

## Supplementary Information

### A Leach solution configuration and leaching method

#### A.1 Configuration method of leaching agent

Configuration of acidic leaching agent: H<sub>2</sub>SO<sub>4</sub>-HNO<sub>3</sub> method, H<sub>2</sub>SO<sub>4</sub>, and HNO<sub>3</sub> according to the mass ratio of 2:1 to prepare a mixed solution, take a few drops of the mixture to 1 L of ultrapure water, adjusted to the final pH of 1, 3.21 and 5 leaching agent.

Configuration of neutral (weakly acidic) leaching agent: ultrapure water and carbonated water were used to simulate the leaching agent with pH values of 7 and 6, respectively.

Alkaline leach agent: NaOH method, NaOH solution will take a few drops of the mixture to 1 L of ultrapure water, adjusted to the final pH of 12 and 13 leach agent.

#### A.2 Leaching experiment

The water content was determined by drying the LLR twice at 105°C with an error of less than ±1%. According to the water content, the LLR was put into the extractant at a 10:1 (L/kg) liquid-solid ratio and then shaken in a water-bath shaker (30±2r/min) at room temperature (23±2°C) for 18±2 h. After the end of the shaking process, it was removed and left to stand for 16 h. The supernatant was passed through the microporous membrane with a pore size of 0.45 μm, adjusted the pH to <2 with dilute HNO<sub>3</sub>, and then stored at 4°C in the refrigerator to wait for the measurement. The pH was adjusted to <2 with dilute HNO<sub>3</sub>. The pH value was determined by a pH meter (Starter 3100C, China), and the contents of Tl, Be, Pb, Hg, Cd, Cr, As, Ba, Cu, Ni, Co, and Zn were determined by inductively coupled plasma-mass spectrometry (ICP-MS, PinAAcle 900H). For the accuracy and precision of the experiment, standards and blanks were placed at intervals in the samples to be measured for calibration. Three parallels were set up for each sample, and the results were averaged (RSD<5%). One multi-element calibration standard was used for every 10 samples analyzed.

The reagents (HNO<sub>3</sub>, H<sub>2</sub>SO<sub>4</sub>, and NaOH) used in the leaching experiments were purchased from Xilong Science Co. Ltd., and the heavy metal samples from China Nonferrous Metals Research (CNMR) were used.

## **B Determination of metal content and accumulation pattern in soil samples**

### **B.1 Determination of total metal elements**

Weigh 0.2g of LLR, add HNO<sub>3</sub>-HCl-HF (9-3-2mL), and then use a microwave digestion instrument for digestion. At the end of the digestion, 2 mL of HF was added to the crucible at 130 °C, and 1 mL of HClO<sub>4</sub> was added to the crucible at 170 °C to drive the acid, and the contents were viscous when the white smoke was almost exhausted, and then the sample was fixed with 1% HNO<sub>3</sub> to 50 mL for measurement.

### **B.2 Sequential extraction method for Tl**

Weigh 1.0 g of the sample in a 50mL crucible, add 40mL CH<sub>3</sub>COOH (0.1 mol-L<sup>-1</sup>) at 240r/min shaking bed shaking 18h to get the exchangeable state (Tl<sub>Exc.</sub>); To the remaining slag, 40 mL of HONH<sub>2</sub>HCl (0.5 mol-L<sup>-1</sup>) was added, and the reducible state (Tl<sub>Red.</sub>) was obtained by shaking the bed at 240 r/min for 18 h. Residue, then added 10mL, 30% H<sub>2</sub>O<sub>2</sub>, and 50mL CH<sub>3</sub>COONH<sub>4</sub> (mol-L<sup>-1</sup>) two times, shaking the bed shaking at 240r/min for 18h to get an oxidizable state (Tl<sub>Oxi.</sub>). Then, the residual state (Tl<sub>Res.</sub>) was obtained by referring to the total metal ablation method. The solution of the forms obtained in the above steps was centrifuged by centrifuge for 20 min, and the supernatant was obtained by fixing with distilled water (50 mL volumetric flask). The supernatant of each form obtained from the experiment was passed through a 0.45um filter membrane and refrigerated at 4°C to be measured. The metal concentrations were determined by inductively coupled plasma mass spectrometry (ICP-MS, PinAAcle 900H). The reagents used in the leaching experiments were all of superior purity, and the heavy metal samples from China Nonferrous Metals Research (CNMR) were used, and the water used in the experiments was ultrapure.

## C Criteria for determining environmental risks based on the $I_{geo}$ index

Table C.1

Basis for environmental risk classification.

$I_{geo} \leq 0$	No risk
$0 < I_{geo} \leq 1$	Low risk
$1 < I_{geo} \leq 2$	Moderate risk
$2 < I_{geo} \leq 3$	Moderate to high risk
$3 < I_{geo} \leq 4$	High risk
$4 < I_{geo} \leq 5$	High to very high risk
$I_{geo} > 5$	Very high risk

## D Analysis of basic characteristics of soil samples

Therefore, basic physicochemical indicators were measured for the soil and the data (Table 1). Significant differences ( $P < 0.05$ ) were found in the soil pH values of all sampling sites except site Z17. The pH range of plot Z1 was 7.38-8.22, with a mean value of 7.88, which is alkaline soil; the pH range of plot Z2 was 5.99-8.42, with a mean value of 7.01, which is weakly acidic soil; and the pH range of Z3 farmland plots was 7.8-8.15, with a mean value of 7.98, which is alkaline soil. The mean values of SM of soils in Z1, Z2, and Z3 were respectively 1.9%, 1.29%, and 2.02%, with significant differences ( $P < 0.05$ ). Soil CEC varied significantly ( $P < 0.05$ ) with mean values of 3.31, 3.93, and 7.42 cmol/kg, respectively.

**Table. D.1**

Physical and chemical properties of sampling point

Sampling point	pH	SM (%)	CEC (Mol/kg)
Z11	8.18±0.04a	2.64±0.03b	0.8±0.01l
Z12	7.69±0.04d	1.12±0.03i	4.02±0.02h
Z13	7.4±0.02e	1.41±0.03fg	3.32±0.03i
Z14	8.15±0.05a	1.38±0.02gh	6.73±0.04d
Z15	8.14±0.01a	3.7±0.03a	0.7±0.01m
Z16	7.68±0.03d	1.48±0.03f	3.33±0.03h
Z17	7.93±0.07bc	1.58±0.03e	4.32±0.03g
Z21	7.31±0.02e	1.05±0.05j	0.7±0.02m
Z22	6.02±0.04h	1.41±0.03g	2.98±0.02j
Z23	6.58±0.03g	1.65±0.02e	9.04±0.05a
Z24	6.8±0.14f	1.31±0.05h	4.95±0.05f
Z25	8.35±0.08a	1.05±0.06j	2.01±0.02k
Z31	7.95±0.06b	2.08±0.12c	7.43±0.03c
Z32	7.85±0.04c	1.84±0.04d	8.53±0.03b
Z33	8.15±0.07a	2.14±0.03c	6.3±0.02e

Note: Values are the mean ± SD (n = 5). Different letters indicate a significant difference ( $p < 0.05$ ) among different soils.