Introduction and objectives

The site of Gyöngyösörszö (Hungary) is heavily polluted with toxic metals, such as Zn, Pb, Cd, Cu and As, due to former mining activity in the area. The remediation strategy applied is to apply combined chemical and phytostabilisation on the disturbed pollution sources and the residual pollution, that remains after removal of the point sources. The toxic metals remain in the soil, but their chemical form, mobility, bioavailability, and as a result of these, their risk is drastically reduced. To select the most suitable combination of chemical stabilisers and plants several experiments were performed from laboratory to field scale: laboratory microcosms, pilot lysimeters and field plots. In the microcosms we tested 12 chemical stabilisers, while in lysimeters and field experiments we applied also plants. The most promising stabilising agents were fly-ash and lime which were applied on the field.

The stabilising effect of fly ashes and their mixture with lime was studied in constructed field plots. Lime addition was necessary because of the strongly acidic character of the waste. The water collection from the plots allowed us to predict the stabilising action of the stabilisers. The complex processes going on in the soils were monitored on long term (1 to 2 years), by combined physico-chemical analysis with biological and ecotoxicity testing.

Microcosms experiments

Long-term microcosms experiments were performed in laboratory for the characterisation of the effect of the different stabilising agents. Chemical analyses and rapid bioaccumulation of plants showed the best one:

1. alkaline fly ash (type 'A' and 'B'),
2. hydrated lime,
3. mixture of non-alkaline fly ash 'T' and lime,
4. mixture of non-alkaline fly ash 'V' and lime.

However, the phytoaccumulation of the soils only decreased effectively in the case of the alkaline fly ashes, which is very important from the point of view of the land rehabilitation. Therefore this stabilisation method is an effective tool in reducing metal mobility and the risk of metals to surface and subsurface waters and living organisms in the contaminated area of the former lead and zinc mine in Hungary.

Amendments

- Tested at all scales (mixed into the soil): fly ashes (No. 5) and their combination with lime (in lysimeters alkaline fly ash was also tested as reactive barrier).
- Tested only in microcosms: alkaline, hydrated lime, raw phosphate, lignite, Fe-Mn-hydroxide precipitate from drinking water cleaning (No. 3 and 5), mud from ballast processing (No. 4).

Plants

Grass mixture, Sorghum vulgare, Sorghum sudanese, Zea mays

Characteristics of the soil and waste

Agricultural soil (No. 1) and mine waste (No. 2) — total metal contents: As 60–333 mg/kg, Cd 4–23 mg/kg, Cu 170–479 mg/kg, Pb 956–1680 mg/kg, Zn 925–4420 mg/kg. According to the different extractions 26–24% of Cd and 23–24% of Zn are in mobile form (in acetate extract) compared to total metal content and 7–13% of Cd and 6–11% of Zn are water soluble.

Field scale:

Stabilisation of an intensively weathered acidic waste-rock with fly ash and lime

The stabilisation effect of fly ashes and their mixture with lime was studied in constructed field plots. Lime addition was necessary because of the strongly acidic character of the waste. The water collection from the plots allows us to predict the risk connected to the transport of toxic metals by water (e.g. the infiltrated precipitants). The combination of fly ashes and lime was highly efficient in reducing the mobile metal content and the toxicity of the waste and a healthy vegetation was developed on the treated plots. The metal content of plants grown on the field plots was under or close to the limit value for food and fodder.

Lysimeters: Stabilisation with fly ash

The stabilisation of soil was monitored in lysimeters. The short term results (3 months) of drain water from mine waste and agricultural soil showed that both alkaline and non-alkaline fly ashes are effective in reducing mobility of Cd and Zn and the phytotoxicity of the drain water. The fly ash applied as a reactive barrier gave similar results to the mixed form.

Field scale: Stabilisation of agricultural soil with fly ash

In this field experiment agricultural soil (pH=6.8) contaminated with metal containing river sediment was treated with the non-alkaline fly ash 'T'. The other half of the area was left untreated and used as a control. The soil and water extractable metal content of the plants applied for phytostabilisation decreased by 80–92% due to the treatment. In the treated area higher biological activity was measured in the soil and the toxicity decreased with 25–30%.

Conclusions

Combined chemical and phytostabilisation is an effective technology for the risk reduction of toxic metal polluted soil and waste. The unvegetated, barren, diffusely polluted surface of the former mining site became a suitable habitat for plants and as a result the quality of runoff and infiltrated waters improved. The best chemical stabiliser, which could be used in combination with phytostabilisation on the metal polluted site was selected after microcosms and lysimeter experiments. The alkaline fly ash showed the best immobilising effect on the acidic mine waste on long term (2 years), but the non alkaline one mixture with lime gave similar results. One single treatment with 5 wt% fly ash reduced the acute toxic extractable metal content by 45–49% and the water solubility part by more than 99%. Soil toxicity and bioaccumulation decreased by 70% and the Zn and Cd in the drain water of the field plots decreased from 96–98% and the phytotoxicity of the soil diminished to 25%. The non-alkaline fly ash without lime was inefficient in reducing the water and water extractable Zn and Cd amount in contaminated agricultural soil by 92–99% and the plants grown on the area accumulated 70–98% of Zn and Cd. According to the results from both experiments the fly ash treatment combined with phytostabilisation is an effective tool in reducing metal mobility and the risk of metals to surface and subsurface waters and living organisms in the contaminated area of the former lead and zinc mine in Hungary.

Monitoring by an integrated methodology

The complex processes going on in the soils were monitored on long term (1 to 2 years), by combined physico-chemical analysis with biological and ecotoxicity testing.

Chemical analysis

- Soil water- and ammonium-acetate (pH=4.5) extractable and total metal content (Aqua Regia digestion).
- Plant nitric acid + hydrochloric acid (1:1) digestion.
- The metal content of these different soil extracts and the pore water was determined by ICP-AES.

Toxicity testing and bioaccumulation

In order to assess the actual risk of the treated soil toxicities measurements were also used. Therefore the combined toxicity testing was performed by specific ecotoxicity and bioaccumulation testing: Vibrio fischeri luminiscence inhibition test, Azomonas agilis dehydrogenase enzyme activity inhibition test, Sinapis alba (white mustard) root and shoot growth inhibition test, Five days bioaccumulation test with Sinapis alba.

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Combined chemical and phytostabilisation of metal polluted soils – From microcosms to field experiments

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Microcosms experiments

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