Ecosystem Services Provided by Earthworms: A global Perspective with Special Reference to India

केंचुओं द्वारा प्रदत्त पारिस्थितिकी तंत्र सेवाएं: भारत विशेष संदर्भ सहित एक वैश्विक दृष्टिकोण

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सारांश

केंचुए, जिन्हें प्रायः "पारिस्थितिकी तंत्र के अभियंता" कहा जाता है, मृदा स्वास्थ्य बनाए रखने और पारिस्थितिकी तंत्र की क्रियाओं को सतत बनाए रखने में एक महत्वपूर्ण भूमिका निभाते हैं। ये भूमिगत अकशेरुकी जीव पोषक तत्वों के चक्रण, मृदा संरचना में सुधार, कार्बन अवशोषण, जल विनियमन तथा कीट नियंत्रण सहित अनेक पारिस्थितिकी तंत्र सेवाओं में महत्वपूर्ण योगदान देते हैं। इनकी गतिविधियाँ मृदा पर्यावरण के जैविक और अजैविक दोनों घटकों को प्रभावित करती हैं, जिससे कृषि उत्पादकता और जैव विविधता संरक्षण को बढ़ावा मिलता है।

यह समीक्षा केंचुओं द्वारा प्रदान की जाने वाली विविध पारिस्थितिकी तंत्र सेवाओं के वर्तमान ज्ञान को एकत्र करती है, तथा वैश्विक और क्षेत्रीय–विशेष रूप से भारतीय परिप्रेक्ष्य में–उनकी महत्ता को रेखांकित करती है। वर्ष 2024 के हालिया अध्ययनों ने यह स्पष्ट किया है कि केंचुए कार्बन स्थिरीकरण के माध्यम से जलवायु परिवर्तन को कम करने और कृषि-पर्यावरणीय तंत्र में लचीलापन बढ़ाने की क्षमता रखते हैं। समीक्षा में उन चुनौतियों पर भी चर्चा की गई है जो केंचुओं की जनसंख्या और उनके द्वारा प्रदत्त सेवाओं के लिए खतरा बन रही हैं, जैसे आवासीय क्षरण, कीटनाशकों का अत्यधिक उपयोग और जलवायु परिवर्तन। यह लेख वैश्विक शोध और भारतीय अध्ययन निष्कर्षों को एकीकृत करते हुए यह दर्शाता है कि दीर्घकालिक पारिस्थितिकीय और कृषीय स्थिरता सुनिश्चित करने के लिए केंचुआ समुदायों के संरक्षण हेतु सतत भूमि प्रबंधन प्रथाओं को अपनाना अत्यावश्यक है।

कुंजी : केंचुए, पारिस्थितिकी तंत्र सेवाएं, मृदा स्वास्थ्य, पोषक तत्व चक्रण, कार्बन अवशोषण, कृषि पारिस्थितिकी, भारत, जलवायु परिवर्तन शमन

Abstract

Earthworms, often referred to as "ecosystem engineers," play a crucial role in maintaining soil health and sustaining ecosystem functions. These subterranean invertebrates contribute significantly to various ecosystem services, including nutrient cycling, soil structure improvement, carbon sequestration, water regulation, and pest control. Their activities influence both biotic and abiotic components of the soil environment, thereby enhancing agricultural productivity and biodiversity conservation. This review synthesizes current knowledge on the diverse ecosystem services provided by earthworms, emphasizing their importance at both global and regional scales, particularly in the Indian context. Recent studies from 2024 have further highlighted the potential of earthworms in mitigating climate change through carbon stabilization and enhancing resilience in agroecosystems. The review also discusses challenges such as habitat degradation, pesticide use, and climate change that threaten earthworm populations and, consequently, the services they provide. By integrating scientific findings from global research and local Indian studies, this article underscores the urgent need for sustainable land management practices that conserve earthworm communities to ensure long-term ecological and agricultural sustainability.

Keywords: Earthworms, Ecosystem services, Soil health, Nutrient cycling, Carbon sequestration, Agroecology, India, Climate change mitigation

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1. Introduction

Introduction Soil is one of the most vital natural resources, supporting terrestrial ecosystems and underpinning global food security. Within this complex matrix, earthworms (phylum Annelida, class Oligochaeta) play an indispensable role. Often described as "nature's plough" (Darwin, 1881), earthworms are key contributors to soil formation, fertility, and overall ecosystem functioning. They exert profound effects on physical, chemical, and biological soil properties through their feeding, burrowing, and casting activities (Lavelle et al., 1997). As ecosystem engineers, earthworms modify their environment in ways that create or alter habitats for other organisms, thereby influencing entire ecological networks (Jones et al., 1994).

Globally, over 6,000 species of earthworms have been identified, distributed across diverse climatic zones and soil types (Blakemore, 2023). In India alone, more than 500 species have been documented, reflecting the country's rich biodiversity and varied agroecological conditions (Sharma & Garg, 2021). Indian soils, ranging from the alluvial plains of the Indo-Gangetic region to the lateritic soils of peninsular India, host a variety of earthworm species that contribute to the maintenance of soil fertility and ecosystem stability.

The ecosystem services provided by earthworms can be broadly categorized into four main domains: provisioning, regulating, supporting, and cultural services. These include but are not limited to nutrient cycling, organic matter decomposition, soil aeration, water infiltration, carbon sequestration, and pest suppression. Recent advancements in soil ecology have underscored the importance of these services in the face of global environmental challenges such as climate change, soil degradation, and declining agricultural productivity.

This review aims to comprehensively assess the multifaceted roles of earthworms in delivering critical ecosystem services, with particular emphasis on recent scientific developments, including those from 2024. Furthermore, it integrates global insights with specific examples from India to illustrate how earthworms contribute to sustainable agriculture and environmental conservation in diverse socio-ecological contexts.

2. Soil Formation and Structure Maintenance

One of the most fundamental contributions of earthworms to ecosystem functioning lies in their role in soil formation and structure maintenance. Through their burrowing and casting activities, earthworms enhance soil porosity, aggregate stability, and root penetration capacity (Shipitalo & Butt, 2023). Earthworm burrows serve as conduits for air and water movement, improving soil aeration and drainage (Bottinelli et al., 2024). These structural modifications are essential for maintaining healthy rhizospheres and promoting plant growth.

In India, where soil compaction due to intensive agriculture is a growing concern, earthworm activity has been shown to mitigate this issue effectively. Studies in the semi-arid regions of Rajasthan have demonstrated that earthworms like *Perionyx excavatus* and *Eisenia foetida* improve soil texture and reduce bulk density, leading to better crop yields (Kumar et al., 2024). Similarly, in the Eastern Ghats, native earthworm species

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such as *Drawida nepalensis* contribute to soil aggregation through mucus secretion and casting, which enhances microbial activity and nutrient retention (Reddy et al., 2023).

Earthworms also facilitate pedogenesis by mixing mineral and organic layers of the soil profile. This vertical translocation of organic matter leads to the formation of stable soil aggregates, which are resistant to erosion and support long-term soil fertility (Six et al., 2023). The incorporation of organic residues into deeper soil horizons increases the availability of nutrients to plant roots and promotes the development of fertile topsoil.

Moreover, earthworms interact synergistically with other soil organisms, including bacteria, fungi, and arthropods, to enhance decomposition and humus formation. Their digestive system processes organic material into nutrient-rich casts, which act as hotspots of microbial activity and biochemical transformation (Gupta & Senapati, 2024). These casts are enriched with nitrogen, phosphorus, potassium, and micronutrients, making them highly beneficial for plant nutrition.

3. Regulating Services: Nutrient Cycling and Organic Matter Decomposition

Nutrient cycling is a cornerstone of ecosystem functioning, and earthworms play a pivotal role in this process. By consuming dead plant material and excreting nutrient-enriched casts, earthworms accelerate the mineralization of organic matter and release nutrients in forms readily available to plants (Scheu, 2023). Nitrogen mineralization, in particular, is significantly enhanced by earthworm activity, as their gut-associated microbes convert organic nitrogen into ammonium and nitrate forms (Pramanik & Chung, 2024).

In tropical and subtropical climates like those found in India, where rapid decomposition rates are common, earthworms help regulate nutrient dynamics by stabilizing organic matter and reducing leaching losses. Field experiments conducted in West Bengal have shown that vermicomposting using *Eisenia foetida* can increase nitrogen content in compost by up to 30%, compared to traditional composting methods (Zhang et al., 2024).

Phosphorus cycling is another area where earthworms exert considerable influence. Their casts contain higher concentrations of available phosphorus due to the presence of phosphatase enzymes secreted during digestion. In low-phosphorus soils prevalent in parts of South India, such as Tamil Nadu and Kerala, earthworm-assisted nutrient recycling can enhance phosphorus bioavailability and improve crop productivity without external inputs.

Carbon cycling is also intimately linked to earthworm activity. While some studies suggest that earthworms may increase CO_2 emissions through enhanced microbial respiration, others indicate that their role in forming stable soil aggregates can lead to long-term carbon sequestration (Zhang et al., 2024).

4. Provisioning Services: Enhancing Agricultural Productivity

Earthworms contribute directly to agricultural productivity by improving soil fertility, enhancing water-holding capacity,

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and stimulating plant growth. Their presence in cultivated soils has been correlated with increased crop yields, reduced input requirements, and improved resistance to pests and diseases (Edwards & Arancon, 2023).

Vermicompost, produced through the action of earthworms on organic waste, is rich in nutrients and beneficial microorganisms. It serves as a potent biofertilizer that enhances soil fertility and suppresses plant pathogens (Garg et al., 2024). In Andhra Pradesh and Karnataka, farmer cooperatives have successfully implemented large-scale vermicomposting units, transforming agricultural waste into valuable soil amendments (Nagaraju et al., 2024).

Earthworms also influence plant growth indirectly by modifying rhizosphere conditions. Their casts contain plant growth-promoting hormones such as auxins and gibberellins, which stimulate root development and enhance nutrient uptake (Yadav et al., 2024). Additionally, earthworm activity increases the population of mycorrhizal fungi, which form symbiotic associations with plant roots and facilitate nutrient exchange (Rajendran et al., 2024). In paddy fields of Odisha, researchers have observed that earthworm-inhabited soils exhibit higher mycorrhizal colonization and improved rice yields compared to worm-deprived plots (Dash et al., 2024).

Moreover, earthworms have been implicated in suppressing soil-borne pests and diseases. Certain species produce antimicrobial compounds that inhibit the growth of pathogenic fungi and bacteria (Sarkar et al., 2024). In organic farms across Himachal Pradesh, integrated pest management strategies incorporating earthworms have shown promising results in reducing incidences of fungal blight and nematode infestations (Thakur & Sharma, 2024).

5. Regulating Services: Water Regulation and Erosion Control

Water regulation is another critical service provided by earthworms, particularly in rain-fed and drought-prone agricultural systems. Their burrowing activity increases soil porosity and hydraulic conductivity, enabling faster water infiltration and reducing surface runoff (Capowiez et al., 2023).

In the dryland farming regions of Gujarat and Maharashtra, studies have shown that earthworms significantly enhance water infiltration rates and reduce soil crusting. These benefits translate into improved moisture retention and reduced irrigation requirements, which are crucial for water-stressed environments. Moreover, earthworm-enhanced soil structure reduces the risk of erosion by increasing aggregate stability and root anchoring capacity (Shukla et al., 2024).

In the Western Ghats, where deforestation and land degradation are widespread, earthworms have been recognized as key agents in restoring degraded soils. Their presence in reforestation projects has led to faster recovery of soil hydrological properties and vegetation cover (Joseph et al., 2024).

6. Regulating Services: Climate Change Mitigation

Emerging research highlights the potential of earthworms in climate change mitigation through carbon sequestration and greenhouse gas regulation. By

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promoting soil aggregation and organic matter stabilization, earthworms can enhance the storage of carbon in soil pools (Lal, 2023). In addition, their interactions with soil microbes influence the production and consumption of methane (CH_4) and nitrous oxide (N_2O), two potent greenhouse gases (Butterbach-Bahl et al., 2024).

Recent studies from 2024 have explored the dual role of earthworms in mediating greenhouse gas fluxes. While some experiments suggest that earthworms may increase N_2O emissions due to enhanced nitrification and denitrification processes (Wang et al., 2024), others argue that their contribution to carbon stabilization outweighs these concerns (Zhao et al., 2024). In Indian rice ecosystems, which are major sources of CH_4 emissions, the introduction of earthworms has been shown to reduce methane emissions by altering redox conditions and microbial community dynamics (Jain et al., 2024).

7. Cultural Services: Awareness, Education, and Traditional Knowledge

Although less quantifiable than other ecosystem services, the cultural value of earthworms should not be overlooked. Across many agrarian societies, including in India, earthworms have long been revered as symbols of fertility and prosperity. Traditional farming communities in states like Madhya Pradesh and Chhattisgarh have historically used earthworm abundance as an indicator of soil health, integrating this knowledge into their farming calendars and practices (Tripathi & Bhardwaj, 2024).

In modern times, earthworms have become important tools for environmental education and public awareness campaigns. NGOs and grassroots organizations have also leveraged earthworm-based technologies to engage rural youth and women in income-generating activities related to organic farming and composting (Gandhi et al., 2024).

8. Threats to Earthworm Populations and Conservation Strategies

Despite their ecological importance, earthworm populations are increasingly threatened by anthropogenic activities such as intensive agriculture, pesticide use, soil pollution, and climate change. The widespread application of synthetic fertilizers and pesticides has been linked to declines in earthworm diversity and abundance, particularly in intensively farmed regions of Punjab and Haryana (Kaur et al., 2024). Heavy metal contamination from industrial effluents and mining operations also poses a significant risk to earthworm health, impairing their physiological functions and reproductive success (Sinha et al., 2024).

Climate change exacerbates these pressures by altering temperature and moisture regimes, which affect earthworm survival and behavior. In central India, prolonged dry spells and erratic rainfall patterns have disrupted seasonal earthworm activity cycles, leading to reduced soil processing and nutrient turnover (Verma et al., 2024).

To address these challenges, conservation-oriented approaches must be integrated into land-use planning and agricultural policies. In India, the Paramparagat Krishi Vikas Yojana (PKVY) and Rashtriya Krishi Vikas Yojana (RKVY) have begun incorporating earthworm-friendly practices into their guidelines, signaling a

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shift toward ecologically informed agriculture (Ministry of Agriculture, 2024).

4. Conclusion

Earthworms are unsung heroes of the soil, providing a wide array of ecosystem services that sustain life above and below ground. From nutrient cycling and soil structure improvement to water regulation and climate change mitigation, their contributions are integral to ecological balance and agricultural productivity. In India, where soil health and food security are pressing concerns, harnessing the potential of earthworms offers a sustainable pathway forward.

Recent scientific advances, including those from 2024, have deepened our understanding of earthworm ecology and their multifunctional roles in agroecosystems. However, much work remains to be done in terms of policy integration, farmer education, and conservation planning. Protecting earthworm populations requires a holistic approach that combines traditional wisdom with modern science, ensuring that these vital organisms continue to thrive in the face of mounting environmental challenges.

As we strive toward a more sustainable and resilient future, the humble earthworm reminds us that solutions often lie beneath our feet—silent, unseen, yet profoundly impactful.

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