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Influence of land use and land cover patterns on seasonal water quality at multi-spatial scales

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ABSTRACT

The influence of land use patterns on stream water quality is scale-dependent in space and time. Understanding the relationship between landscape characteristics and water quality is of great importance to improve water contamination prediction in unmonitored watersheds and for providing guidelines for watershed land use planning. In this study, five water sampling sites in the upper Dan River basin were established to monitor seasonal water chemical contamination over the period of 2000 to 2008. The relationships between land use patterns and water quality were analyzed across multiple-scales using redundancy analysis. The results showed that stream water quality variables displayed highly temporal variations, with electrical conductivity (EC), ammonium nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^-N), and total suspended solids (TSS) all generally displaying higher levels in the wet season, while there were higher concentrations of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD_{cr}), and dissolved oxygen (DO) in the dry season. The total contribution of land use patterns on overall water quality was stronger at the riparian scale than at the catchment and reach scales during the wet season. However, different land use metrics had different scale effects. Urban land had a higher positive relationship with degraded water quality at small scales than at large scales, whereas agricultural land displayed the opposite scale effects. Forest and grassland explained more water quality variations at the riparian scale than at other scales. Analyses of spatial development patterns suggested that size, density, aggregation, and diversity of landscape patterns were important factors impacting on stream water quality. The results provide important information regarding sustainable land use and landscape planning at multiple-scales that can be used to improve water quality.

1. Introduction

Water quality plays a pivotal role in habitat protection, agriculture, industry, and public health (Akasaka et al., 2010; Lu et al., 2015). Maintaining water quality is challenging, primarily due to point source (PS) and non-point source (NPS) pollution. PS pollution mainly includes industrial and domestic wastewater loads, which can be relatively easily identified (Wang et al., 2016). Unlike PS pollution, NPS pollution usually originates from diffuse sources, such as agriculture, street runoff, and the deposition of atmospheric pollutants (Ongley et al., 2010). The complex interaction between rainfall and landscape characteristics increases the difficulty of NPS identification (Liu et al., 2016).

The influence of land use on water quality has been a concern since the 1970s (Rimer et al., 1978). Early studies correlated water chemistry with different land use types within a watershed (Bolstad and Swank, 1997; Donohue et al., 2006). The improper land use may amplify transference of nutrients to water bodies (Valle Junior et al., 2014; Pacheco and Fernandes, 2016). Intense agricultural activities and rapid urbanization created an immense pressure on water quality. The percentage cover of agricultural land is significantly positively correlated with water pollution due to fertilizer application entering surface water through runoff (Tu, 2011). Urbanization is associated with changes in land uses through infrastructure development. As cities expand, the increase in impervious surfaces (i.e., roads, roof tops, and parking lots) results to an increase in runoff, which in turn creates additional avenues for the transportation of NPS pollutants to rivers (Wilson and Weng, 2010). While, forest lands were considered as net sinks of nitrate (Pacheco et al., 2015). Land use composition is generally linked with water quality within a watershed, and landscape configurations may be more sensitive predictors of water quality. Recently, with the rapid development of Geographic Information System (GIS) technology and landscape ecology, landscape metrics have provided a useful approach to quantify land use configurations. Sun et al. (2013) and Bu et al. (2014) found that landscape metrics such as aggregation (refers to the

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tendency of path to be spatially aggregated) and diversity (describe the compositional makeup of the landscape) were significantly associated with river water quality.

Landscape metrics are sensitive to change with spatial pattern, and the scale dependence is referred to as grain size and spatial extent (Wu et al., 2002). Three spatial scales including reach, catchment and riparian have been widely used to relate landscape variables to stream water quality: (1) reach is usually described by a buffer of several hundred meters in width on the studying site; (2) riparian is often defined as a buffer with a similar or larger width compared to reach extending to the entire upstream above the studying site; (3) catchment is typically the entire catchment upstream above the studying site (Allan, 2004; Ding et al., 2016). However, the results have not consistently determined which spatial extent is the best predictor of water quality. Some studies have indicated that the entire catchment was important for determining the effects of anthropogenic activities or water quality (King et al., 2005; Meneses et al., 2015; Ding et al., 2016), while other studies have found that land use at the reach or riparian scale better accounted for water quality variability (Sahu and Gu, 2009; Collins et al., 2013; McMillan et al., 2014). Riparian buffer has a filtering ability to remove sediment from land runoff (Santos et al., 2015). These inconsistent results were attributed to the unique characteristics of each catchment that influenced water quality (Sliva and Williams, 2001). Thus, more research is needed to quantify the effect of different land use scales on water quality to improve water resource management.

Water scarcity is one of the most important issues in China. To relieve water shortages in the north and northwest of China, three routes (west, middle, and east) of the South to North Water Transfer Project (SNWTP) were established in 2002 (Zhang, 2005). The Dan River is the water source area of the middle route of the SNWTP, supplying water to Beijng and Tianjing in northern China for drinking, industrial uses, and agricultural purposes (Li et al., 2009). Thus, maintaining good water quality in the basin is of great importance for domestic economic development and social stability. Previous studies have reported that NPS pollution in the Dan River basin has increased dramatically due to intensive anthropogenic activities since the 1980s (Li et al., 2008; Ai et al., 2015), although there is still a lack of information regarding the spatial and seasonal patterns in water contamination in this basin. The objectives of this paper were to: (1) present the spatial and temporal variability of stream water contamination in the Dan River basin, (2) quantify the relationship between watershed land use patterns and water quality, and (3) identify the scale effects in measuring the influence of land use patterns on water quality.

2. Materials and methods

2.1. Study area

The Dan River basin is located in the southeast of Shaanxi Province, China (33°12′–34°11′N, 109°30′-111°1′E) and covers an area of 1.68×10^4 km^2, with a total length of 443 km (Fig. 1). The watershed has a typical subtropical monsoonal climate, with an annual cycle of dry and wet seasons (Ai et al., 2015). The average annual air temperature is 14 °C, and the average annual amount of sunshine is 1974 h (Xu et al., 2013). The annual mean precipitation is 800 mm, 60% of which occurs in the summer months from July to September (Fig. 2). The stream flow mostly occurs during the wet season, while the dry season experiences lower flows (Fig. 2). The topography in the watershed is characterized by mountain ranges and hills, and the elevation ranges from 203 to 2068 m (Fig. 1). Soil types in this area are dominated by yellow-brown soil (Haplumbrepts) and sandy soil (Cheng et al., 2016). The natural vegetation in the area is dominated by coniferous, broad-leaved, deciduous forest, and shrubs and herbs. The main agricultural crops are corn (*Zea mays* L.), rice (*Oryza sativa* L.), peanut (*Arachis hypogaea* L.), and wheat (*Triticum aestivum* L.).

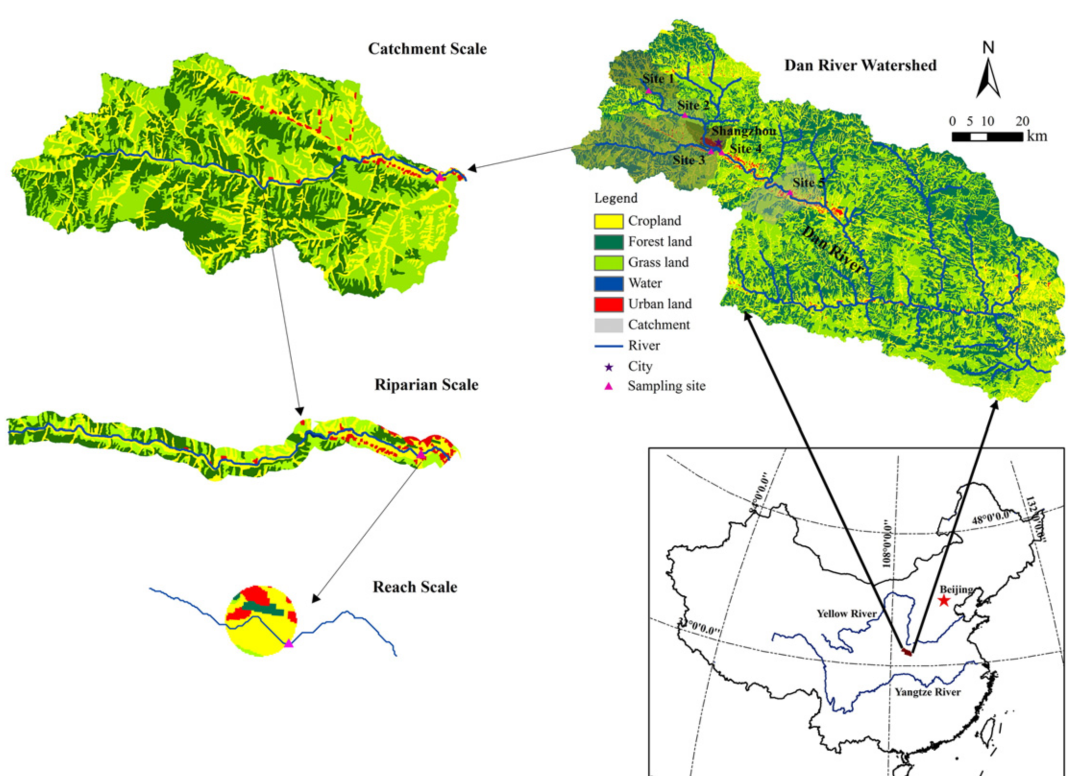

Fig. 1. Spatial distribution of five stream water quality monitoring stations in the Dan River basin and the three spatial scales (catchment, riparian, and reach) used in the analysis of land uses and land cover patterns.