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Analysis of the contribution of groundwater to evapotranspiration in an arid irrigation district with shallow water table

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ABSTRACT

Groundwater from the shallow aquifers can supply substantial water for evapotranspiration of crops and other vegetation (the groundwater supported evapotranspiration). Regional scale evapotranspiration and the groundwater contribution to evapotranspiration were estimated by the soil water balance equation in Jiefangzha sub-district (JFZSD), a sub-district with shallow aquifers in Inner Mongolia, China. Estimates used an 8-year (2006–2013) hydrological dataset including soil moisture, the depth to water table, irrigation amounts, rainfall data, and drainage water flow. Soil moisture and the groundwater depth varied substantially with irrigation, the fluctuations in rainfall, and the stage of crop growth. The soil moisture with very shallow groundwater depth was greater than it was with groundwater at greater depth. The 8-year mean evapotranspiration was estimated to be 664 mm, the mean section evapotranspiration were ranged from 538 mm to 899 mm during the crop growth period in JFZSD. The mean groundwater supported evapotranspiration (ET_g) was estimated to be 228 mm, with variation from 145 mm to 412 mm during the crop growth period in JFZSD. Analysis of the positive correlation between evapotranspiration and the sum of irrigation and rainfall, and the analysis of the negative correlation between ET_g/ET and the sum of irrigation and rainfall, reflect the need of groundwater to meet the evapotranspiration demand. Approximately 20% to 40% of the evapotranspiration is from the shallow aquifers in JFZSD. With the policy of decreasing the amount of Yellow River water diverted to the HID in the future, the more groundwater would be used. However, the local groundwater in return depends on irrigation. Besides, the fraction of drainage to irrigation is already low, suggesting that future decreases in water deliveries will lead to soil salinization and loss of productivity in the sub district. These results could be useful for the government to understand the significant role of the groundwater and make reasonable water use policy in the semiarid agricultural regions.

1. Introduction

Irrigated agriculture supplies approximately 40% of the human food supply on less than 18% of the arable land and is anticipated to have an important role in meeting the projected future world food demand (Ayars et al., 2006). Irrigated agriculture is the backbone of the local economy in many arid and semi-arid areas. With water resource scarcities intensifying, improving irrigation efficiency is becoming increasingly important in arid and semi-arid areas throughout the world. On a regional scale, irrigation water use efficiency depends on water cycle, including soil water and groundwater migration processes.

Groundwater evapotranspiration is an important part of the hydrological cycle. It is one of the main sources of the regional evapotranspiration and the main consumption of groundwater in areas with shallow water table (Yeh and Famiglietti, 2009; Babajimopoulos et al., 2007). The water cycle is complex for irrigated land, especially for a region with shallow groundwater. In arid and semi-arid areas, the drying of the surface soil moisture can lead to an upward capillary flux from the shallow groundwater to sustain evapotranspiration demands and crop water use (Luo and Sophocleous, 2010; Yeh and Famiglietti, 2009). Climate models using surface parameterizations indicate that 5%–33% of evapotranspiration can be supplied directly from shallow aquifers (Yeh and Famiglietti, 2009). Using the HYDRAT2D model for a watershed in central Minnesota, groundwater-supported evapotranspiration accounts for as much as 12% (100 mm) of evapotranspiration (Cohen et al., 2006). Furthermore, groundwater evapotranspiration

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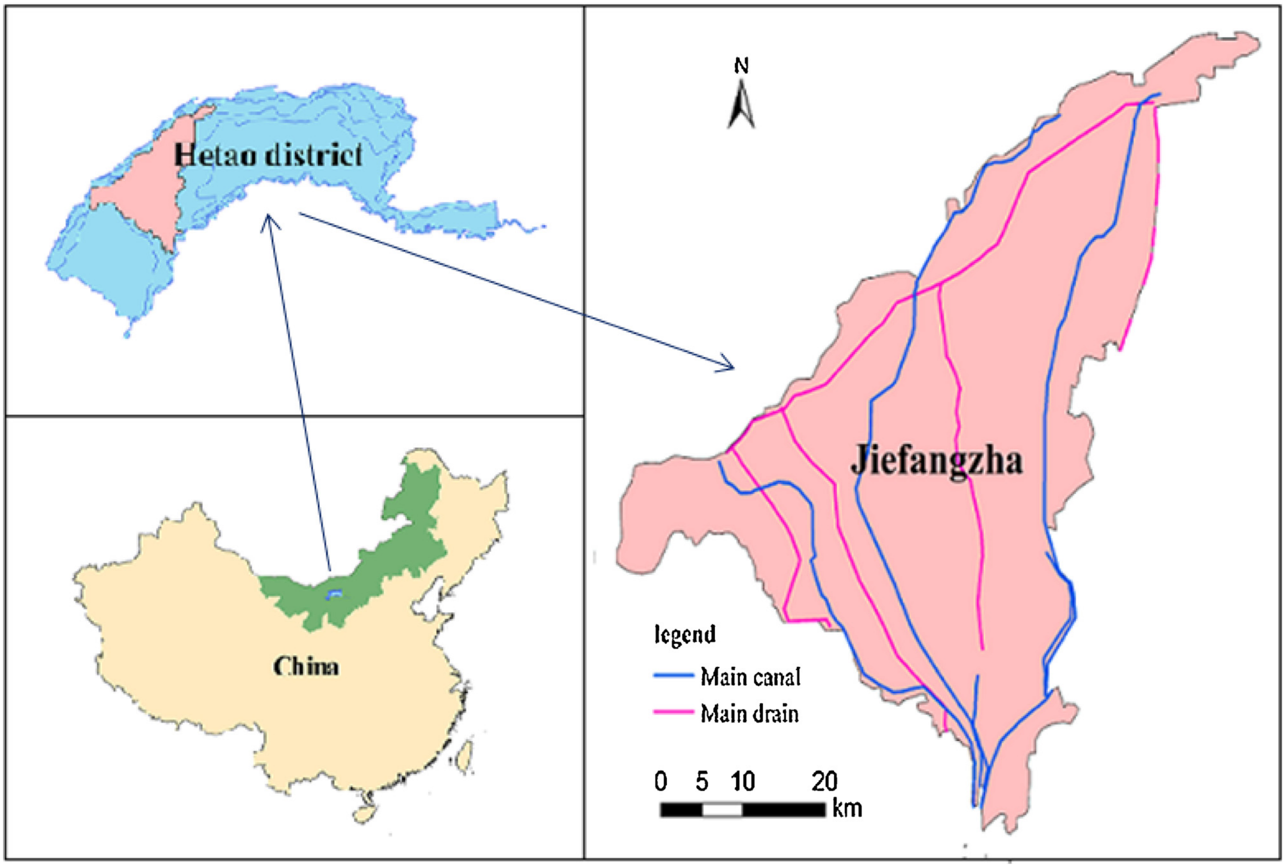

Fig. 1. Location of JFZSD in HID, Inner Mongolia, China.

Table 1
Basic information of the four sections in JFZSD, Inner Mongolia, China, 2006–2013.

Irrigation section	Irrigation area (ha)	Annual average canal diverted water from Yellow River (mm)	Annual average groundwater depth (m)	Number of soil moisture monitoring sites	Number of groundwater depth monitoring sites
Wula	19940	913	1.5	5	10
Yangjia	44389	852	1.8	6	16
Huangji	53387	933	2.1	9	22
Qinghui	13613	830	2.3	2	7

Table 2
Soil hydraulic properties in JFZSD (Xu et al., 2010).

Soil type	θ_s(cm³/cm³)	θ_r(cm³/cm³)	θ_{FC}(cm³/cm³)	θ_{WP}(cm³/cm³)	K_s(cm/d)	ρ(g/cm³)
Sandy loam	0.446	0.111	0.305	0.081	18.3	1.51
Clay loam	0.486	0.135	0.335	0.084	9.8	1.42
Silty clay loam	0.511	0.149	0.342	0.085	6.5	1.28
Loamy clay	0.504	0.256	0.361	0.092	3.5	1.18
Silty clay	0.547	0.318	0.382	0.096	2.0	1.12

Note: θ_s and θ_r are the saturated and residual soil water content, respectively; θ_{FC} and θ_{WP} are the soil water content at field capacity and wilting point, respectively; K_s is the saturated hydraulic conductivity, and ρ is the bulk density.

can be a major source of water for crops and plants in semiarid area and salt march site (Scott and Huxman, 2006; Dahm et al., 2003; Hughes et al., 2001; Tyler et al., 1997; Wallender et al., 1979).

Depending on the information of study area and hydrological process, the groundwater contribution to evapotranspiration can be quantified by various methods. In past several decades, lysimeters have been used to measure groundwater contribution to evapotranspiration at field scale (Grasso et al., 2003; Scanlon et al., 2002; Soppe and Ayars, 2003; Xu and Chen, 2005; Kahlown et al., 2005; Fahle and Dietrich, 2014). Kahlown et al. (2005) found that the contribution of groundwater in meeting the crop water requirements varied with the water table depth. With the water table at 0.5 m depth, wheat met its entire water requirement from the groundwater and sunflower absorbed more than 80% of its required water from groundwater. Huo et al. (2012) investigated the relationship between water flux at the water table, irrigation amount, and groundwater depth using lysimeters with controlled groundwater depths. The lysimeters method is very accurate but has limitations. The construction, operation, and maintenance of the lysimeters are very expensive. Furthermore, this method is focused on a specific field experiment and cannot always be extrapolated to a regional scale. The water table fluctuation (WTF) method is also