Postprint of Ecological Network Construction in the Aksu River Basin

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Abstract

The Aksu River Basin is located in the arid region of northwestern China, featuring a typical oasis-desert landscape pattern. The construction of watershed ecological networks is of significant importance for building ecological barriers in areas along the Belt and Road Initiative. Focusing on five counties and cities within the Aksu River Basin, this study extracts watershed ecological corridors based on ecological sources and resistance surfaces, comparatively analyzes changes in the watershed ecological network from 1980 to 2020, and optimizes the 2020 watershed ecological network according to ecological "pinch points" and barrier points. The study found: (1) During the study period, the area of watershed ecological sources increased by 6%, accompanied by certain spatial fragmentation issues. (2) Watershed resistance values exhibited a slight overall increase, with high-resistance zones centered on towns emerging in economically more developed areas. (3) Six new ecological corridors were added during the study period, resulting in a denser ecological network compared to previous conditions. (4) The 2020 watershed ecological network contained 12 pinch points and 7 barrier points, with corresponding improvement measures proposed based on land cover types. This study can provide insights for ecological network restoration, key area identification, and regional green development in arid regions.

Full Text

Construction of the Ecological Network in the Aksu River Basin

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Abstract

The Aksu River Basin, located in the arid region of northwestern China, exhibits a typical oasis-desert pattern. Constructing a watershed ecological network is crucial for building an ecological barrier along the Belt and Road Initiative. This study examines five counties and cities within the Aksu River Basin, extracting ecological corridors based on ecological sources and resistance surfaces. During the study period, the area of ecological sources in the watershed increased, though spatial fragmentation issues persist. High-resistance zones emerged around urban centers in economically developed areas. The 2020 watershed ecological network contained 31 ecological corridors, with six new corridors added during the study period, resulting in a denser and more stable network compared to previous periods. The network included 12 ecological pinch points and seven barrier points, for which targeted improvement measures were proposed based on land cover types. This research provides insights for ecological network restoration, identification of critical areas, and regional green development in arid zones.

Keywords: ecological networks; ecological sources; ecological corridors; Aksu River Basin

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1.1 Study Area and Data Sources

The Aksu River Basin is situated on the northern edge of the Taklamakan Desert, approximately 80 km from Aksu City, representing the frontline in Xinjiang' s battle against desertification. Over the past 30 years, multiple million-mu ecological engineering projects have been implemented, effectively improving the local ecological environment and climate. The basin serves as a critical ecological barrier along the Belt and Road Initiative, making the construction of its ecological network both valuable and significant.

For this study, five counties and cities—Wushi County, Wensu County, Aksu City, Awati County, and Alar City—were selected as the research area [Figure 1: see original paper]. Land use data were obtained from the Chinese Academy of Sciences Resource and Environmental Science Data Center (https://www.resdc.cn) using the 30 m resolution China Multi-Period Land Use Remote Sensing Monitoring Dataset (CNLUCC). DEM data were sourced from the Chinese Academy of Sciences Geographic Space Data Cloud (https://www.gscloud.cn) using SRTMDEM 90 m resolution elevation data.

1.2 Research Methods

1.2.1 Identification of Important Ecological Sources Morphological Spatial Pattern Analysis (MSPA) was employed to classify raster pixels based on mathematical morphology principles, identifying patches and corridors that play crucial roles in spatial form and connectivity. The analysis yields nonoverlapping landscape types. Based on these results, thresholds were established to screen important ecological sources from the core areas. Forest land, cultivated land, high-coverage grassland, medium-coverage grassland, and water bodies (excluding permanent glaciers and snow) were designated as foreground elements, while urban-industrial-mining residential land, unused land, and permanent glaciers/snow were classified as background elements. The GuidosToolbox software was used to obtain different landscape types [Figure 1: see original paper]. Considering the geographical spatial connectivity and referencing the *Aksu River Basin Gazette* compiled by the Xinjiang Aksu River Basin Management Office, the study area was delineated as described above.

1.2.2 Construction of Ecological Resistance Surface The Minimum Cumulative Resistance (MCR) model was used to calculate the minimum cost distance for ecological flows by accumulating resistance across the landscape. Seven factors were selected based on the natural and anthropogenic characteristics of the study area: land use type, distance to water bodies, distance to towns, distance to rural settlements, distance to industrial sites, slope, and elevation. These factors were weighted and overlaid to generate a comprehensive ecological resistance surface for the Aksu River Basin. The calculation formula is:

$$MCR = f_{\min} \sum_{j=1}^{n} (D_{ij} \times R_i)$$

where MCR represents the minimum cumulative resistance value, f is the resistance function, D_{ij} is the minimum resistance value from ecological source j to patch i, and R_i is the resistance coefficient of patch i.

1.2.3 Ecological Security Network Analysis Linkage Mapper was used to extract ecological corridors and calculate the lowest-cost connections between source areas. Different landscapes and urbanization levels affect animal habitats, creating varying resistance factors when animals move between sources. Cost-weighted analysis calculates the cumulative resistance of movement to identify the lowest-cost path, which represents the ecological corridor:

$$G_{ij} = \frac{N_i N_j}{L_{ij}} = \frac{1}{D_{ij}} \times \frac{\ln P_i \ln P_j}{\ln S_{ij} \ln P_i P_j}$$

where G_{ij} is the interaction force between points i and j; N_i and N_j are the weight values of the two patches; D_{ij} is the standardized cumulative resistance of the potential corridor from point i to j; L_{ij} is the cumulative resistance value of the potential corridor from point i to j; and P_i and P_j represent other relevant parameters.

Based on circuit theory, the Circuitscape model was applied to calculate current density in ecological corridors. In this modeling framework, ecological "pinch points" represent high-current-density areas that indicate irreplaceable zones requiring priority protection. Ecological barrier points identify areas where organism movement is obstructed, necessitating ecological restoration measures tailored to local land use types and infrastructure conditions.

2.1 Identification of Important Ecological Sources

The changes in ecological sources across five periods (1980, 1990, 2000, 2010, and 2020) in the Aksu River Basin are shown in . In 1980, the core area accounted for 5.99% of the watershed, with 11 important ecological sources covering 8.76% of the total area. The 1990s represented a decade of rapid environmental change, with the number of important ecological sources decreasing slightly but the total area of ecological sources increasing. Fragmentation improved, with adjacent sources merging into larger patches. By 2020, the number of ecological sources had increased to 13, covering 14.75% of the watershed area—nearly double the 1980 figure. The ecological environment gradually recovered, demonstrating the significant achievements of ecological restoration projects.

2.2 Construction of Ecological Resistance Surface

Based on the basin' s physical geography, secondary land use classifications were used to refine resistance values for landscape types. Low-coverage grassland, which covers a large area in the Aksu River Basin, is vulnerable to human activities and climate change, differing significantly from medium- and high-coverage grassland. Therefore, its resistance value was set accordingly. Cultivated land, with high productivity and coverage during the growing season, was assigned a lower resistance value. Since unused land dominates the study area, relying solely on primary land use classification would limit the results. Secondary classification allowed for nuanced treatment of unused land: saline-alkali land and swamp land received moderate resistance values, while other unused land received higher values. The Analytic Hierarchy Process determined factor weights .

The ecological resistance surface revealed three distinct gradients from river to oasis to desert. High-resistance zones concentrated in the high-altitude areas of northern Wensu County and near urban-industrial land in Aksu City, gradually expanding due to glacier melt, industrial development, and urban expansion. However, ecological engineering projects focused on afforestation effectively mitigated resistance increases. A small low-resistance area in southwestern Wushi County expanded continuously after 2000, forming a systematic low-resistance zone.

2.3 Extraction of Ecological Corridors

The ecological network underwent substantial changes from 1980 to 2020 [Figure 3: see original paper]. Ecological sources concentrated toward the central and northern parts of the basin, with central corridors becoming denser and more complex. In 1980, corridors were sparse and showed little variation. By 1990, two important corridors disappeared: one connecting Aksu City and Awati County, and another linking northern and southern sources in Wensu County. New sources emerged in Wushi and Wensu counties by 2000, with corridor numbers increasing accordingly. By 2010, larger new sources appeared in both counties, with existing sources expanding to form a tighter network.

Wensu County' s sources differed markedly from other regions, appearing more intact without significant fragmentation or large pores, attributable to high-quality forest areas. The disappeared corridors were located in economically developed areas where urban expansion altered landscape patterns and resistance values, changing habitat connectivity pathways. Rapid economic development enabled advanced restoration technology and environmental investment, creating a virtuous cycle. During the study period, source fragmentation improved, and new sources emerged systematically.

2.4 Ecological Pinch Points and Ecological Barrier Points

A total of 12 pinch points were identified based on current intensity [Figure 4: see original paper]. The largest pinch point was located in central Aksu City, dominated by river channels and low-coverage grassland. Protection strategies should focus on river dredging and water quality management, particularly addressing pollution from agricultural fertilizers and pesticides used in extensive irrigated cropland. Pinch points in northern Wensu County were situated in forest and grassland areas near high-mountain water sources, requiring integrated glacier meltwater utilization plans and balanced grazing policies.

Seven ecological barrier points were identified, primarily in unused land such as sand and saline-alkali areas. Barrier points in northern Aksu City overlapped with agricultural production spaces within ecological farmland redlines, where appropriate conversion of farmland to forest or grassland could be implemented. The remaining barrier points did not coincide with pinch points and were mostly in unused land with challenging restoration conditions. Restoration should focus on reducing human disturbance in sandy areas and gradually rebuilding vegetation cover.

2.5 Ecological Security Pattern and Optimization Strategies

The 2020 ecological security pattern was constructed from the identified sources and corridors. Central Wensu County and northern Wushi County contained large ecological sources with good environmental conditions, benefiting from northern forest areas and mountain meltwater that significantly contributed to the basin' s ecological network and regional climate improvement. However, Wushi County' s network remained sparse with poor connectivity due to high elevations and complex terrain. Dense networks characterized southern Wensu County, northern Aksu City, Alar City, and Awati County. Despite high urbanization and resistance values in Aksu City, its economic and technological advantages facilitated positive ecological development. The Aksu River Basin has transitioned from independent economic development and ecological management to integrated green development.

Future planning should prioritize restoration of ecological barrier points, considering biological migration pathways during urban development and road construction to achieve green development. Economic growth from urbanization has enhanced restoration capabilities but also damaged ecological networks. Barrier points may increase migration difficulty or even block movement entirely, requiring careful attention in future ecological planning.

3 Discussion

Arid regions generally have low vegetation coverage with strong seasonal variation. This study constructed the ecological network during the vegetation growing season. The land cover situation in the study area is unique, with unused land, cultivated land, and grassland as the main types. When assigning values to different landscape types, secondary classification should be fully considered based on the role of landscape types. Regional grassland is sparse and poor, and low-coverage grassland was included as background while cultivated land was included as foreground due to its superior soil nutrient structure and higher ecological value during the growing season compared to low-coverage grassland.

The generation of ecological sources and construction of corridors in the basin both centered on Aksu City. Despite high resistance values from urbanization, Aksu City' s economic advantages and technical capabilities enabled ecological improvement. However, this study has limitations. Due to the large study area scale, elevation was linearly classified to represent terrain resistance in the resistance surface construction. A more scientifically rigorous approach would consider vertical and horizontal zonal distributions, which could be applied in future small-scale studies. Additionally, cultivated land cover changes dramatically with seasons; this study focused on growing-season crops' impact on the landscape and ecological resistance. Future research could deepen the temporal analysis to examine the role of cultivated land at different growth stages.

4 Conclusion

This study examined the Aksu River Basin in an arid region, analyzing changes in ecological sources, resistance surfaces, and corridors across different periods using MSPA models and circuit theory. Ecological restoration measures were proposed based on identified pinch points and barrier points. The main conclusions are:

1) From 1980 to 2020, the ecological source area in the Aksu River Basin

increased by 6%, though spatial fragmentation persists. Sources are concentrated in the central and northern parts of the basin.

2) Spatial distribution of ecological resistance values shows clear differences, with high values 主要分布在阿克苏市城镇建设聚集地和温宿县北部高海拔地区. (Note: This sentence appears to have mixed Chinese and English in the original and should be translated as: "Spatial distribution of ecological resistance values shows clear differences, with high values 主要分布在阿克苏市城镇建设聚集地和温宿县北部高海拔地区" → "Spatial distribution of ecological resistance values shows clear differences, with high values 主要分布在阿克苏市城镇建设聚集地和温宿县北部高海拔地区" - actually, let me check the original again. The original has: "高阻力值主要分布在阿克苏市城镇建设聚集地和温宿县北部高海拔地区。" which translates to: "High resistance values were mainly distributed in urban construction agglomerations of Aksu City and high-altitude areas of northern Wensu County.")

3) The basin contained 31 ecological corridors in 2020, with a dense ecological network formed in the central region, indicating a more stable ecosystem and gradually improving ecological environment.

4) In 2020, the Aksu River Basin contained 12 ecological pinch points and seven ecological barrier points, requiring targeted ecological protection and restoration measures based on different landscape types.

These findings provide references for ecological network restoration, identification of critical areas, and territorial space optimization under the dual-carbon background, offering new insights for green development in arid basins along the Belt and Road Initiative.

References

[1] Xu Liting, Liu Haihong, Huang Lijie, et al. Spatial and temporal changes of ecological environment and water conservation in Fenhe River Basin from 2000 to 2020[J]. Arid Zone Research, 2023, 40(2): 313-325.

[2] Huang Jianping, Yu Haipeng, Dai Aiguo, et al. Drylands face potential threat under 2 °C global warming target[J]. Nature Climate Change, 2017, 7: 417-422.

[3] Wu Zhenhua, Lei Shaogang, Yan Qingwu, et al. Landscape ecological network construction controlling surface coal mining effect on landscape ecology: A case study of a mining city in semi steppe[J]. Ecological Indicators, 2021, 133: 108403.

[4] Miao Zuohua, Pan Lei, Wang Qiaozhi, et al. Research on urban ecological network under the threat of road networks—A case study of Wuhan[J]. ISPRS International Journal of Geo-Information, 2019, 8(8): 342.

[5] Chen Zhuan, Ma Binbin, Wei Xiaojian. Construction and optimization of

ecological network in Xiong' an New Area based on the supply and demand of ecosystem services[J]. Acta Ecologica Sinica, 2020, 40(20): 7197-7206.

[6] Shi Fangning, Liu Shiliang, Sun Yongxiu, et al. Ecological network construction of the heterogeneous agro-pastoral areas in the upper Yellow River basin[J]. Agriculture, Ecosystems & Environment, 2020, 302(38): 107069.

[7] Jin Aibo, Zhang Shiyang, Wang Xiangrong. Spatial temporal pattern and optimization of the green space ecological networks in the Ningshao Plain[J]. Journal of Ecology and Rural Environment, 2022, 38(11): 1415-1426.

[8] Dindaroglu T. Determination of ecological networks for vegetation connectivity using GIS & AHP technique in the Mediterranean degraded karst ecosystems[J]. Journal of Arid Environments, 2021, 188: 104385.

[9] Rong Yuejing, Yan Yan, Wang Chenxing, et al. Construction and optimization of ecological network of Nanchang City based on MSPA and MCR model[J]. Bulletin of Soil and Water Conservation, 2021, 41(6): 139-147.

[10] Fu Fengjie, Liu Zhenhuai, Liu Hai. Identifying key areas of ecosystem restoration for territorial space based on ecological security pattern: A case study in Hezhou City[J]. Acta Ecologica Sinica, 2021, 41(9): 3406-3414.

[11] Tarabon S, Calvet C, Delbar V, et al. Integrating a landscape connectivity approach into mitigation hierarchy planning by anticipating urban dynamics[J]. Landscape and Urban Planning, 2020, 202: 103871.

[12] Almeida M R, Andrello M, Pressey R L, et al. Biologically representative and well connected marine reserves enhance biodiversity persistence in conservation planning[J]. Conservation Letters, 2018, 11(4): e12439.

[13] Dong Jianquan, Peng Jian, Xu Zihan. Integrating regional and interregional approaches to identify ecological security patterns[J]. Landscape Ecology, 2021, 36: 2151-2164.

[14] Wu Maoquan, Hu Mengmeng, Wang Tao, et al. Recognition of urban ecological source area based on ecological security pattern and multi-scale landscape connectivity[J]. Acta Ecologica Sinica, 2019, 39(13): 4720-4731.

[15] Wang Ranghui, Zhang Weidong, Zhou Limin. Coupling relationship between climate change, landscape pattern and ecological security[J]. Journal of Nanjing University of Information Science & Technology (Natural Science Edition), 2022, 14(5): 509-515.

[16] Regan R S, Juracek K E, Hay L E, et al. The U.S. Geological Survey National Hydrologic Model infrastructure: Rationale, description, and application of a watershed scale model for the conterminous United States[J]. Environmental Modelling & Software, 2019, 111: 192-203.

[17] Zhu Liangjun, Qin Chengzhi, Zhu Axing. Spatial optimization of watershed best management practice scenarios based on boundary adaptive configuration

units[J]. Progress in Physical Geography: Earth and Environment, 2021, 45(2): 207-227.

[18] Xu Chen, Yang Guishan, Wan Rongrong, et al. Toward ecological function zoning and comparison to the Ecological Redline Policy: A case study in the Poyang Lake Region, China[J]. Environmental Science and Pollution Research, 2021, 28: 40178-40191.

[19] Peng Jian, Pan Yajing, Liu Yanxu, et al. Linking ecological degradation risk to identify ecological security patterns in a rapidly urbanizing landscape[J]. Habitat International, 2018, 71: 110-124.

[20] Pierre S, Peter V. Morphological segmentation of binary patterns[J]. Pattern Recognition Letters, 2009, 30(4): 456-459.

[21] James D W, Kurt H R, Timothy G W, et al. A national assessment of green infrastructure and change for the conterminous United States using morphological image processing[J]. Landscape and Urban Planning, 2010, 94(3/4): 186-195.

[22] Wu Jinhua, Liu Siyu, Bai Shuai. Identification and optimization of ecological corridors in Shenmu City based on landscape ecological security[J]. Arid Zone Research, 2021, 38(4): 1120-1127.

[23] Zhang Yali, Shen Wenjuan, Li Mingshi, et al. Assessing spatio-temporal changes in forest cover and fragmentation under urban expansion in Nanjing, eastern China, from long-term Landsat observations (1987-2017)[J]. Applied Geography, 2020, 117: 102190.

[24] Mcrae B H, Dickson B G, Keitt T H, et al. Using circuit theory to model connectivity in ecology, evolution, and conservation[J]. Ecology, 2008, 89(10): 2712-2724.

[25] Xu Xinliang, Liu Jiyuan, Zhang Shuwen, et al. Multi-period land use and land cover remote sensing monitoring dataset in China (CNLUCC)[DB/OL]. http://www.resdc.cn. [2023-3-25].

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