**Supporting Information**

**Contamination and potential health risks of Heavy metals in permafrost-affected soils and lichens: A case-study in Yamal Peninsula, Russia Arctic**

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**Table S1.** Characterizations of soils collected from Yamal Peninsula.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| No. site | Horizon | Depth (cm) | CN | PH-H20 | PH-KCl | TOC (%) | BR (mg CO2 100 g-1 24h-1) |
| M1 | LP (1) | 0-5 | 8.76 | 7.22 | 5.57 | 0.63 | 57.1 |
| LP (2) | 5-20 | 8.36 | 7.08 | 5.54 | 0.78 | 109.6 |
| M2 | LP (1) | 0-5 | 9.43 | 7.35 | 8.14 | 0.16 | 93.1 |
| LP (2) | 5-20 | 13.98 | 6.92 | 5.48 | 5.75 | 127.5 |
| M3 | LP (1) | 0-5 | 15.13 | 6.37 | 5.56 | 0.63 | 125 |
| LP (2) | 5-20 | 9.56 | 6.4 | 5.76 | 7.77 | 115.5 |
| M4 | LP (1) | 0-5 | 12.07 | 6.17 | 5.52 | 13.51 | 93.5 |
| LP (2) | 5-20 | 10.06 | 6.27 | 6.00 | 10.02 | 175.4 |
| M5 | LP (1) | 0-5 | 12.69 | 7.01 | 5.99 | 5.13 | 43.5 |
| LP (2) | 5-20 | 11.36 | 7.35 | 5.9 | 2.49 | 50.2 |
| M6 | LP | 0-20 | 9.88 | 7.19 | 6.17 | 0.54 | 62.1 |
| M7 | Um | 0-3 | 10.96 | 5.74 | 5.45 | 1.72 | 52.5 |
| Um | 3-4 | 12.59 | 4.52 | 5.39 | 2.90 | 85.3 |
| CR | 4-25 | 10.03 | 6.88 | 5.36 | 0.80 | 118.7 |
| M8 | O | 0-4 | 13.63 | 6.96 | 5.98 | 3.01 | 52.2 |
| Um | 3-20 | 14.51 | 6.36 | 5.98 | 7.44 | 140.4 |
| M9 | CR | 0-25 | 12.64 | 6.09 | 5.40 | 20.85 | 109.1 |
| tu | 25-30 | 11.34 | 6.24 | 5.20 | 11.61 | 98.4 |
| M10 | St | 0-25 | 4.79 | 6.73 | 5.48 | 0.14 | 139.8 |
| F1 | AC | 0-5 | 15.87 | 5.74 | 3.87 | 2.13 | 75.6 |
| AC | 5-20 | 14.21 | 4.64 | 3.69 | 1.46 | 70.2 |
| F2 | Um | 0-3 | 19.91 | 5.73 | 4.59 | 4.35 | 130.2 |
| PZ | 3-4 | 16.86 | 5.92 | 3.84 | 7.46 | 83.3 |
| St | 4-25 | 9.79 | 5.43 | 3.57 | 0.53 | 43.1 |
| F3 | hi | 0-5 | 14.96 | 5.89 | 5.63 | 11.97 | 115.1 |
| GL | 5-22 | 14.32 | 5.92 | 4.31 | 3.25 | 76.2 |
| E1 | hi | 0-25 | 13.31 | 5.04 | 4.68 | 10.49 | 129.7 |
| E2 | hi | 0-5 | 28.55 | 4.93 | 3.73 | 4.64 | 135.9 |
| CR | 5-40 | 13.32 | 6.32 | 4.33 | 2.52 | 64.8 |
| E3 | hi | 0-10 | 24.98 | 4.32 | 2.92 | 2.21 | 170.2 |
| E4 | hi | 0-15 | 20.96 | 5.52 | 3.61 | 1.50 | 144.8 |
| GL(1) | 15-25 | 12.06 | 8.52 | 4.06 | 0.91 | 37.1 |
| GL(2) | 25-45 | 11.65 | 6.52 | 4.20 | 0.93 | 77.2 |
| A1 | TC | 0-9 | 12.26 | 8.26 | 7.87 | 0.51 | 34.6 |
| rd | 9-50 | 11.12 | 6.50 | 4.44 | 0.75 | 31.1 |
| A2 | fo | 0-9 | 15.85 | 8.03 | 6.51 | 1.04 | 65.2 |
| AR | 9-50 | 1.83 | 6.07 | 5.68 | 0.03 | 120.5 |
| A3 | Um | 0-2 | 12.40 | 5.70 | 5.71 | 0.88 | 73.2 |
| BF | 2-30 | 9.35 | 7.55 | 5.71 | 0.59 | 51.2 |
| G | 30-50 | 2.02 | 6.39 | 5.71 | 0.05 | 62.4 |

**Table S2.** Geoaccumulation index (Igeo) and pollution load index (PLI) of heavy metals in soil samples collected from 30 sites in the Yamal Peninsula.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **No. site** | **Cu** | **Pb** | **Cd** | **Zn** | **Ni** | **Mn** | **Hg** | **Cr** | **PLI** |
| **M1** | -2.10 | -3.05 | **2.61** | -2.13 | **4.90** | 0.05 | **6.05** | -6.41 | **4.958** |
| **M2** | -2.39 | -5.43 | **2.53** | -5.39 | **4.90** | -2.39 | **6.75** | -0.56 | **2.562** |
| **M3** | -1.70 | -1.64 | **2.64** | -0.73 | **5.01** | 0.18 | **8.44** | -7.59 | **25.154** |
| **M4** | -2.00 | -1.10 | **2.49** | -0.85 | **4.79** | **0.93** | **9.74** | -4.76 | **126.580** |
| **M5** | -1.70 | -1.83 | **2.31** | -1.35 | **4.53** | -0.13 | **8.26** | -6.94 | **15.121** |
| **M6** | -2.38 | -3.05 | **2.40** | -1.96 | **4.66** | 0.33 | **6.22** | -7.92 | **2.824** |
| **M7** | -1.96 | -2.34 | **2.57** | -1.71 | **4.37** | 0.37 | **6.86** | -6.59 | **8.753** |
| **M8** | -2.34 | -3.08 | **2.57** | -1.42 | **0.67** | -0.47 | **7.05** | -6.76 | **1.366** |
| **M9** | -1.28 | -1.26 | **2.75** | -0.96 | **4.53** | 2.17 | **9.54** | -4.35 | **241.735** |
| **M10** | -4.24 | -4.21 | -2.50 | -3.59 | -2.70 | -2.93 | **5.61** | -8.94 | 0.001 |
| **F1** | -1.41 | -2.44 | **0.68** | -1.35 | **1.20** | -0.39 | **7.05** | -4.25 | **3.720** |
| **F2** | -1.01 | -2.46 | **0.82** | -1.22 | **2.20** | -0.27 | **8.09** | -6.83 | **4.026** |
| **F3** | 0.44 | -2.58 | **0.68** | -1.71 | **1.20** | -0.39 | **7.05** | -5.36 | **4.305** |
| **E1** | **1.54** | -2.46 | **0.82** | -1.32 | **1.20** | -0.01 | **9.00** | -7.01 | **9.409** |
| **E2** | -4.80 | -3.62 | -1.64 | -2.46 | -2.67 | -0.15 | **8.75** | -6.40 | 0.056 |
| **E3** | -4.87 | -4.42 | -2.16 | -3.36 | -1.85 | -2.20 | **9.18** | -5.58 | 0.026 |
| **E4** | -4.94 | -3.97 | -2.06 | -2.80 | -2.65 | -1.55 | **8.69** | -7.87 | 0.013 |
| **A1** | -3.28 | -2.74 | -0.83 | -1.67 | -2.67 | -1.50 | **5.37** | -7.25 | 0.033 |
| **A2** | 0.09 | -3.02 | 0.36 | -1.54 | -1.05 | -0.22 | **6.96** | -6.72 | 0.853 |
| **A3** | -4.55 | -4.02 | -2.26 | -2.90 | -3.01 | -2.61 | **6.86** | -8.85 | 0.003 |

**Table S3.** Rotated component matrix for soil samples in Yamal Peninsula.

|  |  |  |
| --- | --- | --- |
|  | Component |  |
|  | F1 | F2 | F3 |
| TOC | 0.793 | -0.307 | 0.139 |
| Cu | 0.240 | -0.529 | 0.593 |
| Pb | 0.894 | -0.120 | -0.125 |
| Cd | 0.737 | 0.601 | 0.006 |
| Zn | 0.800 | -0.260 | -0.071 |
| Ni | 0.666 | 0.679 | -0.011 |
| Mn | 0.743 | 0.114 | -0.124 |
| Hg | 0.582 | -0.435 | 0.122 |
| Cr | -0.078 | 0.511 | 0.771 |
| Variance explained (%) | 44.569 | 19.355 | 11.303 |

**Table S4.** The concentrations (mg kg-1) ± standard deviation and TFs of heavy metals in lichens.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Cu | Pb | Cd | Zn | Ni | Mn | Hg | Cr |
| Concentration | 21±4 | 6.6±1.6 | 3.4±1.7 | 22±4 | 1100±400 | 540±160 | 26±11 | 2.037±0.3 |
| TF | 1.40 | 0.83 | 0.92 | 0.69 | 1.22 | 0.57 | 1.86 | 2.21 |



**Figure S1**. Soil particle size distribution (%) from soil samples collected from Yamal Peninsula.



**Figure S2.** Boxplot comparison of log-transformed concentrations (mg kg-1) for 7 heavy metals in soils from different sampling areas in the Yamal Peninsula.