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Editorial: Effects and challenges of ecological protection and restoration strategies on elemental cycles

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Editorial on the Research Topic
Effects and challenges of ecological protection and restoration strategies on elemental cycles

Carbon, nitrogen, phosphorus, and sulfur, as the most biologically active and abundant elements, play crucial roles in terrestrial ecosystems and are key factors in plant growth and productivity (Rey Benayas et al., 2009). However, their biogeochemical cycles have been considerably impacted by intensive human activities and climate change, including global warming, the Grain for Green Program, wetland and farmland restoration, and the reuse of saline–alkali farmland (Zong et al., 2025). In response to biodiversity loss and environmental degradation, ecological restoration has become a global priority, with projects steadily increasing over recent decades. However, these efforts are not a cure-all for ecosystem recovery (Marchand et al., 2021). Notably, the effectiveness of restoration measures remains uncertain, and their impact on elemental cycles remains unclear (Li et al., 2019). Given the critical role of these elements in terrestrial ecosystems, understanding how ecological restoration affects biogeochemical cycles is essential.

The migration, transformation, and accumulation of heavy metals are also associated with intensive human activities and changes in ecosystems (Shi et al., 2022). The occurrence of heavy metals in the environment is of great concern due to their high bioaccumulation and toxicity, which can have various acute and chronic adverse effects when humans are excessively exposed to contaminated media (Zamora-Ledezma et al., 2021). Human activities have been identified as the primary source of the spreading and increasing quantities of heavy metals found in soil, sediments, and aquatic environments (Carolin et al., 2017; Shi et al., 2022). However, there are limited studies that have quantitatively investigated the effects of ecological projects and restoration strategies on the concentration of heavy metals in the process of restoring and protecting the ecological environment. Particularly, more efforts are needed to quantify the interactions between human factors (e.g., transportation programs, land use changes, and dam construction) and landscape patterns, as well as how they impact the geochemical behaviors of elements (Huang et al., 2021; Vareda et al., 2019). This would aid conservation and sustainable utilization activities to achieve greater ecological benefits. Therefore, we organized this Research Topic to better understand the positive or negative impacts of human restoration activities on elemental cycles within improving ecosystems.

Farming activities are among the major processes shaping agro-ecosystems. These activities often differ in severity, scale, and frequency, leading to changes in soil quality and carbon and nitrogen cycles that deviate from natural variability (Viaud et al., 2018). Understanding how soil function changes in response to these disturbances is critical for predicting the varying states of agricultural production and the many services they provide. The application of agro-geotextiles and the adoption of conservation tillage are useful measures to decrease soil erosion, increase soil carbon sequestration, and enhance crop production. Roy et al. found the soil organic carbon (SOC) accumulation rate of up to 0.5 $Mg{\cdot}ha^{-1}$ yr^{-1} and a reduced soil loss rate from 10.39 to 3.75 $Mg{\cdot}ha^{-1}$ yr^{-1} upon implementing *A. donax* mats and incorporating a legume into the cropping system in the Indian Himalayas. A different technique was adopted by Wang et al., who explored applying cement as a binding material in conjunction with other organic matters and habitat amendment materials to improve the quality of Yellow River sediments. These restoration efforts significantly increased the fertility quality and planting performance of the sediments. These results suggest that human amendment activities can have a positive influence on carbon sequestration, soil quality, and crop production.

Salinization-related crop production losses ranged from 18% to 43% in arid and semi-arid regions, making soil salinization management a crucial Research Topic for agricultural sustainability (Singh, 2021). However, its impact on carbon and nitrogen transformation remains poorly understood due to the complexity of salinization processes. A comprehensive meta-analysis by Tao et al. found that pH, total N, soil organic carbon, and C/N ratio strongly influence net N mineralization and nitrification rates, highlighting the need to consider salinity levels when optimizing nitrogen fertilization in saline drylands. One effective management strategy is applying soil amendments. Tian et al. demonstrated that desulfurized gypsum combined with organic fertilization significantly improved soil nutrients and quality while reducing soil pH and exchange sodium percentage. Their findings emphasize that tillage practices are key to mitigating soil salinity and enhancing carbon and nitrogen cycling.

Heavy metals are naturally occurring elements that have natural and human sources. However, the latter is more significant, contributing to the release, migration, and accumulation of pollutants in a more toxic and mobile form (Carolin et al., 2017; Ma et al., 2022). For instance, dam construction disrupts the natural ecosystem of rivers and significantly influences the geochemical behavior of heavy metals. Xu et al. revealed that the Three Gorges Reservoir increased sediment adsorption effects and largely contributed to the migration of heavy metals from soil/sediment upstream to the dam. Changes in hydrological regimes, physiochemical characteristics, and vegetation coverage disrupt the natural distribution of heavy metals.

When comparing the difference in heavy metal concentration of surface water between the buffer and core zones of the Qinling Giant Panda Reserve, Zheng et al. found that the former had higher pollutant levels due to the pollution sources from traffic-related activities and metal mining. Human activities have significantly increased the accumulation of heavy metals in the earth surface ecosystems. Cadmium is one of the most harmful and toxic metals in soil ecosystems to plants and animals, and its local concentrations can be increased by several orders of magnitude under the influence of various human activities and geological features. Xu et al. conducted a study to examine the ecotoxicological effects of various cadmium concentrations on soil microorganisms and earthworms. Although high cadmium levels negatively impact earthworms biomass, low cadmium concentrations enhance microbial diversity. These studies provided evidence of how human activities impact elemental cycles in natural ecosystems and contribute to the spread of heavy metals.

In conclusion, the compiled papers demonstrated how intensive human activities have altered elemental cycles, posing new challenges for ecosystem restoration. While this Research Topic primarily highlights the effects of dam construction, farming, and transportation on heavy metals, carbon, nitrogen, and soil properties, it underscores the need for a comprehensive assessment of geochemical alterations under ecological protection. Hence, project objectives and short- and long-term environmental impacts should be carefully considered when evaluating ecological programs. This approach will help mitigate ecological risks and pave the way for effective restoration strategies.

Author contributions

XL: Writing – original draft, Investigation. JM: Methodology, Investigation, Writing – review and editing, Formal Analysis, Project administration, Funding acquisition. CQ: Supervision, Writing – review and editing, Validation. KW: Validation, Supervision, Writing – review and editing.

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