Assessment of Eco-environmental Quality of the Tarim River Mainstream Based on an Improved Remote Sensing Ecological Index (Postprint)

Authors: Liu Wei, Ling Hongbo, Gong Yanming, Chen Fulong, Shan Qianjuan

Date: 2025-02-27T00:00:00+00:00

Abstract

The main stream of the Tarim River constitutes one of the critical ecological barriers in the arid region of northwestern China. As a direct beneficiary zone of ecological water conveyance, investigating its ecological environment quality changes holds significant importance for understanding the efficacy of ecological water conveyance projects and evaluating watershed ecological environment quality. Based on Landsat remote sensing imagery from 1998 to 2022, an improved Remote Sensing Ecological Index (RSEIS) was developed by integrating five indicators: greenness (NDVI), wetness (WET), dryness (NDBSI), heat (LST), and salinity (SI_T). The Mann-Kendall test, Theil-Sen Median trend analysis, Hurst exponent, and coefficient of variation were employed to analyze the development trend and stability of the ecological environment quality of the Tarim River main stream, while the geographical detector method was utilized to examine the influence of various driving factors on RSEIS. The results indicate: (1) From 1998 to 2022, the overall ecological environment quality of the Tarim River main stream exhibited a fluctuating upward trend, with an average increase of $0.023 \cdot (10a)^{-1}$, and the multi-year average RSEIS displayed a spatial distribution pattern characterized by higher values in the north and west, and lower values in the south and east. (2) Over the 25-year period, areas with improved ecological environment accounted for 55.06% of the watershed, indicating significant changes in ecological environment quality; however, 54.59% of the region still faces potential risk of transitioning from improvement to degradation. (3) Causation analysis reveals that among the eight influencing factors, land use type (0.534) demonstrates the strongest explanatory power for the spatial differentiation characteristics of RSEIS, and the interaction between land use type and potential evapotranspiration (0.659) represents the key driving factor for ecological environment quality in the study area. These findings can provide scientific reference for the sustainable development of ecological environment quality in the Tarim River main stream ecological zone.

Full Text

Evaluation of Ecological Environment Quality in the Mainstream of the Tarim River Based on Improved Remote Sensing Ecological Index

LIU Wei[1], LING Hongbo[2], GONG Yanming[2], CHEN Fulong[1], SHAN Qianjuan[2]

[1]College of Water Conservancy & Architectural Engineering, Shihezi University, Shihezi 832000, Xinjiang, China
[2]Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China

Abstract

The mainstream of the Tarim River serves as a crucial ecological barrier in northwest China's arid region. As a direct beneficiary of ecological water transfer projects, analyzing changes in its ecological environment quality is essential for evaluating the effectiveness of these projects and assessing basin-wide ecological conditions. Using Landsat remote sensing imagery from 1998 to 2022, we constructed an improved Remote Sensing Ecological Index (RSEIS) by integrating five indicators: greenness (NDVI), humidity (WET), dryness (NDBSI), heat (LST), and salinity (SI_T). We analyzed temporal trends and stability of ecological environment quality using the Mann-Kendall test, Theil-Sen median trend analysis, Hurst exponent, and coefficient of variation. Geographic detector methods were employed to identify key driving factors influencing RSEIS. The results showed: (1) From 1998 to 2022, the overall ecological environment quality in the mainstream of the Tarim River exhibited a fluctuating upward trend, with an average increase of $0.023 \cdot (10a)^{-1}$. The multi-year average RSEIS displayed a spatial distribution pattern characterized by higher values in the north and west, and lower values in the south and east. (2) Over the 25-year period, 55.06% of the basin area experienced ecological environment improvement, indicating significant quality enhancement; however, 54.59% of the area still faces potential risk of shifting from improvement to degradation. (3) Causality analysis revealed that land use type (LUCC) had the strongest explanatory power for RSEIS spatial variation, and the two-factor interaction between land use type and potential evapotranspiration ($LUCC \cap PET$) was identified as the key driving factor for ecological environment quality in the study area. These findings provide scientific references for sustainable development of ecological environment quality in the Tarim River mainstream region.

Key words: improved remote sensing ecological index; ecological environment quality; geodetector; the mainstream of the Tarim River

---

Introduction

The ecological environment serves as the fundamental guarantee for human survival and the material basis for social development, directly affecting human quality of life [1]. Intensified climate change and frequent human activities have damaged ecosystems in many regions, leading to increasingly prominent environmental problems such as droughts and floods, species invasion, and biodiversity loss [2]. The Tarim River Basin, located in the heart of a globally typical arid region, is China's largest inland river basin and plays a vital role in promoting economic development and ecological civilization construction in arid inland areas [3]. Numerous scholars have employed various methods to assess the ecological environment quality of the Tarim River Basin, including the Remote Sensing Ecological Index (RSEI) [4], landscape ecological risk assessment [5], and salinity-adapted RSEI [6]. In recent years, researchers have conducted extensive studies on the ecological environment quality and influencing factors of the Tarim River mainstream. Wang et al. [7] utilized MODIS remote sensing data to analyze vegetation coverage dynamics, revealing ecological differences among the upper, middle, and lower reaches. Ren et al. [8] evaluated ecological restoration status from 2000–2020 through hydrological responses, vegetation responses, and ecological water transfer benefits. The Tarim Basin is a closed inland region rich in Tertiary saline strata; over the past two decades, cropland expansion and irrational irrigation have exacerbated water scarcity, triggering severe soil secondary salinization [9]. In the 1970s, improper water resource utilization in the upper and middle reaches and the construction of the Daxihaizi Reservoir caused downstream flow cutoff, ecological damage, and intensified desertification [10]. Since 2000, the government has implemented ecological water transfer projects in the Tarim River mainstream, achieving positive results. By 2021, 22 water transfers had significantly improved the ecological environment [11]. Rapid assessment of ecological environment quality using remote sensing technology enables quantitative understanding of spatiotemporal variation patterns and their driving factors, holding important practical significance for desert ecological construction and improvement in arid regions.

In remote sensing-based ecological environment assessment, multi-factor analysis methods can more comprehensively, accurately, and objectively reflect ecological quality conditions than single-factor analysis, earning favor among many scholars and finding wide application. Xu [12] first integrated four factors—greenness (NDVI), humidity (WET), dryness (NDBSI), and heat (LST)—using remote sensing imagery, employing principal component analysis to objectively weight each indicator for regional ecological environment evaluation. Some scholars have validated this method's effectiveness across different regions, including urban ecological quality [13], plateau cold zones [14], and basin oases [15]. Arid regions constitute over 40% of global land surface area, and increased ecological vulnerability in these areas directly expands the scope of globally ecologically fragile zones. Constrained by harsh natural conditions, conflicts between socioeconomic and ecological water use, and accelerated urbanization, arid region ecological environment quality faces unprecedented challenges, presenting new research directions for scholars. Zhang et al. [16] introduced comprehensive salinity indicators and a water network density remote sensing estimation model to the original RSEI, constructing an ecological environment quality assessment and applying it to the Hohhot-Baotou-Ordos-Yulin urban agglomeration in northwest arid regions using Google Earth Engine. Chen et al. [17] integrated desertification indices into the RSEI model to construct an improved remote sensing ecological index, examining spatiotemporal changes in Lanzhou's environmental quality from 2000–2020.

The Tarim River mainstream lies in the Tarim Basin of northwest China's arid region, one of the most water-scarce areas in China [18]. The region features a temperate continental climate with perennial dryness, low precipitation, and large temperature differences, resulting in fragile ecological structures [19]. The mainstream stretches 1,321 km, with the upper reach (Aral to Yingbaza) spanning 428 km, the middle reach (Yingbaza to Qiala) 495 km, and the lower reach (Qiala to the terminal lake, Taitema) 398 km [20].

---

1 Data and Methods

1.1 Study Area Overview

The Tarim River mainstream is located in the Tarim Basin of northwest China's arid region. [Figure 1: see original paper]

1.2 Data Sources

Landsat Level-1 surface reflectance data products from Landsat 5, Landsat 7, and Landsat 8 were used, which have undergone radiometric, atmospheric, and geometric corrections. Due to the close relationship between vegetation and ecological environment quality, with vegetation greenness as the core indicator, images from the vegetation growing season were selected to ensure result accuracy [21]. This study selected images from June to September between 1998 and 2022, then performed cloud removal, median compositing, mosaicking, cropping, and water body removal in the cloud environment. Years with missing images were replaced with data from adjacent years.

Annual mean temperature, annual precipitation, and growing season potential evapotranspiration data were obtained from the National Tibetan Plateau Data Center platform shared by scholar Peng Shouzhang (http://data.tpdc.ac.cn/). Land use data were derived from the China Annual Land Cover Dataset by Yang Jie and Huang Xin from Wuhan University (http://doi.org/10.5281/zenodo.4417809). Population data were sourced from the Landscan Population Dataset website (https://landscan.ornl.gov/); nighttime light data were obtained from the China Annual Nighttime Light Data by Wu Yizhen, Shi Kaifang, et al. (https://dataverse.harvard.edu/).

Slope and aspect data were extracted from the USGS SRTMGL1_003 dataset (https://www.usgs.gov/) using ArcGIS. Digital Elevation Model (DEM) data were also processed accordingly.

1.3 Research Methods

1.3.1 Improved RSEI Model The RSEI model incorporates four natural indicators: greenness, humidity, heat, and dryness. Based on this foundation and considering the actual conditions of the Tarim River mainstream, this study improved the RSEI. The dryness indicator comprises building index and bare soil index, which is suitable for urban construction land. However, the study area is an arid region with water scarcity, sparse vegetation, and low proportions of buildings and artificial surfaces, so the building index was removed [22], with bare soil index representing dryness. The Tarim River mainstream is primarily distributed in salinized soil areas, where soil salinity severely constrains vegetation growth and ecological stability. Therefore, this study added a salinity index (SI_T) to characterize soil salinization [23]. Calculation methods for each indicator are shown in Table 1 .

The formulas are:

$$RSEIS_0 = 1 - PC_1[NDVI, WET, NDBSI, LST, SI_T]$$

$$RSEIS = \frac{RSEIS_0 - RSEIS_{min}}{RSEIS_{max} - RSEIS_{min}}$$

where $RSEIS_0$ represents the residual value after subtracting the first principal component; $RSEIS_{min}$ is the minimum value of $RSEIS_0$; $RSEIS_{max}$ is the maximum value of $RSEIS_0$; and $RSEIS$ is the normalized remote sensing ecological index value. Following the Technical Specification for Eco-environmental Status Evaluation, RSEIS was divided into five grades: poor (0.0–0.2), relatively poor (0.2–0.4), moderate (0.4–0.6), good (0.6–0.8), and excellent (0.8–1.0) to characterize different ecological environment quality levels [24].

1.3.2 Mann-Kendall Test and Sen Trend Analysis The Mann-Kendall (M-K) test is a non-parametric statistical method suitable for significance testing of trends in non-normally distributed sequences, where P is the test value. When $P < 0.05$, the trend is considered significant. The Theil-Sen Median (Sen slope estimator) is another non-parametric trend analysis method. Combined, they effectively reveal trend change characteristics of time series RSEIS [25].

1.3.3 Hurst Exponent This study employed Hurst exponent analysis to examine the persistence characteristics of RSEIS in the Tarim River mainstream. H represents the Hurst exponent value, which includes three cases [26]: when $H = 0.5$, the time series is a random sequence with independent observations and finite variance; when $0.5 < H < 1$, future changes will follow the same trend as past changes, showing persistence; when $0 < H < 0.5$, past changes are not sustainable.

1.3.4 Coefficient of Variation The coefficient of variation (Cv) primarily reflects the dispersion degree of data time series [27]. Higher Cv values indicate greater volatility in RSEIS time series, while lower values suggest greater stability. To more intuitively reflect RSEIS changes in the Tarim River mainstream, Cv was divided into five categories: low fluctuation ($Cv \leq 0.1$), relatively low fluctuation ($0.1 < Cv \leq 0.2$), moderate fluctuation ($0.2 < Cv \leq 0.3$), relatively high fluctuation ($0.3 < Cv \leq 0.4$), and high fluctuation ($Cv > 0.4$).

1.3.5 Geodetector Geodetector is a statistical method for detecting spatial stratified heterogeneity of variables and revealing their driving factors [28]. This study selected nighttime light index (DMSP), slope (SL), aspect (AS), potential evapotranspiration (PET), temperature (TEMP), population (POP), land use type (LUCC), and precipitation (PRE) as independent variables. Factor detection and interaction detection were used to analyze driving factors of RSEIS.

---

2 Results

2.1 Spatiotemporal Variation Characteristics of RSEIS

The RSEIS values in the Tarim River mainstream from 1998 to 2022 generally exhibited a spatial distribution pattern of higher values in the north and west, and lower values in the south and east. The northern and western regions consist primarily of cropland and grassland or areas adjacent to cultivated land with good vegetation cover and better ecological environment quality. The southern region borders the Taklamakan Desert with severe soil desertification, while the eastern region lies in the lower reaches of the Tarim River with sparse vegetation and bare land, resulting in poorer ecological environment quality.

Figure 2 [Figure 2: see original paper] shows the proportion of different ecological environment quality grades in the Tarim River mainstream from 1998 to 2022. During this period, the coverage area of poor and relatively poor grades showed a declining trend, decreasing from 58.12% in 1998 to 41.23% in 2022. The area of good grade showed an upward trend, increasing from 12.35% in 1998 to 23.45% in 2022. Conversely, the proportion of areas with poor and relatively poor ecological environment quality decreased, indicating significant improvement in the ecological environment quality of the Tarim River mainstream over the past 25 years. Figure 3 [Figure 3: see original paper] illustrates the spatial distribution of ecological environment quality across the study period.

2.2 Trend Analysis of RSEIS

The Mann-Kendall test and Sen slope estimator were combined to analyze RSEIS trend changes. The results were categorized into five levels: significant improvement ($Sen \geq 0.0005$, $P < 0.05$), slight improvement ($Sen \geq 0.0005$, $P > 0.05$), no change ($-0.0005 < Sen < 0.0005$, $P > 0.05$), slight degradation ($Sen \leq -0.0005$, $P > 0.05$), and significant degradation ($Sen \leq -0.0005$, $P < 0.05$). According to this classification, significantly and slightly improved areas accounted for 55.06% of the basin (9,179.4 km² and 6,358.72 km² respectively), while significantly and slightly degraded areas accounted for 7.35% (2,521.33 km² and 813.79 km² respectively). Areas with no significant trend accounted for 37.59%.

The coefficient of variation analysis revealed that 90.78% of the RSEIS area showed fluctuation below moderate level, indicating good overall stability. Moderate fluctuation areas covered 6,396.85 km² (33.04%), mainly distributed in the middle reach from Yingbaza to Qiala. Relatively low and low fluctuation areas accounted for 54.60% and 3.14% respectively, primarily located in the central region from Aral to Wusiman. Relatively high and high fluctuation areas covered only 1,345.66 km² and 437.75 km² respectively (9.22% total), mainly distributed in the southern region near the Taklamakan Desert.

The Hurst exponent analysis showed an average value of 0.43, indicating anti-persistence as the dominant pattern. Theoretically, this suggests stronger variability in ecological environment quality. Combined with previous RSEIS trend classification results, future change trends were divided into five categories: continuous degradation, future degradation, stable, future improvement, and continuous improvement. Continuous degradation and continuous improvement areas accounted for less than 10%, while future improvement and future degradation areas accounted for 37.17% and 54.59% respectively, indicating a deteriorating trend where degraded areas exceed improved areas. Figure 4 [Figure 4: see original paper] presents the spatial distribution of these trends.

2.3 Driving Factor Analysis of RSEIS

Geodetector was used to analyze factors influencing the spatial heterogeneity of RSEIS. All influencing factors showed significant P-values ($P < 0.05$), indicating significant effects on the spatial distribution of ecological environment quality in the Tarim River mainstream. The influence (q) of each factor on RSEIS, from strongest to weakest, was: $LUCC > PET > TEMP > PRE > DMSP > POP > SL > AS$. Land use type (LUCC) had the largest q statistic (0.534), making it the primary driving factor. Other factors had smaller q values and weaker explanatory power, but their influence significantly increased when interacting with LUCC. Table 3 presents the detailed factor detection results.

Interaction detection analysis revealed that the interaction between driving factors showed bi-factor enhancement and nonlinear enhancement characteristics, with q values greater than individual factor influences. The interaction between land use type and potential evapotranspiration ($LUCC \cap PET$) had the most significant impact on RSEIS spatial distribution ($q = 0.659$), followed by $LUCC \cap PRE$ and $LUCC \cap TEMP$. This demonstrates that under the combined effects of human factors (LUCC) and natural factors, the explanatory power for ecological environment quality significantly improves. Figure 5 [Figure 5: see original paper] illustrates these interaction effects. Therefore, management and protection strategies for the Tarim River mainstream must consider the importance of multi-factor interactions.

3 Discussion

3.1 Applicability of RSEIS

RSEI is currently one of the mainstream methods for evaluating ecological environment quality in arid region oases, with certain universality in urban ecological environment assessment, capable of efficiently and objectively reflecting changes in surface ecological conditions [29]. In this study, we removed the building index from the RSEI dryness indicator to adapt to the desert riparian and sparsely populated characteristics of the Tarim River mainstream. Simultaneously, to accommodate salinization features, we incorporated the mean salinity index (SI_T). These modifications better adapt the index for ecological quality evaluation in the Tarim River mainstream.

Compared with traditional RSEI, this study used Landsat imagery as the data source, improved RSEI by adding salinity indices based on the Google Earth Engine platform, better reflecting salinization impacts on the ecological environment. Additionally, the 30m resolution enables precise characterization of small-scale ecological changes. In summary, this study conducted rapid spatial measurement and temporal evolution analysis of ecological environment quality through RSEIS, enabling quantitative dynamic monitoring of ecological environment quality in the Tarim River mainstream. This approach provides new ideas and scientific basis for ecological restoration and sustainable development decision-making in the region, aiming to promote regional ecological balance and long-term prosperity between humans and nature.

The first principal component eigenvalue contribution rate in RSEIS was not less than 85%, and the role of each sub-indicator was consistent with previous research results. NDVI and WET showed positive correlations with RSEIS, while NDBSI showed negative correlations, consistent with existing research [14, 17]. The results indicate that greenness and humidity positively influence ecological quality, while dryness negatively affects it. Climate and terrain had weak explanatory power due to small regional differences in the Tarim Basin's arid climate and gentle topography, consistent with previous studies [24, 34]. DMSP showed low explanatory power because most areas in the Tarim River mainstream have sparse populations and minimal nighttime production. However, as urbanization progresses, the impact of construction land on ecology is increasing.

3.2 Driving Factors of Ecological Environment Quality Changes in the Tarim River Mainstream

On the temporal scale, the overall ecological environment quality of the Tarim River mainstream from 1998–2022 showed an upward trend, with improved areas significantly exceeding degraded areas, consistent with conclusions from other scholars [13, 15, 34]. In recent decades, oasis expansion and excessive water resource utilization have fragmented natural *Populus euphratica* forests, shrunk forest areas, and degraded ecological functions, seriously affecting Xinjiang's economic development and social stability [38]. To restore the Tarim River's ecosystem on the verge of collapse, since 2000, a series of comprehensive management projects have been implemented including water-saving irrigation, river channel regulation, and water transfer projects [39], strengthening legal protection and limiting human activities' destructive impact on the basin ecosystem.

Since 2000, the Daxihaizi Reservoir has implemented ecological water transfer, discharging 9.12×10^3 m³ of ecological water by 2021. During flood seasons, ecological sluices provide both flood discharge and ecological replenishment functions, raising groundwater levels and promoting vegetation recovery [40]. During 2013–2020, cropland and grassland area changes stabilized while construction land continued increasing and bare land decreased [41]. This is closely related to the policy proposed at the Third Plenary Session of the 18th CPC Central Committee to "delineate ecological protection red lines" and orderly implement fallow periods for cropland, rivers, and lakes, stabilizing the human-ecology relationship in the basin. Additionally, increased construction land from urbanization facilitates adjustment and improvement of local land use structures, enabling effective ecological water transfer policies that restore basin ecology. The Tarim River Basin ecological water transfer project aimed at "ecological restoration" has positively impacted regional ecological protection and reconstruction. The transformation of human activity consciousness has gradually restored the ecological environment quality of the Tarim River mainstream [42].

3.3 Limitations and Future Directions

This study used Landsat imagery data as the basis, applying statistical methods and geodetector to comprehensively analyze dominant factors influencing regional ecological environment quality and explore various influencing factors. However, vegetation gross primary productivity, river channel density, and other natural characteristic ecological factors were not included. Therefore, in future research, to more accurately evaluate regional ecological environment quality, we will consider significant spatial differences in natural resource characteristics and optimize the ecological evaluation index system.

---

4 Conclusions

(1) From 1998 to 2022, the ecological environment quality in the Tarim River mainstream showed an overall fluctuating upward trend, with an average increase of $0.023 \cdot (10a)^{-1}$, and a spatial distribution pattern of high in the north and low in the south, high in the west and low in the east.

(2) Over 25 years, improved ecological environment areas accounted for 55.06% of the basin; 90.78% of RSEIS area showed fluctuation below moderate level, indicating high stability and good ecological restoration. However, 54.59% of the area faces potential risk of shifting from improvement to degradation, indicating that maintaining basin ecological stability remains a challenging task.

(3) Through analysis of natural and socioeconomic factors in the Tarim River mainstream, ecological environment quality was mainly influenced by land use type (LUCC) and potential evapotranspiration (PET). Among driving factors, land use type had the most significant impact on ecological environment quality. Therefore, future efforts must emphasize sustainable human and environmental needs, slowing land use processes and implementing reasonable policies to reduce environmental damage.

References

References

[1] Che L S, Yin S Y, Jin J F, et al. Assessment and simulation of urban ecological environment quality based on geographic information system ecological index[J]. Land, 2024, 13(5): 687, doi: 10.3390/land13050687.

[2] Singh V, Nema A K, Chouksey A, et al. Assessment of eco-environmental vulnerability using remote sensing and GIS tools in Maharashtra region, India[J]. International Journal of Environment and Climate Change, 2024, 14(4): 119-129.

[3] Zhu C G, Shen Q, Zhang K, et al. Multiscale detection and assessment of vegetation eco-environmental restoration following ecological water compensation in the lower reaches of the Tarim River, China[J]. Remote Sensing, 2022, 14(22): 5855, doi: 10.3390/rs14225855.

[4] Duo L H, Wang J Q, Zhang F Q, et al. Assessing the spatiotemporal evolution and drivers of ecological environment quality using an enhanced remote sensing ecological index in Lanzhou City, China[J]. Remote Sensing, 2023, 15(19): 4704, doi: 10.3390/rs15194704.

[5] Shi M, Lin F, Jing X, et al. Ecological environment quality assessment of arid areas based on improved remote sensing ecological index: A case

study of the Loess Plateau[J]. Sustainability, 2023, 15(18): 13881, doi: 10.3390/su151813881.

[6] Zhang K L, Feng R R, Zhang Z C, et al. Exploring the driving factors of remote sensing ecological index changes from the perspective of geospatial differentiation: A case study of the Weihe River Basin, China[J]. International Journal of Environmental Research and Public Health, 2022, 19(17): 10930, doi: 10.3390/ijerph191710930.

[7] Aurora R M, Furuya K. Spatiotemporal analysis of urban sprawl and ecological quality study case: Chiba Prefecture, Japan[J]. Land, 2023, 12(11): 2013, doi: 10.3390/land12112013.

[8] Yang X Y, Meng F, Fu P J, et al. Time frequency optimization of RSEI: A case study of Yangtze River Basin[J]. Ecological Indicators, 2022, 141: 109080, doi: 10.1016/j.ecolind.2022.109080.

[9] Xia T T, Xue X, Wang H W, et al. Mechanism of vegetation greenness change and its correlation with terrestrial water storage in the Tarim River Basin[J]. Land, 2024, 13(5): 712, doi: 10.3390/land13050712.

[10] Liu Y, Xue J, Gui D W, et al. Agricultural oasis expansion and its impact on oasis landscape patterns in the southern margin of Tarim Basin, northwest China[J]. Sustainability, 2018, 10(6): 1957, doi: 10.3390/su10061957.

[11] Zhang J J, Hao X M, Li X W, et al. Evaluation and regulation strategy for ecological security in the Tarim River Basin based on the ecological footprint[J]. Journal of Cleaner Production, 2024, 435: 140488, doi: 10.1016/j.jclepro.2023.140488.

[12] Hou Y F, Chen Y N, Ding J L, et al. Ecological impacts of land use change in the arid Tarim River Basin of China[J]. Remote Sensing, 2022, 14(8): 1894, doi: 10.3390/rs14081894.

[13] Zhang Qifei, Chen Yaning, Sun Congjian, et al. Changes in terrestrial water storage and evaluation of oasis ecological security in the Tarim River Basin[J]. Arid Land Geography, 2024, 47(1): 1-14.

[14] Wang Luchen, Han Haihui, Zhang Jun, et al. Spatio-temporal evolution of land use and human activity intensity in the Tarim River Basin, Xinjiang[J]. Geology in China, 2024, 51(1): 203-220.

[15] Wang Yue, Jiang Zhihui, Chu Jiaqi, et al. Study on the spatiotemporal matching relationship of agricultural water and land resources in the Tarim River Basin[J]. Journal of Agricultural Resources and Environment, 2024, 41(2): 360-370.

[16] Xu H Q. A remote sensing index for assessment of regional ecological changes[J]. China Environmental Science, 2013, 33(5): 889-897.

[17] Wang X, Huo A D, Lü J Q, et al. Dynamic changes and driving factors of vegetation coverage in the mainstream of Tarim River, China[J]. Trans-

actions of the Chinese Society of Agricultural Engineering, 2023, 39(8): 284-292.

[18] Ren Q, Long A H, Yang Y M, et al. Analysis on remote sensing monitoring of eco-environment variation of mainstream basin of Tarim River in recent 20 years[J]. Water Resources and Hydropower Engineering, 2021, 52(3): 103-111.

[19] Jiao A Y, Wang Z K, Deng X Y, et al. Eco-hydrological response of water conveyance in the mainstream of the Tarim River, China[J]. Frontiers in Environmental Science, 2022, 10: 1019695, doi: 10.3389/fenvs.2022.1019695.

[20] Chen W, Wang J J, Ding J L, et al. Detecting long-term series eco-environmental quality changes and driving factors using the remote sensing ecological index with salinity adaptability (RSEI-SI): A case study in the Tarim River Basin, China[J]. Land, 2023, 12(7): 1309, doi: 10.3390/land12071309.

[21] Wang G Y, Ran G Y, Chen Y N, et al. Landscape ecological risk assessment for the Tarim River Basin on the basis of land use change[J]. Remote Sensing, 2023, 15(17): 4173, doi: 10.3390/rs15174173.

[22] Zhang W, Du P J, Shanchuan G U O, et al. Enhanced remote sensing ecological index and ecological environment evaluation in arid area[J]. National Remote Sensing Bulletin, 2023, 27(2): 299-317.

[23] Li X H, Guo M. The impact of salinization and wind erosion on the texture of surface soils: An investigation of paired samples from soils with and without salt crust[J]. Land, 2022, 11(7): 999, doi: 10.3390/land11070999.

[24] Douaoui A E K, Nicolas H, Walter C. Detecting salinity hazards within a semiarid context by means of combining soil and remote sensing data[J]. Geoderma, 2005, 134(1): 217-230.

[25] Jiao A Y, Wang W Q, Ling H B, et al. Effect evaluation of ecological water conveyance in Tarim River Basin, China[J]. Frontiers in Environmental Science, 2022, 10: 1019695, doi: 10.3389/fenvs.2022.1019695.

[26] Wang J F, Xu C D. Geodetector: Principle and prospective[J]. Journal of Geographical Sciences, 2017, 72(1): 116-134.

[27] Brunner P, Li T H, Kinzelbach W, et al. Generating soil electrical conductivity maps at regional level by integrating measurements on the ground and remote sensing data[J]. International Journal of Remote Sensing, 2007, 28(15-16): 3341-3361.

[28] Wang X N, Tian J Y, Li X J, et al. Benefits of google earth engine in remote sensing[J]. National Remote Sensing Bulletin, 2022, 26(2): 299-309.

[29] Hanati G, Zhang Y, Guan D H, et al. Numerical simulation of groundwater flow at cross section scale in the lower reaches of Tarim River under the

condition of ecological water conveyance[J]. Advances in Water Science, 2020, 31(1): 61-70.

[30] Lin J, Zhao C Y, Ma X F, et al. Optimization of land use structure based on ecosystem service value in the mainstream of Tarim River[J]. Arid Zone Research, 2021, 38(4): 1140-1151.

[31] Luo M, Jiapaer G, Guo H, et al. Spatial and temporal variation of growing season NDVI and its responses to hydrothermal condition in the Tarim River Basin from 2000 to 2013[J]. Journal of Natural Resources, 2017, 32(1): 50-63.

[32] Luo R J, Wang H T, Wang C. Ecological quality evaluation of Gulang County in Gansu Province based on improved remote sensing ecological index[J]. Arid Land Geography, 2023, 46(4): 539-549.

[33] Wang X X, Zuo X Q, Yang Z N, et al. Spatiotemporal changes of precipitation in Chengdu from 1980 to 2016 based on Mann-Kendall test and information entropy[J]. Science of Soil and Water Conservation, 2019, 17(4): 26-33.

[34] Zhang J D, Li J L, Bao A M, et al. Effectiveness assessment of ecological restoration of Populus euphratica forest in the Tarim River Basin during 2013–2020[J]. Arid Land Geography, 2022, 45(6): 1824-1835.

[35] Chu Z, Xu C C, Luo Y X, et al. Land use simulation and ecological benefit evaluation in the Tarim River Basin based on ecological protection red line management[J]. Acta Ecologica Sinica, 2021, 41(18): 7380-7392.

[36] Tan K L, Wang X F, Gao H J, et al. Analysis of ecological elements of comprehensive harnessing in Tarim River Basin using remote sensing[J]. Geo-information Science, 2013, 15(4): 604-610.

[37] Khan N M, Rastoskuev V V, Sato Y, et al. Assessment of hydrosaline land degradation by using a simple approach of remote sensing indicators[J]. Agricultural Water Management, 2004, 77(1): 96-109.

[38] Zeng J, Li J F, Yao X W. Spatio-temporal dynamics of ecosystem service value in Wuhan urban agglomeration[J]. Chinese Journal of Applied Ecology, 2014, 25(3): 883-891.

[39] Ma Y F, Chen C S, Yuan F X, et al. Dynamic evaluation of ecological environment quality and climate response in Northeastern China Tiger and Leopard National Park[J]. Acta Ecologica Sinica, 2023, 43(7): 2614-2626.

[40] Li Y P, Chen Y, Ye Z X, et al. Ecological responses of ecological water conveyance in the lower reaches of Tarim River for 20 years[J]. Arid Land Geography, 2021, 44(3): 700-707.

[41] Wei G H, Gui D W, Zhao X F. Irrigation area carrying capacity in Tarim River Basin in different years[J]. Arid Land Geography, 2018, 41(2): 230-237.

[42] Hu R Y, Chang J X, Deng M J, et al. Multi-dimensional response of hydrological connectivity to ecological water conveyance project: A case study of Tarim River[J]. Journal of Hydraulic Engineering, 2023, 54(11): 1359-1370.

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