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Editorial

Editorial Board Members' Collection Series: Soil Contamination and Remediation

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Soils constitute a critical component of the Earth system, particularly in the context of a growing and progressively ageing global population. In 2024, the global population reached approximately 8.2 billion and is projected to increase to around 10.3 billion by the mid-2080s [1]. Moreover, by the late 2070s, the number of individuals aged 65 years and older is expected to reach 2.2 billion, surpassing the population under 18 years of age [1]. Within this framework, two interrelated challenges are becoming increasingly prominent: (i) the sustainable intensification of high-quality food production, and (ii) the ability of soils to function as long-term carbon sinks.

The intrinsic physicochemical properties and biogeochemical processes of soils confer a high capacity to accumulate and retain contaminants originating from urban emissions, intensive agricultural inputs, and industrial activities [2]. In addition, certain regions exhibit elevated baseline concentrations of trace metals due to geogenic sources. Consequently, total concentrations of potentially toxic elements (PTEs) in soils may exceed guideline values, thereby compromising the reliability of human health and ecological risk assessment.

Soil organic carbon (SOC) is a key determinant of soil fertility, influencing nutrient availability, soil structure, and water retention, and is positively associated with crop productivity. However, climate change—particularly rising temperatures—is projected to reduce the global soil carbon sequestration potential [3], with especially pronounced effects in surface (topsoil) horizons. This decline may result in decreased agricultural productivity, reduced carbon storage capacity, or even a net release of CO_2 into the atmosphere. Such processes constitute a positive soil–climate feedback mechanism, thereby accelerating agroecosystem degradation and further intensifying climate change.

Soil pollution poses a significant threat to human health, both through direct exposure to soil-borne aerosols and indirectly via the consumption of contaminated agricultural products, meat from grazing livestock, and water resources. The presence of PTEs in soils is associated with increased risks of both carcinogenic and non-carcinogenic effects, contributing to a rise in disease prevalence and a decline in quality of life, particularly among aging populations. In this context, soil monitoring is increasingly being established as a regulatory requirement, highlighting the urgent need for systematic assessment and management strategies. The scientific community plays a crucial role in advancing the understanding of this global environmental challenge. At the policy level, the European Union has recently introduced a soil monitoring framework to systematically map and evaluate soil health across Member States [4].

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Population growth drives increased demand for food, which in turn promotes higher agricultural productivity and the expansion of land used for food production. For example, urbanization has led to the use of traditionally non-agricultural soils in so-called urban gardens, providing communities with means to supplement their food supply. In this context, it is essential to identify critical areas and, where possible, implement appropriate remediation strategies. Given the widespread nature of soil degradation and contamination, the development of sustainable soil remediation methodologies is of paramount importance.

This Special Issue aims to advance both the understanding and the practical application of soil remediation technologies. It encompasses contributions addressing fundamental aspects of contaminant behavior in soils, the development of novel remediation materials, and innovative technologies designed to mitigate the impacts of chemical contaminants. The selected works emphasize the development of cost-effective, integrated site management strategies that preserve and enhance critical soil functions while prioritizing environmental sustainability. It focuses on the latest scientific advancements in monitoring soil quality, soil degradation, and soil remediation.

This collection comprises sixteen papers covering a wide range of key topics in soil research and recent studies [Contributions 1–16]. Monitoring of soil quality, particularly in agricultural systems, remains insufficient in less-developed countries, limiting proper assessment of risks to human health. At the same time, in developed countries, urban community gardens are increasingly being adopted as alternative food production systems. Three papers in this collection focus on identifying heavy metal contamination in soils from regions of Bangladesh, Mozambique, and Canada.

The study conducted in Bangladesh revealed evidence of anthropogenic contamination by metals such as Cr, Mn, Cu, Zn, Pb, and Ni [Contribution 1]. A human health risk assessment further indicated that inhalation constituted the primary exposure pathway. In contrast, the characterization of soils from Manica Province, Mozambique, showed an imbalanced agronomic and environmental composition associated with reduced agricultural productivity [Contribution 2]. In this region, relatively high concentrations of geogenic Cr, Co, V, and Ni were detected, with no evidence of anthropogenic contamination. The use of urban areas for food production is considered a sustainable alternative to supplement food supply for certain population groups. However, the quality of soils used in community gardens must be carefully assessed to rule out significant health risks. Research on the impact of an industrial fire on a community garden in New Brunswick (Canada) showed that concentrations of Pb, Zn, Cu, and Sn exceeded permissible limits and that children are at risk from As exposure [Contribution 3].

The search for sustainable soil remediation strategies remains an ongoing scientific and technological priority. In the context of metal-contaminated soils, hyperaccumulator plants characterized by rapid growth and high biomass production have been proposed as a viable phytoremediation approach. The capacity of sunflower (*Helianthus annuus* L.) to accumulate and translocate Ni in soils under Mediterranean and semi-arid water conditions has been investigated [Contribution 4]. Results indicate that Ni predominantly accumulates in the roots, with limited translocation to the aerial parts of the plant. Additionally, this collection includes research on the bioaccumulation and translocation factors of Ni and Cu in sunflower, wheat, and maize [Contribution 5]. These crops were cultivated in non-contaminated soils to establish a physiological baseline.

Induced phytoremediation of soils contaminated with Zn, Cu, and Pb, using Indian mustard (Brassica juncea) in combination with a chelating agent (EDTA), has proven to be an effective remediation strategy [Contribution 6]. Furthermore, soil-washing methodologies based on EDTA, coupled with reducing agents, have demonstrated the capacity to remove Pb from highly polluted soils under continuous-flow conditions [Contribution 7].

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Research on biochar as a multifunctional agricultural amendment is a current and evolving topic. One paper in this collection evaluated the use of biochar produced through the pyrolysis of waste wood to mitigate the phytotoxic effects of polycyclic aromatic hydrocarbons and heavy metals resulting from waste tire fires [Contribution 8]. The incorporation of biochar into the soil reduced growth inhibition caused by phytotoxicity and improved seed germination rates. Soils in mining areas can become highly contaminated with heavy metals, requiring remediation before they can be used productively. Research conducted in Lubumbashi (DR Congo) focused on the use of municipal compost and limestone in highly polluted mining soils to create favorable conditions for tree growth and to promote reforestation [Contribution 9]. Another study examined the environmental impact of the overuse of fertilizers in forest nurseries and proposed a more sustainable approach for seedling production [Contribution 10], including the use of plant-growth-promoting bacteria as alternatives to mineral fertilizers.

The remediation of soils contaminated with organic chemicals generally requires approaches different from those used for inorganic pollutants. When non-persistent contaminants are considered, bioremediation is often a suitable option. Soil contaminated with the pesticide chlorpyrifos was treated with earthworms (Eisenia fetida) [Contribution 11], resulting in both qualitative and quantitative improvements in the soil microbial community. Petroleum and its derivatives are also common soil pollutants [Contributions 12, 13]. One study on petroleum-contaminated soils proposes an infrared (FTIR) methodology for assessing contamination. This procedure, based on extraction with aqueous dimethyl sulfoxide (DMSO), may facilitate comparisons across cases and support the selection of appropriate remediation strategies. Diesel-contaminated soil, which is typically considered difficult to remediate, was addressed using nanosilica to modify the physical and mechanical properties of clayey sand [Contribution 13].

This collection also includes three review papers. One review addresses bioleaching and biometallurgical processes, with particular emphasis on the use of bacterial consortia composed of *Acidithiobacillus thiooxidans* and *Acidithiobacillus ferrooxidans* [Contribution 14]. Given the current high demand for critical metals, another review explores the potential of contaminated soils as secondary sources of high-value raw materials and highlights approaches such as phytomining, electrokinetic technologies, and soil washing [Contribution 15]. A further review examines arsenic contamination in soil and the associated risks to human health [Contribution 16].

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