

Analysis of Labile Aluminium Form in Grain Size Fractions of Tsunami Deposits in Thailand

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Abstract

Our study presents the results of determining labile aluminium form in samples from the 2004 tsunami-affected coastal zone of Thailand. The samples were collected from tsunami deposits, beach sediments, sediments underlying the tsunami deposits (pre 2004 tsunami soil), as well as from soils from areas, that were not flooded. The extraction of the labile form of aluminium was performed using 3 mol L⁻¹ HCl in twelve grain size fractions. In the surface layer samples the highest concentrations were determined in the tsunami deposits in fractions <0.063 mm (5850 mg kg⁻¹). The highest determined concentration in the whole set of investigated samples occurred in soil sample in fractions 0.09-0.125 mm (19770 mg kg⁻¹). An increase in concentration of labile aluminium form, along with decreasing grain diameter, was observed in samples from all the studied settings. In general, concentrations were higher in soil samples not affected by the tsunami. This is probably due to steady weathering of minerals during soil forming processes and removal of sediment grain surface coatings potentially enriched in labile Al during high energy transport by tsunami.

Keywords: aluminium, labile fraction, tsunami deposits, grain size fractions, Thailand

Introduction

The huge Indian Ocean tsunami on 26 December 2004 was caused by a strong earthquake of magnitude Ms=9.0, with the epicenter located westward from the northern tip of Sumatra [1]. The tsunami wave hit the coast surrounding the Indian Ocean (coastlines of Indonesia, Thailand, Sri Lanka and India) with devastating power. In the most affected areas the wave height exceeded 10 m [2], reaching a maximum of over 30 m at Sumatra [3]. The distance the wave penetrated the land was estimated at a maximum of several kilometres. The effects of the tsunami wave affected various ecosystems, such as coral reefs, mangrove forests and dunes. Moreover, environmental effects of the tsunami included: increased salinity of soil, ground and surface waters; release of pollutants from marine and terrestrial

dumping sites (as happened in Somalia [4]); or deposition of a significant amount of sediments, mainly of marine origin, in the flooded areas [5-8]. The last factor has been especially important as it caused not only covering of the former soil, but the deposited sediments were also salinated [9-14] and could potentially contain pollutants – for example heavy metals, metalloids or mercury [9, 10, 13-16] which, if present in the increased concentrations in exchangeable fractions (labile fractions), might be released into ground water or become “accumulated” in plants. Fractionation [15] and speciation analyses [10, 16] were also performed for selected toxic elements in order to describe the potential threat from tsunami-generated sediments.

The previous research on the environmental impacts of tsunami deposits have not involved the analysis of aluminium in terms of the total content of this metal, and especially of its labile form. Moreover, none of the potentially toxic elements was studied in separated sediment

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Table 1. Basic datasheet on samples used in the study. Locations of sampling points, thickness of layer from which the samples were taken and sediment type according to Folk and Ward [29] classification, as well as the genetic type of the sediments are reported.

Sample No.	GPS coordinates		Depth [cm]	sediment type	genetic type
	N	E			
1	7.88588	98.27456	0-8	medium sand	tsunami deposits
2	7.88183	98.28866	0-2	fine sand	tsunami deposits
3	7.8827	98.28845	0-3	fine sand	tsunami deposits
4	7.88255	98.2888	0-2	medium sand	tsunami deposits
5	9.00165	98.25976	0-3	fine sand	tsunami deposits
6	8.73521	98.22296	0-2	fine sand	tsunami deposits
7	8.89028	98.26433	0-10	medium sand	tsunami deposits
8	8.88411	98.26592	0-1	fine sand	tsunami deposits
9	8.98695	98.26228	0-2	very fine sand	tsunami deposits
10	8.87351	98.26693	0-5	fine sand	beach deposits
A	9.00078	98.25383	0-2	medium sand	tsunami deposits
			2-5	medium sand	
B	9.00098	98.25701	0-5	fine sand	tsunami deposits
			5-10	fine sand	
			10-17	fine sand	
			20-25	medium sand	pre 2004 tsunami soil
C	8.8853	98.26703	0-3	very fine sand	tsunami deposits
			3-5	medium sand	
D	8.98696	98.2632	0-4	fine sand	tsunami deposits
			4-9	medium sand	
R	8.8961	98.27823	0-5	medium sand	Soil
			20-25	medium sand	
			35-40	medium sand	
			50-55	medium sand	

grain-size fractions. Graining has been considered one of the factors influencing the ability of sediment to accumulate pollutants. The analysis of labile aluminium form in variable grain size classes might then be of great importance in results extrapolation, as the tsunami deposits are characterized by significant textural variability [17, 18].

Aluminium is one of the four most common elements occurring in soil. It is one of the most important components of soils and, to the same extent as silicon, it makes the crystal framework of soil minerals. Due to its high reactivity (standard redox potential for Al^{3+} $E^{\circ} = -1.662V$), it almost exclusively occurs in soils in a chemically bounded state, most often as Al^{3+} ion in sparingly soluble crystal lattices. Aluminium may also be present as a ligand in combination with organic substance, and in the form of complex bonds with fulvic and humic acids included in the soil organic substance. Moreover, aluminium can create mineral and organic complexes of different hydration levels. These compounds may be easily transformed into different forms and high solubility in acidic environment. The main factor significantly influencing the activity level and the form of aluminium in soil environment is its reaction [19, 20]. In the soil solution with $pH < 3$, aluminium mainly occurs as

an ion $[Al(H_2O)_6]^{3+}$ (in short Al^{3+}). Reduction of the soil solution reaction to $pH < 4$ causes the release of H_3O^+ ions and, as a result of aeration, aluminium ions are released from mineral crystal lattices and transformed into an active hexaaquaaluminium complex $[Al(H_2O)_6]^{3+}$ (in short Al^{3+}). The ion may then dissociate H^+ ions as the solution pH increases, replacing a water particle with an OH^- ion. These forms, referred to as active forms (which include non-labile and labile aluminium), constitute only a minor part of aluminium concentration in soils. Despite that, they participate in processes shaping the basic physicochemical and biological features of soils and their increased concentrations may significantly affect these processes [21-24].

The presence of aluminium in the form of Al^{3+} ion in soil causes damage to root systems and weakens immunity of plants. As a trivalent cation, it competes for the places of ion exchange with bivalent calcium. Such a situation results in the deficiency of this element, which limits the reproduction of plants and trees. Moreover, the possibility of aluminium migration in soil profile and its presence in soil surface layer increases the risk of migration of the toxic forms to water and, consequently, to the entire matter circulation system [24-27].

The objectives of the present study were twofold. The first aim was to determine concentrations of labile form of aluminium in deposits left by the 2004 Indian Ocean tsunami in Thailand and in soil samples from the same region, to evaluate the significance of marine flooding and deposition for potential increase in toxicity of coastal zone soils. The second objective was to assess the relation of grain size fraction with concentration of labile form of aluminium.

Materials and Methods

Tsunami deposit samples of about 250 g each were collected shortly after the tsunami (February 2005) but before the rainy season, which could alter the composition of the deposits [10, 28]. They were taken from pits made in tsunami deposits in the vicinity of Patong Bay on Phuket Island and nearby Nham Kem in Phang Nga Province (Table 1). Single samples from beach and sediments underlying tsunami sediments (pre 2004 tsunami soil) were also collected in the same areas. Moreover, soil samples were collected from a pit in the vicinity of the village of Thung Tuk, which was not flooded by tsunami.

The samples were dried and subjected to standard grain size analysis using the 0.063, 0.09, 0.125, 0.18, 0.25, 0.35, 0.5, 0.71, 1, 1.41 and 2 mm sieves [29]. The separated fractions were then subjected to further analyses. Altogether 24 samples were analyzed in up to 12 grain size fractions.

One Step Extraction

In order to determine the labile form of aluminium in particular grain size fractions, a one-step extraction was performed using 3 mol L⁻¹ hydrochloric acid (I) as extractant. A sample of 1.5 g was placed in a conical flask and 10 ml of the acid was added. In order to limit the analyte losses, a glass Vigroux column was placed at the mouth of the conical flask. The extraction was performed in water bath, at a temperature of 95°C for a period of 1 h. The sample was then cold filtrated into polyethylene Falcon test-tubes and refilled with deionized water up to 15 ml.

Analytical Technique

The aluminium determinations were performed with the use of absorption spectrometry with flame atomization FAAS technique on a two-beam Perkin Elmer instrument, model AAnalyst 300 (Perkin Elmer, Norwalk, Connecticut, USA). This instrument is equipped with an autosampler made by Perkin Elmer, model AS 90 (Perkin Elmer, USA). Hollow Cathode Lamps (HCL) were used for the determinations (Perkin Elmer, USA). The optimized conditions for aluminium determinations and quality control are presented in Table 2.

Reagents

All the used reagents were of analytical purity, and water deionized to a resistivity of >18 MΩ in a Milli Q-RG apparatus (Millipore, France). The reference standard solutions

Table 2. The optimized conditions for determination of aluminium by FAAS technique.

Parameter	Aluminium		
Wavelength (nm)	309.3		
Slit width (nm)	0.7		
Lamp current (mA)	25		
Flame type	C ₂ H ₂ /N ₂ O		
Oxide flow (L min ⁻¹)	3.0		
Fuel flow (L min ⁻¹)	8.5		
Signal measurement mode	Time average		
Background correction	D ₂		
Limit of Detection (LOD)	0.02		
Limit of Quantification (LOQ)	0.06		
Linearity (mg L ⁻¹)	to 100		
Precision (%)	0.7		
Sensitivity (mg L ⁻¹)	0.06		
Quality control SRM 2709 (n=6)			
Certificate value	mg kg ⁻¹	75 000±600 [30]	
Obtain value	mg kg ⁻¹	method	HCl
		EPA 3050	3 mol L ⁻¹
Recovery	%	74 500± 1 700	19 200 ±540
		99.3±2.3	25.6±0.7

were made of commercial standards for AAS analysis by Merck (Merck, Darmstadt, Germany)

Results

The concentrations of labile forms of aluminium are presented for all the investigated fractions in surface samples, then in five studied vertical profiles. In the end, the results concerning all samples in fraction 0.18-0.25 mm are presented. The choice of the fraction for comparison was determined by a sufficient amount of sediment within it in all samples.

Concentrations of aluminium labile form in surface samples varied depending on the grain size fraction (Fig. 1). The median and mean values for surface samples were in the range of 326-1500 mg kg⁻¹ and 340-2070 mg kg⁻¹, respectively. In the tsunami deposits the highest concentration of aluminium was determined in sample No. 5 in fractions <0.063 mm (5850 mg kg⁻¹), in the soils - in fractions 0.125-0.18 mm (4110 mg kg⁻¹), while for the sample collected from the beach (No. 10) - in fractions 0.09-0.125 mm (603 mg kg⁻¹). In most samples the concentrations of labile form of aluminium were increasing along with increasing

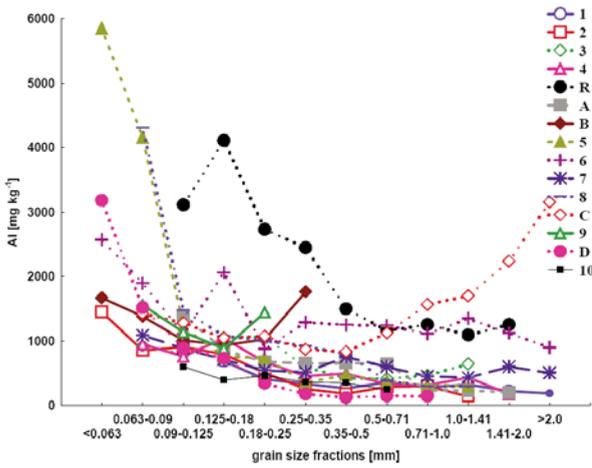


Fig. 1. Variation in the concentration of labile aluminium in particular granulometric fractions for the surface samples.

grain size. The only exception in the whole set is sample C (0-3 cm), which revealed a reverse tendency. In that case, the highest concentration was observed in fraction >2.0 mm (3150 mg kg⁻¹), next in fraction 0.063-0.09 mm (1420 mg kg⁻¹) and the lowest in fraction 0.35-0.5 (833 mg kg⁻¹). In the tsunami deposits, in the fractions from 0.09 to over 2 mm, the analyzed concentrations of labile form of aluminium were generally at a similar level.

The aluminium labile form concentration in particular grain size fractions for samples from the vertical profiles revealed variable changability (Figs. 2-6). In profile A (tsunami deposits) variations of concentrations with depth were irregular and mainly were observed in fine fractions (Fig. 2). The highest concentration was determined in the surface layer in fraction 0.09-0.125 mm, while at a depth of 2-5 cm, the highest concentration was determined in fraction 0.25-0.35 mm.

In profile B the maximum concentration form with depth is high only in the upper part of the profile, where a decrease of concentration was observed for all granulometric fractions common for the investigated samples (Fig. 3). For example, for fraction 0.25-0.35 mm, the highest concentration reached 1760 mg kg⁻¹ in the surface layer (0-5 cm), and at a depth of 5-10 cm it decreased more than fourfold. In the case of finer fractions, the downward decrease was less pronounced. In fraction 0.09-0.125 mm, the highest concentration reached 1010 mg kg⁻¹ in the surface layer, while the lowest concentration at a depth of 10-17 cm was 925 mg kg⁻¹. The lower-most sample in the profile is from pre the 2004 tsunami soil layer. Importantly, it did not reveal any significant variation from the overlying tsunami deposits.

Fig. 4 presents profile C, where the concentration of labile forms of aluminium decreased with depth for fractions 0.125 to >2.0 mm. However, for finer fractions (from 0.125 mm), higher concentrations were determined in the deeper layer. The maximum concentrations of labile form of aluminium were determined in the surface layer (0-3 cm) in fractions >2 mm.

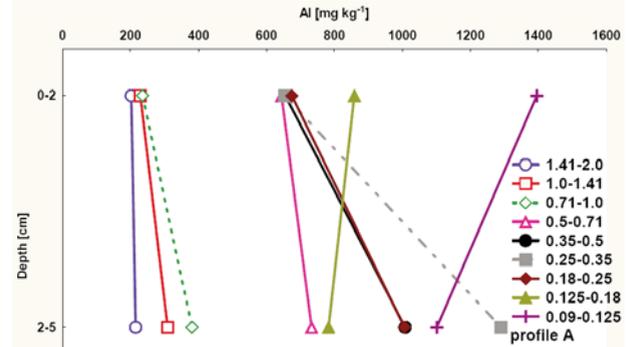


Fig. 2. Variation in the concentration of labile aluminium with depth for all common granulometric fractions in profile A.

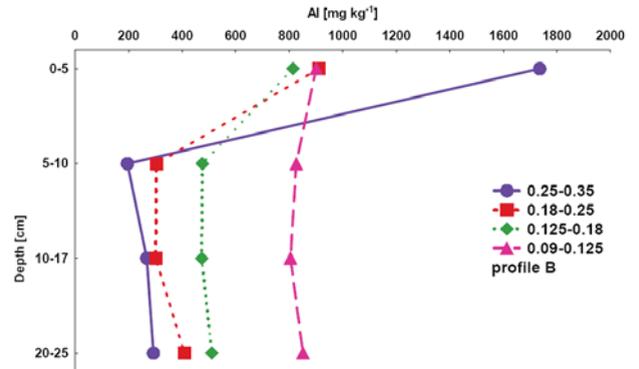


Fig. 3. Variation in the concentration of labile aluminium with depth for all common granulometric fractions in profile B.

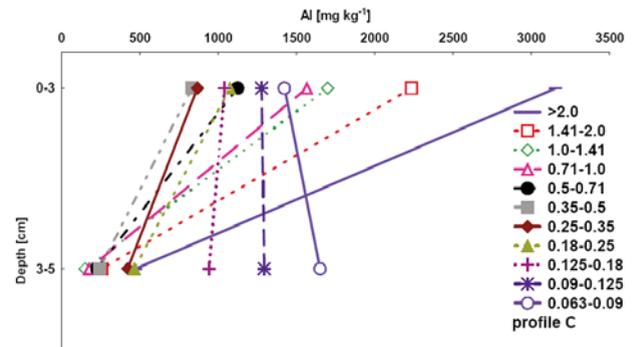


Fig. 4. Variation in the concentration of labile aluminium with depth for all common granulometric fractions in profile C.

In profile D (Fig. 5) the highest concentration was determined in the finest fraction (0.09-0.125 mm) at a depth of 4-9 cm. The determined concentrations of Al in the particular grain size fractions did not show significant variability with depth.

Soil profile R is characterized by the variability of aluminium concentrations depending both on grain size and depth (Fig. 6). The concentrations increased significantly with decreasing grain size. The highest concentration was determined in fractions 0.09-0.125-mm (19770 mg kg⁻¹) at a depth of 35-40 cm. In this layer, the increase of Al concentration was observed in all the investigated fractions.

The comparison of results for all the samples, both from surface and from vertical profiles, was presented on the example of one granulometric fraction 0.18-0.25 mm., which occurs in all investigated samples (Fig. 7). In the tsunami deposits, the highest concentration was determined for this fraction in sample No. 9 (1442 mg kg⁻¹), while the lowest concentration was observed in profile D (341 mg kg⁻¹). In both cases the samples came from the surface layer (0-4 cm). Much higher concentrations were determined for the samples from soil profile R, where the highest concentration

reached 3850 mg kg⁻¹ in the sample collected at a depth of 35-40 cm. The beach samples (No. 10) as well as those collected at the lower part of profile B (pre 2004 tsunami soil) showed the concentrations at the lowest levels of those determined in the tsunami deposits.

Discussion

Sediments left by tsunami belong to a category of so-called event deposits, which occur in nature with variable frequency. The 2004 Indian Ocean tsunami was the first large one since the development of advanced analytical techniques. So, environmental chemical investigations of tsunami deposits were conducted for the first time following the Indian Ocean tsunami [9, 12, 13]. That is the reason why there are no literature data concerning aluminium determinations and its forms in the tsunami deposits.

The conducted investigations belong to the group of the first ones, which is connected with the lack of possibilities to compare the obtained results of aluminium concentrations with other researchers. The available literature data mainly concern depositional [31-33] and geomorphological [34-36] samples of tsunami deposits collected at different places affected by the tsunami wave, including some areas in Thailand from where the research material came.

Research using hydrochloric acid (I) was carried out in order to conduct extraction from soil and sediment samples [e.g. 37], for one granulometric fraction [10, 38] and for many granulometric fractions [e.g. 39-42]. This research, however, did not involve the determination of labile aluminium form. Due to the lack of literature data concerning aluminium analysis in tsunami deposits, the obtained results are compared with data from researchers who used hydrochloric acid (I) in determinations of labile aluminium form in solid samples for single grain size fraction [43] and for various grain size fractions [44].

Sutherland [45] determined aluminium in the range of 2200 to 17,400 mg kg⁻¹ using HCl (0.5 mol L⁻¹) as the reagent in one-step extraction in soil samples and road deposits in granulometric fractions <0.125 mm (the samples

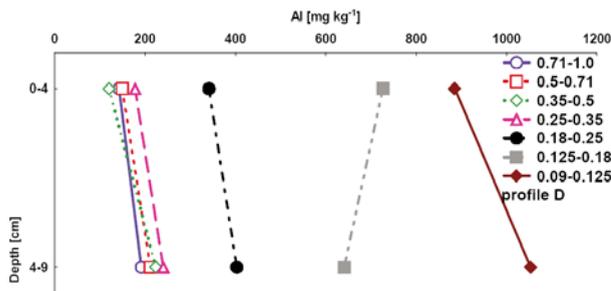


Fig. 5. Variation in the concentration of labile aluminium with depth for all common granulometric fractions in profile D.

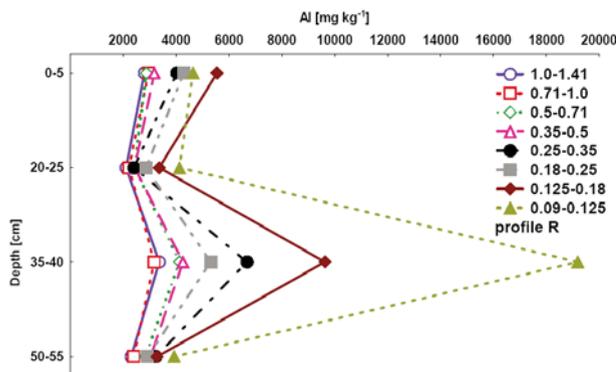


Fig. 6. Variation in the concentration of labile aluminium with depth for all common granulometric fractions in profile R.

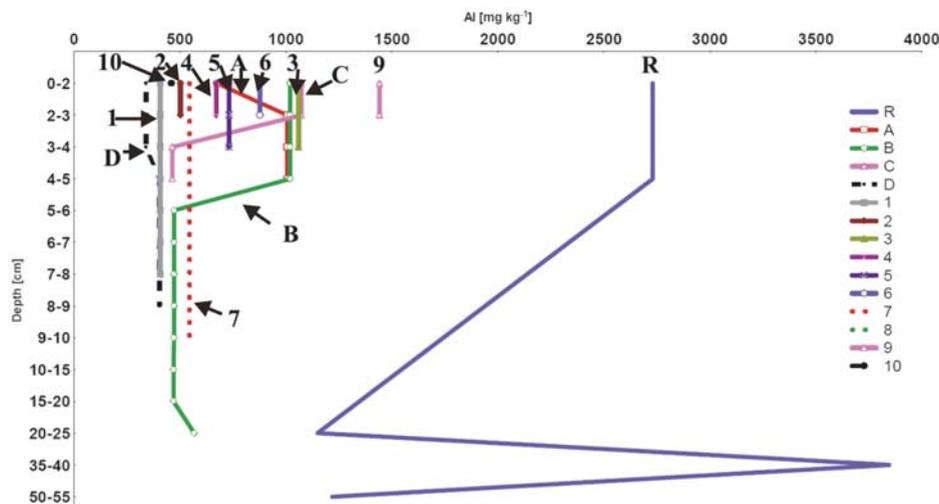


Fig. 7. Spatial distribution of labile aluminium form for 0.18-0.25 mm grain size fraction (one common grain size fraction).

were grounded for homogenization). In another study, Sutherland et al. [44] determined aluminium in road deposit samples at $10,000 \text{ mg kg}^{-1}$ in granulometric fractions 0.1-0.063 mm using the same conditions for determination as previously. In the case of tsunami deposits for fraction <0.063 to 0.125 mm, the concentration of aluminium reached values of 760 (no. 4) to 5850 (no. 5) mg kg^{-1} , while for soil samples (profile R) the concentration was determined at the level from 2330 (50-55 cm) to 19,770 (35-40 cm) mg kg^{-1} . However, the samples were not grounded and extracted with $3 \text{ mol L}^{-1} \text{ HCl}$. In another study, Sutherland et al. [38] determined aluminium in road deposit samples at $10,000 \text{ mg kg}^{-1}$ in granulometric fraction 0.1-0.063 mm using the same conditions for determinations as the above.

Matúš et al. [46, 47] conducted one-step extraction using numerous extractants (including CaCl_2 , EDTA, $\text{Na}_2\text{S}_2\text{O}_4$, $\text{HCl } 0.5 \text{ mol L}^{-1}$) in samples of rocks and soils from mining areas. Extraction using $\text{HCl } (0.5 \text{ mol L}^{-1})$ caused the highest level of aluminium extraction from the samples. The concentrations were in the range of 250 to 2500 mg kg^{-1} , and were determined in fine dust fraction obtained as a result of grounding samples which were previously sifted through a 2 mm sieve. Compare those results with present study data for <0.063 mm. That is the reason why the samples from granulometric fraction of unground sediments <0.063 mm were chosen for the comparison revealed. The concentrations determined in this study for the same fraction are much higher both in tsunami deposits (the highest aluminium concentration amounted to 5850 mg kg^{-1} (no. 5) while the lowest one reached 1450 mg kg^{-1} (no. 2), similar to the soil samples (profile R) (5570 to 19770 mg kg^{-1}).

Kubová et al. [48], using $\text{HCl } (0.5 \text{ mol L}^{-1})$ in strongly acidic soil samples from mining areas in fraction <2.0 mm, determined the highest concentration of aluminium at 1900 mg kg^{-1} . The highest concentrations in the investigated samples were determined in fine fractions, but a similar concentration was also determined in a profile C sample (0-3 cm), where in fraction 1.41-2.0 mm the concentration reached 2230 mg kg^{-1} . For group R (35-40 cm) samples, the concentration of aluminium in fraction 1.0-1.41 mm reached 1710 mg kg^{-1} .

The above-presented examples of studies concerned one selected grain size fraction. The determination of labile aluminium form in six fractions in road deposit samples in Hawaii using (0.5 mol L^{-1}) in one-step extraction was the subject of research conducted by Sutherland and Tack [49]. The authors determined the labile form of metals, including aluminium, in the following granulometric fractions: <0.063, 0.063-0.125, 0.125-0.25, 0.25-0.5, 0.5-1.0, and 1.0-2.0 mm. Their research presents average concentrations obtained by them compared with mean values of aluminium in tsunami deposits and soils from the present study in Table 3. A comparison of their results with the mean values for respective fractions in tsunami deposits and soils presented in this study is shown in Table 3. The present study results revealed much stronger dependence on grain size fraction. Moreover, the values are in most cases higher,

Table 3. Comparison of the obtained average results on labile aluminium concentrations in selected grain size fractions with those from Sutherland and Tack [44]. Note that the aluminium was extracted with 3 and $0.5 \text{ mol L}^{-1} \text{ HCl}$ for the present study and [44], respectively.

Grain size fraction [mm]	tsunami deposits [mg kg^{-1}]	soils (profile R) [mg kg^{-1}]	road deposits [after 34] [mg kg^{-1}]
1.0-2.0	540	1290	670
0.5-1.0	455	1170	744
0.25-0.5	585	2030	529
0.125-0.25	820	2370	350
0.063-0.125	1360	7810	247
<0.063	2730	11050	888

which is probably mainly due to stronger acid used in extraction procedure.

The source of aluminium in the case of investigated samples can be connected with litogenic conditions of the investigated area. Considering the fact that the dominating minerals in the area of Thailand and Indonesia are caolinite, smectit, mica and vermiculite, which are formed by Al-Si bounds [50]. Besides, it is also noteworthy that diluted HCl used in one-step extraction caused the extraction at the surface of the sediment grain of labile form of aluminium, and it did not cause the release of aluminium built in mineral structures. Moreover, the lower concentrations of aluminium determined in tsunami deposits compared with the determinations in soil samples (profile R) may be connected with high salinity of tsunami deposits, which was the distracting factor affecting the determinations conducted using the FAAS technique.

Spatial analysis of the labile aluminium form indicates significant variability in concentration of this element on a small surface (Fig. 2). For sample No. 9 and sample D (0-4 cm) located in close vicinity from one another, which did not exceed several hundred meters, the highest and the lowest concentrations of aluminium were determined for tsunami deposits in the surface layer in granulometric fraction 0.18-0.25 mm (despite the similar lithology of these samples: fine sand).

Extraction by $\text{HCl } (3 \text{ mol L}^{-1})$

The presented comparisons indicate a potentially significant role of the applied extraction scheme. The Soil Reference Material 2709 analysis extracted with $3 \text{ mol L}^{-1} \text{ HCl}$ enabled the isolation of 25% of the total aluminium concentration. In the case of tsunami deposits the use of $3 \text{ mol L}^{-1} \text{ HCl}$ enabled us to obtain concentrations which did not require dilution, thus eliminating the need for further intervention into samples. Moreover, sample SRM 2709 was subjected to extraction using different concentrations of HCl .

For concentrations 3, 1, 0.5, 0.1, 0.001 mol L⁻¹, the following recovery values were obtained: 25.6±0.7; 11.5±0.5, 3.2±0.3, 0.12±0.01 and 0.017±0.005%, respectively. This type of comparison of the analyzed concentrations may provide a general view of the labile form of aluminium concentration. In their study, Matúš et al. [46] obtained recovery of 0.2-3.6% in soil sample extracted with 0.5 mol L⁻¹ HCl.

Walna et al. [21] obtained recovery of the labile aluminium form for the first 3 stages of Tessier procedure [51] 13.7% (acid extractable, reducible and oxidizable), while Sutherland obtained it for material SRM 2710 and SRM 2711 respectively 12.6 and 12.8, for aluminium extracted for chemical fraction acid extractable, reducible and oxidizable [52]. In the research on road sediments, in the study by Sutherland et al. (2001), the authors obtained recovery of method within the range 6.8-43.6% using 0.5 mol L⁻¹ HCl [53]. In the research by Matúš et al. [46], the recovery value was obtained using 0.5 mol L⁻¹ HCl depending on the sample type from 0.3-8.2%. Thus, the variability of extractants of different elution values imposes the above-mentioned comparisons, which enable a reliable comparison of research results by other authors.

The obtained results of concentrations of labile aluminium form indicate a significant difference between the samples of well-developed soil (profile R), which had relatively high contents of Al, and tsunami deposit samples, the former soil covered with tsunami deposits and beach sediments with lower concentrations. Because the general features of the studied materials were similar (mineralogy, grain size), it is possible that some in situ ongoing processes are responsible for the difference.

In the studied soil profile several horizons were distinguished. The upper horizon (0-5 cm) contained large amounts of organic material in varying stages of decomposition. The next horizon, represented by a sample from 20-25 cm, was leached of its mineral and organic content, leaving a pale layer largely composed of silicates. Below (35-40 cm), was illuviated horizon enriched in fine-grained material. The lowermost sample (50-55 cm) was from a horizon similar to the second one. The labile aluminium was significantly enriched in a zone of illuviation and to a minor degree in upper surface horizon. So its distribution follows general trends observed in soils, where organic reach layer and illuviated horizon are enriched in various elements. A similar relation was observed in the same profile for heavy metals [54]. Although the other analyzed sediments (e.g. tsunami deposits) have similar or even finer mean grain size, they are depleted in labile form of aluminium in comparison to the soils. One of the possible explanations may be related to the mode of sediment transport during the tsunami and in the beach zone. Many grain collisions during transport could remove the outer surface layer, where labile forms could be precipitated or adsorbed. The second factor is salinity and pH of seawater, which could be limiting factors for Al release from the minerals. In some studies on soils flooded by tsunami, a rapid increase in pH was noted [e.g. 55]. Sediments of marine origin are also rich in calcium carbonate (e.g. bivalve shells), which during dissolution may cause a decrease in acidity of sediments and protect the minerals containing alu-

minium from leaching. Moreover, the lower concentrations of aluminium determined in tsunami deposits rather than in soil samples may be related to high salinity of tsunami deposits, which was the distracting factor affecting the determinations conducted using the FAAS technique.

The lower concentrations of labile form of aluminium in tsunami deposits in relation to soils is in contrast to labile Cd, Cu, Zn, Pb and As, which were enriched in tsunami deposits [9, 10, 16], probably tied with Cl and SO₄. However, the concentrations of acid-leachable heavy metals in particular grain size fractions of tsunami deposits, similar to aluminium, are also the highest in finer sediments [54].

Environmental Aspect

It seems noteworthy that aluminium in its labile form, (an easily soluble form) from tsunami deposits which covered over 20,000 hectares in the area of Thailand itself, may migrate to groundwater and then the determined high concentrations of this metal may pose a real threat to the whole natural environment. It should be remembered that aluminium built in mineral structures is harmless, while the decrease of pH <4.0 of the sorption soil (deposit) complex will cause activation of labile forms of labile (exchangeable) aluminium forms into ground water, and next to surface water [e.g. 23, 26, 56-58].

The fact that tsunami waters caused high salinity of soil, ground and surface waters and destroyed sewage systems, sewage purification systems and dumping sites, may result in changes in the acidity level in the natural environment. Moreover, as chemical analyses showed, tsunami sediments, whose deposited layers had a thickness of up to several dozen cm, contained very high concentrations of salt, but also heavy metals (Cd, Cu, Zn and Pb) and metalloids (As) in easily elutable and bioavailable fractions [9, 10, 54]. That is why the determination of labile aluminium forms in these samples becomes so important, especially that this metal is the element commonly occurring in the Earth's crust, and its soluble forms show negative reaction to particular components of the natural environment. In the case of tsunami sediments, this may cause long-term effects.

Conclusions

Based on the study of samples collected in Thailand carried out in January 2005 (after the tsunami), the following conclusion can be formed:

1. Although tsunami deposits left in the coastal zone of Thailand are potentially environmentally dangerous because of elevated contents of heavy metals, salts and arsenic, they were not enriched by a potentially toxic, labile form of aluminium. Its concentrations were lower than in soils not flooded by tsunami.
2. The determined values of labile aluminium fraction extracted with 3 mol HCl are in the range documented from other sediments for extraction with 0.5 mol HCl.
3. In the case of tsunami deposits, no significant changes in concentration of labile aluminium form with depth

were observed. Significant changes in aluminium concentration were observed in soil profiles not affected by tsunami.

4. Concentration of labile aluminium form depends on grain size. Higher concentrations were found in finer sediments. This relation was observed in the tsunami deposit samples, as well as in soil samples.
5. The use of one-step extraction using 3 mol L⁻¹ HCl makes it possible to extract HCl-labile species of aluminium from tsunami deposits.

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