Editorial for Special Issue "Sustainable Use of Abandoned Mines"

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Editorial

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Abandoned mines are an abundant and widespread feature [1–3], as there are an estimated number of 500,000 in the US [3], 50,000 in Australia [4], and 10,000 in Canada [1]. Tallying the number of abandoned mines is basically meaningless unless there is information on their reclamation needs and monitoring of reclamation effectiveness available [1,4]. Abandoned mines are the source of multiple hazards, from collapsing of tunnels and shafts to contamination of soils, streams, and groundwater. Making land usable again where mining once occurred requires the removal or minimization of such hazards [1,3]. Whenever possible, the conversion of these sites and their mining wastes into valuable assets is sought [5]. However, most abandoned mines lack an owner or responsible party to pay for remediation, plus remediation has not always been successful [1,4]. Often, entities in charge of site cleanup either forego remediation or restrict remediation actions to the most affected areas [2,4]. Research conducted at former mining sites continues on many fronts and focuses on finding an appropriate remediation plan or, if the site has already been remediated, to the monitoring and assessment of the effectiveness of remediation.

Considering the many types of ores and processes involved with mining and differences in landscape, road accessibility, etc., the approach to find a best possible use of land is site-specific [1,3]. Some recent work conducted worldwide in the identification and remediation of abandoned mines is comprised in this special issue of *Minerals*, "Sustainable Use of Abandoned Mines".

A first step into knowing the extent of the problem associated with an abandoned mine site consists of the identification of the site and its reclamation needs [4]. Geographical information systems and related spatial technologies such as remote sensing are great resources to map the areas more highly affected and for keeping a database of improvement of rehabilitation and reclamation with respect to time [6], among other site characteristics. One such database (location, nature of mine, reclamation needs) was reported by Werner et al. [4] for Australia. An additional application of these databases is that they can be paired with studies on remediation effectiveness, health, water scarcity, and potential effects of climate change, among others [4].

Excavations, piles of waste, and tunnels and shafts associated with abandoned mines entail serious physical hazards and safety concerns. In cases where the land was profoundly disturbed, remediation of these hazards may involve moving large amounts of soil and mine wastes, which can be costly. Mhlongo et al. [7] applied the Ruled-Based Expert System to rank physical burdens and their hazards [7]. In a second paper, Mhlongo et al. [8] applied the semi-quantitative methods of strengths, weaknesses, opportunities, and threats (SWOT) and Quantitative Strategic Planning Matrix (QSPM) to two mines in South Africa to find the most attractive strategies to address physical hazards, such as filling and improvement of slope stability.

The presence of metals and metalloids released from abandoned mine tailings is often a concern because of their toxicity and long residence time in soils and stream and lake sediments. Remediation of the generally extensive land disturbances of metal mines have consisted, in the most part, of passive remediation actions such as biostabilization, where vegetation is planted to cover areas where mine wastes were either spread-over [9] or used to fill mine cavities [10]. The former remediation method was applied to floodplain areas in Złoty Stok, a historical center of gold and arsenic mining in Poland. Dradrach et al. [9] conducted bioassays (Phytotox and MARA) on pore water from soils mixed with mining wastes to determine the areal extent and the soil depth with high content of arsenic. The study also found that manure and mineral fertilization caused additional release of arsenic, exacerbating toxicity to bacteria and plant seedlings [9].

Another area where phytostabilization had been used to remediate a highly disturbed area of zinc and lead mines in southwest Missouri was analyzed for metal content and metal mobility by Gutiérrez et al. [10]. Sediment samples collected from streams traversing this remediated area showed that toxic concentrations persist in the sediments. However, metal concentrations followed no specific pattern along the stream, likely a result of the disturbance of sediments created by recent remediation procedures [10]. The results also showed that lead was less mobile than zinc and cadmium, and that cadmium with higher mobility has a greater potential to move through the food chain [10].

In the search for a more rapid and cost-effective technology to map zones of higher metal content, Gabarrón et al. [11] utilized electrical resistivity tomography (ERT), a non-invasive geophysical method, to determine salinity and clay content along profiles traversing a tailings pond in the Cartagena–La Unión mining district, Spain. Salinity and clay content of collected sediment samples had previously correlated to metal content and mobility. The results estimated by ERT were then used to locate zones of accumulation of metals within the tailings ponds [11].

When high toxicity persists and a further remediation step is deemed necessary, in situ methods can remove contaminants from, e.g., a stream channel or floodplain. One such method is adsorption. Jordan et al. [12] considered the removal of heavy metals zinc and cadmium via adsorption on biochar and red clay (a waste product from the aluminum industry) as a remediation technology to diminish the toxicity of metals in the River Teign, England. Both adsorbents proved effective to adsorb zinc and cadmium in laboratory experiments, a promising first step into a more comprehensive cost-and-benefit study towards an in situ remediation.

In the geo-ecological regeneration of disturbed areas, a systematic approach to revegetate the area with native vegetation to foster positive natural ecological processes is an attractive approach. Baethke et al. reported efforts conducted in semi-arid grasslands in British Columbia, Canada [13]. They found that native seedling establishment is primarily seed-limited, and that proper raking and tilling help keep incursion of exotic species at bay. Haigh et al. [14] followed the changes observed in an area with coal spoils after 20 years that the area has been remediated using mosaic tree planting. Among their observations, they found that 14 years of forestation reduced the soil loadings of five metals by 35–52% [14].

Another case of rehabilitation of a mining affected area involves technosols constructed from limestone mine spoils. Ruiz et al. [15] presented a successful case of mine rehabilitation where limestone wastes were converted into soils suitable for growing tropical grasses. This use of technosols is encouraging as a strategy to overcome both land degradation and waste production.

McCullough et al. [5] contributed a review paper on the repurposing of abandoned pit lakes to a beneficial use, such as a place of passive and active recreation, nature conservation, fishery and aquaculture, etc. In their review, they discuss common attributes and reasons that led their transformation from a liability at mine closure to becoming an asset to the community nowadays.

In addition, in this Special Issue, a crystallographic analysis of a mineral occurring in mine wastes from a northern Arizona mine by Avasarala et al. [16] identified it as carnotite, a uranium–vanadium mineral $K_2(UO_2)_2(VO_4)_2{\cdot}3H_2O$. The authors used integrating spectroscopy, electron microscopy, and X-ray diffraction analyses to obtain evidence of the crystallographic properties and were able to discard the possibility of this mineral being its polymorph vandermeerscheite. A complete identification of minerals present in mining wastes provides insight into their reactivity and mineral associations and adds accuracy to further investigations of, e.g., mine reclamation and environmental transport.

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