Postprint: Assessment of Ecological-Economic Coordination and Sustainable Development Zoning at the County Level in Southern Xinjiang

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Abstract

Based on the equivalent factor method, the ecosystem services value (ESV) of the Southern Xinjiang region from 2000 to 2020 was estimated, the Ecological-economic harmony (EEH) model was applied to analyze the coordination level of ecological-economic development and its spatial distribution characteristics at the county scale, and finally, the ecological contribution rate model was used to reveal the main contributing factors to ESV changes in each county, and differentiated sustainable development zoning was conducted based on their ESV gain/loss status and ecological-economic coordination level. The results show that: (1) From 2000 to 2020, the overall ESV of the Southern Xinjiang region exhibited a trend of first increasing and then decreasing, with a total reduction of 167.99$×$10ˆ8 yuan; the ESV of grassland and water bodies accounted for more than 70% of the total; among individual ESVs, regulating services (57.1%) > supporting services (27.5%) > cultural services (10.0%) > provisioning services (5.4%); grassland and cropland were the dominant land types in most counties where ESV gains (or losses) were realized. (2) From 2000 to 2020, ESV in 37 counties of the Southern Xinjiang region experienced varying degrees of loss, while a total of 9 counties achieved ESV gains; approximately 80% of the counties were initial ecological-economic deterioration zones, while the remaining counties exhibited an ecological-economic coordinated and stable state. (3) The Southern Xinjiang region as a whole exhibited a mild ecological-economic disharmony state, with a few ecological-economic coordinated and stable counties mainly distributed in the central and eastern parts of Southern Xinjiang. Comprehensive analysis divided the counties of Southern Xinjiang into five types: forest-grassland ecological-economic unsustainable zones, cropland ecological-economic unsustainable zones, water body ecological-economic unsustainable zones, forest-grassland ecological-economic sustainable and stable zones, and cropland ecological-economic sustainable and stable zones.

Full Text

Introduction

In recent years, Xinjiang has achieved remarkable economic progress. However, rapid socioeconomic development has generated negative environmental impacts, including air pollution, ecological degradation, and excessive carbon emissions. In response, the government has proposed high-quality development goals that aim to balance economic growth with human welfare and ecological health. Against this backdrop, investigating the coordination between regional economic systems and ecological environments, and subsequently exploring sustainable development zoning, holds significant academic and practical importance.

Ecological-economic coordination represents a development state in which the internal elements of ecological and economic subsystems cooperate and promote each other during regional development, while maintaining a mutually beneficial symbiotic relationship between the two subsystems, thereby continuously improving overall regional welfare. Establishing a long-term mechanism for coordinated development between ecological civilization and economic construction constitutes the core of sustainable development. Current research on ecological-economic coordination primarily focuses on three aspects: (1) evaluation studies that construct indicator systems through integrated utility functions and comprehensive assessment methods to explore coordination degrees, internal relationships, and spatial evolution patterns; (2) empirical studies employing various scientific models for regional characterization and quantitative analysis; and (3) derivative studies including scenario simulation and forecasting analyses that examine coordination or coupling dynamics between industries (industrial, agricultural, tourism) and ecological environments.

Ecosystem Service Value (ESV) evaluates the capacity of regional ecosystems to serve human needs. ESV assessment not only provides a foundation for regional ecological environment evaluation but also facilitates better decision-making in situations involving trade-offs. The equivalent factor method expresses ESV in monetary terms, offering strong comparability with Gross Domestic Product (GDP). Consequently, scholars have constructed the Ecological-Economic Harmony (EEH) model using the ratio of ESV change rate per unit area to GDP change rate per unit area, which effectively reflects the degree of mutual influence, constraint, or synergy between ecological environmental changes and economic development.

Previous ESV applications have primarily focused on determining regional ecological-economic relationships, analyzing their causes, driving forces, or causal disturbances, with hotspot regions concentrated in ecologically asset-rich areas, key watersheds, economic zones, and cities of specific scales. Southern Xinjiang serves as a crucial gateway for China's westward opening and an important node in the ecological barrier of the "Silk Road Economic Belt." Characterized as a typical inland arid region, it suffers from severe desertification, weak ecological carrying capacity, and lagging socioeconomic development. Implementing the "Two Mountains" transformation, resolving increasingly prominent contradictions between social development and ecological environmental protection, and achieving regional sustainable development remain urgent challenges.

Comprehensive analysis reveals that research on ecological-economic coordination in southern Xinjiang remains relatively scarce, particularly lacking county-level studies that integrate ESV profit/loss status and ecological-economic coordination levels for sustainable development zoning of ecological-natural complex systems. Therefore, this study employs the equivalent factor method to calculate ESV, applying regional difference coefficients and social development correction factors for refinement, to analyze regional ESV status and environmental change characteristics at the county scale. The EEH model is then used to investigate the coordination state between economic development and ecological environment at the county level. Finally, an ecological contribution rate model identifies dominant factors influencing county-level ESV changes, which, combined with county ESV profit/loss status and ecological-economic coordination levels, enables differentiated sustainable development zoning based on land type carriers, providing quantitative references and scientific support for decision-makers implementing green sustainable development planning and management.

1.1 Study Area

Southern Xinjiang refers to the region south of the Tianshan Mountains in Xinjiang Uygur Autonomous Region, encompassing China's largest basin (Tarim Basin), largest desert (Taklamakan Desert), and longest inland river (Tarim River) [Figure 1: see original paper]. Administratively, it includes Bayingolin Mongol Autonomous Prefecture, Kizilsu Kirghiz Autonomous Prefecture, Hotan Prefecture, Aksu Prefecture, Kashgar Prefecture, and four cities managed by the Xinjiang Production and Construction Corps (Alar, Tiemenguan, Kunyu, and Tumushuke, hereafter classified as counties), covering a total area of 1.06×10^{6} km^2 (63.67% of Xinjiang's total area). The oasis area spans 4.27×10^{4} km^2, while snow-covered regions and desert areas perennially occupy over 90% of the total regional area. Situated deep inland with oceanic airflows blocked by high mountains, the region features a typical temperate continental arid climate with long, cold winters and dry, rainless summers. Annual average precipitation ranges from 17.4 to 42.8 mm, exhibiting extreme spatial heterogeneity. The fragile ecological environment, combined with human activity interference, imposes a heavy load on ecological carrying capacity, making high-quality green sustainable development imperative.

1.2 Data Sources and Processing

The required data primarily include: (1) Land use data comprising five periods from 2000 to 2020, sourced from the Resource and Environmental Science Data

Center of the Chinese Academy of Sciences (https://www.resdc.cn/). Based on Landsat imagery as the primary information source, data were obtained through manual visual interpretation with accuracy exceeding 90%. The dataset classifies land use into 6 primary categories and 25 secondary categories. ArcMap extraction tools were used to extract study area data, and reclassification tools merged the initial secondary categories into the required primary categories: cropland, forestland, grassland, water bodies, construction land, and unused land. (2) Statistical data: grain cultivation area, yield data, Engel coefficients, and population data were obtained from the Xinjiang Statistical Yearbook, Xinjiang Production and Construction Corps Statistical Yearbook, and China Statistical Yearbook for corresponding years. Xinjiang grain market price data were sourced from the National Agricultural Product Cost-Benefit Data Compilation for corresponding years. Meteorological data were obtained from the China Meteorological Yearbook for corresponding years.

1.3.1 Ecosystem Service Value Accounting

This study employs the equivalent factor method to calculate ESV in southern Xinjiang, referencing Xie Gaodi's research results from 2015, which achieved the highest survey response rate and demonstrates strong scientific credibility. In this method, the economic value of one ecosystem service equivalent factor equals 1/7 of the market price of average grain yield per unit area. The formula is:

$$ESV_y = \sum_i A_i \times E_{ij} \times F_a \times N \times Q_y$$

where A_i represents the area of land use type i (hm^2); E_{ij} denotes the equivalent coefficient for ecosystem service function j of land use type i; N is the regional difference correction coefficient; Q_y is the social development correction coefficient for year y; and F_a is the economic value of one equivalent factor.

The regional social development coefficient l' is calculated as:

$$l' = \frac{1}{1 + e^{-(l-3)}}$$

where l represents the social development coefficient, calculated as:

$$l = L \times (W_1 \times l_1 + W_2 \times l_2)$$

Here, l_1 and l_2 are urban and rural social development coefficients, respectively; W_1 and W_2 are urban and rural population proportions; and L is the willingness to pay under affluent conditions (typically valued at 2). Considering crop cultivation conditions in southern Xinjiang, three staple food crops (corn, wheat, and rice) were selected for calculating sowing area and unit yield. The economic value of one equivalent factor was determined to be 6216.3 kg · hm^{-2} based on average grain prices in Xinjiang from 2000 to 2020.

Different regions exhibit variations in ecological environment, biodiversity, and willingness to pay for ecosystem functions due to socioeconomic level differences. Therefore, this study adopts the regional difference correction coefficient using net primary productivity to replace biomass, as used by Liu Qian et al. in their study of Qinglong County, along with the social development correction coefficient based on traditional economic theory. The calculated regional difference coefficient for southern Xinjiang is 0.405, and annual social development correction coefficients are presented in Table 1 .

The sensitivity index, commonly used in economics to calculate elasticity coefficients, assesses ESV accuracy and dependence on equivalent factors. The formula is:

$$C = \left| \frac{(ESV_j - ESV_i)/ESV_i}{(E_{kj} - E_{ki})/E_{ki}} \right|$$

where C is the sensitivity index; ESV_j and ESV_i are adjusted and original ESV values, respectively; and E_{kj} and E_{ki} are adjusted and original equivalent coefficients for land use type k.

1.3.3 Ecological-Economic Harmony Analysis

Currently, no unified standard exists for coordinated development between ecological and economic systems, making EEH a relative indicator that quantitatively reflects coordination between regional ecological conditions and economic development. This study analyzes the ratio of county-level ESV change rate per unit area to GDP change rate per unit area, which demonstrates the degree of interaction, constraint, and influence between environmental changes and economic development. The formula is:

$$EEH = \frac{(ESV_{td} - ESV_{tc})/ESV_{tc}}{(GDP_{td} - GDP_{tc})/GDP_{tc}}$$

where EEH represents ecological-economic harmony degree; ESV_{tc} and ESV_{td} are initial and final ESV values per unit area; and GDP_{tc} and GDP_{td} are initial and final GDP values per unit area. Since EEH reflects regional economic development and ecological environment evolution trends, calculation results are classified into five types based on realistic conditions (Table 2).

1.3.5 Sustainable Development Zoning in Southern Xinjiang Counties

Based on the impact degree of various land types on ESV changes and their proportional contributions, the ecological contribution rate model reveals dominant factors affecting regional ESV changes. A land type with contribution rate exceeding 50% is identified as the dominant factor causing ESV gain (loss) in a county. The formula is:

$$CR = \frac{EA_{ib} - EA_{ia}}{EA_b - EA_a} \times 100\%$$

where CR is the contribution rate of each land type to total ESV change; EA_{ia} and EA_{ib} are initial and final ESV values for land type i; and EA_a and EA_b are initial and final total ESV values for the region.

Combining county ESV profit/loss status and ecological-economic coordination levels, southern Xinjiang counties are differentiated into sustainable development zones based on land type carriers. The zoning yields five types formed by combining four land type categories (forest, water, grassland, cropland) with two ecological-economic coordination states (Table 3).

Results

2.1 ESV Accounting and Change Analysis in Southern Xinjiang

From 2000 to 2020, southern Xinjiang's total ESV initially increased then decreased, with an overall reduction of 167.99$\times10^{8}$ Yuan. The period 2000–2015 was a growth phase, with ESV increasing from 1754.40$\times10^{8}$ Yuan to 185.25$\times10^{8}$ Yuan (a net increase of 17.26$\times10^{8}$ Yuan, or 0.99%). During 2015–2020, ESV declined to 1737.14$\times10^{8}$ Yuan, a decrease of 112.24$\times10^{8}$ Yuan (10.56%) [Figure 2: see original paper].

Grassland and water bodies constituted the main ESV components, with grassland accounting for over 57.1% and water bodies for over 27.5% of the total. Cultural services (10.0%) were primarily provided by unused land, while supply services (5.4%) mainly originated from grassland and cropland. Grassland and unused land showed consistent changing trends, while cropland ESV increased most rapidly, growing from 77.84$\times10^{8}$ Yuan to 103.82$\times10^{8}$ Yuan (33.38%). Water bodies experienced the largest reduction, decreasing by 112.96$\times10^{8}$ Yuan (19.24%). Regulation service values, the highest among individual services, continuously declined during the study period [Figure 3: see original paper].

2.2 Sensitivity Analysis

Sensitivity indices for all land use types were less than 1, indicating that the accounting results are inelastic to equivalent factors and thus credible. Grassland exhibited the highest sensitivity index (>0.301), followed by water bodies (>0.194) and unused land (>0.045), while wetland showed the lowest sensitivity (<0.007). Consequently, adjusting grassland equivalent coefficients would significantly alter regional ESV, whereas wetland coefficient adjustments would produce only minor changes .

2.3 Regional Ecological-Economic Harmony Analysis

From 2000 to 2020, southern Xinjiang demonstrated mild ecological-economic imbalance. With relatively low EEH values, the region could be classified as having low-level coordinated stability. However, as regional economic growth slowed and environmental protection systems were implemented, the initially uncoordinated state gradually improved. By 2020, the regional EEH reached 0.0115, indicating enhanced coordination .

2.4 County-Level ESV Profit/Loss Analysis

To fully express ESV profit/loss in southern Xinjiang, this study analyzed county-level ESV changes using per-unit-area values to eliminate area-size dependencies and more accurately reflect ecosystem quality changes. Most counties exhibited low-to-moderate ESV loss (-294.36 to 0 Yuan · hm^{-2}), indicating relatively stable but gradually deteriorating habitat conditions. ESV gain counties (0 to 356.38 Yuan · hm^{-2}) were mainly distributed in central and eastern southern Xinjiang, totaling nine counties with significantly improved forest-grass ecosystems [Figure 4: see original paper].

2.5 County-Level Ecological-Economic Harmony Analysis

County EEH values in southern Xinjiang ranged from -0.0356 to 0.0115, with all counties showing mild ecological-economic coordination (or deterioration). Counties with EEH < 0 were classified as initial deterioration zones, where economic growth rates far exceeded ESV change rates, indicating contradictions between economic development and ecological maintenance. ESV gain counties were primarily located in central and eastern regions, while deterioration counties showed no clear spatial distribution pattern .

2.6 Sustainable Development Zoning Results

Based on county ESV profit/loss status, ecological-economic coordination types, and dominant land types, southern Xinjiang counties were classified into five sustainable development zones [Figure 5: see original paper]:

1. **Forest-Grass Ecological-Economic Unsustainable Zone**: The most numerous type, distributed in central and western southern Xinjiang, including Moyu County, Qiemo County, Baicheng County, and 30 other counties.

2. **Forest-Grass Ecological-Economic Stable Zone**: Located in northern and southwestern southern Xinjiang, including Hotan City and Wushi County.

3. **Farmland Ecological-Economic Unsustainable Zone**: Concentrated in Kashgar Prefecture in western southern Xinjiang, including Kashgar City and Zepu County.

4. **Farmland Ecological-Economic Stable Zone**: Mainly distributed across the region, including Shufu County, Yingjisha County, Korla City, Ruoqiang County, and 14 other counties.

5. **Water Ecological-Economic Unsustainable Zone**: Located in western southern Xinjiang, including Akqi County, Luopu County, and Taxkorgan Tajik Autonomous County.

Discussion

Ecosystem services constitute the nexus linking human welfare and natural environments, representing a critical issue in current human-environment relationship and green development research. ESV assessment translates natural resource and ecological issues into publicly comprehensible indicators, while GDP effectively measures social operation status and economic development. Their integration plays a vital role in regional habitat management and ecological decision-making optimization. Therefore, ensuring ESV assessment accuracy and timeliness is paramount.

Previous Xinjiang ESV studies predominantly used 2010 grain prices, whereas this study employs average grain prices from 2000–2020, providing stronger timeliness. Correction factors incorporate prefecture- and corps-level natural, grain, and economic data, yielding more accurate and reasonable estimates. Against a backdrop of continuous regional economic growth, the EEH model simultaneously reflects consistency in ecological-economic change rates and regional ecological-economic management efficiency. Quantitative assessment reveals intrinsic connections and dynamic balances between ecological and economic systems, enabling sustainable development zoning that clarifies functional positioning and development directions for different regions, thereby facilitating resource optimization and ecological environmental protection.

Our southern Xinjiang ESV results align with studies by Ma Lina et al., Wang Xiyi et al., and Mayila Reheman et al., all showing an overall declining trend. Research on the Yanqi Basin indicates that ecological-economic coordination remains in a state of low conflict and low coordination, consistent with our findings. Xiong Chuanhe et al.'s research on Xinjiang's ecological-economic system sustainability and southern Xinjiang's sustainable economic scale under ecological constraints similarly concludes that southern Xinjiang's ecological environment and ecological-economic system sustainability still face challenges.

Conclusions

From 2000 to 2020, southern Xinjiang's total ESV initially increased then decreased, with an overall reduction of 167.99$\times10^{8}$ Yuan. Grassland and water bodies contributed over 70% of ESV, while regulation services accounted for 57.1% of individual service values. Grassland and cropland were the dominant land types for ESV gains (losses) in most counties. Approximately 80% of counties were initial ecological-economic deterioration zones, with the remainder showing coordinated stability. Grassland and cropland were the dominant land types driving county-level ESV gains (losses). Southern Xinjiang counties can be classified into five sustainable development zones: forest-grass ecological-economic unsustainable zone, farmland ecological-economic unsustainable zone, water ecological-economic unsustainable zone, forest-grass ecological-economic sustainable stable zone, and farmland ecological-economic sustainable stable zone.

Recommendations

For the five sustainable development zone types:

1. **Forest-Grass Ecological-Economic Unsustainable Zone**: Socioeconomic development and urban expansion should integrate grassland restoration and management. Implement effective grazing prohibition and supervision measures while improving grassland and forest ecological compensation mechanisms. Enhance utilization efficiency of existing pastoral and cropland areas, increase financial and technical support for natural grassland protection and improvement, and expand grazing prohibition zones when necessary to restore grassland ecological environments.

2. **Water Ecological-Economic Unsustainable Zone**: Protect existing lakes and river runoff. While rising temperatures in arid regions may temporarily increase meltwater runoff, water resource utilization efficiency must be optimized. Industrial layout and production expansion should proceed under scientifically planned water resource utilization. Simultaneously, vigilance against water storage deficits from glacial retreat is essential. Early warning systems for oasis sustainable development risks should be established from perspectives of water storage, development, allocation, and utilization efficiency to mitigate water resource change impacts.

3. **Forest-Grass Ecological-Economic Stable Zone**: Continue strengthening natural forest and grassland protection, adhering to grassland and shrub-dominated natural vegetation restoration policies to maximize natural vegetation area. Government departments should rationally control cropland scale, actively manage oasis land use, and develop ecological landscape tourism industries to achieve continuous ecological asset appreciation while consolidating ecological protection achievements and conducting desertification control.

4. **Farmland Ecological-Economic Unsustainable Zone**: Protect basic cropland while enhancing existing farmland productivity and efficiency. Strengthen management and protection of grassland and water resources, clarify cropland resource and ecological environment baselines, improve regional ecological quality, and consolidate ecological security to achieve coordinated sustainable development.

5. **Farmland Ecological-Economic Stable Zone**: Fully utilize ecological environmental advantages to adjust industrial structure, appropriately control farmland cultivation scale, and strengthen investment in existing green organic agricultural technologies. Develop ecological agriculture and tourism agriculture projects to transfer high-energy-consumption, high-pollution industries and enhance regional ecological environmental competitiveness.

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