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Original Articles

Seasonal variability of hyporheic water exchange of the Weihe River in Shaanxi Province, China

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ABSTRACT

Interactions between surface water and groundwater play a major role in hydrological processes. Understanding the seasonal variations of the water exchange is important to clear drivers of water transferring in a catchment. However, the seasonal variations of water exchange have been limited by the resolution of methods and the experimental problems. In this paper, the Weihe River, in Shaanxi Province, China was chosen, as a case study area to access the seasonal variability of water exchange in the hyporheic zone (HZ). Five testing sites were in the main channel of the river, and seasonal field data were collected from fall 2012 to summer 2014. The temperature profiles and heat convection-diffusion equation were applied to analyze the hyporheic water exchange pattern (the type of movement) and its magnitude, as well as characterizing the seasonal variability of the water exchange features. The results indicate that the patterns and magnitudes of water exchange in the hyporheic zone vary significantly in seasons and test sites. The water exchange general in the fall season (71.5 mm/d) is larger than in other seasons (i.e., spring 54.14 mm/d, summer 56.19 mm/d and winter 23.26 mm/d). This study provides the guidelines for the water resources management in different seasons.

1. Introduction

Understanding the transfer dynamics in hyporheic zone is essential for water quality and river ecosystem (Gerecht et al., 2011; Cranswick et al., 2014; Zhang et al., 2017), and has paramount ecological implications (Pacioglu and Moldovan, 2015; Rode et al., 2015). The hyporheic zone (HZ) is the main area of interactions between surface water and groundwater (Krause et al., 2009), and it is an importance part of fluvial and groundwater ecosystem (Brunke and Gonser, 1997; Trauth et al., 2014), and it has been regarded as river's liver because of importance in stream biogeochemical processing (Brunke and Gonser, 1997; Mendoza-Lera and Datry, 2017), which is fundamental to restoring ecological functions of streams (Hester and Gooseff, 2010). The specific ecological services including pollutant attenuation, secondary production, hydraulic regulation, environmental buffering, and ecological protection (Kalbus et al., 2007; Gerecht et al., 2011; Mermillod-Blondin, 2011; Stubbington, 2012; Haria et al., 2013; Min et al., 2013).

Accurate estimation of hyporheic water exchange and its spatial and seasonal change is crucial for evaluating water resource demands and impacts on groundwater dependent ecosystems (Banks et al., 2011). Previous studies demonstrated the existence of spatial and temporal variations in HZ (Genereux et al., 2008; Kennedy et al., 2008; Song et al., 2010a, 2010b; Anibas et al., 2011). More specifically, spatial changes alter the path of water exchange between groundwater-surface water and influence residence times of solute (Cardenas et al., 2004); Changes in time scale directly affect the amount and time heterogeneity of spatial distribution patterns (Genereux et al., 2008; Wei et al., 2012).

Several methods have been applied to quantify the hyporheic water exchange. These include seepage meters (Kelly and Murdoch, 2003), the hydraulic gradient method (Chen et al., 2009), isotope or solute tracer methods (Jackman et al., 1984), temperature gradient methods (Schmidt et al., 2007; Fleckenstein et al., 2010; Anibas et al., 2011), remote sensing (Loheide and Gorelick, 2006), and electrical resistivity (Ward et al., 2010). Those methods suffer the challenge in estimation of water exchange in HZ (Kalbus et al., 2009; Zhang et al., 2014). Although Darcy's law has been widely employed to calculate the water exchange mass between surface water and groundwater (Winter et al., 1988; Harvey and Bencala, 1993; Baxter and Hauer, 2000), however

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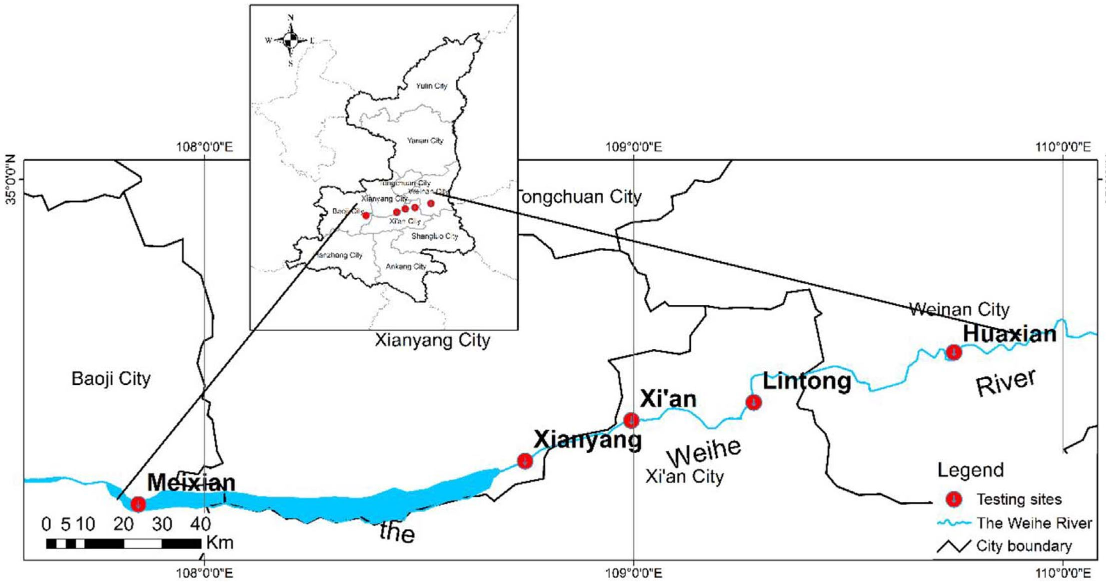

Fig. 1. The study area and testing sites in the Weihe River in Shaanxi Province, China.

Table 1
River hydrologic conditions in the study area of the Weihe River in Shaanxi Province.

Test Site	Latitude and Longitude	Average Stream Velocity (m/s)	Number of Tests	Average Water Depth(m)	Test Date	Season
Meixian	N 34°14′31.13″ E 107°48′43.63″	0.10	8	0.4	November 6, 2012	Fall, 2012
		0.10	8	0.38	March 21, 2013	Spring, 2013
		0.26	8	0.42	June 2, 2013	Summer, 2013
		Null	8	0.43	December 23, 2013	Winter, 2013
		0.20	7	0.70	July 6, 2014	Summer, 2014
Xianyang	N 34°18′33.48″ E 108°40′36.96″	0.29	8	0.8	November 3, 2012	Fall, 2012
		0.13	8	0.76	March 21, 2013	Spring, 2013
		0.05	8	0.46	December 21, 2013	Winter, 2013
		0.26	9	0.48	June 16, 2014	Summer, 2014
Xi'an	N 34°22′22.19″ E 108°48′37.91″	0.18	8	0.34	November 1, 2012	Fall, 2012
		0.13	8	0.2	March 14, 2013	Spring, 2013
		0.28	8	0.42	June 19, 2013	Summer, 2013
		0.02	8	0.07	December 19, 2013	Winter, 2013
		0.41	9	0.97	June 26, 2014	Summer, 2014
Lintong	N 34°25′13.52″ E 109°10′43.53″	0.1	8	0.45	October 28, 2012	Fall, 2012
		0.14	8	0.83	March 14, 2013	Spring, 2013
		0.35	8	0.33	July 19, 2013	Summer, 2013
		0.29	8	0.67	December 1, 2013	Winter, 2013
		0.36	9	0.43	June 12, 2014	Summer, 2014
Huaxian	N 34°32′04.27″ E 109°38′18.09″	0.25	9	0.31	November 5, 2012	Fall, 2012
		0.15	8	0.22	March 19, 2013	Spring, 2013
		0.34	8	0.42	June 25, 2013	Summer, 2013
		0.24	8	0.81	December 24, 2013	Winter, 2013
		0.46	9	0.38	June 11, 2014	Summer, 2014

the small spatial scales and related stringent conditions limited its application in practical works. Furthermore, it needs to use high-resolution testing methodologies to estimate and assess the seasonal variability of hyporheic water exchange. Thermal method (i.e. heat as a tracer) has been widely used to investigate the interactions between surface water and groundwater (Anderson, 2005; Westhoff et al., 2011). Thermal diffusion and convection can reflect hydrologic features at different spatial resolutions (Brunke et al., 2003; Conant et al., 2004; Kalbus et al., 2007). It has been used in several studies because of the low cost and easy access (Kalbus et al., 2006; Anibas et al., 2011; Engelhardt et al., 2011). Since temperature profiles are susceptible to seasonal changes (Vogt et al., 2012; Daniluk et al., 2013), the thermal method can able to better explain the hyporheic water exchange type and provide the quantitative estimate of the water transfer volume (Kalbus et al., 2006; Fleckenstein et al., 2010).

In this study, the sediment temperatures are measured from a field work of the Weihe River in Shaanxi Province. At a catchment scale, the hyporheic water exchange in such big river and loess region is scarcely understood. This study provides the significant information of the spatial and temporal dynamics in HZ, including the amount and its distribution of hyporheic water exchange volume and its seasonal variations. Specific objectives of this paper are: (1) to determine the