ENVIRONMENTAL PROBLEMS ASSOCIATED WITH THE MINING ACTIVITIES IN THE APUSENI MOUNTAINS, ROMANIA

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Mining is one of the oldest industries, and abandoned mines with the potential to release harmful substances into soil, water and air are found throughout Romanian territory. Due to the mining activity of ore deposits for more than 2000 years, in Romania there are over 550 tailings dumps, covering an area of approximately 800 ha and storing over 200 million cubic meters of tailings and 64 tailings ponds, which covers an area of almost 1350 ha and stores over 350 million m3 of waste.

Mining activities create a potential impact on the environment, both during exploitation and in the years after mine closure. Underground exploitation presents the risk of collapsing galleries and surface overflowing and involves the dislocation of a large amount of rocks. Quarrying is one of the most common forms of mineral extraction, being particularly harmful to the environment, as strategic minerals are often available in low concentrations, which increases the amount of ore extracted.

Although mining activities are currently stopped in most areas, the potential risk of environmental contamination exists due to the huge quantities of tailings in the tailings ponds and the tailings dumps very close to the watercourses. These are permanent sources of pollution for surface and groundwater, soil and air in the area (Fig. 1).

The oxidation of sulphide minerals led to the removal of soluble metal ions from the mineralization found in mining related wastes under the effect of water. As the water takes over the concentrations of minerals and heavy metals, it becomes a contaminant and a source of dispersion that can pollute the region around the mine and for considerable distances from the source.

The South Apuseni Mountains territory is crossed by a dense network of fluvial courses included in the fluvial system of the Mureș and of the Crișul Alb, both of them discharging their waters into the Tisa and implicitly into the Danube.

The Mureș River is the main collector of the waters in the studied region. The main tributaries of the Mureș, from the Southern Apuseni Mountains, are the Aries, the Ampoi and the Geoagiu rivers.

Downstream Câmpeni, the *Arieș River* receives, from the Metaliferi Mountains, a series of right-bank small rills such as Stefanca, Musca, Sesei, which receive the waters from the Roșia Poieni and Baia de Arieș mining perimeter. The Abrud is the most important right-bank tributary of the Arieș (Fig 1. C). It gathers the rills that flow radially around the igneous massif of Detunata and of Izbicioara, Abruzel and Bucumanilor triburaties reciving waters from Bucium Poieni, Bucium Șasa and Bucium Izbita old mining perimeters. The Corna Valley and the Roșia Valley (Fig 1. A) are among the most important tributaries of the Abrud, receiving the waters from the Roșia Montană and Roșia Poieni mining perimeter. The pollution sources of the Arieș basin proceed from the mining objectives of Roșia Montană, Roșia Poieni, Bucium and Baia de Arieș.

The main water collector within the Roșia Montană mining perimeter is the Roșia Valley stream, called Foieș (Fig 1.A), where the hydrographic network has been totally disorganized by mining activities. From the opencast pit, the pluvial waters infiltrate into underground through the old mining galleries, being collected at the level of the transport gallery "Sfanta Cruce din Orlea" from where they are discharged into the Foieș stream (Fig 1. B). Exceeding values are registered for almost all indicators of the mine waters, including very noxious elements and heavy metals such as lead, copper, zinc, arsenic, cadmium and manganese, with strong acidic conditions (table 1).

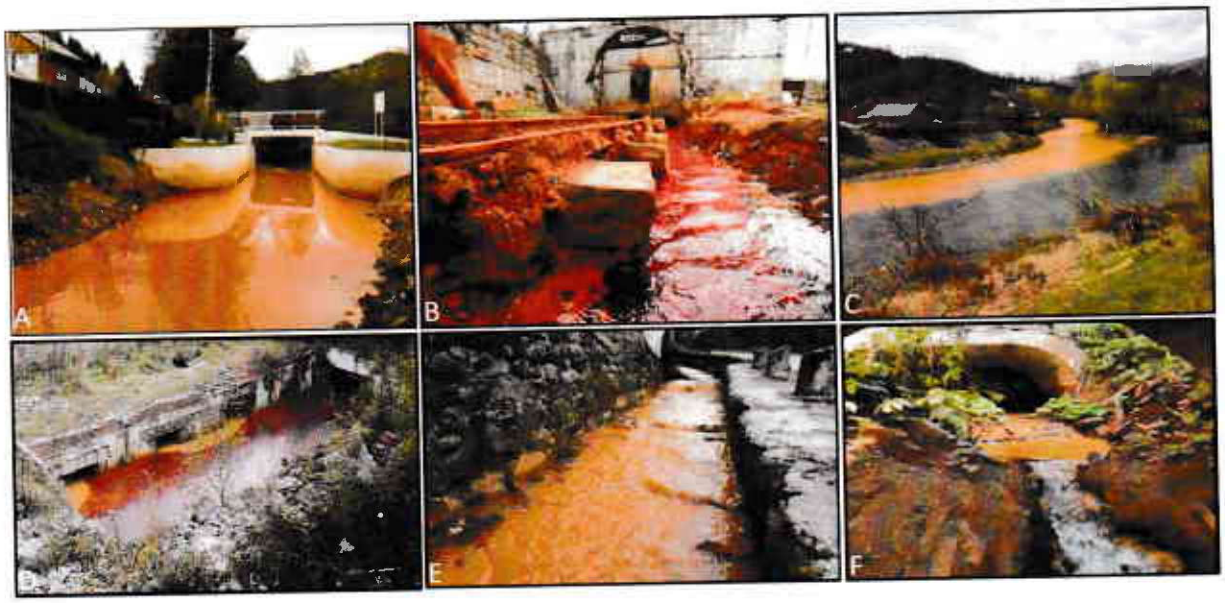

Fig. 1. Waters affected by mining: A. Foieș stream (Roșia Montană Valley), B. "Sfânta Cruce din Orlea" (Roșia Montană) gallery waters, C. the confluence of Abrud river (reddish-yellowish color) with Arieș river, D. Barza gallery waters, E. Barza Valley, F. Grimm gallery waters (Troița).

In the Roșia Poieni mining perimeter, the local hydrographic network, which collects the waters from the opencast pit and the mine waste dumps, is represented by the Steregoi, Ștefancei, Șesei, Mușca and Fîntînilor Valleys, right-bank tributaries of the Arieș River, as well as the Geamăna and Cuibarului Valleys, right-bank tributaries of the Abrud River. The analysis of the collected samples from the area present exceeding values for all the water quality indicators, with highly acidic pH and alarming values of copper, zinc, cadmium and iron contents.

In the Baia de Arieș mining perimeter, the local hydrographic network has been disorganized as result of stream blocking with mine wastes (Hermăneasa and Cioara Valleys) and with processing wastes (Sartăș Valley, Brazesti Valley). Mine waters are collected gravitationally into two basins and the quality of the waters discharged in the Arieș River is influenced by their mineralization degree. Values exceeding the admitted values are registered for suspensions, fixed residuum, sulphides and metallic ions (Cu, Pb, Zn, Fe, Mn, Cd, As) (Duma, 2009).

Several studies have been carried out in order to evaluate the water quality and the level of metal contamination in the Arieș river and its tributaries affected by the mining operations. The physico-chemical parameters indicated the contamination of the water by mining activities. In the tributaries of Arieș, the pH values were in the acid range (Senila et al., 2015). The water of the Arieș river has been found to be mostly polluted with Cu, Mn and Fe (Levei et al., 2014). The concentrations of metals (Fe, Zn, Cu and Mn) were higher in tributaries (Senila et al., 2015). The sediments in the Arieș river were highly contaminated with Cd, Cu and As, considerably with Zn, moderate with Pb and Ni and low with Cr (Levei et al., 2014). Their impact on the water quality of the river is strongly felt along the entire length of the Arieș river, from Câmpeni to the confluence with the Mureș river, and the intensity of pollution varies depending on the flow of the river (Corches, 2011).

Certej-Săcărâmb, Zlatna, Troița-Bolcana and Vorța are the mining units that have affected aquatic environment in *Ampoi Basin*.

In the *Zlatna* mining perimeter, the hydrographic network has been disorganized due to the construction of the tailing ponds on Sfârci Valley and on Valea Mică and through the mine waste dumps blocking the Hanes and Larga rills. The waters flowing from the tailings settling ponds of Zlatna register exceeding values for copper, lead, zinc, iron, manganese and cyanides. The mine water is affected by the presence of metallic ions (Cu, Pb, Zn, Fe) causing an acid pH (table 2).

Table 1. Chemistry data of analyzed waters from Arieș basin ([1]Whitehead, 2009; [2]Friedel et al, 2008; [3]Duma, 2009; [4]Corcheș, 2011; [5]Iatan, 2019).

Water quality indicators	Rosia Valley (Foies)[1]		Rosia Mine waters[1]		Corna-Valea Verde waste dump waters[1]		Saliste Valley[1]		Abrnzel Valley[1]		Abrnzel-Mine waters[1]		Sevei Valley[2]		Baia de Aries[3]	Aries River-Campeni[4]	Aries River-Baia de Aries[4]
µg l	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max			
As	2.15	46.9	361.18	1738	0	684.2	0.9	42.8	0	22.1	0	265	0	0	-	-	-
Cd	1.9	432	331.09	875	0	54.3	1.22	73.2	1.29	73.2	2.04	107.3	0.1	50.6	-	0.3	2
Cu	134	1216	3361.5	12370	1.6	381	14.6	211	98	3175.7	107	8070	0.6	14900	350	23	437
Pb	0	16.8	59.01	266	4.4	67.9	0	4.8	0	6.4	0	66.7	0.08	88	400	2	14
Zn	138	14825	52288.57	169313	28.4	14590	250.3	3129	45.5	3763.5	478	13090	4	7190	1000	88	302
Cr	4.2	1438	2387.84	14650	3.5	2964.25	5.36	532	3.5	278.17	6.4	954	3.33	3.33	-	-	-
Mn	12.38	90	5381.4	77200	0.02	603000	26.6	188	0.01	1121	1.13	14640	0.4	3730	1300	133	620
Fe	-	-	-	-	-	-	-	-	-	-	-	-	64200	64200	4700	240	480
pH[5]	3.1		2.6		4.5		6.0		4.3		3.5		3.5		6.9	7.2	7.0

In the Certej – Săcărâmb mining perimeter, waters are collected into the hydrographic basin of the Certej River, a right-bank tributary of the Mureș River. The mine waters run freely into the emissary, the ones from the Bocșa Mine into the Bocsa Rill, the ones from the Hondol-Băiaga Mine into the Certej River, and the ones from the Săcărâmb Mine into the Nojag Rill. The mine and the opencast pit waters are characterized by high contents of solid suspensions, fixed residuum, metallic ions (Cu, Zn, Fe, Mn) and sulphate ions (SO4). The waters flowing from the Mealu Valley tailings settling pond are characterized by exceeding values for suspensions, fixed residuum, metallic ions (Pb, Zn, Mn), SO4, chlorine and cyanides. The waters of the Certej Rill have polluted through infiltrations also the phreatic waters, which, in certain periods of the year become undrinkable (table 2).

The waters from the Troița Mine have a discharge of 420 m3/day and run freely at the level of the Grimm gallery (Fig 1. F) into the Bolcana Rill, a left-bank tributary of the Caian Rill, downstream the locality of Șoimus. These waters are characterized by low values for pH as well as exceeding sulphates and metallic ions (Cu, Pb, Zn, Fe). Mine waters have only little influence upon the water quality of the Caian Rill due to their low discharge value, as well as to the share of carbonates containing waters of the Crăciunești lime opencast pit that regulate the pH.

Table 2. Chemistry data of analyzed waters from Ampoi basin (Duma, 2009).

Water quality indicators mg l	Hanes Mine	Larga Mine	Baiaga	Bocsa	Sacaramb	Houdol-Coranda	Valea Mealu	Caian	Troita	Paraul Baii gallery	Valea Heius gallery	Vorta Valley
Cu	17.4	1.9	-	1.95	0.43	15.62	0.09	0.14	1.06	0.13	0.13	0.1
Pb	0.6	0.25	-	-	-	0.11	0.01	0.20	26.5	0.16	0.14	0.11
Zn	720.5	25.6	4.64	55.39	50.88	246.0	0.73	0.18	94.5	0.18	0.18	0.12
Fe	1695	158	0.09	3.90	0.59	302.78	2.0	1.24	83.3	2.47	2.47	1.06
Mn	830	20.8	7.30	36.54	39.29	150.40	5.60	-	-	-	-	-
Ca	410	254	527	348.0	253.3	339.2	339.2	-	-	-	-	-
Mg	50	62.4	102.8	92.25	121.40	64.92	43.7	-	-	-	-	-
pH	2.2	2.5	7.11	4.76	5.31	2.8	7.30	8.09	2.78	8.45	2.47	8.65

The waters evacuated from the Vorța Mine through the two flank galleries from Heius Valley and Băii Creek (table 2) are discharged into the Vorța Valley, their quality being characterized by the presence of metallic ions (Cu, Zn, Pb, Fe), but their influence upon the waters of the Vorța Valley is insignificant due to the low discharges of the mine waters (Duma, 2009).

The Crișul Alb River is the main collector of the waters in the northern sector of the Metaliferi-Zarand Mountains. At Criscior it receives the left-bank waters from the Valea Arsului-Valea Morii, Barza and Rovina Mines and at Brad the ones of the Luncoi Valley (Ruda-Brad mine) (table 3).

Table 3. Chemistry data of analyzed waters from Crisul Alb basin (Sima et al., 2008)

Water quality indicators µg/l	Barza Valley	Barza Mine	Ribita tailling	Arsului Valley	Valea Ruda	Rovina tailling	Cris Alb River before mining sectors	Cris Alb River after mining sectors
Cu	310	190	1	32000	1	0.2	23	50
Pb	2	4	0.04	<5	<5	0.2	2	3
Zn	2200	5700	2	11000	1	11	7	106
Fe	940	28000	8	410	<11	190	52	4
Cd	11	375	0.06	100	<0.05	<0.01	0.05	0.7
As	5	-	18	-	10.3	7	1	-
Mn	5300	14400	270	18000	20	110	22	212
pH	4.6	3.2	7.4	4.0	8.3	7.1	8.0	7.8

Heavy metal contaminations in the Criş Alb basin (table 3), combined with high sulfate concentrations and low pH values, are found in valleys, Arsului Valley and Barza Valley (Fig 1.E). The outflow of the open pit mined for copper situated in Valea Arsului, exhibits clearly high dissolved metal contents. The drain of underground galleries and waste dumps in Valea Barza, shows high manganese, iron, zinc and cadmium concentrations. Due to the high contents of dissolved iron and particulate Fe, these waters display an ochre-brownish color, the distinct and classical optical sign of mining pollution (Duma, 2009) (Fig 1. D).

Results and conclusions: High values of the contents of metallic ions were recorded for the waters from Roşia Montană, Hanes Mine, Larga Mine, Săcărâmb Mine, Barza Mine and Troiţa Mine (tables 1, 2, 3). In Roşia Poieni, high contents of copper were registered in the waters flowing from the mine waste dumps.

High contents of cyanides were recorded in the waters of the Săliste Valley tailings settling ponds - Roşia Montană (0.32 mg/l), in the Sartăş tailings settling pond - Baia de Arieş (0.75 mg/l) and in the Valea Mealu tailings settling pond of Certej- Săcărâmb (0.040 mg/l) (Duma, 2009).

The potential for acid generation is directly related to the potential oxidation of sulphide minerals to sulphate (sulphuric acid). The experiments made by Jennings et al. (2000) demonstrated that under strongly oxidizing conditions, pyrite, marcasite, pyrrhotite, arsenopyrite, chalcopyrite and sphalerite are acid-producing minerals but chalcocite and galena were found to be non-acid producing minerals. In the studied area, the main sulphide-producing acid is pyrite.

In the Southern Apuseni Mountains, long-term mining activities have caused environmental problems, affecting waters, soils and sediments, which must be remediated. The rehabilitation of the environment in the Southern Apuseni Mountains has to be done, in order to reduce the impact of mine waters and of the ones flowing from the tailings settling ponds and waste dumps, by the construction of water treatment stations.

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