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Environmental Risk Management of an Abandoned Mining Site in Hungary

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Abstract. An Environmental Risk Management methodology was developed for the Toka catchment area, an abandoned base metal mining site in Gyöngyösoroszi, Hungary. The postmining activities on the Hungarian site require the management of both the point and diffuse sources. The mobile Cd and Zn content of the mine waste, soil and sediment transported by water pose the highest environmental risk in the area. The approach is „GIS based" (Geographical Information System) and „catchment scale", using a three tiered, iterative Environmental Risk Assessment methodology. The model parameters of the metal transport were determined in leaching microcosms. The risk reduction concept aims at reducing the runoff water quantity and contamination by removal of the point sources and chemical & phytostabilisation of the residual and diffuse pollution. The planning of the field application was based on the results of the stabilisation microcosms.

Introduction

The management of point and diffuse pollution of mining origin is a current issue in Europe [1]. Considerable effort is being invested to develop a general management methodology that could handle the existing situation, assess and compare potential problems on a cross-border and catchment basis. An Environmental Risk Management approach focussed on the risk of the metal content in the surface water was developed for the Toka creek catchment in Gyöngyösoroszi [2] an abandoned Pb and Zn sulphide ore mining area in Hungary, the Hungarian demonstration site of the Difpolmine EU Life Project [3]. The main environmental pressures in the Toka catchment are related to the mobile Cd and Zn content of the mine wastes, surrounding soils and sediments [4,5,6]. The toxic metals originate from the mined out sulphide ore veins hosted in Miocene age andesite rocks. 1–3 pH leachate is being produced around the waste rock heaps due to the complex chemical and biological oxidation of the pyrite containing material in contact with the rainwater and runoff. The mine had been abandoned for 20 years, but mine closure and remediation activities started only in 2005.

Objectives

The objective was to develop a GIS based and catchment scale Environmental Risk Management methodology in support of a risk based remediation approach. A tiered Environmental Risk Assessment method was employed whereby qualitative and quantitative characterization of the risk on the basis of hazardous emissions from point and diffuse sources is possible at catchment scale.

Concept

The Environmental Risk Management methodology is substantiated by an integrated conceptual risk model [6], that includes the point and diffuse sources, the transport routes and the land-use specific exposure routes and receptors.

According to the developed conceptual model the dominant risk is the metal content of the sources. The transport pathways are the surface runoff and the surface water network, therefore the most exposed receptors are the members of the water-ecosystem. The transport routes of the infil-

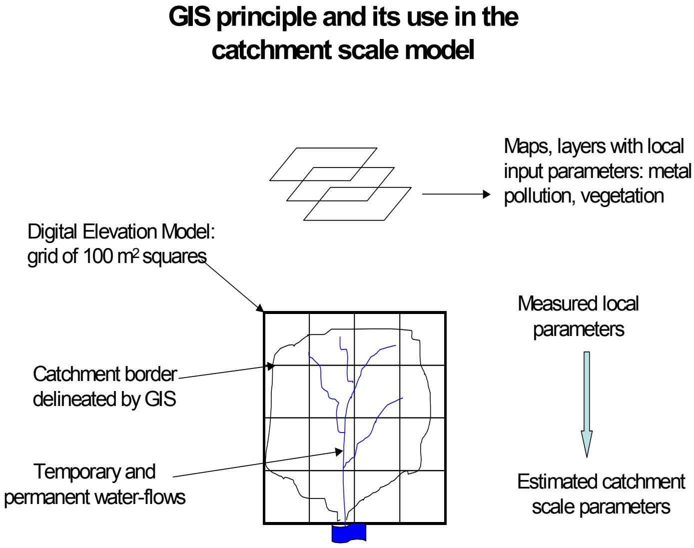

Figure 1 The GIS principle and its use

trated water cannot be followed, due to the depth of the underground water level. The Environmental Risk Assessment handles the risk at catchment scale basis with the support of the GIS. The GIS approach allows estimation of every pollution source (mine waste dump) within its individual water catchment and integrates the estimated local parameters at catchment scale (Fig. 1) [7].

Components of the methodology

The main components of the methodology are: the conceptual model at catchment scale and pollution source basis; GIS database including inventory of the pollution sources, laboratory microcosm test results and site assessment data; GIS work; three tiered iterative risk assessment; risk reduction planning with the aid of the quantitative risk model focusing on fulfilment of the effect based quality criteria targeted for the surface water ecosystem.

The conceptual model shows, that the risk posed by the contaminants leached out from the pollution sources is distributed amongst the surface waters, subsurface waters [8] and plant uptake [9]. The employed Environmental Risk Assessment was not focussed at this stage on the solid phase (sediment) transport by runoff but more on the mobile metal transport by surface runoff.

The GIS database includes: site-specific data and parameters taking into account the Water Balance of the area [10, 11], geological data [12], the results of the microcosm leaching experiment [13], the natural risk reduction capacity of the site, and the results of the chemical stabilisation microcosm experiment [14].

To produce the Water Balance the main water pathways were identified. Input of the catchment is the annual average rainfall based on the 20 years average (756 mm/year), the outflow of the catchment is the Toka creek, having an average flowrate of 2450 m^3/day. Given the topography (steep slopes), hydrogeology (high infiltration rate) and geology of the area and the site-specific processes due to the mineralogical composition of the ore, mine waste material and country rock (leaching, bioleaching, partition) the runoff water is the main pollution pathway in the conceptual risk model, and to a lesser extent the pore water.

The site-specific processes were modelled in soil microcosm experiments. Leaching of metals from pollution sources and the characteristic parameters of the process were given based on a complex (physical-chemical-biological) leaching test using the mine waste material from the area. Weathering of the sulphide ore containing waste rock and leaching coupled with microbiological sulphide oxidation, as well as the natural decontamination of the leachate by high sorption capacity forest soil was simulated in microcosms for three years. The quantity and quality (pH, As, Cd, Cu, Pb, Zn content) of the leachate was measured at regular time intervals. The key parameters of the risk were determined: the rate of acidification and metal mobilisation and the metal concentration of the emitted leachate. Three mine waste qualities were used to simulate the minimum, medium and maximum emission [13]. Total metal concentration of the typical mine wastes used in the bioleaching microcosm test and metal concentration of the microcosm leachates giving the estimated metal emission of the waste sources is shown in Table 1.

Because the risk reduction concept aims at reducing the runoff water quantity and contamination by chemical & phytostabilisation of the residual and diffuse pollution, immobilisation/stabilisation of contaminants in soil was modelled in microcosms to determine the most efficient amendment to be added to the soil [14, 15, 16, 17].

Table 1. Total metal concentration and emission from typical Gyöngyösoroszi mine wastes

Metals	Total metal* (minimum) [mg/kg]	Total metal* (medium) [mg/kg]	Total metal* (maximum) [mg/kg]	Minimum emission [µg/lit]	Average emission [µg/lit]	Maximum emission [µg/lit]
As	44	100	216	150	340	700
Cd	1	3	12	100	300	1 200
Cu	25	50	107	400	800	4 710
Pb	295	600	13 100	100	203	3 600
Zn	370	800	2 155	25 000	54 135	163 000

- aqua regia extract ICP-MS

The contaminated soil from the mining site was treated with 1w%, 2w% and 5w% flyash in microcosms. The efficiency of the stabilisation process was characterised by the mobile metal content of the water- and different acidic extracts of the treated soil [14]. The microcosm experiments demonstrated that 2% and 5% fly ash addition to the polluted soil resulted 66–100% reduction in the Zn and Cd content of the water extract of the soil after 3 weeks and 94–100% after 4 months chemical stabilisation. The experiments showed that the metal mobility decrease persisted even after 2 year.

In the GIS work TIN-based (Triangulated Irregular Network) DTM (Digital Terrain Model) was derived from the contour line data, consisting of more than 250 000 triangles, using ArcView3.1 3D Analyst [18]. The TIN model was transformed into a 10 meters GRID (Fig 1). The 10 meters resolution satisfied the 14 km long study area. Several GIS layers were created from DTM: slope, aspect, flow directions, creek network, watershed and sub watersheds.

Three tiered iterative risk assessment methodology is based on the integrated risk model of the catchment, and includes three levels of risk assessment: ***1. Qualitative Risk*** Assessment for initial hazard identification and rough ranking based on risk score, ***2. GIS-based Quantitative Hazard*** (Generic Risk) Assessment resulting refined ranking according to the emission of the sources, subareas or the total water catchment. The surface area of the waste dump and the topography around the pollution source determine the size of the watershed of every individual waste dump, and therefore the water volume likely to run through it from upstream (indirect flow) and directly on its surface (direct precipitation). As shown in Figure 2 the GIS based calculations were done on 100 m^2 grid units per catchment and the temporal scale was not considered in the model. The accumulated flow is based on the flow directions grid, which considers the upslope cells (Fig. 2). The analysed toxic metal emissions (Table 1) in the leachates of the leaching microcosm test were used to calculate at catchment scale the yearly emitted metal amount from the point, diffuse and the residual pollution sources, taking into account the GIS runoff model (Fig 2) and the annual average precipitation. The calculated emitted metal amounts are the basis of determining the hazard of point and diffuse pollution sources. The risk assessment considered the average and maximum metal emission values (Table 1) from the leaching microcosm experiments. **3.** ***The Quantitative Risk*** of the Toka catchment is characterized by the risk quotient RQ = PEC/PNEC, where PEC is the Predicted Environmental Concentration, estimated from the measured water and sediment concentration in the Toka creek (As: 50 µg/l; Cd: 2 µg/l; Pb: 30 µg/l; Zn: 800 µg/l) and PNEC is the Predicted No Effect Concentration, determined as an effect based target concentration (EBQC) from measured toxicity, literature and regulatory data [19, 20, 21]. EBQC for Toka creek is: As: 10 µg/l; Cd: 1 µg/l; Pb: 10 µg/l; Zn: 100 µg/l. Given that in the catchment RQ>1 for all metals, the target of risk reduction is to reach RQ≤1.

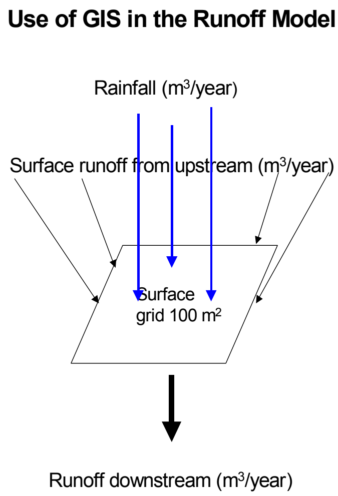

Figure 2 GIS Flow Accumulation

Risk reduction planning aims at reducing the PEC to the PNEC, namely the estimated concentration to the targeted concentration in the Toka water. In planning the risk reduction scale a generic catchment scale parameter, the Natural Risk Reduction Capacity (NRRC), as well as the efficiencies of the remediation by chemical stabilisation were taken into account. The NRRC of the site is a conservative estimate comparing the minimum heavy metal emissions of the leachate: As: 150 µg/l; Cd: 100 µg/l; Pb: 100 µg/l; Zn: 25 000 µg/l (Table 1) with the metal concentration in the surface water: As: 50 µg/l; Cd: 2 µg/l; Pb: 30 µg/l; Zn: 800 µg/l. The NRRC of As: 1/3; Cd: 1/50; Pb: 1/3.4 Zn: 1/30 were used. The NRRC alone cannot reduce the pollutant concentration to the target EBQC of As: 10 µg/l; Cd: 1 µg/l; Pb: 10 µg/l; Zn: 100 µg/l. Further decrease of the pollutant flux is achieved by chemical stabilisation of the pollutants in the soil. According to the microcosm experiments, 5w% fly ash addition to the polluted soil resulted 99% reduction in the dissolvable Zn and Cd content of the soil and 33% and 50% reduction in the dissolvable As and Pb, respectively. The joint effect of chemical stabilisation and the NRRC of the site are enough to reduce Cd and Zn emission to the EBQC even in case of the most polluted waste of the following emission: As: 700 µg/l; Cd: 1 200µg/l; Pb: 3 000 µg/l; Zn: 163 000 µg/l (Table 1). To reduce Pb and As concentrations to the targeted EBQC the joint effect of NRRC and chemical stabilisation is not enough in case of a maximum emission scenario, but the additional phytostabilisation is able to mitigate risk by reducing solid erosion. The effect of phytostabilisation is estimated from the results of the ongoing field experiments.

Conclusions

The work was focused on the two main aspects of Environmental Risk Management: Environmental Risk Assessment and Risk Reduction, demonstrated on an abandoned sulphide ore mining site in Hungary. Since the introduced Environmental Risk Management methodology is GIS based, tiered, iterative and PEC/PNEC based, it can be used also in case of incomplete datasets. The concept enables calculation not only of the relative and absolute risk values but also forecasting the results of the selected risk reduction measures, the effect of point source removal and of the effect of emission reduction of diffuse sources by the combined chemical- and phytostabilisation. The model can be further refined with additional data input, assuming various water uses and considering the solid transport. The scale can be extended from the point/diffuse source scale to water catchment or regional scale.

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