Postprint: Ecological Response to 20 Years of Water Conveyance in the Lower Tarim River

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Abstract

To replenish the dried-up river channels in the lower reaches of the Tarim River and rescue the dying desert communities, an ecological water transfer project has been implemented in the Tarim River since 2001, which has preliminarily improved the watershed' s ecological environment and achieved a win-win situation for watershed socioeconomic development and ecological conservation. On the occasion of 20 years of ecological water transfer, to assess the ecological effects of water transfer, the spatiotemporal variations of Normalized Difference Vegetation Index (NDVI) and vegetation coverage in the lower reaches of the Tarim River were investigated using mathematical statistical methods based on multi-source remote sensing data MOD13Q1 and MCD12Q1. The results indicate that after nearly 20 years of ecological water transfer, NDVI in the lower reaches of the Tarim River increased from 0.14 in 2000 to 0.21 in 2020, representing an increase of 33.3%, while vegetation area expanded from 492 km^2 in 2000 to 1423 km^2 in 2020. Specifically, the areas of low, medium, and high vegetation coverage increased by 277 km^2, 537 km^2, and 132 km^2 respectively compared to 2000, with growth rates reaching 20.8%, 448.0%, and 190.0% respectively. The increases in both vegetation area and vegetation coverage in the middle section were higher than those in the upper and lower sections. Both NDVI and vegetation coverage exhibited higher values and greater increases within 2 km of the river channel, gradually decreasing beyond 2 km with smaller increases. Spatially, approximately 57.1% of the area showed a significant increasing trend in NDVI and vegetation coverage, while areas with significant decreases did not exceed 2.0%. The Hurst index indicates that the greening trend will continue in the future for over 75.0% of the area, while only 6.1% of the area will continue to experience ecological degradation. Comprehensive assessment of the ecological effects of the Tarim River water transfer project holds important scientific significance for desert conservation, restoration, and management, as well as ecological water resource management in arid regions.

Full Text

Ecological Responses of 20-Year Water Conveyance in the Lower Reaches of the Tarim River

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Abstract

To replenish the dried-up river channel and rescue dying desert communities in the lower Tarim River, an ecological water conveyance project has been implemented since 2001, leading to initial improvements in the basin’ s ecological environment and achieving a win-win situation for both socioeconomic development and ecological conservation. On the 20th anniversary of this project, we evaluated its ecological effects by investigating spatiotemporal changes in the Normalized Difference Vegetation Index (NDVI) and vegetation cover using mathematical statistical methods based on multi-source remote sensing data (MOD13Q1 and MCD12Q1). The results show that after nearly two decades of ecological water conveyance, the NDVI in the lower Tarim River increased from 0.14 to 0.21 (a 33.3% increase), while vegetation area expanded from 492 km^2 to 1423 km^2 (a 188.0% increase). Specifically, areas with low, medium, and high vegetation coverage increased by 277 km^2, 537 km^2, and 132 km^2, respectively, representing growth rates of 20.8%, 448.0%, and 190.0%. Both NDVI and vegetation coverage exhibited larger increases within 2 km of the river channel, with progressively smaller gains at greater distances. Spatially, approximately 57.1% of the region showed significant increasing trends in NDVI and vegetation cover, while less than 2.0% exhibited significant decreases. The Hurst index indicates that over 75.0% of areas with greening trends will continue this trajectory, while only 6.1% of regions will experience continued ecological deterioration. A comprehensive assessment of the Tarim River water conveyance project’ s ecological effects holds important scientific significance for desert conservation and restoration management as well as ecological water resource management in arid regions.

Keywords: lower reaches of Tarim River; ecological water conveyance; normalized difference vegetation index (NDVI); vegetation cover

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1. Introduction

The lower Tarim River segment generally refers to the stretch from Daxihaizi Reservoir to Taitema Lake, spanning approximately 428 km. Based on regional variations, this section can be further divided into upper, middle, and lower reaches: the upper reach (Daxihaizi Reservoir to Yingsu), middle reach (Yingsu to Alagan), and lower reach (Alagan to Taitema Lake) [Figure 1: see original paper]. The area is flanked by the Kuruk Desert to the east and the Taklamakan Desert to the west, serving as a crucial green corridor that prevents the merging of these two deserts. The region experiences a typical temperate continental climate and ranks among China' s most arid areas, with a mean annual temperature of 10.7–11.5°C, abundant light and heat resources (total solar radiation of 6360 $MJ \cdot m^{-2}$, sunshine duration of 2780–2980 h, and accumulated temperature >10°C of 4100–4300°C), scarce precipitation (17.4–42.0 mm), and strong evaporation (2500–3000 mm). Elevations range from 800–846 m, with terrain sloping from northwest to southeast. Soils are predominantly sandy, with surface layers consisting mainly of sub-sandy soil. Riparian plant communities are primarily composed of herbaceous species such as reeds, *Apocynum venetum*, and *Alhagi sparsifolia*, shrubs dominated by tamarisk, and trees dominated by poplar.

Previous studies have quantitatively assessed the ecological effects of water conveyance through field observations and vegetation remote sensing. Research based on high-precision Landsat 8 OLI and Sentinel data revealed continuously increasing vegetation area in the lower Tarim River, with particularly significant shrub recovery concentrated within 1.0–2.5 km of the river channel. Analysis of MOD13Q1 data showed increasing trends in high and medium vegetation coverage areas. Using a time-trajectory method, Wang et al. analyzed land use changes from 2000–2018, finding increased forest and grassland areas and decreased cropland, wetland, and artificial surfaces, with changes primarily occurring in overflow areas along both banks. Cui et al. estimated net primary productivity (NPP) across the Tarim River Basin using the CASA model, reporting a fluctuating upward trend from 2000–2018, with growth and negative growth regions accounting for 64.1% and 35.9% of total grassland area, respectively, and an average growth rate of 1.31$×10^{3}$ g $C \cdot m^{-2}$. However, previous research often focused on single indicators or specific aspects. On the 20th anniversary of the ecological water conveyance project, a systematic and comprehensive evaluation of its multifaceted effects is needed to provide scientific guidance for desert conservation, restoration, and ecological water management in arid regions.

1.1 NDVI Data

To characterize vegetation growth, we used MOD13Q1 data with a temporal resolution of 16 days, spanning 2000–2020, and a spatial resolution of 250 m. To eliminate cloud interference, we applied the maximum value composite method to obtain monthly NDVI data, which was further aggregated to annual NDVI data. Regions with NDVI > 0.05 were defined as vegetated areas.

1.2 Vegetation Cover Data

Vegetation cover refers to the percentage of vertical projection area of vegetation relative to the total statistical area and is closely related to NDVI. We extracted vegetation cover information for the lower Tarim River region by establishing a relationship between these variables using the pixel binary model. This algorithm assumes that each pixel' s NDVI value comprises contributions from vegetation and soil components, as expressed by:

$$NDVI = f \times NDVI_V + (1 - f) \times NDVI_S$$

where f is vegetation cover, $NDVI_V$ is the NDVI value for fully vegetated pixels, and $NDVI_S$ is the NDVI value for soil or non-vegetated pixels. The vegetation cover f can be calculated as:

$$f = \frac{NDVI - NDVI_S}{NDVI_V - NDVI_S}$$

Due to the coarse spatial resolution of MOD13Q1 data, it is difficult to find pure vegetation or bare soil pixels. To exclude water and ice/snow cover, we used the maximum and minimum values of NDVI as $NDVI_V$ and $NDVI_S$, respectively. Following national technical specifications and considering the study area' s vegetation characteristics, we classified the region into high vegetation cover areas (60-100%), medium vegetation cover areas (20-60%), low vegetation cover areas (5-20%), and bare land (<5%).

1.3 Assessing Distance Effects from River Channel

To evaluate how distance from the river channel influences ecological variables, we created 1 km buffer zones along the main channel and calculated the area of each ecological element within each buffer. Longitudinally, we compared changes in different ecological elements across upper, middle, and lower reaches. Trend calculations for each variable were based on simple linear regression equations.

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2. Results

2.1 NDVI Changes in the Lower Tarim River

[Figure 2: see original paper] shows vegetation area changes in the lower Tarim River based on MOD13Q1 data. Following ecological water conveyance, NDVI values increased along the riverbanks, with particularly strong increases within 2 km. Vegetation area decreased sharply beyond this zone, showing a slow decline in more distant regions. Trend analysis revealed that the rate of vegetation area increase diminished with distance from the river channel, indicating effective ecological improvement. Overall, vegetation area in the lower Tarim River increased from 492 km^2 in 2000 to 1423 km^2 in 2020 (a 188.0% increase). NDVI in the upper, middle, and lower reaches increased by 10.7%, 87.9%, and 61.8%, respectively, with the middle reach showing the greatest increase rate.

Spatially, the entire region exhibited increasing NDVI trends, particularly near the river channel. Statistical analysis indicates that approximately 57.1% of the area showed significant increases, 41.2% showed no significant change, and only 2.0% showed significant decreases, primarily in bare land areas far from the river. [Figure 3: see original paper] presents the Hurst index for NDVI in the lower Tarim River. The index shows that the greening trend will continue in most regions (76.2% of the area), while 17.3% of regions will experience trend reversal, mainly concentrated on the right side of the lower river channel.

2.2 Vegetation Cover Changes in the Lower Tarim River

[Figure 4: see original paper] illustrates spatiotemporal changes in vegetation cover in the lower Tarim River. The region' s vegetation cover showed overall improvement, with significant increases along both banks. From 2000 to 2020, areas with low, medium, and high vegetation coverage increased by 277 km^2, 537 km^2, and 132 km^2, respectively (increase rates of 20.8%, 448.0%, and 190.0%). In the upper and middle reaches, low vegetation cover area decreased while medium and high vegetation cover areas increased, particularly in the middle reach. In the lower reach, all vegetation cover types increased, dominated by low vegetation cover expansion.

Spatially, approximately 90.1% of the region showed increasing vegetation cover trends, with 75.6% showing significant increases and only 2.0% showing significant decreases. [Figure 5: see original paper] displays the Hurst index for vegetation cover, indicating that the improvement trend will continue in 57.7% of the region, while 18.1% will experience trend reversal, also concentrated on the right side of the lower river channel.

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3. Discussion

This study analyzed the ecological impacts of water conveyance in the lower Tarim River from multiple perspectives. However, the effects extend beyond vegetation changes. Previous research has documented improvements in plant diversity, with Li et al. reporting that new biomass of poplar trees increased from 16.6 $kg \cdot hm^{-2}$ to 54.3 $kg \cdot hm^{-2}$, though this effect was concentrated within 700 m of the river channel—consistent with our finding that high and medium vegetation cover areas are concentrated near the river channel. The most pronounced response was groundwater level rise, with monitoring wells showing effective groundwater recharge. Within 2-6 m of the river channel, groundwater depth reached 2-5 m, meeting suitable conditions for plant growth. Rising groundwater also improved water quality, with mineralization decreasing from 5.3-7.8 $g \cdot L^{-1}$ to 1.1-3.0 $g \cdot L^{-1}$ within 3 km of the main channel. Taitema

Lake' s restoration represents another important ecological benefit, with water area gradually expanding over 20 years, surrounding dead vegetation reviving, wetland area significantly increasing, and dust storm frequency decreasing.

The Tarim River ecological water conveyance project ended the river' s 30-year dry period, rejuvenating riparian poplar forests and effectively restoring the ecosystem. This has greatly inspired local communities to protect the environment and develop agricultural production. However, several challenges remain: (1) Structural water scarcity persists, with agricultural water consumption dominating total water use and conflicts among production, ecological, and domestic water demands remaining prominent. (2) Integrated management of surface water and groundwater has not been fully implemented, with groundwater overextraction causing significant declines in some areas. (3) Achieving the "three red lines" control targets across the basin remains difficult. (4) An effective coordination mechanism for ecological water conveyance has not been established, making it difficult to ensure sustained ecological water supply.

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4. Conclusions

Based on multi-source remote sensing products, this study comprehensively evaluated ecological responses to water conveyance in the lower Tarim River, examining spatiotemporal changes in NDVI and vegetation cover across upper, middle, and lower reaches and their relationship with distance from the river channel. The main conclusions are:

1) NDVI in the lower Tarim River increased by 33.3% (from 0.14 in 2000 to 0.21 in 2020). Vegetation area expanded from 492 km^2 to 1423 km^2 (a 188.0% increase). NDVI in the upper, middle, and lower reaches increased by 10.7%, 87.9%, and 61.8%, respectively. The rate of vegetation area increase decreased with distance from the river channel.

2) Vegetation cover in the lower Tarim River also increased significantly from 2000 to 2020, with marked improvements along both banks. Areas with low, medium, and high vegetation coverage increased by 277 km^2, 537 km^2, and 132 km^2, respectively (increase rates of 20.8%, 448.0%, and 190.0%). The relationship between vegetation cover and distance from the river channel was similar to that of NDVI, with near-river vegetation cover increasing faster than distant areas.

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