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Solid phase speciation and mobility of thorium in soil samples from a case study in Sri Lanka

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Abstract

Sri Lanka has high background radiation due to naturally occurring radionuclides like U-238, Th-232, and K-40 containing minerals. This study investigates the radiological characteristics of soil samples from the Matale District in central Sri Lanka, focusing on thorium (Th) and its potential mobility/bioavailability. Spectrometric data indicate that Th contributes most significantly to the elevated background radiation levels in this area. Thorium, present at approximately 0.2 wt.% in the bulk soil, was analyzed across various mineral phases, including oxides, silicates, and phosphates, using multiple extraction and characterization techniques. Light rare earth elements (REEs) were also examined due to their natural association with Th-bearing minerals. This study provides, for the first time, relevant information on Th minerals in central Sri Lankan soil, addressing a critical research gap in radiological assessments of inland soils in the country. Findings provide insights into radiation exposure risks and the environmental behavior of radionuclides, serving as an important starting point for future studies on radioactive risk assessment in central Sri Lanka. The results contribute to the understanding of soil properties and emphasize the importance of further comprehensive studies to fully assess health risks and develop potential environmental safety measures.

Keywords: natural radionuclides; Th-minerals; light REE; selective extractions; environmental mobility; radioactive risk assessment

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Appendices

See tables Tables A1–A5

Table A1:

Radionuclides with the energy of gamma ray.

Parent radionuclide	Daughters	Energy (keV)	Abundance P_{γ} [a] (%)
Th-232	Pb-212	238.63	43.20
	Ac-228	338.32	11.27
		911.23	25.80
		968.97	15.80
	Tl-208	583.19	30.37
Ra-226	Ra-226	186.10	3.50
	Pb-214	295.22	19.30
		351.93	37.60
	Bi-214	609.31	46.10
		1,120.29	15.10
		1,764.49	15.10
K-40	K-40	1,460.81	10.67

[a] P_{γ} is the absolute transition probability.

Table A2:

Analytical quality assurance of the ED-XRF measurements.

	La	Ce	Th	Nd
Sy-3-M	1,340 ± 11	2,267 ± 21	1,019 ± 8	649 ± 3
Sy-3-S	1,317 ± 20	2,251 ± 20	904 ± 10	796 ± 10
Accuracy (%)	100 ± 1	102 ± 1	102 ± 1	97 ± 0
Sy-2-M	70 ± 1	174 ± 6	402 ± 7	76 ± 4
Sy-2-S	77 ± 5	161 ± 10	386 ± 10	77 ± 5
Accuracy (%)	94 ± 2	99 ± 3	106 ± 2	104 ± 6
BE-N-M	92 ± 1	180 ± 4	17 ± 1	74 ± 6
BE-N-S	82 ± 5	153 ± 10	11 ± 5	66 ± 5
Accuracy (%)	113 ± 2	118 ± 3	163 ± 7	111 ± 9

[a]M– measured value, S – standard value. All the analysed elements were checked with certified reference materials of rock samples (units are in mg kg^{-1}).

Table A3:

Averaged results from analytical quality of the ICP-MS measurements.

	La	Ce	Th	Nd
SPS-SW1-M	503 ± 6	496 ± 18	519 ± 19	504 ± 16
SPS-SW1-S	500 ± 10	500 ± 10	500 ± 10	500 ± 10
Accuracy (%)	101 ± 1	99 ± 4	104 ± 4	101 ± 3
Detection limit	0.04–0.14	0.06–0.14	0.04–0.10	0.07–0.13

[a]M– measured value, S – standard value. The analysed trace elements were checked with certified reference material of SPS-SW1 and detection limits (units are in ng L^{-1}).

Table A4:

(a) Amount of Th extracted in sequential (Sq) and single (Sin) extractions.

	F1 (μg L^{-1})		F2 (μg L^{-1})		F3 (μg L^{-1})		F4 (m
	Sq	Sin	Sq	Sin	Sq	Sin	Sq
L-03	4.45 ± 1.91	4.46 ± 0.33	330 ± 5	433 ± 6	402 ± 12	438 ± 1	2.58 ± 0.03
L-04	6.11 ± 1.40	5.80 ± 1.25	445 ± 8	542 ± 29	372 ± 20	350 ± 6	4.28 ± 0.07
L-05	3.51 ± 0.59	4.85 ± 1.31	977 ± 21	2,236 ± 17	960 ± 31	1,160 ± 33	6.38 ± 0.01
L-06	4.40 ± 1.36	4.65 ± 1.65	988 ± 1	1,115 ± 9	897 ± 4	1,060 ± 8	5.78 ± 0.01

Table A4:

(b) Amount of Th extracted in sequential (Sq) and single (Sin) extractions; mass of Th released from the soil.

	F1 (ng g^{-1})		F2 (μg g^{-1})		F3 (μg g^{-1})		
	Sq	Sin	Sq	Sin	Sq	Sin	
L-03	44.5 ± 19.1	44.6 ± 3.3	4.94 ± 0.01	6.49 ± 0.09	4.02 ± 0.12	4.38 ± 0.01	25.8
L-04	61.1 ± 14.0	58.0 ± 12.5	6.68 ± 0.11	8.13 ± 0.44	3.72 ± 0.20	3.50 ± 0.05	42.8
L-05	35.1 ± 5.9	39.3 ± 0.0	14.6 ± 0.3	33.5 ± 0.26	9.60 ± 0.31	11.6 ± 0.3	63.
L-06	44.0 ± 13.6	46.5 ± 16.5	14.8 ± 0.0	16.7 ± 0.1	8.97 ± 0.04	10.6 ± 0.1	57.

Table A5:

Released amounts of elements of interests in the washing steps between each sequential extraction.

	F1 ($mg\ L^{-1}$)	F2 ($\mu g\ L^{-1}$)	F3	F4	F5
Th			**($mg\ L^{-1}$)**	**($mg\ L^{-1}$)**	**($mg\ L^{-1}$)**
L-04	<	16.9 ± 2.9	1.5 ± 0.0	0.3 ± 0.0	1.6 ± 0.0
L-05	<	8.7 ± 2.6	1.6 ± 0.0	0.2 ± 0.0	1.5 ± 0.0
U			**($\mu g\ L^{-1}$)**	**($\mu g\ L^{-1}$)**	**($\mu g\ L^{-1}$)**
L-04	<	7.6 ± 0.2	23.5 ± 0.0	16.5 ± 0.4	23.5 ± 0.0
L-05	<	<	19.3 ± 0.5	7.0 ± 0.1	19.3 ± 0.5
La			**($mg\ L^{-1}$)**		**($mg\ L^{-1}$)**
L-04	1.7 ± 0.3	40.4 ± 2.2	0.6 ± 0.0	15.0 ± 1.2	0.6 ± 0.0
L-05	0.7 ± 0.1	14.3 ± 1.1	0.4 ± 0.0	11.7 ± 0.2	0.4 ± 0.0
Ce					
L-04	0.3 ± 0.0	11.0 ± 1.4	2.3 ± 0.0	34.4 ± 0.7	2.3 ± 0.0
L-05	0.3 ± 0.0	10.4 ± 0.5	1.9 ± 0.0	33.7 ± 1.6	1.9 ± 0.0
Nd					
L-04	1.1 ± 0.1	39.9 ± 2.0	0.3 ± 0.0	14.6 ± 0.7	0.3 ± 0.0
L-05	0.4 ± 0.1	16.1 ± 0.0	0.2 ± 0.0	12.2 ± 2.7	0.2 ± 0.0

* "<" - below the detection limit. Data only for Th, U, La, Ce, and Nd per gram of soil (L-04 and L-05) are given in this table.

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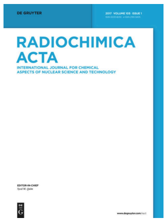

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