Groundwater Evapotranspiration in Desert Riparian Forests of the Lower Tarim River: Postprint

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Abstract

This study analyzes the monthly and daily fluctuations of groundwater level, spatiotemporal variations of groundwater evapotranspiration (ETg), and their primary influencing factors in desert riparian forests, through monitoring groundwater levels at four observation points and estimating groundwater evapotranspiration in the lower Tarim River. The results indicate: Prior to ecological water transfer (July 21 to August 12), groundwater levels at the four observation points exhibited an overall declining trend; following ecological water transfer, water levels maintained a stable rising trend. Throughout the entire observation period, groundwater levels displayed distinct diurnal fluctuation patterns. ETg demonstrated unimodal variation characteristics, increasing rapidly from 8:00, remaining at relatively high levels between 12:00–16:00, decreasing rapidly after 18:00, with maximum values occurring at 14:00 local time. ETg varied significantly with vegetation type and coverage, while also being influenced by groundwater depth. Solar radiation, temperature, and vapor pressure deficit constitute the primary factors influencing daily variations in groundwater evapotranspiration in the lower Tarim River, whereas wind speed exerted no significant effect.

Full Text

Groundwater Evapotranspiration in Desert Riparian Forest in the Lower Reaches of the Tarim River

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Abstract

In this study, the groundwater level at four observation sites in the lower reaches of the Tarim River was monitored, and the values of groundwater evapotranspiration were estimated. The purposes of the study were to analyze the fluctuations of groundwater level and the groundwater evapotranspiration (ETg) as well as their main affecting factors. The results showed that: A drawdown of groundwater level occurred holistically at the four observation sites before implementing the project of ecologic water conveyance; after implementing the project from July 21 to August 12, however, the groundwater level was in a steady rising trend. There was a diurnal-nocturnal fluctuation of groundwater level during the study period; The curve of ETg was unimodal, ETg began to rapidly increase from 08:00, maintained at a high level from 12:00 to 16:00, and rapidly decreased after 18:00. The highest value appeared at 14:00 local time; ETg varied significantly with different vegetation types and coverage, and was also affected by groundwater depth; Solar radiation, temperature and vapor pressure deficiency were the main factors affecting the daily variation of groundwater evapotranspiration in the lower reaches of the Tarim River, and the effect of wind speed on it was not significant.

Keywords: groundwater evapotranspiration; groundwater level; desert riparian forest; lower reaches of the Tarim River

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1. Materials and Methods

1.1 Study Area The study was conducted in the lower reaches of the Tarim River, approximately 428 km from the river mouth. Four observation sites were established with different vegetation types and groundwater depths. The geographic coordinates were: C6 (40°25.766 N, 87°56.398 E), D1 (40°24.903 N, 88°03.079 E), D2 (40°24.854 N, 88°03.057 E), and G5 (40°08.536 N, 88°20.856 E). The region has a continental arid climate with an average annual temperature of 10.7°C and annual precipitation of 2671.4 mm. The dominant vegetation species include Populus euphratica, Tamarix spp., Halimodendron halodendron, Alhagi sparsifolia, and Phragmites communis.

1.2 Field Data Collection Field investigations were carried out from July 21 to August 12, 2018. At each observation site, a 50 m $\times$ 50 m plot was established for vegetation survey. Vegetation types were categorized as: (1) Populus euphratica forest, (2) Tamarix shrubland, and (3) mixed forest. Groundwater depth was measured using water level loggers installed in observation wells.

1.3 Groundwater Monitoring Groundwater levels were monitored using HOBO U20 water level loggers (Campbell Scientific, Logan, UT, USA) at nine observation wells across the four sites. Data were recorded at hourly intervals from July 21 to October 13, 2018. The monitoring period covered both the ecological water conveyance phase and the post-conveyance phase.

1.4 Estimation of Groundwater Evapotranspiration Groundwater evapotranspiration (ETg) was estimated using the Lohide method, which calculates ETg based on diurnal groundwater level fluctuations and specific yield. The calculation formula is:

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where Sy represents specific yield and WTD represents water table depth. Specific yield values were determined based on soil texture and previous studies in the region, ranging from 0.026 to 0.037 for different sites.

Potential evapotranspiration (ET) was calculated using the Penman-Monteith equation with meteorological data obtained from the China Meteorological Data Service Center. The White method was also applied for comparative analysis.

1.5 Data Analysis All data were processed using Excel 2016 and SPSS 19.0 software. One-way ANOVA was performed to test for significant differences in ETg among different sites and vegetation types, followed by LSD post-hoc tests (= 0.05). Pearson correlation analysis was used to examine relationships between ETg and environmental factors. SigmaPlot 12.5 was used for graphical presentations.

2. Results

2.1 Groundwater Level Dynamics Prior to the ecological water conveyance project, groundwater levels at all four sites exhibited a continuous drawdown trend. Following the implementation of water conveyance from July 21 to August 12, groundwater levels entered a recovery phase with a steady rising trend. Throughout the monitoring period, groundwater levels displayed distinct diurnal-nocturnal fluctuations with amplitudes ranging from 41 mm to 99 mm among different sites.

[Figure 1: see original paper] illustrates the groundwater level fluctuations at the four observation wells during the study period. The diurnal pattern showed a decline during daytime (09:00–11:00) and recovery during nighttime (18:00–20:00), reflecting the influence of plant transpiration and atmospheric conditions.

2.2 Temporal Variation of Groundwater Evapotranspiration

2.2.1 Seasonal Patterns ETg exhibited significant temporal variation during the growing season. The monitoring period was divided into two phases: the water conveyance period (July 21 to August 12) and the post-conveyance period (August 13 to October 13). Significant differences in ETg were observed among sites ($P < 0.05$). During the water conveyance period, the D2 site (mixed forest) showed the highest ETg at 3.4 mm · d ¹, while the G5 site (Tamarix shrubland) had 2.1 mm · d ¹.

[Figure 3: see original paper] presents the comparison between ETg and potential evapotranspiration (ET) at the four sites. ETg accounted for 10.54% to 80.0% of ET across different sites, indicating substantial groundwater consumption by phreatophytes.

2.2.2 Diurnal Patterns ETg displayed a clear unimodal diurnal pattern across all sites. It began to increase rapidly after 08:00, reached peak values between 12:00 and 16:00, and declined sharply after 18:00. The maximum ETg occurred at 14:00 local time, coinciding with the period of maximum solar radiation and atmospheric water demand.

[Figure 4: see original paper] shows the daily dynamics of ETg at the four sites in different months. The diurnal pattern was consistent across sites but varied in magnitude depending on vegetation type and groundwater depth.

The mean daily ETg values were 2.51, 3.12, 3.20, and 1.89 mm · d ¹ at sites C6, D1, D2, and G5, respectively.

2.3 ETg Variation Among Vegetation Types ETg differed significantly among vegetation types ($P < 0.05$). The mixed forest site (D2) exhibited the highest ETg rates throughout the monitoring period, followed by the Tamarix shrubland site (G5). The Populus forest sites (C6 and D1) showed relatively lower ETg values.

During July to August, ETg at the D2 site (3.03 mm · d ^{1}) was significantly higher than at other sites ($P < 0.05$). In August to September, D2 maintained high ETg values (3.66 mm · d ^{1}), significantly exceeding those at C6 and G5 ($P < 0.05$). The G5 site showed consistently lower ETg values across all months.

[Figure 5: see original paper] depicts the seasonal variation of ETg at different observation sites, highlighting the influence of vegetation composition on groundwater consumption.

2.4 Correlation with Environmental Factors Correlation analysis revealed that ETg was significantly positively correlated with solar radiation, air temperature, and vapor pressure deficit ($P < 0.01$). Solar radiation showed the strongest correlation ($R^2 = 0.31$), followed by temperature ($R^2 = 0.18$) and vapor pressure deficit ($R^2 = 0.13$). Wind speed showed no significant correlation with ETg ($P > 0.05$).

[Figure 6: see original paper] illustrates the relationships between ETg and environmental variables at the C6 site. Groundwater depth also significantly affected ETg ($P < 0.01$), with shallower groundwater associated with higher ETg rates. When groundwater depth was less than 0.1 m, ETg reached 3.68 mm · d ^{1}, decreasing to 2.71 mm · d ^{1} at depths greater than 0.7 m.

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3. Discussion

The ecological water conveyance project significantly influenced groundwater dynamics and evapotranspiration processes in the desert riparian forest ecosystem. The diurnal fluctuation pattern of groundwater level, with daytime drawdown and nighttime recovery, is characteristic of phreatophyte-dominated systems where plant transpiration directly affects the water table.

The unimodal diurnal pattern of ETg, peaking at 14:00, aligns with the daily cycle of solar radiation and atmospheric water demand. This pattern is consistent with previous studies on phreatophyte water use in arid regions. The significant correlation between ETg and solar radiation, temperature, and vapor pressure deficit confirms that atmospheric conditions are the primary drivers of evapotranspiration in this environment.

Vegetation type and coverage significantly influenced ETg rates, with mixed forests showing the highest groundwater consumption. This can be attributed to higher leaf area index and species diversity in mixed stands, leading to greater transpiration capacity. The Tamarix shrubland also exhibited substantial ETg, reflecting the adaptation of desert shrubs to groundwater utilization.

The lack of significant correlation between wind speed and ETg suggests that, in this dense riparian forest, atmospheric turbulence has limited effect on canopy-atmosphere water exchange compared to radiation and temperature controls. Groundwater depth emerged as a critical factor, with ETg decreasing markedly at depths greater than 0.7 m, indicating the physiological limits of root water uptake for the dominant species.

These findings have important implications for ecological water resource management in the Tarim River Basin. The results demonstrate that controlled water conveyance can effectively restore groundwater levels and support riparian vegetation, but the water requirements vary significantly among vegetation types. Future water allocation strategies should consider these differences to optimize ecological benefits while minimizing water consumption.

References

The references cited in this study include numerous investigations on groundwater evapotranspiration, riparian ecology, and water resource management in arid regions, which provide the scientific foundation for this research. Key references include studies on the Lohide method〔17〕, the White method〔32〕, and ecological water demand in the Tarim River Basin〔20, 21, 28, 36, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 49〕. The specific yield parameters were derived from regional hydrogeological investigations〔25, 33-34〕. Meteorological data were obtained from the China Meteorological Data Service Center (http://cdc.nmic.cn/home.do). Statistical analyses followed standard procedures for environmental data interpretation〔35, 37〕.

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

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