GIS-BASED CATCHMENT SCALE MODELLING OF TOXIC METAL TRANSPORT BY EROSION

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Abstract

Erosion through water was studied in the 1062 ha Northern catchment area of the Toka creek, within an abandoned base metal mining site in Gyöngyösoroszi, Hungary. The rainfall and runoff produced erosion of the non-vegetated toxic metal sulphide containing mine waste dump surfaces pose the highest threat on water and soil quality in the area. The runoff delivered water soluble and the eroded solid phase related toxic element (As, Cd, Cu, Pb, Zn) emission was estimated by GIS-based Flow Accumulation and erosion modelling. The solid phase related yearly As and Pb emission was predicted by the GRASS GIS erosion model. According to the GRASS GIS erosion model As and Pb emission due to average and heavy rain induced erosion of minimum and maximum concentration mine waste is higher than the Cd and Zn emission dominating in the water phase. The necessary emission reduction was planned to be achieved by combined chemical and phytoremediation (CCP). The erosion mitigation effect of CCP in the 0.5 ha mine waste dump area was studied with the GRASS GIS model in case of minimum and maximum concentration mine waste, assuming average (A) and heavy (B) rain events.

Location

Fig 1 Location of Gyöngyösoroszi in Hungary

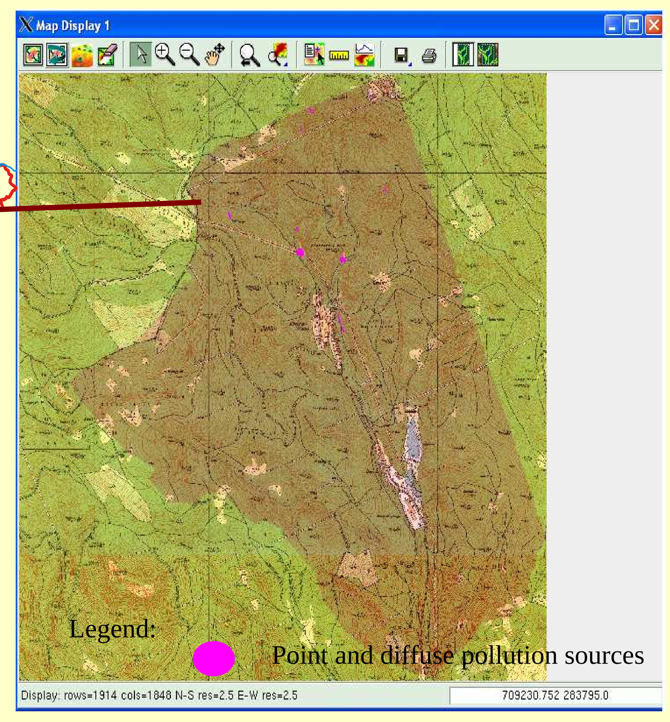

Fig 2 Toka N. watershed and mine waste dumps

The studied area is located in NE Hungary, in the Northern catchment of the Toka creek, 90 km from Budapest (Fig 1), in the vicinity of the Natural Park of the Mátra hills, between the 708342,279010–712955,283778 EOV coordinates. Elevations range from 800–320 m b.s.l., the terrain has steep slope (Fig 3), climatic conditions are typically of temperate continental character. The reminisces of historical mining are dispersed in the area (Fig 2).

Topography of the terrain

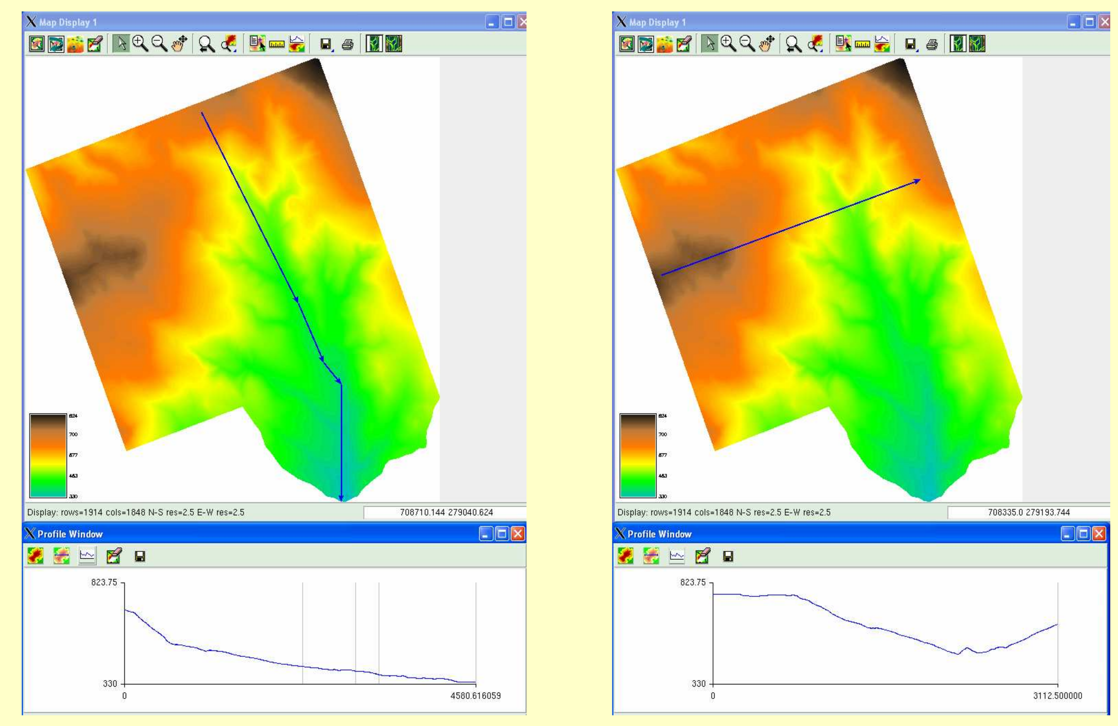

Fig 3 Longitudinal and cross section of the Toka watershed

GIS based soil erosion modelling

Erosion modelling was done with the GRASS 5.4 (http://www.grass.itc.it) software. The model is based on the Revised Universal Soil Loss Equation (RUSLE). Average annual soil erosion rates (A) in (t/ha/yr) were assessed by multiplying 6 different factors: rainfall erosivity factor (R), a soil erodibility factor (K), a topographic factor (LS), land cover and land use factor (C) and soil protection factor (P): $A = R*K*L*S*C*P$. The "P" factor in this study is assumed to be 1.0, meaning that there is no erosion protection in the area. These factors were assessed at 2.5 m resolution using 20 years average rainfall data, CORINE Land Cover data (Fig 5), flow direction, slope and Flow Accumulation map developed from the Digital Terrain Model (DTM) (Fig 4). The reclassified CORINE map (Fig 5) of the 1062 ha Northern catchment shows the three main land cover categories: forests (yellow coloured), mine waste dumps (red coloured), residential area (green coloured). Two cases were discussed: 1) „A": the erosivity of the average intensity annual rain, 2) „B": the erosivity of the high intensity annual rain.

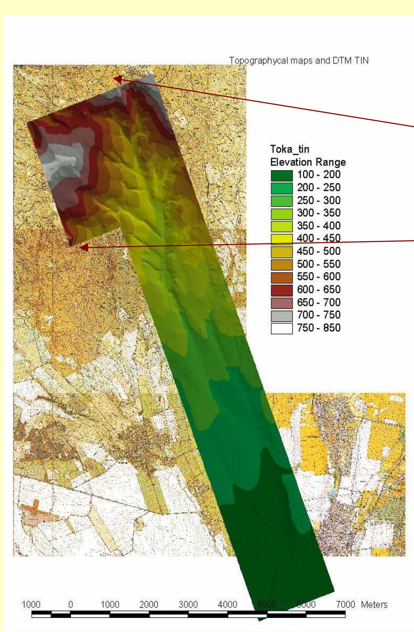

Fig 4 Digital Terrain Model

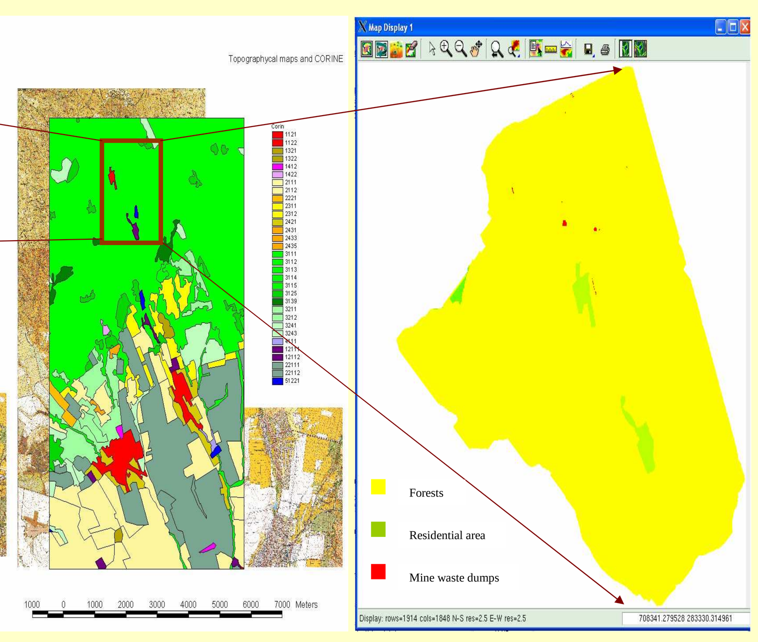

Fig 5 CORINE landcover map and reclassified map

The erosion calculation parameters for the studied cases are summarised in Table 1 below. The erosion map was produced based on the quantitative output ranges (Fig 6). According to Fig 6 the very high erosion class is represented by the nonvegetated mine waste dump areas (red coloured).

Table 1 Erosion parameters in case A and B

Rain intensity	Annual average rain [mm/year]	24 hours rainfall with a recurrence of 2 years [cm/24 hours]	1 hours rainfall with recurrence of 2 years [cm/hour]	Soil erodibility K [–]
A (average)	756	7.4	0.18	0.12 and 0.23
B (high)	756	10.5	0.53	0.12 and 0.23

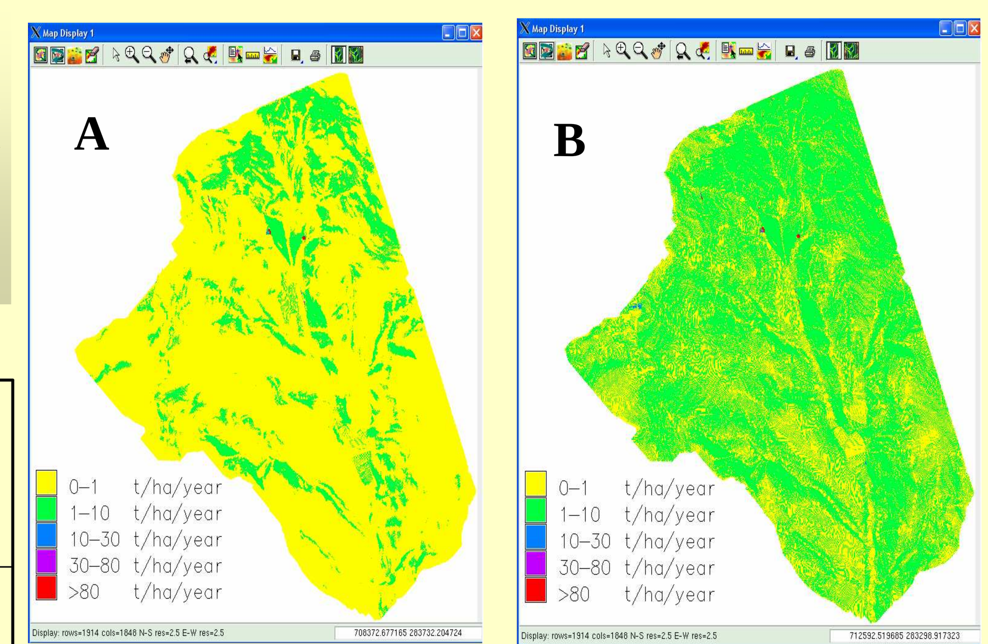

Fig 6 Potential erosion classes in case A and B

Results and Discussion

The average annual solid material loss and total erosion were calculated for the Northern catchment of Toka creek and for the identified mine waste dumps within the watershed. The erosion results were classified in 5 classes. Table 2 shows the areas within the Toka watershed relevant to the GRASS GIS erosion classes (Fig 6) and gives the % distribution of each area compared to the total Northern Toka watershed (1 062ha). The relatively small area in the very high erosion class is identical with the area of the mine waste dumps.

Table 2 Areas and erosion classes in the N. Toka watershed in case A and B

Erosion class	Ranges t/ha/year	Area (ha) case A	% Area case A	Area (ha) case B	% Area case B
0 very low	0–	882.968750	83	379.405625	35
1 low	1–10	178.417500	16	681.669375	64
2 moderate	10–30	0.078125	0.007	0.311250	0.29
3 high	30–80	0.080000	0.0075	0.078125	0.0073
4 very high	>80	0.182500	0.017	0.262500	0.024
Total		1062	100	1062	100

The mine waste dumps area is only 0.5% of the Northern catchment of the Toka creek, however it produces 14% of the total erosion (Table 3, 4). According to the model only the waste dumps belong to the maximum erosion category. The mine waste dumps produce 150 times more solid loss (t/ha/year) in the minimum solid loss range while within the average range 300 times more than the total Northern watershed. The solid loss in case of the very high erosion category areas, represented by the mine waste dumps, is identical with the solid material loss of the total Northern Toka watershed. Maximum concentration mine waste dump areas emit by yearly erosion 4.5 times more As, 2.6 times more Cd, 7.0 times more Pb and 2.7 times more Zn, than the Toka Northern watershed forest soil (less mine waste dumps). The heavy rain produced yearly erosion (B) results three times the metal emission of the average rain. Having identified the eroded material source, the Grass GIS model enabled also the estimation of the necessary risk reduction scale by the selected CCP remediation technology. The targeted mitigated toxic metal (As, Cd, Pb, Zn) emission related to the eroded solid phase was based on the assumption that the erosion of the mine waste dump area is reduced to the erosion level of the vegetated surface of the local forest area.

Table 3 Erosion of the waste dumps compared to the total N. Toka watershed (A)

A case: average rain	Total Northern watershed	Mine waste dumps	Ratio of mine waste dumps %
Total erosion t/year	337	47	14%
Cell numbers	1698763	773	0.5%
Area ha	1 062	0.5	0.5%
Minimum t/ha/year	0.006	0.9	15 000%
Maximum t/ha/year	348	348	100%
Standard deviations	3.2	111	
Average t/ha/year	0.3	97	30 000%

Conclusions

According to the GRASS GIS model the mine waste dump area in the Northern catchment of Toka creek is the land use category exposed to the highest erosion through water. Although the mine waste dump area is only 0.5% (0.5 ha) of the Northern Toka catchment area, it results 14% of the erosion. The modelled yearly erosion rate enabled calculation of the yearly metal emission for Environmental Hazard Assessment.

Table 4 Erosion of the dumps compared to the total N. Toka watershed (B)

B case: heavy rain	Total Northern watershed	Mine waste dumps	Ratio of mine waste dumps %
Total erosion t/year	1053	147	14%
Cell numbers	1698763	773	0.5%
Area ha	1062	0.5	0.5%
Minimum t/ha/year	0.02	2.8	14 000%
Maximum t/ha/year	1088	1088	100%
Standard deviations	9.9	348	
Average t/ha/year	1	304	30 400%

The metal emission of the 0.5 ha mine waste dump area is several times higher than of the 1061.5 ha forest soil. 99.7% reduction of the solid phase related metal emission due to erosion is the target to be achieved by CCP. The mitigated emission targeted by the GRAS GIS model was validated in CCP field experiments (see poster E41).

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