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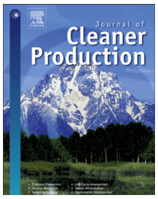

Influences of land use metrics at multi-spatial scales on seasonal water quality: A case study of river systems in the Three Gorges Reservoir Area, China

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ABSTRACT

The impact of land use metrics on watershed water quality is scale-dependent on a seasonal - spatial basis. Exploring the associations between land use metrics and riverine water quality provides useful information for effective land use planning for water quality security, whilst, these relationships remain poorly understood. 94 water samples covering entire tributaries in the Three Gorges Reservoir Area were collected and analyzed over the time period of 2015–2016, and consequently, multivariate statistics and empirical models were used for understanding the associations between land use metrics and water quality across multi-scales. Analysis of variance (ANOVA) revealed significant spatial differences in water temperature (WT), potential of hydrogen (pH), dissolved oxygen (DO), total nitrogen (TN), total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), TDN/TDP, nitrate nitrogen (NO_3^--N), ammoniacal nitrogen (NH_4^+ -N) and permanganate index (COD_{Mn}). Meanwhile, Oxidation-Reduction Potential (ORP), electrical conductivity (EC), DO, TN, TDN, TP, TDP, NO_3^--N, NH_4^+-N and COD_{Mn} generally appeared higher values in the dry season. Redundancy analysis (RDA) showed that the total explained variation of land use metrics on overall water quality was slightly stronger at catchment scale than at 100 m and 500 m buffer scales. The influence of land use metrics on water quality was a little stronger in the dry season than the wet season, but there were multi-spatial scale effects of different land use metrics. Our results can provide important information in land use planning and making multiple scales measures for water quality conservation.

1. Introduction

Water quality plays a critical role in industry, agriculture, public health and habitat protection (Shi et al., 2017). Riverine water quality could be influenced by both natural and anthropogenic sources (Ahearn et al., 2005). Precipitation and erosion are two possible natural contamination sources. Anthropogenic contamination sources, on the other hand, include point sources (PS) and non-point sources (NPS) (Li et al., 2008, 2013). PS pollution generally includes domestic and industrial effluents, which can be easily identified (Shi et al., 2017), but NPS pollution usually drives from diffuse sources, which emphasizes nutrient pollutants that contribute to water eutrophication (Chau, 2007; Huang et al., 2013). Furthermore, various studies applied a framework model based on the concept of "pressure-pathway-receptor'' to grasp the interplay between anthropogenic pressures and natural processes as well as water quality (measured by the concentrations of nitrate, phosphorus) in forested watersheds (Santos et al., 2015; Pacheco et al., 2015) with great efforts.

Since the 1970s, researches have explored the effects of land use on water quality (Rimer et al., 1978). For instance, pervious studies ascribed the presence of contaminants to human land uses (Bolstad and Swank, 1997; Rimer et al., 1978). Water quality might become degraded provided there were no controls on pollution sources (Pacheco and Sanches Fernandes, 2016; Shi et al., 2017). Environmental land use conflicts that occur in which land use deviates from land capability (natural use) are a fundamental cause of accelerated

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water quality deterioration (Pacheco and Sanches Fernandes, 2016; Valle Junior et al., 2014). In addition, anthropogenic activities such as intense farmland cultivation and rapid urbanization affected water quality considerably (Shi et al., 2017). The proportion of farmland and urban land were significantly positively correlated with water pollution (Tu, 2011; Li et al., 2013). Increasing infrastructure construction (e.g. impervious roads and roof tops) followed rapid urbanization provided additional avenues for NPS pollutant (e.g., urban runoff, agriculture activities and the deposition of atmospheric pollutants) (Shi et al., 2017; Wilson and Weng, 2010). Forest and grass lands act as net sinks in nutrient circulation (Pacheco et al., 2015).

Landscape metrics may be better predicting water quality than land use types (Shi et al., 2017). With rapid development of landscape ecology, Geographic Information System (GIS) technology and Remote Sense (RS) technology, landscape metrics offered a useful method for quantifying land use structures Ding et al., 2016; Shi et al., 2017). For example, Lee et al. (2009) revealed that the high value of landscape metrics (e.g., patch and edge densities) tightly associated with water quality degradation; Bu et al. (2014) and Sun et al. (2013) reported that landscape metrics (e.g., aggregation and diversity) were significantly correlated with stream water quality. Ding et al. (2016) and Shi et al. (2017) showed that landscape metrics (i.e., patch density (PD), the largest patch index (LPI) and landscape shape index (LSI)) were strongly linked with riverine water quality.

Furthermore, increases in land use degree (L) generally related to a bulk of adverse effects on ecosystem functioning, such as soil and water quality degradation, air pollution and loss of biodiversity (Hall, 2014; Matson et al., 1997). However, there have been few studies which linked L to water quality, previous studies focused on ecosystem services, biodiversity and geodiversity (Burgi et al., 2015; Rüdisser et al., 2015). For example, Tukiainen et al. (2017) utilized generalized additive models and reported a negative correlation between L and geodiversity. Xu et al. (2016) used correlation method and analysis of variance (ANOVA) and indicated that L also linked with changes in aquatic ecosystem service.

Impacts of land use metrics are variable in scale. This scale difference refers to differences in grain size or areal extent (Wu et al., 2002). Spatial scales, i.e. catchment and buffer scales, have been diffusely used in linking land use metrics with watershed water quality (Ding et al., 2016; Shi et al., 2017). However, these results have not been uniformly recognized which spatial scale is the strongest influence when it comes to on water quality. Some studies have reported that land use on riparian scale can better predict water quality than which on catchment scale (Shi et al., 2017; Tran et al., 2010), while other studies demonstrated that land use at catchment scale to be better predicting changes in water quality (Ding et al., 2016; Sliva and Williams, 2001; Li et al., 2012). These contrary consequences were probably due to differences in geographic locations and study designs (Schiff and Benoit, 2007).

The Three Gorges Reservoir Area (TGRA) is located within a 600 km basin between Chongqing and Yichang, with a total watershed area is about 58,000 km^2. TGRA distributes the world's largest hydropower dam (i.e., the Three Gorges Dam) and the most important water control project in China (i.e., Three Gorges Project) (Mao et al., 2017). There have been several studies that related land use to water quality in small catchments of the TGRA (e.g., Xiangxi River and Heigou River) (Huang et al., 2016; Ye et al., 2009), and information is unavailable on land use and landscape metrics influences on water quality at multi-scales covering the whole area of the TGRA. Therefore, we explored the influences of land use on water quality covering the TGRA using redundancy analysis (RDA) in this study. Our objectives are to: (1) reveal the temporal and spatial variability of watershed water quality in the TGRA, (2) quantify the linkages between land use metrics and stream water quality, and (3) identify the multiple scales effects of land use metrics on water quality. Our original contribution to literature includes (1) determining the impacts of land use metrics on water quality in the entire TGRA, as well as (2) examining land use influences on riverine water quality at multi-spatial scales.

2. Materials and methods

2.1. Study area

The TGRA (105°44’ ~ 111°39′E, 28°32’ ~ 31° 44′N) is lied in the south-central and southwest China (Fig. 1). Climate in the TGRA is subtropical monsoon, with average annual temperature ranges between 15 and 19 °C (Mao et al., 2017; Li et al., 2018). The average annual precipitation ranges from 1000 to 1400 mm, within which, 80% annual precipitation were falling in April–October with relative humidity of 70% (Ye et al., 2011). Soil types in this region are composed of purple soil, calcareous soil and yellow soil, which accounting for 47.8%, 34.1% and 16.3%, respectively (Ma et al., 2016). The farm and profitable crops of the TGRA are famous for rice, corn, peanut, wheat, medicinal plant and tea (Ma et al., 2016).

2.2. Water sampling and analysis

From late October to early November in 2015 and late June to early July in 2016, 94 water samples were collected from 15 first-order branches and 30 second-order branches, which covered the majority of branches of the Yangtze River in this region (Fig. 1). Of which, from late June to early July in 2016 are wet season, and the rest are dry season. Every individual running water sample was collected for each tributary with a 5-L acid-washed plastic container at water depth of 10 cm (Mao et al., 2017). We used pre-baked Whatman GF/F 0.7 μm filter papers to filter water samples during the sampling day, and then stored these filtered samples in pickled high-density polyethylene bottles (Hosen et al., 2014). Before further processing, samples were stored in the darkness at 4 °C then transported in refrigerated condition to the laboratory within 10 days following the collection processes.

We chose twelve water quality parameters for measurement during and after sampling. These parameters are important indicators for anthropogenic markers of water pollution. Water temperature (WT, °C), potential of hydrogen (pH), oxidation–reduction potential (ORP, mv), electrical conductivity (EC, $\mu s\ cm^{-1}$) and dissolved oxygen (DO, mg L^{-1}) were determined in situ by HQ40d (HACH, USA), which the measurement error of the temperature, pH, ORP, EC and DO are ± 0.3 °C, ± 0.002, ±0.1 mv, ±0.5% and ±1%, respectively. The following water physico-chemical properties were measured in the laboratory. Total nitrogen (TN, mg L^{-1}), total dissolved nitrogen (TDN, mg L^{-1}) and nitrate nitrogen (NO_3^--N, mg L^{-1}) were measured using the digestion-UV spectrophotometric method, and the measurement error of TN, TDN and NO_3^--N are ± 5%, ±5% and ±1.1%, respectively. Total phosphorus (TP, mg L^{-1}) and total dissolved phosphorus (TDP, mg L^{-1}) were measured by molybdenum-antimony anti-spectrophotometry, and the measurement error of TP and TDP are ± 1.85%. Ammonia nitrogen (NH_4^+-N, mg L^{-1}) was determined using salicylic acid-hypochlorite photometric method, and the measurement error of NH_4^+-N is ±4.4%. Permanganate index ($COD_{Mn,}$ mg L^{-1}) was analyzed by the potassium permanganate method, and the measurement error of COD_{Mn} is ±4.2%. TN and TP were determined by unfiltered samples, while TDN, TDP, NO_3^--N, NH_4^+-N and COD_{Mn} were determined by the filtered samples (Li et al., 2018). Storage, preservation and chemical analysis followed the national standard method for the detection of water and wastewater in China (NEPB, 2002).