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Perspective

Nature as an ecological theater: Multiscale interactions among vegetation function, hydrological processes and human health

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Nature functions as an ecological theater where complex interactions among vegetation, hydrological cycles and human societies shape ecosystem resilience and human well-being. Vegetation influences carbon and water fluxes, microclimates and soil stability, while hydrological processes mediate nutrient cycling, water availability and flood regulation. These ecological dynamics directly and indirectly impact human health by modulating exposure to clean water, air quality, heat stress and vector-borne disease risk. This article synthesizes evidence across multiple spatial and temporal scales, exploring how vegetation function and hydrological processes interact to regulate ecosystem services and human health outcomes. We examine natural, restored and urban landscapes, highlighting the role of ecosystem management, biodiversity and landscape connectivity in sustaining ecosystem services and health benefits. Understanding these multiscale interactions is essential for designing nature-based solutions that integrate ecological and societal objectives under global environmental change.

Keywords: Vegetation function, Hydrological processes, Human health, Ecosystem services, Landscape ecology, Flood regulation, Nature-based solutions, Multiscale ecology.

Introduction

Ecosystems operate as dynamic theaters in which biotic and abiotic components interact to produce functional outcomes that sustain life. Vegetation, as a central actor in this theater, regulates primary productivity, carbon sequestration, water cycling and microclimatic conditions. Hydrological processes—including rainfall interception, groundwater recharge and streamflow regulation—mediate the delivery of essential ecosystem services and maintain landscape resilience. Humans, both as beneficiaries and modifiers of ecosystems, are influenced by these ecological processes through water security, nutrition, disease regulation and climate buffering. Recent environmental changes—land-use conversion, deforestation, urbanization and climate variability—have disrupted these interactions, reducing ecosystem service provision and increasing human vulnerability. In parallel, restoration initiatives, urban greening and sustainable landscape management offer opportunities to reinforce ecological functions and safeguard health (Pohl M, et al. 2011). This article explores multiscale interactions among vegetation, hydrology and human health, examining how these dynamics manifest across natural, restored and human-modified landscapes.

Description

Vegetation drives primary productivity, capturing solar energy and converting it into biomass. Leaf photosynthetic capacity, stomatal conductance and water-use efficiency determine carbon assimilation and transpiration rates. These physiological traits influence microclimates by regulating temperature, humidity and wind patterns, while also contributing to soil fertility through litter deposition and root exudates. Forests, wetlands and grasslands with diverse vegetation support higher ecosystem productivity and resilience, which in turn underpin key ecosystem services such as food production, carbon storage and climate regulation. Vegetation modulates hydrological processes through canopy interception, transpiration and root-mediated infiltration. Dense vegetation reduces surface runoff, enhances soil water retention and stabilizes streamflow regimes (Liu X, et al. 2022). Riparian vegetation buffers flood peaks, maintains water quality and supports aquatic biodiversity. Leaf area index, root depth and plant functional traits determine the efficiency of these hydrological controls, illustrating the importance of vegetation structure and diversity in sustaining ecosystem services.

Functional diversity within plant communities enhances ecosystem stability. Species with complementary traits stabilize water fluxes, nutrient cycling and carbon dynamics, reducing vulnerability to droughts, storms and disease outbreaks. Biodiversity also increases adaptability to environmental change, as species with varying tolerances ensure that key functions persist despite perturbations. Loss of functional diversity diminishes resilience, amplifying the risk of ecosystem service collapse. Hydrological processes regulate the movement and storage of water across landscapes. Precipitation, infiltration, groundwater recharge, evapotranspiration and streamflow are interconnected with vegetation dynamics (Zhang W, et al. 2022). Forested watersheds, wetlands and riparian zones enhance water storage, mitigate floods and sustain baseflows during dry periods. Hydrological variability influences plant growth, microbial activity and nutrient availability, creating feedbacks that affect ecosystem productivity and resilience. Vegetation and soil structure influence the filtration of pollutants, sediment retention and nutrient cycling. Root systems and microbial communities reduce nitrogen and phosphorus leaching, improve sediment capture and regulate soil organic matter decomposition. Wetlands act as natural buffers, removing contaminants and providing safe water for human consumption (Dubos R 1976). These ecosystem functions are critical for public health, particularly in regions dependent on surface and groundwater resources.

Hydrological extremes—droughts, floods and storms—threaten both ecosystems and human health. Vegetation-mediated hydrological regulation reduces vulnerability by slowing runoff, enhancing infiltration and buffering against soil erosion. Restoration of degraded landscapes, such as floodplain reconnection and wetland rehabilitation, improves resilience by restoring natural hydrological regimes and supporting diverse plant communities. Vegetation and hydrological interactions directly influence water availability and quality. Forested and wetland ecosystems enhance groundwater recharge and filter contaminants, reducing the risk of waterborne diseases (Craig JM, et al. 2016). Reliable water supply supports agriculture, sustains nutritional security and reduces stress associated with scarcity. Human health benefits are thus tightly coupled to ecological processes at multiple scales. Vegetation-driven transpiration and canopy shading moderate local temperatures, reducing heat stress in urban and rural landscapes. Trees and green infrastructure mitigate urban heat islands, lower exposure to extreme temperatures and reduce cardiovascular and respiratory health risks. Hydrological moderation of microclimates complements vegetation functions, creating healthier environments for communities.

Conclusion

Nature functions as an ecological theater in which vegetation, hydrology and human systems interact across multiple scales. Vegetation regulates carbon and water fluxes, modulates microclimates and supports soil and aquatic ecosystems. Hydrological processes mediate nutrient cycling, water availability and flood regulation, directly influencing human health outcomes. Restoration and management of natural and human-modified landscapes can enhance ecosystem functions, sustain biodiversity and improve public health through multiscale ecological interactions. Recognizing and managing these interconnected systems is essential for building resilient ecosystems and healthy societies under the pressures of climate change, urbanization and environmental degradation.

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Conflict of Interest

The authors declare no conflict of interest.

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