Reflections on the Restoration of River and Lake Ecological Environment in the Yellow River Basin

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Abstract

Water is the lifeline of the Yellow River, and the health of river and lake ecosystems constitutes one of the core elements of ecological protection and high-quality development in the Yellow River basin. How to achieve comprehensive recovery of the river and lake ecological environment in the Yellow River basin represents both a current hot topic and a significant challenge. This study employs an entropy weight model to evaluate the evolution characteristics of the basin' s river and lake ecological environment through a comprehensive assessment index of river and lake ecological environment quality, analyzes the problems confronting the recovery of the Yellow River' s river and lake ecological environment, explores the recovery objectives and patterns for the river and lake ecological environment in the Yellow River basin, and consequently proposes approaches for the recovery of the river and lake ecological environment. The results demonstrate that: (1) the river and lake ecological environment system in the Yellow River basin is undergoing a transition from disordered to ordered development; (2) measures such as unified regulation of the Yellow River main stream and soil and water conservation exert a positive promoting effect on the recovery of the river and lake ecological environment in the Yellow River basin; and (3) coordination among upstream and downstream areas, left and right banks, and water and land zones should be implemented, with goals of ecological protection and governance, groundwater over-exploitation control, and comprehensive soil erosion management, to continuously promote the comprehensive recovery of the river and lake ecological environment in the Yellow River basin.

Full Text

Reflections on the Eco-Environmental Recovery of Rivers and Lakes in the Yellow River Basin

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Abstract

Water is the lifeblood of the Yellow River, and the ecological health of its rivers and lakes constitutes a core element for ecological protection and high-quality development in the Yellow River Basin. Achieving comprehensive eco-environmental recovery of rivers and lakes in this basin represents both a pressing challenge and a prominent research focus. This study employs an entropy weight model to evaluate the evolution characteristics of the basin' s river and lake eco-environment through a comprehensive Environment Development Index (EDI). The analysis identifies key problems facing ecological recovery, explores recovery objectives and spatial patterns, and proposes strategic approaches for implementation. The results demonstrate that: (1) the river and lake eco-environmental system of the Yellow River Basin is transitioning from disordered to ordered development; (2) measures such as unified regulation of the main stream and soil-water conservation effectively promote ecological recovery; and (3) coordinated management across upstream-downstream, left-right banks, and water-land interfaces—targeting ecological protection, groundwater over-extraction control, and comprehensive soil erosion management—is essential for continuously promoting full ecological recovery.

Keywords: Rivers and lakes; Ecological environment; Recovery; Reflection; Yellow River Basin
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The Yellow River, the mother river of the Chinese nation, traverses China's eastern, central, and western regions, forming an ecological corridor connecting the Qinghai-Tibet Plateau, Loess Plateau, and North China Plain. It constitutes a critical ecological barrier and economic zone, serving as an important region for poverty alleviation and playing a pivotal strategic role in safeguarding national ecological, energy, economic, and food security. On September 18, 2019, President Xi Jinping chaired a symposium in Zhengzhou on ecological protection and high-quality development of the Yellow River Basin, identifying flood risk as the greatest threat, highlighting severe water resource challenges, and calling for improved development quality. He issued the historic call to "make the Yellow River a happy river that benefits the people" [?], setting higher requirements for the ecological health of rivers and lakes in the basin. The Yellow River' s characteristics of low water volume, high sediment load, uncoordinated water-sediment relationship, and frequent flood disasters have long constituted its complex and challenging management problems [?]. The Yellow River Basin represents a complex mega-system encompassing rivers, lakes, forests, grasslands, wetlands, deserts, and Gobi ecosystems, all playing vital roles in ecological recovery [?]. With intensifying climate change and human activities, the basin' s river and lake eco-environment continues to evolve [?], making it imperative to understand how to ensure sustained recovery and achieve system stability.

This paper addresses the challenge of eco-environmental recovery in the Yellow River Basin by evaluating evolution characteristics, identifying existing problems, clarifying recovery objectives and overall patterns, and proposing strategic approaches to support the implementation of ecological protection and high-quality development strategies.

1.1 Data and Analytical Methods

Data Requirements

Following principles of systematic comprehensiveness and data availability, and considering the ecological and environmental characteristics of Yellow River Basin rivers and lakes, this study constructs an evaluation system comprising 10 indicators closely related to eco-environmental recovery. The system addresses three dimensions: river-lake protection and management, groundwater over-extraction control, and soil erosion management [?], structured across target, criterion, and indicator layers (detailed in).

The indicator data incorporate remote sensing, surveying, geographic information, and sector-specific data. Land use and NDVI data were obtained from the Chinese Academy of Sciences' Resource and Environmental Science and Data Center (www.resdc). Wetland area data for typical regions were derived from interpretation of US Landsat satellite imagery. Sector-specific data were primarily provided by the Yellow River Conservancy Commission of the Ministry of Water Resources, covering 1980–2019. Given the substantial temporal and spatial span, data preprocessing was necessary, employing linear interpolation, spline interpolation, Lagrange interpolation, and grey prediction methods [?] for gap filling and correction.

Analytical Methods

An entropy weight model was applied to comprehensively evaluate the status of the river-lake eco-environmental system. Through indicator normalization, the study defines the Environment Development Index (EDI) to assess ecological conditions, with calculation methods detailed in previous research [?]. Higher EDI values indicate better eco-environmental quality and more virtuous cycles, while lower values signify poorer conditions and existing problems.

1.2 Evolution Characteristics of River-Lake Eco-Environment

Analysis reveals an overall upward trend in the Yellow River Basin’ s EDI, with a maximum value of 0.77 (2019), minimum of 0.57 (1981), and average of 0.64 (see [Figure 1: see original paper]), indicating improving eco-environmental conditions and a gradual transition from chaotic to stable, ordered development.

[Figure 1: see original paper]

Examination of ecological base flow guarantee rates at key sections (Lanzhou, Huayuankou, and Lijin) from 1980–2019 shows that Lanzhou maintained 100% guarantee rates, demonstrating sufficient ecological water volume upstream to support native fish species. However, Huayuankou and Lijin experienced flow deficits during 1980–2003, with Lijin dropping below 30% in some years. Since 2004, all three major sections have achieved nearly 100% guarantee rates, reflecting systematic improvement in main stream ecological water volume.

[Figure 2: see original paper]

Analysis of habitat quality index changes across the basin and provincial regions indicates overall system stability from 1980–2009, with slow fluctuations (annual change rate <0.1%). This suggests that despite socioeconomic development, urbanization, and agricultural intensification, critical wildlife habitats have been effectively protected and restored. Inner Mongolia exhibited the most significant variation, with initial large fluctuations gradually stabilizing—likely reflecting the effectiveness of systematic projects for returning farmland to forests, grasslands, and wetlands. Henan’ s Yellow River region, primarily within levee-protected floodplains, experienced periodic habitat quality declines but showed an upward trend after 2006, indicating potential for further recovery through comprehensive floodplain enhancement and ecological corridor construction.

[Figure 3: see original paper]

These trends reflect distinct developmental phases. During 1980–1997, post-reform economic growth prioritized GDP expansion through extensive development models, causing ecological degradation and declining EDI values. However, the Three-North Shelterbelt Program (1979) and Yellow River Shelterbelt Program (1984) provided some mitigation. From 2002–2019, economic transformation toward intensive models emphasized ecological protection alongside growth. Mature water resource regulation systems following the Xiaolangdi Reservoir, combined with Loess Plateau soil conservation and pollution control, promoted effective recovery. Nevertheless, challenges persist, including river drying, severe anthropogenic soil erosion, water pollution, and groundwater over-extraction, demanding higher standards for comprehensive recovery.

2. Challenges Facing River-Lake Eco-Environmental Recovery

As China reaches the historic intersection of its “Two Centenary Goals,” the Yellow River Basin’ s ecological protection and high-quality development has been elevated to a major national strategy, presenting both unprecedented opportunities and new demands. The "weak and sickly" Yellow River suffers from poor ecological foundations and limited resource-environment carrying capacity. While historical water security issues remain unresolved, emerging problems are increasingly urgent, creating a severe situation for eco-environmental recovery.

(1) Ecological Fragility as a Critical Weakness

First, the Qinghai-Tibet Plateau' s glaciers, grasslands, and the Three-River-Source and Qilian Mountain regions constitute fragile alpine ecosystems that are prone to degradation and slow to recover. Compared with the 1980s, permanent glacial snow areas in the source region have decreased by 52%, wetlands have shrunk by 20%, and grasslands have reduced by 5.5%, leaving water conservation capacity still inadequate. Second, ecological protection pressure continues mounting, with production water use encroaching on ecological water. Annual ecological water deficits reach approximately 2 billion m^3, particularly affecting tributaries like Fen River, Qin River, Dahei River, and Dawen River. Third, severe pollution persists in tributaries such as Fen River, Yan River, and Jing River, with 11.3% of sections classified as inferior Class V. Additionally, rural water systems face problems of siltation, shrinking water areas, flow interruption, severe pollution, and ecological degradation.

(2) Groundwater Over-Extraction as a Critical Problem

Current water resource development utilization in the Yellow River Basin reaches 80%, far exceeding the 40% ecological warning threshold for typical basins. Thirteen prefecture-level cities (22% of total) suffer from surface water over-extraction, while 62 county-level administrative regions (14% of total) face groundwater over-extraction. The Fenwei Plain still experiences groundwater over-extraction, with shallow groundwater over-extraction reaching 940 million m^3 annually. Compared with the 1980s, river wetland areas in Ningxia-Inner Mongolia reaches, Xiaobeiganliu, and lower reaches have decreased by 30–40%, while the estuary delta' s natural wetlands have shrunk by 50%.

(3) Soil Erosion Control as a Critical Challenge

In 2019, nearly half of the basin' s soil erosion area remained uncontrolled. The 78,600 km^2 of coarse sediment-producing areas face extremely harsh natural conditions, particularly the 18,800 km^2 of concentrated coarse sediment source areas that are exceptionally difficult to manage. Terraces and check dams generally have low construction standards and high risk rates, requiring quality improvement. Meanwhile, anthropogenic soil erosion persists, and monitoring/regulatory capacity needs strengthening. Urbanization, industrialization, and resource development have generated numerous large-scale production projects across extensive areas, creating prominent anthropogenic soil erosion problems that demand expanded monitoring and supervision.

3.1 Objectives for River-Lake Eco-Environmental Recovery

As the world' s most sediment-laden and difficult-to-manage river, the Yellow River historically breached every three years and changed course every century, causing catastrophic disasters. Since 1949, extensive water conservancy construction has continuously improved the eco-environment. However, the basin' s complex natural conditions and unique river characteristics determine the long-term, complex, and arduous nature of its management [?]. Current challenges include ecological fragility, groundwater over-extraction, and soil erosion control. High-quality eco-environment represents the most inclusive public welfare, and in the new development stage, public demand for a healthy environment is increasing. Improving water eco-environmental quality and stability has become core support for maintaining healthy river life, ensuring sustainable river functions, and achieving human-water harmony. Accordingly, three recovery objectives are proposed:

(1) River-Lake Ecological Protection and Management Objective

Water flow is fundamental to river health. Following requirements for reshaping and maintaining healthy river life, ecological flow targets should be determined by zone and category to revive river-lake eco-environments. River-lake spatial control boundaries should be delineated with zoning management for water areas and shorelines. River-lake space belt restoration should be implemented to create green ecological corridors along rivers and lakes.

(2) Groundwater Over-Extraction Control Objective

Based on determined control indicators for groundwater extraction volume and water levels, development intensity should be strictly controlled to reduce over-extraction. Multi-source water replacement measures should enable groundwater recharge in overloaded areas, gradually achieving balance between extraction and replenishment.

(3) Comprehensive Soil Erosion Control Objective

Focusing on the upper and middle reaches, construction of terraces, check dams, and gully control projects should enhance control benefits. Using the goals of green mountains, clean water, and beautiful villages, small watershed construction through gully control, water conservation, and ecological restoration should effectively eliminate anthropogenic soil erosion in these regions.

3.2 Overall Pattern for River-Lake Eco-Environmental Recovery

Following ecological priority, comprehensive governance, basin coordination, and collaborative sharing principles, relationships between main and tributary streams, upstream-downstream, and left-right banks should be coordinated. Based on integrated basin-region, water-land, and resource-environment approaches, a "Three Zones and One Corridor" pattern should be constructed to achieve main-tributary coordination, human-water harmony, and healthy rivers-lakes for comprehensive recovery.

The "Three Zones" comprise: (1) water source conservation zones centered on the Three-River-Source, Ruoergai, Gannan, Qilian Mountains, Qinling, and Liupan Mountains; (2) soil conservation zones focused on the Loess Plateau in eastern Qinghai, Longzhong-Longdong, northern Shaanxi, northwestern Shanxi, and southern Ningxia; and (3) wetland protection zones centered on important wetlands like the Yellow River estuary. The "One Corridor" consists of the main Yellow River stream and major tributaries including Huangshui, Daxia, Tao, Wuding, Wei, Fen, Yiluo, Qin, Jindi, and Dawen Rivers, forming a vertically integrated ecological corridor.

4. Strategic Approaches for River-Lake Eco-Environmental Recovery

Targeting enhanced protection and management of rivers-lakes, groundwater over-extraction control, and comprehensive soil erosion management, these approaches coordinate water quantity, quality, and ecology across upstream-downstream, left-right banks, and water-land interfaces. They strengthen river-lake spatial control, implement ecological protection and restoration, advance water environment prevention and control, ensure water quality standards, and continuously improve eco-environmental conditions.

4.1 Strengthening River-Lake Supervision

(1) Enhancing River-Lake Water Area Protection and Supervision

River-lake water spaces should be delineated targeting flood control, water supply, and ecological security. Management boundaries for flood storage areas, drinking water sources, and water conservation/soil erosion prevention zones should be established, reserving necessary space and corridors for water infrastructure. Functional positioning and uses of different water spaces should be defined with clear management boundaries, units, and requirements. Coordination with territorial spatial planning should ensure integration into the unified territorial spatial information platform and planning map.

River-lake shoreline control should be strengthened through planning constraints. Shoreline protection and utilization plans should designate protection zones, preservation zones, controlled utilization zones, and development zones with strict zoning management and use regulation. River-related construction permits should be strictly regulated with enhanced supervision.

(2) Strengthening Ecological Flow Regulation

Ecological flow guarantee schemes should be formulated with clear measures and responsible entities, strengthened water quantity regulation, and total water use control. Important tributary ecological flow regulation schemes should be developed with tailored measures to guarantee basic ecological flows. Monitoring and early warning systems for main and tributary streams should be established with improved monitoring facilities. The Ministry of Water Resources should determine early warning levels and thresholds based on ecological flow targets and release timely warnings. Monitoring stations at important control sections should be enhanced, with ecological flow discharge facilities and online monitoring installed at hydropower stations. Existing water projects should be ecologically retrofitted with necessary monitoring facilities to improve the supervision system.

4.2 Enhancing River Ecological Corridor Functions

(1) Strengthening Main Stream Ecological Corridor Protection

In the upper reaches, deep water-saving and control actions should be implemented in Ningxia-Inner Mongolia irrigation districts, optimizing cascade reservoir operations to improve ecological flow guarantee rates at important sections. Groundwater levels should be reasonably controlled to maintain oasis ecological balance in arid northwest regions. In the middle reaches, unified water quantity regulation should be strengthened, leveraging the Guxian Water Control Project' s flow regulation to guarantee basic ecological flows at the Tongguan section. Fish spawning ground restoration should be promoted with fishing moratoriums and appropriate fish stocking. Ecological 航道 construction, natural shoreline protection, and creation of deep pools and shallow beaches should provide diverse habitats. Unified regulation of key reservoirs should guarantee basic ecological flows and water volumes reaching the sea. Flexible river training projects and other eco-friendly engineering pilots should be promoted, with ecological shelterbelt construction along both banks for soil conservation, windbreak, sand fixation, and embankment reinforcement.

(2) Constructing Important Tributary Ecological Corridors

Water resource allocation in tributaries should be optimized to gradually return encroached ecological water and reverse flow interruption in tributaries like Fen, Qin, and Dawen Rivers. Basic ecological flows should be guaranteed at control sections of tributaries including Huangshui, Datong, Tao, Wuding, Wei, and Yiluo Rivers. Protection should be enhanced in source area tributaries and sections important for native fish habitats, such as Huangshui above Duoba, upper-middle Datong River, upper Tao River, and middle-lower Yiluo River. Excessive small hydropower development should be rectified in national parks, important water source areas, and rare species habitats. Damaged fish habitats should be restored with appropriate fish passage facilities. River sand mining should be strictly regulated, illegal excavation severely cracked down upon, and unreasonable activities like waste dumping, reclamation, and mining prohibited. Comprehensive measures including riparian vegetation restoration, habitat rehabilitation, and water environment protection should restore river connectivity and enhance corridor functions.

(3) Strengthening Important Lake Protection and Restoration

For lakes like Ulansuhai and Shahu, surrounding agricultural non-point source pollution should be controlled at the source to improve water quality. Lake shore ecological protection and restoration should improve surrounding environments with emergency ecological water replenishment to control human impacts and restore ecological functions. In the Hongjiannao Basin, water resource allocation should be optimized to guarantee inflow volumes, implement emergency replenishment, protect important habitats like those of relict gulls, and implement comprehensive ecological management through enclosure protection and vegetation restoration. Dongping Lake comprehensive improvement should implement ecological protection and restoration measures while ensuring flood safety downstream, improving water environment and biodiversity through pollution control, habitat reconstruction, and protection.

4.3 Implementing Groundwater Over-Extraction Control and Supervision

(1) Conducting Groundwater Over-Extraction Control

Following the principle of gradually reducing over-extraction to achieve balance, comprehensive control actions should be implemented. Focusing on over-extraction areas including Ordos Plateau, Fenwei Valley, lower Qin River, and Yellow River irrigation districts, control and protection plans should be formulated. Water saving, irrigation area reduction, water source replacement, and well shutdown measures should accelerate pressure reduction, with strict dual control of groundwater quantity and level to gradually achieve extraction-recharge balance.

(2) Strengthening Groundwater Supervision

At the county level, management indicators should be established for groundwater metering rates, monitoring well density, and irrigation well density. Dual control of quantity and level should be implemented, with supervision strengthened in overloaded administrative regions and new water permits suspended. Groundwater level observation should be enhanced in Ningxia reaches, Xiaobeiganliu, Sanmenxia-Xiaolangdi interval, and tributaries like Huangshui, Fen, and Qin Rivers to control extraction and maintain reasonable levels with strict management of restricted/forbidden extraction zones. Joint prevention and control should be strengthened in key over-extraction areas of Shanxi, Shaanxi, and Henan. Systematic evaluation of over-extraction areas, supervision of control effectiveness, and dynamic assessment should be conducted, leveraging the national groundwater monitoring project to improve monitoring and metering systems, establish early warning mechanisms and supervision platforms, and create national-basin-provincial monitoring information sharing mechanisms.

4.4 Intensifying Loess Plateau Soil Erosion Control

(1) Vigorously Developing Check Dam Construction

Focusing on Shanxi, Shaanxi, Inner Mongolia, and Gansu, check dam construction should be vigorously implemented in loess hilly-gully regions with active gully development, severe gravity erosion, and intense soil erosion. Standardized guidance should promote new standards, technologies, and processes to build high-standard, high-quality check dams. In nine major tributaries including Huangfuchuan, Qingshuichuan, Gushanchuan, Kuye River, Tuwei River, Jialu River, Wuding River, Qingjian River, and Yan River, priority should be given to constructing sediment interception projects in concentrated coarse sediment source areas to raise gully erosion base levels and consolidate soil. Risk 隐患排查 of existing check dams should be intensified, with reinforcement of dangerous dams and upgrading of old dams to fully exploit their sediment reduction benefits.

(2) Promoting High-Quality Dry-Farming Terraces

Focusing on hilly-gully regions in Shaanxi, Gansu, Shanxi, and Ningxia, high-standard dry-farming terraces should be constructed on sloping farmland (5–15°) that is near villages and roads, concentrated, and currently cultivated, particularly in areas with precipitation above 300 mm. New dry-farming technologies and models should be promoted to develop high-value-added crops. Rainwater harvesting technologies should be widely applied with supporting facilities including field roads, drainage ditches, water cellars, and reservoirs. Narrow, poorly equipped old terraces with low yields should be upgraded. Planned conversion of sloping farmland to forests and grasslands should proceed in conjunction with rural population transfer and ecological migration policies.

(3) Implementing Vegetation Protection and Restoration According to Local Conditions

Following Loess Plateau vegetation zone distribution patterns and the principle of appropriate tree-planting or grass-planting, artificial afforestation, aerial seeding, and other measures should be implemented. In arid areas below 200 mm precipitation (southern Yinshan, eastern Helan Mountain), grass planting, grassland improvement, and enclosure protection should dominate. In semi-arid areas with 200–400 mm precipitation (Ordos Plateau), shrubs and grasses with enclosure protection should be primary, with trees planted in gullies or better-watered areas. In semi-humid areas above 400 mm precipitation, combinations of trees, shrubs, and grasses should be implemented, reducing human disturbance in ecologically fragile areas. Appropriate species should be scientifically selected based on landforms, soils, climate, and technical conditions to improve forest structure and increase survival rates. Economic forests and understory economies should be moderately developed to improve ecological and economic benefits. In the feldspathic sandstone areas of Shanxi-Shaanxi-Inner Mongolia, seabuckthorn ecological construction combined with check dams and other sediment interception projects should control soil erosion, reduce sediment inflow, and improve environments while promoting regional development and poverty alleviation.

(4) Advancing Gully Consolidation and Plateau Preservation Projects

Focusing on plateau areas including Dongzhi Plateau in eastern Gansu, Taide Plateau in western Shanxi, Luochuan Plateau in northern Shaanxi, and Weibei Platform in Guanzhong, the principle of "preserving plateaus by consolidating gullies and sustaining plateaus through gullies" should guide implementation. Four defense lines should be constructed: plateau surface, gully head, gully slope, and gully channel. On plateau surfaces, terraces should be built with economic plants on ridges and small/medium rainwater harvesting and runoff regulation systems. Gully heads should have protection works and ponds. Gully slopes should have terraced fields and economic forests in upper sections and soil conservation forests in lower sections. Gully channels should have check dams, weirs, and erosion-control forests to reduce gravity erosion.

Making the Yellow River "a happy river that benefits the people" represents the ultimate goal of eco-environmental recovery. River and lake ecological recovery should be integrated into happy river construction featuring quality water resources, healthy aquatic ecosystems, and livable water environments, meeting public expectations for ecological protection and high-quality development.

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ZHANG Jinliang: Conceptualization, methodology design, experimentation, data collection/cleaning/analysis, original draft preparation, and final manuscript revision.

Note: Figure translations are in progress. See original paper for figures.