UNIVERSITATEA BABEŞ – BOLYAI
FACULTATEA DE ŞTIINȚA MEDIULUI

OANA – CRISTINA MODOI

INTEGRATED MANAGEMENT OF MINE WASTE RESULTED FROM THE ORE EXPLOITATION ASSOCIATED TO BAIA MARE METALLOGENETIC PROVINCE

PhD THESYS

(Abstract)

Scientific supervisor:
Prof.univ.dr. Şerban – Nicolae VLAD

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Contents:

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Introduction

A connected activity of the exploitation of mineral resources and one that at the same time has a significant impact on the environment is the storage of mining waste that results from the exploitation of mineral underground deposits. It is a well known fact that useful mineral deposits are present in the Earth’s crust associated with other non-valuable minerals, but very often require extraction together, due to technical and stability considerations, consequently to the fact that these waste-rock are most of the time intercalated in the pay ore. These non-valuable minerals are generally known as barren gangue, becoming mining waste, after the separation from the pay ore. The correct management of these mineral wastes is one of the greater challenges of the mining industry, due to its high demand of financial resources needed in the handling and storing process, and due to the significant impact on the environment and the risks generated along with the entire process.

Mining waste management consists of an ensemble of different activities that converge towards to the same purpose, reducing environment pollution, due to the waste storage in the studied region. In order to adopt the most efficient management solutions for this area, the present study investigates the region from a geological point of view, presents the geographical characteristics, emphasize the possibility of unusual phenomena to occur with a potential to produce natural hazards. Given these circumstances, next, technical characteristics, site characteristics, chemical and mineral composition are described. For the same purpose of implementing the best solutions regarding mining waste depositing management, the study makes an assessment on environmental impact and environmental risks that may occur due to the presence of these deposits in the studied area, taking into account the geological structure of the soil, the permeability of the sedimentary upper seam and the probability that stored tailings could produce acid drainage. By processing this information, an analysis of the possible ecological rehabilitation is done, the study also belonging to the Baia Mare Preparation Plant, Central tailing dams, which has a sufficient concentration of pay ore in their composition, so that it can be recommended as poor mineral waste dumps, that can be then re-processed under economical efficiency conditions.

The thesis is structured in 8 chapters, as following:

- First chapter presents general information about waste resulted from the ore exploitation, about the environmental impact generated by these waste dumps, ways to manage mining wastes contextually of sustainable development, emphasis the importance of waste management as a key in environmental management. In this chapter there are references to national and European legislation regarding sustainable development, mining waste management and the best practices in environmental management systems in mining.
- The second chapter presents the reasons for having chosen the Baia Mare region as the studied region, followed by the display of some information concerning the geography of the area, the morphology of the land – including here, human made land use, characteristic to mining activities – also specific climate phenomena – underlining precipitation particularities (concentrating here more on the quality and characteristics of the precipitation that on the quantity) – to the main characteristics of soils in the region, to water resources and the region's biodiversity. The chapter continues with the presentation of the region's general geology, followed by highlighting of the existing mineral ore and surrounding rocks, which form the tailings, focusing afterwards on the formation process of the Baia Mare depression

and the sedimentary rock blanket, the superior part of this blanket represents one of the pollution receptors which accidentally infiltrates from mineral waste deposits.

- In chapter three, details how tailing heaps are placed within the Baia Mare region, lithologic characteristics of the soil on which the tailings are deposited, technical features of the mining waste deposits, also the chemical and mineral composition of the tailings included in this study.
- The fourth chapter is dedicated to the assessment of environmental impact, which is generated by mining waste dumps in Baia Mare. This environmental impact assessment bases on the characteristics of the tailings, estimating the possibility that these tailings might be able to produce acid drainage (ARD), the migration and accumulation of pollutants in the environment, through interpretation of the tests conducted on tailings, soil and water, all of these taken from the heaps and their proximity. The assessment of the impact that mining waste dumps have on the environment is done by comparing the results of the tests with the maximum accepted concentrations that are presented in the legislation, also keeping track of the natural background existent in the studied area.
- In chapter five, environmental risks related to the existence of waste dumps generated by the mining industry in the Baia Mare region are studied, revealing the extreme natural phenomena and technological accidents, and the effect the two may have, if combined- accidents that may occur at the tailing dams. These accidents can have bad repercussions which will very likely affect the environment, human life and human health.

  The analysis and assessment of environmental risks is done by identifying possible risk scenarios, their quality analysis with the risk matrix (probability-consequences), evaluation of the consequences and measures proposed for reducing risks in the studied region.
- Chapter six propose the measures for the ecological rehabilitation for the mining waste dumps existent in the Baia Mare area, taking into account the effective stage in the life cycle of these deposits. In this chapter the necessity and opportunity for a reconstruction is presented, also proposals and recommendations concerning the ecological rehabilitation of mineral waste dumps from this region. The reconstruction measures based on the tests and evaluations done on the degree of pollution in the environment that has been presented in the preceding chapters.
- The seventh chapter of this study reveals a life cycle assessment for waste mining deposits, with the example of a new life cycle for an old tailing heap which can still be used as a poor mineral deposit, which may be exploited once again for what it still contains. Therefore, is proposed, that as a sustainable option, for an old mining waste dump, reprocessing the Central tailing dam from the Baia Mare region, by doing this the remaining metals from the deposit are extracted by using modern and currently available technologies. Reprocessing the poor mineral from old waste dumps is an integrated activity in the environmental management program, generating economical and ecological benefits.
- In the last chapter, chapter eight, we deal with the integrated management system of the mining waste from the Baia Mare region whose purpose is the reduction of pollution in the environment that has been generated by the existence of waste deposits, through closing and rehabilitating them adequately contextually a sustainable development of the region. The management proposed for the tailing

heaps in the Baia Mare region is done by taking into account the morphological and mineralogical characteristics of the studied deposits, the lithology of the soil on the surface and under the deposits, the distance from potential receptors, the legislation and not least the decision factors (the environmental authority in collaboration with the owner of the deposit) and the public interest (local and regional community that could be affected). In this context, the solution for each deposit is presented and motivated, then followed by the proposal for the monitoring schedule and finally the presentation of the conceptual model proposed for the integrated management of mining waste in the Baia Mare region.

The mining waste deposits from the Baia Mare region are currently in closure/conservation or post closure stage, so the management solutions need to be limited to this situation. The proposed mineral waste dumps management is focused on assuring physical and chemical stability of the deposits by adopting ways for leveling slopes, reducing the general deposit angle, complete drainage system and passive treatment of acid drainage.

1. Mining waste management – theoretical premises

One of the main goals of the mining industry is, satisfying the demand for resources of the society, in order to continue the development of infrastructure or production of goods which increase the population's quality of life.

No matter what method for recovery is chosen for the mineral ores, numerous and diverse operations will be required. These operations, of a physical or chemical nature are used to obtain raw ore and then used for the concentration and refining of the mineral.

As a result of these operations, we have, useful mineral substance and tailing, which can vary from 25-90% (sometimes even more, in the case of precious or rare metals) from the total of extracted rock.

However, it is a known fact that the mining industry is, on a worldwide level one of the principal sources of waste production, the surfaces occupied by the tailing heaps being very large.

Adopting best practices in mining, means, adopting an environmental management plan by the mining companies and best practices regarding the communication with the local communities, regarding accident prevention, decisional transparency, publication of annual reports that are accessible to the public, ongoing social dialog, implementing the newest technologies and collaborating with the research-development sectors and profiled universities towards the growth of performance standards and insuring that projects and investments have a reduced impact on the environment.

2. Region selection: Baia Mare

The mining industry has been meant for Baia Mare and their inhabitants one of the main resources and at the same time a traditional occupation that has been passed on for centuries. The waste deposits resulted from the exploitation of mineral resources situated on the administrative territory of Baia Mare, take a important part of terrain, that this way is taken out of usage in the field of agriculture and other uses for a long time. Mining waste from the studied region consists of tailing from exploitation, tailing that comes from preparation plants, traces of different granulations minerals, different compositions and often with a high dangerous potential. These deposits represent a constant pollutant for the environment in the studied area, and a potential risk source for the environment and the local community.

Starting with these premises, the necessity of adopting an integrated management plan for mining waste, according to the legislative demands and also with the current responsibilities taken by the companies concerning the environmental protection, including for the future generations, is necessary.

We will go on to studies the adequate solutions for reducing the impact on environment and population caused by the mining waste deposits resulted from the recovery of minerals, finally a scheme for a integrated management for these wastes is proposed.

The proposed structure for the realization of integrated management of mineral waste deposits from the Baia Mare region contains the stages shown in fig. 1.

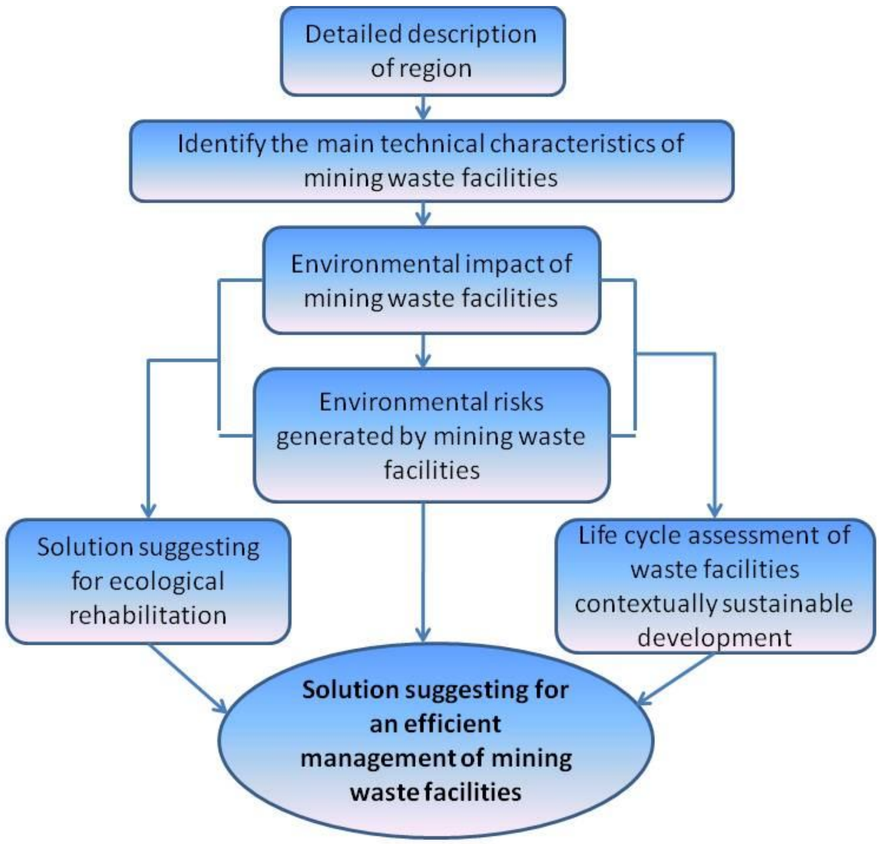


Fig. 1. The stages that need to be underwent to realise an integrated mine waste management in the Baia Mare region.

Baia Mare is placed in the western part of Maramureş County, the city occupying partially some of the depression area, also the mountainous northern part. So, Baia Mare is situated at the contact zone between the Baia Mare depression and the Ignis Masive, at an altitude of 194 m above sea level.

Baia Mare County is based on a rather wavy geomorphology, made from a complex of hills with altitudes between 450-800m, separated by the tributaries of the Somes, Lapus and Sasar rivers. The entire area has a kind of amphitheater aspect, with a large opening towards the west, while on the northern side the Ignis and Gutai mountains lie.

The relief made from human activities in Baia Mare is represented by a distinct unit in the landscape of the area due to the mining activities that have been taking place since the oldest times and that have produced important modifications in the landscape, affecting every single component of the environment. (Filip, 2008)

The form of relief diversity determines, also, a great climatic difference, concerning the precipitations aspect, which may be one of the most important links in the water cycle in nature.

The practical value of precipitations consists more in their character rather than the quantity. When presenting a moderate intensity, the water infiltrates in the soil very deep, but when torrential rain occurs, a big part of the water does not manage to infiltrate, and remains flowing on the surface.

The climate characteristics of the area, together with the precipitations regime and direction and intensity of winds are climatic phenomena with a deciding role in the placement of the mining waste deposits. The precipitation characteristics influence also the intensity of erosion phenomena at the surfaces of tailing dams, those that contain fine particles of tailing.

On Baia Mare's surfaces there are the following classes of soils: luvosol, cambosol, interzonal soils. (OJSPA Baia Mare, 1995, Damian F., et.al.,2008). The soil in Baia Mare region has been formatted on the volcanic bedrocks specific to mountain area from north and north-east part and on the sedimentary rocks from depression area, constitute from clays minerals, marls, alluvial deposits as sand and gravel. (Damian, F., et.al., 2008)

In Baia Mare area, due to the rich precipitation all along the year, the surface water are rivery, and are grouping in two catchments: Someş river and Lăpuş river.

Lengthwise Baia Mare area flows the Săsar River, tributary stream on right side of Lăpuş River. Săsar River sweeps the town from Est to West and collect the Chiuzbaia and Firiza rivers and Sfântul Ioan, Racoş and Borcuț creek.

The ground waters from the depression are directly influenced by the presence, in the bedrocks of depression, of argillaceous marl with purple colour, pannonian age over lying newest alluvial formation. In the town, groundwater is finded in two layers: phreatic water and depth aquifer. The phreatic layer is encounter in the Săsar River terrace and in Baia Mare slope glacis. (Ujvari, I, 1979)

Because we are in a contact zone between plain, hills and mountain, the vegetation in Baia Mare consists of plants characteristic to all this relief forms: plain, hills, and mountain.

The investigations realized in time to the lopolith and the mineral prospecting in the Gutâi Mountain area guide to the evolution of conception concerning the characteristics and deployment of magmatic process. The first investigation has marked out only the existence of volcanic processes, ulterior, has marked out an intrusive activity too, concretize by sub volcanic corps.

Actual image concerning to the Gutâi Mountain magmatic process was completed through markt out, on base on geophysics data to a plutonic in the region foundation. Cycle and eruption phase delimitation and district and metallorgenetic phase delimitation represented an important stage in understanding of magmatic and metallogenetic process evolution. The ulterior investigation, based on modern analizys begins from this conception, updating and improving this conception.

On the strength of paleontological contents of sedimentary deposits from the Gutâi Mountains, the beginning of the sedimentary phases was placed to the beginning of middle Miocene. The sedimentary process has been continued, with some locals or regional interruption until in Pannonian or in Pontian and actually in Pleistocene. That fact that radiometric ages of rocks indicate a cease of volcanic activities in Pannonian (Pécskay et al., 1994) suggest a reconsideration of sedimentary formation ages find out in direct relationship with volcanic, considerate younger than Pannonian age.

Sedimentary formations from inferior Badenian age, localized in the south –west of the Gutâi Mountains are dissonant disposal over the Paleocene flysch formations belonging to the Pienides. These formations appear in direct relationship with primary acid piroclastics rocks and re-sedimentary, and from lithologic point of view there are representated from clays, marls, sansdstones and alternate bands of micro conglomerates and limestone.

The upper Badenian is represented from clays, marls, sandstones and limestone, the same ages formations having the same areal extinction. Nearby Baia Mare basin the detritic character became more evident, and the alternate band of piroclastic material is more abundant.

The Sarmatian sedimentary deposits are disposal over the Badenian deposits in continuity or discordant, too. From lithological point of view, the Sarmatian is a compound of clays, marns and sandstones. The first formations from the Sarmatian are from inferior Volhynian age and are prevailing in the south – west and south-east of the Gutai Mountain and Maramures basin. The formations of Volhynian – Bessarabian inferior age constituted from clays and sandstones alternances represents the main part of succession of sarmatian sedimentary deposits. Those formations are widespread in all region of Gutâi Montain.

Over the sarmatian deposits there are discordant disposed pannonian sedimentary formations with a lithologie represented of: clays, marls, sands, sandstones with conglomeratic alternates bands. The age of those deposits considered to have a transgressive character is Pannonian Superior. The pannonian formations are majorly widespread in the east part of a Gutâi Mountain region (the zone of Baia Sprie – Cavnic – Băiuț). The sandstone horizon descript on the top of succession of pannonian deposits, preceding was considered of Pontian age. The newest sedimentary formations (Pannonian superior – Pontian – Pliocen), represented from clays, marls and sands with alternates bands of coal was reconsidered to be Pannonians, too.

Due to their rich content in metals, metalliferous vein was considerate a long time, the most important metalliferous concentrations. The progress in the geological and technological field, from 20th century favourized the graded introduction of massive sulfides minerals or of porphyry minerals in the economical circuit, determined significant mutation in gemology, without minimized the importance of minerals ore concentration.

The veins in Baia Mare region have frequently a characteristic disposal on upright, with Au-Ag on the top, Pb-Zn on the middle and Cu enrichment to the depth. Usually, the surface change around the vein is well represented and underlined of potassic new-formations (frequently adularia) and / or filitic new-formations (frequently sericite) around argilice veins or advanced argilice in superficial section and propilitic to the periphery, that last one having, often a generalized character. (Vlad, S.N., 2005)

The definitive characteristic of Carpathian metallogenesis in Baia Mare metallifer region consist in the predominance of endogenous typology, involved, with major ponderosity the Neocene volcanic. The units are represented from volcano-plutonic complexes, and the associated digging (next to the Gold Quadrilateral) are recognized around the world for the richest gemological data offered and for the quantities of noble metal that was exploited.

Baia Mare depression was born after dipping of an area from transcarpathian flysch zone and an area of post tectonic cover of crystalline intermediate from the west part of Maramures County. Baia Mare depression has evolved, in the same way, from Badenian to Pliocen.

On tectonic point of view, Baia Mare Depression do not present some complication, but the foundation, segmental in blocks has influenced the sedimentation process, especially concerning the thickness of deposits. (Mutihac, V., 1990)

In the region are described over 400 species of minerals, some of them was discovered here for the first time (ex: andorit, dietrichit, rhodonite, black tellurium etc.). Over 100 minerals arise in Baia Sprie and Cavnic digging. (Borcoş, 1968).

3. Identification of main technical characteristics of mine waste deposits from Baia Mare region

The description of the geological structure of the area was realized to determine the tailing types that, were exploited together with pay-ore. The useless tailing from an economic point of view, was stockpiled on the earth surface in mining waste deposits, that derived from exploration and/or exploitation, or derived after processing in the preparation plants.

The assessment of soil pollution for determination of the possibilities of migration of the pollutants in the soil – subsoil and aquifer is realized from geological environment investigation, especially of soil lithology, for determined their structure, texture, permeability, geochemical characteristics, respective the possibility to interact with the pollutant resulted from mine waste deposits. Knowing the soil lithology, it can forecast the soil capacity to retain the pollutants or to allow their migration in the depth to the aquifer and their drainage characteristic that influenced directly the physical stability of deposit.

The locating of studied mine waste deposits from Baia Mare area are illustrating in the figure no 2:

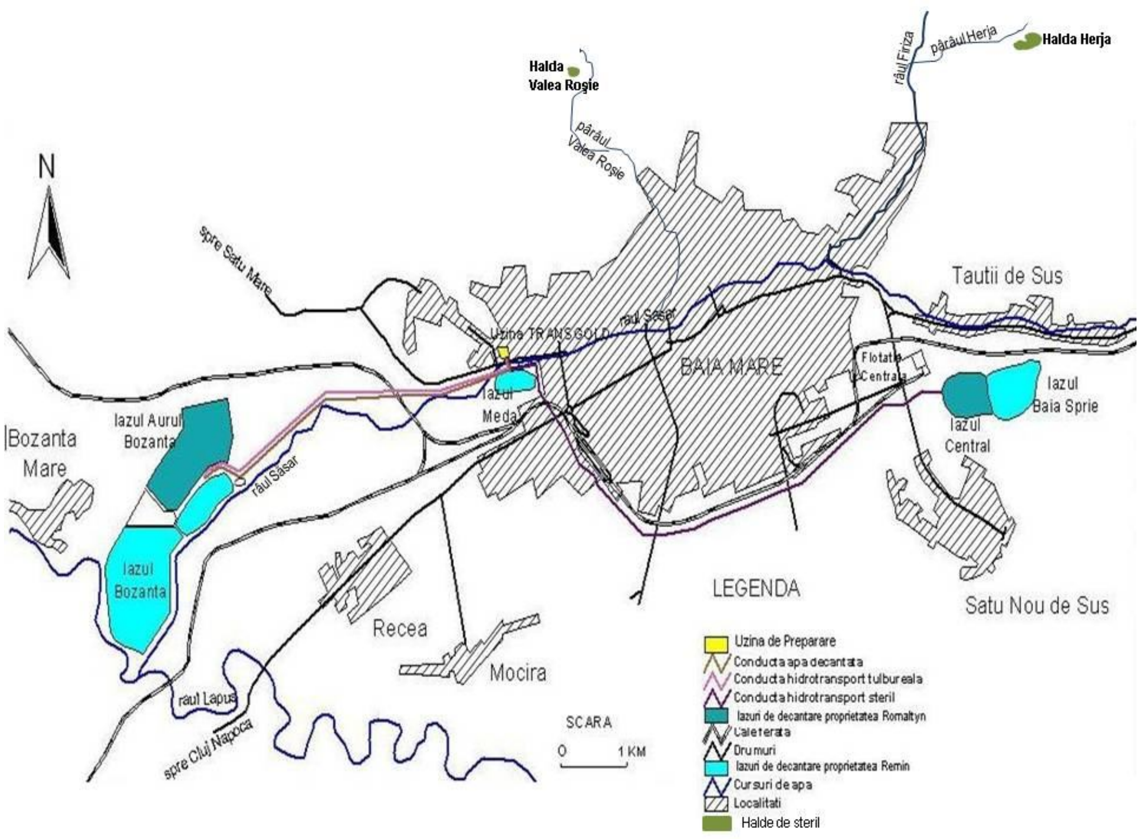


Fig. 2. The locating of studied mine waste deposits from Baia Mare area

The main technical and structural characteristics of the mining waste deposits analyzed are shown in table no.1.

Table 1. Technical and structural characteristics of the tailing dams (Source: The presented data were collected and assessed from EPA Maramures)

Crt No.	Tailing deposits	Begin-ning year	Closure year	Surface	Volume of deposited tailings	Provenience of tailings
1.	Aurul Tailing Dam	1999	2006[a)]	89 ha at the base	5,3 mil. tonnes	Flotation tailings (tailing exploitation on Meda tailing dam)
2.	Bozanta Nou Tailing Dam	1976	2006	105 ha at the base/ 60 ha top of the dyke	43,59 mil. Tonnes	Flotation tailings + waters from Săsar mine; At the moment sludge from the municipal wastewater treatment plant
3.	Bozanta Vechi Tailing Dam	1972	1982	15 ha top of the dyke	8,5 mil. tonnes	Flotation tailings
4.	Central Tailing Dam	1962	1976	48 ha at the base/ 39 ha top of the dyke	8,9 mil. tonnes +80 thousand tonnes arsenic pyrites	Flotation tailings; + arsenopyrites (in 2004)
5.	Tăuţii de Sus Tailing Dam	1962	2006	48,6 ha at the base	13,7 mil. tonnes	Flotation tailings; + waters from Baia Sprie mine
6.	Herja Tailing Heap (mine precincts) -old tailing heap -new tailing heap	 1960 1975	 1997 2001[b)]	 0,45 ha 0,16 ha	 11 250 m^3 5 260 m^3	Tailings from Herja mine
7.	Valea Roşie Tailing Heap	Before 1990	Before 1990	0,6 ha	44 300 m^3	Tailings from exploration, IPEG

a) Aurul tailing dam has been temporarily closed in 2006, at the moment being under preservation conditions.

b) The new tailing heap of Herja mine has been considered an active one until 2008, even though after 2001, the tailing coming from Herja mining exploitation has been deposed in the underground, for the back filling of the exploited spaces; the deposition of tailings on the heap after 2001 has been discontinuous.

From the mineralogical point of view the mining waste deposits in the analyzed area have the following composition:

- ✓ Tailing minerals: in particular – quartz, feldspar, amphiboly, pyroxenite;
- ✓ Carbonate;
- ✓ Clay minerals;
- ✓ Metal minerals: mostly metal sulphides: pyrite, pyrrhotite, marcasite, chalcopyrite, arsenopyrite, galena, sphalerite;
- ✓ Secondary sulphide minerals: secondary minerals of iron, HOF, created on the amphiboly and pyroxenite; (Benciu, 2007)
- ✓ Metal slag.

4. Environmental impact generated by the presence of mining waste facilities in the Baia Mare area

The environmental impact of mining waste facilities is generated in all life cycle of facilities: before construction, in the operational phase, in the closure and post-closure phase of mining operation. Environmental impact includes: move away the vegetation, construction of infrastructures and access ways, using the land with the major quantities of tailing resulted from the exploitation and preparation of mineral, that will be deposed in waste heap and tailing dams, excessively using of water resources and acid rock drainage, destruction of naturals habitats and a lot of pollutant emission, in different forms in the environment.

The environmental impact generated by mine waste, waste heaps or tailing dams is associate to:

- Land under deposits and their geomorphological characteristics;
- The dimensions of affected area and the deposit influence in the adjacent area, include there the possibility of tailings slip;
- The emission of contaminants in the environment that on the airy way, or transported in the water stream contaminate the soil, subsoil, aquifer, and surfaces water, generated also, a negative impact also, to the biocenosis and to the human health.

The contaminants resulted from mine waste, released in the environment, are the consequences of sulfide minerals that exist in the mining waste. The tailing facilities resulted from exploitation and preparation of metallic minerals (Cu, Pb, Zn, Au - Ag, Fe) abound in sulfide mineral, that determine imminent expose of sulfides to weathering condition, in the presence of atmospheric oxygen. The expose of the sulfide minerals to the weathering condition in the mining waste deposits will generate acid rock drainage, ARD, and will release the metals ions in solution, and will determine their migration in the environment.

In order to characterize the state of the environmental factors in the proximity of the mining waste facilities in the Baia Mare region and to concisely assess the impact on the environment due to their presence, there have been taken several soil samples, tailing samples and water samples in the analyzed area, as follows:

- Tailing samples from the tailing dams in the analyzed region;
- Tailing samples from the analyzed tailing heaps;
- Water samples analyzed in situ for the tailing dams and drainage canals of the dams;
- Surface water samples from the streams in Baia Mare, upstream and downstream of the location of the waste deposits;
- Sediment samples from the streams, in the same locations as above.

In addition, from the monitoring data of the Environmental Protection Agency Maramures, it was done the interpretation of the following determinations:

- Pollutant concentrations in soil, in the proximity of the tailing deposits (tailing heaps and dams) in the analyzed region;
- Groundwater samples from the hydro monitoring drilling in the proximity of the mining waste deposits;

The analysis of the samples has been done in the laboratory (RENAR Certified) of the Research and Analytical Instrumentation Institute, ICIA, Cluj Napoca, using:

- ✓ X rays fluorescence spectrophotometer, to determine the chemical composition of the tailings;
- ✓ Spectrophotometer of atomic emission in plasma inductively coupled, ICP-OES, to determine the pollutant concentrations in surface waters;

- ✓ Spectrophotometer of flame atomic emission Perkin Elmer 3030B (IU-06), to determine the concentrations of the elements from the river sediments;
- ✓ -In order to determine the parameters which modify their value with the microclimate conditions (temperature, pressure, conductivity, pH, redox potential, total dissolved solids) the water samples were analyzed in situ using the electrochemical analyzer type WTW Series Multi 720.

It is important to note the fact that the tailing dams in the analyzed region are situated in the proximity of some surface water streams. An explanation for choosing the location the analyzed tailing deposits can be that the foundation land being constituted out of alluvial deposits (gravel) from the river banks, assures a good drainage with positive consequences in what is concerned the physical stability of them. The issue that is brought up is that the infiltrations and seepage of acid waters from the deposits are not entirely collected, fact that leads to the pollution of soil, subsoil, groundwater and surface water from the vicinity.

The tailing analysis from the tailing dams done with the XRF spectrophotometer highlighted important concentrations for sulfur, some metals- copper, zinc, lead, manganese, cadmium, cobalt, chromium etc. and metalloids- arsenic, antimony.

The accumulation of metal ions in surface waters is quite important (fig. 3) classifying their quality, in more sections, in inferior quality classes. Thereby, due to the zinc and cadmium content, the Sasar River falls into the 5th quality category, and the arsenic content classifies the surface waters in the 3rd and 4th category. River sediments sampling was done from the same locations as for the surface waters (fig. 4). In the river sediments were determined overflows for the concentrations of cadmium, lead, arsenic, zinc and copper. River and sediment pollution have cumulative causes, generated by the mining activities upstream of Baia Mare (including metallurgy) but also by the mining waste deposits in the studied region. It cannot be exactly stated the involvement of each and every activity, due to the fact that the sediments are being swayed away by waters currents, at different distances based on the seasonal variation of the river flow rate.

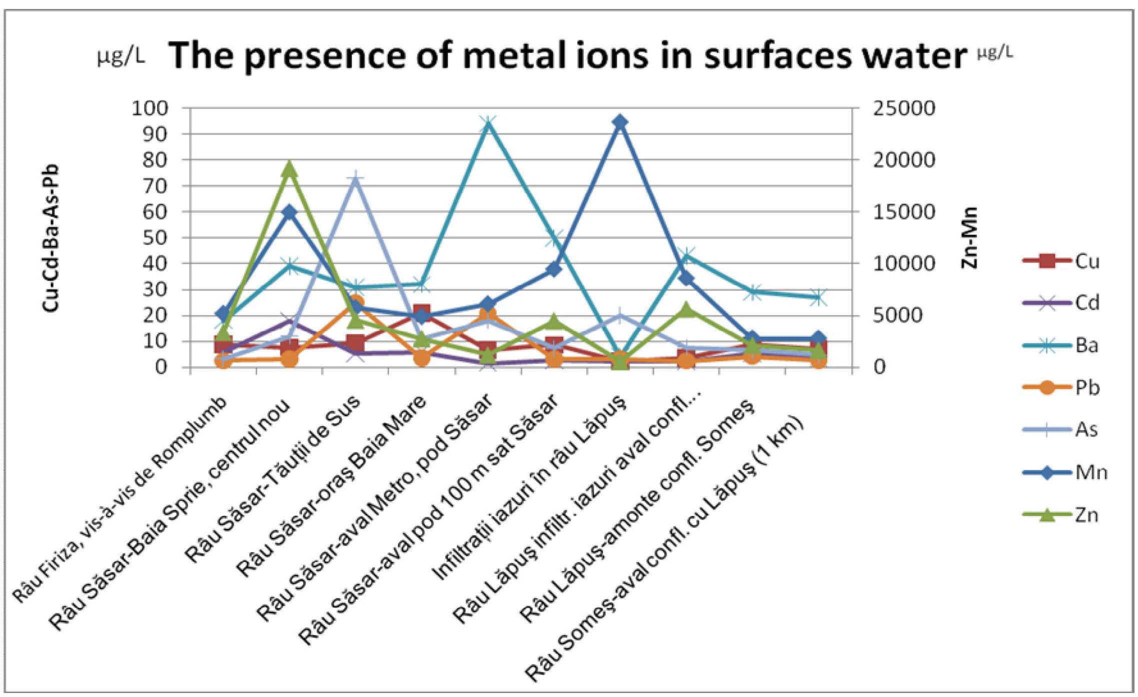


Fig. 3 Pollutants content determined in the surface waters in Baia Mare region

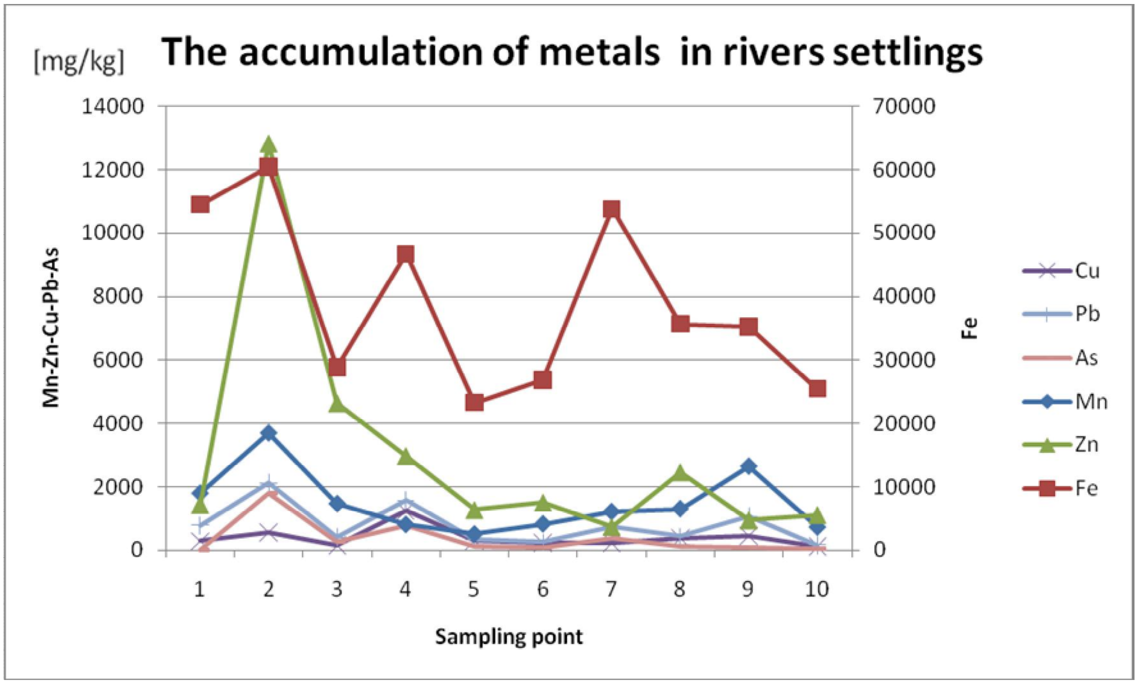


Fig. 4 Metal accumulation in river sediments in Baia Mare region
(the sampling locations are the same as for surface water)

The contribution of waste deposits, from the exploitation of ores in Baia mare region, to the pollution of surface waters is not evidential in the analysis as being significant. The most polluted sample is taken the Sasar river in Baia Sprie (fig. 5) and comes from mining activities run upstream Baia Mare. A mitigation of the water pollution in Sasar river can be noticed by increasing the distance from Baia Sprie town.

For the Lapus river it has been identified a section with an important pollutants concentrations, downstream of the junction with Sasar river, and further on by the junction with the Somes river the concentrations of the pollutants are diminishing (there do not appear other pollution sources, the flow rate of the river increases and implicitly the dilution of the pollutants).

The water acidity raises the mobility and the bioavailability of the elements, respectively the total concentration of dissolved solids. Many of the metals enlarge their ionic solubility in acid and oxidant conditions, even more, metals are not being absorbed at the surface of the solids at a low pH. In many cases the high concentrations of heavy metals in water are associated to acid and oxidant conditions.

Environmental factors pollution in the area of the mining waste deposits is highlighted by the analyzed that were done.

The cyanide was not evidentiated in none of the analyses with values above the threshold values; the explanation is due to the fact that on the mining waste deposits in the analyzed region was not stored anymore leach-ate with cyanide content in the last 3 years, and the cyanide that was there by then has been naturally degraded, by biological oxidation processes to compounds that are not hazardous for the environment.

It is noticed the presence of lead in all soil, tailing, sediment and water samples taken in Baia Mare as well as in all the monitoring reports of the Environmental Protection Agency, having, most of the times values above the threshold limits. The presence of lead in all the samples, including in the tell-tale soil samples, is probably the consequence of historical pollution in the area. The main lead pollution source in Baia Mare area is the metallurgical industry. As a difference of the pollution resulted from the metallurgical industry, the lead pollution generated by the mining waste facilities appears on smaller areas in the near vicinity of the deposits.

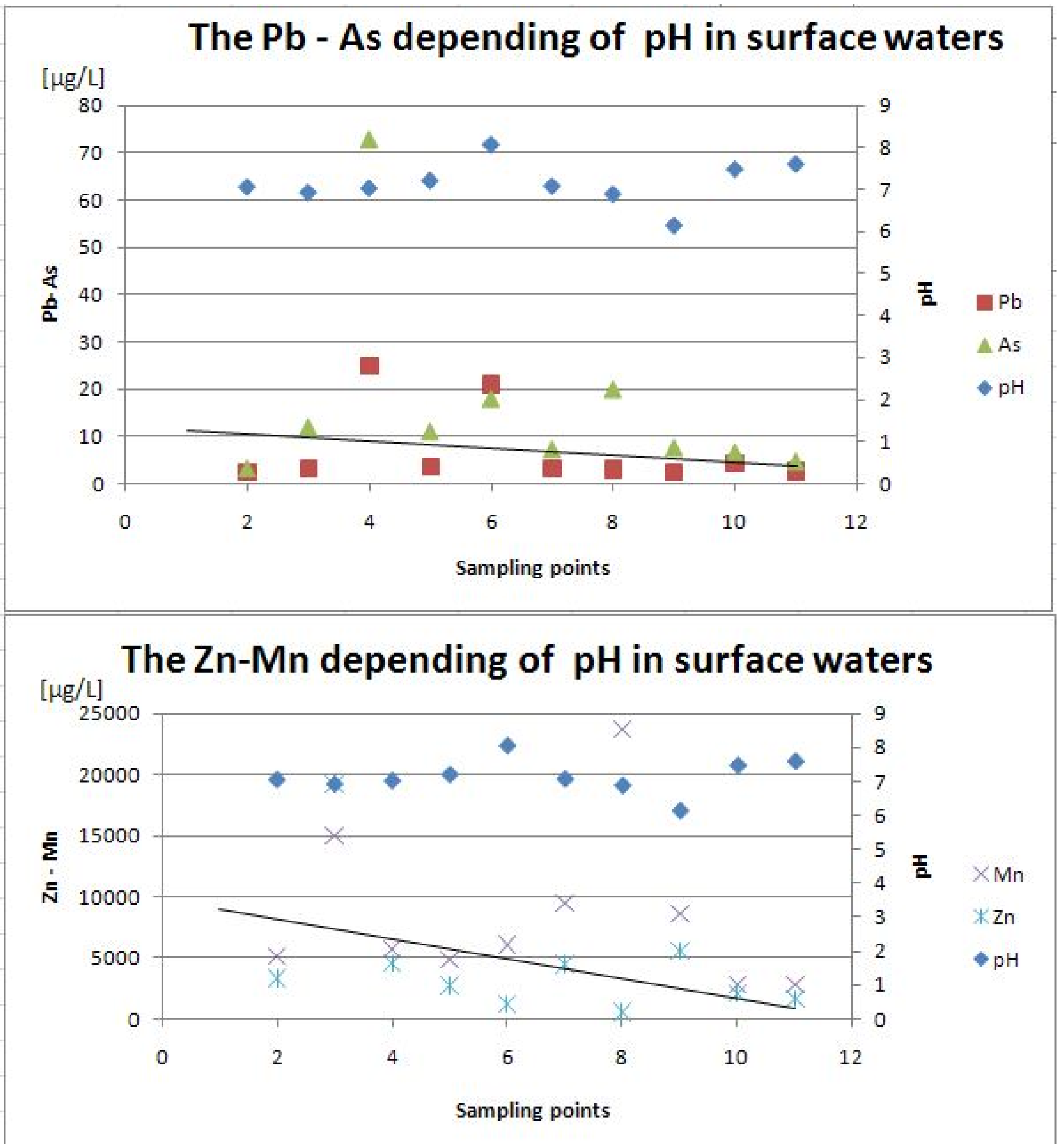


Fig. 5 The evolution of the heavy metal concentrations and the pH variation in the surface water samples taken in Baia Mare region

The mining waste deposits can also produce atmospheric pollution, mainly during longer drought periods, when the fine particles can be carried by the wind and transported towards the nearby area. Covering the deposits with vegetation diminishes this type of pollution up to a insignificant impact (the case of Bozanta Vechi Tailings Dam where it grew plenty of diverse vegetation).

The environmental impact generated by the mining waste deposits in Baia Mare region has been estimated, comparing the determined concentrations of the pollutants from the analyses of the samples or of the monitoring results of APM Maramures, with the threshold values regulated by the present legislation.

5. Risks generated by the existence of the mining waste deposits

Through the way of formation, structure and geomorphological aspect of anthropogenic relief of the mining waste deposits as well as by the way they are located in the environment, often the technological accidents at these deposits that are difficult to prevent, are initiated by natural hazards. These types of accidents are named in the literature of competence Na-Tech accidents, technological accidents triggered by natural disasters and can have as consequences human accidents, including casualties, material damages and negative effects of different intensities on the environment.

Most of the times the causes of accidents at these mining waste deposits are not sole. It exists the triggering cause, but, this does not action independently, it just assures the initiation of the event, afterwords coming a sequence of causes generated by the vulnerable existing points at a certain moment in the deposits' body or of a sequence of natural causes that trigger technological accidents.

The analysis and assessment of the risks for the mining waste deposits in Baia Mare region has been done following the next steps:

- Risk identification for the mining waste deposits in Baia Mare region, resulted from the possible accident scenarios for the mining waste deposits depending on their construction structure;
- Risk assessment for the mining waste deposits in Baia Mare region, using the qualitative assessment method, which offers a general understanding of the risks which can appear and a hierarchy of them depending on the events that are triggering;
- Measures for mitigating the risks for the mining waste deposits, already implemented on the site as well as measures proposed to be adopted for a better management of risks in the analyzed region.

Specific accident scenarios were proposed for the studied tailing dams and tailing heaps. Were taken into account the main receptors in case of accident and it was estimated the probability of an accident to occur using information from the literature in the domain, in the context of the present stage in the life cycle of the analyzed waste deposits. It was created the quantification matrix of risks, elaborated according to the possible accident scenarios that were described.

The results of the risk analysis identified as risks with a high potential the ones regarding the generation of ARD. Acid waters are generated almost for sure from the tailing deposits in Baia Mare region, most of the tailing deposits (except for Aurul tailing dam) are located directly on the soil, without any measures of waterproofing of the base, and the tailings in these deposits have a high potential of generating acid waters.

The scenarios regarding the instability and rupture of the deposit dams are included in the category of moderate risk, because they have low probabilities of occurrence, but if they occur, the resulting damages are major. Generally, these types of accidents take place due to cumulative causes, including technological causes and extreme natural events, the so called Na-Techs. The independent causes have a lower potential of triggering an accident that can lead to the instability or ruptures of the contour dam, because often are shown by collapses, small scale erosions or other clues that can be detected during a daily monitoring and that if remediated in time, can avoid the accident.

Low risk scenarios are the ones that in particular cannot occur in the present conditions, because the deposits are not functioning, but in closure/conservation, respectively post-closure.

Risk reduction measures for the mining waste deposits firstly consist of a correct and complete monitoring of their behavior during time, by endowing all the deposits with specific monitoring equipment, by customizing the monitoring programs and implementing emergency plans, in order to assure the adequate answers for emergency situations for each deposit.

6. Ecological rehabilitation measures for the mining waste deposits in Baia Mare area

The recommendations for the ecological reconstruction of an area needs the assessment of the natural fund often, due to, in the mining regions where the mineral resources are situated at different depths, the minerals can appear as abruptions near the surface, and because of this the natural fund can present high values regarding the presence of some substances in the environment. Under these conditions, the ecological reconstruction and/or decontamination of a surface will not be done at the values of the parameters in the legislation if these are more restrictive then the natural characteristics of the environment in that area.

It has been noticed that the old mining waste deposits in the analyzed region had naturally regenerated, with a minimum involvement of the mining companies. This is the case of the Bozanta Vechi dam and partially of the tailing heaps which are 75% covered with vegetation on the entire surface, but also of the exterior embankments of the other deposits.

In order to do ecological reconstruction for all the mining waste deposits in the studied region it is necessary the endowment with monitoring equipments for the physical stability and for the variation of the chemical parameters. Covering the deposits with vegetative soil is a problem for the mining companies in the area because in most of the cases the soil was not removed before locating the deposit in order to reuse it for the ecological reconstruction. Thereby the soil will need to be sampled and brought from the areas situated in the vicinity without damaging the areas from where it is taken.

Beneath the vegetative soil will need to be assured 1-2 drainage layers which will be reverse filters so as not to allow the raise of the groundwater level in the deposit, above the limit at which it might affect the physical stability. It is indicated to apply a layer of organic matter, as a biotic barrier, a limestone layer for the neutralization of ARD and a geosynthetic filter (geosynthetic membrane) at the contact with the tailings.

The analysis of leaching from tailings facilities (in the chapter 4), set off following:

- In the proximity of mine waste, the collector channels the pH values are both, acid or near neutral values, but for the groundwater samples the pH values are mostly acid;
- pH values for the soil sample near of mine waste is usually acid;
- heavy metal and metalloids concentration in soil samples, groundwater and settlings mostly exceed the values accepted from legislation.

These reasons lead us to the conclusion that the mine wastes from Baia Mare area produce acid drainage, ARD. So, rehabilitation for the mine waste deposits in this area means not only physical stability monitoring, and soil cover of mine waste. It is very important to collect and treat acid drainage result from the waste. The long term solution is passive treatment of acid drainage, used the compound method (biochemical method), with anoxic limestone drain and constructed wetland.

US EPA propose to use natural attenuation for reduced groundwater pollution. Often, intrinsic degradation can be more efficient than some artificial processes with technical remediation of groundwater. If the leaching from mine waste will be collected, the source of groundwater pollution will be put away, perhaps not totally, but sure partially. Monitoring of natural attenuation is a long term process (minimum 30 years, the same with waste deposits monitoring). Natural attenuation depends on the geochemical characteristics of the area, the soil and subsoil process (like sorbtion), and the microorganisms community that exist on the contact surfaces between groundwater and the saturated zone of subsoil can accelerate and enhance the process of natural attenuation.

7. Life cycle assessment – a sustainable option for mine waste management from Baia Mare area

Life cycle assessment is a global and complex evaluation that can help to identify the opportunity of enhance environmental protection aspects, through reducing the environmental impact in different stage of life cycle, can help to decision making as regards economical and ecological efficiency.

Mine wastes management is a principal constituent for life cycle assessment. Thus, tailing management trough life cycle assessment will include alternative options of evaluation for:

- ✓ minimized the volume of tailing, using the adequate method of extraction;
- ✓ marks out and application the opportunities of using tailing in other activities (ex: infrastructures, concrete incorporated, some site restoration or to fill out some underground spaces;
- ✓ complete processing of tailing in plant facilities for extraction all of metals, pyrite separation and add the inactivated material for the tailing.

For the environmental impact the assessment of old mine waste facilities, like the mining waste deposits from the analyzed area that are in different stages of life cycle like operational phase or closing phase, the beginning of evaluation cannot be the design phase, that is it the existing mine waste deposit that already, have been polluted the land under deposits and in the proximity.

It was analyzed another tailing dams from the Baia Mare area, in order to determine the concentration of pay-ore in the tailing rocks, and the conclusion is, that their exploitation could be profitable from economic point of view. It take count of fact that tailing dams has resulted after processing in the Processing Plant, were has used oldest technologies, with low profitability of extraction on pay-ore, was possible that deposits has having enough concentration on pay-ore that, helping new technologies could be extract with economic profit and ecologic benefits from tailing.

An ample study in that direction, was realized for Central Tailing Dams, that together with the arsenopyrites spread on their surfaces and treated with *Acidithiobaccilus,* is economically profitable to be re-processed, thus suggesting a new life cycle for this deposit, as sustainable option to re-use of their tailing content.

Application of multi-criteria analysis for Central tailing dam management suggests the next possible alternatives:

1. No change, continuation of environment pollution in the proximity of tailing dam;
2. Ecological rehabilitation through encapsulated of tailing dams, cover with vegetative soil and treatment of acid drainage;
3. Exploitation of tailing dam, reducing environmental risk associates to the tailing dams and fructify of pay-ore from the tailing contents.

Suggested assessment criteria are:

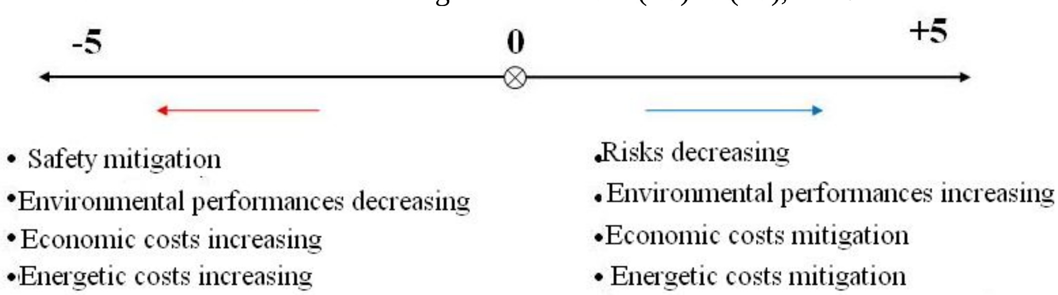
a. Economic criteria;
b. Ecologic criteria;
c. Risks criteria;
d. Energetic criteria.

That result a reasoning matrix like the matrix from figure 6:

Alternatives	**Economic criteria**	**Ecologic criteria**	**Risks Criteria**	**Energetic criteria**
1. No change	0	-5	-4	0
2. Ecological rehabilitation and ARD treatment	-3	+4	+1	0
3. Exploitation of tailing dam and re-use like poor ore source	+3	+3	+1	-3

Fig.6. Reasoning matrix suggested for Central Tailing Dam management

The considerate scale for reasoning matrix is from (- 5) to (+5), thus:



The reasoning used for matrix filling is following:

The reasoning used for matrix filling is following:

- For first alternative (1):
  - On the short term the economic costs seems to be zero, because do not necessitate more intervention;
  - Beyond the ecologic criteria, the negative impact is maximum, because of not using any methods to prevent environment pollution; that will be influenced the economic criteria in the near future;

    - Beyond the risk criteria given (-4) point, owing to human health risks for the inhabitant from proximity of tailing dam, generated by acid drainage in the environment, without treatment; there is also the risk of tailing slip, but this is only a potential risk;
    - Beyond the energetic criteria, actually state does not need energetic consumption.
- For the second alternative (2):
    - Ecological rehabilitation of tailing dam needs important funds that cannot be recuperated at the moment owing to tailing dam condition (without activities from most of 30 years);
    - From an ecologic point of view it means the reduction of environment pollution, and the exigency of acid drainage treatment to an indefinite period of time;
    - Environmental risks decreased and will exist only like potential risk, connected with physical stability of tailing dam;
    - For ecological rehabilitation is not necessary energetic consumption.
- For the third alternative (3):
    - From an economic point of view it will be an increase due capitalization of pay-ore from tailing dam facilities, but will be the operational costs that have to covered: (+5) + (–2) = (+3);
    - From an ecologic point of view, after exploiting tailing dam, the area will be rehabilitated, on the initial form (before the tailing dams construction); the poor tailing resulted, will be deposited on another location; the other location can be the Aurul tailing dams that have enough capacity to stock up all poor tailing resulted after Central tailing dams processing;
    - The risk will be potential, too, and owing to storage of poor tailings waste resulting after re-processing of Central tailing dam, on Aurul tailing dam which, will contain a bigger quantities of waste;
    - Energetic consumption is necessary for tailing processing in Processing Plant.

From multi-criteria analysis perform foregoing, result that re-processing of tailing is more efficient than only ecological rehabilitation of tailing dams. The conclusion resulted is sustained by the fact that, in case of re-processing of Central tailing dam will result economic and ecologic benefits, and for ecological rehabilitation, that means many operational expenses, and only ecological benefits.

Of course, from Central tailing dams re-processing will result wastes, expressly poor tailing, but there are an acceptable solution for their storage, without pollution another unpolluted areas, specially Aurul tailing dams, that detains an enough storage capacity to take in the resulted wastes, in safety condition.

The SWOT analyze to perform for Central tailing dam re-processing conduct to the same conclusion, the economic and ecologic benefits afferent re-processing of Central tailing dams to excel the weakness and the threat resulted from re-processing.

8. Integrated system for mine waste management in Baia Mare area

It takes count of fact that the mine waste facilities from Baia Mare area is, at the moment, closing / preservation or post-closing, the adequate management of them have the purpose, environmental protecting and human community protecting, in this stage of life cycle of tailing dams facilities from Baia Mare area.

In this context, a basis component of mine waste management from Baia Mare area is represented by prevention and control of acid drainage forming, respective for oldest facilities, treatment of ARD, for avoidance / limited ARD migration in the environment. Necessity of prevention, control and treatment of acid water consist in the property of that acid water to release the heavy metals from deposit and to transport them in the environment on different distances, with the possibilities of bioaccumulation and affectation of living organisms.

The production of acid drainage by oxidized of sulfide minerals depending on pH values on deposit wastes, and is slowly at neutral pH values, and increases with decrease of pH to values around 4.5, and intensifies at the pH value around 3.0 (Kleinmann, 1980, Wisconsin Department of Natural Resources Bureau of Solid & Hazardous Waste Management, 1997). pH values determinate in situ in Baia Mare area diversify in the interval 3.25 ÷ 7.91, the minimum values was registered by the water from Aurul and Tăuții de Sus tailing dams, that two dams that has operational until lately.

Responsibility of acid drainage is not only owing to sulfides minerals, but also to the small dimension of particle, that presented a large exposed area to weathering condition and also to the specific microorganism activities in acid environment.

Another important reaction that takes place in the mining waste facilities is the carbonates' dissolution (ex: calcite $CaCO_3$, dolomite $CaMg(CO_3)_2$), that exist nearby sulfide minerals in tailing from mining wastes. Contrarily to the sulfide minerals that produced acidity, the carbonates consuming acidity, ensured, thus the buffering of acid solution. Except the carbonates, there are other minerals that consume acidity, for example, some feldspar, pyroxenite, olivine etc., but their role is less important than calcite in the buffering of acidity (Lapakko, 1994).

The near neutral values of water pH resulted from mining waste facilities from Baia Mare region are the consequence of carbonates existence in the waste facilities and consequence of organic matter contribution (in case of Bozanta Nou tailing dam, dam where it deposes the sludge resulted from purification plant of Baia Mare city).

It dignify the active management constituent of mining waste facilities that ask to realize acid - base balance for assurance of the efficient management on long term and especially post-closure phase. In case of increasing leaching acidity, at a moment, it brings amendments for neutralizing consist in limestone, or lime contribution or other buffering material. Such as, the interception of acid leaching from tailings facilities in post-closure phase to entail the necessity to intervention on the location, for detecting the cause and remedial the arisen issues, in case of mining waste facilities suiting closed and ecologies.

In the same way that other dangerous waste deposits derived from industry, and for mining waste deposits, a well management begins with an isolating the facilities from the vicinities, and from general environment.

For sequestration of mining waste facilities from Baia Mare area, the adequate cover system is the dry one, corporate from successive layers with different granulosity (for operate like filter layers that controlling the increase of hydraulic gradient in the deposit) and different composition (limestone for buffering, clay minerals and geosynthetic for waterproofing). On the surface is stipulated sowing of specific vegetation species, with role of stabilization of the surfaces of deposits and role of slowing / stopping of erosion.

The purpose of using an appropriate waste management is to avoid the stage of acid mining drainage treatment because it is an expensive long term solution witch necessitates maintenance. In the case of old mining wastes deposits, covered with vegetation, when the prevention of acid mining drainage is not suitable, the solution is passive treatment of ARD (as shown in chapter 6)

The physical stability, as well as chemical stability are induced by a complete waste deposit management.

Without proper stabilization, the tailings from the unstable tailing dam are exposed to erosion, gliding, frosting, defrosting, and even to the unwanted action of some plants and animals. Nevertheless, without proper physical stabilization of the waste deposit the prevention of acid mining drainage may be difficult taking into consideration an eventual accident that would induce destabilisation.

For the Baia Mare region one of the most important parameters taken into account in maintaining the dam's stability is the intensity of the usual rainfalls. This is because of the climate tendency of the region characterised by frequent and heavy rainfalls, especially in February and March when the discharge may grow as a result of the melting snow. In projecting the deposit it must be taken into account the characteristics of the slide slopes that need to insure an adequate drainage without intensifying the soil erosion.

For an appropriate rainfall water management at the closing of the waste deposit the surface soil of the deposit needs to be adequately stabilised. The stabilisation of the deposit is ensured by creating the appropriate conditions for vegetation growth on the slide slopes and on the top of the deposits.

The growth of vegetation on a mining waste deposit has a lot of advantages: it reduces the erosion and the possibility of material sliding from the upper part of the deposit, stabilises the side slopes, insures appropriate water drainage and provides conditions for a natural habitat. In order for vegetation to grow, the top of the deposit should be consisted of fertile soil, that needs to be treated periodically with mixed fertilizers.

To guarantee the success of the waste deposit management the implementation of an appropriate monitoring system is absolutely necessary. The deposit needs to be monitories for a period of 30 years. Most of the deposits in Baia Mare area have been closed more or less naturally, based on the capacity of nature to auto regenerate. The studied deposits are currently covered with natural vegetation. In this case the prevention of acid drainage is undue, being necessary an appropriate treatment. The Tautii de Sus tailings dam consists a good example. Despite of being partly covered with vegetation it presents an accelerate erosion and acid water drainage. The water's Ph shown in measurements is around the value of 4.8.

For the tailing dams situated in the eastern part of Baia Mare, the acid water will need a more expensive treatment and a longer term monitoring then the ones on the western part, where water analysis has shown values close to normal.

In the case of the studied tailings hips, differences can be noticed in the compositions of water leaching. On one hand studies show a Ph close to normal for the Herja tailing hip but on the other hand they show an acid Ph for the Valea Rosie tailing hip where treatment of the acid water is needed.

Management measures have been detailed in this paper for every studied tailings dam in particular. After that a deposit monitoring program has been proposed and a general mining waste management scheme has been elaborated for the Baia Mare region. (fig. 7.)

According to the scheme from fig. 7 the most important stages in the mining waste management are:

- Conformation with the currant legislation

- Risk assessment of the waste deposits in the studied region; after quantifying the risks measures are proposed concerning the safety of the deposit and the reduction of ARD generation from deposits.
- Reprocessing the tailings as a sustainable development measure in the studied region
- Improvement in the work of direct operators of the deposit, the monitoring personal and in the use of the best available techniques in reducing the pollution generated by the mining waste deposit.

The purpose and proper realisation of the stages shown above are complete by applying the measures of ecological reconstruction necessary. The evaluation of the performances is established by a continuous monitoring program that assures a sustainable future for the studied mining waste deposits.

The actors involved in the realisation and implementation of this integrated waste management program are: the mining operators (mining companies, mining waste deposits owners), local and regional authorities (APM, City Hall, The Emergency Situations Inspectorate) that have responsibilities and decisional role in the protection of the environment, public health and civil society made out of non-governmental organization, local community and persons directly interested. .

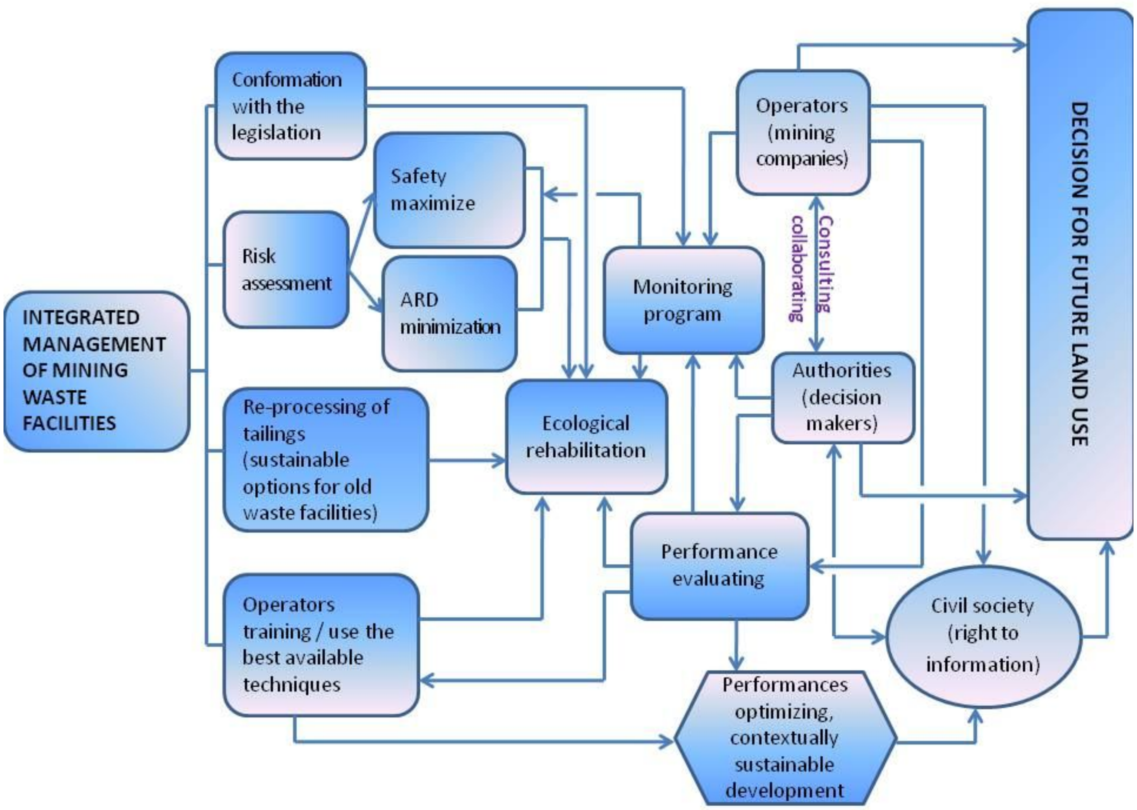


Fig. 7. Mining Waste management in the Baia Mare region

The implication of the community is important because of its right to public environment information – according to the Declaration of Human Rights, the Aarchus convention in 1998 and the European Directive 2003/4/CE concerning the public access to environment information - and the decision making that implies the after administration of the land.

Conclusion

The analyses of the tailing in the studied mining waste deposits highlighted important concentrations for sulfur and for some metal and metalloids. The important concentrations of metals determined in the samples taken from the old tailing dams recommend them as ore deposits not suitable for exploitation at the present level of technology. This is one of the motives why it was not proposed that the management of the dams in the analysed region would include the use of tailings as filling material for the spaces resulted from the exploitation in the quarries and mines located in the vicinity. The filling of some exploitation spaces would also generate transportation costs, but on the other hand reprocessing of the tailings in the dams would generate profit, and so the further advantages would be both economic and ecological.

We can notice important concentrations of metals in the surface water and soils in the sections/areas with a low pH.

It can also be observed a mitigation of water pollution once with a longer distance from the pollution sources, either mining activities or other industrial activities developed in Baia Mare as well as towards the dilution that is inherent, the raise of flow rates of the rivers, consequence of the sweet water contribution because of some tributary rivers that are not polluted.

The reprocessing of the old mining waste deposits in Baia Mare region imposes that after finishing the proposed management plan to implement the post-closure monitoring plan. The purpose of the post-closure monitoring is doing a long term assessment of the regions' evolution, of the residual pollution in the area as well as the variation (mitigation) of the impact upon the direct receptors. The necessity of implementing the monitoring plan is given both by the requirement of watching the mitigation of pollution in the area, and the present legislative needs in the context sustainable development.

It was proposed the specific management measures for each mining waste facilities.

The main stage of mining waste facilities management from Baia Mare area is constitute in actions for environment protection and human community protection:

- Prevention ARD formation by selected waste that can produce ARD, and non produced ARD waste, through:
  - Fructify the sulfide minerals to potential beneficiary;
  - Selective deposing of sulfide minerals in the middle of the tailing facilities and cover with a minimum 2 m thickened layer of non generating acid minerals, for obstruct water and oxygen access to sulfides;
- Mining waste facilities embedding:
  - Trough multilayer dry cover, that can be used for mining waste facilities from Baia Mare area;
  - Trough wet cover, sub aquatic (that method is better to use for valley tailings dams, or for fill up the open pit);
- Collect and treatment of ARD, for the old mining waste facilities, where embedding is not possible (for ex, because the rich vegetation that, already, exist on the waste facilities, and for embedding this vegetation should cutting – too expensive procedure, and not necessary profitable for environment and for tailing dam stability);
  - Long term passive treatment for ARD, with limestone anoxic drain and constructed wetland;

- Mining waste monitoring, a active component of waste management; according as monitories values of determined parameter closing plan can be enhanced, to adopt additional measures;
  - Best choice of monitoring parameter and the networks spatial and temporal point for sampling is the ***key of a successful long term management*** for mining waste facilities;
- Mining waste facilities sustenance and monitoring equipment it is important for long term operation on site.
  - In operational stage and in post-closing stage are necessary sustenance activities on the site and in the proximity of mining waste facilities; for post-closing phase the sustenance ask keeping topographic marker for physical stability monitoring, mud off prevention for hydro observation drilling used for groundwater sampling, according to monitoring program.

To realized of suggesting measures about mining waste facilities management form Baia Mare area to ask that, after to perform the proposed management plan, to be implement the post-closure monitoring plan. The purpose of post-closure monitoring is the long term evaluation of region evolution, of residual pollution in that area and the variation (or decreasing) of the impact to the receptors. The necessity of monitoring plan implementation is given by the requirement to pursue the pollution decreasing in that area, but also by the legislative exigency, according to sustainable development.

The present paper can be a starting point for the research projects regarding decontamination and ecological reconstruction of the surfaces in the areas located in the vicinity of the mining waste deposits. The decontamination and reconstruction of these areas is important because the mining waste deposits are located close to the urban area (periurban space) of which benefits the entire population in the region.

Selected references:

Abraitis PK, Pattrick RAD, Kelsall GH, Vaughan DJ (2004) Acid leaching and dissolution of major sulphide ore minerals: processes and galvanic effects in complex systems. Min Mag 68:343-351

Alpers CN, Blowes DW (eds) (1994) Environmental geochemistry of sulfide oxidation. American Chemical Society, Washington DC (Symposium Series 550)

Alpers CN, Nordstrom DK (1999) Geochemical modeling of water-rock interactions in mining environments. In: Plumlee GS, Logsdon MS (eds) The environmental geochemistry of mineral deposits. Part A: Processes, techniques and health issues. Society of Economic Geologists, Littleton (Reviews in economic geology, vol 6A, pp 289-323)

Alpers CN, Blowes DW, Nordstrom DK, Jambor JL (1994) Secondary minerals and acid mine-water chemistry. In: Jambor JL, Blowes DW (eds) Environmental geochemistry of sulfide mine-wastes. Mineralogical Association of Canada, Nepean (Short course handbook, vol 22, pp 247-270)

Baciu, C. şi Costin, D. (2008), Geologie ambientală, Casa Cărții de Știință, Cluj-Napoca

Banks, D. (2004), Groundwater management in mining areas, Proceedings of 2nd Image-Train, Advaced study course, Pecs, Hungary, Published by Umweltbundesamt GmbH, Vienna, 110 p.

Banks D, Skarphagen H, Wiltshire R, Jessop C (2004) Heat pumps as a tool for energy recovery from mining wastes. In: Gieré R, Stille P (eds) Energy, waste, and the Environment: a geochemical perspective. Geological Society London (Special Publications 236, pp 499–513)

Banks SB (1997) Mine-water chemistry: the good, the bad and the ugly. Environ Geol 32:157-174

Banks D, Younger PL, Arnesen R-T, Iversen ER, Banks SB (1997) Mine-water chemistry: the good, the bad and the ugly. Environ Geol 32:157–174

Bălteanu, D., Şerban, M., 2005 Modificările globale ale mediului – O evaluare interdisciplinară a incertitudinilor, Ed. C.N.I. „Coresi" S.A.

B. C. Acid Mine Drainage Task Force, 1989. Draft Acid Rock Drainage Technical Guide. Prepared by Steffen, Robertson and Kirsten (B.C.) Inc. in association with Norecol Environmental Consultants and Gormely Process Engineering.

Benciu, F., 2007, Poluarea cu metale grele, Editura Didactică şi Pedagogică R.A. Bucureşti

Berger AC, Bethke CM, Krumhansl JL (2000) A process model of natural attentuation in drainage from a historic mining district. Appl Geochem 15:655-666

Bird, G., Brewer, P.A, Macklin, M.G., Bălteanu, D., Driga, B., Şerban, M., Zaharia, C., 2003, The solid state partitioning of contaminant metals and As in river channel sediments of the mining affected Tisa drainage basin, northwestern Romania and eastern Hungary, Applied Geochemistry 18 (2003) 1583–1595,

Bird, G., Macklin, M.G., Brewer, P.A., Zaharia, S., Bălteanu, D., Driga, B., Serban, M, 2009 - Heavy metals in potable groundwater of mining-affected river catchments, northwestern Romania, Environ Geochem Health (2009) 31:741–758

Blowes DW, Jambor JL, Hanton-Fong CJ, Lortie L, Gould WD (1998) Geochemical, mineralogical and microbiological characterization of a sulphide-bearing carbonate-rich gold-mine tailings impoundment, Joutel, Québec. Appl Geochem 13:687-705

Borcoş, M., Lang, B., Peltz, S., Stan, N., 1973 a. Volcanism neogene des Monts Gutâi. Rev. Roum., Geol., Geophys., Geogr., Ser. Geol. 17/1, 81-93.

Borcoş, M., Lang, B., Boştinescu, S., Mîndroiu, V., Volanschi, E., 1973 b. Considerații privind activitatea metalogenetică asociată andezitelor piroxenice ponțiene din Munții Gutâi (zăcămintele Herja, Baia Sprie, Şuior). St. Tehn. Econ. I/9, 95-135.

Borcoş, M., Fotopolos, F., Peltz, S., Socolescu, M., Stan N., 1979. Observații preliminare asupra structurii regiunii vulcanice neogene Oaş – Gutâi, dedusă din corelarea datelor geologice şi geofizice. St. Tehn. Econ. I 16, 109-130.

Borcoş, M., Andrei, J., Crahmaliuc, R., Găbudeanu, B., Stanciu, C., Crahmaliuc, A., Milu, V., Iamandei, E., Iamandei, S., Georgescu, A., Szabo, E., Andrei, C., Rădulescu, D., Măldărescu, I., Calotă, C., Ion, D., Milesi, J.P., Marcoux, E., Piantone, P., Genna, A., Nehlig, P., 1996. Analiza structurală – metalogenetică a regiunii vulcanice neogenă Oaş-Gutâi – Țibleş, cu privire specială asupra masivului Gutâi. Anuarul IGR 69, partea I: Raport de activitate al IGR pe anii 1994-1995, 236-248.

Bud, I, Duma, S., Denuţ, I., Benciu, O., Pintea, D., 2005, Accidente la iazuri de decantare, Ed. Risorpint Cluj-Napoca, 154 p.

Damian, F., 2001, Geochimia mediului, Editura Universității de Nord, Baia Mare

Damian, F., Damian Gh., 2008, Geochemical characterization of some old mine waste dumps from Baia Mare area and their influence on the natural vegetation, Carpth. J. of Earth and Environmental Sciences, Vol. I, No. 2, p. 63 – 72

Damian F., Damian Gh., Lăcătuşu, R., Macovei, Gh., Iepure, Gh., Năprădean, I., Chira, R., Kollar, L., Raţă, L., Zaharia, D, 2008, Soils from the Baia Mare zone and the heavy metals pollution, Carpth. J. of Earth and Environmental Sciences, 2008, Vol. 3, No. 1, p. 85 - 98

Frenţiu, T., Vlad, S.N, Ponta, M., Baciu, C., Kasler, I., Cordos, E., 2007, Profile distribution of As (III) and As (V) species in soil and groundwater in Bozânta Area, Chem. Pap. 61(3)186-193, Institute of Chemistry, Slovak Academy of Sciences;

Jambor JL (2000) The relationship of mineralogy to acid- and neutralization-potential values in ARD. In: Cotter-Howells JD, Campbell LS, Valsami-Jones E, Batchelder M (eds) Environmental mineralogy: microbial interactions, anthropogenic influences, contaminated land and waste management. Mineralogical Society, London (Mineralogical Society Series no 9, pp 141-159)

Jambor JL, Nordstrom DK, Alpers CN (2000a) Metal sulfate salts from sulfide mineral oxidation. In: Alpers CN, Jambor JL, Nordstrom (eds) Sulfate minerals: crystallography, geochemistry and environmental significance. Mineralogical Society of America, Washington (Reviews in mineralogy and geochemistry, vol 40, pp 303-350)

Jambor JL, Blowes DW, Ptacek CJ (2000b) Mineralogy of mine wastes and strategies for remediation. In: Vaughan DJ, Wogelius RA (eds) Environmental mineralogy. EMU Notes in Mineralogy, vol 2,pp 255-290

Jambor JL (2000) The relationship of mineralogy to acid- and neutralization-potential values in ARD.In: Cotter-Howells JD, Campbell LS, Valsami-Jones E, Batchelder M (eds) Environmental mineralogy: microbial interactions, anthropogenic influences, contaminated land and waste management. Mineralogical Society, London (Mineralogical Society Series no 9, pp 141–159)

Lottermoser, B.G. (2007) Mine Wastes: Characterization, Treatment, Environmental Impacts, Second Edition, Springer Verlag Berlin Heidelberg

Lottermoser BG, Ashley PM (2006) Mobility and retention of trace elements in hardpan-cemented cassiterite tailings, north Queensland, Australia. Environ Geol 50:835-846

Modoi O.C, Ozunu A., Arghius V.I., Stefanescu N.L, Bungardean S. F, 2009, Management of risks associated to mining wastes (tailings dams and waste heaps), IOS Press , http://www.iospress.nl/loadtop/load.php?isbn=9781586039486, Optimisation of Disaster Forecasting and Prevention Measures in the Context of Human and Social Dynamics, 2009, P.130-144

Modoi, O.C., Roşu, C., Costin, D., Ozunu, Al., Study on risks assessment associated to surfaces water, generated by tailing dams in Baia Mare area, Workshop on Optoelectronic Techinques for Environmental Monitoring and Risk Assessment (OTEM), INOE, Bucharest, Editor: Doina Nicolae, 973-85818-8-5, INOE, 2009, P. 44-48

Modoi, O.C., 2009 – Managementul deşeurilor miniere în contextul dezvoltării durabile. Studiu de caz: Iaz Central, Baia Mare, simpozionul cu tema “Dezvoltarea şi creşterea durabilă – aspecte esenţiale privind închiderea unor depozite de deşeuri industriale din industria metalurgică şi minieră, în contextul Directivelor Europene actuale.”, Universitatea Babeş – Bolyai, Facultatea de Ştiinţa Mediului, 3 iulie 2009, prezentare orală;

Modoi, O.C., Costin, D., Ozunu, Al., Petrescu, I., 2008, Waste management from mining industries in the Baia Mare area, Slovak University of Technology, 978-80-227-2903-1, p.295, Bratislava, SK, Editori: J. Markos, V. Stefuca

Modoi, O.C., Ştefănescu, N.L., Hening, H., Ozunu, Al., Petrescu, I., 2007, Ecological reconstruction of mining wastes – Taiex event; Workshop on Mining and the environment, poster

Modoi O C, Ozunu Al, Cosara V., *Management of wastes resulted from the demolition of industrial plants Case study: S.C. MARATEX S.A. Baia Mare*, ENVIRONMENT & PROGRESS, Categ CNCSIS C, 11, 2007, P.310 - 316

Modoi, O.C., 2005 Costuri ecologice la nivel macroeconomic şi proiecţia lor în structura financiară a firmei – Lucrare de disertaţie, Universitatea Babeş-Bolyai, Facultatea de Studii Europene

Modoi, O.C. – 1998, Evaluarea impactului asupra solului datorat activităţilor industriale din Valea Jiului – Lucrare de disertaţie, Universitatea din Petroşani, Facultatea de Mine

Moncur MC, Ptacek CJ, Blowes DW, Jambor JL (2005) Release, transport and attenuation of metals from an old tailings impoundment. Appl Geochem 20:639-659

Mutihac, V., (1990). Structura geologică a teritoriului României. Ed. Tehnică, Bucureşti, 419 p.

Nordstrom DK, Alpers CN, Ptacek CJ, Blowes DW (2000) Negative pH and extremely acidic mine waters from Iron Mountain, California. Environ Sci Technol 34:254–258

Nordstrom, D. K & Southam, G., 1997, Geomicrobiology of sulfide mineral oxidation Reviews in Mineralogy and Geochemistry; January 1997; v. 35;1; p. 361-390

Ozunu, Al, Anghel, C., 2007, Evaluarea riscului tehnologic şi securitatea mediului, Ed. Accent, Cluj Napoca

Ozunu, Al. Ştefănescu, L.N., Costan, C., Miclean, M., Modoi, O.C., Vlad, Ş.N., 2009 – Surface water pollution generated by mining activities. Case study: Aries River middle catchment basin, Romania

Ozunu Alexandru, Baciu Laurentiu Calin, Costan Camelia, **Modoi Oana Cristina**, Cosara Viorel, *Case Studies Regarding Contamination Remediation of Polluted Soils from Industrial Establishments with Closed Activities*, Environmental Engineering Science, Environmental Engineering and Management Journal, 2009, P.923 – 930.

Ravindra W., Gaikwad, S.A., Misal, Dhirendra and D.V.Gupta, 2009 - Removal of metal from acid mine drainage (AMD) by using natural zeolite of Nizarneshwar Hills of Western India, Springer Berlin / Heidelberg ISSN1866-7511 (Print) 1866-7538 (Online), 2009

Skousen, J., Rose, A., Geidel, G., Foreman, J., Evans, R., Hellier W.,1998, - Handbook of technologies for avoidance and remediation of acid mine drainage; Published by The National Mine Land Reclamation Center located at West Virginia University in Morgantown, West Virginia, June 1, 1998

Skousen, J. 2001. Overview of passive systems for treating acid mine drainage, West Virginia University Extension Service.

Smith, A., and Mudder T. 1991. The chemistry and treatmentof cyanidation wastes, London: Mining Journal Books Ltd.

Smith ACS, Mudder TI (1999) The environmental geochemistry of cyanide. In: Plumlee GS, Logsdon

Vlad, S.N., 1993 – Geologia resurselor minerale, curs, Partea I, Zăcăminte metalifere şi nemetalifere, Universitatea Ecologică, Bucureşti.

Vlad, S.N., 2005 – Tipologia şi gestiunea resurselor minerale metalifere, Casa Cărții de Ştiință, Cluj - Napoca.

Vlad, S.N., 2006 – Resursele minerale – oportunitate irosită sau alternativă viabilă?, Dezvoltarea durabilă în secolul XXI, Revista 22, nr. 195, 13 iunie, Supliment apărut cu sprijinul Universității Ecologice Bucureşti

Wong-Chong, G.M., Dzombak, D.A., Ghosh, R.S., (2006) – Introduction. Cyanide in water and soil, p. 1-15, Taylor & Francis Group 6000 Broken Sound Parkway NW, Suite 300.

Wong-Chong, G.M., Nakles, D.V., Dzombak, D.A., (2006) – Management of Cyanide in Industrial Process Wastewaters. Cyanide in water and soil, p. 523-570, Taylor & Francis Group 6000 Broken Sound Parkway NW, Suite 300

Yong, R.N., Muligan, C.N. Masaharu, F., (2007). Geoenvironmental sustainability Taylor and Francis Group, 409 p.

Younger, P.L., 2004, Wetland treatment of mine waters, Newcastle University, Department of Civil Engineering, UK, Groundwater Management in Mining Areas, Proceedings of the 2nd image-train, Advanced Study Course, Pécs, Hungary, June 23-27, p. 72 – 101.