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Assessment of water quality due to Wolfram mining in Portugal

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Abstract
Water has an important role in creating pollution problems in the mining regimes influencing the surrounding surface environment. The purpose of this study is to make an assessment of groundwater quality in an underground mine site in Portugal with a view of determining the pollution potential of groundwater. In the corresponding surface area of this underground mine, intersections of four faults form rock blocks which delimit the surface subsidence influencing the flow pattern of the surface streams and the groundwater table resulting in inflow of groundwater and rainwater into mining excavations. When this water comes into contact with the virgin rock mass containing pyrites in presence of atmospheric air, acid mine water is formed. This acidic water reacts with the broken rock material dissolving metallic sulphides into solution and also carrying suspended solids. When discharged in the "Boldehão" River, these waters produce diverse environmental impact levels such as pH low and Zn high levels risk cause for irrigation, pH, Cu, Fe and Mn high level risk for consumption human, and pH, Cu and Zn cause high level for fishes.

Keywords: *Mine water quality, the "Boldehão" River, Panaqueira mine, Wolfram mine*.

1. Introduction
The underground mining of the ore body lowers the groundwater table resulting in inflow of groundwater and rainwater into mining excavations. When this water comes into contact with the virgin rock mass containing pyrites in presence of atmospheric air, acid mine water is formed [7]. This acidic water reacts with the broken rock material dissolving metallic sulphides into solution and also carrying suspended solids [1]. These waters, when discharged in the river and natural superficial waters produce pollution causing significant environmental impacts to the aquatic life and the ecosystem [9, 10].
The mine water quality assessment of the Panasqueira mine involves two steps: (1) taking 25 water samples from the mine and (2) carrying out a chemical analysis of the water samples in the laboratory. Six water samples were taken from level 1, six from level 2 and 10 from level 3. In addition, three water samples were also taken from the Bodelbão River on upstream, mid stream and downstream side of the mine. Parameters measured in each water sample were pH value, total suspended solid in g/L, copper, Zinc, Iron, Manganese and arsenic (measured in ppm).
It was observed that metal concentration in old workings above level 1 is lower than that in the active part of the mine in level 2 and level 3. It can also be seen that the arsenic concentration in level 3 is comparatively high. The pH value of water at the downstream side of the mine is below 4.5 (acidic) and does not meet the international standards for use of water for irrigation and human consumption. The characterization of mine water environmental impact is very important for prevention and remediation actions [4] for environmental sustainability of mining.

2. General Aspects of Mine Water in Panasqueira

2.1. The site of investigation

The site of investigation is the Panasqueira wolfram mine which is located 300 km northeast of Lisbon at a distance of 35 km from small town of Fundao. This underground mine is one of the largest tungsten producers in the world. The mine has produced some 100,000 tonnes of Wolframite from some 29 million tonnes of ore since its inception in 1947 (Figure 1).

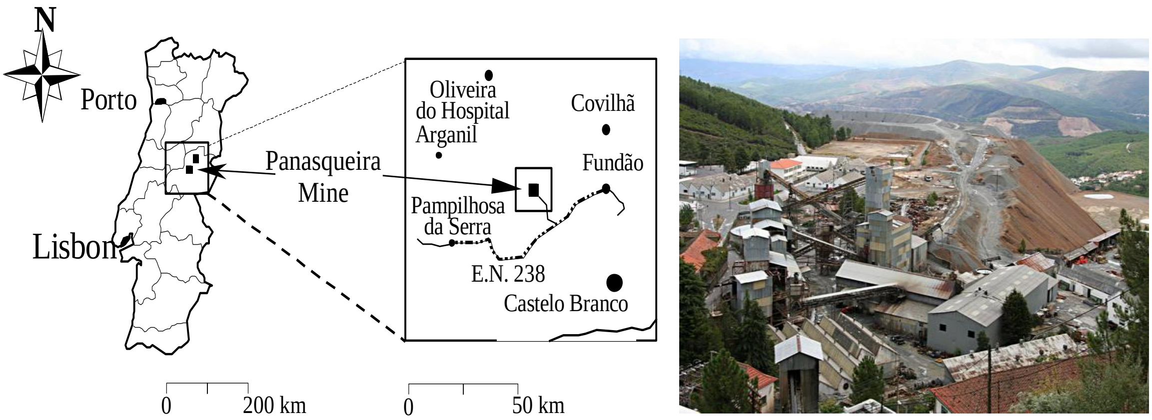

Figure1. Location of Panasqueira mine

2.2. Wolfram ore body and the surrounding rock mass

The rock mass basically consists of shale with different degrees of metamorphisms, originating from an underlying granite intrusion forming quartzitic veins where the wolfram ore body is formed (Figure 2). The mineralized zones consisting of quartzitic veins contains sub-horizontal lines that overlap and fill the joints and fracture in schist rocks, with average thickness of 30 to 40 cm of Wolframite, which is the main mineral for mining. Beside this mineral, a great variety of other minerals such as cassiterite, chalcopyrite, hornblend, topaz, apatite, fluorite, mica and marcassite occur with the ore. The ore has an average mineral content of 4.2 kg WO_3/ton (31.04 kg/m^2), which is currently extracted above level 2 and 3, with some possibility to extend the mine workings to level 4 in the future

2.3. Hydrology of Panasqueira mine area

As reported in the publication of the National Institute of Water - INAG of the Ministry of the Environment, Portugal [3], the surrounding area of the Panasqueira mine had an average precipitation of 1600 mm/year for the hydrology year of 1998/99.

As the highest pluvial precipitation level at the mine site occurs in January, the measurements of mine water quality were made during January 2001 in order to correspond to the largest make of the water in the mine. The surface area overlying the actual underground operations is mountainous with the altitude varying between 650 m to 950 m above the mean sea level. There are six well-defined surface water streams which discharge into the Bodelhão River as shown in Figure 3.

As shown in Figure 3, due to the underground openings, a subsidence zone is formed in the corresponding surface area of the underground mine. There are four faults striking from South to North direction and dipping 80º to 87º in East direction. These faults are designated as Vale das Freiras fault, Lameiras fault, Y fault and IW fault. These faults are intersected by three other orthogonal faults striking east to west direction and dipping from 63º to 89º in North direction. These faults are designated as 8E fault, D19 fault and normal fault. Intersections of these faults on the surface form rock blocks which delimit the surface subsidence influencing the flow pattern of the surface streams. Figure 3 illustrated the influence of subsidence in altering the natural flow pattern of the surface water creeks which prevents water draining from the underground galleries causing water logging of underground mine workings.

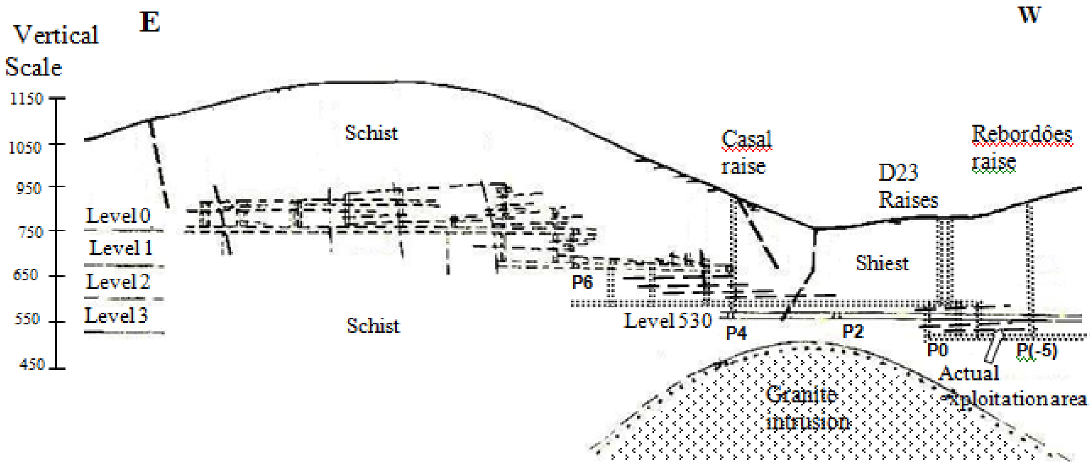

Figure 2. Rock mass and wolfram ore in Panaqueira mine (Navarro Torres, 2001)

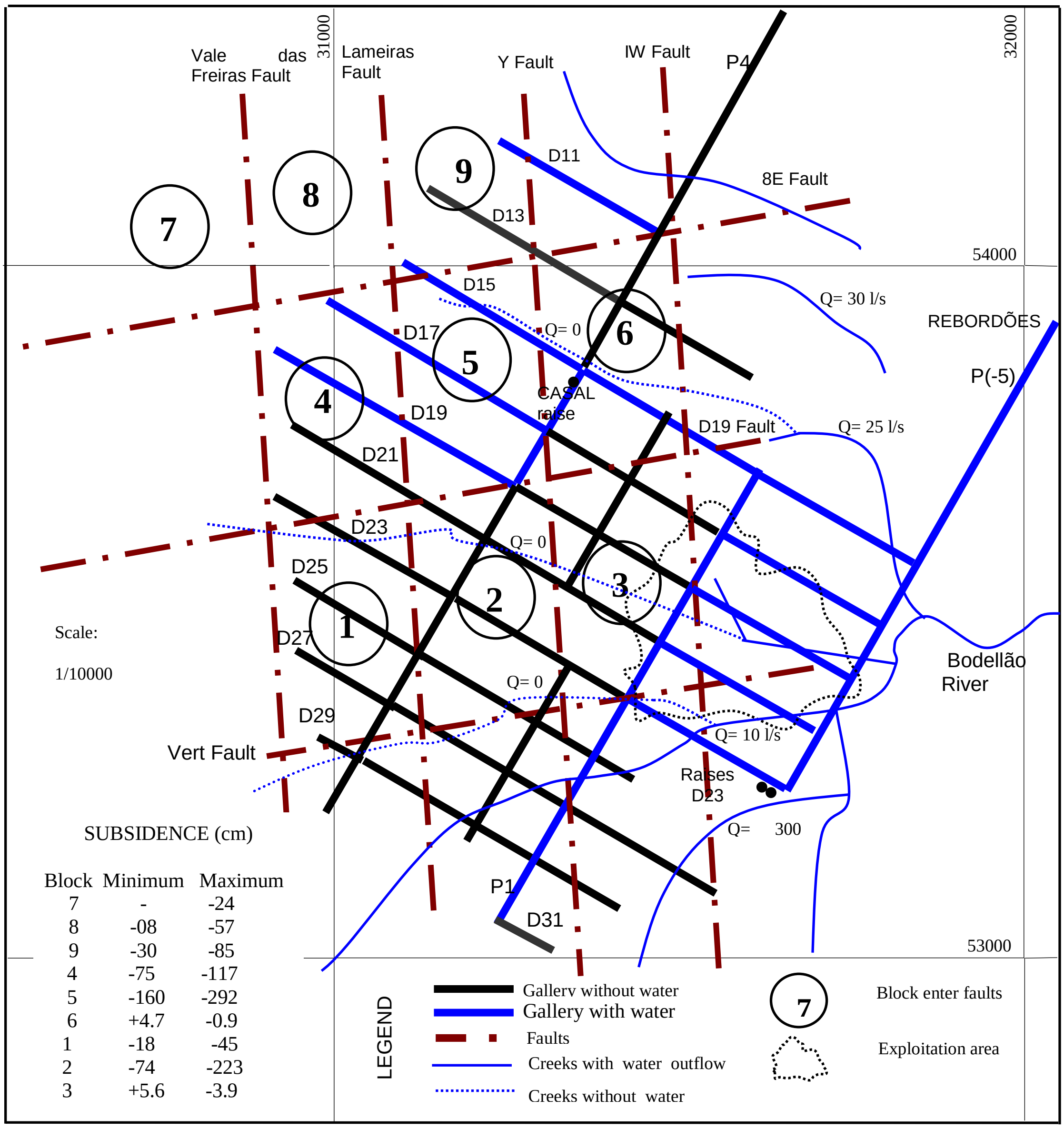

Figure 3. Hydrogeology of Panasqueira mine area (Navarro Torres, 2003).

3. Mine water characterization

3.1. Quantitative measurements

The measurement of mine water inflow in the underground openings were systematically carried out and the results indicate that in total 810.22 l/s water is discharged from Salgueira gallery to the surface streams. It may be noted that 45% of water is discharged from the North of the Salgueira gallery. It originates from the old discontinued mining areas from level 0, 39% of water corresponds to levels 1 and 2, 16% correspond to level 3, that needs to be controlled by the pumping system (Figure 4).

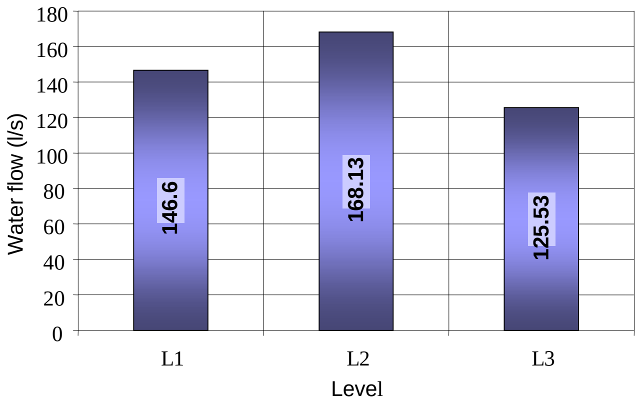

Figure 4. Mine water distribution in underground openings

3.2. Characterization of mine water quality

The results of the laboratory analysis of mine water samples in underground openings are illustrated in Figures 5, 6, 7 and 8. The pH values of mine water at these sites vary between 3.0 and 6.5 and at the discharge point in Salgeuira and Fonte de Masso galleries pH value is 4, indicating acidic mine water. Therefore, the mine water polluted by metals solid particles and metals (Cu, Zn, Fe, Mn and As) are finally discharged into the Bodelhão River.

3.3. Measurement of mine water quality and its influence on surface water

The water samples were taken from four points, three from the “Bodelhão” River and one from mine water discharge point in the Salgueira gallery. It may be noted that the other discharge point in the Panasqueira mine is called “Fonte de Masso” gallery as shown in Figure 8. The results of laboratory analyses are presented in Table 1.

4. Assessment of Mine Water

4.1 Water quality assessment criteria

The present study for water quality assessment is based on the European Laws (DC nº 75/440/CEE de 16-06-1975, 79/923/CEE de 30-10-1979 and nº 80/778/CEE de 15-07-1980) [2] and Portuguese water law (Portuguese law D.L nº 236/98) [8]. Based on these standards, the mine water quality has been assessed in relation to pH and metal concentrations to examine its suitability for irrigation, human consumption and survival of fish in the river water.

4.2. Mine water quality assessment results

In Panasqueira mine the pH of the mine water in the underground openings is less than 7. Therefore, mine water can be characterized as acidic water. This is, however, not evident from the analyses of water from underground environment but water samples from discharge points of the Bodelhão River. Therefore, mine water quality assessment was based on the laboratorial analysis results of water sample at four measurement points shown in Figure 9.
The environmental impacts are assessed based on the mine water quality assessment criteria shown in Table 2 to the mine water and surface water quality results presented in Table 3. The assessment results presented in Table 3, Figure 10 and Figure 11 show a strong reduction in pH value and a sharp increase in the metal concentration in the surface water of the Bodelhão River at the points of discharge at the Fonte de Masso and Salgeuira galleries.

Table 1. Chemical analyses for pollutants in four measurements points.

Monitoring Site	Pollutants (ppm) pH	Cu	Zn	Fe	Mn	As
1	5.27	0.04	0.52	0.13	0.09	0.00
2	5.16	0.15	1.04	0.03	0.87	0.00
3	3.99	2.01	12.605	4.09	8.60	0.03
4	4.18	3.11	15.80	2.91	8.20	0.03

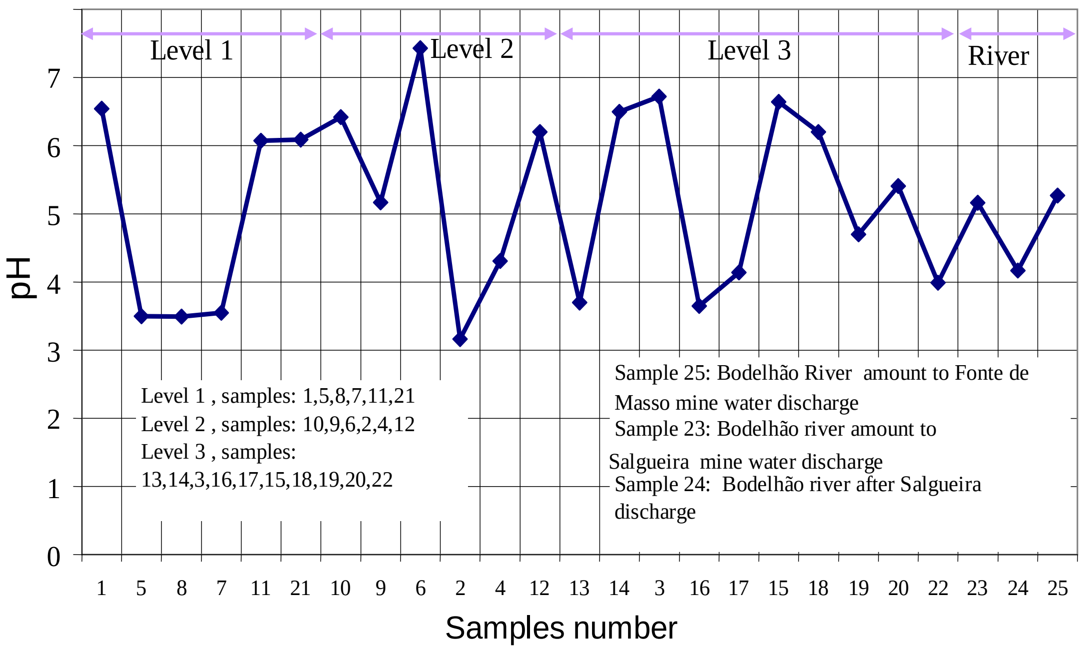

Figure 5. pH of groundwater in underground openings and the Bodelhão River

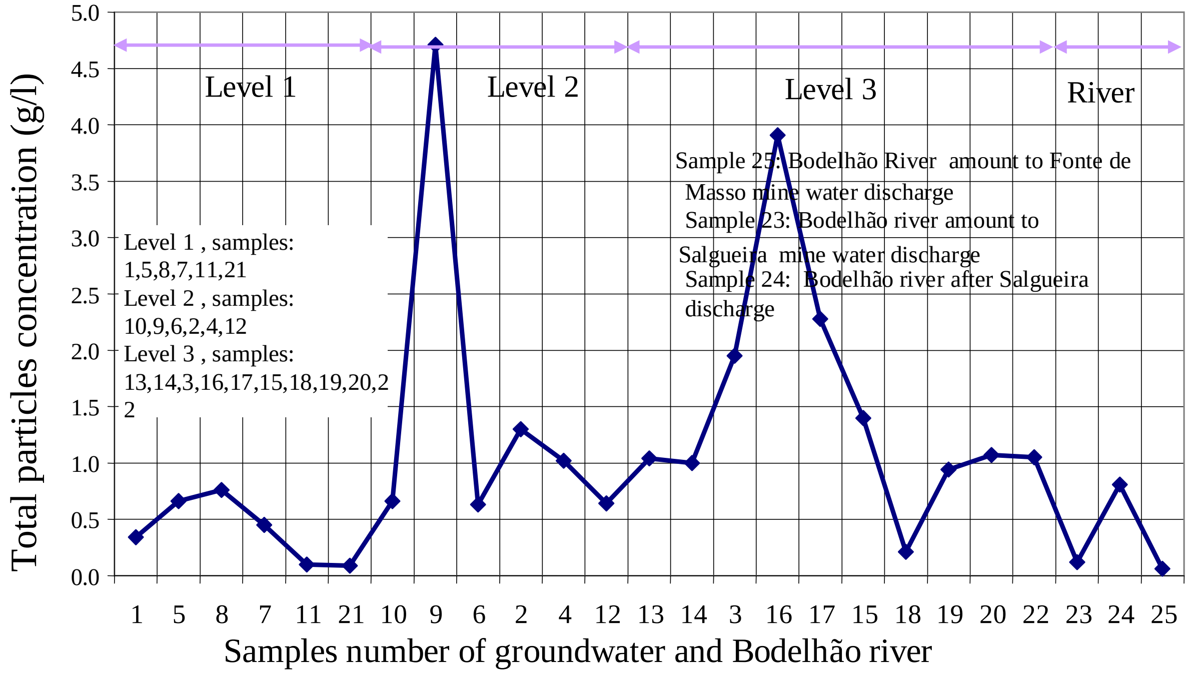

Figure 6. Particles size distribution in groundwater and the Bobelhão River

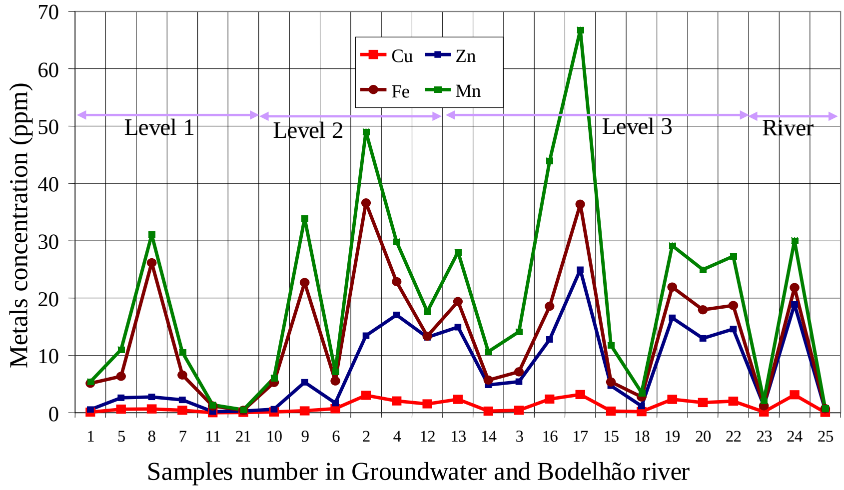

Figure 7. Metals concentration in groundwater and the Bodelhão River

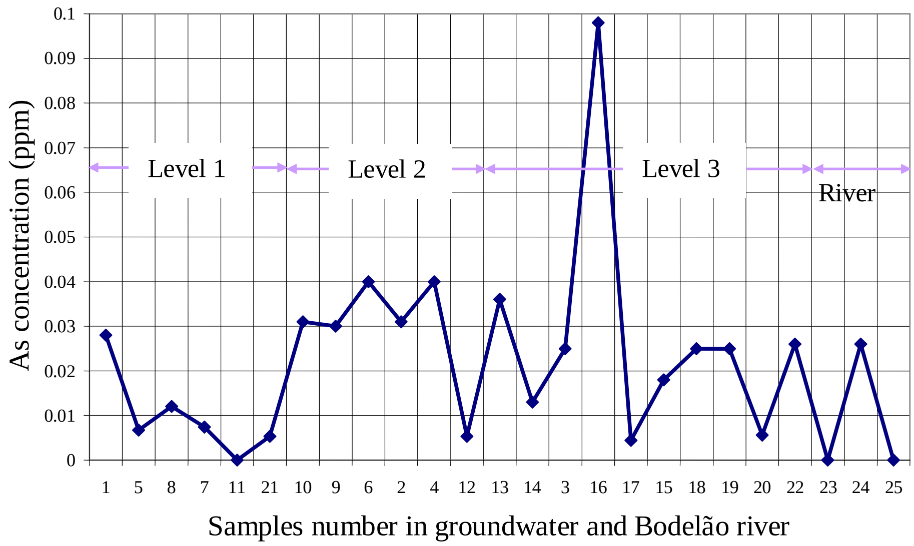

Figure 8. As concentration in groundwater and the Bodelhão River

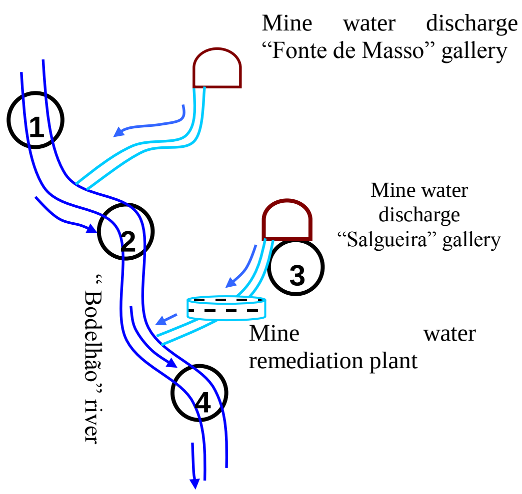

Figure 9. Measurements points of mine water discharge and the "Bodelhão" River

Table 2. Matrix for mine water quality assessment

Assessment		pH			Metal concentration
		Irrigation	Human cons.	Fish	
Low	∇	4.5 ≥pH >3.5	6.5 ≥pH >5.5	6 ≥pH >5	1.05CVLA ≥ Cr> CVLA
Moderate	⊗	3.5 ≥ pH >2.5	5.5 ≥ pH >4.5	5 ≥ pH >4	1.10CVLA ≥ Cr> 1.05CVLA
High	♦	pH ≤ 2.5	pH ≤4.5	pH ≤4	Cr> 1.10 CVLA

Cr. Pollutant concentration, CVLA: Concentration Level admissible

Table 3. Panasqueira mine water assessment result (Navarro Torres, V.F., 2003)

Measurement points	*Water Pollutants*	*Measure Cr (ppm)*	*Environmental impact level*				
			For irrigation		For human consumption		For fishes
			CVLA (ppm)	Risk	CVLA (ppm)	Risk	Risk
1	pH	5.27	4.5 - 9.0	-	6.5 -	∇	∇
	Cu	0.04	5	-	8.5	-	-
	Zn	0.52	10	-	0.10	-	-
	Fe	0.13	-	-	-	-	
	Mn	0.09	10	-	0.20	♦	
	As	0.00	10	-	0.05	-	
					0.05		
2	pH	5.16	4.5 - 9.0	-	6.5 -	⊗	∇
	Cu	0.15	5	-	8.5	♦	-
	Zn	1.04	10	-	0.10	-	-
	Fe	0.03	-	-	-	-	
	Mn	0.87	10	-	0.20	♦	
	As	0.00	10	-	0.05	-	
					0.05		
3	PH	3.99	4.5 - 9.0	∇	6.5 -	♦	♦
	Cu	2.01	5	-	8.5	♦	♦
	Zn	12.60	10	♦	0.10	-	♦
	Fe	4.09	-	-	-	♦	
	Mn	8.60	10	-	0.20	♦	
	As	0.026	10	-	0.05	-	
					0.05		
4	pH	4.18	4.5 - 9.0	∇	6.5 -	♦	⊗
	Cu	3.11	5	-	8.5	♦	♦
	Zn	15.80	10	♦	0.10	-	♦
	Fe	2.91	-	-	-	♦	
	Mn	8.20	10	-	0.20	♦	
	As	0.026	10	-	0.05	-	
					0.05		

5. Conclusions

As a result of underground mining operations, the surface and groundwater come into contact with the virgin rock mass in presence of atmospheric air and acid mine water and heavy metals are formed. When this water is discharged in the river and to natural surface waters, it produces important environmental impacts. In the case study of Portuguese Wolfram Panasqueira Mine, the subsidence due to underground mining influenced by geological faults which causes an increase in inflow quantity and the total alteration of surface water quality. In this mine, the balance of mine water distribution in underground openings result 18% in level 1, 21% in level 2, 16% in level 3 and 45% in level 0 and other levels. The results of laboratory analysis of systematic mine water samples in underground mining openings indicate that the mine water is very acidic in all areas and the metal concentrations are very high in the areas of intensive mining activities.

Discharge of mine water in the Bodelhão River increases Zn concentration and lowers pH in water, and this in turn increases the environmental risk for irrigation. Lowering of pH and increase in the concentration of Cu, Fe and Mn in water presents a high level of risk for human consumption. Similarly, lowering of pH and increase in Cu and Zn concentration causes high risk against survival of fish in river water.

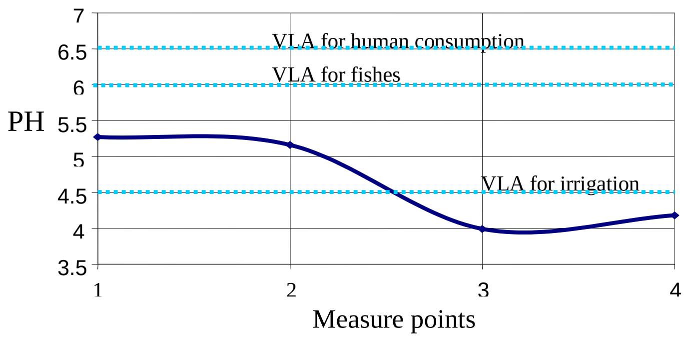

Figure 10. pH assessment in discharged mine water and influenced in surface water of the Bodelhão River

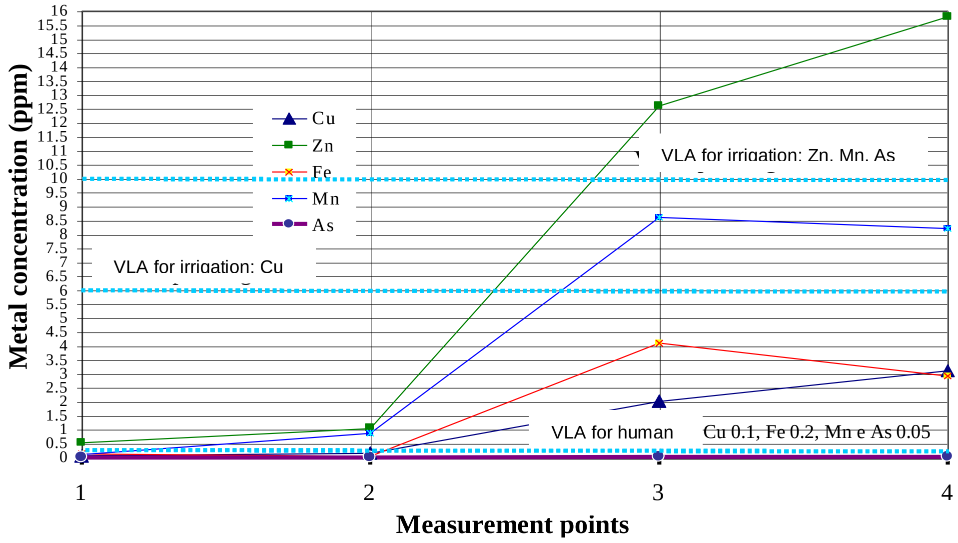

Figure 11. Metal concentration assessment in discharged mine water and its influence on the Bodelhão River water

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