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Literature Review on the Coupling Coordination between "Social-Ecological" Resilience and Human Well-Being in Watershed Systems

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Abstract
The coupling coordination between social-ecological resilience and human well-being is vital for watershed ecological protection and livelihood improvement. Based on the PRISMA framework, this paper systematically reviews core literature from 2020 to 2026. Results show that an “evaluation-coupling-spatial-driving” analytical framework has been established, and distinct coupling patterns exist between southern river-lake watersheds and northern water-deficient watersheds. However, inconsistencies in indicators, insufficient multi-scale analysis, and weak theory-practice integration remain as major limitations. Future research should strengthen comparative studies, scale optimization, technical integration and policy application.

Keywords: Watershed System; Social-ecological Resilience; Human Well-being; Coupling Coordination; Literature Review

Introduction
With global climate change and rapid urbanization, a variety of intertwined risks threaten the present and future of human development (Yi et al., 2025). The resilience level of "social-ecological" systems profoundly affects regional ecological environment quality and human well-being development. On the one hand, an ecological environment lacking resilience cannot sustainably support human well-being; even if a fragile ecosystem is improved through short-term governance, its service functions may still collapse when exposed to external disturbances. On the other hand, resilience construction that ignores human well-being is difficult to win social support. If governance measures sever the connection between humans and nature or restrict sustainable livelihood sources, social resistance is likely to arise. Therefore, human society urgently needs to transcend the traditional isolated environmental protection mindset and pursue the long-term health and stability of the overall resilience of "social-ecological" systems. This is the premise and guarantee for ensuring that the achievements of ecological civilization construction are continuously transformed into people's well-being, thereby promoting the coupled and coordinated development of the two.

Linked by water systems, watersheds closely integrate natural processes and human activities, serving as typical natural-social complex systems characterized by strong overall relevance, spatial mobility, and cross-regional impacts (Shong et al., 2026). Against this backdrop, any fluctuation in the watershed "social-ecological" resilience system will directly affect the production, life, health, and safety of nearly 70 million people, and exert a significant impact on China's economy. Meanwhile, watersheds feature dense river networks, complex water systems, large water exchange volumes affected by monsoons and tides, and pollution control is highly challenging. Rapid urbanization and social structural changes also continuously impact watershed resilience. In this context, how to scientifically assess the "social-ecological" resilience of watersheds, quantify their coordinated development level with human well-being, and predict future evolution trajectories have become key urgent issues to be addressed.

This paper systematically reviews relevant studies on watershed "social-ecological" resilience, human well-being, and their coupling coordination, aiming to comprehensively summarize the theoretical contributions and methodological experiences of existing achievements and lay a solid academic foundation for this research. Conducting a literature review serves three purposes: first, to extract mature theories and research paradigms, and clarify the core logic and mainstream frameworks for resilience assessment, well-being measurement, and coupling analysis; second, to summarize scientific methods and empirical experiences, and draw on mature technical means such as multi-source data fusion, quantitative assessment, and spatial analysis; third, to absorb

insights from typical watershed governance, and summarize the regular understandings and optimization paths of the Yangtze River, Yellow River, Poyang Lake and other watersheds.

The literature review plays a key supporting role in this research. First, it provides a theoretical basis to help construct a coupling analysis framework adapted to watershed characteristics; second, it offers methodological references to ensure the scientific standardization of indicator selection, model application, and empirical analysis; finally, it provides experience references to promote cutting-edge and innovative research, and strongly support the in-depth analysis of the coupling coordination and evolution mechanism between "social-ecological" resilience and human well-being in watershed systems.

Literature Screening and Research Methods

To ensure the quality of literature samples, Chinese literature in this paper is obtained from the CNKI platform, selecting articles published in CSSCI and Peking University core journals. English literature is retrieved from the Web of Science core database, and full texts are acquired via Science Direct and Sci-hub.

This paper systematically reviews relevant domestic and foreign studies in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure the rigor and objectivity of the research process. PRISMA is an internationally recognized guideline for systematic literature reviews, guiding researchers through steps such as literature retrieval, screening, and data coding (Wang et al., 2026). On the CNKI platform, retrieval is conducted using the Boolean logic formula: SU% = (Watershed+Water System+Lake Reservoir) AND SU% = ("Social-Ecological" Resilience+Social Resilience+Ecological Resilience) AND SU% = (Human Well-being + Well-being + Ecological Well-being) AND SU% = (Coupling+Coordination+Synergy), with the time limit from January 1, 2020 to April 1, 2026, and restricted to CSSCI and Peking University core journal papers. In the Web of Science database, the core database is selected, and retrieval is performed using the Boolean logic formula: TS = ((river basin OR watershed OR lake basin) AND (social-ecological resilience OR socio-ecological resilience OR ecological resilience OR resilience) AND (human well-being OR well being OR welfare OR human welfare) AND (coupling OR coordination OR interaction OR synergy)), with the time period from January 1, 2020 to April 1, 2026, and article type limited to "Article". According to the above retrieval strategy, 256 Chinese literature and 478 English literature are retrieved.

Most of the articles retrieved in this study focus on the coupling coordination between social-ecological system services and human well-being, comprehensively adopting literature research, indicator system construction, quantitative evaluation, and spatial econometric analysis methods. In data processing, the range standardization method is used to make raw data dimensionless raw data, eliminating differences in indicator dimensions and magnitudes; a combination of subjective and objective weighting via the entropy weight method and analytic hierarchy process is adopted to improve the scientificity of indicator weights. In system evaluation, a dual-system evaluation indicator system for social-ecological system services and human well-being is constructed, and the comprehensive index method is used to calculate the system development level. In coupling relationship research, the coupling coordination degree model is introduced to judge the system coupling degree and coordination level, and the relative development degree model is used to identify system lag types. In spatial analysis, the spatial autocorrelation model is adopted to explore spatial agglomeration characteristics; the spatiotemporal geographically weighted regression model and geographic detector are used to analyze the spatiotemporal heterogeneity and interaction of driving factors; finally, grey correlation analysis and multiple regression analysis are applied to reveal the impact mechanism, forming a complete analysis framework of "Evaluation-Coupling-Space-Driving".

Research Results and Analysis

Domestic and foreign scholars have formed rich research results on the coupling relationship between "social-ecological" resilience and human well-being in watersheds, with obvious differences and internal correlations in regional selection and core conclusions.Foreign studies are primarily driven by multi-source data, focusing on the comparison of coupling rules at the global scale and in typical watersheds: Luo, Z. et al. (2023) focused on the Yangtze River Basin, revealing the trend of increasing ecosystem service supply but faster growth in demand, and polarization of human well-being between rich and poor, finding that the coupling coordination degree between the two gradually evolved from moderate imbalance to moderate coordination, providing a benchmark framework for large-scale watershed coupling research; Zhen Zhang et al. (2023) conducted a comparative study of Qiandao Lake and the Yellow River Basin, finding that lake-type watersheds are more vulnerable to local ecological disturbances such as cyanobacterial blooms, hydrological fluctuations, and pollution emissions, with significant fluctuations in ecological service value and direct socio-economic driving factors, while large river-type watersheds face more prominent problems of unbalanced benefit distribution between upstream, midstream and downstream, requiring cross-regional ecological compensation and collaborative governance to balance protection

and development; Huang Xianjin and Georgia Destouni's team (2025) further confirmed at the global transboundary watershed scale that watershed well-being levels are generally low, with prominent shortcomings in the supply of basic services such as clean drinking water and ecological security, providing a universal reference for watershed coupling research.

Domestic studies mainly target the Yangtze River, Yellow River, and Poyang Lake basins, taking the interaction between social-ecological systems and humans as the core logic, exploring coordinated paths for natural and socio-economic development: Studies by Yang Xueting et al. (2022, 2023) on key ecological function areas in the upper reaches of the Yangtze River show that per capita ecosystem service value is negatively correlated with regional development and human well-being, and non-ecological factors make more prominent positive contributions to low well-being levels, reflecting the coupling contradictions in ecologically constrained regions; Zhang Chaozheng, Yang Shanxin et al. (2023, 2024) found that ecosystem services and resident well-being in the middle reaches of the Yangtze River are mainly in a trade-off relationship, with high coupling degree but widening gaps in coordinated development, in sharp contrast to the negative correlation pattern in the upper reaches; Chen Yingfen et al. (2024) confirmed that ecological service value and comprehensive well-being in the Poyang Lake Basin increase synchronously, with a steady rise in coupling coordination degree and positive spatial autocorrelation characteristics, serving as a typical reference for coordinated development of southern river-lake watersheds; Studies by Sheng Yanchao, Chen Xin, Zhang Yongfang et al. (2025) on the Yellow River Basin highlight the characteristics of northern water-deficient watersheds, where ecological resilience plays a significant positive driving role in high-quality economic development, and aquatic ecological resilience presents a two-way feedback mechanism with urban development, significantly different from the coupling logic centered on ecosystem service supply and demand in southern watersheds; Jiang Enhui's team (2024) further pointed out the decoupling between economy and social welfare in the Yellow River Basin, pointing out common pain points for improving watershed coupling coordination.

Overall, although existing studies have constructed a comparative framework for typical watersheds, there are still obvious gaps and shortcomings: For watershed systems, which are typical regions characterized by "high-intensity human activities, high ecological pressure, high well-being demand, and cross-provincial administrative division", special studies on the coupling relationship between social-ecological resilience and human well-being are still insufficient, with no horizontal comparisons with the Yangtze River, Poyang Lake, Yellow River and other basins, nor responses to core issues such as cyanobacterial blooms and transboundary governance. Meanwhile, existing studies are obviously inadequate in coupling dimension analysis, adaptation of research scales and spatiotemporal dynamics, and practical transformation capabilities, lacking multi-scale analysis adapted to the Taihu Lake ring structure and an evaluation system including characteristic indicators such as water quality safety and drinking water security, resulting in weak connection between theoretical achievements and practical implementation, and difficulty in effectively supporting governance practices for coordinated improvement of ecological protection and people's well-being in watershed systems.

Research Trends and Challenges

Based on authoritative empirical findings from the Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, and the Watershed System Supervision Bureau of the Ministry of Ecology and Environment, current research on the coupling of social-ecological resilience and human well-being in watershed systems has shifted from separate assessment of the ecological environment or human quality of life to analyzing their mutual influences and change laws. Combining Taihu Lake sediment records, remote sensing monitoring, and socio-economic data, the research clearly reveals the two-stage coupling evolution law of watershed systems: ecological degradation driven by industrialization since the 1950s, and "decoupling and win-win" between ecological restoration and economic growth after 2000.

In terms of research methods, the application of coupling coordination degree models, XGBoost-SHAP machine learning, threshold regression and other methods is increasingly widespread, helping to effectively identify core factors affecting the coupling relationship such as land use intensity, population density, and water eutrophication, while focusing on connecting practical policies such as "watershed ecological compensation" to strengthen the application value of research results. In the future, research will pay more attention to the superimposed impacts of climate and urbanization, ecological-well-being balance thresholds, digital dynamic monitoring, and cross-regional collaborative governance.

However, research in this field still faces many practical challenges: first, the concept and indicator system are not yet unified, and the multi-dimensional definition of resilience and the quantification dilemma of dimensions such as fairness and culture in well-being assessment lead to insufficient cross-study comparability; second, it is

difficult to accurately analyze the complex interaction between the two, and cross-scale integration is difficult due to the misalignment between administrative boundaries and natural watershed boundaries; third, there are obvious obstacles in data collection, with a scarcity of long-term high-resolution social-ecological monitoring data, great difficulty in the fusion and calibration of multi-source heterogeneous data such as remote sensing, statistics, and field surveys, and difficulty in obtaining well-being perception and behavioral data at the micro-community level; fourth, the integration of research technology and actual governance is not close enough, the coupling accuracy of multiple models is limited, and the application of big data, artificial intelligence and other technologies in real-time early warning of watershed governance is not mature, restricting the effective transformation of research results into practical governance.

Summary and Outlook

Through a systematic review of domestic and foreign studies on the coupling coordination between "social-ecological" resilience and human well-being in watersheds from 2020 to 2026, based on the PRISMA-standardized literature analysis framework, this paper summarizes the core achievements of the field into three dimensions: theoretical consensus, methodological system, and empirical laws, while clarifying the key shortcomings of current research.

In terms of theory, existing studies have established the core logic of "overall resilience of social-ecological systems", clarified that the coupling coordination of the two is a key link for transforming the achievements of ecological civilization construction into people's well-being, and broken through the limitations of traditional isolated environmental protection thinking; in terms of methodology, a complete analysis framework of "Evaluation-Coupling-Space-Driving" has been formed, integrating technologies such as the entropy weight method, coupling coordination degree model, and spatial econometric analysis, realizing quantitative integration and dynamic analysis of multi-source data; in terms of empirical evidence, the regional differentiation law of watershed coupling has been revealed: southern river-lake watersheds such as the Yangtze River and Poyang Lake take the balance of ecosystem service supply and demand as the core coupling logic, while northern water-deficient watersheds such as the Yellow River highlight the feedback mechanism between aquatic ecological resilience and economic development, providing a benchmark reference for cross-watershed comparison.

At the same time, current research still has obvious shortcomings: for the typical characteristics of watersheds "high-intensity human activities, high ecological pressure, high well-being demand, cross-provincial administrative division", special coupling research is seriously insufficient, failing to respond to core issues such as cyanobacterial blooms and transboundary governance; lacking multi-scale analysis adapted to the watershed system structure and an evaluation system including characteristic indicators such as water quality safety and drinking water security; the multi-dimensional definition of resilience and the quantification dilemma of well-being fairness and cultural dimensions lead to insufficient cross-study comparability; the coupling accuracy of multiple models is limited, the application of big data, artificial intelligence and other technologies in real-time governance early warning is not mature, and the connection between theoretical achievements and watershed collaborative governance practice is weak.

Based on the above existing watershed coupling research results, this paper summarizes three practical references for the coordinated improvement of social-ecological protection and people's well-being in watershed systems: in regional governance, it is necessary to draw on cross-watershed comparative research experience, establish an adapted coupling coordination evaluation system according to the particularity of watershed systems, focus on characteristic indicators such as water quality safety, drinking water security, and cross-regional ecological compensation efficiency, and accurately identify the core contradictions of watershed coupling coordination; in practical methods, relying on the above analysis framework and combining with the ring structure characteristics of watershed systems, carry out multi-scale analysis of "watershed-city-county-community" to reveal the interaction laws between the two at different scales; in technological transformation, draw on interdisciplinary research experience, integrate multi-source data such as remote sensing monitoring, socio-economic statistics, and micro-community surveys, explore the application of artificial intelligence technologies in scenarios such as cyanobacterial bloom early warning and water quality safety guarantee, and promote the transformation of research results into governance practice.

"Social-ecological" resilience is an inherent requirement for the coordinated promotion of ecological civilization construction and human well-being. In the future, research on the two in watershed systems can achieve breakthroughs in the following four aspects:

First, focus on special research on watershed systems, construct a horizontal comparison framework of "southern river-lake watersheds - northern water-deficient watersheds - special watersheds", focus on analyzing the impacts

of characteristic issues such as cross-provincial administrative division and industrial structure conflicts on the coupling relationship, and fill gaps in regional research;

Second, optimize dimension and scale design, take into account the multi-dimensional attributes of resilience (ecological, social, economic) and the multi-level connotations of well-being (material, health, fairness, culture), solve quantification dilemmas, and carry out multi-scale coupling analysis to improve the adaptability and scientificity of research;

Third, strengthen technological integration and methodological innovation, use technologies such as XGBoost-SHAP and spatiotemporal geographically weighted regression optimization models to improve data fusion and calibration accuracy and dynamic monitoring capabilities, construct an integrated analysis framework for threshold identification, dynamic prediction and policy simulation, and break through research bottlenecks;

Fourth, deepen the connection between theory and practice, carry out simulation evaluation around policy needs such as cross-regional collaborative governance, optimization of watershed ecological compensation mechanisms, and green transformation of industrial structure, build a closed-loop governance platform from digital dynamic monitoring to real-time early warning and then to policy response, and realize the deep integration of theoretical research and governance practice.

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