Scoring based Risk Assessment in an abandoned base metal sulphide mining area

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Abstract

To characterise the environmental risk of the Gyöngyösoroszi abandoned base metal mining site in Hungary a tiered, iterative risk assessment methodology was developed and applied at catchment scale. The aim was to support environment- and cost-efficient decision-making for building up the risk-management strategy and for using it in the course of the complex rehabilitation of the site. The methodology includes: 1) a Preliminary Qualitative Risk Assessment to produce an inventory of the pollution sources, 2) a scoring based Semi-Quantitative Risk Assessment tool for initial hazard identification and rough ranking, 3) a GIS (Geographical Information System)-based Quantitative Hazard Assessment tool for refined ranking with the quantification of the hazard based on the emission of identified pollution sources, diffusely contaminated sub-areas and the whole catchment area, as well as 4) a site-specific Quantitative Risk Assessment tool for the calculation of the necessary Risk Reduction by remediation. This paper presents the site specific scoring based Semi-Quantitative Risk Assessment and its implementation and results. By applying the Semi-Quantitative Risk Assessment tool the risk potential of the site and subsites was assessed assigning scores to the sources, transport routes, target environmental compartments and the receptor ecosystems and humans. A number of 34 pollution sources were assessed, consisting of primary and secondary, point and diffuse sources. The results of the completed scoring based Semi-Quantitative Risk Asessment were refined by GIS aided Quantitative Hazard Assessment. The assessment showed that the most sensitive receptor at the site is the water ecosystem and the highest threat to water and soil in the area is caused by erosion due to rainfall/runoff of the non-vegetated/bare mine waste dump surfaces which contain toxic metal sulfides.. The findings of the scoring based Semi-quantitative Risk Assessment were used in the preliminary decision making during the Mine Closure and Remediation Project of the Gyöngyösoroszi area currently still in progress. The designed semi-quantitative Risk Assessment tool may have applicability to similar base-metal mines around the world.

Keywords: *environmental risk management, tiered risk assessment, Semi-Quantitative Risk Assessment, GIS based Quantitative Hazard Assessment, abandoned base metal mining site, runoff, erosion*

1. Introduction

Risk assessment (RA) tools are used to quantify potential exposure of a contaminant and to determine either generic environmental quality criteria (such as water or soil guideline values) or site specific quality criteria. In case of contaminated sites the selection of the proper risk assessment tool-box must be made on a site specific basis informed by the integrated risk model of the area/site. The risk model integrates transport and exposure models (Gruiz et al 2005, 2009).

Environmental Risk Assessment (ERA) is a systematic and iterative process that can be employed at various tiers of decision-making, whether it is policy, project or activity. It may be employed at early stages of decision-making to include readily available scientific and other information relevant to the strategy or policy initiative at hand (Cardenas, http://www.unep.or.jp /ietc). Most risk assessment protocols follow tiered approaches offering alternatives to make decisions based on a limited amount of information and possibilities for risk refinement. Risk assessments can be performed using various levels of sophistication depending on the amount and accuracy of data available (Gruiz 2006, Gruiz et al 2009, Vaszita et al 2009b).

Qualitative Risk Assessment means relative evaluation, its result is generally % or a score, valid only in the relevant system and it serves to rank the contaminated sites according to their risk potential and to form a basis for the decision if further action is required (CCME 1992).

The success of a qualitative risk assessment depends on: 1. the adequacy of the risk model, which identifies the sources, transport routes, the associated environmental compartments, land uses and receptors; 2. the adequacy of the information base and 3. the subjective judgements made in each step. The quality of the risk assessment, therefore, is dependent on the experience of the assessors (Van Zyl, 2007).

To improve the accuracy of the Qualitative Assessment tool and still use the advantage of the additivity of the scores, a Semi-Quantitative tool could be developed and applied for preliminary risk assessment and ranking. A site specific Semi-Quantitative Risk Assessment tool was developed and implemented in a water catchment area affected by mining at Gyöngyösoroszi, Hungary. The developed tool whenever possible refers to basic quantitative criteria when creating the score. The quantity based scoring makes the assessment much more precise, it allows ranking and it can serve as basis of decisions (Gruiz et al 2009).

The quantity based scoring was complemented by a model-based quantitative estimation of the amount of the emitted contaminant from point and diffuse sources (Vaszita 2009a). This Quantitative Hazard Assessment step made possible the differentiation between the high, medium and low risk sources in an abandoned Pb and Zn sulfide ore mine area in Gyöngyösoroszi, northern Hungary prior and during mine closure and complex rehabilitation of the area (Gruiz et al 1993, 2005, 2007a,b, 2009, Vaszita et al 2009b).

The work financed by EU and national projects (DIFPOLMINE, BANYAREM) included the identification of the pollution sources, transport pathways and receptors, risk characterisation by a tiered approach offering alternatives to make decisions based on a limited amount of information and possibilities for risk refinement, estimation of the target risk levels for remediation planning with the aid of GIS (Geographical Information System) modelling, microcosm tests to model site specific processes, microcosm and field experiments to assess the efficiency of the selected risk reduction alternatives (Feigl et al. 2009a, b, Gruiz et al. 2005, 2007a,b, 2009, Vaszita et al 2009a).

Risk characterisation in the Gyöngyösoroszi mining area included the following levels:

- Development of the risk model of the catchment, which integrates the transport and the exposure models (Gruiz et al 2005, 2007a,b, 2009).
- Preliminary Qualitative Risk Assessment for inventory of the sources (Gruiz, 2007, 2009).
- Semi-Quantitative Risk Assessment for ranking and for preliminary differentiation between sources (Gruiz, 2005, 2007a, 2009).
- GIS-based Quantitative Hazard Assessment for refined ranking and for quantification of the hazard based on the emission of pollution sources, sub-areas or catchment area and for preparing the decision on Risk Reduction (Gruiz, 2007a, 2009; Vaszita, 2009b).
- Quantitative Risk Assessment for the calculation of the necessary Risk Reduction by remediation. (Gruiz, 2007a, 2009; Vaszita, 2009b).

As part of the complex methodology this paper introduces the scoring based Semi-Quantitative Risk Assessment tool and its implementation at the Gyöngyösoroszi abandoned mining site in NE Hungary.

2. Site description

The studied Gyöngyösoroszi Pb and Zn mine area is located in Hungary, 90 km north-east from Budapest, near the town of Gyöngyös, in the vicinity of the Natural Park of the Mátra hills, between the 708342,279010–712955,283778 EOV (Hungarian Uniform Projection System) coordinates (FÖMI 2003). Elevations range from 150 to 824 meters (Figure 1).

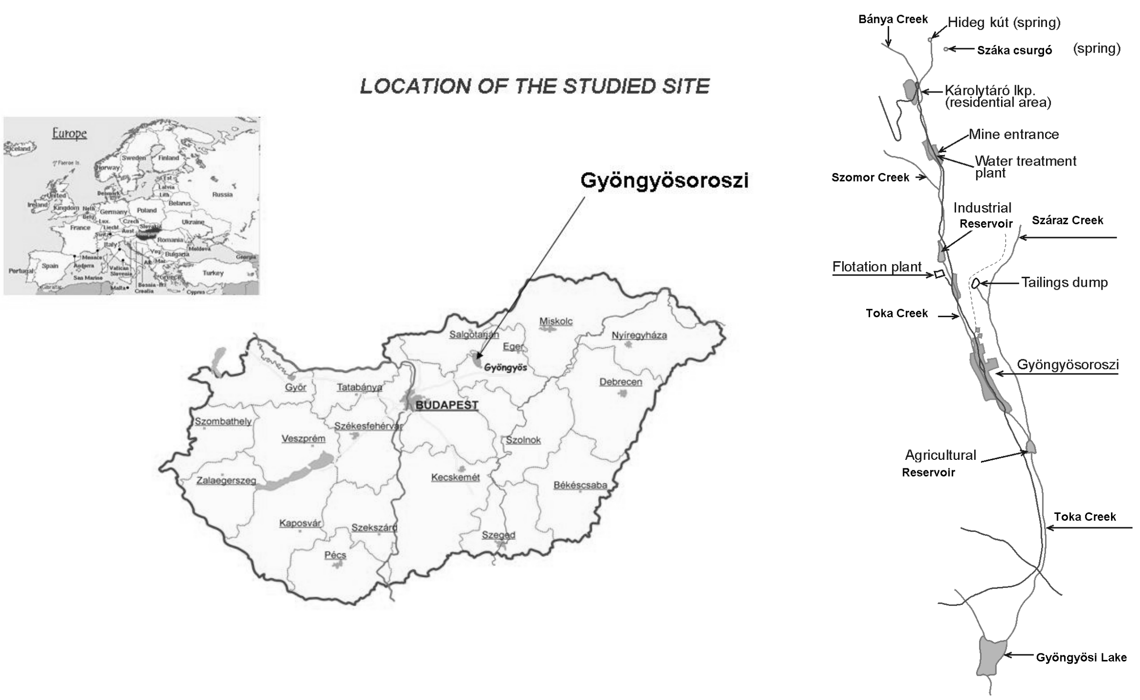

Figure 1 Location of Gyöngyösoroszi in Hungary and the scheme of the main mine objectives along the Toka Creek

The Toka catchment area in Gyöngyösoroszi covers 25 km^2 from the emerging spring area down to the inflow into the Gyöngyösi Lake (altitude 150m). The relatively small catchment area is very much diversified. The northern catchment extends along 10 km^2 and it locates the former mining area and its premises. The northern area is defined by volcanic features. Here the elevations range from 800–820 m b.s.l., the terrain has steep slope, the climatic conditions are typically of temperate continental character with a mean annual temperature of 10.3 ^{o}C and mean annual precipitation of 650–800 mm. The wettest periods of the year are the end of autumn and end of winter. Evaporation is important. According to the National Meteorological Service (OMSZ 2003) estimates more than 10% of the rainfall is lost by evapotranspiration. Geologically, the area includes andesite rocks of Miocene age hosting vein-type base metal sulfide mineralisation overlain by Tertiary formations (MÁFI 1975). Hydrogeologically, the northern catchment area is characterised mainly by cracks, faults in the andesite rock formations resulting in high infiltration rates, while the permeability of the clayey tertiary formation is medium. The main stream, Toka collects the waters of small seasonal creeks. The streams flood at winter snowmelt and during summer rainstorms. Otherwise they have dry beds in summer. The northern watershed covers 10 km^2 from altitude 450 m to altitude 750 m. The average slope in the northern catchment is 13 %, the maximum slope is 43 % and the average slope for the total Toka catchment area is 11 % (Gruiz et al 2007a). Historical mining for gold started in the area as early as in the Middle Ages and underground mining of the lead and zinc bearing vein type mineralisation intensified during the last century and was suspended in 1986 (Kun 1985). Mine waste dumps of various ages were left over at the exit of the exploration and access adits within the studied abandoned mining area. The bare surface of the waste dumps is prone to erosion. Acidic (pH = 1–3) leachate is being produced within the waste rock heaps due to the complex chemical and biological oxidation of the pyrite containing material in contact with rainwater and runoff water. The acidic leachate delivers As, Cd, Pb, Zn in various chemical forms to the surroundings, polluting soil and the surface water system. The mine was abandoned in 1985 but mine closure and remediation activities started only in 2005 and have been in progress since then. The mined base metal ore was milled and processed in the local flotation plant. The flotation tailings were discharged into a tailings pond from 1955. Acid mine water exiting via the main adit has been treated by lime from 1985. The sludge was settled in 3 storage ponds and the treated water discharged into the Toka Creek. The treated mine drainage provides the main volume of the central surface water flow of the Toka Creek. Springs, temporary water flows and runoff waters create the surface water system upstream the main mine entrance. Downstream the mine they join the treated mine water discharged from the acid mine water treatment plant. The toxic metal content ranges and the pH of the Toka Creek water upstream and downstream the mine water treatment facility measured at various times is given in Table 1 (Gruiz et al 2005).

Table 1 Toka Creek water upstream and downstream of the acidic mine-water treatment plant

Location Year Metal	MU	**EQC-HU***	**PNEC****		Toka Creek upstream of the AMD treatment plant 2004	Toka Creek water (downstream of the AMD[#] treatment plant)			
			for sensitive aquatic ecosystem	for not sensitive aquatic ecosystem		1991	1992	2004	2005
As	µg/lit	25	3	10	2.9	40	no data	2–112	7–50
Cd	µg/lit	5	0.3	1	0.5	30–50	5–16	1–5	0.5–4
Pb	µg/lit	10	2	10	28.0	30	6–55	1–120	4–105
Zn	mg/lit	0.2	0.02	0.1	1.62	9–14	0.5–6	0.1–1.6	0.3–1.65
pH	–				4.4	2.0–5.0	2.6–5.0	5.0	5.0

**EQC-HU: Hungarian Environmental Quality Criteria for subsurface water*
***PNEC: Predicted No Effect Concentration: site specific limit values for the water ecosystem*
[#] *AMD: Acid Mine Drainage*

From North to South the mining operation included the following facilities (Figure 1): various historical mine workings whose remnants (mine waste dumps) are to be found dispersed in the forest North of the mine entrance, acidic mine water treatment plant at the main mine entrance and the sedimentation ponds/reservoirs associated with it, the ore transportation route from the mine entrance to the flotation plant, the industrial reservoir which supplied water to the ore processing plant, the flotation plant, the tailings pond.

Table 2 below shows the average metal concentrations of the typical mine waste material and soil in the Northern Toka catchment area based on a number of 1 200 XRF in situ measurement points (Gruiz et al 2005, 2007a, 2009, Tolner et al 2009). The average of the low and high metal concentration mine wastes typical for the area are given separately.

Table 2 Total metal concentration of the mine waste and soil in the Toka catchment

Mine waste and soil	**Total metal concentration**** (XRF* in situ measurements) **mg/kg**				
	As	**Cd**	**Cu**	**Pb**	**Zn**
Typical mine waste with low metal concentration	240	5	120	500	500
Typical mine waste with high metal concentration	2 000	20	200	10 000	8 000
Typical forest soil in the N. Toka catchment	50	0.7	50	100	95
HU Environmental Criteria for soil (B) (KÖM. 2004)	**15**	**1**	**75**	**100**	**200**

* X ray Fluorescense Analyser
** average of 1 200 in situ XRF measurements

Before the establishment of the neutralisation plant (in 1985), the acid mine drainage ran directly into the surface water system (downstream the main mine entrance), where it was in situ neutralised. The lime precipitate was part of the sediment delivered downstream by the Toka Creek. In the lower section of the Toka Creek the sediment reached the soil of the surrounding agricultural land and hobby gardens either by means of irrigation or floods. Table 3 shows the metal content decrease of the flooded soil as a function of the distance from the Toka Creek.

Table 3 Metal content of the flooded allotment soil*

Soil	Distance from Toka	As mg/kg	Cd mg/kg	Cu** mg/kg	Pb mg/kg	Zn mg/kg
Allotment	5 m	110	7.5	210	462	1685
Allotment	15 m	63	1.0	127	248	998
Allotment	30 m	31	0.6	200	120	520
Allotment	50 m	–	0.6	131	63	208

*Gruiz and Vodicska 1993; the analysed material was a mixture of soil and creek-sediment
**Cu-content of the soil is associated with the agricultural use of Cu-containing plant protection pesticides

Cd and Zn mainly occur in dissolved/ionic form, while Pb and As are predominantly bound to solid phase elements: soil and sediments.

3. Scoring based Risk Assessment

The site specific scoring-based Risk Assessment methodology was developed to compare and set a priority amongst the point and diffuse sources. The scoring tool has as a basis the integrated risk model of the site (Gruiz et al 2005, 2007) and some elements of the National Classification System for Contaminated Sites (NCSCS) of the Canadian Council of Ministers of the Environment (CCME 1992). The developed scoring based Risk Assessment methodology differs from the CCME 1992 qualitative rating system in having most of the assigned scores based on measured quantitative values.

3.1 General concept

The site specific scoring based Risk Assessment concept developed to and demonstrated at the Gyöngyösoroszi abandoned mining site in Hungary follows a risk based rating system used to prioritize formerly identified contaminated subsites of the catchment area. The system was developed in 2002 after detailed assessment and mapping of the pollution sources of the catchment area.

The system applied to the Gyöngyösoroszi abandoned mining area has screened the contamination sources with respect to the need for further action (*e.g.*, characterization, risk assessment, remediation, etc.) to protect human health and the environment.

The procedure uses an additive numerical method that assigns scores to a number of site characteristics or factors. The methodology presented herein (wherever possible) creates/derives the scores from measured/estimated quantitative characteristics selected based on the integrated risk model of the site (Figure 2). In determination of the scores and their distribution the recommendations of the National Classification System for Contaminated Sites (NCSCS) of the Canadian Council of Ministers of the Environment (CCME 1992) were taken into account

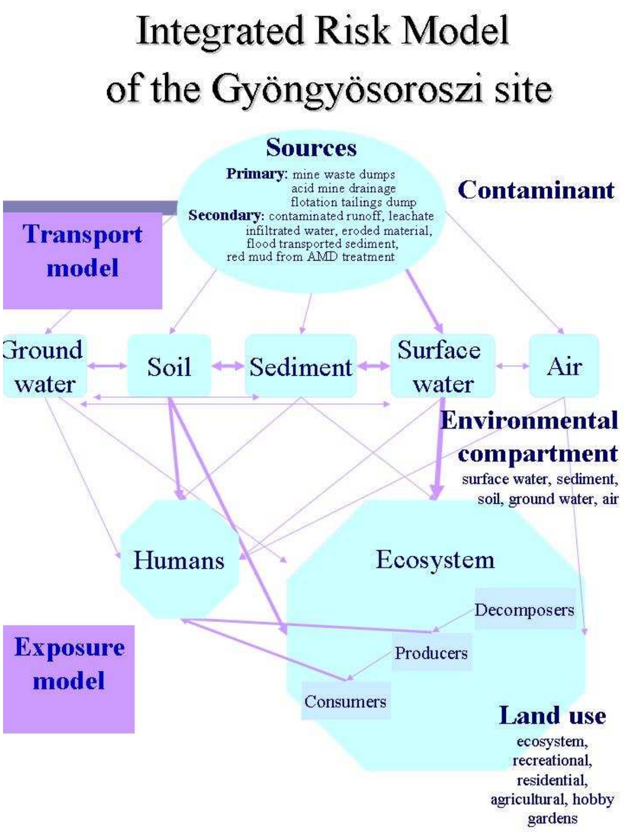

Figure 2 Integrated Risk Model of the Gyöngyösoroszi site (Gruiz et al 2005, 2007a)

3.2 Technical Basis for the performed Scoring-based Risk Assessment

The Scoring-based Risk Assessment system was designed to compare the hazard, or hazard potential of the point and diffuse sources of mining origin in the catchment and to prioritize them (Table 4).

Source Characteristics – This category relates to the relative hazard of contaminants present at the site. The source characteristics include contaminant and site specific factors such as waste quantity, contaminant concentration, physical-chemical properties of the waste material and contaminants, such as pH, mobility, pyrite (FeS_2) content, etc.

The creation of the site-specific scores is presented below on three examples. The contaminant content, the tonnage and the properties of the area of the individual sources were transformed into scores using the following rating (Table 4, 5 and 6).

Table 4 Scale for scoring the type of contaminant and estimated concentration

Hungarian soil quality criteria (B_{soil})	Score
B_{soil} is exceeded by 1 metal	1
B_{soil} is exceeded by 2 metals	2
B_{soil} is exceeded by more metals	5

$2xB_{soil}$ is exceeded by 1 metal	6
$2xB_{soil}$ is exceeded by 2 metals	7
$2xB_{soil}$ is exceeded by more metals	8
$5xB_{soil}$ is exceeded by 1 metal	9
$5xB_{soil}$ is exceeded by 2 metals	10
$5xB_{soil}$ is exceeded by more metals	11
$10xB_{soil}$ is exceeded by 1 metal	12
$10xB_{soil}$ is exceeded by 2 metals	13
$10xB_{soil}$ is exceeded by more metals	14

Table 6 Scale for scoring of the properties of the contaminated area/source

Properties of the contaminated area and contaminant	**Scores**
Non-weathered, non acidic mine waste in concentrated mass (point)	2
Non acidic flotation tailings, concentrated (point)	2
Lime precipitate under water in concentrated mass	3
Non acidic flotation tailings scattered	3
Acidic, leached flotation tailings	4
Contaminated sediment under water	5
Weathered, acidic mine waste	5
Contaminated acidic sediment exposed to weathering	8
Contaminated soil with vegetation cover	8
Contaminated bare soil	9
Contaminated surface water	9
Contaminated underground water	9
Contaminated pore water	9

Table 5 Scale for scoring the waste quantity

Tonnage (t)	**Scores**
≤10	2
10–100	3
101–1000	4
1001–10 000	6
10 001–100 000	8
100 001–1 000 000	9
>1 000 000	10

Transport routes – This category includes aspects of transport pathway. The transport pathway is the route a contaminant may follow (*e.g.* groundwater, surface water, direct contact) to a receptor. Contaminants that are mobile and have the potential to move off-site may require action on a higher priority basis than those which are stable. Specific transport pathways in the Gyöngyösoroszi mine area are: the runoff water, infiltrated water and subsurface waters, the acid mine drainage (AMD), direct waste material transport by erosion, partiton between water and solid phase both in solid mine waste, soil and sediment. These transport pathways are strongly influenced by site specific processes such as bioleaching (Vaszita et al 2009a), partition between soil and pore water (Gruiz et al 2005, 2007. 2009), partition between surface water and sediment, weathering of the mine waste (Gruiz et al 2005, 2007a. 2009),) and by the level of accessibility of the contaminated source.
The site-specific scoring of the amount of precipitation, quality of surface water, runoff and groundwater and of the water conductivity (hydraulic permeability of the soil) are important parameters of contaminant transport. Their scoring is shown in Table 7, 8, 9 and 10.

Table 7 Scoring of the annual precipitation

Annual precipitation	**Score**
<600 mm	0
600–700 mm	0.5
>700 mm	1

Table10 Scale for scoring of the hydraulic conductivity of the aquifer

Hydraulic conductivity of the aquifer	**Score**
$<10^{-4}$ cm/s	0.5
10^{-2} cm/s–10^{-4} cm/s	1.5
$>10^{-2}$ cm/s	3

Table 8 Scale for scoring the metal contamination of surface water

Effect based Quality Criteria for surface waters ($EBQC_{surface\ water}$)	**Score**
Equal or below limit value	0
Limit value exceeded by 1 metal	2
Limit value exceeded by 2 metals	3
Limit value exceeded by 3 or more metals	4
2 x Limit value exceeded by 1 metal	5
2 x Limit value exceeded by 2 metals	6
2 x Limit value exceeded by 3 or more metals	7
3 x Limit value exceeded by 1 metal	8
3 x Limit value exceeded by 2 metals	9
3 x Limit value exceeded by 3 metals	10
Limit value exceeded by more than 3 metals	11

Table 9 Scale for scoring the metal contamination of ground water

Hungarian ground water Quality Criteria (B_{gw})	**Score**
Drinking water quality	0
B_{gw} exceeded by 1 metal	1
B_{gw} exceeded by 2 metals	2
B_{gw} exceeded by 3 or more metal	4
2x B_{gw} exceeded by 1 metal	5
2x B_{gw} exceeded by 2 metals	6
2x B_{gw} exceeded by 3 metals	7
3x B_{gw} exceeded by 1 metal	8
3x B_{gw} exceeded by 2 metal	9
3x B_{gw} exceeded by 3 metal	10
More x B_{gw} exceeded by more metals	11

Receptors – Receptors are the environmental compartments along and at the end of the transport routes, and the users – humans and ecosystem – of the endangered environmental compartments, exposed to and affected by contamination. The surface water, its ecosystem and the humans (due to residential and recreational land uses) were identified to be the most endangered receptors. (Gruiz et al 2005, 2007a,b), Sipter et al 2005, 2008).
The scoring system for the impact on land uses and the adverse effects on humans and the ecosystem is shown in Tables 11–13.

Table 11 Scoring guidelines for non-confirmed impact on various land uses

Contamination of various land uses	**Score function of thedistance from the neighbouring landuses**		
	0-300m	300m-1km	1km-5km
Residential land use	5	4	3
Recreational landuse	5	4	3
Hobbygarden landuse	5	4	3
Natural (ecosystem) land use	5	4	3
Agricultural landuse	5	4	2,5
Industrial/commercial landuse	3	1	0,5

Table 12 Scoring guidelines for adverse effects on humans and animals

Adverse effects on humans and animals	**Score**
No adverse effect	0
Strongly suspected adverse effect	15
Known and confirmed adverse effect	**18**

Table 13 Scoring guidelines for adverse effects on environmental receptors

Adverse effects on sensitive ecological area	**Score**
Strongly suspected adverse effect on sensitive ecological area	12
Confirmed stress on water or/and terrestrial ecosystem in the vicinity of the pollution source	14
Confirmed adverse effects on sensitive ecologic area	16

3.3 Score summary and interpretation of the total score-value

Similarily to the CCME NCSCS 1992 a scoring system (maximum of 100 points) was used as a means of assessing the hazard of the site. The three categories of site characteristics (contaminant characteristics, transport pathway, receptors) were considered to be of equal importance under the scoring system, and were therefore weighted equally (33, 33, and 34 points, respectively).
Two alternative assessment routes and scoring systems were applied: a) assessment of cases of confirmed or strongly suspected adverse effects b) assessment of not known but suspected adverse effects cases. In case of the suspected adverse effects the assessment focused on hazard parameters which make the existence of unacceptable risk probable (CCME, 1992).

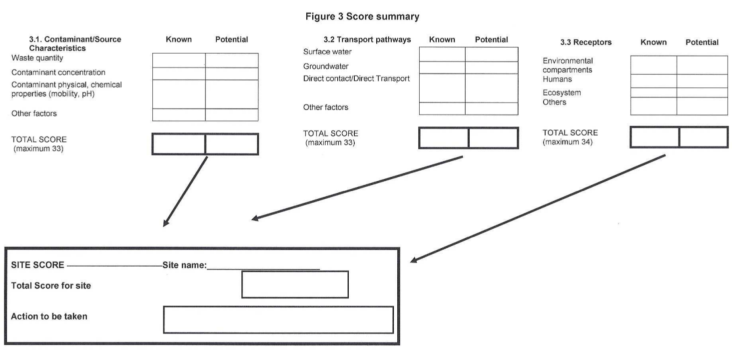

Figure 3 Score summary

The method developed to the Gyöngyösoroszi abandoned mining site evaluated the subsites and contamination sources by scoring them on a scale from 0 to 100 as shown in Figure 3.
A low total site score means not only low ranking of the site, but also no risk source or site, given that the scores are based on quantitative values (if possible in comparison with EQCs (Environmental Quality Criteria)). A score of 100 would represent a site for which all the factors were assigned the highest possible score and the scores close to 100 draw the attention on assessment and on the necessity of risk reduction measures.

4. Implementation of the Scoring-based Risk Assessment at Gyöngyösoroszi

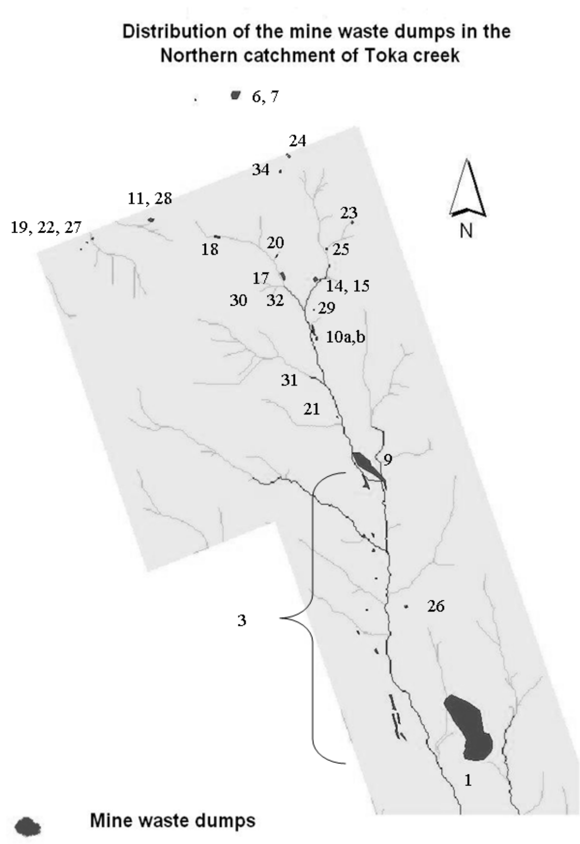

Figure 4 Pollution sources

Figure 4 shows the location of the mine waste dumps in the Toka catchment and in its NW vicinity belonging to the Hasznosi water catchment. The pollution sources are given a current number (Crt. No.) from 1 to 34 in the order of the hazard assigned by the Scoring based Risk Assessment. The sources (in dark grey) are visualised on the Flow Accumulation map (Figure 4) of the Toka water catchment (light grey delineation).

The listed mine waste dumps in the Toka and Hasznosi water catchment were assessed separately.

The mine waste dumps incorporate waste rocks from historical mine workings, ore fragments lost during haulage by mine cars. The mine waste dumps are located in the mine field area mostly at the entrance of the historical mine adits or shafts.

The assessment includes also other pollution sources than mine waste dumps such as flotation tailings, lime precipitate from acid mine water treatment, and polluted sediments.

The lime precipitate resulted from acid mine drainage treatment got settled in the settling ponds (4) of the water treatment plant. The emergency dam (16) of the flotation plant incorporates not only flotation tailings but also various chemicals (reagents). The flotation tailings pond (1) includes the flotation tailings from the plant. The sediments include the runoff and surface water delivered eroded solid material lime precipitate. The flotation tailings are contained in the sediment of the Toka Creek (13) and in the sediment of the three reservoirs: the industrial reservoir (2), agricultural reservoir (5), Gyöngyösi reservoir (12). The 34 pollution sources were classified according to the assigned scores in terms of the actions to be taken: to be remediated, to be treated as diffuse pollution source, detailed assessment is needed or to be excluded from further assessment and remediation.

5. Results of the scoring based Risk Assessment in Gyöngyösoroszi

According to the resulted total score the identified contamination sources were classified into three categories and the management action relevant to each category was given:

- **A**: 71–100 points: very high risk – action required typically resulting from an immediate risk to human health and/or the environment or insufficient data, more information needs to be collected and collated and risk reduction measures are necessary. Final decision after Quantitative Hazard Assessment.
- **B**: 55–70 points: high risk – Action likely required. Most of these sources are diffuse pollution sources affecting relatively large surfaces. Refined risk assessment and remediation is necessary.
- **C**: 40–54 points low and very low risk – Action: after refined risk assessment probably other action than revegetation is not likely to be required.
- **D**: <40 points: no risk – Remedial action other than revegetation not needed.

Classification of contamination sources in this manner provided an effective screening tool for determining the relative priority that should be placed on sources. The information collected and evaluated during the source/site classification process were used to focus detailed investigations at high priority sites. Specific management actions that may be taken at these sites include further characterization, hazard assessment, risk assessment, and/or remediation.

Table 14 below shows the score based ranking of the assessed pollution sources and the type of action recommended for every individual source. Decisions on the course of the complex rehabilitation of the mining area have been made based on this ranking.
Part of the ranking resulted from scoring was modified by additional considerations and in case of some pollution sources firm conclusions about the remedial actions were dependent on the results of the quantitative hazard assessment.

Table 14 Ranking of the pollution sources according to the total score and the required action

Crt. No.	Name of the source	Assigned scores			Total score	Action decided
		Source	Transport	Receptor		
1	Flotation tailings pond	33	29,5/30	34	99	**A** Action required typically resulting from an immediate risk to human health and/or the environment or *insufficient data, more information needs to be collated*
2	**Industrial reservoir sediment**	31	25,8/31	31	93	
3	*Ore transportation route*	31	27	34	92	
4	**Lime precipitate settling ponds**	32	27,8	31	90,8	
5	Agricultural reservoir sediment	31	26,8	31	88,8	
6	Mátraszentimre mine waste dump I	31	25,5	31	87,5	
7	Mátraszentimre mine waste dump II	29/31	26,5	31	87,5	
8	**Mud retention dam**				85,5	
9	Altaro mine waste dump	29	24,5	31	84,5	
10	Károly adit mine waste dump	27	27,5	27	81,5	
11	Bányabérci mine waste dump				81,5	
12	Gyöngyösi reservoir sediment	29	25,3	27	81,3	
13	Toka Creek sediment				>80	
14	Új Károly-adit mine waste dump I.				79,5	
15	Új Károly-adit mine waste dump II				79,5	
16	**Flotation plant emergency pond**	29	20,3	29	78,3	
17	Péter-Pál shaft waste dump	24	22,8	29	75,8	
18	*Katalin adit waste dump*	19	27,5	27	73,5	
19	*Nagytölgy+István waste dump*	23	22,5	27	72,5	
20	Péter-Pál adit dump	21	23,5	29	64,2	**B** Action likely required. Sources to be treated as diffuse pollution Probabaly in situ remediation
21	Ezüstbányabérc dump	21	21,8	20	62,8	
22	Kistölgyesi adit waste dump I	23	19,8	18,2	61	
23	Szákacsurgó waste dump	21	20	18,7	59,7	
24	Pelyhes adit waste dump I.	21	20	18,7	59,7	
25	Hideg-kúti adit waste dump	15	22,5	18,8	56,3	
26	Vereskői adit waste dump	15	20	19,7	54,7	**C** Action other than revegetation not likely to be required
27	Kistölgyesi adit waste dump II	14	21,5	18,2	53,7	
28	Vizeslyuk waste dump	20	16,3	12	48,3	
29	József adit waste dump	12	18,3	17,7	48	
30	Lajos adit waste dump				<40	**D** No other action than revegetation is needed.
31	Lujza adit waste dump				<40	
32	Aranybányabérci waste dump				<40	
33	Bányabérci gallery waste dump				<40	
34	Pelyhes adit waste dump II.				<40	

5. Conclusions

The presented scoring based Risk Assessment tool may have general applicability to similar base-metal mines around the world to screen and rank the contamination sources and sites in an iterative, tiered, risk based assessment process to support decision-making on an efficient and environment friendly remediation alternative. The results of this semi-quantitative risk assessment were used to express the relative risk associated with the identified pollution sources, to document the evaluation and decision making process of the mine closure and remediation plan in the area and select the high priority areas where contaminant release may result significant risks. Firm conclusions about the need for remedial action was still dependent on the results of the quantitive hazard assessment and on a number of factors such as local issues, availability of technology, remediation costs, planned longterm use of the site, etc.

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