Postprint: Ecological Protection Benefit Assessment of the Huangshui River Basin Based on Ecological Assets

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Abstract

Ecological assets are ecosystems capable of delivering benefits and services to humanity, and assessing changes in ecological assets can objectively reveal the effectiveness of ecological conservation. The Huangshui River Basin, located in the transition zone between the Qinghai-Tibet Plateau and the Loess Plateau, features a fragile and sensitive ecological environment with intense human activity, and has served as a key region for implementing ecological conservation policies and projects since the 21st century. This study accounts for the stock and flow of ecological assets in the Huangshui River Basin, comprehensively analyzing the characteristics and changes of basin-wide ecological assets to investigate the benefits of ecological conservation. The results demonstrate that: (1) In 2020, the comprehensive ecological assets index for the Huangshui River Basin was 30.98, exceeding the average level of Qinghai Province, with the flow value of ecological assets reaching 1.07$×10^{11}$ yuan; from 2000 to 2020, the overall quality of ecological assets improved, with the flow value increasing by 343.11%. (2) Socioeconomic factors exert substantial influence on ecological asset gains. (3) Ecological assets within the basin have steadily improved, and ecological conservation and restoration have achieved certain effectiveness; however, spatial differentiation of ecological assets remains significant, and pressure on local ecological conservation is still considerable. This research is of great significance for understanding the ecological condition of the Huangshui River Basin and guiding ecological asset protection.

Full Text

Assessment of Ecological Protection Benefits in the Huangshui River Basin Based on Ecological Assets

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Abstract

Ecological assets are ecosystems that provide benefits and services to human society. Assessing changes in ecological assets can objectively reveal the effectiveness of ecological protection efforts. The Huangshui River Basin, located in the transition zone between the Qinghai-Tibet Plateau and the Loess Plateau, features a fragile and sensitive ecological environment with intense human activity, making it a key region for implementing ecological protection policies and projects since the turn of the 21st century. This study comprehensively analyzes the characteristics and spatiotemporal dynamics of ecological assets in the basin by accounting for both the stock and flow of ecological assets, and evaluates the benefits of ecological protection efforts. The results indicate that: (1) In 2020, the comprehensive index of ecological assets in the Huangshui River Basin reached 30.98, showing a distribution pattern of low values in the southeastern plains and high values in the northwestern mountains. From 2000 to 2020, the comprehensive index increased by 6.71%, indicating overall improvement in ecological asset quality. (2) The flow value of ecological assets in 2020 was approximately 107.374 billion yuan, with regulation services accounting for 69.50% of the total. Over the past two decades, ecological assets increased by 83.116 billion yuan, representing a gain of 342.65%, with regulating services contributing 57.123 billion yuan. Grassland ecological assets contributed most significantly to the flow value, which was also influenced by the quality of asset stocks. (3) Socioeconomic factors (average contribution of 12.95%) exerted greater influence on ecological asset gains than natural factors (average contribution of 10.52%), with notable spatial variation in driving forces. (4) Ecological assets in the basin have improved steadily, demonstrating the effectiveness of ecological protection and restoration efforts. However, significant spatial heterogeneity persists, and local areas still face considerable ecological protection pressure due to constraints from natural conditions and imbalanced economic development. This study provides important insights for understanding the ecological status of the Huangshui River Basin and guiding ecological asset protection efforts.

Keywords: ecological assets; profit and loss of ecological assets; ecological protection benefits; Huangshui River Basin

Introduction

Ecosystems provide essential material products for human life and play a dominant role in regulating the natural environment. Ecological assets are defined as ecosystems that bring benefits to humans within specific temporal and spatial scales under given technical and economic conditions, encompassing both natural capital as stock and ecosystem service value as flow. Previous studies have employed equivalent factor methods to assess ecological asset flows in different regions and ecosystem types, and have conducted stock assessments in areas such as Inner Mongolia and Shannan City, demonstrating the widespread application of ecological assets as an indicator for evaluating ecological conditions and protection benefits. However, a unified standard for ecological asset accounting has yet to be established, and few studies have simultaneously assessed both stock and flow, particularly at the grid scale needed to capture spatial heterogeneity in asset quality and profit-loss dynamics.

The Huangshui River Basin, as the largest tributary of the upper Yellow River, occupies a critical ecological position in the transition zone between the Qinghai-Tibet Plateau and the Loess Plateau. It constitutes an important component of the ecological security barrier in the upper Yellow River region, represents a zone sensitive to global climate change, and serves as the political and economic center of Qinghai Province. The basin concentrates nearly 60% of the province' s population and accounts for approximately 52% of its total industrial and agricultural output, creating substantial ecological pressure. Consequently, it has become a focal area for implementing various ecological protection policies and projects at both national and local levels, with intensified efforts toward integrated protection of mountains, rivers, forests, farmlands, lakes, grasslands, and deserts in recent years. While existing research has examined ecosystem service supply-demand relationships and assessed ecosystem service values in the basin, few studies have integrated both stock and flow perspectives to evaluate ecological protection benefits.

This study addresses this gap by accounting for ecological asset stock and flow at the grid scale in the Huangshui River Basin, analyzing spatiotemporal dynamics and driving factors of asset profit and loss, and assessing ecological protection benefits. The findings provide a reference for evaluating the effectiveness of ecological protection and restoration efforts and offer scientific guidance for future conservation initiatives.

1.1 Study Area

The Huangshui River Basin is located in eastern Qinghai Province, characterized by complex terrain that is wider in the east and narrower in the west, dominated by loess hills and gully landforms. The region has a temperate continental climate with an average annual temperature of 0.6–7.9°C and average annual precipitation of 300–500 mm. The basin includes the main Huangshui River channel flowing from northwest to southeast through Tianjun, Gangcha,

Menyuan, Qilian, Haiyan, Huangyuan, Xining, Huzhu, Ping' an, Ledu, and Minhe counties. In 2020, ecological asset types in the basin included forest, shrubland, grassland, river, farmland, construction land, wetland, glacier/snow cover, and bare land (Fig. 1).

1.2 Data Sources

Land cover data were obtained from the annual land cover dataset (http://doi.org/10.5281/zenodo.4417809). Aboveground biomass, elevation, slope, soil texture, nighttime light, and road network data were sourced from the Resource and Environment Science and Data Center (https://www.resdc.cn/). Precipitation and temperature data came from the National Earth System Science Data Center (http://www.geodata.cn/). Evapotranspiration data were derived from the GLEAM v3 dataset via the Three Poles Environment Big Data Platform (http://www.gleam.eu/). Soil organic matter data were obtained from the Spatiotemporal Ternary Environment Big Data Platform (http://poles.tpdc.ac.cn/zh-hans/). Net Primary Production (NPP) data were based on MOD17A3HGF Version 006 from NASA' s LP DAAC (https://lpdaac.usgs.gov/products/mod17a3hgfv006/). Carbon density data were derived from the China Terrestrial Ecosystem Carbon Density Dataset for the 2010s (http://nesdc.org.cn/sdo/detail?id=5fa53685042ebb70d0c8340b). Remote sensing vegetation indices such as vegetation cover fraction were calculated from Landsat imagery after atmospheric correction during the growing season. Water quality data were obtained from the Qinghai Province Water Resources Bulletin. Socioeconomic data were sourced from the China County Statistical Yearbook, Qinghai Province Statistical Yearbook, and National Agricultural Product Cost-Benefit Data Compilation.

1.3.1 Ecological Asset Stock Assessment

To accurately reflect changes in ecological asset stock, we employed the ecological asset comprehensive index as an indicator, accounting for both area and quality aspects:

$$EQ_i = \sum_{j=1}^{n} (EA_{ij} \times EA_i \times 5)$$

where EQ represents the regional ecological asset comprehensive index; EQ_i is the comprehensive index for the ith ecological asset type; i denotes ecological asset type; j is the quality grade index; n is the number of ecosystem types; EA_{ij} is the area of the ith ecological asset at the jth quality grade; and EA_i is the total area of the ith ecological asset type.

Based on the study area' s characteristics, we selected relative biomass density, vegetation coverage, and slope as evaluation indicators for ecological asset quality (Table 1).

1.3.2 Ecological Asset Flow Valuation

Building upon the national ecosystem service value equivalent factor table developed by Xie et al., we constructed a unit-area equivalent factor table for the Huangshui River Basin from 2000 to 2020 (Table 2) using adjustment factors for NPP, water yield, and soil conservation. The value of one standard equivalent factor was based on the economic value per unit area of three major grain crops. Soil conservation quantity was calculated using the Revised Universal Soil Loss Equation (RUSLE):

$$E = R \times K \times LS \times (1 - C \times P)$$

where E is the unit-area soil conservation quantity ($t \cdot hm^{-2} \cdot a^{-1}$); R is the rainfall erosivity factor ($MJ \cdot mm \cdot hm^{-2} \cdot h^{-1} \cdot a^{-1}$); K is soil erodibility factor; LS is the slope length and steepness factor; C is the vegetation cover factor; and P is the soil conservation practice factor. Water yield was characterized as the difference between water input and output, calculated as precipitation minus evapotranspiration.

1.3.3 Analysis of Ecological Asset Profit-Loss and Driving Factors

Ecological asset profit-loss refers to the reduction or increase in flow value during the accounting period. Based on the study area' s conditions, we selected precipitation, temperature, population, nighttime light, carbon storage, habitat quality, elevation, and slope as potential driving factors. Pearson correlation analysis identified the main factors causing ecological asset changes, while geographical detector analysis revealed the relative contribution of each factor. Carbon storage was estimated using geographically weighted regression models relating field survey data to multiple remote sensing vegetation indices. Habitat quality was calculated using the InVEST model' s habitat quality module, which establishes relationships between land use and stressors such as roads.

2.1 Spatiotemporal Variation in Ecological Asset Stock

In 2020, the ecological asset comprehensive index for the Huangshui River Basin was 30.98, with stock showing an overall distribution pattern of low values in the southeastern plains and high values in the northwestern mountains (Fig. 2). High-value areas were dominated by grassland, while low-value areas were primarily farmland. From 2000 to 2020, the ecological asset comprehensive index increased by 6.71% due to significant increases in forest, grassland, and river area and quality, with notable stock growth occurring in the eastern part of the basin.

2.2 Spatial Variation in Ecological Asset Flow Value

The flow value of ecological assets in the Huangshui River Basin reached 107.374 billion yuan in 2020, with a unit-area value of 326.36$\times$10^{4}$ yuan $\cdot$ km^{-2}.

High values were mainly distributed in grasslands and forests around the basin periphery, while low values concentrated in the central and eastern urban and agricultural areas. Regulation services dominated the flow value, accounting for 69.50% of the total, with grassland ecological assets contributing the highest proportion at 56.07%.

2.3 Ecological Asset Profit-Loss and Driving Factors

From 2000 to 2020, ecological asset flow values in the Huangshui River Basin showed overall gains, increasing by 83.116 billion yuan (a 342.65% increase). River and grassland ecological assets exhibited the most significant value growth, with regulating services increasing by 57.123 billion yuan and supporting services increasing by 23.658 billion yuan. Analysis of driving factors revealed significant correlations for all factors except carbon storage (Fig. 7). Socioeconomic factors (average contribution of 12.95%) demonstrated greater influence on ecological asset gains than natural factors (average contribution of 10.52%), particularly affecting rivers, wetlands, forests, and shrublands. The influence of driving factors showed marked spatial variation across the basin.

Discussion

The ecological asset comprehensive index for the Huangshui River Basin (30.98) is higher than the average for Qinghai Province, primarily because this study included rivers and farmland in the assessment system, whereas previous provincial assessments did not. The unit-area flow value (326.36$\times$10^{4}$ yuan$\cdot$km^{-2}) is lower than that of the Qinghai section of the Yellow River Basin (805.2–999.15$\times$10^{4}$ yuan$\cdot$km^{-2}), mainly due to methodological differences. While the Yellow River study used a fixed standard unit value based on Gross Ecosystem Product accounting, our study referenced grain production benefits for the corresponding years, resulting in different standard values.

Ecological asset changes directly reflect regional ecological protection outcomes. The Huangshui River Basin has continuously implemented ecological restoration projects, including the Huangshui River Ecological Restoration and Management Project and the Grain for Green Program. Previous research indicates that large-scale ecological protection projects have increased ecological asset stock and improved quality, with flow values showing sustained growth. Grasslands and forests have gradually recovered under the combined effects of natural and socioeconomic factors, demonstrating the effectiveness of regional ecological protection efforts. Our findings confirm these conclusions.

Over the past two decades, ecological protection effectiveness has become evident across all counties in the basin (Table 3), with per-unit-area flow value growth exceeding 100$\times$10^{4}$ yuan$\cdot$km^{-2} in most counties. Growth was particularly notable in Xining' s urban area and the northwestern part of the basin, mainly due to forest and grassland recovery, confirming that these ecosystems are critical for watershed protection. However, counties in the central and east-

ern basin, including Minhe, Huzhu, Datong, Huangzhong, Ledu, and Ping' an, show relatively lower per-unit-area flow value growth despite successful grassland and forest restoration, due to extensive agricultural development. These areas should strictly adhere to farmland protection policies, convert slope farmlands unsuitable for agriculture back to forest and grassland, and enhance river and wetland conservation.

The driving influence on ecological asset profit-loss varies significantly across space. Per capita GDP and per capita ecological asset flow value increased by 1004.26% and 953.28%, respectively, while per-unit-area flow value grew by only 285.11% and per capita flow value by 16.06%. This indicates that although ecological assets have increased substantially, their growth lags behind socioeconomic development, creating an imbalance between ecological assets and economic growth with significant spatial differentiation. Local ecological protection benefits cannot keep pace with economic development speeds.

This study accounts for ecological asset stock and flow at the grid scale, achieving comprehensive quantification of ecological assets and enhancing result reliability. The findings have important applications for evaluating regional ecological protection effectiveness and provide scientific guidance for watershed ecological restoration and management, offering methodological references for other regions. However, due to data limitations, the study only considered major ecological assets such as forests, grasslands, and rivers, assessed river ecological asset quality using only monitoring section data, and did not account for crop productivity in farmland ecological assets. These limitations should be addressed in future research.

Conclusions

Based on the accounting of ecological asset stock and flow in the Huangshui River Basin, this study reveals the status of ecological benefits and evaluates the effectiveness of ecological protection efforts. The main conclusions are:

1) **Stock perspective**: In 2020, the ecological asset comprehensive index for the Huangshui River Basin was 30.98, showing a spatial distribution pattern of low values in the southeastern plains and high values in the northwestern mountains, with grassland as the dominant ecological asset type. From 2000 to 2020, the comprehensive index increased by 6.71%, indicating overall improvement in ecological asset quality.

2) **Flow perspective**: In 2020, the ecological asset flow value was approximately 107.374 billion yuan, with regulation services accounting for 69.50%. Over the past 20 years, ecological assets showed net gains of 83.116 billion yuan, with river ecosystem service values increasing by 17.608 billion yuan and regulation service values increasing by 57.123 billion yuan.

3) **Driving factors**: Socioeconomic factors (average contribution of 12.95%)

exerted greater influence on ecological asset gains than natural factors (average contribution of 10.52%), with significant spatial variation in driving influences.

4) **Overall assessment**: The series of ecological protection measures and policies implemented in the Huangshui River Basin have achieved considerable success, effectively protecting vegetation and water resources, improving the ecological environment, and enhancing the overall ecological asset status of the basin. However, due to natural constraints and imbalanced economic development, some areas still face significant ecological protection pressure. Future efforts should implement zoned ecological protection and compensation policies, strengthen compensation policies in counties such as Tianjun, Qilian, and Gangcha, and enhance ecological protection efforts in urban construction areas including Xining, Ping' an, and Ledu districts.

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