

Stepwise Attenuation and Threshold Effects of Soil and Water Conservation Sediment-Reduction Benefits in the Middle Yellow River

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Abstract

Clarifying the regulatory mechanisms of soil and water conservation (SWC) measures on sediment load represents a fundamental scientific challenge for ecological management in the Middle Reaches of the Yellow River. This study integrates multi-source hydrological, meteorological, and SWC data (1950–2020) from the Helong Section and Sanchuanhe Basin, employing trend analysis, correlation methods, and a novel Sediment Reduction Benefit Index (SREI) to quantify erosion control efficacy. Our analysis demonstrates that large-scale SWC implementation after 1970 established human activities as the dominant driver of drastic reductions in runoff (−77.7%) and sediment load (−94.5%). The decoupling from precipitation variability confirms SWC's critical role in sediment reduction. Concurrently, SWC benefits exhibit progressive stepwise attenuation, transitioning through three distinct phases: a high-efficiency period (1970–1985; SREI > 790 t/km²), transitional period (1986–1999), and low-efficiency period (post-2000; SREI < 130 t/km²). Mann-Kendall (M-K) tests further revealed threshold behaviors, with abrupt changes occurring in 2008 for integrated watershed management. Vegetation measures (afforestation/grass planting) mirrored this timing, while structural interventions (terraces/check dams) reached critical points 10–15 years earlier (1990 and 2005). Although sediment load dynamics show significant time-scale dependencies that may bias decadal assessments of SWC efficacy, geographic-scale effects remain negligible. Collectively, these findings underscore the urgent need to transition regional SWC strategies from traditional areal expansion toward structural optimization paradigms to counter diminishing marginal benefits.

Keywords

Yellow River, Soil and Water Conservation, Sediment Reduction, Threshold Effect, Stepwise Attenuation