Postprint: Impact Mechanisms of Intermittent Ecological Water Transfer on Groundwater Level and Vegetation in Arid Regions

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Abstract

The ecosystem of the lower Tarim River, as a typical arid-region ecosystem, exhibits strong dependence on water. To understand the relationship between intermittent ecological water conveyance and variations in groundwater depth and vegetation growth in the lower Tarim River, and to elucidate the mutual influence mechanisms among groundwater depth, vegetation growth dynamics, and the intermittent ecological water conveyance process, this study selects the Yingsu cross-section in the lower Tarim River as the research area. Based on Darcy' s law, calculation methods for plant root water uptake rates, and the coupled relationship between ecological water conveyance, groundwater level changes, and NDVI variations from 2009 to 2015, qualitative and quantitative analyses are conducted on the mutual influence processes and mechanisms among these three factors. The results indicate: (1) The manifestation of water conveyance benefits is a protracted process; both groundwater response and ecological response of downstream vegetation gradually emerge at large spatial and temporal scales. Additionally, due to the seasonal nature of plant growth, groundwater depth in a given year can influence vegetation growth in the subsequent year to a certain extent. (2) Multi-year studies demonstrate that when groundwater depth is less than 7 m, it satisfies the growth requirements of arbor and shrub plants; when less than 6 m, it satisfies the growth requirements of herbaceous plants. (3) Under conditions of fixed annual total water conveyance volume, twice-yearly conveyance represents the optimal frequency for riparian vegetation restoration. Due to the existence of a certain lag period in the ecological water conveyance-groundwater level change-NDVI change relationship, it is recommended to schedule conveyance periods during spring (April–May) and summer (July–August) each year.

Full Text

Influence Mechanism of Intermittent Ecological Water Conveyance on Groundwater Level and Vegetation in Arid Land

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Abstract

As a typical arid area ecosystem, the ecosystem in the lower reaches of the Tarim River in Xinjiang, China, has a strong dependence on water. Taking the Yingsu section in the lower reaches of the Tarim River as the study area, this paper qualitatively and quantitatively analyzed the interaction process and mechanism among ecological water conveyance, groundwater level change, and NDVI change based on Darcy' s law, the calculation method of water absorption rate of plant root systems, and the inter-coupling relationship between ecological water conveyance, groundwater level change, and NDVI change from 2009 to 2015. The results indicate the following conclusions: (1) It takes a long time for water conveyance to take effect. The response of groundwater and the ecological response of vegetation in the lower reaches are gradually revealed at a large spatio-temporal scale, and there is linear growth with the increase of riverbank distance. The study used monitoring wells C3, C4, C5, C6 with distances from the riverway of 59, 300, 500, and 750 meters respectively, and found that there was a lag period of one to nine months during water conveyance. In addition, due to the seasonal nature of plant growth, the groundwater depth value in one year can affect plant growth in the next year to a certain degree. (2) The research over years shows that when the groundwater depth value is less than seven meters, the growth demand of tree and shrub plants is met. For herbaceous plants, when the groundwater depth value is less than six meters, the growth demand is met. (3) When the annual total water supply is fixed, the optimum number of water conveyances for restoration of riparian vegetation is twice a year. Because there is a certain lag period in the ecological water conveyance—the change in groundwater level—the changes in NDVI, it is recommended that water conveyance should be held from April to May and from July to August. In that way, water supply will have an influence on plant germination from March to April, which is the most important period of plant growth, and have an

influence on plant flourishing period from June to August, which is the period of maximum water demand.

Introduction

The lower reaches of the Tarim River represent a typical arid land ecosystem where vegetation growth is strongly water-dependent. From 2009 to 2015, ecological water conveyance events were implemented to restore degraded riparian vegetation. This study examines the complex interactions between intermittent water delivery, groundwater dynamics, and vegetation response as measured by NDVI.

Methods

The Normalized Difference Vegetation Index (NDVI) was calculated using the standard formula:

$$NDVI = \frac{NIR - R}{NIR + R}$$

where NIR represents near-infrared band reflectance and R represents red band reflectance. The study utilized TM imagery to obtain B4 (near-infrared) and B3 (red) band values for these calculations.

Groundwater level changes were monitored at four observation wells (C3, C4, C5, C6) positioned at increasing distances from the river channel at 59 m, 300 m, 500 m, and 750 m respectively. The response lag time between water conveyance and groundwater level change was quantified for each well.

The water absorption rate of plant root systems was calculated based on Darcy' s law and the inter-coupling relationship between ecological water conveyance, groundwater level change, and NDVI change. The coupling diagram illustrating the relationship between ecological water conveyance and groundwater depth change is shown in [Figure 2: see original paper].

Results

Lag Period Analysis: Statistical analysis of groundwater depth changes during 2009–2015 revealed significant variation in response times across the monitoring wells. The lag periods ranged from 1 to 9 months following water conveyance events, with longer delays observed at greater distances from the river channel. Specific lag periods for different wells are detailed in .

Groundwater Depth Thresholds: Long-term observations demonstrated distinct thresholds for different vegetation types. Tree and shrub communities showed satisfactory growth when groundwater depth remained less than 7 meters, while herbaceous plants required shallower groundwater depths of less than

6 meters. These thresholds reflect the differential root distribution patterns and water uptake capacities among growth forms.

NDVI Response: Vegetation response, as indicated by NDVI values, showed seasonal patterns strongly correlated with groundwater availability. The NDVI values from 2009–2015 reveal that vegetation condition in any given year was influenced not only by current-year water supply but also by groundwater conditions from the previous year, highlighting the legacy effects of water availability.

Discussion

The study demonstrates that effective ecological water management must account for significant time lags in the system. The linear relationship between riverbank distance and response time indicates that proximal areas respond more rapidly to water conveyance, while distal areas require extended periods for groundwater recharge and vegetation response.

For optimal vegetation restoration with fixed annual water volumes, two water conveyance events per year are recommended. The timing should target critical plant growth stages: April-May conveyances support spring germination (March-April), while July-August deliveries sustain the peak growing season (June-August) when water demand is maximal. This strategy accounts for the 1-9 month lag period in the water conveyance-groundwater-NDVI cascade.

The groundwater depth thresholds identified (<7 m for woody plants, <6 m for herbs) provide quantitative targets for water management planning. Maintaining groundwater within these ranges ensures that vegetation water demands are met throughout the growing season.

References

[1] Hoffman GJ, van Genuchten MT. Soil properties and efficient water use: Water management for salinity control. In: Limitations to Efficient Water Use in Crop Production. 1983:73-85.

[2] Allen RG, Pereira LS, Raes D, et al. Crop evapotranspiration—Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Rome: Food and Agriculture Organization, 1998.

[3] Kang Shaozhong, Cai Huanjie, Liu Xiaoming, et al. The dynamic model of air, surface, ground, soil and plant water interaction and its application. Journal of Northwest A&F University: Natural Science Edition, 1995, (2):1-9.

[4] Fu Aihong, Chen Yaning, Li Weihong. Water use strategies of the desert riparian forest plant community in the lower reaches of Heihe River Basin, China. Science China: Earth Sciences, 2014, (4):693-705.

[5] Philip JR. Plant water relations: Some physical aspects. Annual Review of Plant Physiology, 1966, 17:245-268.

[6] Liu Yakun. Hydraulics. 2nd ed. Beijing: China Water & Power Press, 2016:358-373.

[7] Klein T. The variability of stomatal sensitivity to leaf water potential across tree species indicates a continuum between isohydric and anisohydric behaviours. Tree Physiology, 2012, 32(3):249.

[8] Rogiers SY, Greer DH, Hatfield JM, et al. Stomatal response of an anisohydric grapevine cultivar to evaporative demand, available soil moisture and abscisic acid. Functional Ecology, 2015, 28(6):1313-1320.

[9] (Additional references appear to be truncated in the original text)

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