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ENVIRONMENTAL HAZARD ASSESSMENT OF FORMER MINES: MAIN METHODOLOGICAL POINTS

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ABSTRACT: The environmental hazard assessment of former mine sites concerns the surface water, groundwater, soils and sediments and allows the listing and location of the potential areas exposed to one or several contaminations with possible harmful consequences on human and the environment. This assessment needs to evaluate the intensity of the potential pollution and the site predisposition or sensitivity to be affected by this (these) pollution (s). The areas characterized by each environmental hazard classes will be mapped for a better understanding. If necessary the results will be used for the PPRM drawing up.

KEYWORDS: Post-mining, prevention, hazard, environment, methodology

RÉSUMÉ : L'évaluation de l'aléa environnement sur les anciens sites miniers concerne les eaux de surface et souterraines, les sols et les sédiments et doit permettre l'inventaire et la localisation des zones potentiellement exposées à une (des) pollution (s) pouvant avoir des conséquences sur la santé humaine et les écosystèmes. Cette évaluation nécessite d'estimer l'intensité des pollutions potentielles mais aussi la prédisposition ou la sensibilité du site à être affecté par ces pollutions. Les secteurs géographiques caractérisés par chaque niveau d'aléa environnemental seront reportés sur carte pour une meilleure compréhension et visualisation. Les résultats pourront si nécessaire être utilisés dans l'élaboration des PPRM.

MOTS-CLEFS : Après-mine, prévention, aléas, environnement, méthodologie

1. Introduction

The discontinuation of mining activities does not necessarily mean an end to the risks and pollution likely to affect the environment and ecosystems located within the area of influence of the former mines. Many disturbances can arise during the period subsequent to mining, traditionally termed 'post-mining'; sometimes immediately following the end of mining, and also sometimes much later.

These disturbances can take various forms such as ground movement (subsidence, collapse), gas emission (CH₄, CO, CO₂, H₂S, radon), quantitative and qualitative changes in the surface water and groundwater circulation systems (flooding, water pollution), soil and sediment contamination.

For the best management of these risks, the government has available an operational regulatory tool known as the Mining Risk Prevention Plan (MRPP) which enables one to a) identify the areas that

are most likely to harbour risks or pollution in the long term, and b) establish regional planning regulations adapted to the various post-mining constraints.

The design and contents of an MRPP in general, which were discussed at the last International Post-Mining Symposium (2005), classically break down into four phases:

- the informative phase: collecting all available information, with additional investigations where necessary;
- the hazard assessment phase: locating and listing areas exposed to potential contamination without taking land use (i.e. type of surface occupation) into account;
- the factor assessment phase: locating areas subject to one or more risks relative to humans and ecosystems;
- the regulation zoning phase: defining homogeneous zones in terms of land-use prohibitions, instructions and recommendations concerning both existing and planned projects.

To help with the two first MRPP phases, informative and hazard assessment, methodology guides have been prepared concerning the ground-movement, flood and mine-gas emission hazards. They are aimed at all the actors involved in drawing up a MRPP (administrative services, local authorities, consulting firms, etc.).

The methodological guide assessing environmental hazard concerns water, soil and sediment contamination. It is currently being finalized by a working group made up of experts from BRGM, GEODERIS and INERIS assisted by representatives from MEDAD/ DARQSI.

The environmental hazard methodology guide drawn up by the working group provides information and advice on the procedure(s) to follow when carrying out the environmental hazard assessment phase regarding the potential contamination of soils, sediments and surface water and groundwater caused by abandoned mines. It starts by outlining a few major principles, followed by the study of the potential hazards, and their consequences, due to the ore type, the mining and the ore-processing methods. The guide then presents the procedure(s) to follow for qualifying the intensity and predisposition levels when determining and assessing the environmental hazards.

2. Environmental hazard assessment: definition and some main principles

2.1. Definition

Environmental hazard assessment includes phases of identification and qualification followed by the construction of maps localizing and ranking areas potentially exposed to anticipated pollution phenomena.

Hazard assessment requires defining a) the intensity of the phenomenon, i.e. the extent or grade of the pollution likely to result from the anticipated phenomenon, and b) the predisposition that, for its part, reflects the sensitivity of a zone to be affected by one or other of the anticipated phenomena. By crossing intensity and predisposition, the pollution hazard is classified into different levels, generally three (low, medium, high) and plotted for each of the defined phenomena, as illustrated by Table 1 for water, sediments and soil.

Table 1 – Hazard classes for water, sediment and soil pollution

Predisposition \ Intensity	Not very sensitive	Sensitive	Very sensitive
Limited			
Moderate			
High			

2.2. Qualitative approach

The principle of hazard assessment is usually based on qualitative studies using available data archived in the offices of central, regional and local authorities, and also from associations, etc. The objective is, as far as possible, to make an inexpensive and rapid assessment in view of the fact that new measurements, surveys, laboratory studies and computer modelling take time and money. The hazard assessment should follow a naturalistic approach.

Nevertheless, depending on the quality and quantity of the available data, some fieldwork with measurements and analyses is generally required in order to reduce the margin of uncertainty. This acquisition of additional data is planned according to the complexity of the studied pollution, the existing or anticipated risks and the available time and funding.

2.3. Relationship with stakeholders

The environmental hazard assessment, like all hazard assessments, requires the preparation of simple and operational documents intended to be read and understood by the concerned population and the administrative services in charge of its implementation. Consequently, the work has to be completed in consultation and dialogue with all the stakeholders involved in the management of mining risks.

3. Potentially dangerous phenomena

3.1. Origin

Within the framework of environmental hazard assessments of former mining sites, the phenomena that are potentially dangerous to humans and ecosystems derive from natural factors arising from the geological, geological, mineralogical, chemical context of the deposit and also from anthropogenic factors related to the mining and processing methods.

Potential pollution sources from mining and processing operations are mine dewatering, mine runoff, new springs containing water from mining aquifer, waste stockpiles, tailings dumps, low-grade ore stockpiles.

One of the fundamental causes of post-mining pollution and environmental nuisance is the interaction between the mine workings and hydraulic flows leading to soil, surface-water and groundwater contamination.

During the mining phase, dewatering is necessary to stop the mine workings from being drowned. The impacts here are either hydrodynamic with a lowering of the water table and modification

(increase or reduction) of the river flows, or hydrochemical with modification of the water quality although the water is generally (or should be) treated during the exploitation before being discharged into the natural environment.

Certain hydrodynamic impacts may remain after mining has ceased, but these are mainly of a hydrochemical nature related to the artificial appearance of surface conditions (air, meteoric water) that develop. Superimposed on this pollution one may find phenomena generated by the high turbidity of the water during mining and likely to result in a high contamination of the sediments once the mine is closed.

When assessing the pollution caused by mining, a major problem is related to the existence of what is called *the geochemical background* which is generally affected by pollution of anthropic origin. To assess the slight difference between contamination of natural origin and pollution deriving from the mine workings, it may be possible to have access to various measurement data obtained during the prospecting and exploration stages.

3.2. *Physical and chemical pollution processes*

The main mining-derived pollution processes affecting surface water and groundwater, soils and sediments have been determined the main sources and identified pathways that are:

- mine workings (open pits and underground workings);
- mine waste storage;
- storage of hydrocarbon and chemical products.

For example Table 2 summed up these pollution processes for the mine waste storage. The table indicates the physical and chemical processes (leaching, suspended matter transport, etc.) that are involved between the source (mine workings, waste storage, etc.) and each pathway (surface- or groundwater, air transport, human activity factors, etc.). The overall impacts on the four exposed environmental milieus (surface water, groundwater, sediments and soils) can be deduced by taking into account a primary impact arising from direct interaction between the source and the pathway and a secondary impact following the first one.

The arrows in the table indicate the pollution dynamics.

Table 2 – Pollution processes and pathways arising from mine waste storage

Pollution processes and pathways arising from mine waste storage					
		Pathways			
		Underground flows	Surface flows	Air transport	Anthropogenic activities
		Waste and tailings leaching	Waste and tailings leaching and gullyng	Air transport and deposit of dust	Waste and tailings spreading
Impact on	Groundwaters	Pollution by contact between waste- tailings and mine runoff	Pollution by surface water percolation	Pollution by surface water percolation	Pollution by waste-tailings unloading and contact soil/water
	Surface waters	Pollution by mine runoff	Pollution by contact waste-tailings and surface water	Pollution by contact soils / waters	Pollution by waste-tailings unloading and contact soil/water
	Sediments	Pollution by contact between waste- tailings and mine runoff	Pollution by contact waste-tailings and water and suspens matter transport	Pollution by dust fall	Pollution by waste-tailings unloading and contact sediment/water
	Soils	Pollution by contact between waste- tailings and mine runoff	Pollution by contact waste-tailings and water and suspens matter transport	Pollution by dust fall	Pollution by waste-tailings unloading as embankment

Primary impact
 Secondary impact

3.3. Ore type and pollution

There is a direct relation between the ore type and the potential pollution. For the French territory a synthesis has been done and gives region by region the nature of the expected pollutions according to the ore type (Artignan D., Cottard F., 2003). An extract is given in table 3.

Table 3 – Example of relationship between ore type and potential pollution for France's ore deposits (Extract)

Region	Main extractive activity	Type of the potential pollution
Alsace	Salt, potash, Pb-Ag-Cu sulphides	- K, Na, Br n the water, - pH, metals - hydrocarbon in the water and soils
Auvergne	Coal, As-Sb sulphides, Pb-Zn,Ag sulphides, W-Li-Sn oxides, REE, Au, U, CaF ₂ , BaSO ₄	- U in the water and soils - Fluorine in the water - pH, metals - Turbidity, SO ₄ , As
Midi-Pyrénées	Gas, Coal, U, Au, W oxydes, Zn-Pb-Ge-Cd sulphides, CaF ₂ , BaSO ₄ , FE Mn.	- pH, metals - hydrocarbon in the water and soils - Turbidity, SO ₄ , As - Fluorine in the water - U in the water and soils

3.4. Typology of mining-related pollution

Two main types of mining-related pollution can occur during the post-mining period:

- diffuse pollution that affects large areas; this is generally due to the spread of liquid or solid materials or due to dust fallout from atmospheric transport;
- point-source pollution affecting small areas and arising from two main sources:

- accidental and point-source pollution associated with the short-term dumping of polluted mining products or materials. It generates severe damage over a limited area and can have a serious, even a tremendous, impact on the different environmental milieus if not treated rapidly and efficiently —an example is the Danube pollution from the Baia Mare gold mine in Romania;
 - chronic and point-source pollution corresponding to a supply of polluted products or materials over a long period; this is frequently caused by polluted effluents from waste storage, tailings dumps or old processing plants, and also by mine water. The impact is mainly on surface water and groundwater.
- Pollution derived from many point sources corresponding to complex phenomena.

These notions are important because they show that the contaminated area can extend beyond the mining concession or commune boundary and so raise difficulties in defining the study area (perimeter).

3.5. Phenomenon description

To describe the potentially dangerous phenomena it is necessary to take into account the different mining (open pit, underground workings) and ore-processing methods, including the different types of waste storage and tailings dumps with their technical specifications and the potential pollution they can generate in the short, medium and long term. These are summarized in Table 4.

Table 4 - Summary of potentially dangerous phenomena likely to arise in the mining environment.

Mine workings and facilities	Impact on		Contamination of		Generation of	
	Groundwater	Surface water	Sediment	Soil	Dust	Gas
Underground workings						
<i>Underground exploitation</i>						
<i>Saline exploitation by dissolution cavity</i>						
<i>Shaft, Adit</i>						
Surface workings						
<i>Outcrops with small works</i>						
<i>Open pit</i>						
Mine facilities						
<i>Slag and steril heaps</i>						
<i>Tailings dumps</i>						
<i>Area of physical processing (crushing, screening...)</i>						
<i>Area of chemical processing (lixiviation, cyanidation,...)</i>						
<i>Storage of chemical products and hydrocarbons</i>						

 Potential pollution

3.6. Contamination scenarios

3.6.1 Surface water and groundwater contamination

The main contamination scenarios to be considered where groundwater is concerned are: leaching in underground workings, leaching of waste stockpiles, hydrocarbon and chemical product discharges, percolation of surface water towards the groundwater.

The main contamination scenarios to be considered where surface water is concerned include: mine runoff, hydrocarbon and chemical-product discharges, surface-water runoff on contaminated soils, tailings, waste, etc., effluents from tailings dumps, runoff of a contaminated groundwater.

3.6.2 Soil and sediment contamination

Several contamination scenarios must be considered where soils and sediments are concerned are: contamination from pollutants transported by surface-water and groundwater flows from mining waste and tailing dumps, voluntary (or otherwise) displacement of contaminated mining waste or tailings for use as banking material, deposit of contaminated dust, leakage of chemical products or hydrocarbons, contamination through contact with contaminated surface water.

4. Hazard assessment

4.1. *Surface and groundwater pollution hazard*

4.1.1 Intensity

Water management on the scale of Europe and France is controlled by a series of directives, laws, acts, decrees, and circulars that have to be taken into account when assessing intensities and hazards. Among other things they define the concept of 'good water status' and provisional Environmental Quality Standards (EQSp), and give the list of substances involved (dangerous, priority, to monitor) in assessing the state of the aquatic environment with values not to be exceeded in order to respect the 'good water status'.

Knowledge of the "background level" and the EQSp is essential for determining the maximum permissible concentration for the environmental milieu. The EQSp are given in Circular 2007/23 or can be calculated from the background level. The background level is either measured directly upstream of the concerned site or estimated on the basis of best available information concerning the concentration of the monitored element in the same type of natural environment but with little anthropic pressure.

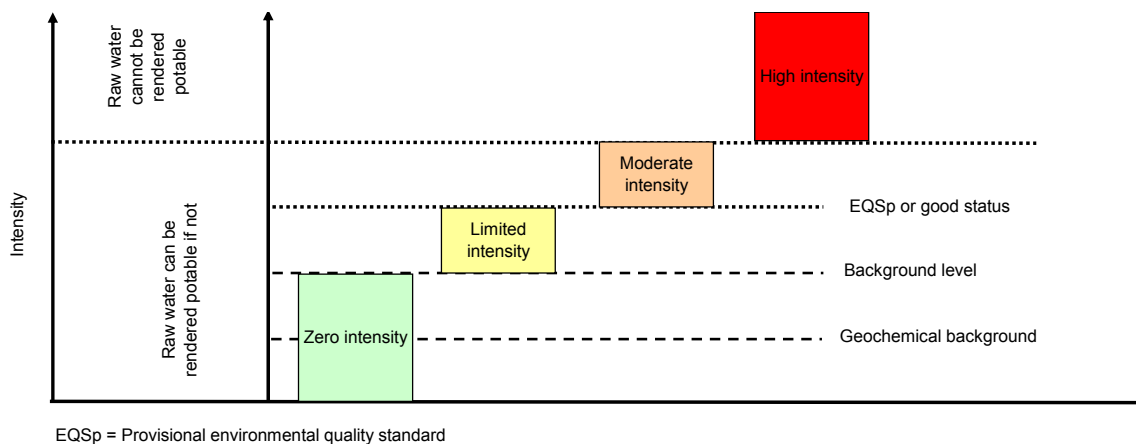
Determining the different levels of concentration can be tied into:

- whether or not the water complies with the "good status" as defined in Circular DCE/2007/23 dated 7 may 2007;
- whether or not specific requirements are respected;
- whether or not there is a deterioration of the reference values characterized by an exceeding of the background levels;
- the influence of the measured values on rendering the raw water potable (Decree of 11/01/07).

For example, the intensity scale can be constructed on the basis of criteria such as those defined in Table 5. This approach is likely to be adjusted by the person in charge of the study so as to take account of the local situation where certain criteria may not be relevant.

A zero intensity is defined by values equal or lower the background level.

Table 5 - Proposed intensity classes for water for one given chemical element



4.1.2 Qualification of the predisposition for potential water pollution

The main factors that can be used for the classification of the predisposition are summarized in the following table 6 for the surface water.

Table 6 – Surface water predisposition factors and classes for surface water

Surface water predisposition			
Predisposition factors	Predisposition classes		
	not very sensitive	sensitive	Very sensitive
Chemical conditions	According to the pollutant		
pH acid, neutral, basic			
Reducing or oxidizing context			
SM abundance			X
Known previous pollutions in the same context			
Yes			X
Non	X		
Known pollution sources with mobile pollutants			
Yes			X
Non	X		
Uncertainties on the data, on the phenomenon	According to the pollutant and the previous conditions		
Phenomenon			
Generalised			X
Intermittent		X	
Limited	X		
Hydrology system (Drainage size, flow rate, pluviometry...)	According to the flow rate ratio between the source and the receptor		

The same kind of table is used for the groundwater

4.2. Soil pollution hazard

4.2.1 Intensity

In the case of soils, the concept of intensity is closely related to the concentration of one or more chemical elements (Pb, Cu, As, Hg, Cd, etc.) present on the site and having an impact on the environment and man. The intensity classes can be defined by taking into account, for each chemical element concerned:

- its exceedance of the natural geochemical background;

- certain physico-chemical parameters influencing the mobility of the concerned pollutants, such as reactivity, chemical mobility and physical dispersion;
- ranges of 'ordinary' values and of natural anomalies in the soils provided by INRA;
- the Interpretation of the Environmental Status (IES) developed within the framework of the new contaminated land management policy.

In any event, an expert opinion is necessary at this stage because each selected tool and parameter must be used critically and with care in order not to over- or underestimate the gradation or the intensity level.

It is possible to establish intensity classes according to the principle of Table 7.

A zero intensity will be characterized by values that do not exceed the natural geochemical background, excluding the values coming from the source of identified pollutions.

Table 7 - Soil pollution: intensity classes

Intensity classes	Alteration criteria
Limited	Values exceeding the geochemical background and close to the high natural anomalies but without harmful effect on human and the environment
Moderate	Values exceeding the high natural anomalies without harmful effect on the human and the environment
High	Values exceeding the high natural anomalies with potential harmful effect on the human and the environment

4.2.2 Weighting the intensity

The intensity is related not only to the concentration value of the selected chemical elements, but also to the granulometry and mineralogy of the concerned materials, the chemical soil conditions (pH ...) and to the bioavailability/bioaccessibility of the chemical element concerned. As these factors can be regarded as intensity multipliers or dividers, it is proposed to weight the intensity level by applying a purely qualitative step based on expert opinion

4.2.3 Qualification of the predisposition for soil

The principal predisposing factors are:

- the physical accessibility of the materials;
- the permeability;
- the abundance of adsorbent phases;
- the chemical conditions of the soil;

- experience feedback (existence of historical or observed pollution in similar contexts);
- the existence or influence of a spring with mobilizable pollutants

4.3. Hazard mapping

One of specificities of the 'water and soil pollution' hazard is that it is able to affect areas that, sometimes widely, extend beyond the area of the mine workings and even of the concession. In fact, the contamination derived from mine workings, insofar as it impacts surface water and groundwater, and also sediments, a priori concerns the entire catchment basin and its structure.

As regards soil pollution, the contamination can also extend beyond the mine site, but over a more limited area, even when one takes into consideration the dispersion of contaminated dust.

Practically, according to the observed and assessed situation, one can have recourse to several types of graphic document. The choice is left to the specialist responsible for drawing up the MRPP documents. He can thus compile a hazard map for each type of phenomenon, which is justified by:

- the great differences between the contaminations in terms of extension, which can justify maps at different scales.
- the level of homogeneity and coherence which needs to be respected in order to provide a comprehensible map.

In many situations the difficulty is in finding a limit to the extension of the pollution phenomena which sometimes extend beyond the boundary of the mine sites, communes or MRPP perimeters. Links have to be established with the "flood" risk for the extension of floods and their relationship with pollutant dispersion. Similarly, in the event of tailings dam rupture, it is necessary to assess the dispersion of the mud.

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