Postprint: Impact of Ecological Water Conveyance on Groundwater Depth Variation in the Lower Tarim River

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Abstract

Groundwater is a critical factor for the survival and growth of desert riparian vegetation and holds significant importance for the restoration of degraded vegetation. Based on measured data of groundwater depth during the ecological water conveyance process in the lower reaches of the Tarim River, this study provides a detailed analysis of the spatiotemporal variations in groundwater depth from 2000 to 2020 and its response to ecological water conveyance. Monitoring results demonstrate that under conditions of ecological water conveyance, groundwater depth on both sides of the river channel in the lower Tarim River has been substantially raised. (1) Longitudinally, from Yingsu in the upstream section, to Ka' erdayi in the middle section, and Yiganbujima in the downstream section, at 100 m from the river channel, groundwater depth increased from pre-conveyance levels of 7.76 m, 9.31 m, and 7.82 m to 3.70 m, 4.48 m, and 2.69 m, respectively; at 300 m from the river channel, groundwater depth increased from pre-conveyance levels of 8.09 m, 9.15 m, and 8.25 m to 4.53 m, 5.00 m, and 3.29 m, respectively; at 500 m from the river channel, groundwater depth increased from pre-conveyance levels of 8.21 m, 9.45 m, and 9.08 m to 6.61 m, 5.46 m, and 3.82 m, respectively. (2) In the direction perpendicular to the river channel, based on monitoring data from groundwater wells, the influence range of ecological water conveyance on groundwater levels in the upper, middle, and lower sections of the lower Tarim River all reached 1050 m, with respective increases of 2.69 m, 1.38 m, and 1.59 m. (3) During the early stage of ecological water conveyance (2000–2009), groundwater levels in the upper and middle sections rose rapidly; after 2009, the magnitude of groundwater level increase in the downstream section Yiganbujima was significantly higher than that in Yingsu (0.88–4.65 m) and Ka' erdayi (0.53–4.07 m). Furthermore, groundwater level fluctuations in 70.5% of monitoring wells tended toward stability, indicating that intermittent ecological water conveyance contributes to raising groundwater depth, serves as a primary source of groundwater recharge,

and exerts a certain promoting effect on maintaining the dynamic equilibrium of relatively high groundwater levels.

Full Text

Effects of Ecological Water Conveyance on Groundwater Depth Variation in the Lower Reaches of the Tarim River

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Abstract: Groundwater is a critical factor for maintaining the survival and growth of desert riparian vegetation and plays an essential role in restoring degraded ecosystems. Based on measured groundwater depth data collected during ecological water conveyance in the lower reaches of the Tarim River from 2000 to 2020, this study comprehensively analyzes the spatiotemporal variation of groundwater depth and its response to ecological water delivery. Monitoring results demonstrate that groundwater depth along both banks of the lower Tarim River increased significantly under ecological water conveyance conditions. (1) In the longitudinal direction (along the river course), from Yingsu in the upstream section through Kaldayi in the middle section to Yiganyuma in the downstream section, groundwater depth at 100 m from the river channel rose from pre-conveyance levels of 7.76 m, 9.31 m, and 7.82 m to 3.70 m, 4.48 m, and 2.69 m, respectively. At 300 m from the river, depths increased from 8.09 m, 9.15 m, and 8.25 m to 4.53 m, 5.00 m, and 3.29 m, respectively. At 500 m from the river, depths increased from 8.21 m, 9.45 m, and 9.08 m to 6.61 m, 5.46 m, and 3.82 m, respectively. (2) In the transverse direction (perpendicular to the river channel), monitoring data from groundwater wells indicate that the influence range of ecological water conveyance extended to 1050 m for all three sections, with water level rises of 2.69 m, 1.38 m, and 1.59 m in the upper, middle, and lower reaches, respectively. (3) During the early stage of water conveyance (2000–2009), groundwater levels in the upper and middle sections rose rapidly. After 2009, the groundwater level rise in the downstream Yiganyuma section (0.88–4.65 m) significantly exceeded that in Yingsu (0.53–4.07 m) and Kaldayi (1.38–2.69 m). Furthermore, groundwater fluctuations in 70.5% of monitoring wells stabilized over time, indicating that intermittent ecological water conveyance effectively raises groundwater depth, serves as the primary source of groundwater recharge, and helps maintain dynamic equilibrium at higher water

table levels.

Keywords: ecological water conveyance; groundwater depth; cross-section; Tarim River

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1.1 Study Area Overview

The Tarim River is located in the Tarim Basin south of the Tianshan Mountains. Its lower reaches flow between the Taklamakan and Kuruk deserts in a region characterized by temperate continental climate with scarce precipitation, dry conditions, and frequent sandstorms. Annual precipitation ranges from 17.4 to 42.0 mm, while annual evaporation reaches 2500–3000 mm. Construction of the Daxihaizi Reservoir in the 1970s completely blocked surface runoff from the Tarim River, causing the main channel to dry up. Combined natural and anthropogenic factors led to severe groundwater decline in the lower reaches, resulting in large-scale degradation and mortality of desert riparian vegetation and activation of inter-dune sands.

1.2 Research Methods

Based on the ecological water conveyance project in the lower Tarim River, we established nine groundwater monitoring cross-sections along the river channel below the Daxihaizi Reservoir: Akedun, Yahefumahan, Yingsu, Abudale, Kaldayi, Tugemalai, Alagan, Yiganyuma, and Kuergan (Fig. 1). Cross-sections were spaced approximately 20–45 km apart, with groundwater monitoring wells installed at varying distances perpendicular to the river channel (50–100 m between wells at the same cross-section). Due to equipment limitations and environmental conditions, some data gaps existed prior to 2009. However, with technological advances, we upgraded to real-time monitoring instruments, substantially improving data continuity.

Given data gaps at some cross-sections, we selected three representative monitoring sections—Yingsu, Kaldayi, and Yiganyuma—to reflect groundwater depth changes since the implementation of ecological water conveyance. These sections represent the upper, middle, and lower reaches of the downstream area, respectively, based on their distance from the water source (Daxihaizi Reservoir).

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2 Results and Analysis

2.1 Groundwater Depth Variation Along the River Course During the initial water conveyance period (2000–2009), groundwater depth at the three monitoring cross-sections was generally at similar low levels, likely resulting from the river channel' s prolonged dry period. As ecological water conveyance continued, groundwater depth increased significantly. At 100 m from the river channel, maximum groundwater depth decreased from 7.76 m to 3.70 m at Yingsu, from 9.31 m to 4.49 m at Kaldayi, and from 7.82 m to 2.69 m at Yiganyuma. At 300 m, depths decreased from 8.09 m to 4.53 m, from 9.15 m to 5.00 m, and from 8.25 m to 3.29 m, respectively. At 500 m, depths decreased from 8.21 m to 6.61 m, from 9.45 m to 5.46 m, and from 9.08 m to 3.82 m, respectively.

During the later conveyance period (2010–2020), Yiganyuma showed an overall declining trend in groundwater depth (range: 2.69–3.82 m), while Yingsu and Kaldayi exhibited ranges of 4.20–6.61 m and 4.38–5.46 m, respectively. This indicates that after 2009, the groundwater level rise in the downstream section significantly exceeded that in the upper and middle sections.

2.2 Groundwater Depth Variation Perpendicular to the River Channel In the lower Tarim River, different cross-sections perpendicular to the river channel share common characteristics: groundwater depth generally decreases with increasing distance from the river channel, and this trend becomes more pronounced with intermittent water conveyance (Fig. 3). Before water conveyance, groundwater depth remained relatively stable regardless of distance from the river, indicating no relationship between depth and lateral distance during the dry period. As water conveyance proceeded, river water infiltrated laterally, affecting groundwater levels more strongly near the channel and less strongly farther away, creating a clear distance-dependent gradient.

2.3 Magnitude of Groundwater Depth Rise The magnitude of groundwater depth rise varied significantly across different periods of intermittent ecological water conveyance. During the initial conveyance stage (2000–2009), all cross-sections showed substantial rises: 2.88–4.17 m at Yingsu, 3.34–3.98 m at Kaldayi, and 2.3–2.42 m at Yiganyuma. During the middle and later stages, groundwater rise magnitudes were noticeably lower than in the initial stage, though with some variation among cross-sections.

2.4 Response Range of Ecological Water Conveyance At distances of 100 m, 300 m, 500 m, and 1050 m from the river channel in the lower Tarim River, groundwater depth showed significant uplift at typical cross-sections (Table 1). Before water conveyance, groundwater depth remained stable at greater distances from the river: at Yingsu, depth was maintained at approximately 8.1 m beyond 150 m from the channel; at Kaldayi, depth remained around 9.20 m; and at Yiganyuma, depth stayed at 8.21 m. After implementing ecological water conveyance, the influence range extended to 1050 m parallel to the river channel, demonstrating that water delivery effectively raises groundwater levels and expands the wetted area.

2.5 Relationship Between Water Conveyance Volume and Groundwater Depth The relationship between water conveyance volume and groundwater depth in the lower Tarim River shows that large water volumes do not necessarily produce immediate significant groundwater rises; instead, a lag effect or slow growth may occur. For example, peak groundwater levels appeared in 2017 following relatively large water deliveries in 2016 and 2017. This indicates that groundwater depth rise depends not only on water volume but also on other factors such as conveyance stage, distance from the water source, and delivery frequency. However, large water volumes can slow groundwater recession rates, maintaining relatively shallow depths for extended periods. By 2020, cumulative water delivery reached 84.45$×10^{8}$ m^3 across 22 events, ensuring channel connectivity and promoting groundwater rise through sustained river infiltration.

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3 Discussion

The Tarim River lies in mid-latitude inland China, far from oceans and surrounded by high mountains adjacent to the Taklamakan Desert, resulting in dry climate, scarce precipitation, and insufficient water vapor. Natural groundwater recharge depends solely on seasonal meltwater from high-altitude glaciers, mid-elevation forest precipitation, and low-mountain bedrock fissure water. Under anthropogenic interference, intermittent ecological water conveyance has become the key factor maintaining groundwater dynamic equilibrium.

Over 20 years of intermittent water delivery, groundwater depth in the lower Tarim River has shown clear rises in both longitudinal and transverse directions, correlating with conveyance frequency and volume. Along the river course, different cross-sections exhibit varying uplift magnitudes related to conveyance timing and distance from the water source. During initial conveyance, Yingsu (closer to Daxihaizi Reservoir) received water first and for longer durations, while more distant sections (Kaldayi and Yiganyuma) experienced greater water losses and reduced volumes, resulting in delayed recharge and smaller depth reductions. With prolonged conveyance, effective groundwater recharge raised water levels throughout the reach, allowing more flow to reach the downstream Taitema Lake area and creating a new water source that particularly benefited Yiganyuma.

Perpendicular to the river channel, pre-conveyance groundwater depths were stable and independent of lateral distance. During conveyance, lateral infiltration created strong distance-dependent gradients, with greater impacts near the channel. Our study demonstrates that the response range extends to 1050 m from the river, with increasing cumulative water volumes expanding the effective wetted area and influence distance over time. Occasional depth declines in some years may result from dry conditions with high evapotranspiration losses, agricultural irrigation consumption, industrial water use, or water infrastructure modifications altering flow paths.

Soil moisture correlates linearly with soil depth, with the highest correlation to groundwater occurring in the 0–20 cm layer. Different soil textures create moisture content variations: sandy soils have lower water content than clay and loam soils. Soil moisture directly affects vegetation growth, with studies showing that 16.75%-18.76% moisture content supports Populus euphratica seedling establishment, while 4.55%-16.75% moisture favors mature trees, and below 4.55% causes vegetation aging. Groundwater influences vegetation primarily through capillary action that retains moisture in soil pores for plant uptake. At 1.5 m groundwater depth, soil moisture reaches 12.90%-10.70% with capillary water content up to 70.80%, creating suitable conditions for plant survival. At 4.50-6.50 m depth, reduced capillary water leads to poor plant growth, while below 9.80 m, absence of capillary water causes severe water stress and vegetation mortality.

Since 2000, ecological water conveyance has significantly raised groundwater depths in the lower Tarim River (overall rise >1.38 m), effectively restoring the degraded desert environment and vegetation. Grassland and forest areas increased by 382.85 km^2 and 738.95 km^2 respectively, while desert area decreased, vegetation coverage increased, and plant species richness expanded. The Taitema Lake area has shown continuous ecological improvement, with water area reaching 492 km^2 and surrounding wetlands forming 223 km^2. The ecological security level of the lower Tarim River has continuously improved, with the water ecological security comprehensive evaluation index rising from 0.53 to 0.70. Landscape ecological risk assessment shows low and relatively low-risk zones now dominate, accounting for 72.61% of the basin area.

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4 Conclusions

Based on nearly 20 years of measured groundwater monitoring data, this study analyzed post-conveyance groundwater depth changes in both longitudinal and transverse directions, yielding the following main conclusions:

(1) Along the lower Tarim River from upstream to downstream (Yingsu–Kaldayi–Yiganyuma), groundwater depth at 100 m from the river channel rose to 3.70 m, 4.48 m, and 2.69 m, respectively; at 300 m to 4.53 m, 5.00 m, and 3.29 m; and at 500 m to 6.61 m, 5.46 m, and 3.82 m.

(2) In the direction perpendicular to the river channel, the influence range of ecological water conveyance on groundwater levels in the lower Tarim River reached 1050 m, with water level rises of 2.69 m, 1.38 m, and 1.59 m in the upper, middle, and lower reaches, respectively.

(3) During the early water conveyance period (2000–2009), groundwater levels in the upper and middle sections rose rapidly. After 2009, the groundwater level rise in the downstream Yiganyuma section (0.88–4.65 m) significantly exceeded that in Yingsu (0.53–4.07 m) and Kaldayi (1.38–2.69 m). Groundwater fluctuations in 70.5% of monitoring wells stabilized, in-

dicating that intermittent ecological water conveyance effectively raises groundwater depth and promotes dynamic equilibrium at higher water table levels.

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