Greening Solutions Applicable in the Tailing Ponds Tăuşani and Bosneag from Moldova Nouă

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Abstract. This study aims to propose solutions for greening of the tailings ponds resulted from mining activities with transboundary impacts. As case study, are proposed for greening the Boşneag and Tăuşani tailing ponds because they pollute Moldova Nouă, Danube and towns on the Serbian side of the Danube with particles in suspension. We analyzed four scenarios of modeling dispersion of particles in suspension (copper and other heavy metals) from the Tăuşani and Boşneag tailing ponds in the theoretical background where pollution has cross-border nature and require studying the transport of pollutants over a long distance from the source and modeling dispersion of particles in suspension in the atmosphere, these were performed using TAPM model, able to simulate the aspects mentioned. After running the software for modeling the dispersion of particles, was revealed that the pollution generated from the pollution sources taked into consideration is very high and significantly affects quality of life on considerable areas both in Romania and Serbia, thus amplifying the need to implement greening solutions of the analyzed area. Following the results obtained are presented three alternatives solutions for greening the area studied, aiming at minimizing the impact on the environmental and population.

1. Introduction
Romania has a long history of mining of useful mineral substances, from which the most important to remember are: precious metals (gold and silver), copper, lead, zinc, uranium, manganese, salt and coal. Thanks to the long exploitation period and the extraction technologies from the mining areas and from the affiliated industrial areas of mineral processing, the environment was affected in a very aggressive manner, leading to an important burden over the soil, water, air and the ecosystems. The problems have extended across the borders due the migration of pollutants through the hydrographic network or due to the wind that carried them, therefore we face a cross border pollution situation [1].

In carrying out of this paper, the tailing ponds Tăuşani – Boşneag were chosen, related to the former mining enterprise from the Moldova Nouă, placed on the left bank of the Danube, on the Moldova Nouă town’s territory, between Moldova Veche town and Coronini town, near the wet area, Ostrovul from the Natural Park Iron Gates. The mining enterprise Moldova Nouă started operating in 1965 through underground exploitation of copper mineral resources with over 0.3 Cu, in Florimunda, Suvarov, The Great Valley, Gărâna, Vărăd areas, with a maximum processing of 1.6 million tons/year. Since 1974, the exploitation in the mining pit of copper banatites has started, with a maximum level
reached in 1988 of 3.3 tons/year. Since the closure of the activity in 2008, an estimated total of sterile material around 128,000 tons accumulated on the tailing ponds [2].

This area was chosen to be analyzed because it represents a major pollution source, with thin particles being carried in the atmosphere by the local wind (Cosava), from the tailing ponds resulted due to the copper processing. We wish to emphasize the necessity of the greening of this area, because the impact of the tailing ponds is reflected over the environment factors, also representing a situation where cross border pollution is present [3,4,5].

Over a total surface of approximately 150 ha, after the decantation of the water coming from the copper preparation plant and after the evaporation of these waters, a dry deposit has resulted, composed of thin powders, with an average thickness of 1.50 – 2 m. The surface that represents the subject of this paper is of 122.2 ha and is presented in figure 1 and the rest of the surfaces are considered to be rehabilitated [5].

![Figure 1. Localization of the studied area.](image)

2. Materials and methods
Because the analyzed area is characterized by a complex field and the pollution has a cross border character, it requires the study of the transportation of the specific pollutant over a wide distance from the source. The dispersion modeling of the powders into the atmosphere has been made using the TAPM model, capable of stimulating the already mentioned aspects.

The TAPM model (The Air Pollution Model, developed by CSIRO – Australia) is capable to stimulate the emissions provided from all types of sources: punctual, linear and surface, also a great number of sources (e.g. all the sources for which there are detailed data at a national level). Also, the model can stimulate the significant spatial variability of the meteorological conditions, induced by the complexity of the topographic surface (the proximity of the sea, tall, complex mountain areas) and also the radiation differences, considering the advection and diffusion of the pollutants in a non-stationary and inhomogeneous field. Thanks to the calculation procedure with included domains through which the calculations are refined, the model can be applied to a mesoscale and also to a local scale [6].

2.1. Entry data
Meteorological data used as entry data for the model are provided from a synoptic scale analysis model (LAPS) and they consist of modeled data in intervals consisting of 6 hours in a geographic network – longitude/latitude with a resolution of 0.75 degrees (approx. 75 km) which covers the Northern Hemisphere.
Field data are provided from the US Geological Survey, Earth Resources Observation Systems (EROS), Data centre Distributed Active Archive Centre (EDC DAAC), with a resolution of 30 seconds (approx. 1 km).

It have been made 4 calculations scenarios, with emission sources of different sizes, to stimulate the existing situation and also the reduction of the concentrations and of the affected areas due to the pollutant concentrations, as the tailing ponds which represent the pollution sources are being rehabilitated, the purpose of making these stimulations being the necessity of rehabilitating this pollution source as fast as possible and for that, infringement procedures against Romania were released, but another reason is to calculate with how much the pollution could be reduced, during the rehabilitation process, when different amounts of the surface of the source would already be rehabilitated, through different greening methods. Four powder stimulations have been made for the total amount of suspension powders (TSP) and also for the fractions PM10 and PM 2.5, but we chose to present the results for the total suspension powders (TSP) being the most conclusive. The modeling domain was of 30 x 30 km, the grid calculation for the pollution having a resolution of 250 m, being used a total amount of 13689 receptors. The thresholds of the atmospheric pollutants established through the legislation in force are presented in table 1.

| No. crt. | Chemical compound / Pollutant | Limit for protection | Mediation period | Maximum admitted concentration (μg/m³) |
|---------|------------------------------|---------------------|-----------------|---------------------------------------|
| 1       | TSP                          | Population          | 24 h            | 150                                   |
|         |                              | Population          | Year            | 75                                    |

3. Results and discussions

3.1. The first scenario (S100)
In the case of the first studied scenario (S100), a source with a surface of 122.2 ha was considered (considered the actual situation, presented in the figure 2), in the subsequent scenarios the surface of this source being reduced by 25% - the 2nd scenario (S75), by 50% - the 3rd scenario (S50%) and by 75% - the 4th scenario (S25). In the figure 2 is represented the distribution of the monthly average concentrations of total suspension powders in the case of the 1st scenario [5].

Figure 2. The distribution of the monthly average concentrations of TSP – S100.
To evaluate the air quality and the areas affected by suspension powders, the results of the mathematical modeling of the dispersion of the pollutants into the atmosphere was compared with the limits of the maximum concentrations from the 104/2011 law, regarding the quality of air. After the map analysis, great exceeding of the imposed limits can be noticed for all the fractions of the analyzed suspension particles. Very high concentrations, obtained as a result of the modeling, which exceed the limit value, can be noticed not only in the proximity of the pollution source, but also on distances exceeding 10 km in the dominant wind direction for the total suspension particles (TSP) [5].

3.2. The second scenario (S75)
This scenario implies that 25% of the total emission surface was rehabilitated, the rest of 75% remaining in the most unfavourable conditions for the quality of air (dry, with a great potential of pollution with suspension powders). In the figure 3 is represented the distribution of the monthly average concentrations of total suspension powders in second scenario.

The analysis of the modeling results of the dispersion of the atmosphere pollutants in the second scenario indicates a great similarity of the spatial distribution of the maximum daily concentrations of total suspension particles (TSP) and a very slight decrease of the maximum obtained concentrations, but the exceeding of the threshold values are of the same order of magnitude as in the case of the first scenario and extended over approx. the same distance in the wind direction (around 10 – 13 km).

3.3. The third scenario (S50)
The third scenario implies that a half of the total emission surface has been rehabilitated, the rest of 50% remaining in the most unfavorable conditions for the air quality (dry, with a great potential of suspension powders pollution). In the figure 4 is represented the distribution of the monthly average concentrations of total suspension powders.

3.4. The fourth scenario (S25)
In this scenario it was implied that 75% of the total emission surface has been rehabilitated, the rest of 25% remaining in the most unfavorable conditions for the air quality (dry, with a great potential for
pollution with suspension powders). In the figure 5 is represented the monthly average concentrations of total suspension powders.

![Figure 5. The distribution of the monthly average concentrations of TSP- S25.](image)

TSP concentrations of which the values exceed the limit threshold of 150 μg/m³ have been obtained after the mathematical modeling in the 4th scenario over a distance (in the dominant wind direction) of approx. 9-10 km. The reduction of the surface on which exceeding of the limit imposed by law are obtained is evident but the maximum concentrations, though reduced compared to the 1st scenario, exceed the limit value with an order of magnitude. After the rolling of the modelling software of the powder dispersion it resulted the fact that the generated pollution by the considered pollution sources is very high and it significantly affects the quality of life on areas on the Romanian territory as well as Serbia, this way amplifying the necessity of the implementation of a greening solutions of the analyzed area [5].

3.5. Greening solutions

For greening the area it is necessary to be made in advanced, a study regarding the stability of the tailing ponds, which must have geotechnical and electrometrical measurements done, laboratory investigations, topographic measurements, to be able to establish the characteristics of the tailing ponds [5]. In relation to the obtained results as following the investigations of the geometrical and geomechanical characteristics of the tailing ponds, these will lead to the choosing of the best greening solutions. Also, an important factor regarding the choosing of a greening solution is the economical factor that has to do with the costs that will be necessary for the implementation technical greening/closing tailing ponds project. The proposed options for the greening of the studied area are presented in table 2.

| Table 2. Proposed options of rehabilitation for the studied area. |
|---------------------------------------------------------------|
| **Option I**                                                  |
| Option I: „in situ“ stabilization - dry remedial              |
| **Option II**                                                 |
| Option 2: capitalizing the useful area of the mixture deposited in the lake and the relocation of the sterile material resulted in the mining enclosure |
| **Option III**                                                |
| Option 3: in which the 1st and the 2nd option are combatted    |

3.6. Option I – „in situ“ stabilization – dry remedial

In the context of Tăuşani and Boşneag tailing ponds, one of the greening methods that have been proposed in the present study is the „dry option“. Through its implementation, the decrease of the
impact on the environment of these tailing ponds is being pursued and also the fitting into the landscape of the studied emplacement.

The steps of the work regarding the greening through „in situ” stabilization – with the placement of a soil cover – “dry option” are the following:

- covering with a layer of **bentonite geocomposites** (0.002 - 0.003m);
- covering with a layer to collecting and evacuate the rain water, the cover being composed of a gravel layer and an absorbent draining and collecting system (0.25 – 0.5 m) (0.25-0.5m);
- covering of the emplacement with a layer of **vegetal soil**, between 0.3 – 1 m which will be on with perennial herbs will be planted, these are presented in the figure 6.

### Figure 6. Scheme of closure and greening of the studied area.

Following the analysis of the decision matrix on the geosynthetic sealing of the tailing ponds, **bentonite geocomposites** have been chosen because they present: competitive cost; impermeability; good resistance to frost/thaw and wet/dry; good behavior on slopes and differentiated deposits; easy installation under adverse climatic and field conditions; replacing compacted clay or geomembranes at ponds, lagoons, canals, irrigation works, marshland, reedbeds; overlays are easily achieved using bentonite paste; have a sealing function, are compatible with cathodic protection. Covering of the area studied with **bentonite geocomposite** of approximately 0.002m-0.003m (consisting of 3 layers of high density polypropylene/geomembrane geotextile layer, bentonite layer in the form of powder or granules, polypropylene nonwoven geotextile coating) having the role of sealing the tailings ponds [7,8,9].

Followed by a **permeable layer for collecting and evacuating rainwater**, consisting of a gravel layer and a system of drainage and collecting drains of approx. 0.25-0.5m. If the water quality in the collection tanks does not comply with the NTPA 001/2005 water quality norms, in order to be discharged into the Danube, it is necessary to construct a treatment plant, where the water is brought to the appropriate parameters in order to be able to be discharged into the Danube through the spillway shown in figure 7. The last stage of the ecological process of the Tăuşa and Boșneag tailing ponds is covering the site with a layer of **vegetal soil** (0.3m-1m) and its grazing with perennial species [10].

### 3.7. Option II

In accordance with Order 95/2005 regarding the establishing acceptance criteria and preliminary procedures for the acceptance of waste storage and the national list of waste accepted in each class of landfill for waste from the excavation of metal ores, identified with the code 01 01 01 it isn't recommended to apply a recovery method.

As a result of the laboratory analyzes carried out within the National Institute for Research and Development in Environmental Protection (INCDPM), the material samples from the tailings ponds...
resulted the values presented in table 3. These analyzes were carried out within the project "Studies for achieving shore protection of wetland area Divici-Pojejena" carried out by INCDPM.

**Table 3.** Results of the chemical analysis of the sterile samples from the Tăuşani-Boşneag tailing ponds.

| Sampling depth | Sampling date | Cu [mg/kg] | Cr [mg/kg] | Cd [mg/kg] | Ni [mg/kg] | Zn [mg/kg] | Pb [mg/kg] | Hg [mg/kg] |
|----------------|---------------|------------|------------|------------|------------|------------|------------|------------|
| 0-15 cm        | 16.07.2014    | 1589       | 25.69      | 2.86       | 3.99       | 904        | 1.16       | 0.31       |
| 15-30 cm       |               | 948        | 34.47      | 1.99       | 13.81      | 505        | 27.82      | 0.30       |

The high concentration of copper from the samples taken and analyzed from the tailings ponds shown that the possibility of utilizing the copper recovery. According to laboratory analyzes, the percentage of copper that can be extracted is about 75% -80% (representing about 12597 tonnes) of the amount of copper present in tailings ponds [11].

It is proposed that the technological processes of capitalization of the useful part by separation from the sterile part be done in the processing plant number 1 of the economic operator in the area, by building a new production capacity, located in the proximity of the Tăuşani and Boşneag tailing ponds and subsequently applying greening option 1 [12,13].

The application of Option 2, in addition to Option 1, brings an economic contribution by capitalizing on existing metals that can be recovered from tailings ponds.

### 3.8. Option III

Option III combines option I and option II, proposing the utilization of useful parts from the sterile site, relocation of the site to the old mining site and subsequent application of "in situ stabilization" - dry remediation. Thus, by applying options II and III, it is possible to solve the problem related to the storage of hazardous wastes directly on the soil, which is a significant a source of pollution. Depending on the existing funds, the application of these solutions will lead to the proper placement of hazardous waste and to minimizing the risks by reducing the impact on the soil, while improving the aspect related to the landscape. Also using the useful part of the tailings ponds would integrate important quantities of cupric concentrates into the economic circuit.

From a technical point of view, we consider the application of option III to be more feasible because it combines the capitalization of the Tăuşani and Boşneag tailing ponds in the economic circle through the use of clean environmental technologies that don’t produce pollution, relocation of the site and subsequently the application of a in situ dry remediation that minimizes the impact of the dispersion of particulate matter on the environment, on the Danube River and cross-border pollution, as well as landscaping of the area.

### 4. Conclusions

Due to the mathematical modeling of the dispersion of pollutants into the atmosphere, results the need to take urgent measures for greening the study area and to maintain a high humidity of the material located on the surface of the tailings ponds exposed to wind erosion.

In accordance with the four simulated scenarios it can be stated that even if 75% of the surface of the Tăuşani - Boşneag tailing ponds would be ecologized (with no further measures to reduce the emission of dust from the non-certified surface), the concentrations of suspended particulate matter transported by the wind would exceed the limits imposed by legislation to protect human health and vegetation. The pollution generated by the analyzed sources is high and significantly affecting the quality of life on considerable areas both on the territory of Romania and on the Serbian side, the cross-border impact being obvious.
Of the three proposed greening options, technically, we consider the application of option III to be more reliable, as it allows the capitalization of the useful part from the sterile material, relocating the site to the old mining area and then applying the in situ stabilization- a dry remediation that contributes to minimizing the impact of suspended particulate matter on the environment, on the Danube River and the Serbian side and also contribute to landscaping the area. It is important to take into account the cost-effectiveness of such an operation and it is necessary to develop a cost-benefit analysis and also performing site stability studies based on geotechnical, electrometric, laboratory, topographical measurements, in order to determine the characteristics of the tailings ponds. The methodology used in the mathematical modeling scenarios as well as the proposed greening options can also be used as a reference for the greening of other tailing ponds.

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References
[1] INCIDPM 2004 Ecological restoration and rendering of urban and industrial landfills in the economic circuit. Solutions on and adjacent to these lands, industrial and/or commercial buildings, leisure areas, dwellings, etc.
[2] Beutură D, Rogobete G, Beutură S, Bertici R, Tudor C and Țimboța O 2005 Estimation of the impact of mining on the soil, water and air in Moldova Nouă, Caraș Severin County Office of Pedological and Agrochemical Studies Timișoara* "Politehnica" University of Timișoara - Pedogenic Factors and Processes in the Temperate Zone 4 S:231-239
[3] INCIDPM, NIBIO and INCDDD 2015- 2016 Mapping and Assessment of the Ecosystem Services in Divici- Pojejena Wetland and Identification of their Contribution to the Economic Sectors (WETECOS)
[4] Matei M, Laslo L, Ciobotaru N, Musat C, Boboc M, Raischi M, Deák G 2016 International Journal of Environmental Science 1(1) 265-271
[5] INCIDPM Core Program 2015 Researches on greening the tailing ponds and dumps resulting from mining activities with cross-border impact
[6] Gillette D A 1980 Major contributors of natural primary continental aerosols: Source mechanisms. In Aerosols, Anthropogenic and Natural Sources and Transport The New York Academy of Sciences 348-358
[7] INCIDPM Core Program 2014 Researches on the use of geosynthetic materials for ecological restoration and rendering in the economic circuit of industrial non-hazardous landfills - Phase 1 - Study on the durability of geotextiles for hydrotechnical constructions; Phase 2-Analysis of the impact of geotextiles used in hydro-technical constructions on biodiversity on the Danube and preventive solutions for ecological recovery 09060132
[8] INCIDPM 2015 Long-term performance of geotextiles used for Danube River banks protection, Conference Trabzon Turkey
[9] INCIDPM Core Program 2013 Researches on the criteria identification for the selection of geomembranes used for the closure of non-hazardous industrial landfills in order to their ecological rehabilitation 09060132.1
[10] Matei M, Raischi M, Ciobotaru N, Laslo L, Boboc M, Zamfir S A, Deák G 2017 Journal of environmental protection and ecology 18(1) 235-245
[11] INCIDPM 2014-2015 Studies for achieving shore protection of wetland area Divici-Pojejena (Europe-Aid/134910/4/SER/RO, CODE 1344)
[12] INCIDPM 2003 Preparation of the Environmental Balances for level I and II at the Ovidiu-Constanța Ecological Waste and Industrial Waste Depot
[13] INCIDPM 2004 Technical Expert on the equivalence of the solution adopted by the designer for the Sludge and Sludge Technological Sludge Storage Facility, DUCTIL STEEL S.A