We sincerely thank the Editor and the Referees for their careful evaluation of our manuscript and for their constructive and insightful comments. Their valuable suggestions have greatly helped us improve the quality and clarity of the manuscript.

We have carefully considered all comments and revised the manuscript accordingly. Detailed responses to each comment are provided in this supplementary document. Our responses are highlighted in red.

Thank you again for your time, effort, and thoughtful review.

Referee-1

Q1: I feel the paper would be much improved by the inclusion of analytical results for representative samples of coal ash and other potential contaminating material from Uliastai. The paper infers that metals observed at higher relative levels were due to anthropogenic sources - this conclusion would be reinforced if those sources had also been analysed.

A1: We thank the reviewer for this comment. Regarding to the reviewer's comment, representative samples of household coal and coal ash commonly used in Uliastai were analyzed. The analytical results showed substantial enrichment of several potentially toxic elements in coal ash relative to the original coal. Coal ash contained 53 mg/kg As, 203 mg/kg Cr, 43 mg/kg Pb, 48 mg/kg Cu, 304 mg/kg Zn, 337 mg/kg V, and 950 mg/kg Ba, compared with 10, 34, 8, 9.18, 62, 63, and 179 mg/kg in coal, respectively. These concentrations were approximately five to six times higher in coal ash than in the original coal. These findings provide direct evidence that household coal combustion and subsequent ash deposition are important anthropogenic sources of potentially toxic elements in residential soils. The inclusion of coal and coal ash analyses strengthens the interpretation of the PCA, EF, and Igeo results and supports our conclusion that the elevated concentrations of As, Pb, Zn, and Cu observed in Uliastai soils are primarily associated with anthropogenic activities related to household coal use. These results will be detailed in Section 3.2.

	As	**Cr**	**Pb**	**Co**	**Cu**	**Zn**
Coal	10	34	8	4	9	62
Coal ash	53	203	43	16	48	304
Ratio between Coal ash / Coal	5.3	6.0	5.4	4.0	5.3	4.9

Q2: The authors have used outdated versions of several key references. Specifically, the 1997 version of the USEPA exposure factors handbook has been used, rather than the 2011 edition, and the 2007 USEPA draft risk assessment of coal combustion wastes has been used, rather than the final risk assessment published in 2014.

A2: We appreciate this important observation. We acknowledge that the USEPA Exposure Factors Handbook (1997) and USEPA Coal Combustion Waste Risk Assessment (2007 draft) are outdated references. In the revised manuscript, all exposure parameters and risk assessment procedures have been updated using the USEPA Exposure Factors Handbook (2011 Edition) and the final USEPA Coal Combustion Residuals Risk Assessment (2014). The relevant text, tables, and references will be revised accordingly.

Q3: The authors elected to determine exposure through three exposure routes: ingestion, dermal and inhalation. The equations for these exposure routes are presented in equations (3), (4) and (5). Equation (4) dermal exposure contains a term FE, which the authors describe as the dermal exposure ratio, with a value of 0.61. However, in the USEPA equation this term is PC, the chemical-specific dermal permeability constant, which for metals has a value of 0.001. This different will obviously have a large impact on estimates of dermal exposure.

A3: Following the reviewer's recommendation, the dermal exposure assessment was re-evaluated using the USEPA methodology and the appropriate chemical-specific dermal permeability coefficient (PC) for metals. The dermal exposure equation and associated parameters have been revised accordingly, and all dermal exposure doses and risk estimates have been recalculated. The updated results will be incorporated into the revised manuscript and corresponding tables.

Q4: Equation (5) for inhalation exposure, contains a term PEF, standing for particle emission factor. This factor does not appear in the USEPA RAGS part F guidance on inhalation exposure and it is not further explained by the authors.

A4: The particle emission factor (PEF = 1.36×10^9 m^3/kg) was adopted from the USEPA Soil Screening Guidance (USEPA, 1996). The corresponding reference will be added to Table 2 and the reference list.

Q5: The authors list reference doses in Table 3, mainly references to USEPA 2007. As noted previously, USEPA 2007 has been replaced by USEPA 2014. Neither reference contains dermal reference doses and it uncertain where those in Table 3 have been derived from. The inhalation reference doses are actually reference concentrations (RFCs) and consequently have different units to those identified in the table. Finally, some of the values presented in Table 3 differ from those in the source reference.

A5: Following the reviewer's comments, all toxicity values presented in Table 3 were thoroughly re-evaluated and updated using current USEPA sources, including the Integrated Risk Information System (IRIS) and the Regional Screening Level (RSL) guidance. References to the outdated USEPA (2007) document have been removed and replaced with the most recent and appropriate sources.

The dermal toxicity parameters used in this study have been clarified, and their derivation and corresponding references are now explicitly described in the revised manuscript. Where direct dermal toxicity values were unavailable, they were derived according to USEPA dermal risk assessment guidance.

In addition, the inhalation toxicity parameters have been corrected and are now presented as reference concentrations (RfCs) with the appropriate units. The terminology and units in Table 3 have been revised accordingly.

Finally, all toxicity values were cross-checked against their original sources, and Table 3 and the related text have been revised to ensure consistency with the latest available references.

Table 3. Reference dose and slope factor values

Parameters	Adult	Children	Unit	Reference
ADI, average daily intake	-	-	[mg/kg day]	-
IngR, soil ingestion rate	100	200	[mg/day]	USEPA 2011
EF, exposure frequency	350	350	[day/year]	USEPA 2014
ED, exposure duration	20	6	[year]	USEPA 2014
BW, body weight	80	15	[kg]	USEPA 2011
SF, skin area exposed to soil contact	6032	2373	[cm^2]	USEPA 2011
AF, soil to skin adherence factor	0.07	0.2	[kg/cm day]	USEPA 2011
ABS, contact factor	0.1	0.1	none	USEPA 2004
InhR, inhalation rate	15	10	[m^3/day]	USEPA 2011
PEF, particle emission factor	1.36×10^9	1.36×10^9	[m^3/kg]	USEPA 1996
AT, average time non-carcinogenic	10,950	2190	[days]	USEPA 2002
AT, average time carcinogenic	25,550	25,550	[days]	USEPA 2002
CR, Conversion factor	1×10^{-6}	1×10^{-6}	[mg/kg]	USEPA 2002
PC, Dermal permeability coefficient	0.001	0.001	-	USEPA 2004

Q6: Equations (6) and (7) show the derivation of HIs and HQs. HIs are conventional used to combine estimates of risk across different exposure routes. Table 5 (line 330) states that the contents of the table are HIs but provides separate estimates for each exposure route, presumably HQs.

A6: Following the reviewer's recommendation, the terminology used for non-carcinogenic risk assessment has been carefully reviewed and clarified throughout the manuscript.

Table 5 presents pathway-specific risk estimates for ingestion, dermal contact, and inhalation exposure routes. To avoid ambiguity, these values are now consistently reported as Hazard Quotients (HQs), representing the non-carcinogenic risk associated with individual exposure pathways. The table title, column headings, and related descriptions have been revised accordingly. In addition, the Hazard Index (HI), which represents the cumulative non-carcinogenic risk across all exposure pathways, has been recalculated and reported separately as the sum of ingestion, dermal, and inhalation HQ values. The corresponding explanation has been expanded in the Results and Methods sections. These revisions improve the clarity of the risk assessment framework and ensure consistency with standard human health risk assessment terminology.

Table 5. Non-carcinogenic risk (hazard quotients HQs) for selected heavy metals

Risk	Pathways	Elements					
		Cr	Co	Cu	Zn	As	Cd
Noncarcinogenic	Child						
	Oral	1.2E-02	8.1E-02	3.2E-03	6.2E-03	1.2E-01	3.2E-03
	Dermal	2.8E-06	-	2.5E-06	7.4E-06	6.8E-05	3.2E-05
	Inhalation	1.3E-05	-	-	-	8.6E-05	1.6E-05
	Adult						
	Oral	7.6E-04	5.1E-03	2.0E-04	3.9E-04	7.4E-03	2.0E-04
	Dermal	3.2E-07		2.8E-07	8.2E-07	7.6E-06	3.6E-06
	Inhalation	2.5E-06				1.6E-05	2.2E-06

Q7: In comparing Tables 5 and 6, ingestion is shown as the major route of exposure for non-cancer risks and inhalation as the major route for cancer risk. This is not possible, as the same exposure estimates should be used for both cancer and non-cancer risk assessments.

A7: We carefully rechecked the exposure estimates and recalculated both non-carcinogenic and carcinogenic risks using the revised exposure parameters and toxicity values. In addition, the carcinogenic risk assessment was revised to reflect lifetime exposure conditions by incorporating exposure contributions from both childhood and adulthood periods.

The revised results now show a consistent exposure pattern between the two risk assessments. For non-carcinogenic risk, oral ingestion was the dominant pathway, while dermal contact and inhalation contributed only minor fractions of the total HI. Similarly, the lifetime carcinogenic risk assessment indicates that oral ingestion is also the dominant exposure pathway, whereas inhalation contributes negligibly to the total carcinogenic risk.

Accordingly, Tables 5 and 6, together with the related Results and Discussion sections, have been revised to ensure consistency between the non-carcinogenic and carcinogenic risk assessments. Table 6 now presents the lifetime carcinogenic risk (CR) associated with exposure to heavy metals in soil, and the revised interpretation clearly states that oral ingestion is the primary exposure pathway for both non-carcinogenic and lifetime carcinogenic risks.

Table 5. Non-carcinogenic risk (hazard quotients HQs) for selected heavy metals

Risk	Pathways	Elements					
		Cr	Co	Cu	Zn	As	Cd
Noncarcinogenic	Child						
	Oral	1.2E-02	8.1E-02	3.2E-03	6.2E-03	1.2E-01	3.2E-03
	Dermal	2.8E-06	-	2.5E-06	7.4E-06	6.8E-05	3.2E-05
	Inhalation	1.3E-05	-	-	-	8.6E-05	1.6E-05
	Adult						
	Oral	7.6E-04	5.1E-03	2.0E-04	3.9E-04	7.4E-03	2.0E-04
	Dermal	3.2E-07		2.8E-07	8.2E-07	7.6E-06	3.6E-06
	Inhalation	2.5E-06				1.6E-05	2.2E-06

Table 6. Lifetime carcinogenic risk (CR) associated with exposure to heavy metals in soil

Pathway	Cr	As	Cd
Oral	1.98×10^{-6}	5.90×10^{-6}	NA
Inhalation	3.56×10^{-11}	1.24×10^{-11}	4.69×10^{-13}
Total CR	**1.98×10^{-6}**	**5.90×10^{-6}**	**4.69×10^{-13}**

Q8: Lines 350-351. The authors determine cancer risk separately for children and adults. This approach is incorrect, as the cancer potency factors refer to exposure over a lifetime. A lifestage weighted exposure could have been used or the adult exposure, as a satisfactory surrogate for lifetime exposure.

A8: Following the reviewer's recommendation, the carcinogenic risk assessment framework was revised to reflect lifetime exposure conditions, consistent with the application of cancer slope factors (SFs) and inhalation unit risks (IURs). The age-specific carcinogenic risk estimates previously presented separately for children and adults have been removed and replaced with a lifetime carcinogenic risk assessment.

Lifetime cancer risk was estimated using a lifestage-weighted approach that incorporates exposure contributions from both childhood and adulthood periods, thereby providing a more representative estimate of cumulative lifetime exposure and risk. Accordingly, the

methodology, results, discussion, and Table 6 have been revised to reflect the updated lifetime carcinogenic risk assessment approach.

Q9: The authors make no mention of the exposure of the population to metals through other sources of exposure. In most cases, dietary exposure will be the major source of exposure, with drinking-water also contributing in some cases. Without an indication of the magnitude of exposure from these sources, the risk estimates from soil only will underestimate the human health risk. These sources of exposure are likely to also be impact by the contamination sources mentioned in the paper.

A9: We thank the reviewer for this important comment. We acknowledge that the present study evaluated only soil-mediated exposure to heavy metals through ingestion, dermal contact, and inhalation pathways and did not consider other potential exposure sources, such as dietary intake and drinking water consumption. Consequently, the estimated risks presented in this study may underestimate the overall human health risk because cumulative exposure from multiple environmental media was not assessed. We also agree that food and drinking water may be influenced by the same contamination sources identified in this study, including household coal combustion and ash deposition. To address this limitation, a statement will be added to the Discussion and Conclusion sections emphasizing that the current risk assessment represents only the contribution of soil exposure and that future studies should integrate multiple exposure pathways, including soil, food, and water, to provide a more comprehensive assessment of cumulative human health risks in the study area.