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Editorial

Geochemical Characteristics and Contamination Risk Assessment of Soil

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1. Introduction

Soil, as a key component of the four circles interconnecting atmosphere, hydrosphere, biosphere, and lithosphere, plays a vital role in sustaining human life and the terrestrial system globally. Meanwhile, soil contamination of toxic trace metals such as mercury is becoming an increasingly serious issue in many countries around the world, along with urbanization and industrialization, both of which pose severe risks to ecosystems and human health [1]. An increased content of trace metals can adversely affect the biological properties of soil, cause changes in the food chain, have a toxic effect on plants, and contaminate groundwater. Measuring the total concentration and geochemical baseline concentration are usually the first steps in the assessment of trace metal pollution [2]. Moreover, the background values can distinguish between natural and anthropogenically influenced concentrations, and through these values, in turn, one can calculate the anthropogenic contribution rate. When the permissible content level is exceeded, heavy metals reduce soil fertility, inhibit soil enzymatic activity, and change soil acidity.

Traditional long-lasting mining and extraction processes are accompanied by severe environmental pollution and ecological damage globally, but at the same time, the mining and mineral extraction processes industry plays a vital role in the development of modern technologies. There is a growing demand for raw material production and supplying invaluable resources for modern life. Modern society achieves greater efficiency by developing innovative waste recycling technologies [3].

The increase in the amount of mining and metallurgical waste represents a big problem for the environment. This is why various methods are used for the processing of flotation tailings, red mud, and slag landfills, which are a potential source of accumulated metals [4]. Unfortunately, they pile up on the ground and create an intractable problem. This is why studying the processing of various landfills is a great challenge affecting the scientific community and, thus, the entirety of humanity [5].

This article provides an overview of advances in understanding the importance of geochemical characteristics and soil contamination risk assessment while also covering new challenges regarding sustainable treatment of bauxite residue and the recovery of valuable elements. In particular, the reduction of iron oxides from bauxite residue before the leaching process can facilitate a decrease in the quantity of disposed material and soil pollution.

2. Contents of This Special Issue

This Special Issue contains eight papers, listed at the end of this article. Focusing on bauxite residues, problems created by residues of metallurgical production and the ways in

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which these problems can be solved via the valorization of critical metals are explained. Understanding the temporal–spatial distribution and influencing factors of heavy metals on a regional scale is crucial for assessing the anthropogenic impacts and natural variations in elemental geochemical behavior. The study by Tian et al. (Contribution 1) evaluated the spatial distributions of heavy metals such as As, Cd, Pb, and Zn, as well as their driving mechanisms, over the past 31 years in Guangxi, China, using three geochemical baseline projects (the Environmental Geochemical Monitoring Network Project (EGMON) project (1992–1996); the Geochemical Baseline (CGB) 1 project (2008–2012); and the CGB2 project (2015–2019)). By calculating the variable importance using the random forest algorithm, it was found that natural factors were the primary drivers of the spatial distribution of heavy metals in the EGMON project, especially for the precipitation of As, while the digital elevation model (DEM) was the primary driver for Cd and Pb, and temperature was the primary driver for Zn. Surface alluvial soils showed obvious heavy metal enrichment in the CGB1 project, with the gross domestic product (GDP) driving the spatial distribution of all heavy metals. In addition, the anomalous intensity and range of heavy metals in the CGB2 project decreased significantly compared to the CGB1 project, likely due to the normalized difference vegetation index (NDVI) serving as a positive anthropogenic factor that improves the degree of rocky desertification, thus reducing the heavy metal contents of As and Pb, and precipitation promoted the decomposition of Fe–Mn concretions and, thus, the migration of Cd and Zn.

The features of structural and phase transformations during the processing of alloyed metallurgical wastes using reduction smelting are discussed herein. This is necessary in order to determine the technological parameters of the melting process that ensure reduction in the losses of alloying components. The use of X-ray phase analysis in combination with the methods of raster electron microscopy and X-ray microanalysis ensured the identification of the microstructure features and the chemical composition of individual phases and inclusions in the metal. The study by Smirnov et al. (Contribution 2) identified new technological aspects of high-alloyed technogenic waste processing using reduction smelting. The obtained parameters of the resource-saving alloying compound make it possible to replace parts of the standard ferroalloys in steelmaking processes.

The study by Silin et al. (Contribution 3) includes a combined hydrometallurgical treatment of an eudialyte ore sample with subsequent preparation of leaching residue using mechanical separation methods. Hydrometallurgical treatment contains dry digestion with sulfuric acid at room temperature and filtration of the obtained product. The objectives of adopting these procedures are to test a new digestion reactor in order to prevent silica gel formation from the eudialyte ore. The obtained results revealed that silica gel formation is prevented during dissolution with sulfuric acid. A high leaching efficiency of light rare earth elements (La, Ce, Nd, and Y) was reached using the dry digestion process with sulfuric acid, where the starting molarity was 12 mol/L. After the filtration process, magnetic separation was studied as the main method to recover weakly magnetic minerals like amphiboles and pyroxenes from the leaching residue in the magnetic fraction and feldspars in the nonmagnetic fraction. A new combined research strategy was developed for the production of different concentrates such as the one bearing Zr, Hf, and Nb.

The more economically viable and environmentally sustainable approach for treating the by-products of coal combustion from thermal power plants entails their collective disposal as opposed to individual disposal methods. This aligns with pertinent EU directives and domestic regulations, ensuring compliance with established standards while optimizing resource utilization and minimizing environmental impact. This study evaluated the resistance to wind erosion of the binding properties of a mixture (comprising fly ash (FA), bottom ash (BA), and additives) using an indoor wind tunnel under simulated ambient conditions. Investigations of the mutual impact of ash, bottom ash, and additives (CaO and $Ca(OH)_2$) with a certain percentage of water were carried out with eighteen samples. The samples consisted of water at six addition rates 5, 8, 10, 15, 20, and 25% (w/w) and an additive at three addition rates (1, 2, and 3% (w/w)). Based on the obtained results, the optimal ratios of the additives (3% (w/w)) and water (15% (w/w)) were determined. Prior to the wind tunnel experiments, and according to the different addition rates of additives and water, eight samples were prepared with different addition rates of ash. The mass concentrations of suspended particles (PM_{10}) and total suspended particles (TSPs) in these samples were measured at three distinct wind velocities, 1 m/s, 3 m/s, and 5 m/s, respectively. The results reported by Petkovic-Papalazarou et al. (Contribution 4) indicate that the samples containing the optimal content of additives and water demonstrate a maximum increase in PM_{10} emission zero values of no more than 1.9 times. This finding can be considered satisfactory from the standpoint of environmental protection.

The study by Lahori et al. (Contribution 5) holds significant implications. It investigates the comparative effect of biochar, zeolite, and bentonite minerals on the stabilization of Ni fractions, bioaccumulation, translocation indices, and the reduction in their absorption by pakchoi in smelter- and mine-contaminated soils. The results, which are of great interest, show that the maximum fresh and dry biomasses of pakchoi were 28.21 and 18.43% for smelter-polluted soil and 61.96 and 67.90% for mine-contaminated soil amended with zeolite compared to the control. Applying zeolite increased pakchoi chlorophyll SPAD values 1.17-fold in smelter soil and 1.26-fold in mine-polluted soil. The highest level of Ni immobilization in the smelter and mine soil was 76.8 and 85.38% with the application of bentonite, which increased soil pH and CEC. The application of biochar, bentonite, and zeolite reduced the Ni residual, oxidizable, and acid-soluble fractions, but biochar and bentonite increased the reducible fraction of Ni in smelter soil. The highest reduction in Ni in the shoot and root was noted as 82.08 and 68.28% of smelter-polluted soil and 77.25 and 89.61% of mine-polluted soil with bentonite compared to the control soil. Overall, it has been concluded that biochar, zeolite, and bentonite can be successfully used to mitigate the Ni concentration in smelter- and mine-polluted soil and reduce uptake by vegetable crops.

The global generation of bauxite residue necessitates environmentally responsible disposal strategies. The included study by Mendy et al. (Contribution 6) investigated the long-term (5-year) behavior of bauxite residue with pH lowered to 8.5, called modified bauxite residue (MBR), using lysimeters to test various configurations—raw MBR or used MBR (UMBR) previously applied for acid mine drainage remediation, sand or soil capping, and revegetation. Throughout the experiment and across all configurations, the pH of the leachates stabilized between 7 and 8, and their salinity decreased. Their low sodium absorption ratio (SAR) indicated minimal risk of material clogging and suitability for salt-tolerant plant growth. Leaching of potentially toxic elements, except vanadium, decreased rapidly after the first year to low levels. Leachate concentrations consistently remained below LD50 for *Hyalella azteca* and were at least an order of magnitude lower by the experiment's end, except for first-year chromium. Sand capping performed poorly, while revegetation and soil capping slightly increased leaching, though these increases were negligible, given the low final leaching levels. Revegetated MBR shows promise as a suitable and sustainable solution for managing bauxite residues, provided the pH is maintained above 6.5. This study highlights the importance of long-term assessments and appropriate management strategies for bauxite residue disposal.

Assessment of the plant's ability to take up mercury (Hg) from polluted soil was affected by location, plant family, and species in two former cinnabar mining areas in the Czech Republic. At each location, seven sampling points were marked out in the vicinity of former shafts and dumpsites connected to the mining activity, where representative soil samples and dicotyledonous plants were collected. The individual locations were characterized by specific plant communities, where, in most cases, different plant species were found within one family at both locations. The total Hg content in the soil, as well as gaseous elemental mercury ($GEM_{soil\text{-}air}$), confirmed elevated levels of this element in the mining-affected environment, along with high data variability. The low Hg accumulation ability of plants, especially the low root–shoot translocation in most plant species, indicated the predominant occurrence of excluders. The results reported by Bauštein et al. (Contribution 7) showed the exceptional position of the Fabaceae family regarding soil Hg pollution, as the highest Hg content in both shoots and roots was determined for *Onobrychis viciifolia*. Therefore, the behavior of Fabaceae plants in polluted soil, the mechanisms of their tolerance to high Hg content, and their Hg accumulation ability deserve further research.

Comparative analysis of red mud reduction techniques was performed by Stopic et al. (Contribution 8) using both carbothermal and hydrogen-based reduction methods, combining thermochemical modeling and experimental validation. The reduction process is important because of the soil contamination risk assessment with disposed red mud. Therefore, the minimization of red mud during the reduction process could be a novel strategy for the production of metallic iron and solid residue for hydrometallurgical treatment. Different strategies of hydrogen and carbon reduction in static and dynamic conditions were studied between 700 °C and 1700 °C. The separation of solid residue and formed iron was analyzed using magnetic separation. The main aim was to study the advantages and disadvantages of using decarbonizing technologies for the treatment of red mud, aiming to develop an environmentally friendly process. Thermochemical analysis of the reduction offered new data about mass losses during our process through evaporation, thermal decomposition, and the formation of metallic carbide.

3. Conclusions

Five years of leaching experiments to evaluate land spreading of a modified bauxite residue before and after acid mine drainage treatment with comparative analysis of reduction techniques, aimed at the minimization of contaminated soil with bauxite residues, represent the recent advances in understanding soil contamination risk assessment. Assessment of mercury uptake by plants in former cinnabar mining areas also represents an additional contribution. Prevention of silica gel formation for eudialyte study using a new digestion reactor can be achieved during bauxite residue treatment. The comparative effect of sustainable materials on the immobilization, geochemical fractions, bioaccumulation, and translocation of Ni in smelter- and mine-polluted soils has also been studied. The effects of wind velocity on the binding properties of ash, bottom ash, and additives were studied via a wind tunnel study. The temporal–spatial distributions and influencing factors of certain heavy metals—namely As, Cd, Pb, and Zn—in alluvial soils in Guangxi, China, have also been studied. In addition, it has been found that recycling of alloyed metallurgical waste depends on structure and phase transformation.

Ultimately, this Special Issue, titled “Geochemical Characteristics and Contamination Risk Assessment of Soil”, comprises eight important papers which offer new insights and results needed for soil contamination risk assessment in the context of geochemical characteristics and metallurgical and mining activities, which expose waste materials. This is a warning to the wider community to become involved in finding solutions to these problems by considering the latest results. Unfortunately, the Editors of this Special Issue do not have high expectations regarding the implementation of the included insights, because all planned actions always come with large costs and problems with securing the necessary funding.

Conflicts of Interest: The authors declare no conflicts of interest.

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