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Spatiotemporal Variation of Ecosystem Services in the Shiyang River Basin from 2005 to 2015: Postprint

Authors: Wang Bei, Zhao Jun, Zhong Juntao, Zhao Jun

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Abstract

Ecosystem services research represents a current hotspot and frontier in ecological science. This study, taking the Shiyang River Basin as the research area and employing GIS technology and methodologies, conducted quantitative assessments of six ecosystem services—water conservation, soil retention, water purification, carbon storage, biodiversity, and food supply—for the years 2005, 2010, and 2015, and explored the variation patterns of these services across different land use types as well as ecosystem functional zoning. The results indicate:
Different service types exhibit distinct spatial patterns: water conservation, biodiversity, and carbon storage display a spatial configuration characterized by high values in the southwest and low values in the northeast, with high-value zones distributed in belts along rivers and their peripheries; high-value areas for water purification are relatively fragmented; regions such as Wuwei, Yongchang, and Minqin Basin constitute high-value zones for food supply services. Among various land use types, grassland and cultivated land serve as critical components in delivering ecosystem provisioning services. The study area is classified into three ecological functional zones: the Qilian Mountains Ecological Conservation Zone, the Basin Oasis Ecological Functional Zone, and the Desert Ecological Functional Zone. Through comprehensive analysis of the spatiotemporal heterogeneity characteristics of ecosystem services in the Shiyang River Basin, this research aims to provide data and methodological support for related studies and scientific references for ecological protection and restoration objectives in relevant watersheds.

Full Text

Preamble

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Spatiotemporal Differentiation of Ecosystem Services in the Shiyang River Basin from 2005 to 2015

WANG Bei[1], ZHAO Jun[2], ZHONG Jun-tao[3]

[1] College of Earth and Environmental Sciences, Lanzhou University, Lanzhou 730070, Gansu, China
[2] College of Geography and Environmental Sciences, Northwest Normal University, Lanzhou 730070, Gansu, China
[3] College of Geographic Sciences, Qinghai Normal University, Xining 810016, Qinghai, China

Abstract: The study of ecosystem services has become a hot topic and frontier in the field of ecology. The Shiyang River Basin was taken as the research object to estimate ecosystem services including water conservation, soil retention, water purification, biodiversity maintenance, carbon storage, and food supply based on GIS technology and InVEST model methods in 2005, 2010, and 2015. Moreover, the evolution of the spatiotemporal pattern of ecosystem services, changes in ecosystem services based on land use types, and compartmentalization of ecosystem functions were explored and studied. The results firstly showed that: The ecosystem services presented spatially differential characteristics. The spatial pattern of water conservation, biodiversity maintenance, and carbon storage showed the characteristic that low-value zones were located in the northeast, and high-value zones were mostly distributed in the southwest. In addition, the distribution of high-value zones of water purification was fragmented. The high-value zones of food supply were located in Wuwei, Yongchang, and Minqin basins. Among the different land use types, grassland and cultivated land played the main role in providing ecosystem services. The basin was divided into three ecological functional areas, namely Qilian ecological conservation area, watershed oasis ecological functional area, and desert ecological functional area. The study and analysis of the spatiotemporal differentiation of ecosystem services in the Shiyang River Basin provided support of data and methods for relevant research, and also scientific references for determining the goal of watershed ecological protection and construction.

Keywords: InVEST model; land use type; ecosystem service function; ecological function zone; Shiyang River Basin

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1 Study Area

The Shiyang River Basin (101°22 E–104°16 E, 36°29 N–39°27 N) is located in the central part of Gansu Province [FIGURE 1]. The basin extends approximately 300 km from east to west, covering an area of 4.16 × 10 km². The region is characterized by a typical continental temperate arid climate with abundant sunshine, low precipitation, high evaporation, and large temperature variations. The terrain slopes from southwest to northeast, forming the Qilian Mountains in the south and the Hexi Corridor in the north. The basin comprises multiple administrative units including Wuwei, Jinchang, and Zhangye cities.

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2 Data and Methods

2.1 Ecosystem Service Assessment Methods

This study utilized the InVEST model combined with GIS technology to assess six key ecosystem services in the Shiyang River Basin for the years 2005, 2010, and 2015: water conservation, soil retention, water purification (nitrogen and phosphorus retention), carbon storage, biodiversity maintenance, and food supply.

2.1.1 Water Conservation The water conservation service was quantified using the water yield and water retention modules of the InVEST model. The water yield module calculates annual water yield per pixel based on the Budyko curve and annual average precipitation. The water retention module estimates water retention capacity using the formula:

$$Retention = Min\left(1, \frac{Velocity \times Yield}{0.9 \times TI}\right)$$

where $Retention$ is the water retention capacity (mm), $Velocity$ is flow velocity, $Yield$ is water yield, and TI is the topographic index. The drainage area was calculated as:

$$DrainageArea = \log(SoilDepth \times PercentSlope)$$

where $SoilDepth$ is soil depth (mm) and $PercentSlope$ is slope percentage.

2.1.2 Soil Retention Soil retention was assessed using the sediment delivery ratio (SDR) module in InVEST, which is based on the Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE). The module calculates potential soil erosion and actual sediment export:

$$USLE = R \times K \times LS \times C \times P$$

$$RUSLE = R \times K \times LS$$
$$SRET = (RUSLE - USLE) + ups\_retain$$

where R is rainfall erosivity, K is soil erodibility, LS is slope length and steepness factor, C is cover management factor, P is support practice factor, and $SRET$ is soil retention (t/ha).

2.1.3 Water Purification Nutrient retention (nitrogen and phosphorus) was evaluated using the nutrient delivery ratio (NDR) module. The model calculates nutrient loads from different land use types and their retention capacity:

$$ALV_x = HSS_x \times POL_x$$
$$HSS_x = \lambda_x = \frac{\log \sum U}{\log \sum U_{total}}$$

where ALV_x is the adjusted loading value at pixel x, HSS_x is the hydrologic sensitivity score, POL_x is the nutrient export coefficient, and λ_x represents the runoff potential.

2.1.4 Carbon Storage Carbon storage was estimated by summing four carbon pools:

$$C = C_{above} + C_{below} + C_{dead} + C_{soil}$$

where C_{above} is aboveground biomass carbon, C_{below} is belowground biomass carbon, C_{dead} is dead organic matter carbon, and C_{soil} is soil organic carbon.

2.1.5 Biodiversity Maintenance The biodiversity module calculates habitat quality based on land use type and threats:

$$Q = Q_{xj} + R_x + H$$

where Q is total habitat quality, Q_{xj} is habitat quality for land use type j at pixel x, R_x is rarity index, and H is habitat connectivity.

2.1.6 Food Supply Food supply was quantified based on crop yield data from statistical yearbooks and land use classification:

$$Ac_j pc_j Ec$$

where Ac_j is crop area, pc_j is per capita consumption, and Ec is ecological footprint.

2.2 Data Sources

Primary data sources included [TABLE 1]: - Digital Elevation Model (DEM) from the "Shiyang River Basin DEM" - Soil data from the "Soil Depth Map" and "PAWC" (Plant Available Water Capacity) - Land use/cover data from Landsat TM/ETM+ imagery with 30m resolution - Climate data from meteorological stations (precipitation, temperature, evapotranspiration) - Statistical data from Gansu Provincial Yearbooks (2006, 2011, 2016) - Soil erodibility data based on Gupta' s formula [45] - Crop coefficients from FAO guidelines and Allen-Wardell method [47]

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3 Results

3.1 Temporal Changes in Ecosystem Services (2005–2015)

From 2005 to 2015, ecosystem services in the Shiyang River Basin showed significant temporal variation. Water conservation capacity decreased overall, with notable declines in the midstream oasis areas. Soil retention remained relatively stable in the Qilian Mountain region but decreased in cultivated areas due to land use intensification. Water purification services showed improvement in some areas due to reduced fertilizer application. Carbon storage increased slightly, primarily from afforestation efforts. Food supply increased by approximately 1.29×10 tons from 2005 (7.016×10 t) to 2015 (7.144×10 t), though per-unit-area productivity decreased in some regions.

3.2 Spatial Patterns of Ecosystem Services

The spatial distribution of ecosystem services exhibited clear differentiation: - **Water conservation**: High-value zones concentrated in the Qilian Mountains (southwest), low-value zones in the northeastern desert areas - **Soil retention**: Highest in forested mountain slopes, lowest in desert and cultivated flatlands - **Water purification**: Fragmented high-value zones associated with riparian vegetation and wetlands - **Biodiversity**: High values in natural grasslands and forest ecosystems of the upper basin - **Carbon storage**: Concentrated in forest and shrub areas of the Qilian Mountains - **Food supply**: High-value zones in Wuwei, Yongchang, and Minqin irrigation districts [FIGURE 3, FIGURE 4]

3.3 Ecological Functional Zoning

3.3.1 Water Conservation Functional Zone Based on water yield and retention capacity, the basin was divided into three functional zones: 1. **Qilian Mountain Water Conservation Zone**: High retention capacity (2.59×10 t), covering 47.52% of the basin area (19,287 km^2) 2. **Oasis Water Use Zone**: Moderate retention, high consumption 3. **Desert Runoff Zone**: Low retention, high infiltration

The zoning was performed using ArcGIS spatial analysis tools, with the 2015 land use map as baseline [FIGURE 5].

3.3.2 Comprehensive Functional Zoning Integrating all six ecosystem services, the basin was compartmentalized into three ecological functional areas: 1. **Qilian Ecological Conservation Area**: Prioritizes biodiversity maintenance and water conservation 2. **Watershed Oasis Ecological Functional Area**: Focuses on food supply and sustainable water use 3. **Desert Ecological Functional Area**: Emphasizes soil retention and desertification control

The spatial distribution of these functional zones shows that 25.11% of the basin area (10,000 km²) is designated as priority conservation zones, primarily in mountainous areas with slopes >10° [FIGURE 6].

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4 Discussion

This study demonstrates that the InVEST model provides an effective framework for quantifying multiple ecosystem services in arid inland basins. The integration of GIS spatial analysis with process-based models enables comprehensive assessment of service trade-offs and synergies. Key findings indicate that:

1. **Land use change** is the primary driver of ecosystem service variation, with grassland and cultivated land being the main service providers. The conversion of grassland to cropland increased food supply but reduced water conservation and biodiversity services.

2. **Spatial heterogeneity** is pronounced due to topographic and climatic gradients. The southwest-northeast gradient from mountains to desert creates distinct service bundles that require targeted management strategies.

3. **Functional zoning** based on ecosystem services can inform ecological conservation and restoration priorities. The Qilian Mountain area should focus on protection of natural vegetation to maintain water source functions, while oasis areas need sustainable agricultural practices to balance food production and environmental protection.

The study has limitations in data resolution and model parameterization. Future research should incorporate higher-resolution remote sensing data and field validation to improve accuracy. The coupling of InVEST with other models (e.g., hydrological models) could enhance predictive capacity for land use change scenarios.

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