Land Use Change and Land Ecological Security Assessment in Northwest River Basins: A Postprint

Authors: Wu Jingquan

Date: 2021-10-10T00:00:00+00:00

Abstract

Using ArcGIS spatial analysis, this study reveals the dynamic change characteristics of land use in the river basins of Northwest China from 1990 to 2018, employs the "Pressure-State-Response" (P-S-R) model and entropy weight method to assign weights to indicators, and analyzes the land ecological security status of the river basins in Northwest China. The results show that: (1) The comprehensive land use dynamic degree of the river basins in Northwest China from 2015 to 2018 was 2.65%, indicating drastic land use changes. After 2000, the average annual single dynamic degree of urban and rural construction land was 4.16%, representing the fastest growth rate. Grassland was mainly converted to sandy land, cultivated land, and other unused land, while the conversion between sandy land and other unused land in the desert areas of the basins remained stable. (2) In the land ecological security evaluation index system for the river basins of Northwest China, the state layer had the highest weight of 0.4985. Based on the ranking of indicator weights, it is evident that economic and social development, wetland area, and population growth are important factors affecting the land ecological security evaluation of the river basins in Northwest China. (3) The land ecological security index of the river basins in Northwest China showed an increasing trend from 1990 to 2018, remaining basically at the "unsafe" level from 1990 to 2014, and transitioning to the "relatively unsafe" level after 2015, indicating that the land ecological security status of the river basins in Northwest China has improved. This study provides a scientific basis for land use management planning in the river basins of Northwest China and offers a case study for research on land use change and land ecological security at the natural watershed scale.

Full Text

Land Use Change and Land Ecological Security Assessment in the River Basins of Northwestern China

WU Jingquan, WU Mingwan, ZANG Chuanfu
School of Geography, South China Normal University, Guangzhou 510631, Guangdong, China

Land is the most fundamental natural resource for human survival and development. Land use/cover change (LUCC), as a critical factor influencing global environmental change, represents the most direct reflection of human activities. Against the backdrop of China' s rapid economic and social development, a significant contradiction has emerged in ecologically fragile regions between the fragile nature of land ecosystems and the enormous demand for urban land development. Insufficient attention to ecological land protection and maintenance, coupled with irrational land resource utilization, has exacerbated land ecological degradation. Consequently, investigating the dynamics of land use change and assessing regional land ecological security status have become essential components of regional sustainable development research.

This study employs ArcGIS spatial analysis software to reveal the characteristics of dynamic land use change in the river basins of northwestern China from 1990 to 2018. Using the Pressure-State-Response (P-S-R) model and entropy weighting method for indicator weighting, we analyze the land ecological security status of the region. The results demonstrate: (1) The comprehensive land use dynamic degree in the river basins of northwestern China from 2015 to 2018 was 2.65%, indicating drastic land use change. After 2000, urban and rural construction land exhibited the fastest growth with an average annual single dynamic degree of 4.16%. Grassland was primarily converted to sand, cropland, and other unused land, while conversion between sand and other unused land remained stable in the desert areas of the basin. (2) In the land ecological security evaluation index system, the state layer carried the highest weight of 0.4985, making it the most influential factor. Based on indicator weight ranking, economic and social development, wetland area, and population growth represent the key factors affecting land ecological security evaluation in the river basins of northwestern China. (3) The land ecological security index showed an overall increasing trend from 1990 to 2018, remaining at an unsafe level from 1990 to 2014 and transitioning to a relatively unsafe level after 2015, indicating improved land ecological security conditions in recent years. Land desertification constitutes a critical limiting factor for the healthy development of basin land ecosystems. To improve land ecological security, greater emphasis must be placed on converting desert land to ecological land, with careful attention to ecological land construction and maintenance. This study provides a scientific basis for land use planning and management in the river basins of northwestern China and offers methodological examples for land use change and ecological security research at the natural watershed scale.

Keywords: northwestern China river basins; dynamic land use change; Pressure-State-Response (P-S-R) model; comprehensive evaluation method; land ecological security

1.1 Study Area

Following existing literature, this study adopts the watershed division results from the "National Water Resources Comprehensive Database Spatial Integration" project, selecting the river basins of northwestern China and their secondary water resource zones as the study area. The river basins of northwestern China (29°30 ~49°14 N, 73°32 ~119°55 E) extend from the Pamir Plateau national border in the west to the Greater Khingan Mountains in the east, and from the northern border of the Altai Mountains in Xinjiang in the north to the Qiangtang region in northern Tibet in the south. The area includes exorheic, endorheic, and international rivers across Xinjiang, Tibet, Gansu, Qinghai, Ningxia, Inner Mongolia, and Hebei, covering a total area of 336.23$\times10^{4}$ km^2, representing over 35% of China's territorial area. The region contains more than 600 rivers, with runoff primarily formed by rainfall and supplemented by glacier melt. Most runoff originates in mountainous areas, with limited surface flow in basins and plateaus. Situated deep within the Eurasian continent, the region features a temperate continental climate with extremely uneven spatiotemporal precipitation distribution. The arid and water-scarce natural environment constitutes the primary limiting factor for local economic development. The geographical location of the river basins of northwestern China is illustrated in [Figure 1: see original paper].

1.2 Data Sources and Processing

The 24 socioeconomic statistical indicators selected for this study (Table 1) were obtained from the China Economic and Social Big Data Research Platform (https://data.cnki.net/). Land use/cover raster data for the study period were sourced from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/), with Landsat TM/ETM remote sensing imagery as the primary data source interpreted through manual visual interpretation.

Since socioeconomic indicator data are statistically compiled at the prefecture-level city unit within each province (autonomous region), this study applied area-weighted parameters based on the ratio of the watershed area within each prefecture-level city to the total area of that city. This approach allocated socioeconomic indicators according to their areal proportion, yielding watershed-scale socioeconomic data.

1.3 Land Use Change Analysis Methods

This study employs single land use dynamic degree, comprehensive land use dynamic degree, and land use transfer analysis with transfer matrices to analyze the spatiotemporal patterns of land use change in the river basins of northwestern China. Detailed calculation procedures and formulas are available in reference [21].

1.4 Land Ecological Security Evaluation

The Pressure-State-Response (P-S-R) model, initially proposed by Canadian statisticians in the 1970s and widely adopted by the OECD and UNEP in the late 1970s, provides a conceptual framework extensively applied in environmental evaluation research. The model captures causal relationships among evaluation indicators, distinguishing pressure indicators (socioeconomic impacts on resources and environment), state indicators (current ecosystem, resource, environmental, and socioeconomic development status), and response indicators (human countermeasures to environmental problems). Drawing upon the P-S-R framework and previous research in northwestern China, this study constructed a land ecological security evaluation index system comprising 24 indicators across three hierarchical levels (target, criterion, and indicator layers). The entropy weighting method determined indicator weights, with specific indicators listed in .

1.4.1 Indicator Data Standardization

As indicators feature different measurement scales and units, standardization was necessary to enable comparison. This study applied extreme value normalization to process indicator data. The calculation formulas are:

For positive indicators:

$$y_{ij}^{+} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$$

For negative indicators:

$$y_{ij}^{-} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}$$

where x_{ij} represents the initial value of indicator j in year i, y_{ij}^{+} is the standardized value for positive indicators, and y_{ij}^{-} is the standardized value for negative indicators.

1.4.2 Indicator Weight Determination

This study employed the entropy method to determine weights, which effectively reflects indicator variability while avoiding subjectivity in manual weighting. The entropy weight calculation formulas are:

First, calculate the characteristic proportion:

$$f_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}$$

Then calculate information entropy:

$$H_j = -\frac{1}{\ln m} \sum_{i=1}^{m} f_{ij} \ln f_{ij}$$

Finally, determine weights:

$$w_j = \frac{1 - H_j}{\sum_{j=1}^{n} (1 - H_j)}$$

where w_j is the weight of indicator j, H_j is information entropy, f_{ij} is the characteristic proportion, m is the number of evaluation years, and n is the number of indicators.

1.4.3 Land Ecological Security Comprehensive Index Calculation

Using the obtained entropy weights and standardized values, the comprehensive evaluation model calculates the land ecological security index:

$$Q = \sum_{j=1}^{n} y_{ij} \times w_j$$

where Q represents the land ecological security index (higher values indicate better security), y_{ij} is the standardized value, and w_j is the weight.

1.5 Ecological Security Level Determination

Given the relative nature of security concepts, this study reduces classification ambiguity through membership functions. Four security levels are defined: Safe, Relatively Safe, Relatively Unsafe, and Unsafe. The membership functions corresponding to each land ecological security level are constructed as follows:

The membership degree calculation determines the security level based on which interval the land ecological security index falls into, providing a quantitative basis for classification.

2.1.1 Land Use Dynamic Degree Analysis

Significant variations exist among different land use types in the river basins of northwestern China ([Figure 2: see original paper]). Grassland exhibited an average dynamic degree of -0.89%, indicating a continuous decreasing trend, while all other land use types showed positive average dynamic degrees, reflecting expansion trends. Urban and rural construction land maintained the highest dynamic degree with dramatic fluctuations, reaching -4.15% during 1990-1995 and 4.16% after 2000, representing the most rapid expansion among all land types. Cropland dynamic degree remained positive throughout the study period with an average annual rate of 1.71%, ranking second in expansion speed. Forestland, water bodies, and unused land showed minimal changes with average annual dynamic degrees between 0.30% and 0.70%.

The comprehensive land use dynamic degree for the entire river basins of northwestern China was 2.65% from 2015 to 2018, indicating drastic land use change. After 2000, the comprehensive dynamic degree stabilized at lower levels, suggesting more stable land use changes and reasonable ecological security variation intervals.

Significant regional differences characterize the comprehensive land use dynamic degree across secondary water resource zones. The Tianshan North Slope Rivers and Gurban Tonggut Desert regions exhibited the highest average annual comprehensive dynamic degrees at 2.71% and 1.77%, respectively, indicating intense land use changes. The Tarim Basin Desert and Tuha Basin Small Rivers maintained consistently low comprehensive dynamic degrees of 0.16% and 0.49%, respectively, reflecting relatively stable land use patterns. Desert areas generally showed low comprehensive dynamic degrees with stable land use patterns, small proportions of cropland and construction land, and relatively secure land ecosystems. In contrast, piedmont and plateau regions with high grassland proportions experienced frequent grassland conversions, large comprehensive dynamic degree fluctuations, intense land use changes, and less secure land ecosystems.

2.1.2 Land Use Type Transfer Analysis

To further investigate spatiotemporal patterns, this study distinguished sand land (highlighting desertification changes) from other unused land categories. The transfer matrix reveals intense conversions among land use types (). From 1990 to 2018, the primary source of cropland expansion was grassland conversion. Grassland losses mainly transferred to sand land (21,000+ km^2), cropland, and other unused land. Forestland losses primarily converted to grassland and cropland. Urban and rural construction land expansion originated mainly from cropland (1,300 km^2), followed by grassland. Water area increases resulted primarily from grassland and other unused land conversions. Sand land reductions involved substantial reciprocal conversions with other unused land rather than transitions to ecological land uses like forestland or grassland.

Land use spatial patterns diverged significantly across the region ([Figure 4: see original paper]). In eastern, southern, and northwestern plateau mountain areas, frequent grassland conversions to other land types occurred. In central and south-central desertification-prone regions, sand land and other unused land predominantly converted between each other with minimal transition to other land types. Within secondary water resource zones, grassland-dominated areas (Tianshan North Slope Rivers, Qiangtang Plateau Inland Region, Inner Mongolia Inland Rivers) showed extensive grassland conversions, while sand-dominated desert regions (Gurban Tonggut Desert, Tarim Basin Desert) exhibited stable spatial patterns with limited conversions to other land types.

2.2 Land Ecological Security Evaluation Indicator Weight Analysis

The indicator weights and rankings for the river basins of northwestern China are presented in . Within the criterion layer, system pressure, system state, and system response weights were 0.3112, 0.4985, and 0.1903, respectively, with the state layer representing the most influential factor. Eight indicators exceeded 0.04 weight: GDP, per capita cropland area, wetland area, education expenditure proportion, total population, fertilizer use, secondary industry value-added, and industrial solid waste generation, indicating significant impacts on land ecological security. These reflect the important influence of population, economic structure, and education on regional land ecological security. Conversely, effective irrigation area, soil erosion control area, population density, urban water supply, and waste removal (all <0.02) represented secondary factors.

2.3 Land Ecological Security Comprehensive Evaluation Results

The land ecological security comprehensive index comprises pressure, state, and response indices. From 1990 to 2018, the comprehensive index exhibited a "W-shaped" trend with minor fluctuations and gradual improvement ([Figure 5: see original paper]). Both state and response indices showed fluctuating upward trends, while the pressure index generally declined but began rising after 2010. The land ecological security level remained basically unsafe from 1990 to 2014, transitioning to relatively unsafe after 2015, indicating gradual improvement in land ecological conditions.

Significant variation exists among secondary water resource zones ([Figure 6: see original paper]). From 1990 to 2018, all sub-basins showed stable growth in ecological security indices (0.3-0.5 range), with most transitioning from "unsafe" to "relatively unsafe" levels after 2010. Inner Mongolia Inland Rivers, Altai Mountain South Slope Rivers, and Qiangtang Plateau Inland Region ranked highest, with the first two reaching "relatively safe" levels after 2010, indicating stable land use patterns and ecological environments. In contrast, the Tarim Basin Desert and Gurban Tonggut Desert, dominated by sand and Gobi, maintained low and stagnant ecological security indices throughout the study period.

3 Discussion

Since 2010, the land ecological security pressure index in the river basins of northwestern China has increased, showing a gradual upward trend that indicates growing pressure on land ecological security. Human activities have become the dominant influence on land ecological environments, with regional socioeconomic development driving urban land expansion. The resulting increased demand for land resources from growing populations inevitably impacts land resources in multiple dimensions, triggering a series of land ecological security issues.

Previous studies on Urumqi, Shiyang River Basin, and Manas River Basin in Xinjiang have similarly identified extremely unbalanced land use structures in northwestern China, with cropland and construction land continuously increasing at varying rates under human influence. Our results align with these findings, showing that from 1990 to 2018, grassland and unused land dominated the river basins of northwestern China (90.39% combined), while construction land expanded rapidly at an average annual rate of 4.16%—the highest among all land types. The "Western Development" policy accelerated economic development and population growth, intensifying conversions between ecological and construction land in this structurally unbalanced region.

This study, conducted at the natural watershed scale, reveals distinct differences between desert and mountainous areas. Desert regions like Gurban Tonggut and Tarim Basin, characterized by small wetland areas and severe ecological land degradation, show frequent sand-other unused land conversions and low, stagnant ecological security indices. In contrast, mountainous regions such as Altai South Slope, Tianshan North Slope, Qiangtang Plateau, and Kunlun North Slope, benefit from snowmelt water supply, higher river runoff, and greater ecological land proportions, maintaining higher ecological security indices with some areas reaching "relatively safe" levels. This demonstrates that desertification is a critical limiting factor for land ecological security, while ecological land plays a vital role in improving security.

The relationship among regional socioeconomic development, land use change, and land ecological security is interactive and mutually influential. Socioeconomic development, as the root cause, significantly impacts regional land ecological security. Therefore, improving land ecological security requires not only controlling population growth and enhancing economic efficiency but also increasing fiscal investment in education to deepen public awareness of land ecological protection, thereby alleviating human-land conflicts and achieving sustainable land use and harmonious human-nature development.

4 Conclusions

Based on analysis of land use dynamic changes and land ecological security status in the river basins of northwestern China from 1990 to 2018, this study draws the following conclusions:

1) The comprehensive land use dynamic degree in the river basins of northwestern China was 2.65% from 2015 to 2018, indicating drastic land use change. Urban and rural construction land showed the highest average annual single dynamic degree at 4.16%, demonstrating rapid expansion. Grassland primarily converted to sand land, cropland, and other unused land. In desert areas, conversion between sand and other unused land remained stable, while in plateau regions, grassland frequently converted to other land types.
2) In the land ecological security evaluation index system, the state layer held the highest weight (0.4985), indicating its crucial role in evaluation. Economic and social development, wetland area, and population growth represent the key factors influencing land ecological security assessment in the river basins of northwestern China.
3) The land ecological security index showed an overall increasing trend from 1990 to 2018, remaining at an unsafe level from 1990 to 2014 and transitioning to a relatively unsafe level after 2015. This indicates improving land ecological security conditions in the river basins of northwestern China. Land desertification is a critical limiting factor; improving land ecological security requires greater emphasis on converting desert land to ecological land and maintaining ecological land construction.

References

[1] Li Xiubin. International research trends in land use/land cover change: A core area of global environmental change research[J]. Acta Geographica Sinica, 1996, 63(6): 553-558.

[2] Zhang Junmao, Zang Chuanfu. Spatial and temporal variability characteristics and driving mechanisms of land use in the southeastern river basin from 1990 to 2015[J]. Acta Ecologica Sinica, 2019, 39(24): 9339-9350.

[3] Li Zhao, Zhang Yongfu, Zhang Jinglu. Forecast of the land ecological security at county level in the arid oasis based on planning of land utilization: A case study of Awati in Xinjiang[J]. Research of Soil and Water Conservation, 2014, 21(6): 148-151, 157.

[4] Hou Lisheng, Cai Yunlong. An essential analysis and review on land use/cover change research[J]. Progress in Geography, 2004, 23(6): 96-104.

[5] Cui Shenghui, Hong Huasheng, Huang Yunfeng, et al. Progress of the ecological security research[J]. Acta Ecologica Sinica, 2005, 25(4): 861-868.

[6] Li Hao, Li Shiping, Yin Minhua. Research progress and prospect of land ecological security in China[J]. Journal of Arid Land Resources and Environment, 2016, 30(9): 50-56.

[7] Xiao Duning, Chen Wenbo, Guo Fuliang. On the basic concepts and contents

of ecological security[J]. Chinese Journal of Applied Ecology, 2002, 13(3): 354-358.

[8] Zhu Yanan, Yan Zhiming, Pu Chunling, et al. Land use/cover change and ecological security evaluation in Urumqi[J]. Forest Resources Management, 2020(1): 79-91.

[9] Li Xiaowen, Fang Chuanglin, Huang Jinchuan, et al. The urban land use transformations and associated effects on eco-environment in northwest China arid region: A case study in Hexi Region, Gansu Province[J]. Quaternary Sciences, 2003, 23(3): 280-290, 348-349.

[10] Li Chunyan, Nan Ling. Dynamic evaluation and diagnosis of obstacle factors on land ecological security in Shaanxi Province[J]. China Land Science, 2015, 29(4): 72-81.

[11] Zhang Xiaohu, Lei Guoping, Yuan Lei, et al. Evaluation on ecological security of land based on entropy weight and matter element model: A case study of Heilongjiang Province[J]. China Population, Resources and Environment, 2009, 19(1): 88-93.

[12] Yu Jian, Fang Li, Cang Dingbang, et al. Evaluation of land eco-security in Wanjiang district based on entropy weight and matter element model[J]. Transactions of the Chinese Society of Agricultural Engineering, 2012, 28(5): 260-266.

[13] Cheng Donglin, Chen Ying, Qiao Hongqiang, et al. Time series evaluation of urban land eco-security in eco-vulnerable areas of northwest China: A case study of Lanzhou[J]. Natural Resource Economics of China, 2020, 33(7): 83-89.

[14] Xie Shenshan, Wang Lei, et al. Dynamic evaluation of land ecological security in rocky desertification mountainous area of Guangxi Zhuang Autonomous Region[J]. Bulletin of Soil and Water Conservation, 2018, 38(6): 315-321.

[15] Han B, Liu H, Wang R. Urban ecological security assessment for cities in the Beijing-Tianjin-Hebei metropolitan region based on fuzzy and entropy methods[J]. Ecological Modelling, 2015, 318(1): 217-225.

[16] Pei Tingting, Xia Pei, Liu Zhifeng, et al. Research progress of urban land use/cover change in the oasis cities of China[J]. Arid Land Geography, 2014, 30(2): 215-221.

[17] Gong J Z, Liu Y S, Xia B C, et al. Urban ecological security assessment and forecasting, based on a cellular automata model: A case study of Guangzhou, China[J]. Ecological Modelling, 2009, 220(24): 3612-3620.

[18] Wang C L, Jiang Q O, Shao Y Q, et al. Ecological environment assessment based on land use simulation: A case study in the Heihe River Basin[J]. Science of the Total Environment, 2019, 697: 133928, doi: 10.1016/j.scitotenv.2019.133928.

[19] Yang Chunhong, Zhang Zhengdong, Tian Nannan, et al. Evaluation on land ecological security in Shantou based on P-S-R model[J]. Research of Soil and

Water Conservation, 2012, 19(3): 209-214.

[20] Aimaiti Mailikai, Shabiti Mansuer, Zhang Xueqi, et al. Study on land use change and land ecological security evaluation in oasis of Yarkant River Plain[J]. Soil, 2019, 51(4): 795-802.

[21] Chen Yiduo, Yang Qingyuan, Yang Renhao, et al. Evaluation of land ecological security based on entropy weighted matter-element model: A case of Jiangjin District, Chongqing[J]. Arid Land Geography, 2018, 41(1): 185-194.

[22] Xu Xinliang, Zhuang Dafang, Jia Shaofeng, et al. Automated extraction of drainages in China based on DEM in GIS environment[J]. Resources and Environment in the Yangtze Basin, 2004, 13(4): 343-348.

[23] Zhang Guoping, Zhao Linna, Xu Fengwen, et al. Study on basin partition scheme of China based on basin structure analysis[J]. Journal of Beijing Normal University (Natural Science Edition), 2010, 46(3): 417-423.

[24] Yang Yanchun, Peng Bo, Liu Guili, et al. Quality evaluation of surface water in the northwest region[J]. Yellow River, 2011, 33(11): 93-96.

[25] Wang Xiulan, Bao Yuhai. Study on the methods of land use dynamic change research[J]. Progress in Geography, 1999(1): 3-5.

[26] Wolfslehner B, Vacik H. Evaluating sustainable forest management strategies with the analytic network process in a pressure-state-response framework[J]. Journal of Environmental Management, 2008, 88(1): 1-10.

[27] Li Xiaoyu, Xiao Duning. Dynamics of water resources and land use in oases of middle and lower reaches of Shiyang River Watershed, northwest China[J]. Advances in Water Science, 2005, 16(5): 643-648.

[28] Liu Lingbing, Li Shiping. Evaluation on land ecological security in desertification areas of northwest China: A case study of Jiuquan City[J]. Research of Soil and Water Conservation, 2014, 21(4): 190-194, 202.

[29] Feng Yixing, Luo Geping, Yin Changying, et al. Change of land use degree and ecological security assessment of inland river basins in the arid area: A case study on Manas River Basin in Xinjiang[J]. Journal of Natural Resources, 2009, 24(11): 1921-1932.

[30] Chen Ying, Zhao Yanan, et al. Evaluation on the ecological security of Baiyin City based on P-S-R model[J]. Chinese Agricultural Science Bulletin, 2014, 30(2): 215-221.

[31] Wang Yihang, Xia Pei, Liu Zhifeng, et al. Research progress of urban land use/cover change in the oasis cities of China[J]. Arid Land Geography, 2019, 42(2): 341-353.

[32] Pei L, Du L M, Yue G J. Ecological security assessment of Beijing based on PSR model[J]. Procedia Environmental Sciences, 2010, 2: 832-841.

[33] Ye H, Ma Y, Dong L M. Land ecological security assessment for Bai Autonomous Prefecture of Dali based using PSR model with data in 2009 as case[J]. Energy Procedia, 2011, 5: 2172-2177.

[34] Pang Yasong, Wang Lin. A review of regional ecological security evaluation[J]. China Population, Resources and Environment, 2014, 24(163): 340-344.

[35] Su Weihua. Research on the theory and method of multi-index comprehensive evaluation[D]. Xiamen: Xiamen University, 2000.

[36] Yue Yaojie, Zhou Hongjian, Wang Jingai, et al. Research on the land use structure of Asian desert regions at ecological security level[J]. Advances in Earth Science, 2006, 21(2): 131-137.

[37] Li Zhiguo, Yang Zisheng. Research progress of land ecological security in China[J]. China Safety Science Journal, 2007, 17(12): 5-12, 197.

[38] Shi X Q, Zhao J Z, Ouyang Z Y. Assessment of eco-security in the knowledge grid e-science environment[J]. Journal of Systems and Software, 2005, 79(2): 246-252.

[39] Zhu Yanan, Pu Chunling. Analysis on landscape pattern change and ecological security of land use in Urumqi[J]. Ecological Science, 2020, 39(2): 133-144.

[40] Zhang Yida, Liu Xuelu, Fan Yahong, et al. Multi-functional evaluation on land use in Lanzhou City based on the improved TOPSIS method[J]. Arid Land Geography, 2019, 42(2): 444-451.

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