THE MIGRATION OF POTENTIALLY TOXIC ELEMENTS DURING THE RECULTIVATION OF THE URANIUM MINING DEPOSIT IN MECSEK

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The ecological risk caused by the potential migration of potentially toxic elements (PTEs) during the recultivation of the abandoned uranium mining deposit in Mecsek in Hungary was estimated by developing a sample strategy. To study the effectiveness of soil covering layer in retardation of migration of PTEs (Ca, Cd, Co, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, and Zn) on the covering soil of deposit No.1, sampling locations were selected based on the results of the running monitoring program at the deposit No.1, where erosion wounding occurred during the recultivation. Top to bottom soil core samples (0–25, 25–50, 50–75 and 75–100 cm depths) and covering plant (grass) samples were taken and analyzed using Inductively Coupled Plasma – Optical Emission Spectrometer. Overall the results of the soil samples collected indicated that there is a possibility of migration of PTEs as water infiltrates from the top to the bottom of the deposit. Transfer factor, TF ≥1 for Cu might be an indication of trace elements’ availability to be taken up by the plants. The fractionation by sequential extraction of PTEs is still in progress which should give more information on their migration.

KEY WORDS: uranium mining, potentially toxic elements, migration, soil, plants

Introduction

Mecsek mine produced 21,000 t of uranium until it was shutdown in 1997 due to being uneconomical (Wallner and Stein, 2012; Malovics, 2014). In 2006, there was a feasibility study of restarting uranium mining in the Mecsek Hills near Pécs in Hungary (Malovics, 2014). Uranium mining poses some unique risks due to the presence of radioactive substances and co-occurring minerals which can contain potentially toxic elements (PTEs) (Sahoo et al., 2014; National Research of The National Academies, 2012). Pollution by PTEs is a significant issue owing to their transport to soils, biota, and water streams (Soltani et al., 2017). The natural weathering is considered to be significantly responsible too for elevated trace metals concentrations in soils (Fite and Leta, 2015). Soils of abandoned mining sites pose a serious environmental threat because of potential mobility of pollutants including PTEs creating a risk of groundwater contamination and health hazards for animals and humans by food chain (Gałuszka et al., 2016; Nazir et al., 2015). Elevated acidity contributes to increasing the mobility of PTEs in aqueous solution, including uranium, as well as copper, arsenic, cadmium (Skipperud and Salbu, 2015). It is important to take into consideration effects such as the chemical toxicity of PTEs and PTE-species (IAEA, 2004; Pérez-Moreno et al., 2018). Regulatory standards for PTE levels in soils have been established, but wide discrepancy exists among different countries regarding the critical value of each contaminant (He et al., 2015). This is relevant in order to better predict the risks of uranium mining discharges in more common and ecologically significant scenarios (Reis et al., 2018).

The present research is joining the large monitoring program that is currently running at abandoned and recultivated Mecsek uranium mine in Pécs. Every three to five years, samples are being taken from all spoil banks and from covering soil to monitor radionuclide migration. The main aim of present research is to study the effectiveness of soil covering layer in retardation of migration of PTEs on the covering soil of deposit No.1 and to estimate the potential risk caused by the migration of PTEs on the environment. During the formation of soil covering, there was an erosion wounding occurrence. To follow the long-term effect of uranium mining, an appropriate additional sampling strategy is developing. Soil and plant samples were collected from the top and the bottom of the slope of this spoil deposit. For this purpose, it is necessary to analyze PTEs and their solubility under given geochemical conditions. Hence, the total soluble PTE concentrations and solubility fractions will be determined by sequential extraction. This is a preliminary step of an extensive study, the research is still in progress. The determination of total soluble element concentration for three classes of
elements; macronutrients (Ca, K, P, and Mg), micronutrients (Co, Na, Fe, Cu, Ni, Mn, and Zn) and toxic elements (Cd, Cr, and Pb) in soil and plant samples were completed. However, the total concentration of PTEs often does not accurately represent their characteristics and toxicity (Okoro, et al., 2017). Therefore, evaluation of the individual fractions to which the metals are bound is necessary to fully understand their actual and potential environmental effects. For this reason, fractionation by sequential extraction of PTEs is still in progress.

**Material and methods**

**Sampling in Mecsek uranium deposit No.1**

Soil and covering plant (grass) samples were collected on the 11th of July 2018 from four sampling points in Mecsek uranium mine deposit No.1 in Pecs, South-west of Hungary: (1) at the top of the deposit – Rn-M11, (2) on the slope of the deposit – Rn-M12, (3) at the bottom field – Rn-M13 and (4) at the bottom edge of the slope of the deposit – radioactive point. For simple reference, the samples were renamed as M11 for Rn-M11, M12 for Rn-M12, M13 for Rn-M13 and RA for radioactive point. The radioactive point was chosen based on the knowledge of its high gamma dose rate ranging between 100 and 200 nGy h⁻¹ to give an indication of whether PTE concentrations would also be high on this location. Deposit No.1 was covered with a different type of soils taken from various locations. Underneath the soil covering layer, there were natural rocks.

**Sampling and sample preparation for total trace element determination**

Plant samples were collected by cutting from the surface of the plants with a knife from the same locations where soil samples were collected (M11, M12, M13 and RA) to determine if there is any biological uptake of radioactivity and PTEs from the soil. Plant sample collected from the radioactive location was divided into two portions, one half was washed in a shower for 5 minutes to simulate the rain. Plant samples were air-dried and ground before microwave digestion preparation. Soil samples were collected using a hand auger instrument labeled with different measurements. Each soil core sample was taken from different depths: 0–25 cm, 25–50 cm, 50–75 cm and 75–100 cm. For M11, 75–100 cm depth could not be sampled as this was hard rock. Radioactive soil was only sampled from the top layer. All samples collected were carefully placed in clean polyethylene bags before transported to the laboratory. Soil samples were homogenized and ground using Retch SM 100 with a 0.25 mm sieve instrument.

**Determination of soil moisture content**

Approximately 25 g of soil samples were dried at 105°C for 72 hours, cooled and weighed for the determination of the soil moisture content.

**Soil and plant sample preparation using microwave digestion and analysis method according to Hungarian Standard MSZ 21470-50:2006 6 chapter**

0.5 g of homogenized plant samples were weighed into the Teflon vessel using an analytical balance. 5 mL of nitric acid (65% Merck), 6 mL of hydrogen peroxide (30% Emsure®) and approximately 9 mL of distilled water were added into the Teflon vessel containing the samples, to make it up to 20 mL. Whereas, 0.5 g of homogenized soil samples were weighed into the Teflon vessel using an analytical balance. 5 mL of nitric acid (65% Merck), 3 mL of hydrogen peroxide (30% Emsure®) and approximately 2 mL of distilled water were added into the Teflon vessel containing the samples, to make it up to 10 mL. The reaction could subside completely before capping the vessels. The microwave digestion vessels containing samples were assembled together and placed in a CEM Mars 5 Xtraaction 230/60 Microwave Accelerated Reaction System 907501. The microwave digestion system was set at the following parameters: Ramp time – 20 minutes (450 Psi or 180°C), Hold time – 18 minutes, Still time – 5 minutes (0 Watt), Hold time – 10 minutes (800 Watt, 450 Psi and/or 180°C) and Cooling time – 20 minutes. When the digestion was completed, each sample was filtered using a 90 nm Filter Discs (Quant.) Grade: 389 into a 25 mL volumetric flask and made up to 25 mL with distilled water. Each sample was physically homogenized by shaking it and transferred into a centrifuge tube for the trace element analysis.

**Elemental analysis**

Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, and Zn content of digested solutions were determined by a HORIBA Jobin Yvon ACTIVA M Inductively Coupled Plasma – Optical Emission Spectrometer (ICP-OES) using operation parameters proposed by the manufacturer and yttrium internal standard.

**The soil/plant transfer factor (TF) determination**

The soil/plant transfer factor (TF) was calculated using Formula 1 to determine the possibility of the trace elements being taken up from the soil by the plants. The TF was calculated only from the total concentrations obtained from the 0–25 depth of soil sample because the grass does not have deep roots to reach a deeper level of the soil. The higher the value of the TF, the more mobile/available the trace metal is (Intawongse et al., 2007; Laţo et al., 2012). According to (Fite and Leta, 2015), if the TF ratios >1, the plants have accumulated elements, the TF ratios approximately 1 indicate that the plants are not influenced by the elements, and if the TF ratios <1, it is the indication that plants avoid the elements from the uptake.

**Soil/Plant Transfer Factor:**

\[ TF = \frac{C_{\text{plant}}}{C_{\text{soil}}} \]
where 
\[ C_{\text{plant}} \rightarrow \text{concentration of an element in the plant material} \]
\[ C_{\text{soil}} \rightarrow \text{total concentration of the same element in the soil where the plant was grown}. \]

**Meteorological conditions**

The average precipitation at Pécs was calculated based on the meteorological data extracted from the Website (https://www.ksh.hu/docs/eng/xstadat/xstadat_annual/i_met002c.html) of the Hungarian Central Statistical Office. The average precipitation was calculated from 1997 when the mine was shut down to 2018 when sampling took place. The average precipitation was 674 mm with a minimum of 405 mm in 2011 and the maximum of 981 mm in 2014. The groundwater level at the time of sampling 2018 was at 160 m from the Balti line.

**Results and discussion**

**Total soluble element concentrations in soil**

The results obtained from this study were compared to the Hungarian Regulation and World Health Organization (WHO) permissible limits of elements in soil and plants. The results of the element analysis in soil samples are presented in three different figures. These results are presented according to the elemental importance in soil e.g. macronutrients, micronutrients, and toxic elements. Macronutrients (Ca, K, Mg, and P) and Fe are presented in Figure 1. Iron is an essential micronutrient, however, within soils and plants, it is not toxic because its average concentration is generally greater than 100 mg kg\(^{-1}\) (Hooda, 2014), hence its placement with macronutrients in Figure 1. Iron may be the most difficult element to make available in the soil for plants because it is needed in relatively large amounts and soil chemical processes sometimes quickly make it unavailable (Lohry, 2007).

Plants require essential macronutrients (such as N, P, K, Ca, and Mg) and micronutrients (such as Fe, Zn, Mn, Ni and Cu) from soil to grow and complete the cycle of life (Kabata-pendias and Pendias, 2001), therefore they are not included on the table of permissible limits of PTEs in plants and soil in Table 1. Soil concentrations for PTEs in dry weight were compared with soil toxic element contamination limit that is regulated by the Hungarian Government (6/2009. IV. 14. 2009) based on the regulation of other European (EU) member countries (Rékási and Filep, 2012). The WHO (1996) permissible limits for elements in the soil are included for reference in comparison of the Hungarian limits to the World’s limits. Results for the micronutrients in the soil are presented in Fig. 2. The concentration levels for Co, Cu and Zn were within Hungarian limits of 30 mg kg\(^{-1}\), 75 mg kg\(^{-1}\) and 200 mg kg\(^{-1}\) respectively, however Zn concentration for samples M11 at 50–75 cm was 60.52 ± 0.08 mg kg\(^{-1}\), M13 at 0–25 mg kg\(^{-1}\) was 67.43 ± 0.12 mg kg\(^{-1}\), at 25–50 was 58.92 ± 0.08 mg kg\(^{-1}\) and at 50–75 was 54.11 ± 0.12 mg kg\(^{-1}\). These Zn concentrations were above the WHO limit of 50 mg kg\(^{-1}\) but they were still below the intervention level of 720 mg kg\(^{-1}\) (VROM, 2000). Nickel concentration levels for sample M12 at 25–50 cm and for RA sample were above the limits recommended for soil by Hungary (limit of 40 mg kg\(^{-1}\)), which were 53.47 ± 0.75 mg kg\(^{-1}\) and 40.54 ± 0.10 mg kg\(^{-1}\) respectively. However, these Ni concentrations were still within the allowed concentrations of 35–75 mg kg\(^{-1}\) recommended by the Commission of the European Communities (1986). The elevated concentration levels of Ni at sampling points M13 and RA might be an indication of the mobility of elements from the top of the deposit to the bottom part of the deposit. As indicated in Table 1, although micronutrients from the soil are essential for plant growth and development (Voss, 1998), high concentration levels can be toxic (Stanojković-Sebić et al., 2017).

![Fig. 1. Total concentration of Ca, Fe, K, Mg and P in soil samples.](image-url)
Table 1. Permissible limits for PTEs in plant and soil

| Trace elements | \(^a\)Target value of soil [mg kg\(^{-1}\)] | \(^b\)Permissible value of plant [mg kg\(^{-1}\)] | \(^c\)Concentration of elements in soil and contamination limit values [mg kg\(^{-1}\)] | \(^d\)Allowed levels in soil [mg kg\(^{-1}\)] | \(^e\)Intervention values [mg kg\(^{-1}\)] |
|----------------|---------------------------------|-------------------|-------------------------------------------------|----------------------|----------------------|
| Cd             | 0.8                             | 0.02              | 1                                               | 1 – 3                | 12                   |
| Co             | -                               | -                 | 30                                              | -                    | 240                  |
| Cr             | 100                             | 1.3               | 75                                              | 100 – 150            | 380                  |
| Cu             | 36                              | 10                | 75                                              | 50 – 140             | 190                  |
| Fe             | -                               | -                 | -                                               | -                    | -                    |
| Mn             | -                               | -                 | -                                               | -                    | -                    |
| Ni             | 35                              | 10                | 40                                              | 35 – 75              | 210                  |
| Pb             | 85                              | 2                 | 100                                             | 50 – 300             | 530                  |
| Zn             | 50                              | 0.6               | 200                                             | 150 – 300            | 720                  |

\(^a\)Target values are specified to indicate desirable maximum levels of elements in unpolluted soils (Denneman and Robberse 1990; Ministry of Housing, Netherlands, 1994).

\(^b\)WHO permissible value of plant (WHO,1996; Adio, 2017).

\(^c\)Contamination limit values for Hungarian soils (6/2009. IV. 14. 2009) (Rékási and Filep, 2012).

\(^d\)Allowed levels in soil (Commission of the European Communities, 1986).

\(^e\)Intervention values (Netherlands Ministry of Housing, Spatial Planning and the Environment (VROM), 2000).

The concentrations for toxic elements in the soil are obtained in Figure 3. The results for the analysis indicated that the soil from deposit No.1 did not contain Cd element and the Pb concentrations were below the Hungarian limits. Although Cr concentrations for sampling points M12 at 25–50 cm with 116 ± 0.36 mg kg\(^{-1}\) and RA with 127 ± 0.01 mg kg\(^{-1}\) were above the Hungarian limits of 75 mg kg\(^{-1}\), these concentrations were still withing the allowed levels of 100–150 mg kg\(^{-1}\) (Commission of the European Communities, 1986). The elevated Cr concentrations in soils at the M12 and RA sampling locations might be an indication that plants did not take Cr from the soil.

ANOVA statistical analysis for the function of soil sampling points and different depths for each sample was determined, the results indicated that there was no significant difference among the means of concentrations for different depths for each sample and also for each of the sampling points at 95% confidence interval.

**Element concentrations in plants**

The results of the concentrations for the elements in plant samples are presented in Table 2. The concentrations for the elements in analyzed plants were compared to the WHO (1996) permissible limits for plants. Chromium results for the sample M11 with a concentration of 14.2 ± 0.02 mg kg\(^{-1}\) was observed to be above WHO (1996) limit of 1.3 mg kg\(^{-1}\). This observation might be an indication that Cr was taken up by plant from the soil on
sampling point M1 which is located on top of the deposit. Copper concentrations for sampling points M12, M13, and RA (both unwashed and washed plant samples) were above the WHO permissible limit of 10 mg kg\(^{-1}\). It was also observed that the concentrations for Cu increased as the topography changed from the top of the deposit to

![Graph showing concentrations of elements](image)

**Fig. 3.** Total concentration of Cr, Cd, and Pb in soil samples.

**Table 2.** Total concentrations for elements in plant samples

| Element | M11 Total Concentration [mg kg\(^{-1}\)] | M12 Total Concentration [mg kg\(^{-1}\)] | M13 Total Concentration [mg kg\(^{-1}\)] | Unwashed plant Total Concentration [mg kg\(^{-1}\)] | Washed plant Total Concentration [mg kg\(^{-1}\)] | Permissible value of plant (WHO, 1996) [mg kg\(^{-1}\)] |
|---------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| Ca      | 5710 ± 54.26                           | 4400 ± 15.61                           | 2133 ± 11.94                           | 5369 ± 0.43                            | 5184 ± 43.05                           | -                                     |
|         | (315.887 nm)                           | (228.802 nm)                           | (228.615 nm)                           | (205.571 nm)                           | (324.754 nm)                           | (240.489 nm)                           |
| Cd      | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.8                                   |
|         | (228.802 nm)                           | (228.615 nm)                           | (205.571 nm)                           |                                         |                                         | (WHO, 1996)                            |
| Co      | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | -                                     |
| Cu      | 14.2 ± 0.02                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 10                                    |
|         | (324.754 nm)                           | (324.754 nm)                           | (324.754 nm)                           | (324.754 nm)                           | (324.754 nm)                           | (324.754 nm)                           |
| Fe      | 5.89 ± 0.09                            | 18.3 ± 0.00                            | 59.5 ± 0.11                            | 21.7 ± 0.22                            | 73.1 ± 0.17                            | -                                     |
|         | (324.754 nm)                           | (324.754 nm)                           | (324.754 nm)                           | (324.754 nm)                           | (324.754 nm)                           | (324.754 nm)                           |
| K       | 265 ± 3.60                             | 94.93 ± 0.56                           | 301 ± 2.01                             | 52.39 ± 0.37                           | 68.59 ± 0.35                           | -                                     |
| Mg      | 7206 ± 20.60                           | 7608 ± 151.90                          | 8861 ± 27.63                           | 13289 ± 12.76                          | 14302 ± 5.50                           | -                                     |
| Mn      | 1781 ± 13.81                           | 1786 ± 8.77                            | 785 ± 0.87                             | 868 ± 7.44                             | 925 ± 2.93                             | -                                     |
|         | (257.610 nm)                           | (257.610 nm)                           | (257.610 nm)                           | (257.610 nm)                           | (257.610 nm)                           | (257.610 nm)                           |
| Na      | 34.2 ± 0.13                            | 21.5 ± 0.20                            | 26.1 ± 0.50                            | 3.68 ± 0.04                            | 8.97 ± 0.10                            | -                                     |
|         | (589.592 nm)                           | (589.592 nm)                           | (589.592 nm)                           | (589.592 nm)                           | (589.592 nm)                           | (589.592 nm)                           |
| Ni      | 73.9 ± 0.53                            | 43.0 ± 0.21                            | 36.9 ± 0.43                            | 33.5 ± 1.51                            | 52.8 ± 0.50                            | -                                     |
|         | (231.604 nm)                           | (231.604 nm)                           | (231.604 nm)                           | (231.604 nm)                           | (231.604 nm)                           | (231.604 nm)                           |
| P       | 5.48 ± 0.06                            | 2.42 ± 0.02                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 10                                    |
| Pb      | 1411 ± 0.48                            | 1150 ± 3.60                            | 1307 ± 0.59                            | 1489 ± 15.61                           | 1631 ± 6.84                            | -                                     |
|         | (253.560 nm)                           | (253.560 nm)                           | (253.560 nm)                           | (253.560 nm)                           | (253.560 nm)                           | (253.560 nm)                           |
| Zn      | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 0.00 ± 0.00                            | 2                                     |
|         | (220.353 nm)                           | (220.353 nm)                           | (220.353 nm)                           | (220.353 nm)                           | (220.353 nm)                           | (220.353 nm)                           |
|         | 20.9 ± 0.05                            | 9.41 ± 0.05                            | 13.6 ± 0.05                            | 8.87 ± 0.03                            | 13.3 ± 0.39                            | 0.6                                   |
|         | (213.857 nm)                           | (213.857 nm)                           | (213.857 nm)                           | (213.857 nm)                           | (213.857 nm)                           | (213.857 nm)                           |

Results highlighted in bold were above the permissible limits.
the bottom of the deposit. The increase in Cu concentration at the bottom of the deposit might be an indication that Cu was transported down the slope of the deposit and have accumulated at the bottom of the deposit. Zinc concentrations for all the plant samples collected were above WHO permissible limits of 0.6 mg kg⁻¹. These results indicate that Zn may have been available from soil to be absorbed in large quantities by plant. Copper, Zn, Fe, Mn, and Ni are all more available at low pH levels because metals are bound very tightly to the soil or exist in solid minerals at high pH (Jones and Jacobsen, 2001). When comparing the results for washed and unwashed plant samples collected from RA, there was no noticeable difference in concentration. This might be an indication that the concentrations of the elements obtained are not due to surface contamination but are due to biological uptake.

ANOVA statistical analysis for the function of plant sampling points was determined. The results indicated that there was no significant difference amongst the plant sampling points at a 95% confidence interval.

### Plant/Soil transfer determination

To assess the availability/mobility of trace metals from soil to plant, TF ratios were calculated on dry weight for both plant and soil samples. The TF ratios are presented in Table 3.

The transfer factor (TF) ratios were calculated to determine the ability of a metal species to migrate from the soil into plant roots. Copper TF values indicated an increasing trend from the M11 with reported TF=0.52, M12 with TF=1.56 and to M13 with TF=3.64. This increasing trend might imply that there was a migration of Cu from the top of the deposit to the bottom of the deposit. Copper TF value for sampling points M12 and M13 were above the limit of 1, whereas the active sample reported the TF value of 1.14. This observation indicates that Cu and K trace metals are available to be taken up by plants (Intawongse et al., 2007, Agic et al., 2015).

### Soil moisture content

The amount of water present in the soil was indicated by calculating the soil moisture content as indicated in Table 4. The results indicated that the soil sample which is located at the bottom of the deposit (M13) had the highest soil moisture content average of 14.94% compared to M11 and M12 with the averages of 9.76% and 8.77% respectively. This observation might be an indication that water containing PTEs might be infiltrated through the soil from the top of the deposit to the bottom of the deposit.

### Conclusion

Most elemental concentrations in soil samples collected from deposit No.1 were lower than the contamination limit values for Hungarian soils and within the permissible limits. The results for micronutrients indicated that there was a trend on the increase of concentrations of elements as the slope of the deposit decreased. Soil samples collected from the top of the deposit (M11) contained less average concentration followed by the sample collected from the slope (M12) and the sample collected from the bottom of the deposit (M13) had the highest average concentration. This observation might be an indication that there is a possibility of migration of these elements. The results for M13 were observed to have the combination of highest average for both soil moisture content PTE concentrations. This might be an indication that there is possibility of water infiltrating through the deposit while migrating PTEs. The results for plant analysis indicated that Cu, Zn and Cr were above the WHO limits of 10 mg kg⁻¹, 0.6 mg kg⁻¹ and 1.3 mg kg⁻¹ respectively for some sampling points.
Table 4. Soil moisture content

| Sample name | Sample layer [cm] | Mass of empty container [g] | Mass of container + sample before drying [g] | Mass of container + sample after drying [g] | Moisture content [%] |
|-------------|-------------------|----------------------------|---------------------------------|---------------------------------|-------------------|
| M11         | 0–25              | 51.8315                    | 75.4234                         | 73.2435                         | 9.24              |
|             | 25–50             | 51.3661                    | 74.1878                         | 72.4906                         | 7.44              |
|             | 50–75             | 49.9757                    | 78.8825                         | 75.2421                         | 12.59             |
| M12         | 0–25              | 50.5424                    | 82.0956                         | 79.1077                         | 9.47              |
|             | 25–50             | 48.7002                    | 78.0861                         | 75.4438                         | 8.99              |
|             | 50–75             | 48.0575                    | 77.6417                         | 75.2200                         | 8.19              |
|             | 75–100            | 49.3037                    | 75.1385                         | 72.9608                         | 8.43              |
| M13         | 0–25              | 49.8464                    | 79.0846                         | 74.0951                         | 17.07             |
|             | 25–50             | 50.4257                    | 82.6054                         | 77.9922                         | 14.34             |
|             | 50–75             | 48.6373                    | 83.1727                         | 78.2866                         | 14.15             |
|             | 75–100            | 48.8749                    | 82.4759                         | 77.7055                         | 14.20             |
| RA          | Top layer         | 35.3620                    | 82.9546                         | 81.4488                         | 3.16              |

location. This might be an indication that these elements were available for uptake from by plants. Even though these micronutrients are essential to plants, elevated concentrations may cause several problems, including the toxicity of the environment. The transfer factor values for Cu and K (≥1) indicate higher absorption of metal from the soil by the plant. The TF value for K in an active sample was above the TF limit of 1, however, K is a macronutrient and is needed in abundance for plants to grow.

The possibility of migration of these elements will be confirmed by fractionation by sequential extraction for PTEs. These results do not provide enough information to conclude on the migration of PTEs. However, based on the plant elemental uptake, it is apparent that 1 meter covering soil for deposit No.1 might not be effective. More information with regards to the mobility of PTEs will be revealed when the fractionation of PTEs in soil samples is completed. Additional samples will be collected from different sampling points of the deposit No.1 to ensure the representation of the samples. This investigation is planned to be repeated two times in the next years to ensure a more reliable conclusion.

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