Environmental contamination related to mine drainage distribution from old mine sites by waterways

Olga Aslibekian, Richard Moles

Dept. Chemical & Environmental Sciences, University of Limerick, Ireland.e-mail:olga.aslibekian @ ul.ie; richard.moles @ ul.ie

Abstract: The most common environmental concern associated with acid mine drainage (AMD) is related to water contamination downgradient from mine sites, which may be particularly damaging in areas where receiving waters have a low buffering capacity. However in a wet climate metal contamination is significantly more severe in soil, where metal compounds are delivered and deposited by means of water, and river sediments. Contamination of natural water receiving mine drainage and its effect on sediment and soils were investigated in the vicinity of the Silvermines Pb-Zn Abandoned Mine Site (AMS). Within the area of carbonate rocks occurrence, contamination of surface water was detected mainly within the immediate vicinity of the mine site and was found to rapidly fade downgradient from the AMS. Resultant Pb/Zn/Cd contamination of river/stream sediments and soil at some locations was significant: metal concentrations in soil within river floodplains are comparable with those at mine sites; excessive metal concentrations were detected within areas of seasonal groundwater seepage; surface runoff deposition of metal compounds in soil downslope from the mine site exceeded that deposited as dust. In addition the content of bioavailable metals in soil in such areas was also high. In wet climatic conditions, as in Ireland, water-related pathways of metal compound distribution from AMS should be considered as the prime mechanism of soil contamination.

1 INTRODUCTION

Mine drainage generation and dust emission from abandoned mine sites (AMSs) may be considered as the most significant sources of environmental contamination associated with mining activity. The amount of contamination produced, the distribution of this from the AMS, and fate along the pollution pathways relate especially to environmental conditions (geology, climate, including water balance, water regime) and mine feature (postclosure rehabilitation measures, ore type, etc.).

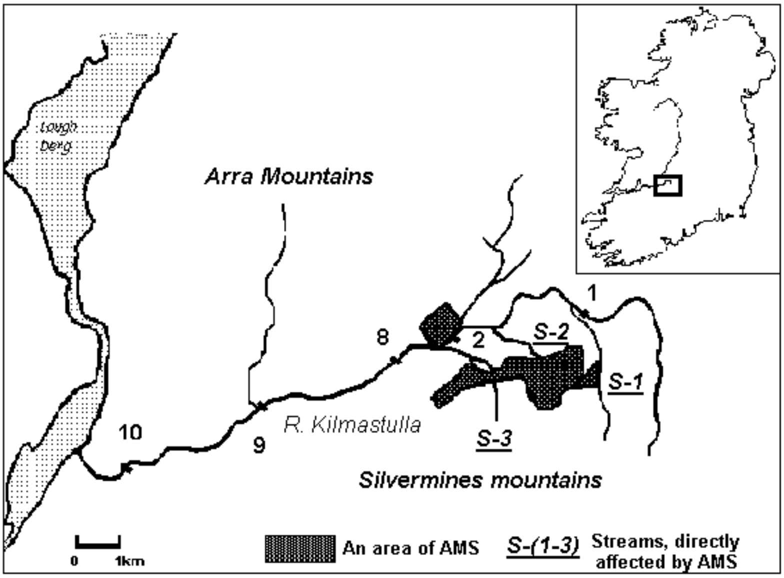
In the mine surroundings, soil contamination is commonly associated with dust emission, while AMD is mainly related to water contamination. However, in many cases precipitation of metal compounds within water receiving mine drainage may also result in contamination of river sediment and soil. Surface runoff from mine sites may cause soil contamination downgradient from its source. Soil may become polluted where seasonal seepage of contaminated groundwater occurs. Discharge of AMD into surface water results in metal compounds being precipitated or adsorbed, which causes sediment contamination. For instance, in sediments of the R. Tinto metal concentrations in the riverbed are extremely high (Fe - 420000; As – 2370; Cu - 1220; Hg – 30; Pb – 13400 mg/kg) (Usero et al., 1999). River sediment redistribution during flooding events can cause contamination of soils on the floodplain downstream from the AMS (Odor et al., 1998; Rader et al., 1997). Metal content here may approach the concentrations typical of mine waste (Macklin et al., 1997; Rowan et al, 1996).

The level of metal concentration in sediments and soils on floodplains may be greater where the environment is characterized by high buffering capacity (Hudson-Edwards et al., 1997). Although alkaline conditions reduce metals content in mine drainage at source, metals in near neutral mine drainage are still present in substantial concentrations. Mine drainage discharging into alkaline surface water results in intensive metal precipitation and leads to river sediment contamination. The metal deposition in such a case may become greater then in systems with acidic conditions, which allows metal compounds to remain in soluble forms.

2 CASE-STUDY

Environmental contamination related to the distribution of mine drainage and its by-products was studied in the locality of the Silvermines old mine site (Figure 1).

Figure 1 Location of the Silvermines AMS (1-10 – water quality monitoring stations)



The Silvermines AMS is located in north Tipperary on the northern slopes of the Silvermines Mountains (490 mOD). Mean annual precipitation is 848 $mm\times y^{-1}$ at lower altitudes (50 mOD) and 1633 $mm\times y^{-1}$ at higher altitudes (490 mOD).

Surface drainage is largely by the Kilmastulla river, which flows approximately 15 km from its source to a confluence with the river Shannon, with a catchment area of 98.9 km^2. There is significant seasonal variation in river discharge (from less then 0.5 to more then 20 m^3×sec), reflecting a greater input of runoff into the river regime in wet seasons (total rainfall- 1130 mm×y^{-1}; surface runoff - 470 mm ×y^{-1}, ground water recharge - 130 mm×y^{-1}) (Aslibekian, 1999). The mining history of the site goes back for centuries. However, most intensive mining activity was related to the XIXth and particularly XXth centuries. In the Silvermines area, Zn-Pb-Ba mineralisation occurs within basal Carboniferous (Courceyan) transgressive siliciclastics and in the overlying carbonate sediments. As a result of mining activity, intensive underground working, open pits, spoil heaps, tailing ponds, and other undefined mine waste are sporadically located along the northern slope of the Silvermines mountain and R. Kilmastulla valley, covering about 5 km^2.

Carboniferous formations (mainly limestones) hosting the main mineralisation (Andrew, 1986) occur in the eastern part of the Kilmastulla river valley. As a result, surface water has a high buffering capacity with pH and alkalinity varying in the range 7.5-8.5 and 114-287 mg×l^{-1} respectively.

Gardens are a common feature in the Silvermines village, located in the immediate vicinity of the AMS. A number of farms are also situated close to the AMS. Terrains, previously considered as mine sites, are often used now as grazing lands. Farm animals have easy access to streams, where water and re-suspended material from stream beds may be consumed by the animals. Fortunately the water supply is based on surface sources upstream of mine sites. Groundwater is not abstracted for domestic or other use.

3 METHOD

The sampling programme was focused on the areas with high risk of contamination from AMS (hot spots), as was described above and shown on Figure 2. Water, sediment and soil samples were collected and analyzed for metal concentration. Additional samples were also collected outside the main risk zones. Two different methods of metal extraction from samples were used to assess Cd, Pb and Zn exchangeable and total concentration. Exchangeable metals in soil were extracted by EDTA at pH=7.0. For the total metal concentration in soil and sediments, samples were digested by concentrated nitric acid attack (5ml conc. HNO_3, 0.500 (±0.001) g, boiled until the liquid volume reduced to one half, filtered and diluted to 25ml). Metal concentrations in filtrates, and also filtered (Watmans No.2 filter) natural water samples, were measured by Atomic Absorption Spectrometer (AAS). Accuracy of the results were controlled by the use of reference materials, duplicate sample collection and duplicate extraction. Monitoring data on R. Kilmastulla water quality, provided by the Irish

Environmental protection Agency, were also analyzed to assess seasonal variation in metal concentrations.

Figure 2 The hot spots of metal contamination

4 RESULTS

As the mine sites are located on a mountain slope surface runoff from the mine sites is significant by volume and the area affected. Together with solid particles captured on the site or delivered by dust emission, runoff may also be contaminated by mine drainage. Metal composition in soil downslope from the mine site varies depending on the location and the characteristics of mined ore. Pb concentration reduces and Zn concentration increases from the western to the eastern part of mineralisation occurrence, and metal composition in soils along the slope follows the same pattern (Figure 3). Metal content in soil exceeding trigger values (Ferguson et al., 1998) were not detected any further than 500m from the site.

Degradation of surface water quality near AMS occurs in a limited area directly affected by contaminated discharge. Here, metal content may reach hazardous concentrations, particularly during periods when surface runoff dominates in river recharge (Table 1) (Aslibekian et al., in press). Groundwater discharge into the R. Kilmastulla does not increase metal concentrations in surface water (Figure 4).

The high neutralizing capacity of the water, a product of its high alkalinity, encourages metal precipitation to start within a short distance from the AMS. This process results in significant metal removal from the surface water, with consequent contamination of river sediments.

Sediments. Metal concentrations in streams and riverbeds are extremely high, particularly (1) within stream sections crossing mine sites and (2) in zones of ground water discharge into the surface water network, downstream from the AMS (Figure 5). An effect of groundwater discharge is illustrated in Table 2: at the stream bank receiving contaminated groundwater discharge, metal concentrations in sediments are higher than at the opposite bank.

Table 1 Seasonal variation in metal concentrations (as an average, mg/L) in stream water (S-3; see Figure1).

Dominated source of river recharge	Cd, mg/L	Mn, Mg/L	Zn, Mg/L
Groundwater (dry season)	0.0039	0.09	0.99
Surface runoff (wet season)	0.0146	0.22	4.38

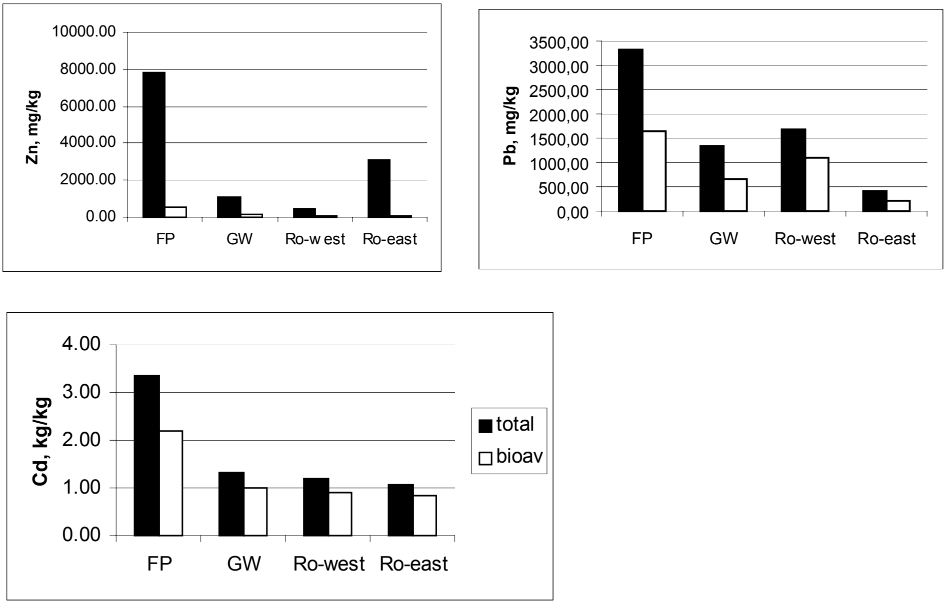


Figure 3 Average metal content in soil on floodplain (FP); in the areas of groundwater seepage (GW) and downslope from AMS (RO).

Floodplains. The highest metal concentrations in soil were found within the R. Kilmastulla floodplain. In some cases total metal concentrations in soil exceed those in the mine sites (Figure 3). Exchangeable Cd, Pb, Zn concentrations are high also. Affected areas are located 2-3km away from mine sites and compose about 6 km^2, which is bigger then the total area covered by the AMS.

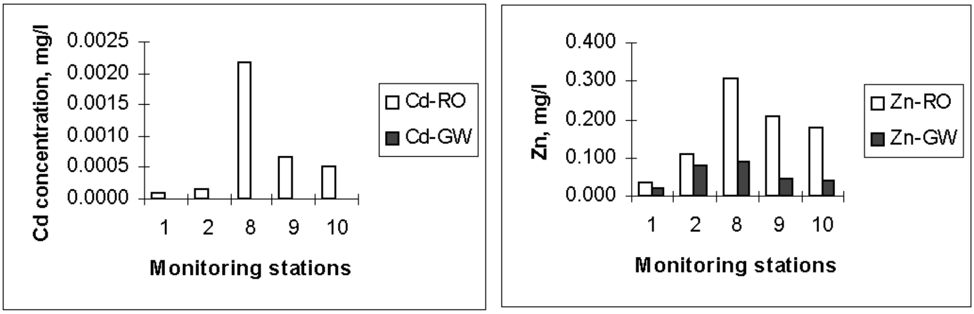


Figure 4 Variation in Cd and Zn concentrations (as an average) in water along the R. Kilmastulla (for monitoring stations see Figure 1).

Table 2 Metal content in streambed and in the seepage zone of polluted groundwater discharge (stream bank).

Location of samples	**Cd, mg/kg**	**Pb, mg/ kg**	**Zn, mg/kg**	**pH**
Polluted groundwater seepage zone on the stream bank	28.5	5353.2	20412.3	6.2
Streambed	14.5	2171.3	9605.8	6.8

Groundwater seepage downgradient from the AMS was found at a number of locations: (1) at the break of slope between mountain side and valley base; (2) in the area of fen occurrence. Total and exchangeable metal concentrations in soil within these areas are high (Figure 3).

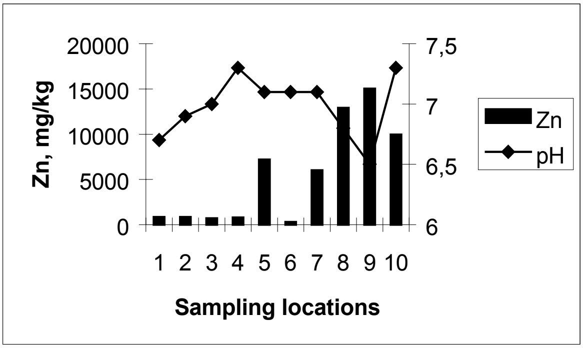
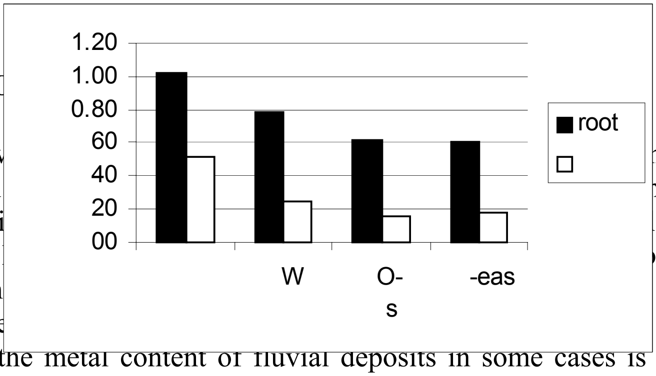


Figure 5 Metal -3 are located within AMS, 5 and 7-10 – stream sections receiving contaminated groundwater discharge.



5 DISCUSSI

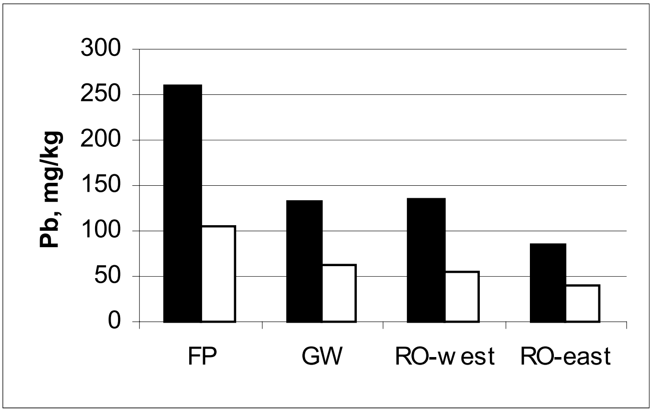
Pollution of w ns for metal contamination iines region water quality i owing from AMS. The R. y the AMS. Survey of fish the basis of an invertebrat

However, the metal content of fluvial deposits in some cases is comparable with that in R. Tinto (e.g., Pb). Soil contamination in the floodplain affected by re-deposition of contaminated sediments is characterized by metal content often as high as those at the mine site. Exchangeable metal concentrations are particularly high on floodplains, which makes soil contamination even more hazardous. Contamination hot spots of this origin were found at a considerable distance from the AMS (2-3km). They are also large in area.

Land affected by surface runoff may be also contaminated by dust emission from the AMS. Total metal concentrations are often higher than the relevant trigger values, but are much less than in floodplain. Contamination is not distributed further than about 500m from AMS.

The metal contents of grass leaves and roots within the contamination hotspots follow the same pattern as for metals in soils (Figure 6), which confirms that the delimited hot spots are associated with high environmental risk.

Figure 6 Metal content in grass leaves and roots within hotspots (on floodplain (FP); in the areas of groundwater seepage (GW) and downslope from AMS (RO).



6 CONCLUSIONS

1. Under wet climatic conditions, when precipitation significantly exceeds the evaporation rate, investigations of environmental pollution from abandoned mine sites must take account of water-related pathways which distribute metal compounds to the environment. Dust emission in such climatic conditions may affect only limited areas (<500 m for Ireland).

2. Although carbonate rock occurrence may reduce deterioration of surface water quality from mine drainage discharge, significant rates of metal precipitation from water leads to deposition of metal compounds in river/stream beds and soil. In the Silvermines region, soil was significantly contaminated at the following locations.

- Areas affected by surface runoff from the AMS (<500 m downslope from the mine sites).
- Areas of seasonal groundwater seepage downgradient from the AMS.
- The R. Kilmastulla floodplains, covering more than 6 km^2.

3. In addition to total metal concentrations, that of biologically available metal compounds may provide additional information regarding the characteristics of metals in soil. In contamination hot spots near the Silvermines AMS the high content of Pb and Cd in grass leaves and roots reflects high concentrations of biologically available metals in soil.

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Skażenie środowiska związane z odprowadzaniem wód ze starych kopalń do cieków powierzchniowych

Olga Aslibekian, Richard Moles

Streszczenie: Najbardziej powszechnym problem środowiskowym związanym z odprowadzaniem kwaśnych wód kopalnianych (AMD) do rzek jest zanieczyszczenie wód powierzchniowych. Proces ten jest szczególnie szkodliwe na obszarach, gdzie wody odbierające zrzuty kopalniane mają małą pojemność buforowania. Jednakże w klimacie wilgotnym znacznie poważniejsze jest skażenie metalami gleby, do której związki metali są dostarczane wraz z wodą i osadami rzecznymi. Skażenie naturalnej wody, do której spływają odprowadzane wody kopalniane oraz ich wpływ na osady i glebę badano w sąsiedztwie opuszczonego wyrobiska kopalni Pb-Zn Silvermines (AMS). Na terenie występowania skał węglanowych, skażenie wód powierzchniowych stwierdzono głównie w bezpośrednim sąsiedztwie wyrobiska i malało ono gwałtownie im dalej i niżej od AMS. Skażenie Pb/Zn/Cd osadów strumienia/rzeki i gleby było znaczne w niektórych miejscach: koncentracja metali w glebie w obrębie równiny zalewowej jest porównywalna z ich koncentracją w wyrobisku kopalni; nadmierną koncentrację metali stwierdzono na obszarze sezonowego przesączania wód podziemnych; wytrącanie się ze spływu powierzchniowego związków metali w glebie wzdłuż zbocza wyrobiska. Zawartość metali w glebie na tym terenie również była wysoka. W klimacie wilgotnym, takim jak w Irlandii, dystrybucja związków metali drogą wodną z AMS powinna być uważana za główny mechanizm skażenia gleby.