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Technical Communication

A Classification System for Environmental Pressures Related to Mine Water Discharges

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Abstract. A survey of information on hazardous mine water discharges in the Central and Eastern European EU Accession Countries and a review of existing ranking systems and studies in Europe indicated a need to establish a common and easily understandable ranking system for environmental pressures that could be used to evaluate the existing situation and to assess and compare potential problems on a multinational and catchment basis. A method is proposed, combining two parameters: the flow rate of the discharge and its qualitative character, expressed as the number of times any environmental standard (maximum permissable concentration, MPC) is exceeded. These two parameters can be combined into one pressure factor (PF), defined as the log of the number of times a standard was exceeded + the log of the emission flow rate, m^3/day. The data can be expressed on a special plot, with five gradations that define the number of times the standards were exceeded (from A = more than 1000 times to E = not exceeded), and a numerical designation that reflects the flow rate. The available information and estimated parameters for different mine sites in Central and Eastern Europe were compared on a single plot that shows the number of times the MPC was exceeded and the flow rates generated by mining of different commodities on various scales.

Key words: Contaminants; environmental pressures; Europe; impact analysis; maximum permissible concentration (MPC); methodology; mine water; ranking

Introduction

Mine accidents in Aznacollar, Spain in 1998, where a dam burst poisoned the Guadiamar River environment, and the Tisza pollution event, caused by a cyanide spill following a damburst of a tailings pond in Baia Mare, Romania in 2000, increased public awareness of the environmental and safety hazards of mining activities in Europe. In mid-2001, the Joint Research Centre of the European Commission started a project 'Inventory, Regulations and Environmental Impact of Toxic Mining Wastes in Pre-Accession Countries' (PECOMINES), one of the objectives of which was to collect and analyse information on hazardous mine sites and mine wastes in Central and Eastern European candidate countries.

An assessment of waste generation showed that in many candidate countries (Czech Republic, Estonia, Bulgaria, Romania, Poland, and Slovakia), the extraction and processing of mineral resources produces more waste and creates greater environmental problems than any other industry. The number of sites depended on the level of detail of the national inventories, but the total number reaches many tens of thousands (the Slovakian inventory alone included 17260 sites). However, there were no commonly accepted criteria by which the huge number of sites could be ranked in order to distinguish and compare the most hazardous ones in one country with those in another.

While comparing situations in different countries, it became clear that criteria were needed to convert an intuitive understanding that the worst cases in different countries can differ in their environmental impact by many orders of magnitude (e.g. gypsum mines versus very large metal mines) into a comprehensive ranking system. This paper summarises the efforts of some previous mine site inventories in Europe, analyses the results of a PECOMINES questionnaire, and proposes a new methodology for a comparative assessment and ranking of mine sites with respect to hazardous mine water discharges. The proposed methodology is envisaged as part of an overall risk assessment (characterisation of the influence of mine water discharges), and does not consider other problems related to mine sites, such as slope stability and on-site soil contamination.

Materials and Methods

A multi-source approach was used to develop a comparative assessment methodology, including a review of previous comparative studies and methodologies in Europe, analysis of the information gathered by a questionnaire, and hydrochemical analysis of the test sites.

In a number of recent multicountry reviews, the source characterization that should be the first step in a complete risk assessment (Figure 1) was based on the amounts of mined commodities and/or disposed waste. However, neither of those can possibly predict even the right order of magnitude of the associated environmental impacts. A small metal sulphide mine with a quartzite host rock producing pH 1-2 leachate and a large brown coal mine with a limestone-dominated overburden with pH 7-8 leachate could be characterized similarly by such an exercise.

One option is a geoenvironmental model of a mineral deposit that provides information about geochemistry and its variations of a particular deposit type, and geochemical variations associated with wastes and effluents (Plumlee and Nash 1995). While this is becoming a useful tool for environmental assessment during the mine planning process, uncertainties related to effluent quality of a particular deposit type remain due to the many parameters that control effluent formation and transport. Therefore, for existing sites, the association between the magnitude of the water pollution-related environmental impacts and the deposit types is not straightforward, even though the problems are known and there are many tens of thousands of sites.

Approaching the risk assessment procedure from the other side (identifying all possible pathways and targets and assessing the existing and potential damage) requires developing a large number of different criteria together with their weighting factors. Many countries have attempted to do this in different ways, and any harmonization of these methodologies would be cumbersome. The categories 'high risk' and 'low risk' in different countries fully depend on the character and magnitude of the existing problems, and are often related to the opinions of local experts.

The underlying assumption in the development of a screening methodology is that qualitative and quantitative characterization (estimates or measured data) of the hazardous water emissions makes it possible to relate pollution potential to the possible environmental impacts. The justification of this statement is based on the differences (by many orders of magnitude) in the discharges, both in terms of the flow and the concentrations of different contaminants. Thus, even rough estimates are potentially useful and can be used to make quantitative comparisons as long as the degrees of uncertainty are provided.

Review of Previous Efforts

A mine site can contain one, some, or all of the sources of contaminated mine water presented in Figure 2. The scheme does not include relatively rare cases, such as in-situ leaching facilities and ex-situ hydrometallurgical leaching plants.

Contaminants leaving the site and entering the catchment can impact surface water bodies, groundwater, soils, and sediments; these systems become both targets and pathways. The final targets could be roughly grouped into human health-material values and ecosystems-protected areas.

Referring to this schematic approach, it is possible to define the scope and describe the content of a number of the previous multi-country and country-level comparative assessment efforts listed in Table 1. The descriptions are not meant as a comprehensive overview of all existing efforts, but merely a demonstration of what the different efforts are based on and how different the approaches are. The information was mainly collected on inventories of closed and abandoned mine sites. The number of sites is very large and the information is usually limited.

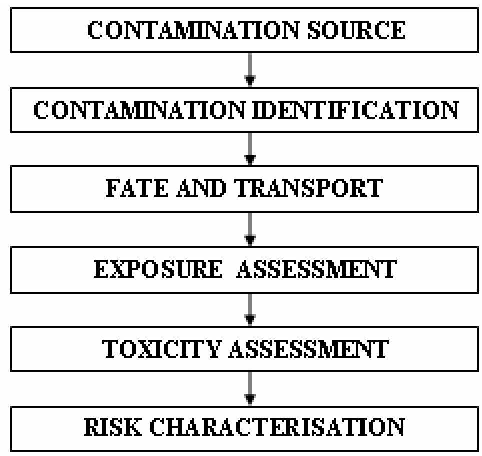

Figure 1. Generalised scheme of the steps of risk assessment

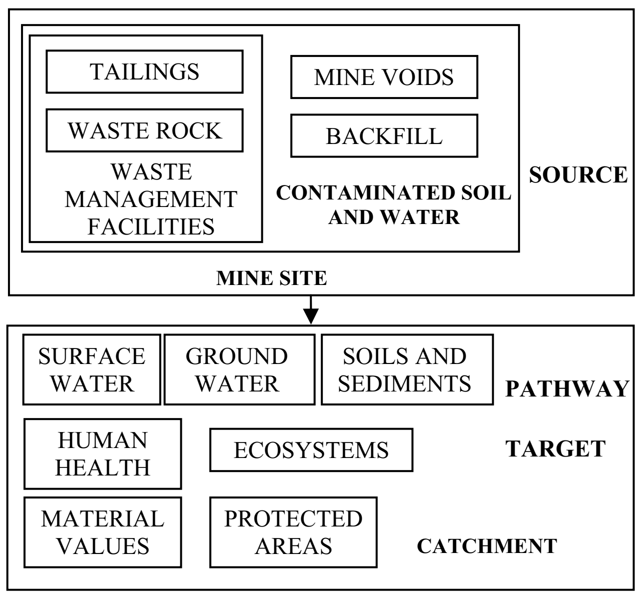

Figure 2. Simplified scheme of the source-pathway-target approach in mine and quarry sites context

Table 1. Examples of previous and on-going efforts to tackle mine site problems

Effort	Scope	Description	Results
		Multi-country efforts	
The Phare Programme – remediation concepts for U mining in the CEEC (MCP) (Tabakov 2002)	124 uranium sites, in 9 Albania, Bulgaria, Czech Republic, Estonia, Hungary, Poland, Romania, Slovakia, and Slovenia	A compiled inventory of the existing situation; implementation of pilot projects; supports co-operation between the involved countries	A systematic approach for classifying sites, collecting, validating and assessing data for liability and environmental impact; uniquely ranks and prioritizes sites using a specially designed system
A preliminary risk inventory of toxic waste storage sites in EU countries (Sol et al. 1999)	Metal mining areas and tailings lagoons in EU countries	Identifies protected wetlands (Ramsar convention sites) that are close to mine sites and vulnerable to pollution from mining activities	Suggests a country-by-country approach and that analysis of satellite remote sensing data could speed process up
Management of mining, quarrying, and processing waste in the EU (BRGM 2001)	Quantitative estimation of mine waste in EU countries	A questionnaire approach combined with calculations based on the world's average production-waste material ratios for different commodities	A rough estimate of mining waste in different EU countries; presents typical hydrogeological settings for waste management facilities
A regional inventory of potential accidental risk sites in the Tisa catchment area (ICPD 2000)	Sites of highest accident risk in the Tisa catchment in Romania, Hungary, Ukraine, and Slovakia	Based on the national information provided, 3 risk categories were established, with high risk defined as an information-based indication of direct or indirect high accident risk (existing leakage, etc.)	Among industrial hot spots, 16 tailing deposits/ponds and 3 mines in Romania, 1 mine in Slovakia, and a complex of reservoirs with mine and industrial metal sludge in Hungary assessed as high risk
		Single country efforts	
Bulgaria – BGP, BGPE (Tabakov 2002)	Concentrated towards problems related to uranium production	A detailed site-specific inventory, but without national standards and real experience in some cases	Identified sites, collected liability data for inventory, field measurements, lab testing of water, soil, and rock samples, site specific risk assessment ranking, grouping of objects, development of complex programme for remediation
Czech Republic, Impact of Mining on the Environment (Reichmann 1992)	1:500000 scale map of the Czech Republic with explanatory text and legend	Using the geological map with deposit boundaries and mining areas as a basis, a methodology assessing the individual impacts of 13 categories was established	Impact of factors was expressed as high, low, or no risk, based on expert estimates. 169 sites and their risks were presented; no quantitative criteria for the risk categories were established.
Poland, Polish Geological Inst. (M. Gientka, personal comm.)	Geo-environmental maps on 1:50000 scale, based on a land use map	Mines are assessed site-specifically, based on how their impact conflicts with local ecosystems, protected areas, etc.	The 1:50000 scale maps provide a basis for solving the problems on local scale, case-by-case
Portugal (Da Silva Daniel 2002)	Program covering all abandoned mines	Mine sites ranked based on safety and environmental issues, with different weighting for mine safety, waste data, chemical impact, visual impact, and human presence and activities	Sites were ranked as: Degree 4 – High hazard Degree 3 - Medium hazard Degree 2 – Low hazard Degree 1 – Negligible hazard

Slovakia (Janova and Vrana 2002)	All active and old mining sites	Registration, inventory, and evaluation of 266 active and 17,260 old mine sites; localities, inventory, environmental impacts of all mine sites, monitoring of the most risky localities of mining sector, proposal and realisation of remediation activities	Sites categorised using weighting factors**:** I. acutely requires remediation; II. not critical or site may be recategorised); III. low or minor. Based on ranking, the 1st category and 3 localities of the 2nd were denoted as hot spots; monitoring system being developed
Sweden, Methods for Inventories of Contaminated Sites (Swedish Env. Protection Agency 2002)	To help local and regional authorities assess environmental quality and aid in planning and establishment of environmental objectives	Assessment of contaminated sites based on the extent that concentrations significantly exceed background levels using environmental quality criteria, such as a hazard assessment, contamination compared to reference values, and amount and volume of contaminated material	Categorises current conditions: exceeding guidance values at least 10 times considered very serious; exceeding reference values 25 times define the sites as having a very large effect (both examples fall into the uppermost class)
United Kingdom (Jarvis and Younger 2000)	National dataset of the damage caused by abandoned mine discharges	UK National Rivers Authority (now the Environment Agency) categorised environmental impact: 1. area affected by deposition of metal precipitates, assessed visually; 2. length affected (m); 3. substrate quality and salmonid reproduction; 4. Fe discoloration; 5. Total Fe; 6. pH, Al, and dissolved oxygen. After this ranking, benthic macro-invertebrates were used to determine water classes.	Abandoned coal and metal mines degrade 400 and 200 km of UK watercourses, respectively; over 90% of this pollution is discharged from mine voids rather than mine waste; suggests that mine drainage in the EU may degrade more than 5000 km of watercourses, with candidate countries adding to that total (Younger 2002).

A comparison of international and country-specific efforts reveals some basic differences. Until now, multi-country efforts have either focused on a certain sector (e.g. uranium mining), focused on certain elements of mine sites (e.g. tailings ponds within a catchment), or just roughly assessed the amount of waste. Each country has established its own approach and methodology, some of which are illustrated in Table 1. The sites, ranked by different systems into high hazard, high risk, class I, very large effect, etc., are not comparable with each other, and no synoptic overview is possible. For many of the top-ranked sites, action plans have been prepared and are being implemented, but the approach used in one country cannot easily be applied in another.

Analysis of the Questionnaire Results

As part of the PECOMINES project, an international steering group, which included 18 members of the ministries, geological surveys, and institutes in 10 Candidate Countries, was established. The experts were asked to fill out questionnaires on the most severe problem sites in their countries. Based on the information submitted and environmental impact analyses of the test sites, 37 'hot spots' were defined, using four different categories to define a hot spot:

(1) Sites generating hazardous emissions of contaminated water with negative impacts;

(2) Large contaminated territories with cavities, waste heaps, and/or tailings ponds;

(3) Tailings ponds with large volumes of contaminated water or heaps with unstable slopes, posing a risk that material might be accidentally released;

(4) Sites with hazards qualitatively recognised but lacking quantitative information.

The results of this inventory showed that determining hot spots is based on local knowledge and impact, and that preliminary screening would not work. Of the 37 sites, 35 were metal, uranium, and fossil fuel mining sites, while two were industrial mineral (phosphate and quartzite) mines; the latter were included because their overburden contained sulphides, causing acid drainage. Thus, although the commodity being mined to a large extent determines the character of the impact, there are exceptions depending on deposit geology.

Also, there is no direct link between the status of a mine and whether the mine site is considered to be a hot spot or not; approximately 1/3 of the hot spots are active mines, while the rest are closed or abandoned mines. It should be pointed out that a closed mine does not necessarily have less significant problems because in the past, environmental standards were considerably lower, and, in some cases, the competence of the authorities may have been limited so that long term problems after closure were not avoided.

The problems in different countries differ by many orders of magnitude. Lithuania has no mines that could cause any significant damage to the environment, and Latvia has several small gypsum mines with small scale impacts. The other 8 countries are facing severe water pollution problems, making it possible to rank the 10 countries into 3 groups:

Group 1 – hazardous water emissions from mine sites a top national priority

Bulgaria – uranium mines

Czech Republic – coal mines, a declining number of uranium mines, and metal mines, inactive since the early 1990s

Poland – coal mines and processing waste from copper, zinc, and lead mines

Romania – metal and coal mines

Slovakia - metal mines, inactive since the early 1990s, and coal mines

Group 2 – mine water problems are serious but not a top national priority, and are being addressed on a case-by-case basis

Estonia – phosphate mines, inactive since the early 1990s, oil shale mines, and uranium processing waste

Hungary – closed uranium and copper mines, red mud at alumina plants

Slovenia – uranium processing waste, brown coal and metal mines

Group 3 – problems are insignificant on a national scale

Latvia and Lithuania

Water Quality Values for Quantitative Comparison

The EU is establishing environmental quality standards for water bodies as part of implementing Water Framework Directive 2000/60/EC, and is developing standards for solid phases, such as soils and sediments. As these and other environmental standards are not yet available, a set was developed from different sources for methodology testing. The maximum permissible concentration (MPC) values listed in the tables below have been estimated on a scientific basis, and indicate that the concentration of a substance or value of a parameter should have no adverse effects on ecosystems or on humans (for non-carcinogenic substances), and a calculated probability loss of human life through cancer risk of less than 10^{-6} per year. The MPCs estimated by scientific communities in different countries vary somewhat, but not so significantly as to change the overall picture regarding mine and quarry waste emissions, where in the extreme cases, the standards are exceeded by 4-5 orders of magnitude.

The MPC values should not be mixed with target values that are set at the level of negligible concentration and should be achieved as the environmental quality in the long-term. The target values often include an additional safety margin, being up to 2 orders of magnitude less than MPCs. However, the MPCs are less than intervention values, and indicate a serious or imminently serious decrease in the functional properties of soil, sediment, or water for humans, plants, and animals.

For the range of parameters, elements and substances relevant for screening mine waste problems, the existing drinking water standards presented in 98/83/EC are very similar to surface water MPCs; the two main exceptions are Cu and Zn, for which drinking water standards permit much higher concentrations because of Cu and Zn pipes. For substances known to be harmful but not limited by EC regulations, the WHO, Dutch, Belgium, Swedish and German quality standards were used (Barkowski et al. 1993; Environmental quality standards in the Netherlands 2001; Swedish Environmental Protection Agency 2002). Although some of the Candidate Countries may use different standards at present, to get the comparative picture and also to understand how EC accession will change the pattern, uniform values were used (Table 2). As for Fe, a drinking water quality standard of 0.2 mg/L was used, the value of which is based on clogging of water pipes. However, no generally accepted standards for mine waters exist and in many regions of Europe, surface water is used for water supply, so the value was not increased (although German mining companies, for example, use 4 mg/L – Christian Wolkersdorfer, personal communication).

Hydrochemical Analysis of Selected Hot Spots

A comparative methodology has been developed based on the PECOMINES project case studies in Slovakia and Estonia, and is illustrated here using the Smolnik mine in Slovakia. The Smolnik underground copper, iron, gold, and silver mine is situated in the Slovenske Rudohorie Mts, in Eastern Slovakia, 4 km from the town of Smolnik. After more than 7 centuries of operation, mining stopped in 1990 and the mine was flooded. In 1994, the stream down-gradient from the mine and the river Hnilec acidified, causing a large fish kill; more than 10 km of the stream continues to be polluted by a discharge of highly acidic leachate averaging 15 L/s. Based on chemical analyses of the mine discharge (averaged for 20 measurements from 1997-2001) and samples from downstream (upstream water did not exceed MPC values), a graph was constructed, presenting the potential of the discharge to pollute natural water courses

Table 2. Maximum permissible concentration values used for testing the methodology

Surface Water and Ground Water		
pH	6.0-8.5	98/83/EC: 6.5-9.5
suspended solids	50 mg/L	
ammonium	0.5 mg/L	98/83/EC
Nitrates	50 mg/L	98/83/EC
Nitrites	0.5 mg/L	98/83/EC nitrate/50+nitrite/3<1
total phosphates	1 mg/L	
COD	30 mg/L	
conductivity	2500 µS/cm	98/83/EC
chlorides	200 mg/L	
sulphates	250 mg/L	98/83/EC
Fluoride	1.5 mg/L	98/83/EC
total cyanides	0.05 mg/L	98/83/EC
Aluminum	0.2 mg/L	98/83/EC
Potassium	12 mg/L	
Sodium	200 mg/L	98/83/EC
Calcium	50 mg/L	
Magnesium	50 mg/L	
Manganese	0.5 mg/L	
Iron	0.2 mg/L	98/83/EC
	Other Metals (µg/L)	
Antimony	5	98/83/EC
Arsenic	10	98/83/EC
Barium	250	
Beryllium	0.2	
Cadmium	5	98/83/EC
Chromium	50 (total)	98/83/EC
Cobalt	20 (total)	
Copper	50 (total)	98/83/EC: 2000 µg/L, because of Cu pipes
Lead (total)	25	98/83/EC: 10 after 2013
Mercury	1 (total)	82/176/EEC, 98/83/EC
Molybdenum	300	
Nickel (total)	20	98/83/EC
Selenium (total)	10	98/83/EC
Silver	10	
Tin	200 (total)	
Vanadium	5	
Zinc (total)	40 (total)	
	*Radioactive Elements	
Uranium	30 µg/L	U.S. EPA
Radium 226 & 228	15 p Ci/L (0.56 Bq/L)	U.S. EPA

*There are no European environmental standards for total U and Ra 226 in water, so U.S. EPA standards were used (http://www.epa.gov/safewater/standard/pp/radnucpp.html)

with certain contaminants (Figure 3). The vertical axis of the log-log plot indicates how many times the MPC value of a particular contaminant in the emission was exceeded, and the horizontal axis gives the measured or estimated quantity of the emission. The grouping on the left describes the mine discharge and the grouping on the right, the situation 100 m downstream. The dilution factor in this case is 1:19.

Dilution occurs downstream or down gradient (including groundwater), and incorporates removal as a solid in the catchment area (on soil, river sediment, groundwater-bearing rocks, etc.). Such considerations are all important for site-scale studies, but the number of parameters and variables to account for gets so large that given the poor quality of existing data in the overall chain (source→emission pathway→target), it was decided that it would not be possible to compare all the important factors on a multinational scale at this time. As a first step in quantitative comparison of existing pressures, the concept of 'the emission rate of the contaminant most exceeding the MPC' is proposed to characterize a site. In the Smolnik case, the major contaminant is Fe, exceeding MPC 3000 times (on average), with Al, Mn, and pH following, in the range of 400-650 times. The Smolnik site is therefore characterized (Figure 3) with a central determination of 3000 (times exceeded) and 1700 m^3/day, with a range of 1500-6000 times exceeded and 850-3400 m^3/day on the log-log plot.

The characteristic diagonal lines on the plot express the 'worst case' extent of the polluting waters from the source within the catchment, where the environmental system downstream is unable to remove the contaminants from the flow and the only improvement occurs through dilution and dispersion. This can be illustrated by plotting, for example, the advancement of the cyanide spill of the Baia Mare accident (basically a 1-day event) on the same graph with river systems not having considerable capacity to remove cyanide (Figure 4).

A Method for Calculating Pressure Factors and Ranking into Categories and Classes

Categories, given by letters, indicate the qualitative hazard of the emissions: Category A = MPC exceeded more than 1000 times; Category B = exceeded 100 – 1000 times; Category C = exceeded 10 – 100 times; Category D = exceeded up to 10 times; Category E = MPC not exceeded. A parameter was developed to characterize the environmental pressure; this pressure factor (PF) is defined as log (times standard exceeded) + log (flow rate, m^3/day), assuming that the log (times standard exceeded) > 0. The value of PF indicates the potential of the discharge to pollute 10^{PF} m^3/day of pure water, assuming that dilution is the only certain mechanism of decreasing the value of the exceeded MPC, until the standard is not exceeded any more. For example, if MPC is exceeded 300 times and the flow rate is 2500 m^3/day, the parameter PF = log (300) + log (2500) = 2.48 + 3.40 = 5.88, meaning that the discharge has the capability to pollute $10^{5.88}$ m^3 of pure water per day. If the log (times standard exceeded) < 0, the discharge water belongs to category E.

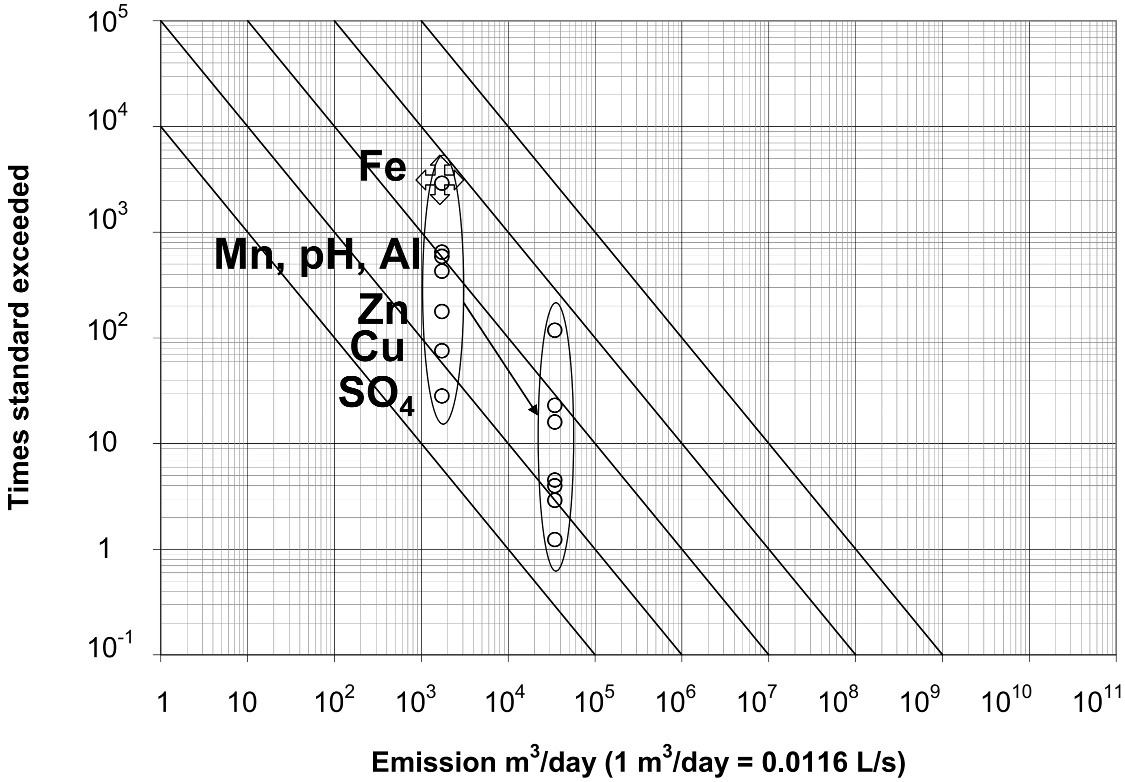

Figure 3. The Smolnik mine discharge is on the left; the situation 100 m downstream is on the right

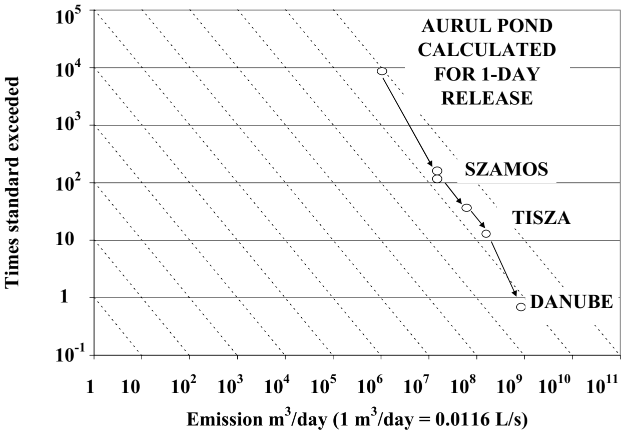

Figure 4. Movement of Baia Mare cyanide plume downstream (averaged 1-day values, times standard exceeded 1 day only; data from BMTF 2000)

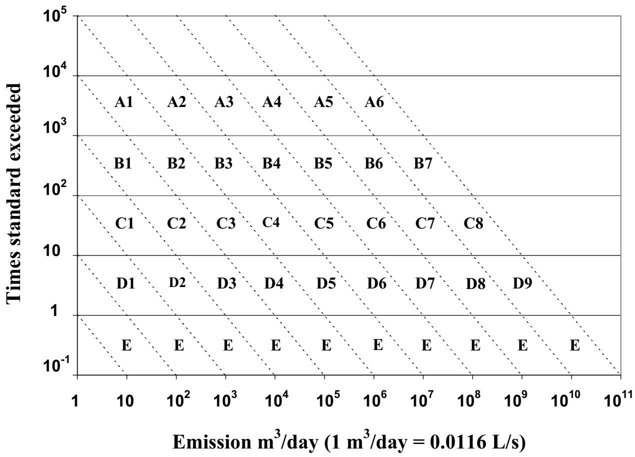

Figure 5. A method of classifying environmental pressures

The proposed system characterises only the environmental pressures and does not consider such ameliorating factors as natural buffering and manmade systems. This is analogous to the Richter scale, which describes only the magnitude of earthquakes, not site-specific impacts based on topography, building characteristics, etc. Nevertheless, the Richter scale is useful because it is a well-defined and uniformly understood parametric scale, and magnitude 4 earthquakes are not as destructive as magnitude 8 ones. Based on this approach, the emissions potential is classified as presented on Figure 5. (The discharge given in the example in the preceding paragraph would belong to class B3).

The system can be also used for a specific contaminant. For example, the Smolnik data (flow: 1300 m^3/day (1 point source); pH: 3.2, SO_4: 7000 mg/L, Al: 85 mg/L, Mn: 320 mg/L, Fe: 580 mg/L, Cu: 3.8 mg/L, Zn: 7 mg/L) allow one to categorise the site. The MPC was exceeded 600 times for acidity, 30 times for SO_4, 430 times for Al, 640 times for Mn, 2900 times for Fe, 76 times for Cu, and 180 times for Zn. The major contaminant, iron, would be plotted on the graph as:

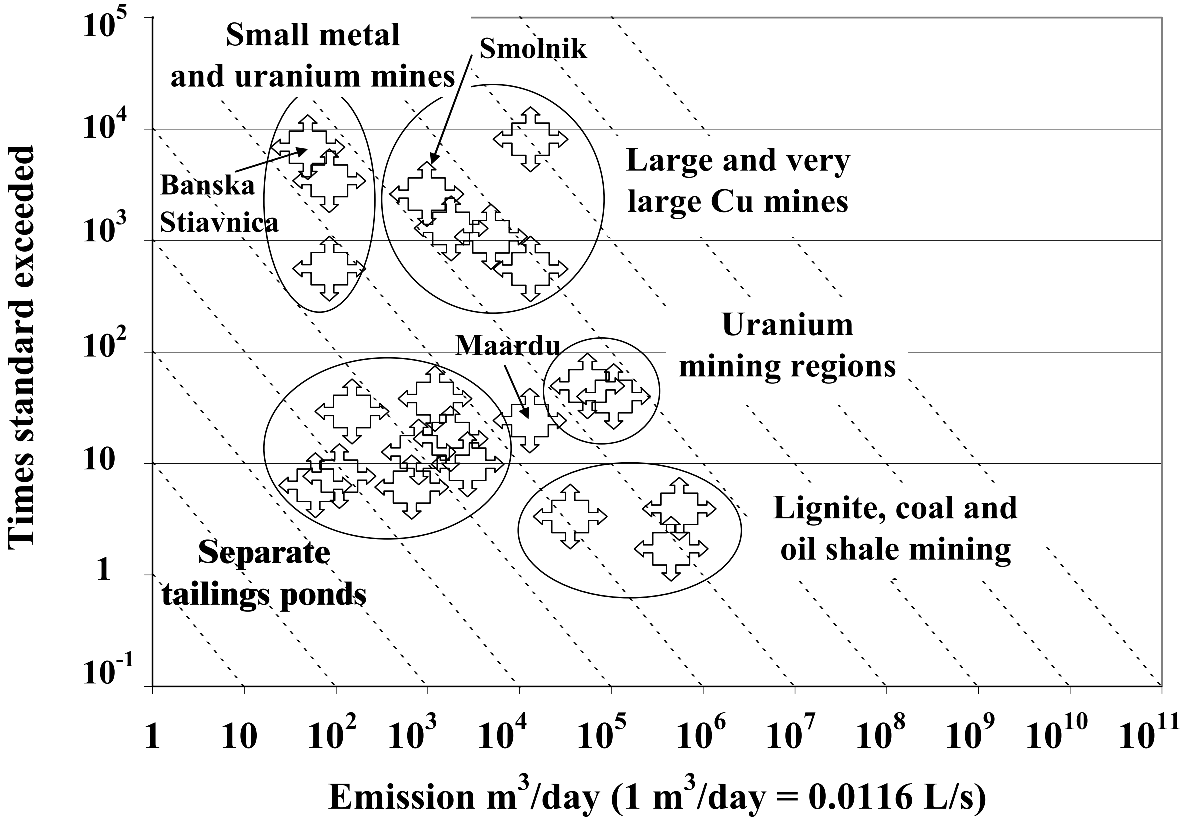

Figure 6. A graph of the assessment of emissions potential of the mine sites hot spots in EU Candidate Countries

1300 m^3/day, 2900 times exceeded, Class A3. Similar characterization of the other contaminants leads to: acidity PF = 5.89, Class B3; SO_4 PF = 4.59, Class C3; Al PF = 5.74, Class B3; Mn PF = 5.92, Class B3; Cu PF = 4.99, Class C3; and Zn PF = 5.37, Class B3. The practical application of this method is that it clearly distinguishes the impact of particular contaminants on a catchment basis and allows one to work out intervention strategies.

Comparative Plot of Mine Sites

As an example of how different sites can be assessed and compared, a plot was constructed with data extrapolated from the PECOMINES questionnaire (Figure 6). The only quantitative flow rate data available were from the three project sites: Smolnik and Banska Stiavnica in Slovakia, and Maardu in Estonia. However, for this example, the area of a site, being a catchment for the discharge, was assumed to approximately predict the magnitude of discharges, using an infiltration rate of 500 mm/year for all sites, with an uncertainty factor of 2 on the log-log plot (± 2, 250 – 1000 mm/year). The water quality data available for the 21 sites were extrapolated to characterize all of the measured or estimated discharge. Also, an uncertainty factor of ± 2 was used to represent the orders of magnitude of problem scope and significance.

The fields presented on the graph are:

Large Cu mines: Rosia Poeni in Romania; Elatzite, Medet and Pangjuriste in Bulgaria; Smolnik in Slovakia – main contaminants (Cu, Fe, SO_4, or acidity), exceeding MPC 500-10,000 times; ranking A3, A4, B4;

Smaller mines: Banska Stiavnica, quartzite mine in Slovakia (acidity, Al); Recsk, metal mine in Hungary (acidity, Fe); Mecsek uranium mine in Hungary (U); ranking A2, B2;

Uranium-mining regions: Eleshnitsa and Buhovo in Bulgaria, main contaminants: U or SO_4; ranking C5;

Lignite, coal and oil shale mining regions in Romania (Motru), Poland (Upper Silesian Coal Basin) and Estonia (oil shale mining region); main contaminant: SO_4, exceeding MPC up to 3 times; ranking D5, D6;

Separate tailing ponds (plot does not include the risk of dam failure) – main contaminants: As, U, Fe, and acidity; ranking C2, C3, D2, D3, D4;

and the Maardu phosphate mine in Estonia, MPC exceeded up to 30 times, main contaminants: Cu, Zn, and Ni; ranking C4.

It should be pointed out that the diagonal lines can serve as environmental pressure factor isolines for the site. Environmental pressure increases towards the upper right corner, and the difference between two consecutive lines is 10 times. On the same isoline, the sources at the upper left corner are more concentrated and can be more efficiently treated. The methodology of ranking and plotting the emission streams could also be an effective tool for river basin management. A similar concept has already been used for identification and visual presentation of main pollution sources within a catchment in South Africa (P. Younger, personal communication).

Figure 6 also shows the severity of the problems: there are many mine sites in Central and Eastern Europe that have the potential to pollute more than a million m^3 of water a day. Since reliable quantitative data was not available, the plot was constructed using the available data and estimates. Obviously, in most of these cases, the full potential of the discharge is not realised, since buffering, adsorption, reduction, precipitation, etc. can all ameliorate the water phase. However, especially in the case of heavy metals, these mechanisms solve one problem, but often create another, such as contaminated soils and sediments, impacts to the ecosystems, etc. Therefore, the characterisation of pressures remains informative.

Conclusions

The order of magnitude of environmental pressures of a mine site to a catchment can be described by a simple assessment of two parameters: the quantitative yearly average flow rate of the emissions and the number of times the environmental standard (MPC) of any contaminant is exceeded. These two parameters can be combined into a single parameter, which represents a site's potential environmental pressure. This pressure factor (PF) is defined as the log of the number of times a standard was exceeded + the log of the emission rate (m^3/day), assuming that the number of times the standard was exceeded > 0, and expresses the capability of the discharge from the given source to pollute 10^{PF} m^3 of pure water per day. Using a system of categories and classes, each site can be ranked, expressing the relative hazard of the discharge with categories A….E and the flow rate with classes 1…8.

Testing the proposed methodology with extrapolated results of the PECOMINES questionnaire shows that despite the large uncertainties in the collected information, mine sites of certain commodities tend to concentrate in certain areas of the test plot. Thus, characterisation of the environmental pressures through the ranking, plotting and isohazard system is informative in the same manner as the Richter scale. It can be used across national boundaries, despite different methodologies of assessment and scales of significance. The proposed methodology makes it possible not only to define which site is locally more significant, but to compare the orders of magnitude of the significance. For example, if the worst cases are determined to be a D2 site in one region and an A4 site in another, the difference in environmental pressures of approximately 5 orders of magnitude is an obvious and informative assessment.

Sites that rank in the same isohazard category, such as A2, B3, C4, D5, indicate the feasibility of possible actions. The discharges from an A2 site are approximately 3 orders of magnitude more concentrated and less voluminous than those of D5, and could be more cost-effectively treated. Such a system can ease river basin management, allowing decision-makers to prioritise problems and expenditures.

The system will need to be modified to reflect, for example, general acceptance of the MPC values on a regional and catchment basis. The standard values used for comparison in this demonstration paper are not standards for mine waters, as these do not exist in Europe. For example, for Fe, the drinking water standard is set at 0.2 mg/L to avoid clogging of water pipes. So, a catchment-based decision could be made to use a more appropriate value where it is appropriate to do so.

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