REMEDIATION OUTLOOK IN A HISTORICALLY CONTAMINATED MINE REGION

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ABSTRACT

From four thousand years Sardinia Island - Italy - has been know for its rich mineral deposits.

The mining activities became more and more intensive in the century between the years 1870 and 1970, starting from the discovery of safety blasting by A. Nobel until the extension of robotized machines to the exploitation of big stopes.

Contemporary metallurgical plants became able to treat complex ores, sometimes coming from external countries.

As a result of mining works, mineral processing, metallurgical smelting and refining plants, a lot of wastes, tailings and slags has been disposed on the land with consequent environmental problems.

The area of Sulcis-Iglesiente, which has been the site of the main mineral deposits and related industrial activities, has been the addressee of all kind of pollution.

The coast and related sea expanse, in the nearness of mines and plant sites, became the final deposit of mobile contaminants after transportation by wind and waters.

In particular conditions, when the cleaning actions of the sea were limited by natural barriers, polluting agents were accumulated into the sediments of basins and lagoons.

The status of this area has been taken into consideration starting from an assessment of pollution sources and a recognition of indicators based on the polluting agents level in soils and air.

The heavy metal contamination of the sediments in certain basins near the mine sites has been exploited considering the relevant example of the Boi Cerbus lagoon.

After the pollution assessment, different remediation technologies have been explored in order to achieve suitable reduction in the environmental impact. Size-classification has revealed itself to be the less expensive way to remove the most of pollution fractions. Flotation tests and leaching experiments have shown that there are some perspectives in reducing heavy metal pollution under certain processing procedures.

Landfilling of contaminated soils appears to be suitable after removing them from coastal area in order to assure proper safety conditions for fishing and swimming.

INTRODUCTION

This work concerns the environmental problems related to a region, named Sulcis-Iglesiente and located in the south west of Sardinia, Italy, well known in the past years for notable lead and zinc mines and the related mineral processing and piro- and hydro-metallurgical plants (see Figure 1).

Figure 1 – The region of Sulcis-Iglesiente in Sardinia: the main industrial (dark grey) and urban (light grey) settlements are reported.
After the closures of the old mines, some operating from thousand years until few years ago, only the activities related to primary metal production are running today.

Relicts of several industrial buildings, dismantled machinery, exhausted r.o.m. and concentrate stockpiles, mine waste land-fillings and soil and water pollution remain to testify the extent of the old works as far as the bearing of the contributes from the actual industrial activities.

The area under investigation, for an extension of 390 km², is characterised by some urban settlements and several industrial plants, the most important being: lead, zinc and magnesium primary and refining metallurgy-plants, two thermo-electrical power plants, alumina and primary aluminium production, secondary aluminium manufacturing (laminating and thin foil forming).

In the site is also operating a coal mine with its shifts and processing plants and the related waste disposal.

As a consequence of the continuous industrial activities a lot of contaminants have been continuously transferred to the environment and most of them are trapped into the soils and the confined waters.

In order to assure a proper land remediation the Italian Government stated the area as characterised by a high level of environmental risk (November 1990) promoting the related actions (DPCM 72, 1993) for the amendment of the actual industrial processes and plants and for waste control and land decontamination.

CONTAMINATION FROM INDUSTRY

Today the contamination of the site is mainly depending from four sources (ENEA, 1999):

- **Lead and zinc production** by Waeltz furnace, Kijvec plant and electrowinning: as a consequence the of waste and slag production, some heavy elements (like Pb, Zn and their associates Cd, As, Bi, Sc, Cu and Ti) and SO₂ (from roasting of concentrates) are continuously transferred to air;

- **Alumina production** starting from bauxite concentrates: as a consequences of leaching of bauxite (Bayer process) high quantities of red mud are settled into a sedimentation basin beside the coast. Furthermore bauxite powders, coming from bauxite and alumina handling, and pure metals (as Cr, V, U and Th after bauxite roasting) are regularly spread into the atmosphere;

- **Aluminium production** by electrolysis: despite the presence of captivation devices, fluorides are frequently dispersed into the environment in different phases.

- **Magnesium production**: fine particles are spread in the atmosphere and sludges are discharged onto the near coast line and directly in the sea.

- **Coal production**: wastes and dusts come from mining activities and mineral processing of the ore.

- **Energy production**: combustion dusts and gases, like CO₂, SO₂, and NOₓ are spread into the atmosphere and fall widely onto surroundings.

As a result of gases and powders emissions, under the action winds of quite permanent direction and intensity, a fall-out of contaminant has involved soils and surface waters of the Sulcis-Iglesiente area.

DETECTION OF POLLUTION

Primary releases affect the surface of soils, the sediments of the water streams and the shallow depths of the sea along the south-west coast of Sardinia.

All these receptors, close together, can be considered as secondary sources since contaminants may migrate under different carrying actions and can affect larger sectors of the area until at a regional scale (Forstner, 1983).

The migration of contaminants out from the primary receptors and their diffusion in the atmosphere are related to some weather conditions (north-west winds are frequently blowing in Sulcis-Iglesiente area).

A net of sensors for monitoring some environmental parameters are settled in the industrial area in order to measure the emissions by industrial plants and to appreciate the mechanism of dispersion of contaminants and to verify the observance of the standards for the quality of the emissions.

Data processing, after a monitoring campaign during 1998, brought to build a model for the contaminant distribution in the atmosphere in the Sulcis-Iglesiente area (Cantoro, 1999): 

- NO₂ content in air achieved the highest concentrations in the neighbours of the most inhabited town of the site (Carbonia rising 50,000 people);

- SO₂ content in air achieved the highest concentrations very close to the industrial plants, in proximity of the small built up area and the near
harbour (Portoscuso), where there’s the evidence of the favourable action of the dominant wind in lessening the contaminant concentration as shown under typical atmospheric conditions in Figure 2;

- Pb is mainly diffused on the soils just around industrial plants caused by the direct fall-out of the plant emissions;
- Dusts are mainly diffused in the nearness of the industrial area, where raw materials are handled and stocked.

Surface waters play a very important role in the diffusion of contaminants in the environment allowing transport of pollutants from their sources to the final destination, generally represented by sea sediments.

Figure 2 - SO₂ concentration [μg/Nm³] in the thermo-electrical plant emissions coming from simulation of diffusion in air in the Sulcis-Iglesiente region under the action of the dominant wind.

Several contaminants, dispersed in water, chemically react with some substances naturally present in waters or in the deep sediments (Alloway and Ayres, 1993).

The area is not subjected to natural geo-chemical processes so relevant to induce some changes in the structure pollutant compounds, from potentially active chemical forms into biologically inert species.

In these conditions an high content of heavy metals (Pb, Zn, Cd and Cu) in the sea waters along the coast line facing the industrial site have been detected, especially when trapped by some artificial structure as in the case of the isthmus connecting an island close to the Sardinia coast (S. Antioco) (see Figure 1).

The situation suggests that there is a likely diffusion of pollutants directly from discharging wharves of the harbour (Portovesme), where all the industrial materials are discharged and stocked in open air.

Even the streams of the surface waters play an important role as carriers of contaminants in the Sulcis-Iglesiente area.

Some rivers (i.e. Canale Paringiato) collecting run-off waters from mining sites and industrial plant, allow contaminants to reach coastal lagoons (i.e. Boi Cerbus lagoon), where they accumulate, settling critical conditions of water sediments, soils and vegetation into the areas surrounding the industrial plants.

Remarkable soil contamination by lead and zinc, spread like wildfire, has been relieved throughout the whole industrial area.

Analyses, carried out on samples of vegetation collected in the nearby vineyards, have been even revealed the presence of some heavy metals like Cadmium and Tellurium, which hazards depend not only by their intrinsic toxicity, but even by their capacity to pass through the absorption barrier of rhizosphere (more easily than the other pollutant, p.e.: lead and zinc) and to get concentrated mostly on the fruits of the plants.

At last but not least is the problem of the management of mine and industrial wastes, with particular reference to the red mud tailings coming from the bauxite treatment (Bayer process), involving 700,000 t/y.

At present the red mud tailings are stocked in an artificial basin (Sa Foxi), situated in the neighbours of the shoreline, 2 km south-westward from the industrial plants, close to the industrial harbour and a small town (Portoscuso rising 10,000 inhabitants).

Environmental problems, related to the disposal of the red mud tailings, primarily concern the enormous volumes to be settled into the landfill: at the moment the waste stock engages a basin with an extension of 120 ha, 12 m in high.

Liquors leaking out of the basin, after draining from the bottom, are responsible of the raising of the pH levels of the waters of the nearby lagoon area and the old mouth of the river (Canale Paringiato) running to the sea (Provincia di Cagliari, 1996).
WATER CONTAMINATION

Some studies have been carried out in order to assess the state of contamination of the surface waters in the Sulcis-Iglesiente area.

A detailed study has concerned the environmental conditions of the water basin (Boi Cerbus lagoon), final receptor for a lot of waste-waters coming from industrial settlements (Portovesme).

The lagoon is situated in the south-western belt of the area under investigation (see Figure 3) with an extension of 200 ha and a border of 6.4 km, slightly trapezoidal shaped.

After surveying of the contaminants in the lagoon, an environmental emergency has been ascertained.

Suitable restoration technologies have been pointed out for the remediation of lagoon sediments, having in mind the significant role that the lagoon plays in the reproduction and conservation of living species and taking into consideration the need to its protection for production of food for human consumption, in accordance with a regional law (L.R.S. 31, 1989).

In fact the lagoon has been inserted into the biotope of an area (Punta s’Aliga), which has been proposed as a natural reserve being its importance for resting of marine birds and for the growth of some interesting vegetable species (Massoli Novelli e Mocci Demartis, 1989).

In order to assess the environmental state and the level of pollution of the lagoon, samples of water, sediments and soils have been collected and analysed (De Giorgi, 1999).

In spite of traces of heavy metals in waters, chemical analyses revealed the occurrence of high contents of Pb, Zn and Cd in the fine size-fractions of the lagoon sediments.

It happens especially for those sediments collected in the internal area of the lagoon close to the old mouth of the river (Canale Parigianu) which collects solid and liquid tailings from industrial plants (see Figure 4).

This situation, due both to the flow system and to the topological characteristics of the lagoon, like the shallowness of the wide mouth to sea, is responsible of the limited hydrological turnover.

As regard to the other hydrological parameters, must be noticed that the pH of the lagoon waters reaches its highest levels in the most internal area, probably referred to the leaking of solution from the red mud basin.

Figure 4 - Distribution of pollutants in the Boi Cerbus lagoon: risk map after considering the occurrence of the different metals, taking into consideration the lower class of acceptance as pointed out by the current Italian rules for lagoon sediments (Protocollo Venezia).

In fact, in the area between the lagoon and the red mud basin, a consistent water runoff (with presumably high level of pH) is conveyed (Provincia di Cagliari, 1996).

As regard vegetables species, chemical analysis relieved high content of heavy metals mostly in the roots of the water-plants which act as a filter-membrane protecting the aerial parts of the species (see Table I). It has been found, moreover, the high occurrence of heavy metals, and in particular of zinc (about 5,000 ppm of Zn in dried materials) in some filamentous algae (as shown...
in Figure 4), which seem to play the role of pollutant accumulators.

Table I - Heavy metal concentrations in the vegetation sampled into the Boi Cerbus lagoon (as shown in figure 3).

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Sample</th>
<th>Cd</th>
<th>Pb</th>
<th>Zn</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[ppm]</td>
<td>[ppm]</td>
<td>[ppm]</td>
<td>[ppm]</td>
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<tr>
<td>Algae</td>
<td>RP1</td>
<td>39</td>
<td>690</td>
<td>3,243</td>
<td>6</td>
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<tr>
<td></td>
<td>RP2</td>
<td>4</td>
<td>149</td>
<td>290</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>RP3</td>
<td>32</td>
<td>193</td>
<td>643</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>RP4</td>
<td>19</td>
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<td></td>
<td>RP5</td>
<td>8</td>
<td>143</td>
<td>229</td>
<td>2</td>
</tr>
<tr>
<td>Roots' apparatus</td>
<td>RP2</td>
<td>11</td>
<td>181</td>
<td>354</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>RP3</td>
<td>63</td>
<td>310</td>
<td>1,277</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>RP4</td>
<td>1</td>
<td>33</td>
<td>46</td>
<td>1</td>
</tr>
<tr>
<td>Aerial parts</td>
<td>RP2</td>
<td>2</td>
<td>44</td>
<td>101</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>RP3</td>
<td>3</td>
<td>52</td>
<td>90</td>
<td>4</td>
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<tr>
<td></td>
<td>RP4</td>
<td>1</td>
<td>23</td>
<td>36</td>
<td>0</td>
</tr>
<tr>
<td>Mucilage</td>
<td>RP3</td>
<td>381</td>
<td>982</td>
<td>4,953</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 4. Filamentous algae accumulating metals.

Furthermore high content of cadmium and lead have been measured in the bodies of mussels cached from the lagoon, to reveal their function of bio-accumulators of pollutants, as well as about the algae.

**REMEDIGATION TECHNOLOGIES**

The research work pointed out several reclamation technologies aiming the remediation of the lagoon sediments (Joziasse et al., 1990; Lake et al., 1984; U.S. EPA, 1996; U.S. EPA, 1997; De Fraya, 1994).

First of all, in order to get a remarkable reduction of the mass of material to be processed, a size-classification has been suggested in order to separate the coarser fraction poor in contaminants. A suitable process has been suggested for the decontamination of the finer size-fraction from lead and zinc. Other technologies taken into consideration as a base for sediment decontamination are:

- phito-remediation, adopting algae as filters for the capture of heavy metals (Cunningham e Berti, 1993);
- flotation, utilising sodium amyl-xanthate as sulphide collector (Massacci, 1992).

**CONCLUSIONS**

Mining, metallurgical and energy production plants are responsible of different kinds of pollution spread in Suélsis-Iglesiente area in Sardinia.

Monitoring of contamination evidenced the dissemination of metals in soils and the diffusion in atmosphere of gases coming out from combustion processes: in this way inner and coastal waters become pollution recipients due to fallout and transportation phenomena. River-, lagoon-, sea-sediments along the coast remain, therefore, liable to the highest environmental impacts. Monitoring data concerning plant emissions allow to ascertain the pollution sources and to point out the strategies for land remediation.

Information coming from this statement has been useful to point out different strategies of remediation as those presented in another paper presented at the same conference: Environmental problems related to old mining and new industrial settlement.

**ACKNOWLEDGEMENTS**

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