Soil Erosion and Mineral Depletion – A Growing Concern

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Introduction

Recent years have seen a rise in awareness of the urgent environmental issues of soil erosion and mineral depletion, which have far-reaching effects on agriculture, the health of ecosystems, and the encouragement of sustainable land use. Both global food security and environmental balance are seriously threatened by the interconnected processes of soil erosion and mineral depletion, which are both defined as the physical removal of the topsoil layer. To support plant development and preserve soil fertility, certain minerals and nutrients are crucial. When vital substances like nitrogen, phosphorus, potassium, and micronutrients are eroded or leached from the soil at a pace that is quicker than they can be naturally supplied, the result is mineral depletion, also known as soil nutrient depletion. This depletion is caused by intensive farming methods, uneven fertilization, and poor soil management.

Soil Erosion

Soil erosion is the natural process where the top layer of soil is worn away and transported by agents like water, wind, or ice, leading to soil degradation and loss of fertile topsoil. This process can be exacerbated by human activities like agriculture, construction, and deforestation. Soil erosion involves three steps, viz., detachment, transport, and deposition of soil particles by different agents. Soil erosion causes the loss of fertile topsoil, and water-induced soil erosion alone poses a serious degradation challenge to the soils of Asia and Africa. Worldwide, approximately 24 billion tonnes of productive topsoil are lost annually due to water erosion (Dubois, 2011). In India, out of 328 M ha total geographical area, 120.7 M ha is suffering from different soil degradation processes, and 68.4% (83 M ha) of this is affected by water erosion (ICAR and NAAS, 2010). According to the latest estimate, India's average soil loss is 15.4 t/ha/yr, and nutrient loss from soil is 5.4 to 8.4 M t/yr (ICARIISWC, 2015). Soil erosion processes alter soil physical, chemical, and biological properties.

Mineral Depletion

Nutrient-depleted soils may have fewer plants present, making them more prone to erosion. As a result of crop nutrition being compromised by mineral depletion, human and animal diets become deficient in minerals. In addition to lowering food quality, it makes it harder for soils to support a variety of plant species and maintain ecological balance. The lack of some minerals, such as phosphate and potassium, also increases dependency on synthetic fertilizers, which have their own negative effects on the environment and the economy (Musa *et al.*, 2024). When outputs from the soil system exceed inputs, the amount of nutrients stored in the soil must decline. In the simplest case, the rate of nutrient depletion reflects the difference between outputs and inputs and can be expressed in terms of an amount of nutrient per unit of area and per unit of time (kg/ha/yr). However, as the system adjusts to the changed levels of inputs and outputs over a long period of time, a measure of the relative rate of change in the soil reserve is more appropriate, with units of reciprocal time. Under continuous cultivation and cereal cropping without replenishment of nutrients removed from the system, there is an inevitable decline in soil OM and nutrients such as N, P, S, and Zn. The ability of the soil to provide adequate nutrients (notably N) to the crop is impaired so that, even on a soil that initially had high fertility, there is a decline in the yield of grain and its protein content.

From a purely economic perspective, soil nutrient reserves can be viewed in the same way as a finite resource, like a coal deposit. Following this logic, it could be considered sound economics to "mine" the soil for its inherent value, provided the land itself is not irreversibly degraded.

However, this viewpoint creates a fundamental contradiction. While it is universally accepted that a mineral resource has a finite lifespan, there is a deeply ingrained expectation that agricultural land can and should produce indefinitely. This common perception overlooks the critical reality that soil's productive capacity can indeed be exhausted, challenging the very notion of perpetual agricultural output without sustainable stewardship (Dalal *et al.*, 1997).

Cause and Effect of Mineral Depletion

The primary cause of mineral depletion is unsustainable land management, which extracts vital nutrients from the soil faster than they can be naturally replenished. Intensive human activities, such as monoculture farming, deforestation, and overgrazing, continuously remove essential minerals. This issue is critically linked with soil erosion, which acts as another direct cause by physically stripping away the most fertile, nutrient-rich topsoil.

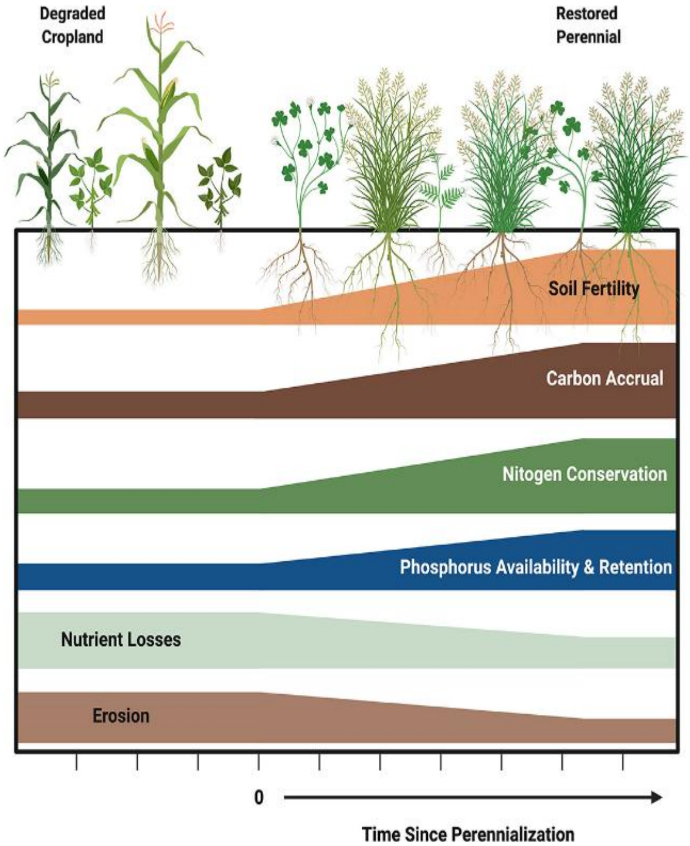

Fig. 1. Patterns of key agronomic and biogeochemical process changes during the restoration of soil fertility via perennialization of degraded cropland (Mosier *et al*., 2021).

The effects of this depletion are severe and create a damaging feedback loop. As the soil becomes nutrient-poor, it supports less vegetation. This lack of protective plant cover makes the land more vulnerable to erosion, which in turn accelerates further mineral loss. The ultimate effects on agriculture include lower crop yields and higher production costs. Environmentally, it leads to a deterioration of biodiversity, harms aquatic ecosystems through sediment runoff, and diminishes the land's overall resilience to climate change (Musa *et al*., 2024).

Impact of Soil erosion on Mineral depletion

There is a complex relationship between soil erosion and mineral depletion. The removal of key nutrients necessary for plant development by eroded topsoil accelerates mineral depletion. Soil erosion washed away vital nutrients from the soil; eroded material contains three times more nutrients compared to eroded locations. Furthermore, soil erosion causes spatial variability of soil nutrients, resulting in eroded locations being deficient, deposited regions being enriched, and non-eroded positions neutral condition (Mariappan, 2016). This erosion-induced spatial variability in soil quality (nutrients) leads to unevenness in crop yield/productivity. In the deposited area, heavy accumulation of macro and micro nutrients can lead to nutritional imbalances in plants due to luxury consumption of certain elements and hyper-accumulation of some trace elements in the plant's edible portion (Kadam *et al.,* 2019).

Eroded soil materials selectively carry away soil organic matter, in which most of the potentially available micronutrients are held, while leaving behind the coarser fraction and causing nutrient imbalance within and outside the landscape. Subsoil exposed by erosion processes is generally higher in pH than topsoil, which may cause a deficiency of some micronutrients (Brady and Weil, 2010).

On the other hand, nutrient-depleted soils may have fewer plants present, making them more prone to erosion. The detrimental effects on ecosystem health and agricultural output are amplified by this feedback loop. As a result of crop nutrition being compromised by mineral depletion, human and animal diets become deficient. In addition to lowering food quality, it makes it harder for soils to support a variety of plant species and maintain ecological balance.

The lack of some minerals, such as phosphate and potassium, also increases dependency on synthetic fertilizers, which have their own negative effects on the environment and the economy. Soil nutrient availability is the prevalent soil limitation in current cultivated land in most regions, particularly in tropical developing countries. This is due in part to the lower availability of natural nutrients than in temperate lands. Sub-Saharan Africa, Southern America, East Asia, Southeast Asia, and Australia and New Zealand have particularly low levels of natural soil nutrient availability. The share of soils with no or minor nutrient availability constraints is highest in high-income countries (76 percent), compared with 68 percent in low-income countries. In addition, the natural fertility status of some soils has deteriorated over time through 'nutrient mining'.

Future Concern

A comprehensive approach is essential to tackle soil erosion and mineral depletion, incorporating sustainable land management practices, regulatory measures, and technological advancements. Key strategies include precision agriculture, which leverages technology to assess soil nutrient levels and optimize fertilizer application, alongside soil testing, conservation agriculture, afforestation, and reforestation. Government policies that enforce regulations and incentivize responsible land use, coupled with ongoing research and education, play a crucial role in addressing these issues. Given their profound impact on ecosystem resilience and global food security, soil erosion and mineral depletion must be urgently addressed. Achieving a sustainable future requires a thorough understanding of its causes, effects, and potential solutions. Collaborative efforts among policymakers, farmers, researchers, and society at large are imperative to preserve valuable soil resources and promote ethical land management practices. (Musa *et al.*, 2024). A comprehensive and meticulous study is required to know the aggregate impact of erosion and mineral depletion by moderating certain controllable factors in the field conditions. Multi-disciplinary approach (soil scientist, agronomist, plant physiologist, and human nutritionist) is to be adopted for a better understanding of linkages between soil erosion processes, nutrient density in plant edible portions, and human nutrition, which in turn can help in framing alternative soil-based policies to restore eroded soils, improve the nutritional quality of food crops, and human wellness.

Conclusion

Soil erosion and mineral depletion are a deeply interconnected cycle threatening global food security and ecosystem stability. Erosion strips away fertile topsoil, causing mineral depletion and initiating a dangerous feedback loop: nutrient-poor soil supports weaker vegetation, which in turn accelerates further erosion. The consequences are severe, extending beyond lower crop yields to include compromised food nutrition that impacts human health, increased dependency on costly synthetic fertilizers, and widespread ecosystem degradation.

Addressing this complex issue demands an urgent, integrated response. The path forward requires a combination of advanced agricultural techniques like precision agriculture and fundamental practices such as afforestation. These efforts must be supported by robust government policies, targeted incentives, and continued research that links soil health directly to human nutrition. Ultimately, protecting our soil is a fundamental imperative for ensuring a healthy and sustainable future.

References

Brady, N.C. and Weil, R.R. 2010. Elements of the nature and properties of soils. Upper Saddle River, NJ, USA, Pearson Prentice Hall.

Dalal, R. C., Probert, M. E., Clarke, A., & Wylie, P. (1997). Soil nutrient depletion. *Sustainable crop production in the sub-tropics: an Australian perspective'.(Eds AL Clarke, PB Wylie) pp*, 42-63.

Dubois, O. 2011. The state of the world's land and water resources for food and agriculture: managing systems at risk. Earthscan.

ICAR and NAAS. 2010. Degraded and wastelands of India: Status and spatial distribution. Indian Council of Agricultural Research, New Delhi, India, 158p.

ICAR-Indian Institute of Soil and Water Conservation (ICARIISWC). 2015. Vision - 2050 report.

Kadam, D. M., Sankar, M., Singh, D. V., Gupta, A. K., Jayaprakash, J., Dinesh, D., & Mehata, H. (2019). Soil Erosion: Hidden Threat to Human Nutrition. *SOIL AND WATER CONSERVATION BULLETIN*, *5000*, 70.

Mariappan, S. 2016. Soil redistribution impacts on the spatial variation of nutrients, net carbon exchange with the atmosphere and soil respiration rates in highly eroding agricultural fields from the foothills of the Indian Himalaya. Diss. University of Exeter.

Mosier, S., Córdova, S. C., & Robertson, G. P. (2021). Restoring soil fertility on degraded lands to meet food, fuel, and climate security needs via perennialization. *Frontiers in Sustainable Food Systems*, *5*, 706142.

Musa, I. O., Samuel, J. O., Adams, M., Abdulsalam, M., Nathaniel, V., Maude, A. M., ... & Tiamiyu, A. G. T. (2024). Soil erosion, mineral depletion and regeneration. In *Prospects for soil regeneration and its impact on environmental protection* (pp. 159-172). Cham: Springer Nature Switzerland.

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