Spatiotemporal Analysis of Eco-environmental Benefits in Hami City: Postprint

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Abstract

This study utilizes three periods of Landsat series data from 2000, 2008, and 2018, employing Principal Component Analysis of greenness, humidity, dryness, and heat to construct the Remote Sensing Ecological Index (RSEI). Simultaneously, standard deviation ellipses and centroids of different ecological grades are adopted to conduct remote sensing dynamic monitoring of ecological quality in Yizhou District, Hami City, an arid region urban area, and to analyze the spatial expansion of ecological quality. The results demonstrate that the mean RSEI value in Yizhou District of Hami City increased from 0.22 and 0.31 to 0.40, exhibiting an upward trend. While the overall ecological quality has improved, it remains at a relatively low level. Areas with improved ecological environment are concentrated around the urban area of Yizhou District, displaying a ring-shaped distribution. Regions of ecological degradation are primarily located in the southern slope zone of the East Tianshan Mountains to the north and the undeveloped Gobi desert in the southwest of the urban area. Based on variations in the standard deviation ellipse and centroids of different ecological grades, areas with better ecological quality in Yizhou District have expanded spatially from north to south, and the overall better ecological areas have maintained a southeast-northwest orientation from 2000 to 2018.

Full Text

Preamble

Time-Space Analysis of Eco-Environmental Benefits in Hami City

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Abstract: Based on Landsat series data from 2000, 2008, and 2018, this study constructed a Remote Sensing Ecological Index (RSEI) using principal component analysis of greenness, humidity, dryness, and thermal components. Concurrently, standard deviation ellipse and centroid analysis of different ecological grades were employed to conduct dynamic remote sensing monitoring of ecological quality in Yizhou District, Hami City, an arid region, and to analyze spatial expansion patterns of ecological quality. The results indicate that the mean RSEI value in Yizhou District increased from 0.22 in 2000 and 0.31 in 2008 to 0.40 in 2018, demonstrating an overall improving trend. While the general ecological quality has improved, the absolute level remains relatively low. Areas with improved ecological conditions are concentrated in a ring-shaped distribution around the urban core of Yizhou District, whereas degraded areas are primarily located on the southern slopes of the eastern Tianshan Mountains in the north and in the undeveloped Gobi desert to the southwest of the urban area. Analysis using standard deviation ellipse and centroid shifts of different ecological grades reveals that regions with better ecological quality in Yizhou District have expanded spatially from north to south, maintaining a southeast-northwest orientation throughout the 2000–2018 period.

Keywords: remote sensing ecological index; standard deviation ellipse; ecological quality; spatiotemporal distribution; Hami City

With the implementation of China’ s Western Development Strategy, cities in the arid northwestern regions have experienced rapid spatial expansion, intensifying conflicts between urban construction land and ecological land. Remote sensing technology has been widely applied in urban expansion and ecological monitoring due to its broad coverage, high timeliness, and relatively low cost. This technology has also been utilized to assess and monitor geographical units such as urban areas, grasslands, wetlands, deserts, and rivers [1-9]. For instance, watershed eco-environments have been monitored using water body indices and modified water indices [10-11]. Regional heat island effects have been studied by extracting land surface temperature from MODIS data [12], while remote sensing has been applied to examine land use change [13-14], impervious surface coverage [15], and regional vegetation coverage and dynamic changes [16-17] to investigate relationships between urban ecology and expansion. However, most of these studies focus on single factors or provide only qualitative descriptions of urban ecological changes. In qualitative analyses, evaluation systems often rely on subjectively assigned weights, which may not fully reflect natural processes.

To address this limitation, Xu Hanqiu [18] proposed a novel Remote Sensing Ecological Index (RSEI) that integrates multiple indicators while using principal component analysis to determine weights and contribution rates objectively. Since its introduction, this index has been widely applied in urban areas [19-20], nature reserves [21-22], and soil erosion studies [23-24], demonstrating its effectiveness in reflecting regional eco-environmental quality.

Hami City, known as the "gateway to Xinjiang," serves as a crucial entry point to the region and represents an important node city in the "Belt and Road" development initiative, as well as a significant town on the ancient Silk Road. Hami plays a vital role in transportation and wind power generation across Xinjiang. Over the past two decades, with the implementation of the Western Development Strategy and related policies, the city has undergone substantial spatial expansion and ecological transformation. Studying these ecological changes has become a research priority, particularly in response to the *Hami City Land Use Master Plan (2010-2020)*, which emphasizes strengthening dynamic monitoring and evaluation of plan implementation. Therefore, this study employs the RSEI to investigate eco-environmental quality changes in Yizhou District, Hami City from 2000 to 2018, while using standard deviation ellipse analysis to explore urban spatial expansion, aiming to provide scientific support for urban expansion monitoring and eco-environmental construction in the region.

1. Study Area Overview

Hami City is located in the easternmost part of Xinjiang, bordering Jiuquan City in Gansu Province to the east, Turpan City and Changji to the west, Bayingolin to the south, and Mongolia to the north, with a national border of 586.663 km. The city spans both sides of the Tianshan Mountains, which divide it into Barkol County and Yiwu County in the north, and Yizhou District in the south. The region features forests, grasslands, and glaciers, with landforms comprising high mountains (4.5% of total area), deserts (1.5%), Gobi (27.9%), and hills (65.5%). Only 29.35% of the total area has been utilized by humans, with major towns distributed on alluvial plains along the southern slopes of the eastern Tianshan Mountains. Hami experiences a typical temperate continental arid climate with abundant sunny days and an average annual sunshine duration of 3,358 hours, ranking among the highest in China.

Given that Yizhou District contains extensive desert and Gobi areas while urban settlements and artificial oases are relatively concentrated, this study focuses on the urban core area of Yizhou District and surrounding regiment farm oases as the research area (Figure 1 [Figure 1: see original paper]).

2.1 Data Sources and Preprocessing

This study utilized three periods of Landsat series remote sensing data as the primary data source: Landsat 5 TM imagery from September 6, 2000, and August 11, 2008, and Landsat OLI/TIRS imagery from September 15, 2018. All data have a spatial resolution of 30 m. Three time periods with good weather conditions, cloud cover below 1%, and similar seasonal timing were selected to ensure comparability. Data were obtained from the United States Geological Survey (http://glovis.usgs.gov). Land use data were derived from a global 10 m resolution land classification map produced by Tsinghua University.

In ENVI 5.3, the Radiometric Calibration tool was first applied to perform radiometric calibration on the three temporal datasets. Subsequently, FLAASH atmospheric correction was conducted on the calibrated images, with the average elevation of Yizhou District set at 0.85 km and aerosol type designated as urban. Image registration was performed using a second-order polynomial and nearest-neighbor resampling method, with root mean square error constrained within 0.5 pixels.

2.2.1 Remote Sensing Ecological Index

The Remote Sensing Ecological Index (RSEI) is a comprehensive index for assessing regional eco-environmental quality [25]. The index integrates four environmental components: greenness, humidity, dryness, and thermal conditions. Greenness is represented by the Normalized Difference Vegetation Index (NDVI), humidity by the wetness component from the Tasseled Cap transformation, dryness by a composite of bare land and built-up indices, and thermal conditions by land surface temperature. This approach is superior to the Ecological Index (EI) issued by the Ministry of Environmental Protection in 2006 [26].

(1) Greenness Indicator
The greenness indicator is the optimal factor for reflecting plant growth status and nutrient information, closely related to leaf area index, coverage, and biomass [27].

$$NDVI = \frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R}$$

where ρ_{NIR} and ρ_R represent reflectance in near-infrared and red bands, respectively.

(2) Humidity Indicator
The wetness component obtained from Tasseled Cap transformation effectively reflects moisture conditions of vegetation, water bodies, and soil [28].

$$WET = A_1\rho_B + A_2\rho_G + A_3\rho_R + A_4\rho_{NIR} + A_5\rho_{SWIR1} + A_6\rho_{SWIR2}$$

where ρ_B, ρ_G, ρ_R, ρ_{NIR}, ρ_{SWIR1}, and ρ_{SWIR2} are reflectance values for blue, green, red, near-infrared, shortwave infrared 1, and shortwave infrared 2 bands, respectively (same as Equation 3). A_1 through A_6 are wetness coefficients: for Landsat 5 imagery, $A_1 = 0.0315$, $A_2 = 0.2021$, $A_3 = 0.3102$, $A_4 = 0.1594$, $A_5 = -0.6806$, $A_6 = -0.6109$; for Landsat 8 imagery, $A_1 = 0.1511$, $A_2 = 0.1973$, $A_3 = 0.3283$, $A_4 = 0.3407$, $A_5 = -0.7117$, $A_6 = -0.4559$.

(3) Dryness Indicator
Urban area "dryness" primarily results from built-up land expansion and extensive bare land. Therefore, the Normalized Difference Soil Index (NDSI) was constructed using a composite of the Soil Index (SI) and Index-Based Built-up Index (IBI) [28].

$$NDSI = \frac{SI + IBI}{2}$$

$$IBI = \frac{2\rho_{SWIR1}}{\rho_{SWIR1} + \rho_{NIR}} - \frac{\rho_{NIR}}{\rho_{NIR} + \rho_{R}} - \frac{\rho_{G} + \rho_{SWIR1}}{2\rho_{SWIR1} + \rho_{NIR} + \rho_{NIR}(\rho_{NIR} + \rho_{R}) + \rho_{G} + \rho_{SWIR1}}$$

$$SI = \frac{(\rho_{SWIR1} + \rho_{R}) - (\rho_{NIR} + \rho_{B})}{(\rho_{SWIR1} + \rho_{R}) + (\rho_{NIR} + \rho_{B})}$$

(4) Thermal Indicator

The thermal indicator (LST) is represented by actual land surface temperature. This study retrieved land surface temperature from Landsat thermal infrared data, using Band 10 for Landsat 8 imagery due to insufficient accuracy of Band 11 [24].

$$LST = \frac{T}{1 + (\lambda \times T/\rho)\ln\varepsilon}$$

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_{6/10}} + 1\right)}$$

$$L_{6/10} = gain \times DN + bias$$

where LST is land surface temperature, T is sensor temperature value, K_1 and K_2 are calibration coefficients, $L_{6/10}$ represents thermal infrared radiance for TM/TIRS bands (Bands 6 and 10), DN is pixel gray value, $gain$ and $bias$ are band gain and offset values, λ is the central wavelength of the thermal infrared band, ρ is the Boltzmann constant, and ε is land surface emissivity (values referenced in [29-30]). For TM imagery: $K_1 = 607.76\,W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$, $K_2 = 1260.56\,K$, $gain = 0.055$, $bias = 1.18243$, $\lambda = 11.435\,\mu m$. For OLI/TIRS imagery: $K_1 = 774.89\,W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$, $K_2 = 1321.08\,K$, $gain = 3.342$, $bias = 0.1$, $\lambda = 10.900\,\mu m$; $\rho = 1.438 \times 10^{-2}\,m \cdot K$.

(5) RSEI Construction

RSEI is calculated through principal component analysis of the four indicators. After computing each indicator, four single-band images are produced. Due to inconsistent dimensions across bands, normalization is applied to unify values between 0 and 1. The four indicators are then stacked into a multi-band image for PCA analysis.

$$RSEI_0 = 1 - \{PC1[f(NDVI, WET, LST, NDBSI)]\}$$

$$RSEI = \frac{RSEI_0 - RSEI_{0_{min}}}{RSEI_{0_{max}} - RSEI_{0_{min}}}$$

where $RSEI$ is the Remote Sensing Ecological Index synthesized from four indicators: $NDVI$ (greenness), WET (wetness), LST (thermal), and $NDBSI$ (dryness). $PC1$ represents the first principal component obtained from PCA. $RSEI_0$ is the initial RSEI value after normalization of PC1, and $RSEI$ is the final normalized value, with $RSEI_{0_{min}}$ and $RSEI_{0_{max}}$ representing the minimum and maximum values of $RSEI_0$, respectively.

2.2.2 Standard Deviation Ellipse and Centroid Analysis

This study employed a standard deviation ellipse model to analyze spatial variation characteristics of ecological quality in Yizhou District, Hami City. The centroid of the standard deviation ellipse was calculated first [31].

$$M(X,Y) = \left(\sum w_i x_i, \sum w_i y_i\right)$$

where $M(X,Y)$ represents the distribution centroid of a specific ecological grade, n is the number of analysis units, w_i is the attribute value of analysis unit i serving as a spatial weight, and (x_i, y_i) are the central coordinates of unit i.

3.1 Principal Component Analysis of Ecological Indicators

As shown in Table 1 , the contribution rates of the first principal component (PC1) from the PCA of NDVI, wetness component, dryness index, and land surface temperature were 81.85%, 92.10%, and 84.41% for 2000, 2008, and 2018, respectively. All three periods exhibited PC1 values exceeding 80%, indicating that the first principal component captures the majority of feature information and validating the RSEI construction approach. NDVI and WET components showed positive values, while NDSI and LST displayed numerous negative values, demonstrating that greenness and humidity positively correlate with ecological conditions, whereas dryness and thermal components negatively correlate, particularly in years with poorer ecological quality.

Table 2 reveals that mean RSEI values increased consistently from 2000 to 2018 (0.22, 0.31, and 0.40). Constrained by the arid urban environment, the relatively low RSEI values indicate simple ecological conditions and limited vegetation coverage, as evidenced by high NDSI mean values and contribution rates to PC1. NDSI means exceeded 0.87 across all three periods, suggesting numerous poor-quality pixels that negatively impact overall ecological assessment. NDVI mean values increased initially then decreased slightly, with standard deviations following the same trend, indicating relatively stable development directions for urban greening and surrounding artificial oases. WET means remained below 0.4 across all periods, reflecting poor humidity conditions consistent with the arid regional context. LST means decreased from 0.63 in 2000 to 0.48 in 2018, indicating ecological improvement and expansion of green ecological functional zones with evident cooling and humidifying effects, corroborated by changes in NDVI and WET. Overall, Yizhou District' s ecological conditions improved gradually from 2000 to 2018, with dryness and thermal components exerting negative correlations and greenness and humidity showing positive correlations, though the overall ecological level remained low with RSEI means below 0.5.

3.2 Ecological Environment Quality Classification

To enhance spatial clarity of RSEI and facilitate comparison of ecological quality changes across periods, the three temporal RSEI images were normalized to 0–1 range and classified into five grades at 0.2 intervals (Figure 2 [Figure 2: see original paper]): poor (0–0.2), relatively poor (0.2–0.4), moderate (0.4–0.6), good (0.6–0.8), and excellent (0.8–1.0). Spatial area statistics were then calculated for each grade.

The classification results (Table 3) show that the proportion of "poor" grade decreased continuously from 67.94% in 2000 to 50.15% in 2008 and 21.69% in 2018, representing an overall reduction of 46.25%. This indicates that most undeveloped areas around Hami City were rationally utilized, with significant improvements in vegetation coverage and reduced bare land area. The "relatively poor" grade increased from 15.08% to 18.90% and then to 33.80%, expanding mainly in southeastern and northwestern regions as areas transitioned from "poor" to "relatively poor," showing some improvement but remaining in a suboptimal state. The "moderate" grade increased from 10.79% in 2000 to 20.16% in 2018, representing nearly 200% growth. By 2018, the area proportions of poor, relatively poor, moderate, and good grades were relatively balanced at approximately 25% each, indicating substantial overall improvement compared to 2000.

The "excellent" grade exhibited an initial increase followed by decrease, rising from 0.27% in 2000 to 3.44% in 2008 before declining to 0.18% in 2018. This pattern relates to recent industrial and agricultural transformation planning in southwestern and southeastern Yizhou District, including industrial park development. These measures reduced bare land and increased vegetation coverage while expanding construction land. In 2008, cotton was the primary crop in ecologically excellent areas, but by 2018, the same areas were classified as "good" due to Hami' s agricultural transition from cotton to higher-value crops like jujube trees. Since cotton exhibits higher chlorophyll content and NDVI values than jujube trees during the same growth period, this crop change resulted in different ecological grades between the two periods.

3.3 Ecological Environment Quality Change

To further analyze differences in ecological quality over the 18-year period, differential analysis was performed on the bi-temporal RSEI data to identify spatial regions of degradation or improvement and their corresponding areas (Table 4).

From 2000 to 2008, improved ecological areas covered 39 km^2 (2.87%), concentrated in southwestern and southeastern Hami City due to agricultural transformation and extensive cotton cultivation that increased vegetation coverage and humidity. Degraded areas reached 278 km^2, substantially exceeding improved areas. As shown in Figure 3 [Figure 3: see original paper], degraded regions were concentrated in the northeast and central research area, including the Gobi connecting northern Yizhou District with the southern Tianshan slopes, the central urban area, and the Huicheng area south of the city. This resulted from continuous urban expansion and large-scale reclamation of artificial oases around the city, causing severe ecological damage. However, artificial oasis expansion contributed to a slight increase in mean RSEI values. The total area experiencing ecological change from 2000 to 2008 was 1,048 km^2 (76.75%), indicating overall poor ecological conditions with minimal change and low mean RSEI values, consistent with Table 2 results.

Figure 3 reveals that degraded areas were relatively dispersed across the three periods, while improved areas were distributed peripherally in a nested ring pattern. From 2008 to 2018, improvement areas were less conspicuous because new oases emerged around previously degraded artificial oases, becoming the primary improvement zones. This demonstrates that new oasis development consistently accompanies ecological quality improvement. Therefore, urban expansion in arid regions is fundamentally based on oasis expansion, and in Yizhou District, nearly all oasis expansion over the past 18 years has been artificial. Thus, ecological quality can be improved by expanding artificial oases under rational water resource management. Improved ecological quality areas reached 97 km^2 (7.14%), concentrated in western, southern, and eastern Yizhou District, manifested as increased artificial oasis area dominated by agricultural land. Degraded areas were primarily located in the north, the main direction of urban expansion over the past 18 years.

From 2000 to 2018, degraded areas totaled 95 km^2 (6.95%), mainly comprising rapidly expanding urban impervious surfaces. Relatively concentrated poor-quality patches appeared around the Yizhou District center, representing rapidly expanding villages and regiment farm headquarters. Overall, improved areas increased annually while degraded areas decreased substantially, with stable areas also remaining consistent. The data indicate that ecological stability in Yizhou District is at a low level, yet this low-level stability has contributed to improvements in urban economy, ecology, and regiment farm conditions in the arid region.

Improved ecological areas in Yizhou District over the past 18 years have concentrated in the southern region, closely related to the *Silk Road Economic Belt Innovation Pilot Zone (Hami High-tech Zone) Implementation Plan*, which proposes developing a southern circular economy industrial park and promoting efficient agricultural transformation through technology. The northern region shows a decreasing trend in degraded areas, corroborating municipal planning for a northern emerging industrial park and new energy wind power development over the past decade.

3.4 Standard Deviation Ellipse Analysis of Ecological Quality Spatial Distribution

Standard deviation ellipse analysis describes the dispersion and distribution range of spatial points. This study converted each period' s RSEI patch ranges into vector polygon files, then transformed polygons into point files to construct standard deviation ellipses. This approach effectively investigates directional movement of ecological quality within spatial extents.

From a spatial perspective, Figure 4 [Figure 4: see original paper] shows consistent long-axis directions of standard deviation ellipses across the three periods, indicating that urban ecological expansion in Yizhou District maintained a southeast-northwest orientation over the past 18 years. This direction aligns with artificial oasis expansion patterns because Yizhou District' s urban areas and surrounding regiment farms are distributed along railway and highway mainlines. Additionally, Yizhou District is situated on alluvial fans along the southern slopes of the eastern Tianshan Mountains with higher elevation in the north, creating topographic constraints for other development patterns and determining the linear distribution of towns and farms.

From a temporal perspective, the short axis of the 2018 ellipse increased compared to 2000 and 2008, suggesting future ecological quality development will extend primarily north-south, while the long axis showed notable expansion in 2008 but slowed by 2018.

Corresponding to development over the past decade, urban-rural integration has become more compact, evidenced by increasing short semi-axes and decreasing long semi-axes of standard deviation ellipses, with better ecological areas forming continuous patches. This reflects Hami' s accelerated integration of the central Yizhou District with surrounding regiment farms and villages, particularly in areas like Qincheng, which was designated a national tourism poverty alleviation pilot village, promoting ecological sightseeing, orchard picking, and folk experience tourism with evident effectiveness.

3.5 Spatial Transfer Analysis of Different Ecological Qualities

Figure 5 [Figure 5: see original paper] illustrates that the centroid of "poor" ecological grade moved continuously southwestward from 2000 to 2018, shifting 3.81 km. This relatively large spatial deviation compared to other grades indicates that ecological governance in Hami City has primarily targeted compression of poor-quality areas toward the southwest, where large expanses of poor ecological quality remain. To intensify management in this region, Hami

City initiated pollution monitoring and assessment for Luxin Coal Chemical and Da’ an Special Steel in 2017 to strengthen supervision of enterprise pollutant emissions and improve regional ecological quality.

The “relatively poor” grade centroid shifted 4.55 km from northwest to southeast, indicating better improvement in northwestern ecological quality while southeastern poor-quality areas remain extensive, primarily due to large bare land areas, Hongxing No. 1 Industrial Park, and an undeveloped Gobi desert. The “moderate” grade centroid showed minimal deviation, concentrating in the urban core and surrounding artificial oases with stable ecological changes and limited spatial variation. The “good” grade exhibited subtle spatial transfer from northeast to southwest, following improvement directions of poorer grades. The “excellent” grade, despite small patch areas, showed obvious spatial shifts from northeast to southwest and then to southeast, indicating that excellent ecological quality areas in Yizhou District frequently change and cannot maintain stable excellent grades, making them vulnerable to degradation. This demonstrates that overall ecological quality levels in arid region cities and surrounding artificial oases remain relatively low but continuously improving.

Overall, ecological improvement over the past decade has benefited from measures including returning farmland to forest, increasing greening efforts, and forest protection in Yizhou District. Agricultural industrial structure adjustments focusing on characteristic crops have enhanced quality and efficiency, with green ecology as the foundation accelerating agricultural standardization construction. These efforts have gradually reduced poor-quality areas while expanding excellent-quality zones.

4. Conclusions and Discussion

(1) Through principal component and loading analysis, greenness and humidity showed positive correlations with RSEI in Yizhou District, while thermal and dryness components exhibited negative correlations. Greenness and dryness had the greatest influence, with ecological quality improvement primarily attributable to increased greenness and reduced dryness. Humidity had relatively limited impact, and the negative effect of thermal components was less than that of dryness, mainly because Yizhou District is located in a desert region with extensive bare land and Gobi areas affecting the dryness component.

(2) RSEI values in Yizhou District showed an increasing trend with means of 0.22, 0.31, and 0.40, indicating that while overall ecological quality levels remain relatively low due to the arid environment, the increasing trend has significantly improved living standards for urban residents in this arid region.

(3) Ecological quality monitoring revealed localized degradation trends in some areas, which is unfavorable for development in ecologically fragile arid region towns. However, degraded areas showed a decreasing trend,

and with rapid expansion of artificial oases and urban greening, the proportion of relatively poor ecological grade decreased from 68% in 2000 to 21% in 2018, representing exceptionally rapid ecological quality improvement.

(4) Areas with improved ecological quality concentrated around Yizhou District' s urban core, including Hongxing No. 1 Farm and Taojiagong in the east, Huayuanzi and Huicheng in the south, and Huojian Farm and Liushuquan in the west. Over the past 18 years, degraded areas were primarily located in the main urban center and surrounding regiment farm headquarters.

(5) Analysis of standard deviation ellipses and ecological grade centroids reveals that better ecological quality areas expanded from north to south while compressing poor-quality areas in the south. Throughout the three periods, the main direction of urban ecological expansion remained southeast-northwest, determined by urban layout and transportation line distribution of artificial oases.

This study analyzed RSEI applicability in an arid oasis city context, demonstrating that ecological quality in arid regions improves over time from urban centers outward with economic development, rapid urban expansion, and artificial oasis enlargement, though overall ecological quality remains relatively low. From a land use perspective, areas with better and excellent ecological quality in Yizhou District concentrate in grasslands, cultivated land, forests, shrubs, and river zones—primarily natural and artificial oases in arid regions. Field investigations reveal that main crops include cotton and grapes, grasslands are primarily jujube trees, and forests consist of urban greening species such as poplars and elms. Poor ecological quality areas concentrate in unused land—extensive Gobi and bare land—while poor and moderate grades are distributed in anthropogenically modified urban construction land and industrial parks. Given the fragile ecology of arid regions, artificial oases and construction land can degrade into bare land through unreasonable water resource allocation and overexploitation. To improve ecological land quality in arid regions, we recommend rationally increasing vegetation coverage, expanding artificial oasis areas, and intensifying afforestation efforts. In urban construction land, increasing urban greening area will promote rational ecological land development and land use optimization.

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