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The contamination legacy of a decommissioned iron smelter in the Italian Alps

Luigi Gallini[a,b], Franco Ajmone-Marsan[b,*], Riccardo Scalenghe[c]

[a] Istituto Professionale Industria e Artigianato "Plana", Dipartimento di Scienze Integrate, Piazza Robilant 5, Torino, Italy
[b] Università di Torino, Dipartimento di Scienze Agrarie, Forestali e Alimentari, Grugliasco, Italy
[c] Università di Palermo, Dipartimento di Science Agrarie, Alimentari e Forestali, Palermo, Italy

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ABSTRACT

The economically important activity of metal processing can tend to contribute to the degradation of the environment. Smelting is an important source of contaminants, dispersing large quantities of potentially toxic elements (PTE) and coproducts into the environment. Soils in the vicinity of smelters frequently contain high concentrations of PTE. In terms of the quantities processed, the major PTE are iron (Fe), aluminium (Al), copper (Cu), lead (Pb), manganese (Mn), and zinc (Zn); of these Cu, Pb and Zn are, potentially, highly hazardous elements. The general problem addressed by this study is to determine if the PTE concentration in the soils of an area downwind from a decommissioned iron smelter (46°04′16″N, 8°15′47″E) still shows signs of past contamination, and to discuss the options for intervention. The history of pollution of Villadossola soils due to the steel business comprises the last 150 years. We measured pseudo-total (aqua regia) and available (EDTA) PTE in soils over an area of 15 km^2 near to the pollution source. Here we show that four decades after the end of the polluting event, when the total emissions originating from the smelter followed the order of magnitude Zn ≫ Cr ≫ Fe ≈ Pb ≈ Ca > Mn ≫ Cu > Ni ≈ Cd, the soil feedback, presented in terms of enrichment ratios, follows the order Cd > Bi ≫ Pb > Cu > Zn > Sb ≈ As > Cr. The total concentrations of PTE in the topsoil are: 101 mg Cr, 8 mg Co, 41 mg Ni, 70 mg Cu, 143 mg Zn, 6 mg As, 1.3 mg Cd, 0.5 mg Sb, 92 mg Pb, and 1.3 mg Bi kg^{-1} soil, with standard errors exceeding 50%. Our results show that it is unlikely that soils in the vicinity of the former smelter are a source of disproportionate human intake of PTE, and that the cost of reclamation would reach one quarter of the total annual budget of the municipality. Options for reducing the risks rely on the optimisation of the risk assessment factors, by adopting soil conservation practices.

People take sick, for example, from breathing high levels of smoke from fuels used in cooking or heating. There is also pollution that affects everyone, caused by transport, industrial fumes, substances which contribute to the acidification of soil and water, fertilisers, insecticides, fungicides, herbicides and agrotoxins in general. […] *But our industrial system, at the end of its cycle of production and consumption, has not developed the capacity to absorb and reuse waste and by-products.* […] *In some countries, there are positive examples of environmental improvement:* […] *they do show that men and women are still capable of intervening positively.* […] *We need only recall how ecosystems interact in dispersing carbon dioxide, purifying water, controlling illnesses and epidemics, forming soil.*

From the Encyclical Letter *Laudato Si'* by Pope Francis, given in Rome at Saint Peter's on 24 May 2015

1. Introduction

The steel-making industry was developed in Italy beginning in the second half of the nineteenth century. Its major expansion came after World War II but towards the end of the twentieth century most of the industry was transferred to other countries for various reasons, including the inevitable environmental consequences of industrial operations. Many plants were located in the mountains to exploit abundant water resources in terms of hydroelectric energy, and to benefit low income mountain populations. As a consequence, the impact on the surrounding environment was high, considering that environmental protection legislation was only enforced at the national level after 1970.

The decommissioning of the industrial plants, though positive for the environment, has left many critical problems unsolved. Although industrial sites have undergone remediation and reclamation, the surrounding soils might still show the influence of the past industrial

* Corresponding author.
E-mail addresses: luigi.gallini@istruzione.it (L. Gallini), franco.ajmonemarsan@unito.it (F. Ajmone-Marsan), riccardo.scalenghe@unipa.it (R. Scalenghe).

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activities in terms of contamination by metals released into the air by the smelting activity. Steelmaking plants generally emit As, Cr, Cu, Fe, Ni, Mn, Pb, Sb and Zn (Almeida et al., 2015). In fact, smelters and related mining operations have long been known as a considerable source of pollution (Dudka and Adriano, 1997; Pérez Cebada, 2016) and soils have always been a major sink for the emitted potentially toxic elements (PTE) (Ettler, 2016).

The presence of PTE in the soil is a matter of concern because of their persistence in the environment, their predisposition to accumulate in the food chain, and their potential harmfulness to humans and other living creatures (e.g. Alloway, 2013; Codling et al., 2015; Liu et al., 2017; Pierart et al., 2015). Several studies have confirmed the potential dangers associated with the accumulation of PTE in the soil. Nannoni et al. (2016) measured the concentration of As, Cd, Co, Cu, Pb, Sb, U and Zn in soil, and in maize roots and grains in an agricultural area around a smelter in Kosovo, observing a potential translocation from contaminated soil to plant tissues. On the other hand, little or no translocation was found by Dimitrijević et al. (2016) in peach trees growing on smelter-contaminated soils in Serbia. Šajn et al. (2013), who found that the concentrations of by Pb, Zn, As, Hg, and Cu exceeded the Intervention Values on the New Dutch list in an area of 152 km^2 around a smelting plant. Kříbek et al. (2016) determined Cd, Cu, Fe, Mo, Pb, and Zn concentrations in the soils of an area in northern Namibia affected by dust fallout from a local smelter. They could distinguish between anthropogenic contamination and geogenic concentrations by analysing the deeper layers of a soil profile. Qing et al. (2015) observed moderate to high pollution by Cd, Zn, Cu, and Pb in the soils from a steel industrial district in China. Similarly, Yuan et al. (2015), mapping PTE in the soils nearby the Wuhan Iron and Steel Group, found that only 1.5% of the region they studied was not polluted.

The aim of this study was to determine if the concentration of PTE in the soils of an area downwind from a decommissioned iron smelter still showed signs of past contamination and to discuss the options for intervention.

2. Materials and methods

Villadossola (46°04′25″N, 08°16′01″E) is a small town in northern Italy that saw its industrial structure collapse in the final decade of the twentieth century. The main smelting plant — which had employed up to 1800 workers — was finally closed in 2009 after nearly 200 years of activity. The study area extends North-East of the former SISMA steel plant of Villadossola over an area of approximately 15 km^2, wedged between the mountains comprising the Antrona valley and crossed by the Ovesca river (Fig. 1). The district has an average density of about 72 inhabitants per km^2; its agricultural potential is quite modest as three-quarters of the soils of the district show severe limitations that make them generally unsuited to cultivation. Their usage is therefore largely limited to pasture or free range grazing, woodland, or providing food and cover for wildlife. They mainly fall into classes 6 to 8 of the eight land capability classes (Regione Piemonte, 2010). From the climatic point of view, the district belongs to ipomesaxeric subregion of the Bagnouls Gaussen diagram. The mean annual temperature (MAT) is 11.5 °C, with the highest temperatures occurring in July and August, and an average of 64 days of frost per year. The mean annual total precipitation (MAP) is 1518 mm. The rainfall distribution peaks in May and October, while the potential evapotranspiration, according Thornthwaite, peaks in June and July. The climate is considered to be Cfb according to the Köppen-Geiger climate classification. According to the Newhall simulation model, the soil thermal regime is mesic, and the soil moisture regime is udic.

From the pedological point of view, the floodplain soils are generally scarcely developed soils with a cambic horizon, and there are Entisols (Soil Survey Staff, 2014) or Regosols (IUSS WG WRB, 2015) on the slopes.

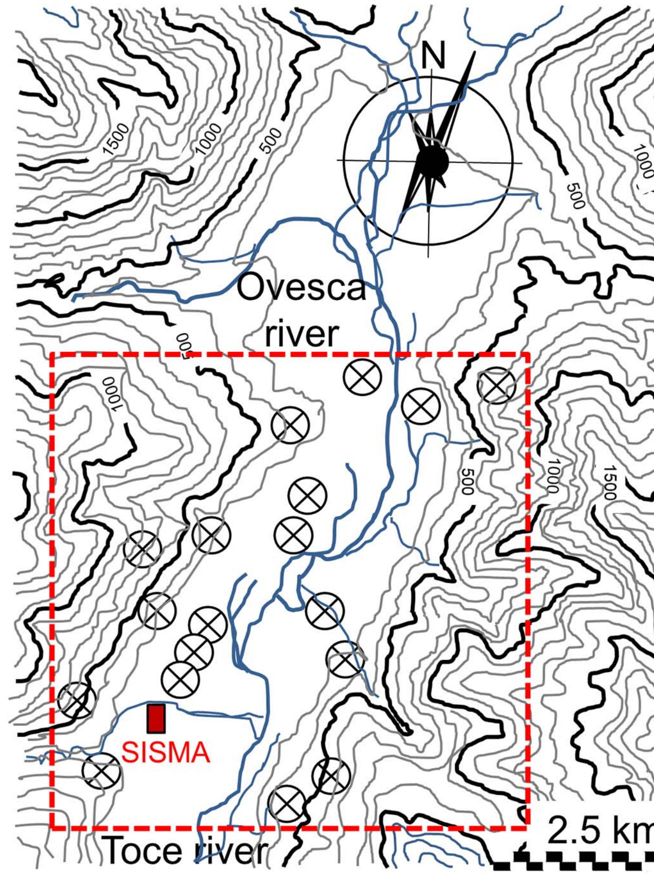

Fig. 1. The square enclosed by the red dashed line shows the study area, in which the sampling points are indicated. The Toce fluvial system is shown in blue, with the Ovesca stream overlapping from the North. The red rectangle identifies the SISMA smelter (46°04′00″N; 8°15′51″E). The wind rose shows the two predominant periodical winds, the principal blowing NNE-SSW. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The lithology of area consists of lherzolites, with titanolivin in places, in large and small masses. In the surroundings, on the upstream side of the valley, mylonites are found along the Insubric Line, followed by phyllites and schists of the Alpine units. In the downstream sector of the valley alternations of metabasites and metapelites prevail (Bertolani, 1964).

The area was exploited for Fe-Ni-Cu-Co magmatic sulphide deposits mostly in the ultramafic layers of the so-called mafic complex of the Ivrea Verbano Zone (Bertolani, 1964). The presence of economically interesting ore deposits promoted the development of the steel industry in the valley; in fact six foundries were established along its axis. Global steel production grew enormously in the twentieth century but following the cessation of activity in local mines, which occurred in the 1950s, the foundries had to use a mixture of scrap and mining materials obtained from foreign deposits. The history of pollution of Villadossola soils due to the steel industry comprises the last 150 years (Fig. 2). Its industrial footprint is demonstrated by the presence, in the northern area of the municipality of Villadossola, of the “SISMA Village”, once reserved for the families of the workers employed in the steel plant. Today the economy of Villadossola is based mainly on the tertiary sector.

The most important polluting event originating from the smelter occurred at the beginning of the 1980s. An estimate of the total emissions of PTE that PTE occurred in the 1982–1983 period is shown in Table 1.

The sampling design was guided by the prevailing wind direction, geomorphology and soil use: slopes, glacial shoulders and alluvial