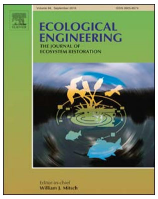
Ecological Engineering 112 (2018) 105–115

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng



The influence of hyporheic upwelling fluxes on inorganic nitrogen concentrations in the pore water of the Weihe River

Weize Wang[a], Jinxi Song[a,b,*], Guotao Zhang[c,d], Qi Liu[a], Weiqiang Guo[a], Bin Tang[a], Dandong Cheng[b,d], Yan Zhang[a]

[a] *Shaanxi Key Laboratory of Earth Surface System and Environmental Carrying Capacity, College of Urban and Environmental Sciences, Northwest University, Xi'an 710127, China*

[b] *State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences, Yangling 712100, China*

[c] *Key Laboratory of Mountain Hazards and Earth Surface Process, Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu 610041, China*

[d] *University of Chinese Academy of Sciences, Beijing 100049, China*

ARTICLE INFO

Keywords:
Hyporheic zone
Nitrogen
Pore water
The Weihe River
Upwelling fluxes

ABSTRACT

Hyporheic zone is an important region of nitrogen removal in river systems. Hyporheic exchange generally leads to heterogeneous redox environments, which are conducive to nitrogen transformation. This study seeks to determine the influence of hyporheic upwelling fluxes on inorganic nitrogen (NH_4^+, NO_3^-, and NO_2^-) concentrations in the sediment pore water of the Weihe River, China. The patterns and magnitudes of hyporheic water exchange on 12 August 2016 were derived by a one-dimensional heat transport model, and inorganic nitrogen concentrations in the pore water, surface water, and groundwater were obtained. The results indicated that hyporheic water exchange was characterized by upwelling at each point during the test period. Moreover, NH_4^+ dominated the hyporheic zone from 0 to 45 cm, likely due to organic nitrogen mineralization. Additionally, a non-linear relationship was observed between NH_4^+ concentrations and upwelling fluxes. This relationship was derived by analyzing the effect of upwelling on biogeochemical activity and nitrogen transformation. Notably, increasing upwelling fluxes less than 400 mm/d resulted in high NH_4^+ concentrations, whereas fluxes exceeding 400 mm/d led to low NH_4^+ concentrations. Overall, the variations in inorganic nitrogen associated with hyporheic water exchange are of great importance for controlling nitrogen pollution and maintaining sustainable health in river systems.

1. Introduction

The global production and application of fertilizers and fossil fuels are of great concern due to their significant effects on human health and the natural environment (Aslyng, 1984; Rankinen et al., 2014). The amount of fixed nitrogen has doubled over the past several decades because of the influence of human activities (Cai et al., 2007). Stream systems are vital to terrestrial transport and the transformation of dissolved inorganic nitrogen (including NH_4^+, NO_3^- and NO_2^-), which can lead to increase in nitrogen loading in surface water, the hyporheic zone, and groundwater (Bardini et al., 2012), especially in arid and semiarid regions (Wang et al., 2008; Wang et al., 2013; Zhang et al., 2014). Many ecological and environmental problems, such as algae blooms, eutrophication, and the extinction of aquatic species, can be caused by high concentrations of inorganic nitrogen in surface waters and the hyporheic zone (Wang et al., 2016; Xue et al., 2016).

The hyporheic zone is the location in the streambed bordered by surface water and groundwater, thus, it is the saturated zone, or kinematic zonation, that connects the stream and groundwater systems (Zarnetske et al., 2012). This zone influences and regulates the biological transformation of inorganic nitrogen (Jones and Holmes, 1996; Boulton et al., 1998; Cardenas, 2015), and it mainly consists of the porous media, which provide suitable living conditions for hyporheic invertebrates and an abundant source of biodiversity (Briggs et al., 2014). In addition, the biological behaviours of hyporheic invertebrates produce inorganic salts, such as NH_4^+ (Ingendahl et al., 2002; Storey et al., 2004). The invertebrates and microorganisms (including bacteria and fungi) in the hyporheic zone are collectively known as biofilm. Thus, the hyporheic zone is an important site of organic matter absorption and inorganic salt release due to its large internal surface area

---

[*] Corresponding author at: Shaanxi Key Laboratory of Earth Surface System and Environmental Carrying Capacity, College of Urban and Environmental Sciences, Northwest University, Xi'an 710127, China.

E-mail address: jinxisong@nwu.edu.cn (J. Song).

https://doi.org/10.1016/j.ecoleng.2017.12.012
Received 29 July 2017; Received in revised form 30 October 2017; Accepted 15 December 2017

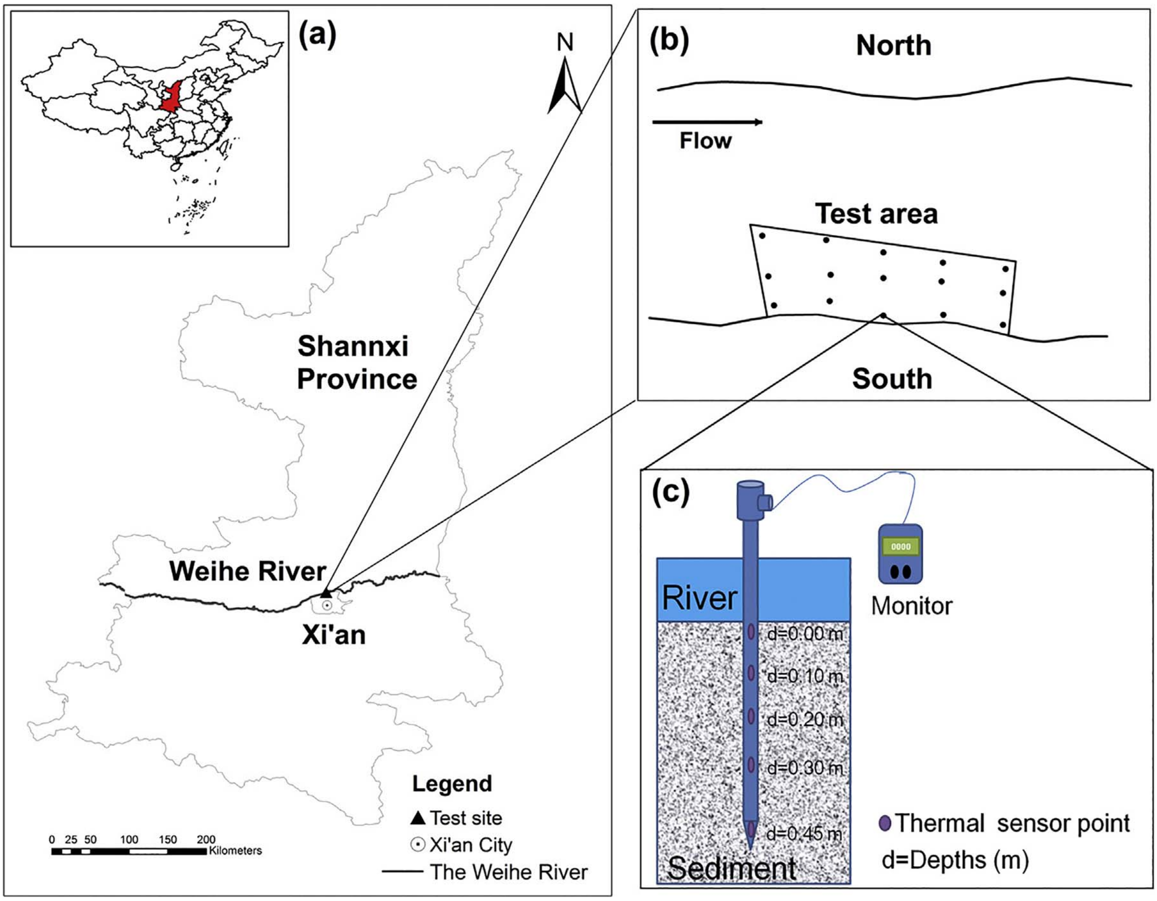


Fig. 1. Map of the study area showing the location of the test site (a), the test points in the study reach (b), and a schematic diagram of the equipment used for temperature measurements in the streambed sediment (c).

(Van Raaphorst and Malschaert, 1996). Moreover, dissolved oxygen (DO) in the hyporheic zone is a primary factor that influences nitrogen transformation and the processes of mineralization, nitrification, and denitrification (Sheibley et al., 2003; Zarnetske et al., 2011; Zarnetske et al., 2012). Organic nitrogen is oxidized by ammonifiers to form NH_4^+ in the process of mineralization, while NH_4^+ is oxidized to NO_2^- and transformed into NO_3^- in the process of nitrification (Stoliker et al., 2016). Both mineralization and nitrification are promoted in aerobic conditions, while denitrification exhibits the opposite trend. Denitrification can facilitate the reduction of NO_3^- to dinitrogen gas, which is an important process or reducing the nitrogen content in aquatic ecosystems (Storey et al., 2004). The dynamics of redox conditions are influenced by the patterns and magnitudes of hyporheic water exchange (Franken et al., 2001), which further influence the variability of solute concentrations in the hyporheic zone, including NH_4^+, NO_3^-, and NO_2^- levels (Briggs et al., 2014). Hyporheic downwelling flow can facilitate the movement of surface waters with high DO concentrations into the sediment, providing abundant DO and organic matter to hyporheic microorganisms (Franken et al., 2001). However, shallow groundwater plays a crucial role in the maintenance and restoration of ecosystems, upwelling flows can facilitate the movement of groundwater with low oxygen levels into the sediment, creating a low-oxygen environment in the hyporheic zone (Franken et al., 2001). Thus, the downwelling and upwelling flow patterns can further influence the inorganic nitrogen concentrations in the hyporheic zone (Storey et al., 2004). Additionally, the water residence time is affected by the dynamics of hyporheic water exchange, which influence the variability of nitrogen concentrations in sediment pore water (Briggs et al., 2014). Overall, the fate and transport of inorganic nitrogen are spatially and temporally complex, especially in the hyporheic zone.

A number of field studies have focused on the importance of hyporheic water exchange on nitrate transformations in the hyporheic zone (e.g. Hester et al., 2016; Briggs et al., 2014; Stelzer et al., 2011). However, few studies analysed the effect of hyporheic water exchange on inorganic nitrogen concentrations in pore water. Moreover, many river systems are controlled by human beings, such as dams and water transform project, which can cause the fluctuating of hyporheic water exchange flux (Zachara et al., 2016). These systems commonly exist so that stream-groundwater exchange flux is easily influenced by human activities (Liu et al., 2017). Hence, it is important to determinate of the influence of hyporheic water exchange on inorganic nitrogen concentrations in the pore water, which is crucial to estimate stream-groundwater interaction as well as being highly effective and beneficial for water quality management.

The patterns and magnitudes of hyporheic water exchange can be measured by several methods, including head piezometers (Nowinski et al., 2011), seepage metres (Zhu et al., 2015), differential discharge gauging (Lowry et al., 2007), thermal methods (Hatch et al., 2006), and other methods (Wei et al., 2012). Hatch et al. (2006) noted that heat tracers can be effectively used to determine the patterns and magnitudes of hyporheic water exchange in rivers at various spatial scales. Recently, heat has been increasingly used as a natural tracer to evaluate and quantify hyporheic water exchange (Anderson, 2005; Arriaga and Leap, 2006; Cranswick et al., 2014; Briggs et al., 2016). In addition, the methods of measuring temperature data are convenient and relatively inexpensive. Therefore, heat transport has been increasingly applied to evaluate hyporheic water exchange in different scenarios and simulations (Boano et al., 2014). Stallman (1965) evaluated the temporal and spatial distributions of water exchange at various scales using a one-