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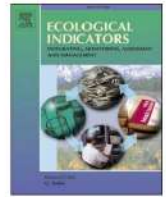
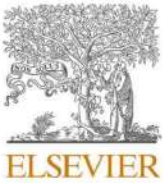
Multiscale assessment of ecosystem sustainability coordination and its drivers in Yangtze River basin megacity clusters: A water-energy nexus perspective

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Multiscale assessment of ecosystem sustainability coordination and its drivers in Yangtze River basin megacity clusters: A water–energy nexus perspective

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ABSTRACT

Rapid urbanization has intensified ecosystem sustainability challenges, particularly within the “water–energy” nexus ecosystem that closely links human societal development with natural ecological processes. However, scale-dependent ecological differences within urban agglomerations remain insufficiently explored. Therefore, this study aims to reveal the multi-scale spatiotemporal patterns and driving forces of the “water–energy” nexus ecosystem sustainability. To achieve this, an Ecosystem Sustainability Coordination Index (ESCI) is developed by integrating ecological supply–demand ratio, coupling coordination degree, and spatial variability index to assess the overall sustainability of interconnected ecosystems. Across three spatial scales (grid–county–city), this study analyzes the spatiotemporal evolution of ESCI in two major urban agglomerations of the Yangtze River Basin: the Chengdu–Chongqing Urban Agglomeration (CUA) in the upstream and the Yangtze River Delta Urban Agglomeration (YUA) in the downstream. The XGBoost–SHAP model is employed to identify the nonlinear driving forces of human societal development and environmental change on ESCI. A key contribution of this study is the development of the novel ESCI to fill the research gap in evaluating ecosystem sustainability. Results show that ESCI exhibited clear scale-dependent patterns from 2000 to 2020. At the grid scale, ESCI in CUA was higher, whereas at the county and city scales YUA showed higher values, with maximum differences exceeding 0.3. Core cities in both urban agglomerations remained at low ESCI levels, with surrounding areas showing gradual declines. Driving forces displayed significant scale dependency and regional heterogeneity: as spatial scale increased, the influence of environmental factors on ESCI rose by about 30%, while the explanatory power of human societal development varied from over 60% to about 15%. These findings support the implementation of differentiated ecological space management strategies across scales and urban agglomerations, providing scientific insights for ecological spatial planning and sustainable urban development.

1. Introduction

With the continued global population growth and the acceleration of urbanization (Chrisendo et al., 2025), significant pressure has been placed on the natural environment (Wei et al., 2022), resulting in unprecedented damage to ecosystems. Ecological issues such as water scarcity, ecosystem function degradation, frequent extreme weather events, and biodiversity loss have become increasingly prominent (Liao et al., 2025; Wong et al., 2021), leading to the gradual loss of essential ecosystem functions. These ecological challenges hinder the realization of sustainable development. Particularly, the “water–energy” nexus

ecosystem, as a fundamental ecosystem type that supports both human societal activities and the cycles of natural ecological processes (Luo et al., 2026; Yin et al., 2023), plays a crucial role in achieving sustainable development. To address this challenge, it is essential to conduct comprehensive assessments of the sustainability of the “water–energy” nexus ecosystem and uncover the driving relationships between changes in ecosystem sustainability and external factors. By evaluating the sustainability and changing patterns of the “water–energy” nexus ecosystem, we can more clearly identify regional ecological issues. This not only provides a basis for policymaking but also effectively guides the achievement of sustainable development goals. Conducting such a study

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