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Extractive waste management: A risk analysis approach

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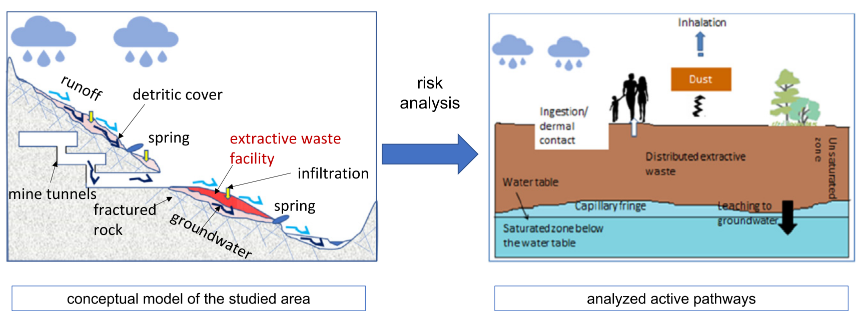
HIGHLIGHTS

- Extractive waste in abandoned mines pose risk to human health and groundwater.
- Risk analysis under current situation and assuming transport to nearest plain
- Comparative risk analysis considering no change in properties of waste
- There was unacceptable risk due to extractive waste in both situations.
- Future use of waste should consider mitigation activities for reducing risk.

GRAPHICAL ABSTRACT



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ABSTRACT

Abandoned mine sites continue to present serious environmental hazards because the heavy metals associated with extractive waste are continuously released into the environment, where they threaten human life and the environment. Remediating and securing extractive waste are complex, lengthy and costly processes. Thus, in most European countries, a site is considered for intervention when it poses a risk to human health and the surrounding environment. As a consequence, risk analysis presents a viable decisional approach towards the management of extractive waste.
To evaluate the effects posed by extractive waste to human health and groundwater, a risk analysis approach was used for an abandoned nickel extraction site in Campello Monti in North Italy. This site is located in the Southern Italian Alps. The area consists of large and voluminous mafic rocks intruded by mantle peridotite. The mining activities in this area have generated extractive waste.
A risk analysis of the site was performed using Risk Based Corrective Action (RBCA) guidelines, considering the properties of extractive waste and water for the properties of environmental matrices. The results showed the presence of carcinogenic risk due to arsenic and risks to groundwater due to nickel. The results of the risk analysis form a basic understanding of the current situation at the site, which is affected by extractive waste.

1. Introduction

Mining waste, which is also referred to as extractive waste (EW) generated during mining activities for metal exploitation, is represented by huge amounts of materials that are often contaminated by heavy metals and toxins and stored in dumps near the mining sites. After the cessation of mining activities at many sites, the EW facilities were left abandoned, leaving large amounts of waste subjected to erosion and leaching. Climate conditions, topography, hydrology, soil and EW textures, vegetation and site management influence the dispersion of contaminants towards adjacent ecosystems. Due to this dispersion and erosion, high contents of heavy metals have often been reported in ecosystem compartments near metal extraction sites (Béjaoui et al., 2016;

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Balint et al., 2014; Balint et al., 2015). These heavy metals tend to persist in the environment due to their non- degradable characteristics (Yuan et al., 2004). To measure their environmental impacts and determine future courses of action for the sustainable management of extractive waste, risk analysis approaches can be used.

The use of risk analysis as a formal component of environmental policy is of relatively recent origin. An original aim of this methodology was to help set priorities for environmental protection in an objective and scientific way, thus avoiding conflicts with political and management objectives. In simple terms, risk analysis can be defined as the process of estimating both the probability that an event will occur and the probable magnitude of its adverse effects, whether health/safety-related or ecological, over a specified time period (Gerba, 2009).

Many previous studies have provided methods for using heavy metal distributions and risk analysis in the context of the effects of mining activities on environmental and human health (Li and Thornton, 2001; Väänänen et al., 2016). For example, soil pollution due to lead, zinc, cadmium and copper has been characterized in mine tailings and soil near a Pb-Zn mine in Spain (Rodríguez et al., 2009). The presence of Ni and Cr has been quantified in open cast coal mining areas in Serbia (Ličina et al., 2017). Another study assessed human health hazards arising from the consumption of fish contaminated by mercury released in gold mining areas in Indonesia (Castilhos et al., 2006). The quantification of human health risks due to soil contamination in mining areas in China was studied by Li et al., 2014. The results obtained from these studies provide an important basis for the quantification and management of environmental impacts at mining sites.

The present study addresses an abandoned Ni mining site at Campello Monti in northwest Italy and differs from past studies by also focusing on a comparative analysis due to a change in the location of the EW. Indeed, this work was undertaken to analyse the risk in Campello Monti due to the presence of EW to 1) human health and groundwater in the present situation and 2) human health and groundwater under the hypothesis that the waste is transported to the nearest plain and used, as a by-product, for land rehabilitation or as filling materials for civil works and infrastructures. The second case has to be considered as an alternative to in situ intervention activities; using the waste as a resource is a viable alternative to remediating polluted areas and contemporaneously boosting natural resource savings. The principle of recovering and using waste (with or without treatment) as valuable secondary raw materials for integration with raw materials (RM and critical raw material – CRM) is in line with present EU policy regarding landfill mining and circular economies (Dino et al., 2016, 2017a). Indeed, securing a sustainable RM and CRM supply and their circular use in the economy is a growing matter of concern at both EU and global levels (Coulomb et al., 2015; Vidal-Legaz et al., 2016). A circular approach can partially supply RM/CRM due to the prominent role of recycling/recovery as an alternative to the exploitation of ore-bodies. Indeed, the recycling rates for each RM (and CRM) are useful for calculating the supply risks connected to single commodities (Blengini et al., 2017). In particular, the integration of extractive waste with natural aggregate supplies is being increasingly realized, and several researchers have investigated opportunities for sustainable recovery and recycling of both clean and contaminated EW, while at the same time reducing pressure on natural aggregate resources, land takes and environmental and landscape contamination. All this entails a general recovery of land, raw materials and eventually the environment (Akbulut and Gürer, 2007; Binici et al., 2008, Careddu et al., 2013; Danielsen and Kuznetsova, 2015; Danielsen et al., 2017; Dino et al., 2017b; Dino and Marian, 2015; Felekoglu, 2007, Hebhoub et al., 2011; Gencel et al., 2012; Luodes et al., 2012).

2. Methodology

2.1. General site setting

An abandoned Ni mine at Campello Monti was chosen for the present study. The Campello Monti site lies on the boundary of the Valstrona municipality in NW Piemonte (Italy) (45°56′09.39″ N and 8°14′13.79″ E), as shown in Fig. 1. The site is located in the Strona Valley, which is oriented WSW-ENE and lies to the east of Monte Rosa. The valley is confined by the Anzasca Valley to the NW, the Ossola Valley to the E-NE, and the Sesia Valley to the S-SE.

The Campello Monti village is located on the valley floor at 1305 m a.s.l. The Strona Valley reaches its maximum altitude at the terminal sector, which is bordered by the Capezzone Mount (2421 m a.s.l.) and the Altemberg Mount (2394 m a.s.l.).

The extractive waste facilities are mainly located in the north side of the valley, from the eastern margin of the Campello Monti village to approximately 1 km eastward at altitudes ranging from ca. 1200 to 1600 m a.s.l.

2.1.1. Geological setting

A metal extraction site is located in the basement of the southern Alps of northwestern Italy in the Ivrea Verbano Zone, which is a tectonic unit that has been cited as an example of an exposed continental crustal section that has preserved the transition from amphibolite to granulite facies (Bea and Montero, 1999). The Ivrea Verbano Zone extends for a distance of 120 km and has a breadth of approximately 14 km (NW-SE direction). The Ivrea Verbano Zone consists of three main petrographic units (Garuti et al., 2001):

- ultramafic rocks known as Mantle Tectonites,
- mafic rocks of the Mafic complex;
- supracrustal rocks of the Kinzigite Formation.

This area consists of large and voluminous mafic rocks that belong to the mafic complex outcrop, which is intruded by the mantle peridotites of the Mantle Tectonites (Fig. 2). At the western border of the area, the Insubric Line borders the Alpine units of the Sesia Lanzo Zone. On the valley floor, the bedrock is buried by recent glacial deposits and alluvial debris.

The detailed lithology of the area (Fig. 2) consists of lherzolites that are accompanied in places by titanolivine in large and smaller masses. In the surrounding regions, on the upstream side of the valley, mylonites are found along the Insubric Line, which are followed by phyllites and schists of the Alpine units. In the downstream sector of the valley, alternations of metabasites and metapelites prevail.

The area was exploited for Fe-Ni-Cu-Co magmatic sulphide deposits that occur from the Sesia to Strona valleys, primarily in the ultramafic layers of the mafic complex of the Ivrea Verbano Zone. Nickel extraction from the ore occurred intensively from 1863 to the 1940s (Rossetti et al., 2017).

2.1.2. Hydrography

The Strona stream (also known as the Strona di Omegna stream) is the main stream of the Strona Valley and flows in a WNW-ESE direction (Fig. 1). It is fed by runoff, snow-melt springs and small lakes located in the surrounding relief. The Strona stream begins in the village of Campello Monti and ends in the Toce river, and its total length is approximately 28 km. The hydrographic basin of the Strona stream has an area of approximately 170 km^2 (Fig. 1). The final destination of the waters of the Toce River is Lake Orta, which is located a few hundred metres from the confluence of the two streams towards the south.

2.1.3. Hydrogeological setting

Campello Monti is located in extremely complex formations of crystalline rocks that consist of metamorphic lithotypes. According to the regional hydrogeological framework, these rocks are essentially impermeable or weakly permeable for fracturing and belong to the hydrogeological series of crystalline complexes of the Alpine chain. A conceptual scheme of groundwater flow in the area is represented in Fig. 3, which shows that groundwater circulation in the area occurs in