Environmental risk assessment of red mud contaminated land in Hungary

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ABSTRACT

The red mud catastrophe of October 2010 in Hungary draw the attention to the problem of red mud disposal sites, storage reservoirs and other wastes of mining origin that pose severe threats to humans and the environment all over the world. Present study introduces the results of the risk assessment that supported management of the priority risks and decision making on the necessary and most efficient risk reduction measures.

INTRODUCTION

The red mud spill case in Hungary has highlighted in addition to the "usual" static uncertainties of reservoirs other basic shortcomings in the management of wastes and in the handling of unprecedented complex environmental problems similar to the Ajka case. The main conceptual problem was the lack of a risk based approach in the environmental regulations pertaining to/controlling waste management and disposal in Hungary. Instead of a risk-based, rather an EWC (European Waste Catalogue) code based approach is practiced without detailed assessment of the risks posed by the waste and by the individual chemical substances contained in it.

Actually there is scarce knowledge about the behavior of the highly alkaline sodium-hydroxide solution (NaOH) in the environment and about the characteristics of sodium-hydroxide saturated soils similar to what has been encountered downstream the broken red mud storage dam in the flooded Torna Creek area. Many seemingly simple questions have been raised but no answers were given:

- What are the transport and fate characteristics and mobility of Na^+ and OH^- ions?
- How much Na^+ and alkalinity is acceptable in the soil and groundwater?
- How the NaOH flooded soil will function as a habitat?
- How the effect of NaOH will change the water and air household of the soil?
- How the red mud influences soil characteristics when mixed to soil?
- How much red mud can be mixed into the soil without adverse changes?
- What will be the response of the soil microbiota to NaOH and/or red mud?
- What will be the response of the plants grown on red mud contaminated soil?
- Which plants can grow in the NaOH and the alkaline red mud contaminated soil?
- How risky is contaminated soil for the residents and farmers on the long term?
- What are the most risky exposure pathways?
- Which short term and long term changes, deteriorations are foreseen in soil?
- What should be the quality target in the soil?
- How much effort, labor and money may be spent for the remediation?
- What will be people's response to products (vegetables, grains etc) grown on red mud contaminated soils?

All of these questions will not be answered in this study, but some points are covered to get a more detailed picture on the risk of the red mud catastrophe.

1 THE RED MUD CATASTROPHE OF AJKA – A SHORT OVERVIEW

On the 4th October 2010, the corner of the No. 10 red mud storage pond at the alumina production facility MAL, in Ajka, Hungary broke. An estimated amount of 800 000 m^3 red mud of high alkalinity (pH 13) streamed with high velocity has swept bridges, cars and unfortunately led to human casualties (10 people died, 60 injured). It flooded three villages, thousands of hectares of agricultural land and caused intense environmental damage. The most impacted villages were Kolontár (1 km) and Devecser (5 km) below the storage pond. Somlóvásárhely, the village 10 km away from the pond was also reached and flooded by the mud flow (Gruiz, 2010; Reeves *et al*., 2011).

1.1 Geology and surface waters

The site is located in the Ajka basin bordered in the East by the projection of the Bakony Mountains. The geomorphology in the vicinity is characterized by a shallow valley, which contains the westerly flowing Torna Creek. Springs are present on both the north and south sides of the valley. The lowest altitude (187 m Baltic Sea) is at the red mud storage facility, the highest is 255 m, close to Somlóvásárhely. Average precipitation is typically 710 mm/annum. The Torna valley is the upper watershed area of Marcal River, ending into the Rába River, which reaches a Danube arm, then the Danube.

1.2 The soil

Most of the red mud flooded area is covered by silty sand loess, fluvial and run off residual. The topsoil has a typical light mechanical composition (gravelly coarse sand, sand, loamy sand) with 30% gravel in the depth of 0–30 cm. The thickness of the humus layer is more than 30 cm and organic matter content is around 2%. The depth of the groundwater level is generally 0.5–1.5 m meters with seasonal changes. The groundwater normally has calcium-magnesium hydro-carbonate content.

1.3 Risk management of the catastrophe and the contaminated site

Risk management of the red mud catastrophe had three main stages:

1. Catastrophe response;
2. Risk mitigation by rapid measures;
3. Remediation of waters, soils and rehabilitation of the whole area

Catastrophe response was the short term management of the situation, with the aim of protecting human life, animals and other values. In this phase risk prioritization and managing these priority risks were the most important tasks. Risk reducing measures were determined by availability of the materials and technologies and by socio-economic aspects. The short term beneficial effects of the measures were decisive, the long term consequences were less taken into account in this phase.

Risk mitigation and final ***reduction*** required the assessment of the sources, environmental compartments and the receptors, as well as of their linkage to each other. After having satisfactory information, the preparation of the conceptual risk model of the area became possible and the risks could be assessed.

The conceptual risk model of the Ajka case shown on Figure 1 illustrates the transport pathways of the red mud from the pond (through the broken dyke), via the reached environmental compartments to the ecosystem members and human receptors exposed to the contaminated and destroyed environment (Gruiz, 2010).

Risk assessment tiers consist of preliminary and detailed steps. First step was the identification of the hazards. Second was the score-based assessment of the risk scenarios; third was the detailed quantitative assessment of the main ecological and human risk components before and after the application of the risk reduction measures.

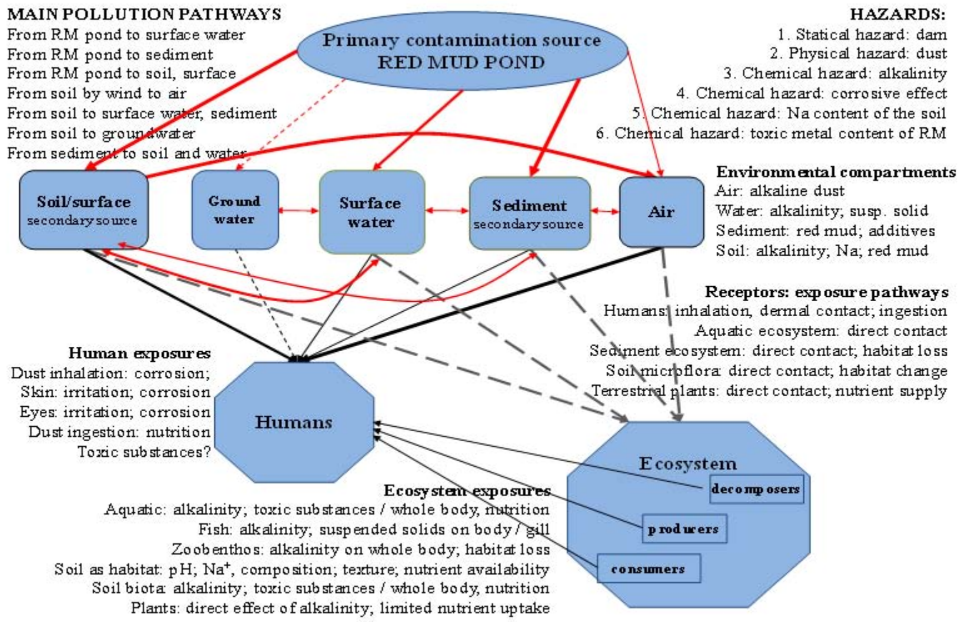

Figure 1 The conceptual risk model of the red mud flooded Torna-valley

Risk reduction started after quantitative characterization of the risk of the most hazardous risk components. The main steps of risk mitigation and risk reduction:

- Protection of human life and exclusion of life threatening hazards.
- Isolation of the dyke: it was finally closed 7 months after the accident.
- Neutralize alkaline flux gypsum was added in large quantities to adjust pH to 9.5 and protect aquatic ecosystem of the Torna Creek and the rivers downstream. Gypsum settled together with the red mud in the Torna and Marcal causing additional pollution in the river-beds (Mayes *et al.*, 2011).
- Cleaning residential areas, open surfaces, removing deteriorated buildings, debris.
- Gradual cleaning of the river bed.
- Removal of the secondary contaminant sources, including red mud inundated surfaces, wetlands and ponds.
- Reducing risk on more thousands of hectares of agricultural land. Two evaluated alternatives: removal of the red mud layer or leaving it and mixing it into the soil.
- Risk assessment focused on soil, with special emphasis on:
    - Air pollution by particulate matter and its human health risk;
    - Human health risk of alkaline soil inhalation, ingestion, dermal contact;
    - The effect of the alkaline/caustic slurry seeping into the soil;
    - The effect of red mud mixing into soil;
    - Groundwater and soil toxicity;
    - The risk of toxic metals in soil.
- Risk reduction by removal or incorporation of red mud.
- Long term monitoring of the fate and transport of Na, alkalinity and sodification.
- Revegetation.
- Verification of the applied soil treatment technologies.

2 RISK ASSESSMENT OF CONTAMINATED SOIL

A three-tiered risk assessment was applied for identifying hazards and priorities as well as for evaluating risk reduction alternatives. The following risk scenarios were evaluated – in accordance with the risk reduction alternatives:

- No action;
- Removal of the red mud from the surfaces and its isolated storage;
- Mixing the red mud into soil by plowing;
- Revegetation of the soil after removal or mixing red mud into soil;
- Storage of the removed red mud or its mixture with soil, and isolation of the dumped red mud by vegetation cover or physical encapsulation.

2.1 Risks of red mud on agricultural soil

The Torna-valley is primarily agricultural and minimum 1000 hectares are flooded by the alkaline red mud. A detailed inventory is listed below showing all possible changes and risk components, which may affect adversely the agricultural soil.

Infiltration of the alkaline liquid phase into soil and groundwater

- Soil and groundwater alkalinization;
- Elevation of soil and groundwater Na content;
- Modification of the chemical forms and mobility of the elements;
- Changes in soil nutrient and water cycling, as well as in soil's water-balance;
- Increased risk of sodification;
- Soil and groundwater toxicity;
- Plant growth inhibition, limited nutrient supply, deteriorated nutrient household;
- Caustic/corrosive effect of the contaminated soil on humans;
- Detrimental effect of contaminated soil and ground water on humans.

Fine grained red mud on the soil surface and in the soil

- Red mud plugs the soil pores resulting anoxic conditions in the soil;
- Meanwhile the micro-plug hinders penetration of further contaminants;
- Damaging effect of the (temporary) anoxic conditions on soil living organism;
- Detrimental effect of (temporary) anoxic conditions on plant growth.

Hazards subsequent to drying of the fine grained red mud

- Dusting, dust deposition on remotely located surfaces and threat to humans by dust inhalation, hazard of the PM_{10} and $PM_{2.5}$;
- Hazard due to caustic effect, threat to humans by ingestion;
- Toxic element content.

Plowing the red mud into soil means the incorporation of the residual red mud into deeper soil layers to prevent dusting. The hazards are:

- Elevation of alkalinity, Na and Fe content;
- Increase of the sodification potential;
- Toxicity to soil ecosystem and cultivars.

Revegetation/planting

- Successful planting may decrease dusting but it might increase toxicants in the food chain by bioaccumulation in plants and in food chain
- Plant growth inhibition;
- Secondary poisoning through plants grown for human consumption.

2.2 Scoring based preliminary evaluation of the risk scenarios

Table 1 shows the final risk scores of the risk scenarios and the risk reducing alternatives. Site specific creation of the scores utilized the CCME methodology (1992).

Table 1 Results of the qualitative risk assessment of selected scenarios

Evaluated risk scenario		Risk score max.100	Risk characterization	Action necessary?
1. Red mud layer on soil: infiltrated alkaline solution, desiccated red mud				
1.1.	Below5 cm thick red mud layer	63	High risk	Action required
1.2.	5–10 cm thick red mud layer	74	Very high risk	Action required
1.3.	10–20 cm thick red mud layer	85	Very high risk	Action required
1.4.	Above 20 cm red mud layer	91	Very high risk	Action required
2. Red mud removal: caustic solution infiltrated, solid red mud layer removed				
2.1.	Below5 cm thick red mud layer	14	No risk	No action required
2.2.	5–10 cm thick red mud layer	19	No risk	No action required
2.3.	10–20 cm thick red mud layer	38	Low risk	Not likely required
2.4.	Above 20 cm red mud layer	44	Medium risk	Likely required
3. Red mud incorporated into soil				
3.1.	Below5 cm thick red mud layer	16	No risk	No action required
3.2.	5–10 cm thick red mud layer	25	Low risk	Not likely required
3.3.	10–20 cm thick red mud layer	41	Medium risk	Likely required
3.4.	Above 20 cm red mud layer	49	Medium risk	Likely required
4. Soil with planted vegetation				
4.1.	Removed red mud layer >10 cm	21	No risk	No action required
4.2.	Mixed in red mud layer <5 cm	14,5	No risk	No action required
4.3.	Mixed in red mud layer 5–10 cm	20,5	Low risk	Not likely required
5. Disposal of the removed red mud		78	Very high risk	Action required

2.3 Quantitative assessment of human health risk

Human health may be endangered by particulate matter and by the caustic effect of red mud through inhalation, dermal contact, and ingestion by dust or food. All these exposure pathways have been evaluated by using site specific exposure concentrations compared to generic screening values.

Dust inhalation

Risk evaluation concept of the red mud particulate matter in the atmosphere was based on comparing the monitoring data subsequent to the red mud spill of 2010 with the yearly average winter and summer values of the previous years. This way we obtain the additional contaminant load. The additional contaminant load was evaluated in terms of the rehabilitated/cleaned surfaces/areas. Our risk forecast assumed 10% residual load.

Currently valid screening values in Hungary for the PM10 fraction (6/2011 VMR) are: daily limit (24 hours average): 50 μg/m^3; yearly average screening value: 40 μg/m^3; 70% of the daily limit can be exceeded only 35 times per year.

Subsequent to the accident 12 additional (to the existing two) measurement points for continuous measurement of the PM_{10} fraction were placed in the Ajka and Devecser area.

The difference between the winter and summer level of the PM_{10} fraction is on average 30 μg/m^3. During previous winters the quality criterion of 40 μg/m^3 was exceeded, but the daily values were within the 35 occasion's exceedance range. Figure 2 and 3 show monitoring data from 2010 and 2011.

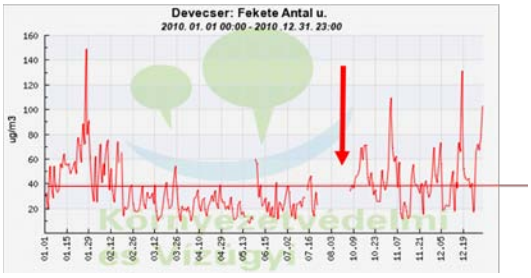

Figure 3 Daily PM_{10} during 2010 in Devecser

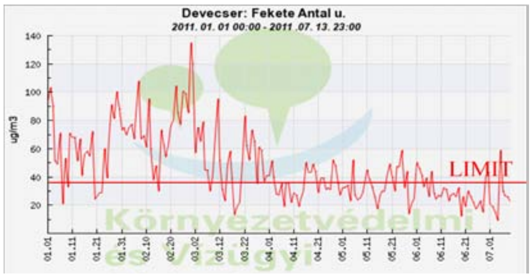

Figure 4 PM_{10} during 2011 in Devecser

After the accident the average PM_{10} values were exceeded at 4 measurement stations from the 12 in a moderate scale: 43–55 compared to the required 40 μg/m^3. The number of exceedances is significantly higher in the first 5 months: 49–72 instead of the maximum of 35.

The estimated PM_{10} for the end of 2011 based on monitoring data and the scale of completion of clean-up was 25–30 μg/m^3 with 5–15 exceedances, which is not higher than the values from previous years.

Risk of the caustic effect on humans

NaOH is irritative and corrosive to the eye, skin and the respiratory system, causing mainly occupational health problems in the practice. As it is also used in households, we have epidemiological data on accidental ingestion and corrosion. NaOH-specific screening values for ambient air or water do not exist.

Human health risk of NaOH has been calculated as an RCR (Risk Characterization Ratio) by the comparison of exposure results to occupational health quality criteria or to epidemiological data. The inhaled amount was calculated from a highly overestimated 10% NaOH content of the desiccated red mud and the measured PM_{10} concentrations. Irritation and corrosion were evaluated based on pH.

Occupational health screening values for NaOH exposure by inhalation are set by OSHA (2011) and the National Institute for Occupational Safety and Health (NIOSH, NaOH) as a permitted workplace air limit value (PEL), which is 2 mg/m^3. Information about dermal contact cases: a concentration of 0.5–4.0% was irritating to the skin, while 8.0% was corrosive for animals. Non-irritant level on animal eye: 0.2–1.0%, the corrosive concentration: 1.2% or more. Experimental results on volunteers: 0.12% NaOH solution (pH 12.2) irritated the skin after 1 hour (INCHEM, 2002).

Inhaled NaOH was calculated in a worst case scenario, assuming the highest dusting rate and 10% NaOH content in the fugitive dust. Using the highest measured average PM_{10} (80 μg/m^3), the inhaled NaOH is 8 μg/m^3. This is only 1/200 of the permissible 2 mg/m^3 occupational exposure limit. In case of the highest ever measured PM_{10} which was 140 μg/m^3, the RCR_{inh} is still only 1/150. Comparing the maximal exposure to the acute inhalation limit of 10 mg/m^3 the RCR values are below 1/1000.

Dermal irritation and corrosion may be significant above pH 12, being equivalent with 500 mg/L NaOH concentration in water. The same amount in soil results in a value of pH 9.7. To reach pH 12 in local soils 70% red mud incorporation would be necessary, which is not a realistic case even the removed material has lower red mud content.

The red mud slurry from the storage pond of pH 13.0 was highly corrosive (RCR=10), the diluted and desiccated slurry with a pH of maximum 12.5 was still irritative and corrosive (RCR=5) but red mud removal or incorporation by plowing results in negligible corrosion risk (RCR ≤0.01). Results are summarized in Table 2.

Table 2 Risk of NaOH and red mud contaminated soil through dermal contact

Red mud / risk scenario	Maximum pH	RCR_{dc}	Verbal risk characterization
Freshly discharged red mud	>13	**RCR_{dc}>10**	Significant
Red mud on soil: after 5 months	12.5	**RCR_{dc}=5**	Significant
Red mud on soil: after 10 months	12.3	**RCR_{dc}=3**	Significant
Red mud removal from soil surface	8.0	RCR_{dc}~0	Negligible
Red mud incorporation, max. 10%	8.8–9.9	RCR_{dc}=0.001–0.01	Negligible
Disposal of removed red mud	11–12.3	**RCR_{dc}=0.1–3**	Moderate–signif.

Risk of NaOH by ***ingestion*** is calculated based on the average ingestion rate for adults and children, 1.7 mg/kg/d and 8.5 mg/kg/d respectively. RCR_{dig} values are 1/1300 and 1/6400 in the worst cases, the risk of contaminated soil ingestion is negligible.

2.4 Risk of alkalinity and sodium on soil quality and function

High alkalinity causes detrimental effects to the soil as a whole, affecting soil texture, function and quality as habitat of microbes, animals and plants. There is no ecological or agricultural screening value set for the soil pH. High pH is generally a benefit in soils, but their ion-composition also influence the judgment.

A risk-scale was established based on experts' judgment for the red mud flooded Torna-valley soils. Based on reference soils average pH (pH 8.15±1.1) and local geological, hydrogeological and soil properties, the following risk classes were created:

pH 8≥ negligible risk
pH 8–8.5 small risk
pH 8.5 threshold of moderate risk
pH 8.5–9.0 moderate risk
pH 9 threshold of significant risk
pH 9< significant risk

Field samples after red mud removal gave an average of pH 8.00±1.0, representing negligible risk. Incorporating the red mud into a 50 cm deep soil resulted in a pH 8.8±0.5, representing moderate risk. Revegetation of the remedied soils further lowered the pH with a value of 1.7 in laboratory pot experiments. Plant growth is inhibited by pH above 9.5. Incorporation of 10% red mud is at the boundary of the acceptable risk, resulting in an alkalinity of pH 9.

High Na-concentration in the soil increases the risk of sodification. A group of professionals created Na-concentration ranges and assigned risk levels to be able to make decisions on removal or incorporation of red mud in soil or the application of other agrotechnologies (e.g. construction of a drainage system) or additives. The starting point of the experts was the average Na-content of 200–300 mg/kg of the floodplain of the Torna Creek. The recommended site specific screening value is: 900 mg/kg with the notification, that whenever Na-concentration is above 900 mg/kg, the sodification potential should be evaluated and the Na-concentrations and forms are to be monitored.

Attenuation of the Na-concentration is significant in the catchment area, due to the groundwater flow. Based on three months measured data the attenuation factors are 0.8 for only red mud; 3.5 for the upper and 2.0 for the deeper soil layer. As an outcome of these findings we estimated a Na^+ half-life time to be three months in the contaminated soils and used this attenuation factor for Na-exposure estimations.

Risk quantification of Na in soil is summarized in Table 3. Removal of the red mud results in an acceptable situation: in spite of elevated Na-levels, the soil is usable for cultivation. Incorporation of 5% red mud may go down to the acceptable limit, assuming a similar attenuation rate than the measured. 10% incorporation is at the borderline of suitability. Validation of the estimated attenuation is necessary by long-term monitoring.

Table 3 Soils Na-content (mg/kg), its predicted attenuation and the risk of sodification

Red mud / scenario	Na 7 months	RCR 7 months	Verbal risk characterization	7 month after removal
Red mud on soil	**3100**	**RCR_{Na}=3.4**	High	Not acceptable, remove
Removal from soil	*200*	RCR_{Na}=0.1	Negligible	Unlimited use
Incorporation 5%	*420*	RCR_{Na}=0.2	Moderate	Unlimited use
Incorporation 10%	*800*	RCR_{Na}=0.8	Moderate	Usable
Incorporation 10% low attenuation	**1600**	**RCR_{Na}=1.6**	Significant	Use specific plants, apply monitoring and control
Deposition of red mud with soil	**15 000**	**RCR_{Na}=15**	Very high	Isolate by vegetation, if plants are able to grow
Deposition of RM	**38 600**	**RCR_{Na}=40**	Very high	Encapsulate

measured value **estimated value** **above screening value** *below screening value*

2.5 Evaluation of the toxic metal content of red mud flooded soils

The toxic metal content of the overflowed red mud is under the screening values for sewage sludge application on soil. On the other hand "alkalic digestion" of the soil (its rather long soaking in NaOH solution) may mobilize some metallic anions such as arsenate, selenate, nickelate, chromate, vanadate or molibdenate both from the soil.

The applied risk assessment approaches are: comparing the soils measured metal content to the Hungarian soil screening criteria and to the criteria for sewage sludge disposable on soil. The ratio of the measured concentration and the screening concentration is the RCR_{metal}.

Table 4 gives the average metal contents of 9 different red mud samples from the area. They contain As, Cd, Co, Cr and Ni in concentrations above the Hungarian soil screening levels, but all are lower than the criteria for sewage sludge application on soil.

Table 4 Metal content of the red mud, soil and sewage sludge screening concentrations

Metal (mg/kg)	As	B	Ba	Cd	Co	Cr	Cu	Hg	Mo	Na	Ni	Pb	Se	Sn	Zn
Red mud average	36.5	22.6	80.1	1.3	47.2	419	38.5	0.5	0.2	38 600	182	84.8	kh	25.2	105
Sewage sludge SC*	75	-	-	10	-	1000	-	10	-	-	200	750	-	-	2500
Soil SC**	15	-	250	1.0	30	75	75	0.5	7	-	40	100	1	30	200

Regulations: *50/2001 **10/2000 SC = Screening Concentration

higher than soil SC but under sewage sludge SC slightly higher than soil CS under soil SC

Metal concentration in red mud flooded soils – field data

The average metal content of reference and flooded soils, – except selenium (Se) – were under the soils' screening concentration. The deviations of As and Ni concentrations were high, but not in correlation with the red mud flood. A site specific limit value of 25 mg/kg was recommended for As. Se is present in the whole area in a concentration higher than 1 mg/kg, the Hungarian screening value, but under the European 3 mg/kg, which was recommended as a site specific limit value by the experts.

The estimated metal content of soils incorporating 5% and 10% red mud and the calculated risk does not pose unacceptable risk to the soils except the case of Na for sodification. Considering the foreseen attenuation, 5% red mud incorporation has a good chance for developing healthy soil conditions, 10% is at the borderline of acceptability.

In summary the risks of the four metals – As, Cr, Ni and Se – most likely to exceed the Hungarian soil screening concentration were calculated for the contaminated soil and the alternative risk reduction scenarios and shown in Table 5. Site specific screening value of 25 mg/kg for As and 3 mg/kg for Se were applied.

Table 5 Risk summary posed by toxic metal contamination on soil

Scenario	As mg/kg	Cr mg/kg	Ni mg/kg	Se mg/kg	RCR_{As}	RCR_{Cr}	RCR_{Ni}	RCR_{Se}	Verbal characteriz	Action required
Soil SC	25	75	40	3						
Sewage sludge SC	75	1000	200	-						
Reference soil	11	29	18	1,8	0,44	0,39	0,45	0,6	Small	No action
RM on top*	38	420	180	not det.	**1,5**	**5,6**	**4,5**	0	Significant	Remove RM or mix in soil
RM mixed in**					0,5	0,4	0,9	0	Moderate	
Removal of RM	14,8	31	25	1,6	0,6	0,4	0,6	0,5	Moderate	Unlimited use
5% RM	9,8	38	19	1,2	0,6	0,5	0,5	0,4	Moderate	Unlimited use
10% RM	11,5	58	29	1,2	0,8	0,8	0,7	0,4	Moderate	Unlimited use
Soil:RM = 2:1	20	157	66	1	0,8	**2,1**	**1,6**	0,3	Significant	Lmtd plant use
Soil:RM = 2:1	25	225	100	0,6	1	**3**	**2,5**	0,2	Significant	Lmtd plant use encapsulation

*considered as soil; **considered as sewage sludge; **above soil SC**

2.6 Direct toxicity testing of red mud in soil

Artificial mixtures of red mud and soil were tested in microcosms for microbial, plant and animal toxicity. From the results we defined the red mud concentration, which causes 10%, 20% and 50% inhibition in growth or survival of the testorganisms (Table 6). 10% adverse effect (inhibition) can be considered as the lower threshold of having an effect at all and 20% inhibition as significant.

Table 6 Inhibitory effect of red mud on soil ecosystem members

Test	% red mud in soil causing 10% inhibition	% red mud in soil causing 20% inhibition	% red mud in soil causing 50% inhibition
Soil microorganisms	30	35	40
Seed germination	13	18	25
Plant shoot growth	5	8	18
Plant root growth	6	8	15
Collembolan lethality	15	20	25

The red mud percentages in soil, having direct effect on microorganisms, plant germination and soil living animals are 35%, 18% and 20%. Plant growth maybe inhibited by 8% red mud in the soil, by the accumulated result of direct inhibition by alkalinity, soil texture changes, and the decreased availability of cationic plant nutrients, such as K^+, Ca^{2+}, Mg^{2+}, etc due to high pH value.

3 SUMMARY OF THE RISK ASSESSMENT OF RED MUD FLOODED SOILS

The aim of the detailed assessment in the Torna-valley is to identify the most risky contaminants and processes endangering agricultural land as well as the interventions reducing their risk. Besides the water of the catchment, a large surface area is impacted by the red mud, more than 1000 ha agricultural land was covered by a 5–20 cm thick desiccated red mud layer. The soil beneath became saturated with NaOH solution and the soil pores were clogged with red mud resulting temporary anoxic conditions.

The information and knowledge about this situation was too few to be able to make responsible decisions on how to reduce the risk, so that a detailed risk assessment was carried out.

Summarizing the risk of the red mud on agricultural soil, the main risks derive from the presence of Na and alkalinity. Na-content of the soils – even in soils set free from red-mud – is significantly higher than the reference. 5% red mud incorporation is likely acceptable, but 10% is requiring further treatment and amendments. Microcosm tests and field assessments indicated that there is chance for long term attenuation of Na due to its mobility and the high groundwater flow rate.

Other, initially suspected hazards, such as dusting and toxic metals concentrations proved not to reach a significant level. The mobilization of the natural Se and As-content of the soils is not considered as a level of risk needing intervention or restrictions.

The first results show that microorganisms, soil dwelling animals and certain plants significantly tolerate red mud concentration.

The uncertainty in the judgment of the risk is high, because there are no screening levels set, the "no risk" situation is very much site specific, depending on other characteristics of the soil and the area.

As a result of the risk assessment the area designated for red mud removal could be well identified and the cleaning works had been implemented and finished.

The validation of the risk estimates by measurements and monitoring are extremely important in the Ajka case, since most of the risks are the results of long-term processes.

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