ChinaRxiv

AI translation · View original & related papers at
chinarxiv.org/items/chinaxiv-202108.00069

Land Use Structure Optimization Based on Ecosystem Service Value in the Main Stream of the Tarim River: Postprint

Authors: Lin Jing

Date: 2021-08-12T00:00:00+00:00

Abstract

By investigating the intrinsic influence mechanisms of land use change on ecosystem service values in the main stream of the Tarim River, the land use structure was optimized based on ecosystem service values. The results show that: (1) Following emergency ecological water transfer, the average annual change rates of cropland, forest land, grassland, desert, and water bodies in the main stream of the Tarim River were 7.26%, 2.68%, -1.90%, 1.22%, and 0.08%, respectively; the increases in cropland and forest land area were primarily derived from grassland, while changes in water body area were mainly influenced by inflow volume. (2) From 1990 to 2015, emergency ecological water transfer caused the ecosystem service value in the lower reaches of the Tarim River to exhibit a "growth-decline-recovery" trend, with a total increase of 2.99×10^{8} yuan; the main stream of the Tarim River showed an overall declining trend, with a total decrease of 39.60×10^{8} yuan. (3) Path analysis revealed that water body area change has the strongest intrinsic relationship with ecosystem service values in the main stream of the Tarim River, with a direct effect of 0.610 and an indirect effect of 0.345. (4) Analysis of conversion relationships among land use types indicated that the optimal land use structure occurs when the area proportions of cropland, forest land, grassland, desert, and wetland are 3.34%, 10.03%, 38.22%, 45.95%, and 0.96%, respectively, corresponding to an ecosystem service value of 533.69×10^{8} yuan. With the expansion of cropland area, the conflict between agricultural water use and ecological water use becomes increasingly prominent; balancing land use structure and its water consumption characteristics is of great significance for maintaining ecosystem service values and rational water resource allocation, and can provide a scientific basis for exploring the optimized state of human-land relationships in the Tarim River Basin.

Full Text

Preamble

Optimization of Land Use Structure Based on Ecosystem Service Value in the Mainstream of the Tarim River

LIN Jing[1], ZHAO Chengyi[1], MA Xiaofei[2], SHI Fengzhi[2], WU Shixin[2], ZHU Jian[3]
[1]Land Science Research Center, Nanjing University of Information Science and Technology, Nanjing, Jiangsu 210044, China
[2]Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, Xinjiang 830011, China
[3]Tarim River Basin Authority, Korla, Xinjiang 841000, China

Abstract: This study investigates the intrinsic mechanisms through which land use changes affect ecosystem service values in the mainstream of the Tarim River, and optimizes the land use structure based on ecosystem service value. The results indicate that: (1) After emergency ecological water conveyance, the average annual change rates of cultivated land, woodland, grassland, desert, and water bodies in the Tarim River mainstream were 2.68%, 7.26%, -1.90%, 1.22%, and 0.08%, respectively. The increases in cultivated land and woodland area primarily came from converted grassland, while water area changes were mainly influenced by inflow volumes. (2) Emergency ecological water conveyance caused the ecosystem service value in the lower Tarim River to follow a "growth-decline-recovery" trajectory, with a total increase of 39.60$×10^{8}$ yuan. The mainstream as a whole showed a declining trend, decreasing by 2.99$×10^{8}$ yuan. (3) Path analysis revealed that water area changes had the strongest intrinsic connection with ecosystem service values in the Tarim River mainstream, with a direct effect of 0.610 and an indirect effect of 0.345. (4) Analysis of interconversion relationships among land use types showed that when cultivated land, woodland, grassland, desert, and wetland occupy 3.34%, 10.03%, 38.22%, 45.95%, and 0.96% of the area respectively, the land use structure is optimal, corresponding to an ecosystem service value of 533.69$×10^{8}$ yuan. As cultivated land expands, the conflict between agricultural and ecological water use becomes increasingly prominent. Balancing land use structure and its water consumption characteristics is crucial for maintaining ecosystem service values and rationally allocating water resources, providing a scientific basis for exploring optimal human-land relationships in the Tarim River Basin.

Keywords: land use change; ecosystem service value; land use structure optimization; Tarim River mainstream

1 Introduction

Land use change impacts on ecosystem service values represent a hotspot issue in the United Nations Millennium Ecosystem Assessment. While Chinese scholars have focused on spatiotemporal dynamics of ecosystem service values, increasing attention is being paid to the driving forces and intrinsic linkages between land use structure and regional ecosystem service values. Previous studies indicate that land use changes affect surface material cycles and energy exchange, as well as ecosystem structure and function, by altering ecohydrological processes. However, understanding of the intrinsic mechanisms through which land use changes affect ecosystem service values remains limited.

The Tarim River mainstream serves as a natural corridor for ecological civilization construction in the arid regions of Central Asia and as an indicator of human-land relationship status in inland river basins. Historically, the land use structure in this area underwent dramatic "reclamation-abandonment" cycles along with river course changes and irrigation oasis development, causing fragile evolution of riparian vegetation centered on the river channel. The lower reaches experienced over 30 years of flow interruption, and the terminal Lake Taitema rapidly shrank until drying up completely. Since 2000, the Tarim River Basin has implemented basin-wide water-saving irrigation, emergency ecological water conveyance to the downstream dry river channel and terminal lake, and artificial reconstruction of riparian vegetation and Lake Taitema. After nearly 20 years of effort, the ecosystem service functions have achieved remarkable results through "downstream ecological water conveyance and terminal lake reconstruction," with groundwater depth along both banks decreasing by 3.75 m and the lake surface area expanding significantly.

As regional environments change dramatically and population grows, meeting the substantial demands of socio-economic sustainable development and ecological civilization construction requires answering critical questions: How should the land use structure in the Tarim River mainstream be optimized to maintain sustainable and healthy ecological service functions? How long must the artificial intervention of "downstream ecological water conveyance and terminal lake reconstruction" be maintained to ensure riparian vegetation does not degrade? What lake surface area is needed to maintain optimal ecological service functions? Ecosystem services bridge natural environments and human well-being, and building a "mountain-water-forest-field-lake-grassland" life community requires shifting from purely pursuing GDP to considering both GDP and GEP (Gross Ecosystem Product). Addressing these challenges urgently requires understanding the intrinsic mechanisms of how land use changes affect ecosystem service values under changing environments.

This study examines the spatiotemporal dynamics of land use structure and ecosystem service values before and after emergency ecological water conveyance in the Tarim River mainstream, quantifies the impacts of land use structural changes on ecosystem service functions, explores the intrinsic driving forces of ecosystem service values, and optimizes the land use structure based on ecosystem service values to provide a basis for exploring optimal human-land relationships in the Tarim River Basin.

1.1 Study Area Overview

The Tarim River mainstream extends 1,321 km, divided into upper, middle, and lower reaches. The upper reach runs from Aral to Yingbazha (495 km), the middle reach from Yingbazha to Qiala (398 km), and the lower reach from Qiala to the terminal Lake Taitema (428 km) [Figure 428: see original paper]. The region has an average annual temperature of 10.6°C, annual precipitation below 80 mm, and annual evaporation exceeding 2,500 mm, characterized by a warm temperate extremely arid climate. Soil parent materials are primarily sedimentary and aeolian deposits, with soil types mainly including aeolian sandy soil, meadow soil, fluvo-aquic soil, saline soil, cracked soil, and wetland soil. The Tarim River itself generates no runoff and relies entirely on source area replenishment. The three source rivers (Hotan, Yarkant, and Aksu) converge at the Aral cross-section with an average annual runoff of 46.5×10^{8} m^3, which decreased to 43.3×10^{8} m^3 in recent years, and further reduced to 24.9×10^{8} m^3 in 2020. The total population in the mainstream area is 3.631 million, with a GDP of 14.41×10^{8} yuan. The economic pillar remains agriculture, accounting for over 50% of the economy. Constrained by upstream inflow conditions, the upper, middle, and lower reaches exhibit prominent conflicts between human-land and human-ecology relationships, with unbalanced development of cropping, characteristic fruit forestry, and animal husbandry, and a weak foundation for ecological civilization construction.

1.2 Data Collection

Nine ecological cross-sections were established along the Tarim River channel, with plant quadrats set at each section. Quadrat sizes were 100 m × 100 m, subdivided into 25 m × 25 m sub-quadrats. Within each quadrat, latitude/longitude, elevation, species type, crown width, tree height, DBH, density, and coverage were recorded. Within each sub-quadrat, 5 m × 5 m plots were randomly established to record herbaceous species names, density, crown width, and height. During vegetation surveys, 30 groundwater observation wells were installed along the river to monitor groundwater depth changes on both banks, yielding groundwater depth variation data for the nine ecological cross-sections. Runoff data were obtained from measured time series at the Aral hydrological station (upstream), Yingbazha station (middle reach), and Qiala station (downstream) from the Tarim River Basin Authority.

Land use type data primarily used the National Third Land Use Survey data, supplemented by Landsat TM and Landsat OLI remote sensing imagery from 1990-2015 to construct land use change sequences. Socio-economic development data were derived from the "National Agricultural Product Cost-Benefit Compilation" and "Xinjiang Statistical Yearbook."

1.3 Methods

1.3.1 Land Use Change Analysis Based on the National Third Land Use Survey data for the Tarim River mainstream, Landsat TM and OLI imagery underwent radiometric calibration, atmospheric correction, remote sensing interpretation, and field survey correction to construct time series data for seven land use types: cultivated land, woodland, grassland, desert, water bodies, wetland, and construction land . To ensure classification accuracy, a confusion matrix-based accuracy assessment was applied, with Kappa coefficients exceeding 0.85 for all interpreted images, meeting research precision requirements.

1.3.2 Ecosystem Service Value Estimation Ecosystem Service Value (ESV) estimation employed the geographic-economic ecology combined ecosystem service value equivalent factor method:

$$ESV = \sum_{j=1}^{n} \sum_{r=1}^{m} E_{rj} A_j$$

where ESV is the ecosystem service value (yuan); j is ecosystem type and n is the total number of ecosystem types; r is ecosystem service type; E_{rj} is the value produced per unit area of service type r for ecosystem type j (yuan); and A_j is the area of ecosystem type j (hm^2). Based on Xinjiang' s average grain yield per unit area in 2015, the ecosystem service value per standard equivalent factor was 2,121.79 yuan/hm^2 .

1.3.3 Impact Analysis of Land Use Change on ESV To clarify the direct and indirect relationships among different land use types and their impact on ESV, path analysis was employed to decompose correlation coefficients based on multiple regression, establishing relationships between predictor and target variables. Path coefficients are unitless, directional correlation coefficients that indicate variable interactions:

$$r_{iy} = P_{iy} + \sum_{j \neq i} r_{ij} P_{jy}, \quad (i = 1, 2, \dots, k)$$

where r_{iy} is the correlation coefficient between predictor x_i and target variable y; P_{iy} is the direct path coefficient between x_i and y; P_{jy} is the direct path coefficient between x_j and y; r_{ij} is the correlation coefficient between x_i and x_j; and $r_{ij}P_{iy}$ represents the indirect effect of x_i on y through x_j.

1.3.4 Land Use Structure Optimization Based on transformation relationships among land use types and ESV changes, regression equations were established between different land types to calculate ESV changes under various land use structures and determine the optimal structure:

$$ESV = \sum_{j=1}^{n} E_{rj} F y_j$$

where x represents the area proportion of a specific land use type (%), y_i represents other land use types, F is the total area of the Tarim River mainstream, and coefficients were derived from regression equations.

2 Results

2.1 Land Use Change Characteristics

2.1.1 Temporal Changes in Land Use Before emergency ecological water conveyance (1990-2000), land use type proportions in the Tarim River mainstream ranked as: grassland (45.72%) > desert (42.48%) > cultivated land (6.94%) > water bodies (2.43%) > woodland (1.34%) > wetland (0.97%) > construction land (0.12%). After water conveyance (2000-2015), the ranking became: desert (55.47%) > grassland (24.04%) > cultivated land (11.59%) > water bodies (6.85%) > woodland (1.37%) > wetland (0.55%) > construction land (0.13%). Grassland area changed most significantly (-8,876.67 km^2), followed by desert (+5,320.58 km^2) and cultivated land (+1,902.94 km^2), while construction land changed least (+70.30 km^2).

From 1990-2000, grassland decreased at -849.32 km^2/year. After ecological water conveyance (2000-2015), the reduction rate slowed to -58.72 km^2/year. With increasing runoff and water conveyance volumes, grassland area stabilized. Overall, the upper reach showed grassland-to-cultivated land conversion, while middle and lower reaches exhibited grassland-to-desert conversion, influenced by water availability. The upper reach had the largest annual change rate in cultivated land (7.26%), while the middle reach showed the greatest grassland area change (-1,105.44 km^2).

2.1.2 Spatial Changes in Land Use Spatial land use changes were most significant from 2000-2015. In the upper, middle, and lower reaches, grassland-to-woodland conversions were 739.03 km^2, 340.85 km^2, and 75.51 km^2 respectively; grassland-to-cultivated land conversions were 995.46 km^2, 446.21 km^2, and 109.67 km^2; and grassland-to-desert conversions were 1,518.16 km^2, 3,976.51 km^2, and 329.33 km^2 . Cultivated land expansion concentrated in water-rich areas near rivers, lakes, and reservoirs, primarily in the upper reach Aral area and along the Aqike-Qiala river section in the middle reach. Woodland expanded outward from river channels where groundwater was abundant. Grassland degradation was severe south of the upper and middle reaches and east of the lower reach, with desert area expanding significantly [Figure 2: see original paper].

2.2 Ecosystem Service Value Changes

2.2.1 Temporal ESV Characteristics Before ecological water conveyance (1990-2000), total ESV in the Tarim River mainstream was 670.09$×10^{8}$ yuan, with contributions ranking as: grassland (47.97%) > desert (21.64%) > water bodies (13.81%) > woodland (10.98%) > wetland (1.91%) > cultivated land (1.80%). After water conveyance (2000-2015), total ESV decreased to 630.49$×10^{8}$ yuan, with contributions ranking as: desert (44.80%) > grassland (26.33%) > water bodies (19.94%) > woodland (12.77%) > wetland (1.20%) > cultivated land (1.01%). Overall ESV decreased by 39.60$×10^{8}$ yuan, with grassland ESV decreasing most (-102.22$×10^{8}$ yuan). The lower reach showed a "growth-decline-recovery" pattern, increasing by 2.99$×10^{8}$ yuan, while the upper and middle reaches decreased by 15.38$×10^{8}$ and 26.33$×10^{8}$ yuan respectively [Figure 3: see original paper].

2.2.2 Spatial ESV Characteristics From 1990-2015, areas north of the river channel showed higher change rates than southern areas, varying systematically with distance from the channel. The Qiala reservoir and Lake Taitema areas exhibited the largest variation rates, followed by riverbanks, while only 1.01% of areas showed stable increases. Water body area changes were the primary factor affecting ESV decline in the Tarim River mainstream [Figure 4: see original paper].

2.3 Impact of Land Use Change on ESV

Path analysis clarified interactions among land use types and their impacts on ESV . The relationship was expressed as: $y = 661.572 - 0.014x_{\text{cultivated}} + 0.319x_{\text{woodland}} - 0.061x_{\text{grassland}} - 0.003x_{\text{desert}} + 0.610x_{\text{water}} + 0.345x_{\text{wetland}}$ ($R^2 = 0.89$, $p < 0.01$). Water bodies had the strongest direct effect on ESV (0.610), with total indirect effects of 0.345. Woodland' s indirect effects exceeded its direct effects, resulting in its overall negative correlation with ESV. Both cultivated land and desert showed negative direct effects and correlation coefficients, indicating their area increases negatively impact ESV growth. Overall, water area changes had the strongest intrinsic connection with ESV.

2.4 Land Use Structure Optimization

2.4.1 Interconversion Relationships Water bodies occupied less than 7% of total area, with changes primarily driven by inflow volumes and weak conversion relationships with other types. Woodland, grassland, cultivated land, wetland, and desert accounted for over 93% of the area, with strong interconversion relationships. Regression analysis revealed grassland area was positively correlated with wetland but negatively correlated with cultivated land, woodland, and desert [Figure 5: see original paper]. When grassland proportion fell below 38.22%, cultivated land exceeded 11.59% and desert exceeded 45.95%. When grassland exceeded 38.22%, desert proportion dropped below 45.95% and riparian corridor ecology improved.

2.4.2 Optimization Results To alleviate agricultural-ecological water conflicts, the optimal structure was determined as: cultivated land 3.34%, woodland 10.03%, grassland 38.22%, desert 45.95%, and wetland 0.96% . This configuration yields maximum ESV of 533.69$×10^{8}$ yuan. The optimization considers water scarcity, grain demand, and permanent basic farmland protection, implementing farmland-to-forest/grassland conversion. With decreasing runoff (24.91$×10^{8}$ m^3 in 2020, below the historical average of 43.26$×10^{8}$ m^3), groundwater levels dropped significantly. The optimized structure coordinates agricultural and ecological water use, maximizing ecosystem service values and improving green corridor environmental quality.

3 Discussion

3.1 Intrinsic Driving Factors of ESV

Land use change results from human-environment interactions and significantly affects ESV. Unreasonable water resource utilization caused major environmental changes in the Tarim River mainstream. Since 2000, emergency ecological water conveyance has raised groundwater depth substantially, improved riparian vegetation evolution, and expanded Lake Taitema' s surface area, all directly related to water conveyance volumes and water/wetland areas. Water bodies contributed 25.90%-31.02% to ESV increases in the lower reach. Path analysis confirms water areas have the dominant influence on ESV (direct effect: 0.610; indirect effect: 0.345).

Studies show that *Populus euphratica* seedling density, shrub/herb coverage, and richness decrease significantly with increasing groundwater depth. In the Tarim River mainstream, increased inflow raises groundwater levels, enhancing seedling density and vegetation productivity. The "downstream ecological water conveyance and terminal lake reconstruction" measures have proven effective, improving ecological security from moderate warning to relatively safe levels. The lower reach' s ESV "growth-decline-recovery" pattern aligns with runoff changes and water conveyance effects (2000-2009: significant growth; 2010-2014: sharp decline; 2015-2020: rapid recovery), highlighting the importance of human water regulation in arid regions [Figure 6: see original paper].

3.2 Trade-offs Between Downstream Ecological Restoration and Land Use Optimization

Global warming accelerates mountain glacier melting, increasing source area runoff. However, expanding irrigated areas in source oases have increased agricultural water consumption, leaving mainstream inflows unchanged. Agricultural water consumption accounts for 95.8% of total basin water use, with artificial oases consuming 7.8 times more water than natural vegetation. Downstream ecological restoration faces increasing challenges. Extensive agricultural development has damaged the Tarim River ecosystem, causing environmental degradation. Land use structure optimization and improved ecological water rights management are crucial environmental governance measures.

The "mountain-water-forest-field-lake-grassland"life community concept requires balancing socio-economic development with ecological protection. Ensuring food security while respecting ecological carrying capacity and determining suitable cultivation areas is essential. With cultivated land expansion, the agricultural-ecological water conflict intensifies. Groundwater level declines in oasis transition zones cause natural vegetation degradation and ecosystem structure damage, reducing ESV. Balancing water use is critical for optimizing land use structure and enhancing ecosystem service values. Under equal water consumption, grassland provides higher economic value than woodland for desert fixation, making grassland-woodland-cultivated land trade-offs particularly important in water-scarce arid regions [Figure 7: see original paper].

3.3 Methodological Scientific Validity

Ecosystem service assessment includes value-based and material-based methods. The value-based approach better facilitates comparison across periods and scenarios, providing cost-benefit analysis for restoration and sustainable development recommendations. Chinese ecological societies have reviewed ecosystem service evaluation models and methods, comprehensively assessing land use change relationships. Studies in the Loess Plateau and Kuche River Basin demonstrate that value-based ESV methods reliably reflect changes in arid regions caused by land use changes. This study' s methodology is scientifically sound and its results accurately represent ecosystem service value variations induced by land use changes in the Tarim River mainstream.

4 Conclusions

(1) From 1990-2015, the average annual change rates of cultivated land, woodland, grassland, desert, and water bodies in the Tarim River mainstream were 7.26%, 2.68%, -1.90%, 1.22%, and 0.08%, respectively. Cultivated land showed the greatest increasing rate, while grassland decreased continuously. Water bodies decreased in the upper reach but increased in middle and lower reaches. Spatially, upper reach conversion was primarily grassland-to-cultivated land, while middle and lower reaches showed grassland-to-desert conversion, influenced by water availability.

(2) Before ecological water conveyance (1990-2000), total ESV was 670.09×10^{8} yuan, decreasing to 630.49×10^{8} yuan after conveyance (2000-2015), a reduction of 39.60×10^{8} yuan. The lower reach exhibited a "growth-decline-recovery" pattern, increasing by 2.99×10^{8} yuan. Water resources are crucial for stabilizing and enhancing ESV in arid regions. Path analysis shows water bodies have the dominant influence (direct effect: 0.610; indirect effect: 0.345), demonstrating that integrated water resource management positively impacts ecological restoration.

(3) With expanding cultivated land, agricultural-ecological water conflicts intensify. Balancing land use structure and water consumption characteristics is vital for maintaining ESV and rational water allocation. Based on average annual inflow, the optimal land use structure (cultivated land: 3.34%; woodland: 10.03%; grassland: 38.22%; desert: 45.95%; wetland: 0.96%) maximizes ESV at 533.69×10^{8} yuan. During low-flow periods, minimum ecological water demand regulation should balance agricultural and ecological water ratios. During high-flow periods, increasing ecological water allocation and expanding woodland/grassland areas can enhance ecosystem service values.

References

[1] Ouyang Zhiyun, Wang Rusong, Zhao Jingzhu. Ecosystem services and their economic valuation[J]. Chinese Journal of Applied Ecology, 1999, 10(5): 635-640.

[2] Tansley A G. The use and abuse of vegetational concepts and terms[J]. Ecology, 1935, 16(3): 284-307.

[3] Millennium Ecosystem Assessment. Ecosystems and Human Well Being: Synthesis[M]. Washington: Island Press, 2005.

[4] Gao Jie, Li Feng, Gao Hui, et al. The impact of land use change on water related ecosystem services: A study of the Guishui River Basin, Beijing, China[J]. Journal of Cleaner Production, 2017, 163: S148-S155.

[5] Meyfroidt P, Lambin E F, Erb K H, et al. Globalization of land use: Distant drivers of land change and geographic displacement of land use[J]. Current Opinion in Environmental Sustainability, 2013, 5(5): 438-444.

[6] Sterling Shannon, Ducharne Agnès, Polcher Jan. The impact of global land cover change on the terrestrial water cycle[J]. Nature Climate Change, 2013, 3(4): 385-390.

[7] Yang Wei, Jin Yuwan, Sun Tao, et al. Trade-offs among ecosystem services in coastal wetlands under the effects of reclamation activities[J]. Ecological Indicators, 2018, 92: 354-366.

[8] Xie Gaodi, Zhang Caixia, Zhang Changshun, et al. The value of ecosystem services in China[J]. Resources Science, 2015, 37(9): 1740-1746.

[9] Kubiszewski Ida, Costanza Robert, Anderson Sharolyn, et al. The future value of ecosystem services: Global scenarios and national implications[J]. Ecosystem Services, 2017, 26: 289-301.

[10] Yong Zheng, Zhao Chengyi, Shi Fengzhi, et al. Variation characteristics of groundwater depth and its ecological effect in the main stream of Tarim River in recent 20 years[J]. Journal of Soil and Water Conservation, 2020, 34(3): 182-189.

[11] Deng Mingjiang, Fan Zili, Xu Hailiang, et al. Ecological function regionalization of Tarim River Basin[J]. Arid Land Geography, 2017, 40(4): 705-717.

[12] Guo Hongwei, Xu Hailiang, Ling Hongbo, et al. Quantitative relationship between cultivated land expansion and natural vegetation degradation in the lower reaches of the Tarim River[J]. Agricultural Research in the Arid Areas, 2018, 36(2): 226-233.

[13] Shi Fengzhi, Zhao Chengyi, Ye Baisong, et al. The scaling up of soil saturated hydraulic conductivity based on PTFs in Arid Area[J]. Journal of Desert Research, 2014, 34(6): 1584-1589.

[14] Liu Jiyuan, Kuang Wenhui, Zhang Zengxiang, et al. Spatiotemporal characteristics, patterns and causes of land use changes in China since the late 1980s[J]. Acta Geographica Sinica, 2014, 69(1): 3-14.

[15] Yuan Shaofeng, Zhu Congmou, Yang Lixia, et al. Responses of ecosystem services to urbanization induced land use changes in ecologically sensitive suburban areas in Hangzhou, China[J]. Environmental Research and Public Health, 2019, 16(7): 1124.

[16] Xie Gaodi, Zhang Caixia, Zhang Leiming, et al. Improvement of the evaluation method for ecosystem service value based on per unit area[J]. Journal of Natural Resources, 2015, 30(8): 1243-1254.

[17] Arowolo A O, Deng X Z, Olatunji O A, et al. Assessing changes in the value of ecosystem services in response to land use/land cover dynamics in Nigeria[J]. Science of the Total Environment, 2018, 636: 597-609.

[18] Zhang Zhou, Wu Cifang, Tan Rong. Application of ecosystem service value in land use change research: Bottlenecks and prospects[J]. Chinese Journal of Applied Ecology, 2013, 24(2): 556-562.

[19] Mamat Zulpiya, Halik Ümüt, Keyim Maierdang, et al. Variation of the floodplain forest ecosystem service value in the lower reaches of Tarim River, China[J]. Land Degradation & Development, 2018, 29(1): 47-57.

[20] Krysanova Valentina, Wortmann Michel, Bolch Tobias, et al. Analysis of current trends in climate parameters, river discharge and glaciers in the Aksu River basin Central Asia[J]. Hydrological Sciences Journal, 2015, 60(4): 566-590.

[21] Zhang Pei. Research on the Coupling System of Society, Ecoenvironment and Water in Tarim River Basin[D]. Beijing: China Institute of Water Resources and Hydropower Research, 2019.

[22] Jiang Bo, Zhang Lu, Ouyang Zhiyun, et al. Ecosystem services valuation of Qinghai Lake wetland[J]. Chinese Journal of Applied Ecology, 2015, 26(10): 3137-3144.

[23] Rukundo Emmanuel, Liu Shiliang, Dong Yuhong, et al. Spatiotemporal dynamics of critical ecosystem services in response to agricultural expansion in

Rwanda, East Africa[J]. Ecological Indicators, 2018, 89: 696-705.

[24] Lawler J J, Lewisb D, Nelson Erik, et al. Projected land use change impacts on ecosystem services in the United States[J]. PNAS, 2014, 111(20): 7492-7497.

[25] Fu Bojie, Su changhong, Wei yongping, et al. Double counting in ecosystem services valuation: Causes and Countermeasures[J]. Ecological Research, 2010, 26(1): 1-14.

[26] Fu Bojie, Chen Liding, Ma Keming, et al. The relationships between land use and soil conditions in the hilly area of the Loess Plateau in northern Shaanxi, China[J]. Catena, 2000, 39(1): 69-78.

[27] Hou Yifeng, Wang Yang, Zhang Shuai, et al. Change in land use and its consequence for ecological systems in Weigan-Kuqa River Basin in Xinjiang[J]. Journal of Irrigation and Drainage, 2020, 39(6): 13-20.

[28] Fan Jincheng, Mei Changlin. Data Analysis[M]. 2nd ed. Beijing: Science Press, 2010.

[29] Liu Guan, Li Guoqing, Li Jie, et al. Study on change in carbon storage and its spatial pattern in Mata Watershed from 1999 to 2016 based on InVEST model[J]. Arid Zone Research, 2021, 38(1): 267-274.

[30] Wang Bei, Zhao Jun, Zhong Juntao. Spatiotemporal differentiation of ecosystem services in the Shiyang River Basin from 2005 to 2015[J]. Arid Zone Research, 2019, 36(2): 474-485.

[31] Li Mengyi, Deng Mingjiang, Ling Hongbo, et al. Evaluation of ecological water security and analysis of driving factors in the lower Tarim River, China[J]. Arid Zone Research, 2021, 38(1): 39-47.

[32] Ning Shan, Zhang Zhengyong, Zhou Hongwu, et al. Optimization of land use structure based on ecological service value in Manas River Basin[J]. Acta Ecologica Sinica, 2019, 39(14): 5208-5217.

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

Source: ChinaXiv —Machine translation. Verify with original.