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Determining the ecological water allocation in a hyper-arid catchment with increasing competition for water resources

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ABSTRACT

Meeting ecological water requirement adequately plays a significant role in guaranteeing the stability of river basin ecosystems in arid lands. The amounts of water leaked through the riverbed and drawn by ecological brakes in Tarim River were ascertained. Based on data related to soil, hydrology, and vegetation of the river basin, the aims of this paper are to 1) analyse the variation in the size of soil particles and in hydraulic conductivity of four sections of the river; 2) calculate the amount of water that leaked from the riverbed and the percentage of ecological water requirement that can be guaranteed at different frequencies of water inflow; and 3) recommend – using a combination of particle size analysis, Darcy's Law, and GIS – the amount of water to be drawn from ecological brakes along both banks of the river for meeting ecological water requirement adequately. The results showed that 1) the size of soil particles in the riverbed ranged from 1.6 μm to 98.9 μm; 2) hydraulic conductivity followed the normal distribution from year to year but varied in spatial terms, that is across different section of the river; 3) riverbed leakage varied with water frequencies, being 11.36×10^8 m^3, 10.62×10^8 m^3, 9.84×10^8 m^3, 9.32×10^8 m^3, and 8.87×10^8 m^3 at the frequencies of 10%, 25%, 50%, 75%, and 90%, respectively; 4) the distance over which the leakage contributed to meeting ecological water requirement in the south bank was greater than or equal to the distance in the north bank; and 5) water drawn from ecological brakes on the north bank exceeded that drawn from the brakes on the south bank by 10.89×10^8 m^3–11.28×10^8 m^3. Ecological water requirement of the desert riparian vegetation was met mainly from riverbed leakage in the south and by drawing from ecological brakes in the north. The present research not only offers a scientific method that could be used for developing suitable schemes for meeting ecological water requirement but also provides a technical guide on running ecological brakes and achieving the optimal allocation of water resources in Tarim River Basin.

1. Introduction

Water is one of the key environmental factors that guarantee the structural integrity and stability of river basin ecosystems (Colloff et al., 2015; Bennetsen et al., 2016; Boithias et al., 2016; Campitelli et al., 2016). In such ecosystems in arid lands, the ecological processes are particularly affected by hydrological processes (Ludwig et al., 2005; Ling et al., 2014; Zhou et al., 2014; Daessle et al., 2016; Gu et al., 2016). Desert riparian vegetation, as the main component of river basin ecosystems in arid lands, is sustained mainly by groundwater, which is recharged by water leakage from the riverbed (Yuan et al., 2014; Viola et al., 2014; Garssen et al., 2015; Hamdan and Stromberg, 2016). This leakage that not only recharges the groundwater but also supports the renewal, population succession, and distribution pattern of vegetation (Wang et al., 2010; Chen et al., 2013; Agapiou et al., 2016). However, with the increasing requirement for water by human settlements in the inland river basins, water for the desert riparian vegetation is becoming increasingly scarce (Zhao et al., 2013; Ye et al., 2014a; Wang et al., 2015). Therefore, judicious allocation of water for ecological purposes based on the characteristics and distribution of the desert riparian vegetation has become a hot topic among many scholars (Davies et al., 1992; Yang et al., 2007; Zhao et al., 2007; Ling et al., 2014; Si et al., 2015; Villeneuve et al., 2015).

Ecological water requirement of desert riparian vegetation in an inland river basin refers to the amount of surface water and groundwater that can guarantee normal growth of such vegetation and restrict further deterioration of the ecosystem (Zhao et al., 2007; Ling et al., 2014; Si et al., 2015). Previous studies provide many references for the calculation and allocation of ecological water (Table 1). Concretely, some scholars present several strategies on the calculation of ecological water requirements (Davies et al., 1992; Yang et al., 2007; Villeneuve et al., 2015), some propose a number of approaches on how to allocate ecological water and solve conflicts while making water allocation

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Table 1
Summary of relevant studies on the calculation and allocation of the ecological water.

Order	Study	Location	Methods	Relevant key results
1	Davies et al. (1992)	Africa, Australia and USA	Propose a world-wide research strategy—IBTs (inter-basin water transfers)	One of the main reasons for inter-basin water transfers is need for ecological ethic.
2	Doupé and Pettit (2002)	Old River, Western Australia	Compared the water requirements of irrigation and ecology in dry seasons	Agriculture water demand is more essential than ecological water demand in dry seasons.
3	Thoms and Sheldon (2002)	Condamine–Balonne River, Australia	Develop an ecosystem approach	Water allocation should obey the hierarchy of ecosystem.
4	Schlüter et al. (2005)	Amudarya delta region, Aral Sea Basin	EPIC (Environmental Policies and Institutions for Central Asia) model	Surface water plays a significant role in long-term modeling of water allocation.
5	Messner et al. (2006)	Spree River, German	Presents an integrated methodological approach (IMA)	This approach could resolve water allocation conflict.
6	Chen (2007)	Yellow River, China	Established an early warning mechanism on flooding or low inflow	Minimum, suitable and maximum ecological flows are essential in ecological water allocation.
7	Yang et al. (2007)	Yellow River, China	Holistic approach in a basin scale to calculate ecological water requirement	(1) 45% of the total surface water resources allocated to ecological system. (2) The ecological water requirements of inside river systems and outside river systems were respectively 261.0×10^8 m^3 and 3.65×10^8 m^3.
8	Bangash et al. (2012)	Catalonia, northeastern Spain	DHI's MIKE BASIN model	Conjunctive use of surface water and groundwater is efficient in water allocation.
9	Villeneuve et al. (2015)	Woodforde River, central Australia,	Field monitoring	(1) 25% of this water recharges the deep aquifer. (2) 75% is used by the riparian vegetation or evaporated directly from the soil.
10	This paper	Tarim River, western China	Particles analysis, water balance and spatial analysis of GIS	(1) Ecological water requirements are supplied mainly by riverbed leakage and water drawn from ecological brakes. (2) Spatial analysis of GIS can be used for spatial distribution of vegetation ecological water requirement. (3) The amount of riverbed leakage and water drown could determine the range of vegetation preserve through under different water frequencies.

plans (Thoms and Sheldon, 2002; Doupé and Pettit, 2002; Messner et al., 2006; Chen, 2007), and the others develop models to determine the water amount of surface and ground water in ecological water allocation (Schlüter et al., 2005; Bangash et al., 2012). But few of them put forward a specific plan on how to meet ecological water requirement by utilizing the surface water and leakage water conjunctively. In Tarim River, the requirement is mainly influenced by water leaked through riverbeds and drawn from ecological brakes (Ling et al., 2014; Chen et al., 2015). Riverbed leakage and water drawn from ecological brakes are the two main sources of ecological water requirement of vegetation. Therefore, if riverbed leakage cannot meet the requirement, the water drawn from ecological brakes should be taken into consideration. Therefore, it is particularly important to conduct research on hydraulic conductivity and transformation of the river-groundwater connection

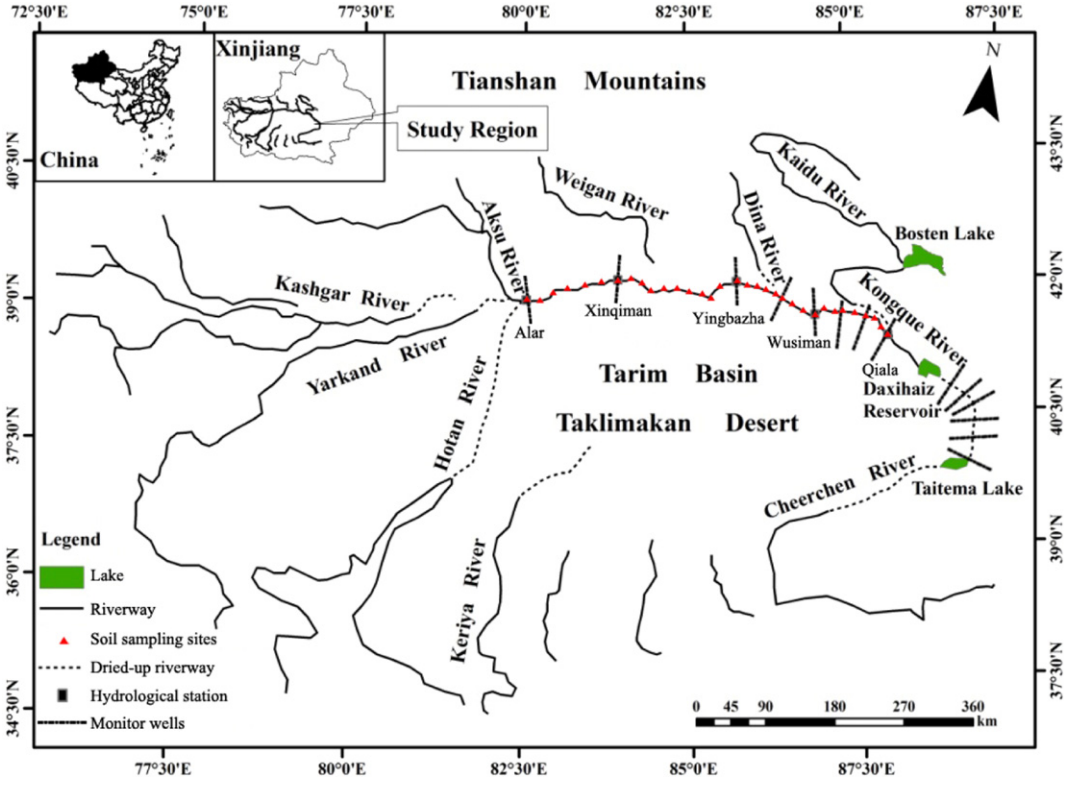

Fig. 1. Sketch map and soil sampling sites in Tarim River Basin.