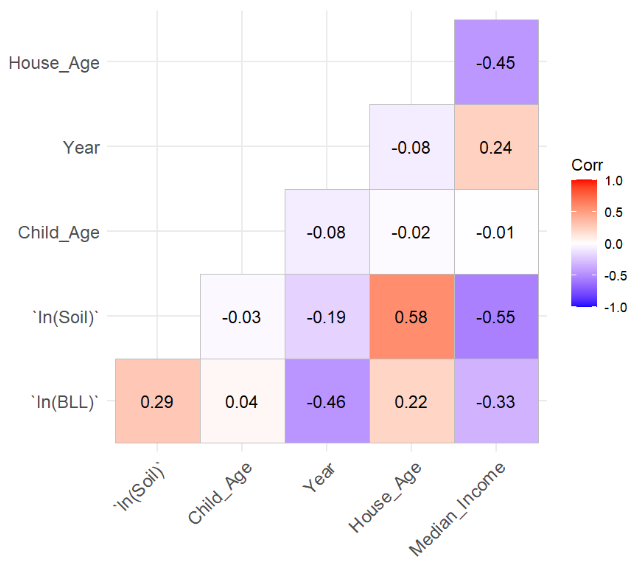

Figure 1: Correlation matrix of variables (N=918)

A correlation coefficient close to 1 indicates a strong positive linear relationship, while a correlation coefficient close to -1 indicates a strong negative linear relationship. Figure 1 demonstrates that the correlation coefficient between log-transformed blood lead levels and log-transformed soil lead levels is 0.29, indicating a weak-moderate positive linear relationship between these variables. We also see a weak-moderate positive linear relationship between log-transformed blood lead levels with house age. The negative correlation coefficients between log-transformed blood lead levels with year and log-transformed blood lead levels with median household income demonstrate weak-moderate negative linear relationships between these variables.

The correlation matrix also demonstrates interactions between predictor variables. For example, a correlation coefficient of -0.45 between median household income and house age indicates a moderate to strong negative linear relationship (higher values of median household income are associated with newer homes). Further, a correlation coefficient of 0.58 between log-transformed soil lead and house age indicates a moderate to strong positive linear relationship (older homes are associated with higher levels of soil lead).

Plots

The following plots explore the relationships between measured blood lead levels with the predictor variables.

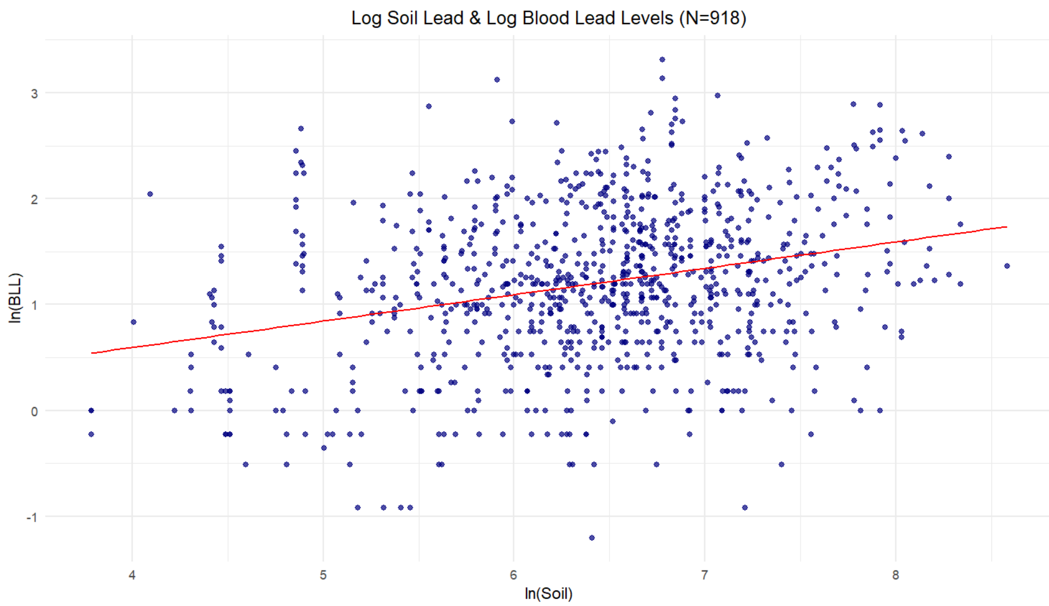

Figure 2: Relationship between log-transformed soil lead and log-transformed blood lead levels from 2007-2023 (N=918). The line of best fit in red demonstrates a positive linear relationship between log-transformed soil lead levels and log-transformed blood lead levels.

While there is not a linear relationship between child age and child blood lead levels, age groups were used to explore differences in blood lead levels due to different child behaviours (e.g. pica, mouthing, etc.).

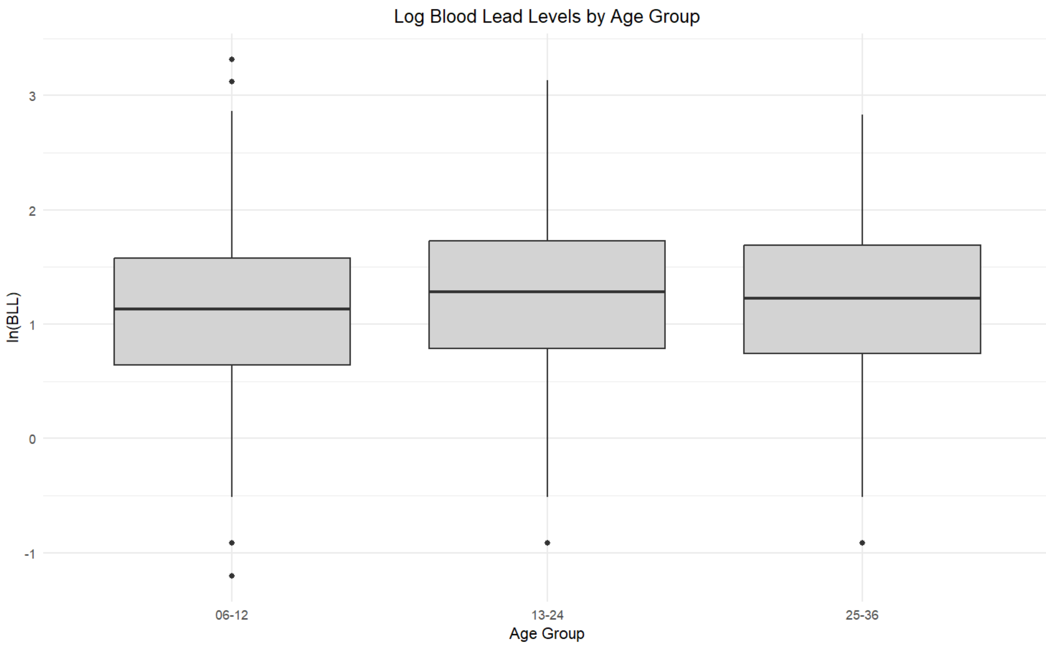

Figure 3: Boxplot for 3 age groups (p-value: 0.06)

The 13-24 month age group is associated with slightly higher blood lead levels than the other age groups due to behaviors such as crawling, walking and exploring with mouths. An ANOVA test of significance, however, did not show a significant difference in mean log-transformed blood lead levels between the 3 age groups. For that reason, age group is not included in the linear models.

House age is a continuous variable representing the age of the home that the child spent majority of their time living at during the time of their blood lead sample. The following plot shows the relationship between house age and log-transformed blood lead levels.

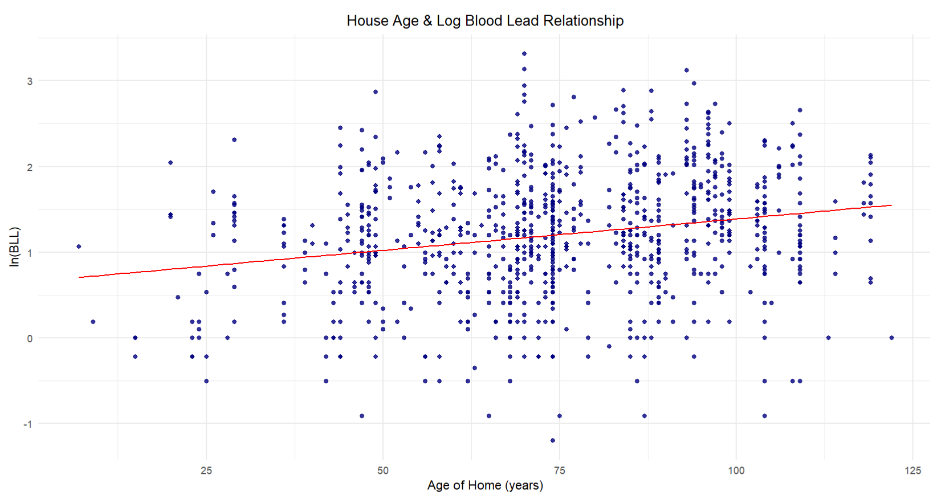

Figure 4: The line of best fit in red demonstrates a positive linear relationship between house age and log-transformed blood lead levels (N=918).

Median household total income levels by Trail dissemination areas were obtained from Canadian Census Data. The plot below demonstrates the relationship between median household income and log-transformed blood lead levels.

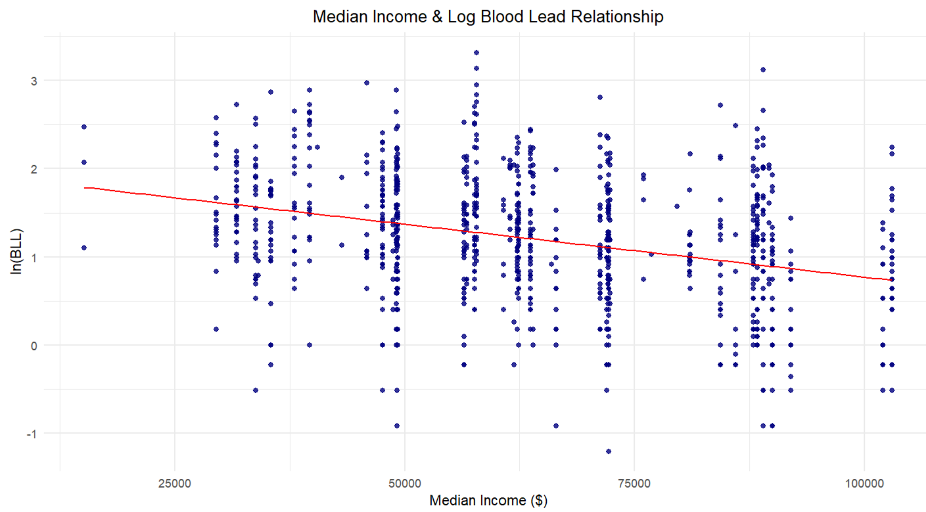

Figure 5: The line of best fit in red demonstrates a negative linear relationship between median income and log-transformed blood lead levels (N=918).

Lastly, log-transformed blood lead levels were explored over time. The yearly trend shows a consistent decrease in blood lead levels due to various programs and interventions such as the Fugitive Dust Reduction Program, Soil Management Program and Healthy Family Healthy Homes program. The general decrease in blood lead levels in the Canadian population are reflected in Trail as well (more details are shown in Question 4).

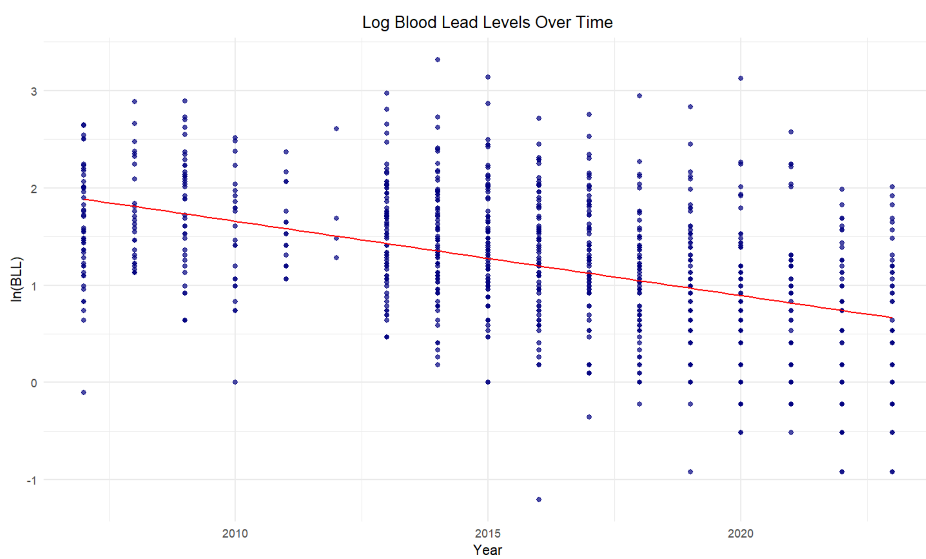

Figure 6: The line of best fit in red demonstrates a negative linear relationship between year and log-transformed blood lead levels (N=918).

Models

Model 1.0

The following scatter plot demonstrates Trail measured blood lead levels and soil lead levels in comparison to predicated values based on estimated risks from HHRA. A simple univariate linear regression model was developed to compare estimates between measured values and predicted values.

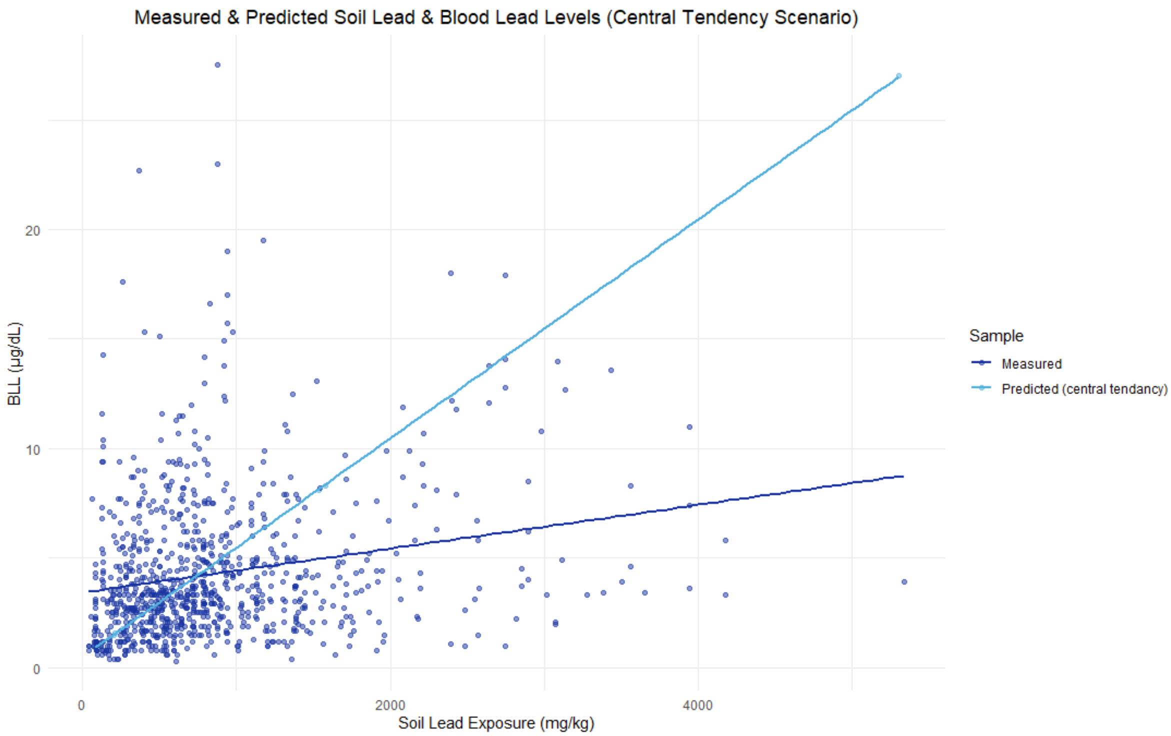

Figure 7: Predicted blood lead levels based on estimated risks (hazard quotients) from HHRA and the basis of the Health Canada Toxicity Reference Value for lead. Central tendency scenario uses mean values.

Table 2: Model 1.0 Model Results for Measured Data in Trail

Term	Estimate	Lower CI	Upper CI	P value
Intercept	3.43302	3.106280	3.759768	0
Soil Lead	0.00100	0.000701	0.001299	0

The model results for measured data estimate that every 100 mg/kg increase of lead in soil is associated with a 0.1 µg/dL increase in BLL. The predicted values from HHRA estimate that every 100 mg/kg increase of lead in soil is associated with a 0.50 µg/dL increase in BLL.

The next models in this section use linear mixed effects with random intercepts for Child ID and Family ID. The data includes 918 samples taken before any form of soil remediation occurred.

Model 1.1

The first univariate model includes log-transformed soil lead levels as the predictor of log-transformed blood lead levels.

Table 3: Model 1.1 Results (N=918)

Term	Estimate	Lower CI	Upper CI	P value
Intercept	-0.35339	-0.78801	0.08171	0.11122
ln(Soil Lead)	0.23923	0.17308	0.30532	0.00000

Model 1.1 results estimate that a 1% decrease in soil lead concentration is associated with a 0.24% decrease in blood lead level. As an example, the model estimates that a decrease in soil lead level from 1000 mg/kg to 400 mg/kg (60% decrease) is associated with a decrease in blood lead level from 3.67 µg/dL to 2.94 µg/dL (19.7% decrease).

Model 1.2

The next model adds house age and median income as predictor variables to the previous univariate model (Model 1.1).

Table 4: Model 1.2 Results (N=918)

Term	Estimate	Lower CI	Upper CI	P value
Intercept	0.67200	0.02680	1.32000	0.04140
ln(Soil Lead)	0.14200	0.05520	0.22800	0.00142
House Age	0.00082	-0.00241	0.00404	0.62100
Median Income	-0.07130	-0.10400	-0.03820	0.00003

Model 1.2 results estimate that a 1% decrease in soil lead concentration is associated with a 0.14% decrease in blood lead level. As an example, if house age is held fixed at the average age of 75 years and median income is held fixed at the average level of $60,000, the model estimates that a decrease in soil lead level from 1000 mg/kg to 400 mg/kg (60% decrease) is associated with a decrease in blood lead level from 3.61 µg/dL to 3.17 µg/dL (12.2% decrease).

The model results also estimate that a $10,000 increase in median income is associated with a 6.88% decrease in blood lead level. As an example, if soil lead level is held fixed at 400 mg/kg and house age is held fixed at 75 years, the model estimates that an increase of median household income by DA level from $37,500 to $60,000 (60% increase) is associated with a decrease in blood lead level from 3.72 µg/dL to 3.17 µg/dL (14.8% decrease).

House age does not appear to be a significant predictor of blood lead levels in this model. The estimate for house age has a p-value higher than a significance level of 0.05, and contains a confidence interval that ranges from negative to positive, indicating no strong linear association.

Model 1.3

The next model adds year as a predictor variable of blood lead levels to the previous model (Model 1.2).

Table 5: Model 1.3 Results (N=918)

Term	Estimate	Lower CI	Upper CI	P value
Intercept	1.31759	0.72430	1.91118	0.00002
ln(Soil Lead)	0.10325	0.02484	0.18165	0.01023
House Age	0.00184	-0.00105	0.00473	0.21386

Term	Estimate	Lower CI	Upper CI	P value
Median Income	-0.04769	-0.07795	-0.01746	0.00203
Year	-0.06373	-0.07449	-0.05300	0.00000

Model 1.3 results estimate that a 1% decrease in soil lead concentration is associated with a 0.1% decrease in blood lead level. As an example, if house age is held fixed at 75 years, median income is held fixed at $60,000 and year is held fixed at 2023, a decrease in soil lead level from 1000 mg/kg to 400 mg/kg (60% decrease) is associated with a decrease in blood lead level from 2.22 µg/dL to 2.02 µg/dL (9% decrease).

With this model building process, we are able to notice how the estimate for log-transformed soil lead levels changes when additional predictors are added. In particular, year is a strong predictor of blood lead levels as it accounts for additional factors such as the consistent reduction of lead in air over time, as well as other interventions put in place to help reduce blood lead levels. When year is added into the model, the estimate for log-transformed soil lead levels decreases slightly in magnitude.

Model 1.4

The next model incorporates household level variables (renovations, pets, smoking, work in lead based industry). These variables are yes/no questions answered by families participating in the blood lead clinics. Consistent answers to these questions did not occur until around 2019. Therefore, the data used for this model is a subset of 289 samples containing answers to these household level variables.

The following correlation matrix includes correlation coefficients for household level variables.

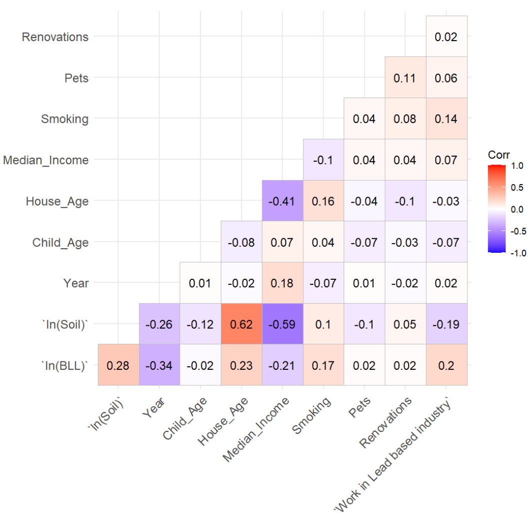

Figure 8: Correlation matrix of variables (N=289)

The correlation matrix demonstrates weak to moderate positive linear relationships between log-transformed blood lead levels with smoking and work in lead variables. Additionally, the correlation coefficients for log-transformed blood lead levels with pets and renovations are close to 0, indicating no linear relationship between these variables.

The following scatter plot shows the relationships between log-transformed blood lead levels with log-transformed soil lead levels for this subset of 289 samples.

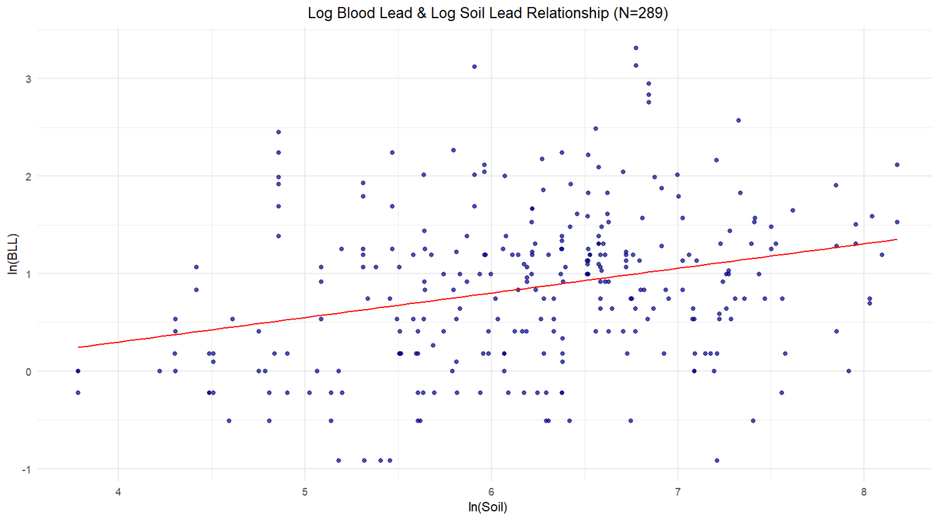

Figure 9: Relationship between log-transformed soil lead and log-transformed blood lead levels for the larger group (N=289). The line of best fit in red demonstrates a positive linear relationship between log-transformed soil lead levels and log-transformed blood lead levels.

Model 1.4 includes log-transformed soil lead levels, house age, median income, year, pets, renovations, smoking and work in lead based industry variables as predictors of log-transformed blood lead levels.

Table 6: Model 1.4 Results (N=289)

Term	Estimate	Lower CI	Upper CI	P value
Intercept	0.06780	-1.25000	1.39000	0.91900
ln(Soil Lead)	0.18200	0.01830	0.34500	0.03320
House Age	0.00341	-0.00297	0.00982	0.30600
Median Income	-0.01340	-0.07410	0.04770	0.66500
Year	-0.06650	-0.10500	-0.03110	0.00030
Pets	0.06800	-0.16500	0.30000	0.57400
Renovations	-0.04710	-0.26500	0.17600	0.67800
Smoking	0.17600	-0.07440	0.42600	0.17800
Work in lead	0.32500	0.11000	0.54100	0.00438

Model 1.4 results demonstrate that estimates for log-transformed soil lead levels, year and working in lead based industry are the only significant variables. The estimate of log-transformed soil lead levels can be interpreted as a 1% decrease in soil lead concentration being associated with a 0.18% decrease in blood lead level. Further, the estimate for working in lead industry indicates that the answer to ‘work in lead industry’ changing from “no” to “yes” is associated with a 38.36% increase in blood lead level.

The confidence intervals for the estimates of house age, median income, renovations, pets and smoking in Model 1.4 range from negative to positive values, and the p-values are larger than 0.05. Since these variables are not significant, interpretations of these estimates are unable to be made.

2. What is the association between lead in ambient air (TSP) with child blood lead levels in East Trail and Shavers Bench, controlling for soil lead concentrations?

TSP data was available for a subset of the main dataset due to lead in TSP levels being measured only in Butler Park, Trail from 2007 to 2023. East Trail and Shavers Bench neighborhoods were determined to be the neighborboods most affected by lead in TSP at Butler Park. The mean TSP levels from mid-August to mid-September were therefore assigned to child blood lead samples from East Trail and Shavers Bench neighborhoods based on the year of their blood sample (N=155).

Summary Statistics

The following table summarizes the continuous variables from the TSP subset.

Table 7: Summary Table of Variables

Variable	N	Mean	Geomean	Std. Dev.	Min	Pctl. 25	Pctl. 75	Max
BLL (ug/dL)	155	5.30	4.25	3.60	0.80	3.00	6.80	18.00
ln(BLL)	155	1.40	0.00	0.68	-0.22	1.10	1.90	2.90
Soil Lead Exposure (mg/kg)	155	1437.00	1154.69	965.00	280.00	746.00	1909.00	5338.00
ln(Soil Lead Exposure)	155	7.10	7.02	0.68	5.60	6.60	7.60	8.60
Pb TSP (ug/m3)	155	0.33	0.28	0.16	0.07	0.25	0.44	0.63
Child Age (months)	155	19.00	17.04	8.50	6.00	12.00	26.00	35.00
House Age (years)	155	81.00	79.05	14.00	36.00	74.00	93.00	103.00
Median Income ($)	155	53257.00	50424.18	17128.00	15165.00	39679.00	63680.00	102000.00

Correlations

The following correlation matrix includes correlation coefficients between continuous variables for the TSP subset.

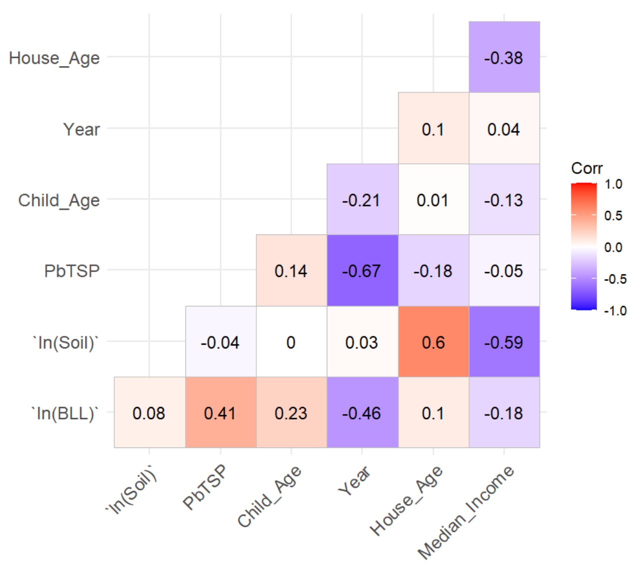

Figure 10: Correlation matrix of variables for TSP subset (N=155)

The correlation matrix demonstrates a correlation coefficient of 0.08 between log-transformed blood lead and soil lead levels, indicating a weak linear relationship for this subset of data. Additionally, the correlation coefficient between log-transformed blood lead levels and lead in TSP is 0.41, indicating a moderate positive linear relationship.

Plots

The following scatter plots explore the relationships between measured blood lead levels with the predictor variables.

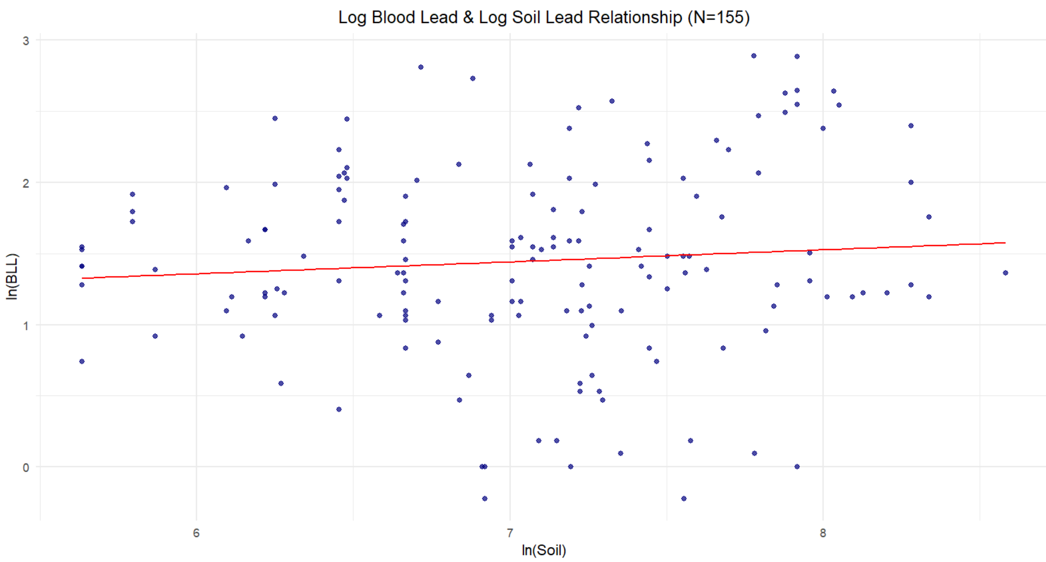

Figure 11: Relationship between log-transformed soil lead and log-transformed blood lead levels from 2007-2023 (N=155). The line of best fit in red demonstrates a weak positive linear relationship between log-transformed soil lead levels and log-transformed blood lead levels.

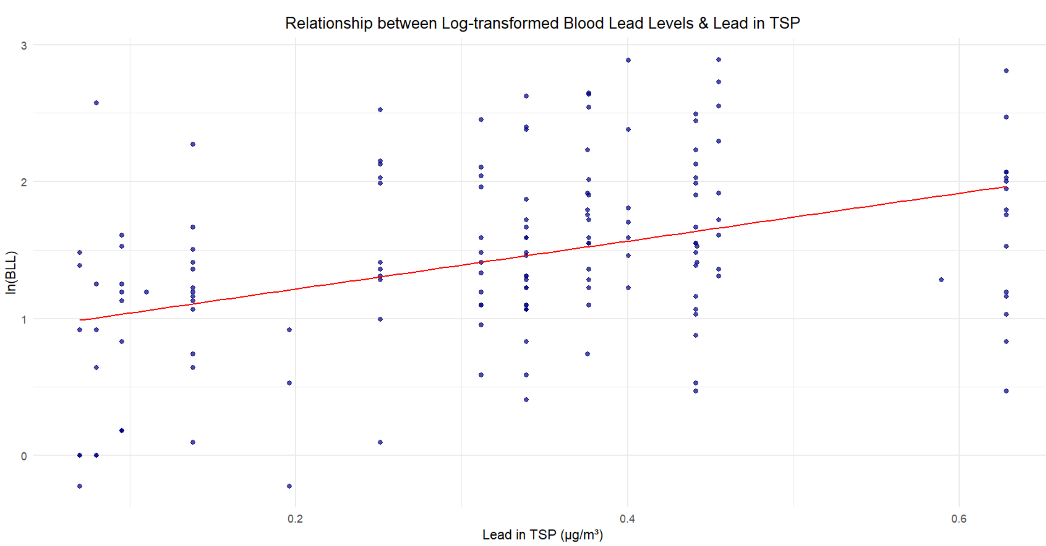

Figure 12: The line of best fit in red demonstrates a positive linear relationship between lead in TSP and log-transformed blood lead levels (N=155).

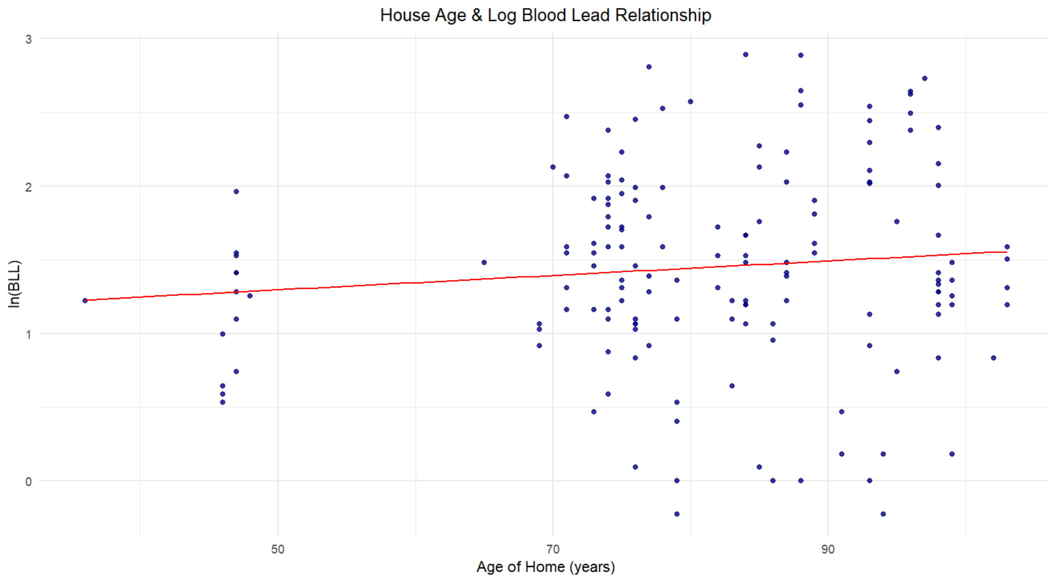

Figure 13: The line of best fit in red demonstrates a positive linear relationship between house age and log-transformed blood lead levels (N=155).

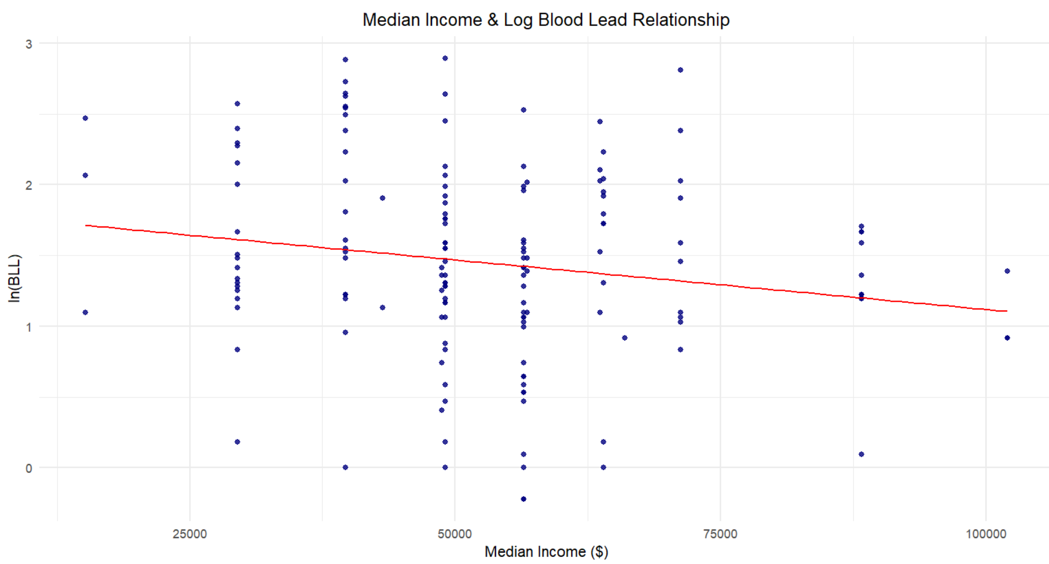

Figure 14: The line of best fit in red demonstrates a negative linear relationship between median household income and log-transformed blood lead levels (N=155).

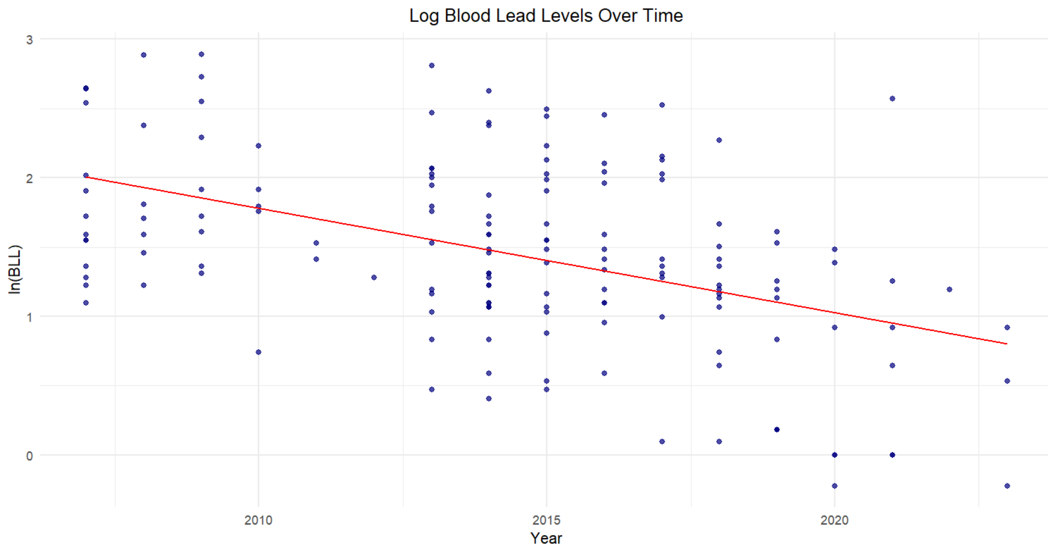

Figure 15: The line of best fit in red demonstrates a negative linear relationship between year and log-transformed blood lead levels (N=155).

Models

Model 2.1

The univariate model below includes log-transformed soil lead levels as the predictor of log-transformed blood lead levels.

Table 8: Model 2.1 Results (N=155)

Term	Estimate	Lower CI	Upper CI	P value
Intercept	0.70835	-0.68662	2.1044	0.32259
ln(Soil Lead)	0.09772	-0.09705	0.2923	0.32796

Model 2.1 results demonstrate that the estimate for log-transformed soil lead levels is not significant with a p-value larger than a significance level of 0.05 and a 95% confidence interval that ranges from negative to positive.

Model 2.2

The next model adds lead in TSP, house age and median income as predictors variables to the previous univariate model (Model 2.1).

Table 9: Model 2.2 Results (N=155)

Term	Estimate	Lower CI	Upper CI	P value
Intercept	1.33000	-0.45900	3.11000	0.15300
ln(Soil Lead)	-0.02590	-0.27900	0.22700	0.84400
Pb TSP	1.43000	0.77900	2.13000	0.00002
House Age	0.00268	-0.00861	0.01400	0.64700

Term	Estimate	Lower CI	Upper CI	P value
Median Income	-0.08100	-0.17100	0.00874	0.08430

Model 2.2 results demonstrate that lead in TSP is the only significant variable in the model. The results estimate that every 0.01 µg/m3 decrease of lead in TSP is associated with a 1.4% decrease in blood lead level. As an example, with soil lead level held fixed at 400 mg/kg, house age held fixed at 75 years and median household income held fixed at $60,000, the model equation estimates that a decrease of lead in TSP from 0.25 µg/m3 to 0.1 µg/m3 (60% decrease) is associated with a decrease in blood lead from 3.47 µg/dL to 2.8 µg/dL (19.3% decrease).

Model 2.3

The next model adds year as a predictor of log-transformed blood lead levels.

Table 10: Model 2.3 Results (N=155)

Term	Estimate	Lower CI	Upper CI	P value
Intercept	1.83000	0.12100	3.5300	0.0424
ln(Soil Lead)	-0.01480	-0.25200	0.2210	0.9050
Pb TSP	0.72900	-0.04900	1.5200	0.0722
House Age	0.00313	-0.00735	0.0137	0.5680
Median Income	-0.06530	-0.14900	0.0187	0.1390
Year	-0.05400	-0.08770	-0.0210	0.0022

Model 2.3 results demonstrate that year is the only significant variable. When year is added as a predictor, the estimate for lead in TSP loses significance. For that reason, the results of this model are unable to be interpreted.

3. What is the association between pre- and post-remediation soil lead concentrations and pre- and post-remediation child blood lead levels?

As stated previously, blood lead samples were classified as post-remediation samples when they were taken 60 days or more after soil remediation was performed. The table below summarizes blood lead levels and soil lead levels by remediation status.

Table 11: Summary Table by Property Remediation Status

Remediation Status	Mean BLL (ug/dL)	Geomean BLL (ug/dL)	Mean Soil Lead Exposure (mg/kg)	Geomean Soil Lead Exposure (mg/kg)	N
Never remediated	3.73	2.92	638.49	466.86	523
Pre-remediation	5.00	3.95	1119.39	912.44	395
Post-remediation	4.30	3.41	103.44	75.14	310

The plot below demonstrates yearly geomean blood lead levels by remediation status.

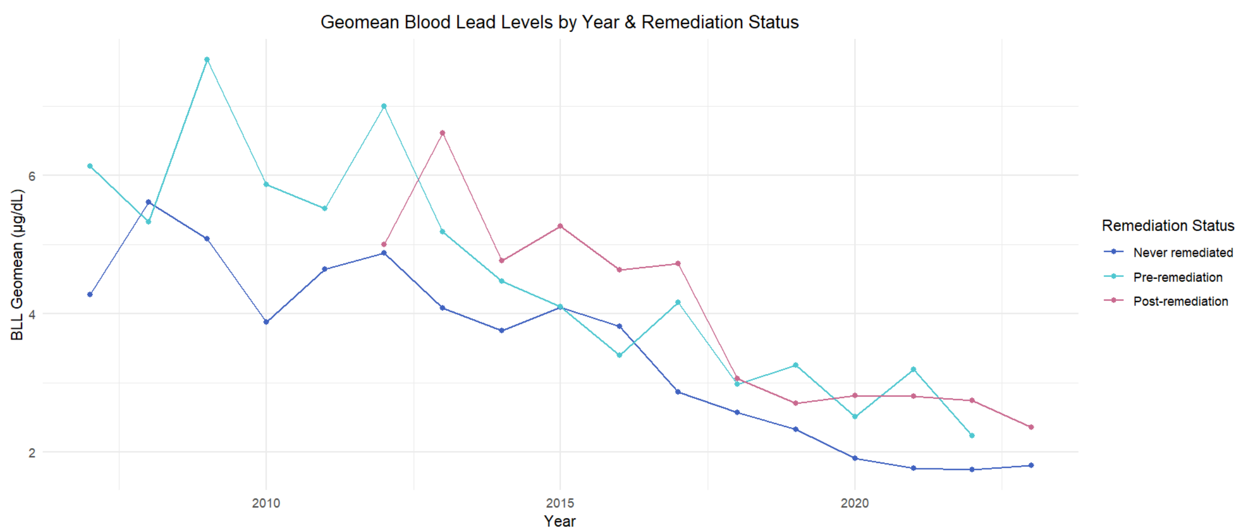

Figure 16: Yearly geometric mean blood lead levels by property remediation status.

Paired samples were used to explore the difference between pre-remediation blood lead samples and post-remediation blood lead samples. A total of 56 children had both a pre-remediation and a post-remediation blood lead sample. These 56 children had blood lead samples taken between 2013-2023. To explore the effectiveness of remediation on lowering blood lead levels, 195 children with multiple samples taken between 2013-2023 were used as a comparison to these 56 children who underwent remediation. These 195 children were associated with properties that never had remediation, or had remediation done after their blood lead samples were taken. The table below demonstrates the differences between first and second blood lead levels and first and second soil lead levels for both groups.

Table 12: First and Follow-up Blood & Soil Samples for Paired Samples

Remediation	N	Geomean of first soil lead (mg/kg)	Geomean of second soil lead (mg/kg)	Geomean of first BLL (ug/dL)	Geomean of second BLL (ug/dL)	Percentage difference (BLL)
Yes	56	1028.71	63.66	3.65	3.40	-6.85
No	195	557.25	542.93	3.17	2.99	-5.68

A t-test comparing the difference between ln(first BLL) and ln(second BLL) for the remediation group and non-remediation group gave a p-value of 0.88, indicating that there is not enough evidence to reject the null hypothesis that the true difference in means is equal to 0.

To further explore the association between pre- and post-remediation soil lead concentrations and pre- and post-remediation child blood lead levels, linear models were developed using the 56 children with paired samples. The scatter plot below demonstrates the pre-remediation blood and soil lead samples in comparison to the post-remediation blood and soil lead samples for these children.

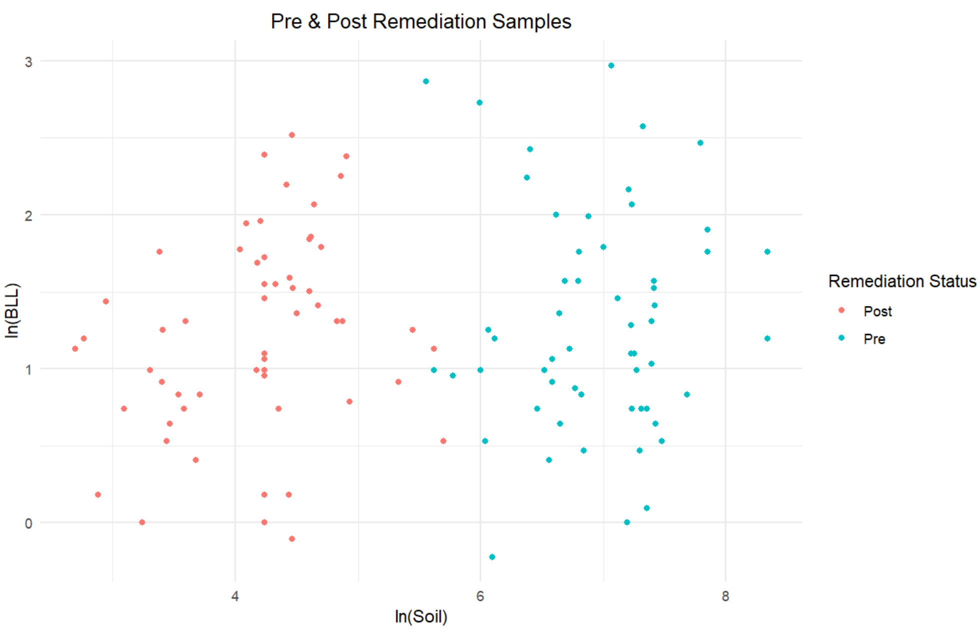

Figure 17: Comparison between blood and soil lead levels before and after soil remediation for 56 children. Blue points represent pre-remediation samples and red points represent post-remediation samples.

Separate linear regression models for pre-remediation samples and post-remediation samples were developed to compare the association of soil lead levels and blood lead levels between pre and post-remediation samples. Below are scatter plots that show the relationship between log-transformed blood lead and log-transformed soil lead levels for pre-remediation and post-remediation samples separately.

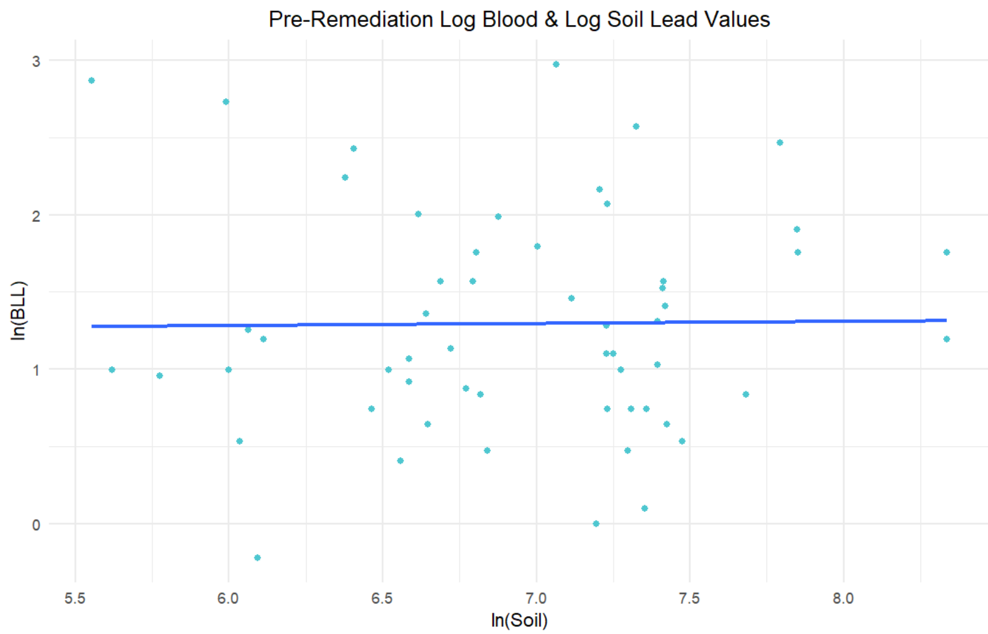

Figure 18: The best fit line depicts a weak linear relationship between pre-remediation log blood lead and log soil lead samples.

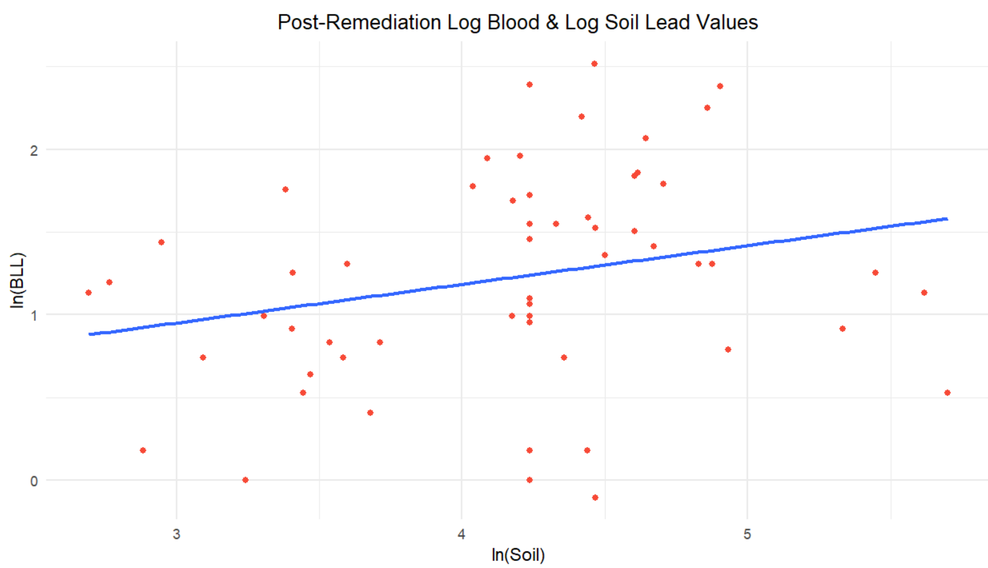

Figure 19: The line of best fit depicts a weak linear relationship between post-remediation log blood lead and log soil lead samples.

Model 3.1: Pre-remediation samples

The following linear regression model uses pre-remediation samples from the 56 children and includes log-transformed soil lead levels, house age, median income and year as predictors.

Table 13: Model 3.1 Results

Term	Estimate	Lower CI	Upper CI	P value
Intercept	4.8600	2.2800	7.44000	0.00042
ln(Soil Lead)	-0.1530	-0.5110	0.20600	0.39600
House Age	-0.0127	-0.0265	0.00121	0.07280
Median Income	-0.2300	-0.3460	-0.11300	0.00023
Year	-0.0216	-0.0861	0.04300	0.50500

Model 3.1 results show that median household income is the only variable with a significant estimate. The confidence intervals for the estimates of the rest of the variables range from negative to positive and the p-values are above the significance level of 0.05. Therefore, we do not see a significant relationship between the predictor variables and blood lead levels.

Model 3.2: Post-remediation samples

The next model replaces pre-remediation samples with post-remediation samples, and includes log-transformed soil lead levels, house age, median income and year as predictors.

Table 14: Model 3.2 Results

Term	Estimate	Lower CI	Upper CI	P value
Intercept	2.57000	0.6070	4.53000	0.0113
ln(Soil Lead)	0.06270	-0.2390	0.36500	0.6780
House Age	-0.00822	-0.0197	0.00329	0.1580
Median Income	-0.12700	-0.2300	-0.02460	0.0161
Year	-0.03230	-0.1060	0.04190	0.3860

Again, the confidence intervals for the estimates of each variable range from negative to positive and the p-values are above the significance level of 0.05.

Due to the small number of children with both pre-remediation and post-remediation samples, we are unable to draw conclusions about the association between pre-remediation and post-remediation blood lead and soil lead levels.

4. What is the comparison between rate of change of blood lead levels in Trail to rate of change from CHMS and NHANES?

The figure below compares the yearly trends of blood lead levels in Trail Areas to Canadian and American blood lead levels.

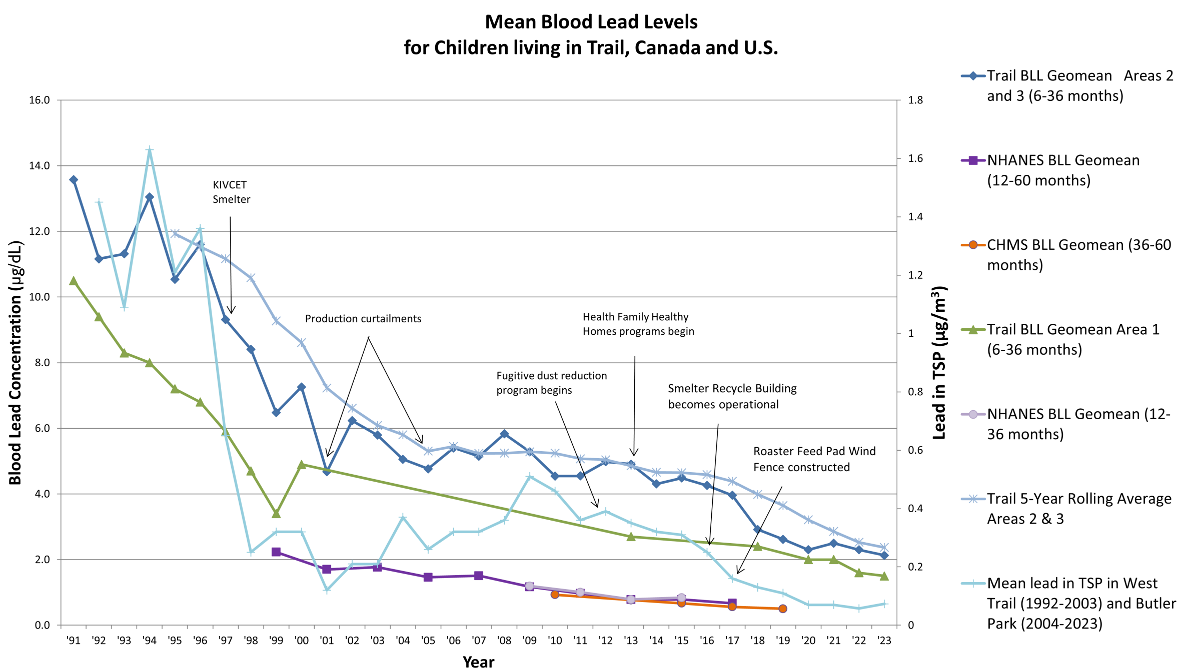

Figure 20: Yearly geometric mean blood lead levels for Trail, CHMS and NHANES

It is important to note that Trail blood lead data includes children aged 6-36 months, while CHMS data includes children aged 3-5 years and NHANES data includes children aged 12-36 months or 12-60 months. Further, CHMS and NHANES blood lead data is provided every 2-3 years. A direct comparison between Trail blood lead levels with CHMS and NHANES blood lead levels cannot be made, but a general comparison of the trends can be shown. The tables below show the rate of change of blood lead levels by year for Trail, CHMS and NHANES.

Table 15: Trail Areas 2 and 3 BLL Rate of Change (6-36 months)

Year	BLL geomean (ug/dL)	BLL rate of change (ug/dL/year)
2007	5.10	-0.30
2008	5.80	0.70
2009	5.30	-0.50
2010	4.50	-0.80
2011	4.60	0.10
2012	5.00	0.40
2013	4.90	-0.10
2014	4.30	-0.60
2015	4.50	0.20
2016	4.30	-0.20
2017	4.00	-0.30

Year	BLL geomean (ug/dL)	BLL rate of change (ug/dL/year)
2018	2.90	-1.10
2019	2.60	-0.30
2020	2.30	-0.30
2021	2.50	0.20
2022	2.30	-0.20
2023	2.13	-0.17

Table 16: CHMS BLL Rate of Change (36-60 months)

Year	BLL geomean (ug/dL)	BLL rate of change (ug/dL/year)
2010	0.93	NA
2013	0.77	-0.053
2015	0.67	-0.050
2017	0.56	-0.055
2019	0.50	-0.030

Table 17: NHANES BLL Rate of Change (12-36 months)

Year	BLL geomean (ug/dL)	BLL rate of change (ug/dL/year)
2009	1.19	NA
2011	1.01	-0.090
2013	0.79	-0.110
2015	0.84	0.025

Overall, Trail, CHMS and NHANES data show that blood lead levels have been decreasing over time. In particular, the blood lead levels in Trail demonstrate higher absolute differences between years in comparison to CHMS and NHANES.

5. What is the association between dustlead levels and child blood lead levels in 2016?

Dust lead levels were collected from 60 properties in 2016. The dust lead variables used for this analysis are the total lead loading for the indoor dustfall container (IDF Pb Loading) and outdoor dustfall container (ODF Pb Loading). When matching 2016 blood lead samples to property dust lead levels, the sample size reduced to 20.

Summary Statistics

Table 18: Summary Statistics for Lead in Dustfall Subset

Variable	N	Mean	Geomean	Std. Dev.	Min	Pctl. 25	Pctl. 75	Max
BLL (ug/dL)	20	3.90	3.03	2.50	0.300	1.80	5.30	9.90
ln(BLL)	20	1.10	1.04	0.82	-1.200	0.59	1.70	2.30
Soil Lead Exposure (mg/kg)	20	620.00	364.08	657.00	84.000	135.00	716.00	2564.00
ln(Soil Lead Exposure)	20	5.90	5.80	1.10	4.400	4.90	6.60	7.80
Indoor Dustfall Lead Loading (ug/dm2/day)	20	0.26	0.22	0.12	0.058	0.18	0.32	0.45
Outdoor Dustfall Lead Loading (ug/dm2/day)	20	2.20	1.83	1.30	0.410	1.20	2.90	5.30
Child Age (months)	20	19.00	16.94	9.20	8.000	12.00	27.00	35.00
House Age (years)	20	66.00	61.77	22.00	24.000	58.00	75.00	97.00
Median Income ($)	20	68653.00	66927.04	14314.00	31718.000	61952.00	74400.00	88320.00

Correlations

The following correlation matrix shows the correlation coefficients for each of the variables from the dust data subset.

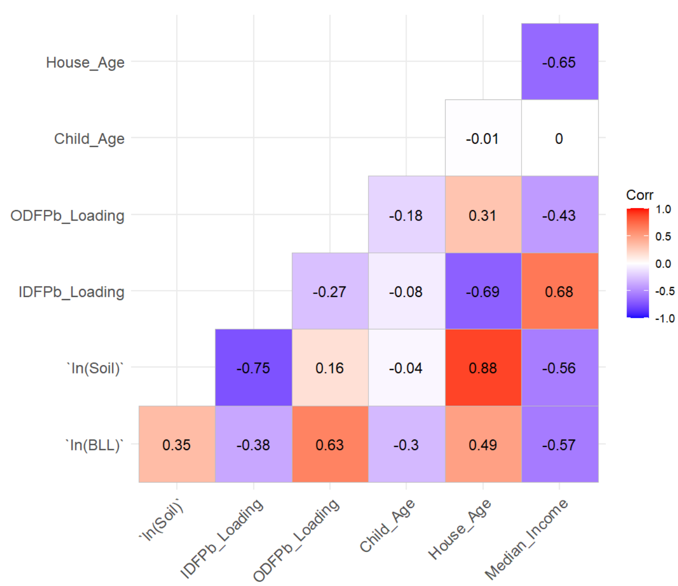

Figure 21: Correlation of variables for dustfall subset (N=20)

Interestingly, the correlation matrix demonstrates a weak-moderate negative linear relationship between log-transformed blood lead levels and indoor dustfall lead loading. This may be due to cleaning prior or during indoor dustfall lead loading testing. The correlation matrix also indicates a moderate-strong positive linear relationship between log-transformed blood lead levels with outdoor dustfall lead loading.

Plots

The following scatter plots show the relationships between blood lead levels and the predictor variables for the dust data subset (N=20).

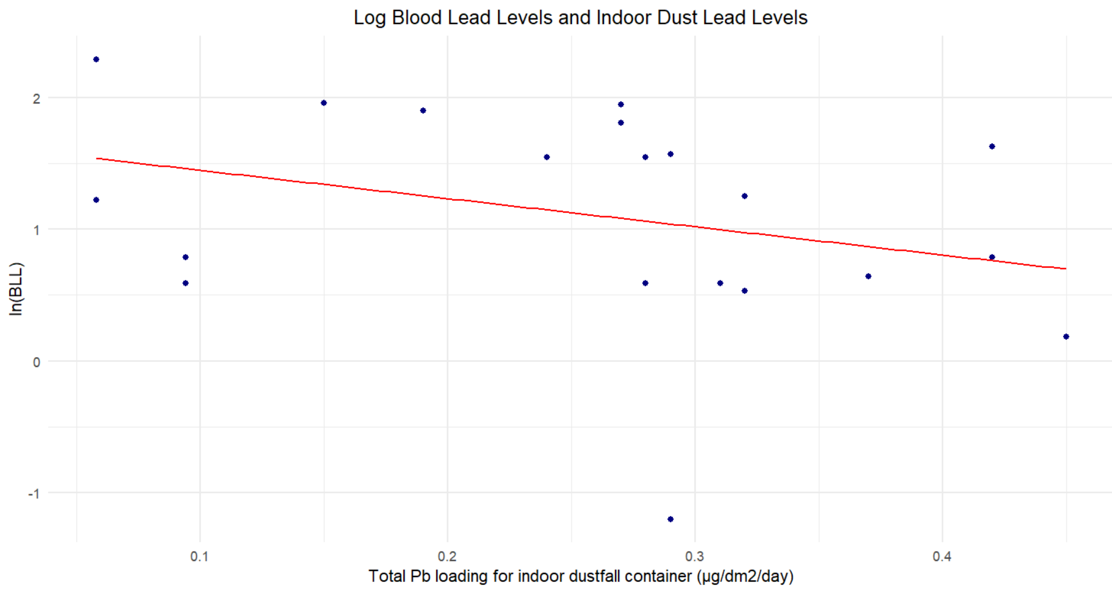

Figure 22: Relationship between log blood lead levels and indoor dust lead levels (N=20).

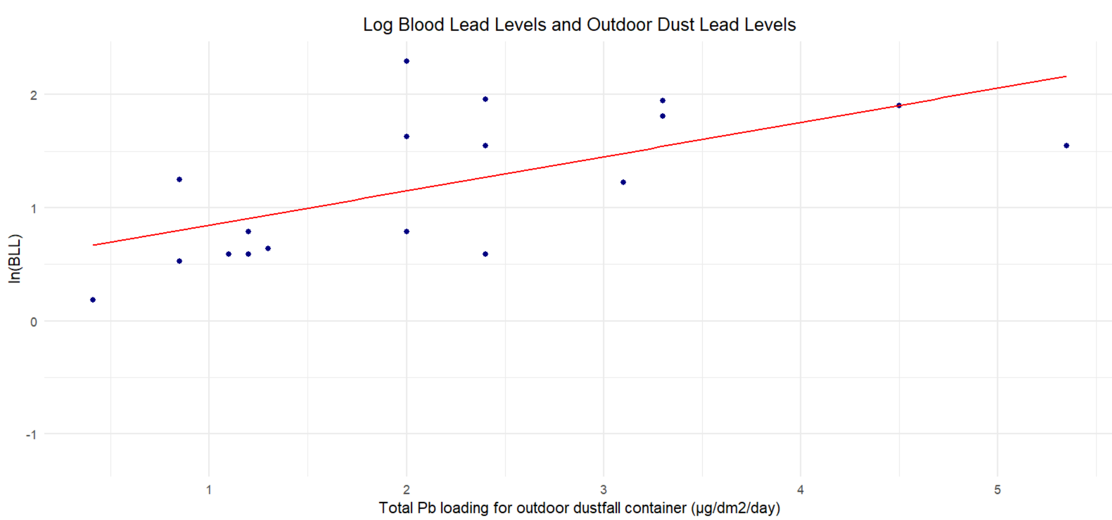

Figure 23: Relationship between log blood lead levels and outdoor dust lead levels (N=20).

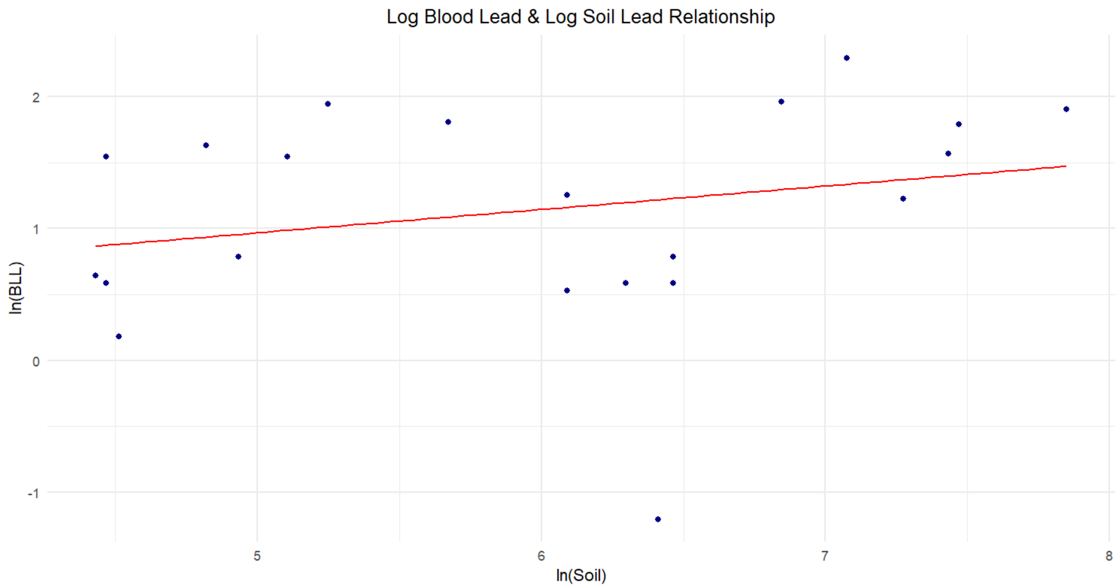

Figure 24: Relationship between log blood lead levels and log soil lead levels (N=20).

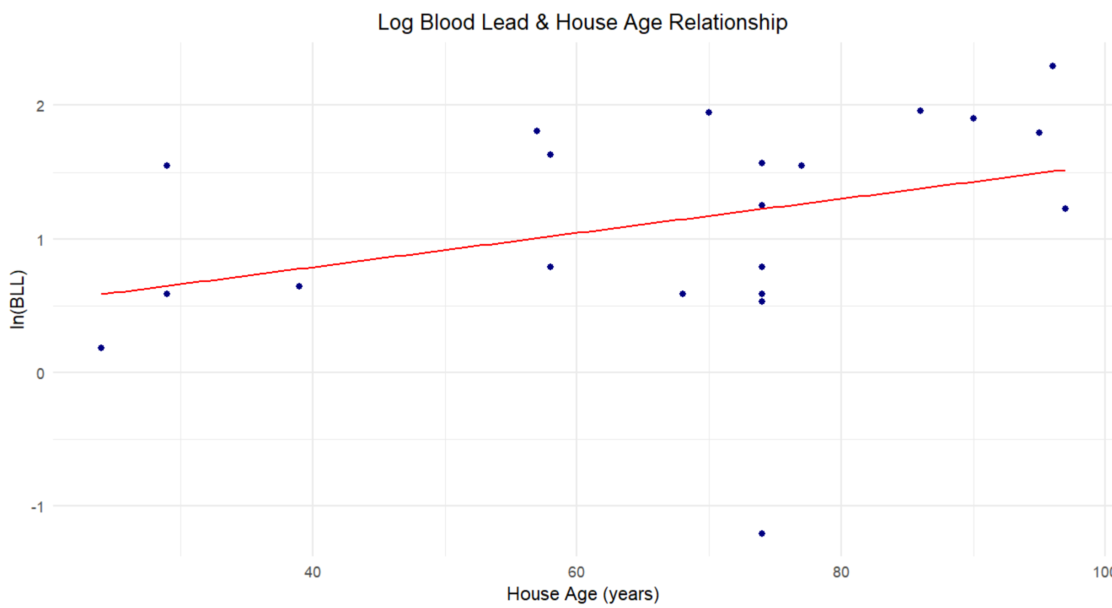

Figure 25: Relationship between log blood lead levels and house age (N=20).

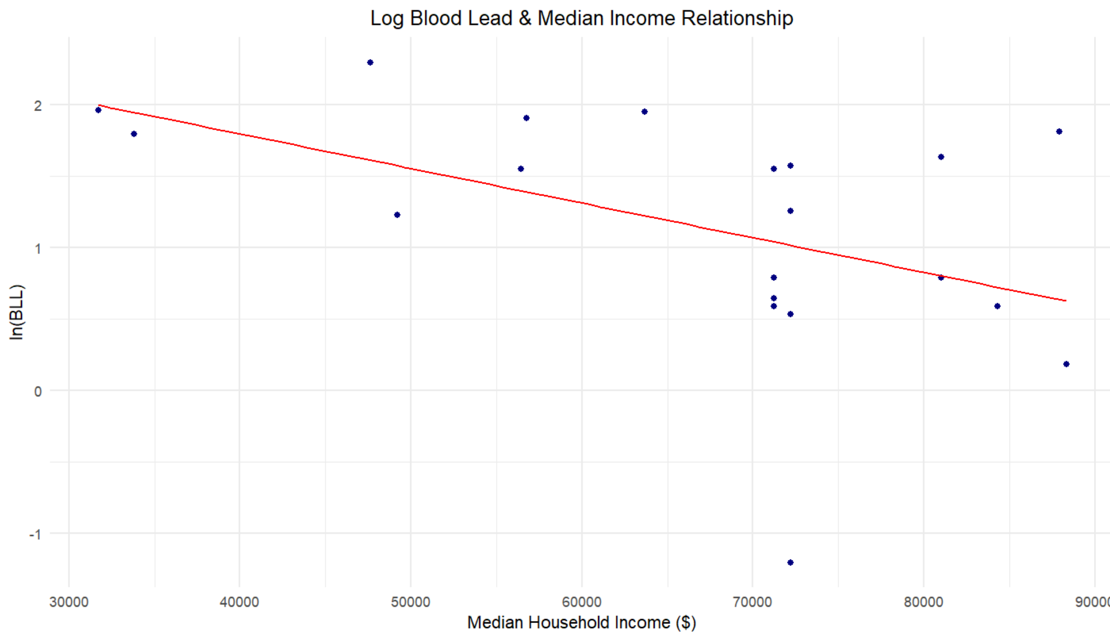

Figure 26: Relationship between log blood lead levels and median household income (N=20).

Models

The first linear regression model uses log-transformed soil lead levels, indoor dustfall lead loading and outdoor dustfall lead loading as predictors of log-transformed blood lead levels.

Model 5.1

Table 19: Model 5.1 Results

Term	Estimate	Lower CI	Upper CI	P value
Intercept	-0.0802	-3.0100	2.85	0.9540
IDF Pb Loading	-0.2860	-3.6000	3.02	0.8550
ODF Pb Loading	0.2790	0.0682	0.49	0.0131
ln(Soil Lead)	0.1300	-0.2410	0.50	0.4660

At a significance level of 0.05, outdoor dustfall lead loading is the only variable with a significant estimate. The estimate coefficient predicts that a 1 unit (µg/dm2/day) decrease in outdoor dustfall lead loading is associated with a 24.3% decrease in blood lead level. As an example, if indoor dustfall lead loading is held fixed at the mean value of 0.26 µg/dm2/day and the soil lead level is held fixed at 400 mg/kg, a decrease in outdoor dustfall lead loading from 2.2 to 0.88 µg/dm2/day (60% decrease) is associated with a decrease in blood lead level from 3.45 to 2.39 µg/dL (30.8% decrease).

Model 5.2

The next model adds house age and median household as predictors.

Table 20: Model 5.2 Results

Term	Estimate	Lower CI	Upper CI	P value
Intercept	1.09000	-2.5100	4.6800	0.5230
IDF Pb Loading	0.50800	-3.3000	4.3100	0.7760
ODF Pb Loading	0.21900	-0.0212	0.4580	0.0703
ln(Soil Lead)	-0.02340	-0.6430	0.5960	0.9360
House Age	0.00749	-0.0214	0.0364	0.5830
Median Income	-0.12300	-0.4050	0.1590	0.3600

Model 5.2 results demonstrate that none of the estimates are significant. Due to limited sample size, interpretation of this model is not able to be made.

IV. Discussion

Through various programs such as Soil Management Program, Fugitive Dust Reduction Program and Healthy Family Healthy Homes program, blood lead levels in children of Trail continue to decrease yearly. Specifically, the geomean blood lead level has decreased from 13.6 µg/dL in 1991 to 2.1 µg/dL in 2023.

Exposures of lead, however, are still present in the community. In particular, lead in soil is an exposure that stays at a constant level over time unless remediated. The results of this analysis demonstrated that there was a weak to moderate positive linear association between log-transformed soil lead levels and log-transformed blood lead levels. Due to small sample sizes, it could not be concluded whether remediation of soil was a contributing factor to lowering blood lead levels.

Further, lead in TSP was shown to have a moderate positive linear association with blood lead levels. Average levels of lead in TSP have been consistently decreasing yearly, starting at 1.45 µg/m3 in 1992 and reducing to 0.073 µg/m3 in 2023.

Additionally, the results of this analysis indicated that median household income by DA level had a moderate to strong negative association with child blood lead levels in Trail. It was shown that higher levels of median household income by DA were associated with lower blood lead levels.

A moderate to strong positive association was also shown between family members working in the lead-based industry with blood lead levels. In addition to Teck Metals Ltd, there are other lead-based jobs in Trail where workers may carry lead back to their homes. Further exploration of relevant protocols at lead-based job sites may be required to determine the impact of worker carry-home on child blood lead levels.

Lastly, total lead loading in outdoor dustfall showed a moderate to strong positive linear relationship with log-transformed blood lead levels. Indoor dustfall lead loading, however, was not a significant predictor of blood lead levels. This could be have been due to the small sample size and/or the influence of indoor cleaning prior or during the indoor dust sampling.

The results of this analysis produce further questions such as how can environmental lead exposures be reduced in order to decrease child blood lead levels? Additionally, how does socio-economic status influence child blood lead levels? Overall, the main purpose of this analysis is to assist in developing recommendations to further reduce child blood lead levels in Trail.

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