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Identifying the influence factors at multiple scales on river water chemistry in the Tiaoxi Basin, China

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ABSTRACT

The catchment environment and landscape is widely used as a predictor of stream-ecosystem condition, and the extent of its influence is closely linked to spatial scale. The aim of this study was to identify the influence factors on river water chemistry at multiple scales in a basin, namely the catchment, riparian corridor, and river reach scales. Information about the catchment and riparian corridor landscapes, reach-scale river properties, and catchment environments and river water chemistry data were collected monthly from 31 streams across the Tiaoxi Basin from July 2011 to June 2012. We used redundancy analysis to identify the relative influences of multi-scale variables on nine water quality indexes over both the whole study period and three sub-periods (before, during, and after rainy seasons). Results showed that all the selected factors helped to explain variations in water chemistry, although the relative effects of these factors changed considerably with variation in the spatial and temporal scales. Stream water chemistry across the entire study period was more sensitive to physiography and landscape variable at the catchment scale than at the reach and riparian corridor scales. From dry seasons to the rainy season, the influence of physiography and landscape variable at the catchment scale decreased slightly, while the effects of variables at the reach and riparian corridor scales increased noticeably. Besides, the influence of variables at the catchment scale was relatively strong and stable while the impacts of variables at the local scale were relatively weak and fluctuated widely with seasons. The findings from this study may improve our understanding of the main drivers of variations in stream water chemistry in different spatial and temporal scales, and will help managers protect and restore stream water environments using a basin-scale perspective.

1. Introduction

Landscape patterns in catchments have important influences on the processes that control different forms of carbon (C), nitrogen (N), and phosphorus (P) discharged in river water (Ahearn et al., 2005; Allan, 2004). Basin landscape pattern was generally characterized by some geographical factors, such as climate, topography, surficial geology, and land use or land cover types (Frissell et al., 1986; Schoonover et al., 2005). In addition, hydrological processes within a basin can affect the water quality of rivers through changing the supply, transport, and transformations of C, N, and P in the river water column (Hynes, 1975; Sheldon et al., 2012; Allan, 2004). Also, the hydrological processes were dominantly affected by basin landscape pattern, which have scale-dependent and seasonally variable influences on river ecosystems (Buck et al., 2004).

Most early studies of the relationships between watershed landscapes and river ecosystems were limited in their spatial scale, such as the areas that were either directly connected with rivers and streams or within a few hundred meters of the river. Less consideration has been given to the importance of elements at larger spatial-scales (Allan, 2004; Marzin et al., 2013). With increasing human disturbance in catchments and riparian zone corridors, later studies related to the

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effects of landscape patterns on river ecosystems, such as biodiversity (Sandin and Johnson, 2004; Weijters et al., 2009), water quality (Johnson et al., 1997; Tong and Chen, 2002) and nutrients in rivers (Udy et al., 2006), have attracted increasing attention (Allan, 2004). Studies examined the importance of the influence of landscape patterns at different spatial scales on nutrient dynamics and variations in river water, however have produced inconsistent results (Buck et al., 2004; Dow et al., 2006; Johnson et al., 1997; Sliva and Dudley Williams, 2001). Some scholars believe that the variations in nutrients and river habitat conditions should be examined using catchment-scale landscape patterns due to their influence on driving the geomorphic processes of a catchment, e.g., shaping channel network, supplying water and sediments (Esselman and Allan, 2010; Frissell et al., 1986; Johnson et al., 1997; Roth et al., 1996), while the others consider that the relationships between river habitat and riparian zone landscape patterns on both sides of a river are much more significant. For examples, Peterson et al. (2011) indicated that upstream land use was more influential in larger streams, while local land use and other factors might be more important in smaller streams; and Sandin and Johnson (2004) concluded that local physical (24.4%) and local chemical (20.4%) variables explained the largest part of the among-site variability of river community assemblages. Moreover, most of these studies have not highlighted the effects of or seasonal variations in, the natural and anthropogenic factors at multi-scale on river habitat.

Multi-scale studies of factors that affect river water chemistry variation are mostly focused on reach, local and catchment scale (Frissell et al., 1986; Esselman et al., 2010; Kings et al., 2005; Marzin et al., 2013). For the purposes of this study, reach-scale factors were selected to reflect local habitat conditions within ≤500 m sections of the river channel. Catchment-scale factors were defined as the integrated conditions in the landscape upstream of a given sampling location (e.g., percentage of different landscape types in a catchment), the geomorphology condition or the position relative to the sampling location (e.g., mean slope, distance from the river mouth etc.). Local-scale factors were restricted in the river riparian zone indicating the hydrological connectivity or the potential resource/sink for nutrient export from upland to downstream. The present study identify the relative importance of reach-, riparian- and catchment-scale landscape factors to variation in water chemistry in Tiaoxi River, one of the main tributaries to Taihu Lake. We then identified the variables that have most influence on the river habitat for individual spatial scales, and their combinations. By acknowledging the influence variables on nutrient dynamics at multiple scales and in different seasons (before, during, and after rainy seasons), we examined the hypothesis that the impacts of selected variables on nutrients varied seasonally. We anticipated that the findings from this study help basin water resource managers optimize the timing of special management measures, which will effectively control the supply, transport, and transformations of nutrients in catchments.

2. Material and methods

2.1. Study area

The Tiaoxi Basin is located in the southwest of the Taihu Lake Basin (E:119°10′–120°11′; N:30°04′–120°02′) (see Fig. 1), and is divided into the east and west tributaries. Two tributaries converge at Bai quetang Bridge (hereinafter referred to as the Tiaoxi River) in Huzhou City and then pour into Taihu Lake (Huzhou City Water District, 2004). The main channel of Tiaoxi River is 157.4 km long, and the basin area covers 4576.4 km^2, accounting for 12.54% of the total area of the Taihu Lake Basin (36500 km^2). Tiaoxi River has a large annual runoff ($14.93 \times 109\ m^3$) and is one of the main tributaries toTaihu Lake (Huzhou Water Resource Bureau, 2004).

2.2. Sampling sites and water chemistry data

Thirty-one river sections (see Fig. 1) were selected as sampling sites in the main channels and tributaries of the Tiaoxi River. Sampling sites were distributed across the entire study area so that, as far as possible, all the characteristics of the natural geographical environment and the spatial layout of all land use types in the study area were included. We identified and sampled a reference site 1000 m upstream of the sampling area before formal sampling began where there were no impacts of industrial sewage outlets, livestock excrement, and a domestic waste disposal site. Sampling was completed monthly from July 2011 to June 2012. Two methods were used to collect water samples, depending on the nature of the river channel at the sampling site. A water collector with a volume of 2.5 L was used to collect water samples from non-wade able rivers in the middle and lower reaches where the water depth in the center of the river was greater than 1.5 m. At these sites, the samples were collected from a depth of 0.5 m and water surface in the center of the channel. The samples were mixed on collection and stored in acid-washed 1000 mL polyethylene bottles. For wadeable rivers in the upper reaches, water samples were collected using plastic cups from water at the surface on both sides of the river. Once collected, the samples were immediately placed in a portable fridge at 4 °C and transported to the laboratory, where they were processed and analyzed within 48 h of collection. The samples were analyzed for total nitrogen (TN), total phosphorus (TP), nitrate nitrogen (NO_3—N), and soluble phosphate using the National Standard Methods (Editorial board of Water and wastewater monitoring analysis method, 2002). The dissolved organic carbon (DOC) concentrations were measured with a total organic carbon analyzer (Shimadzu TOC-V). Samples were filtered and the suspended solids on the filter paper were dried for 24 h at 60 °C, weighed, fumigated with concentrated hydrochloric acid for 24 h, and ground. Particulate organic carbon (POC) concentrations were determined after a series of treatments in an element analyzer (EA 3000 CHNS/O Analyzer). The sum of the POC and DOC concentrations was taken as the total organic carbon (TOC) concentration. The samples were analyzed in the State Key Laboratory of Lakes and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences. Based on the multi-year precipitation and runoff in the Tiaoxi Watershed (Huzhou Municipal Water Conservancy Bureau, 2004), the study period was divided into three periods: before the rainy season from March and May, during the rainy season from June to August, and after the rainy season in November, December and January. All the water quality data were normalized by $\log_{10}$ transformations. Results from normality analysis using the non-parametric K-S test showed all the indexes were normally distributed.

2.3. Selections of variable

2.3.1. Environmental variables

Six natural environmental variables, including altitude, average slope, river discharge, annual precipitation, catchment area, and distance to the river source were used to represent the geomorphic processes of the sampling location and to determine their potential effects on nutrient dynamics in water (see Table 1). Elevation, mean slope, catchment area, and distance to the river source, were derived from spatial analysis of the 1:50, 000 DEM (see Fig. 1) of the study area and its derived data using ArcGIS 9.3 and ARCSWAT software. Annual precipitation data from 42 hydro-meteorological stations located in and around the Tiaoxi Basin were provided by the Hydrological Bureau of Huzhou City and were processed by the Kriging interpolation method in the geostatistical analysis module of ArcGIS 9.3. River discharge data for the middle and lower reaches of the main channel were supplied by the Huzhou Hydrological Bureau, while discharge data for the upstream source streams and other streams were collected using a portable flow meter (SonTek/YSI-Tracker). All environmental variable data were $\log_{10}$-transformed before data analysis to ensure that they met the