

Modeling the relationship between landscape characteristics and water quality in a typical highly intensive agricultural small watershed, Dongting lake basin, south central China

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Abstract Understanding the relationship between landscape characteristics and water quality is critically important for estimating pollution potential and reducing pollution risk. Therefore, this study examines the relationship between landscape characteristics and water quality at both spatial and temporal scales. The study took place in the Jinjing River watershed in 2010; seven landscape types and four water quality pollutions were chosen as analysis parameters. Three different buffer areas along the river were drawn to analyze the relationship as a function of spatial scale. The results of a Pearson's correlation coefficient analysis suggest that "source" landscape, namely, tea gardens, residential areas, and paddy lands, have positive effects on water quality parameters, while forests exhibit a negative influence on water quality parameters because they represent a "sink" landscape and the sub-watershed level is identified as a suitable scale. Using the principal component analysis, tea gardens, residential areas, paddy lands, and forests were identified as the main landscape index. A stepwise multiple regression analysis was employed to model the relationship between landscape characteristics and water quality for each season. The results demonstrate that both landscape composition and

configuration affect water quality. In summer and winter, the landscape metrics explained approximately 80.7 % of the variance in the water quality variables, which was higher than that for spring and fall (60.3 %). This study can help environmental managers to understand the relationships between landscapes and water quality and provide landscape ecological approaches for water quality control and land use management.

Keywords Landscape metrics · Water quality · Spatiotemporal scale · Multiple regression analysis · Jinjing River watershed

Introduction

Landscape patterns have pronounced effects on surface water quality in streams, rivers, and lakes within a particular watershed. Nitrogen (N) and phosphorus (P) are the two primary pollutants that are present in surface water, which are caused by fertilizers, pesticides, and other agricultural activities that produce agricultural non-point source (NPS) pollutants. Although rainfall runoff is the primary pathway for incorporating nutrients into surface water, soil erosion and agricultural drainage also directly or indirectly have the same effect (Chantal et al. 2009; Miller et al. 2011). This transfer process is closely related to the surrounding landscape characteristics.

To understand transfer processes and to improve water quality, many models, such as SWAT, HSPF, and AnnAGNPS, have been established and developed to simulate and predict the fate of pollutants. With the

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help of geographical information systems (GIS) and the landscape pattern index (LPI), recent studies in landscape ecology have paid particular attention to the spatial arrangement of landscapes in analyzing the relationship between landscape patterns and water quality at various scales. Several studies have provided strong evidence that both the composition and the spatial configuration of a landscape have pronounced effects on hydrology and water quality (Broussard and Turner 2009; Chang et al. 2008; Nash et al. 2009; Tran et al. 2010; Zhou et al. 2012) in various regions (e.g., mining areas and urban regions) (Buck et al. 2004; Lee et al. 2009; Riva-Murray et al. 2010; Xiao and Ji 2007). Some ecologists have also established regression models between landscape metrics and water quality at different scales (Bateni et al. 2013; Bu et al. 2014; Lowicki 2012; Ouyang et al. 2010; Xia et al. 2012). However, previous studies on the relationship between landscape characteristics and water quality lacked a focus on the temporal scale, such as during the rainy season and after the rainy season within the same watershed (Shen et al. 2014).

Studying water quality is very complex; such examinations should simultaneously consider the spatial scale and temporal scale. Therefore, we conducted a case study in a small watershed in a highly intensive agricultural area in China to explicitly examine the statistical relationship between landscape characteristics and water quality as function of spatiotemporal scale. The results of this study provide guidance for environment managers to better understand the relationship between landscape characteristics and water quality variables and provide landscape ecological approaches to improve surface water quality, eliminate agricultural pollution risk, and optimize watershed landscape patterns.

Materials and methods

Study area description

The Jinjing River watershed (27°55′–28°40′N, 112°56′–113°30′E) (Fig. 1) is part of the Dongting Lake basin in south central China and has a total drainage area of 13,440 ha. The watershed lies within a subtropical humid monsoon climate zone; the average annual temperature and rainfall are approximately 17 °C

and 1350 mm, respectively. The local topography varies considerably in this area: the terrain is higher in the north and lower in the south. The area includes two rivers: the Tuoja River and the Jinjing River; both rivers discharge into the Xiangjiang River. The dominant land cover in this area is forest (65.45 %); the other land cover classes are representative of towns, agricultural lands, roads, and water bodies. Agricultural lands are concentrated at low elevations and are distributed along rivers; the main field crops include rice and tea.

The Jinjing watershed belongs to a subtropical evergreen and broad-leaved forest zone. Therefore, for the entire year, the forest canopy density was approximately 80 %; the low vegetable cover was only sparse and during fall and winter. Tea gardens are representative of an evergreen landscape; however, in winter, the soil surface is usually uncovered, causing nutrients to be more readily lost. In spring, for growing early season rice, farmers must plough and often apply base fertilizer at a rate of approximately 15 tons/ha and compound fertilizer at a rate of approximately 1.5 tons/ha. Later management may include topdressing twice and spraying pesticides three to five times. Frequent and intensive human activities deteriorate water quality. In summer, early rice is harvested and a portion of the straw crop is returned to the field. Compound fertilizer is typically applied at a rate of 0.6 tons/ha for later season rice and single cropping rice. During this period, the amount of precipitation accounts for 35 % of the annual total, and the vegetation coverage and stream flow of the entire watershed increase. In fall, there are no intensive agricultural activities, with little topdressing and pesticide spraying before rice harvesting. In winter, most paddy fields are exposed, few of which are used to plant vegetables, e.g., oilseed rape and wild rice stem. The number of pig farmers increases and the low vegetation coverage decreases.

The Jinjing River watershed is a typical suburban agriculture area. The characteristics of agricultural practices in this region are indicative of a high-input, high-yielding, and high environmental risk style. Therefore, agricultural production includes the application of large amounts of fertilizers. Urea and ammonium carbonate are the two main components of nitrogen fertilizers, accounting for approximately 285 kg/ha of pure nitrogen input according to the collected data. Waste water from family livestock and poultry farms, domestic sewage, and solid waste are directly discharged into the rivers. These wastes result in numerous environmental problems, including water

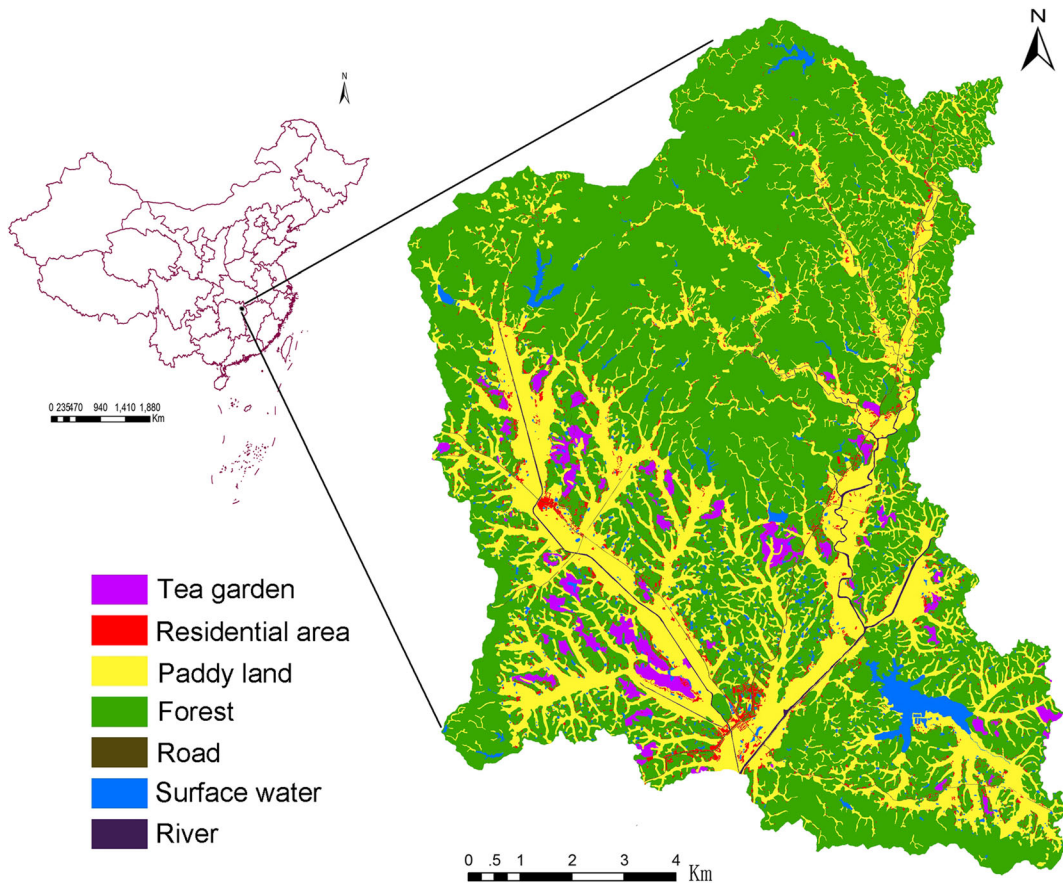


Fig. 1 Land use map of the Jinjing River watershed in 2010

quality degradation. Excessive nitrogen has become an important risk factor in the Jinjing River watershed.

Land use and land cover analysis

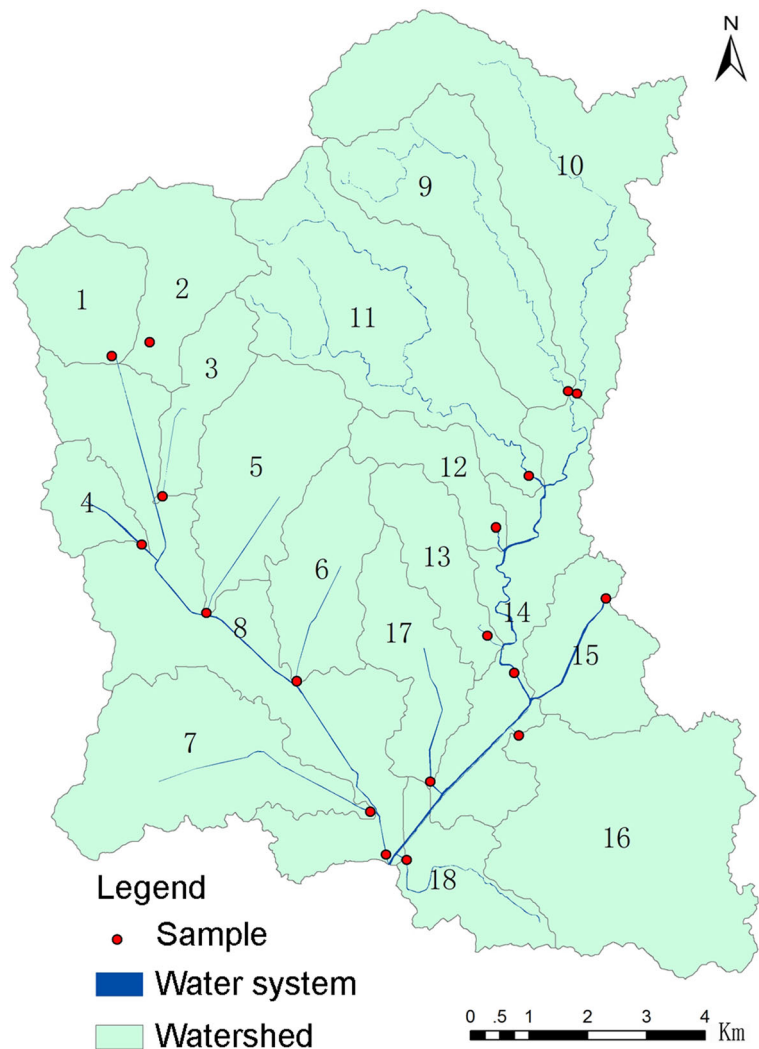
SPOT-5 satellite remote sensing images in January of 2009 with a spatial resolution of 10 m and present land use map in 2005 acquired from Changsha County bureau of land and resources were used to map land use and land cover (LULC) in Jinjing watershed. We classified seven main landscape types: forest areas (FOR), including ecological forests and economic forests; paddy lands (PAD), which are primarily planted with rice; tea gardens (TEA); residential areas (RES), which include residential areas, commercial lands and industrial lands; water (WAT), including reservoirs and ponds; rivers (RIV), which includes rivers, streams and ditches; and roads (ROA). With the help of ArcGIS 10.0, 18 sub-watershed zones were delineated from a digital elevation model (DEM).

Water sampling and analysis

Eighteen water sampling (Fig. 2) sites were placed on the mainstream and tributaries. Sites 1 through 8 were scattered near the Tuoja River on the west, and sites 9 through 18 were distributed near the Jinjing River on the east. Samples were collected monthly from December 2009 to November 2010 during sunny days and at the same location (determined using a GPS device). The water flow rate was also measured using a flow meter tool.

For monitoring water quality, four representative parameters were chosen, which include nitrate nitrogen (NO_3^- -N), ammoniacal nitrogen (NH_4^+ -N), total nitrogen (TN), and total phosphorus (TP). All of the pretreatment and determination procedures were conducted in the laboratory using standard methods; therefore, the results are globally accepted.

Fig. 2 Sub-watershed delineation, sampling sites, and river network



Statistical method

In order to understand how landscape characteristics influence the water quality, landscape ecology knowledge was merged into our study. We designed an integrated method to model the relationship between landscape characteristics and water quality from spatial and temporal scale. The method included the following: identifying a suitable scale and the main landscape types using landscape ecology knowledge, analyzing water quality dynamics by season, and establishing the models for four seasons. The detailed method is as follows:

With respect to the spatial scale, the percentage of land use for each type was computed in all sub-watershed zones by ArcGIS 10.0. Pearson's correlation coefficient measures the strength of linear association

between two variables. Therefore, we tested the correlations between the landscape patterns and the water quality parameters using Pearson's correlation coefficients with statistical significances of $p < 0.01$ and $p < 0.05$ (two-tailed) by SPSS. Principal component analysis (PCA) is a mathematical procedure that transforms a number of correlated variables into a number of uncorrelated variables called principal components. The results of a PCA are usually discussed in terms of component scores or the weight. To compare the contribution of different landscape types to water quality, we calculated the weights using a PCA. Finally, we identified tea gardens (2.44 %), residential areas (2.31 %), paddy lands (26.65 %), and forests (65.45 %) as the four landscape types that exhibited the most significant effects on the water quality of the

study region. To determine a suitable landscape scale for this study, a series of buffers with widths of 250, 500, and 750 m on each side of the river were performed.

With respect to the temporal scale, we selected the percentage of landscape (PLAND), patch density (PD), largest patch index (LPI), landscape shape index (LSI), edge density (ED), Shannon's diversity index (SHDI), and contagion (CONTAG) in landscape and class level (O'Neill et al. 1988) using the software package FRAG STATS 4.2 (McGarigal et al. 2012). These metrics were calculated for each sub-watershed zone. Three consecutive months were considered for a season (i.e., December, January, and February represent winter); the average of each 3-month period was used to represent the season. The water quality variables were regarded as dependent variables, while the landscape metrics were treated as independent variables. Stepwise regression analysis attempts to model the relationship between two or more explanatory variables and response variable. It includes regression models in which the choice of predictive variables is carried out by an automatic procedure (Amiri and Nakane 2009; Gustafson et al 2006; Zhou et al. 2012). For a given water quality variable, the stepwise regression approach was selected to determine a final model with only significant $p < 0.05$ independent variables included for each season using SPSS.

Results

Water quality dynamics

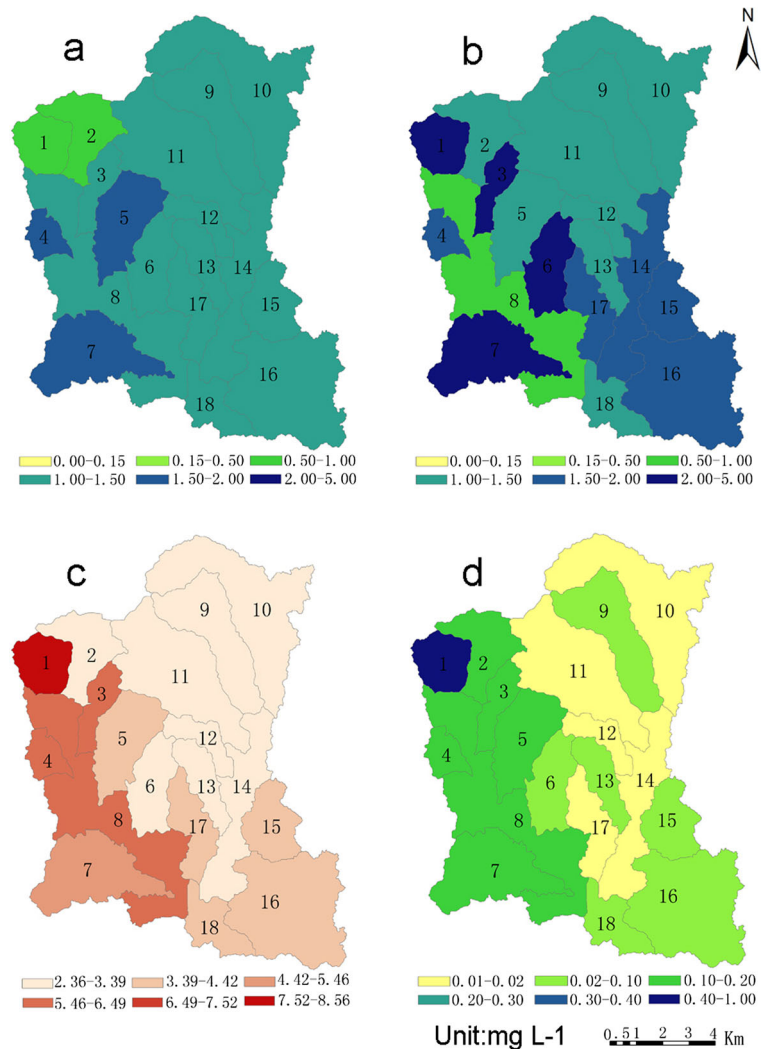
The pollution concentration in the Jinjing watershed varies according to the specific season and sub-watershed. The average concentration of NO_3^- -N was 1.19 mg/L for the entire watershed (Fig. 3), which is below the national standard (10.00 mg/L) (Ministry of environmental protection of the People's Republic of China, 2002). Moreover, the average concentration of NH_4^+ -N was 2.00 mg/L; the concentrations at sites 1, 3, 6, and 7 exceeded the national standard (2.00 mg/L). The average TN concentration was 4.07 mg/L; the concentrations measured in all of the sub-watersheds largely surpassed the national standard (2.00 mg/L). Furthermore, the average TP concentration was 0.10 mg/L; all of the zones were controlled within water quality level III except for site 1.

In general, NO_3^- -N and NH_4^+ -N were the primary forms of nitrogen pollution, accounting for approximately 80 % of the total nitrogen pollution in the studied watershed. Excessive nitrogen pollution was the most pronounced inhibiting factor for improving water quality. Every year, approximately 431 tons of TN was discharged from watershed, including 170 tons of NO_3^- -N and 143 tons of NH_4^+ -N.

Figure 4 shows the pollution concentrations in water for different seasons (Fig. 4). The NO_3^- -N concentration exhibited little seasonal variations; only slightly higher concentrations were observed in spring compared to the other seasons. Moreover, the NH_4^+ -N concentration exhibited large seasonal variations, with concentrations as high as 5.93 mg/L in winter and as low as 0.59 mg/L in fall. Correspondingly, TN exhibited high concentrations in winter and low concentrations in summer and fall. Despite these variations, the TN concentration exceeded the national standard in all seasons. This result suggests that excessive human disturbances, e.g., applying fertilizers, spraying pesticides, ploughing, and other agricultural activities in spring, caused both NO_3^- -N and NH_4^+ -N to be easily lost and increased the TN concentration. In summer and fall, soil microbial and aquatic plant activities were very high, which promoted the transfer of NH_4^+ -N to NO_3^- -N. In addition, high runoff was a positive factor in lowering the pollutant concentrations; therefore, all of the nitrogen pollutant concentrations were at their lowest values during these seasons. In winter, due to very low runoff, vegetation cover, and sewage discharge, both the NH_4^+ -N and TN concentrations were comparatively high. Moreover, by comparing the pollution levels among all zones, zones 9, 10, and 11 exhibited the lowest levels because the dominant landscape type was forest, supporting the claim that landscape characteristics have close relationship with water quality.

As shown in Figs. 3 and 4, the NH_4^+ -N and TN concentrations in zone 1 were considerably higher than those in the other zones. One explanation for this finding is that this sampling site was located near a pig farm; the waste was directly discharged into the stream without treatment. To ensure the accuracy of the results presented herein, zone 1 was disregarded from the subsequent analysis. Given that the phosphorus pollution concentration was far below the national water quality level V standards (i.e., $0.07 < 0.4$ mg/L) and its forms were stable, TP was not considered in the following analysis.

Fig. 3 Annual pollution concentrations in each sub-watershed zone. **a** NO_3^- -N. **b** NH_4^+ -N. **c** TN. **d** TP



Impacts of landscape characteristics on water quality

The scale, pattern, and process are the major aspects to consider in landscape ecology research. Both the spatial and temporal scales should be considered in such research. Different research objectives should utilize an appropriate scale. Studying the relationship between landscape characteristics and water quality is a typical pattern-process relationship. Various types of landscape composition, configuration, context, and connectivity affect water quality within a watershed. Water quality can also change the landscape pattern because these characteristics are interactive.

In the study area, the results confirm that the composition and configuration of the landscape exhibit a relatively large effect on the water quality. To determine the

extent of this effect and to examine the most suitable spatial scale, three buffers with widths of 250, 500, and 750 m were drawn near each of the rivers. Table 1 shows the percentage of land use types for different buffers (Table 1). The total buffer areas occupied 34, 57, and 72 % of the entire watershed, respectively. As the buffer area increased, the proportion of tea gardens and forests increased while the proportion of residential areas and paddy lands decreased.

According to the “source-sink” theory in landscape ecology, the landscape can act as important “source,” “sink,” and “flow” in the process of non-point source pollution. For the ecological process, source landscape is a landscape type which contributes positively to the development of the ecological process, while a sink landscape is unhelpful to the development of the

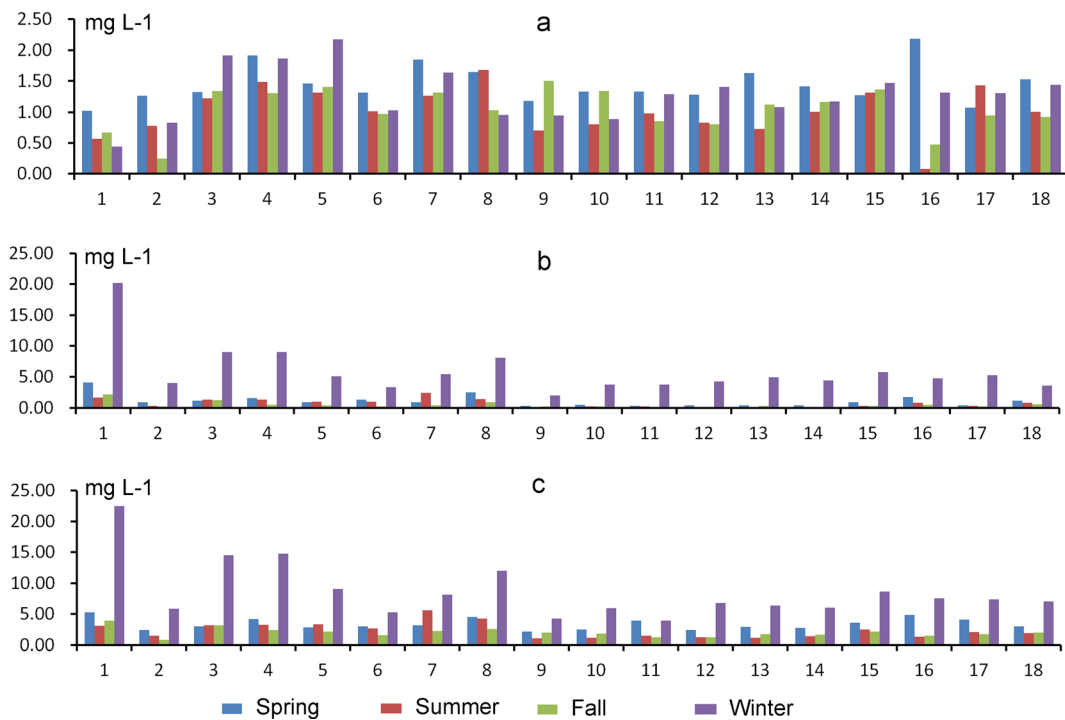


Fig. 4 Pollution concentrations in water for different seasons. **a** NO₃⁻-N. **b** NH₄⁺-N. **c** TN

ecological process. When source-sink theory is applied to non-point source pollution control, the function of source landscape is to promote pollution, sink landscape is to alleviate pollution, and flow landscape is to transmit the pollutants. Pearson’s correlation coefficients were computed to measure the strength of linear association between landscape types and water quality variables for different buffers (Table 2). Table 2 recognizes tea gardens, residential areas, and paddy lands as source landscape that enhance pollution, while forests are considered to be sink landscape, which alleviate or reduce pollution. Rivers and surface water are considered to be flow landscape that transmits pollution to other areas. This result can also be used to test the correctness of final model: source landscape pattern metrics should

show a positive correlation with water quality variables, while sink landscape pattern metrics show a negative correlation.

Table 2 also shows that for the 500-m buffer, the percentage of residential areas, paddy lands, and forests was strongly correlated with NO₃⁻-N, NH₄⁺-N, and TN at the 0.01 level. Pearson’s correlation coefficients for these landscape characteristics exhibited only small variations. As the buffer width increased, tea gardens became more correlated with the water quality variables. For the entire watershed, tea gardens, residential areas, paddy lands, and forests were highly correlated with all of the water quality variables. This result suggests that water pollution produced and transmitted is related to the entire sub-watershed landscape composition and

Table 1 Percentage of land use types for different buffers

Buffer areas	Land use types							
	TEA	RES	PAD	FOR	ROA	WAT	RIV	Total
All watershed	2.44	2.31	26.65	65.45	0.27	2.36	0.51	100
250 m	1.22	3.03	39.80	50.01	0.40	4.10	1.45	34
500 m	2.03	2.95	32.25	58.44	0.37	3.07	0.88	57
750 m	2.54	2.68	29.45	61.47	0.32	2.84	0.70	72

Table 2 Pearson's correlation coefficients between land use types and water quality pollution

Buffer areas	Pollutions	Pearson's correlation coefficient			
		TEA	RES	PAD	FOR
All watershed	NO ₃ ⁻ -N	0.523*	0.599*	0.578*	-0.542*
	NH ₄ ⁺ -N	0.556*	0.691*	0.568*	-0.602*
	TN	0.568*	0.705**	0.612**	-0.626**
250 m	NO ₃ ⁻ -N	0.407	0.668**	0.680**	-0.607**
	NH ₄ ⁺ -N	0.363	0.493*	0.583*	-0.631**
	TN	0.333	0.590*	0.632**	-0.645**
500 m	NO ₃ ⁻ -N	0.447	0.639**	0.686**	-0.594*
	NH ₄ ⁺ -N	0.461	0.655**	0.615**	-0.651**
	TN	0.431	0.675**	0.665**	-0.663**
750 m	NO ₃ ⁻ -N	0.473	0.675**	0.675**	-0.567*
	NH ₄ ⁺ -N	0.494*	0.726**	0.630**	-0.642**
	TN	0.482	0.758**	0.678**	-0.650**

Road, surface water, and river, not significantly correlated with any water quality variables, are not shown in the table

**0.01 level (correlation is significant; two-tailed); *0.05 level (correlation is significant; two-tailed)

configuration. Therefore, in this study, a single sub-watershed was a suitable scale for the research.

Table 3 shows the weight of the individual landscape types for water quality within the different buffer areas. The contributions of all of the landscape types decreased as the scale increased from 250 m to the entire watershed. This finding also suggests that as the area increased, the landscape composition and configuration became more heterogeneous, while the effects on water quality became more complex and variable. Combined with Pearson's correlation coefficient analysis, tea gardens, residential areas, paddy lands, and forests were chosen to be the primary landscape characteristics for modeling the relationships in the following section.

Table 3 Weight of the individual landscape types for water quality

Landscape types	250 M	500 M	700 M	All watershed
TEA	0.515	0.361	0.214	0.301
RES	0.572	0.362	0.350	0.321
PAD	0.426	0.348	0.379	0.274
FOR	-0.413	-0.384	-0.343	-0.302
ROA	0.312	0.234	0.277	0.277
WAT	-0.210	0.044	-0.159	0.148
RIV	-0.211	0.034	0.282	-0.019

Relationship between landscape metrics and water quality

In the Jinjing River watershed, the typical features of the four seasons are closely related to variations in water quality. Therefore, we analyzed water quality and expressed the relationship between landscape metrics and the water quality variables according to distinctive seasons.

Stepwise multiple regression models created the regression equations between the landscape metrics and the water quality parameters for different seasons (Table 4). The results show that the landscape metrics, including both the composition (i.e., percentage of landscape types) and configurations (i.e., LPI, PD, and ED) indices, are helpful for analyzing water quality. Moreover, the relationships between the landscape metrics and water quality variables vary according to the specific season.

From the overall results, tea gardens, residential areas, paddy lands, and forests are strongly correlated with the water quality variables. Tea gardens, residential areas, and paddy lands have positive effects on water quality parameters because they act as source landscape, while forests have a negative effect because they act as sink landscape, these remain consistent on the initial results. PLAND, ED, LPI, and PD were expressed in the models, but only one landscape composition

Table 4 Results of the stepwise regression for the water quality variables against the landscape metrics for different seasons

Parameters	Season	Regression equations	R ²
NO ₃ ⁻ -N	Spring	Y=1.161+11.178*P _{Res}	0.553
	Summer	Y=0.703+1.753*LPI _{Res}	0.715
	Fall	Y=0.260+0.006*ED _{Pad}	0.503
	Winter	Y=1.387+0.260*LPI _{Pad} -0.036*LSI _{For}	0.692
NH ₄ ⁺ -N	Spring	Y=0.101+35.370*P _{Res}	0.652
	Summer	Y=1.271+0.073*LPI _{Pad} -0.013*ED _{For}	0.849
	Fall	Y=0.187+0.184*PD _{Tea}	0.592
	Winter	Y=2.536+1.159*PD _{Tea} +6.604*LPI _{Res}	0.880
TN	Spring	Y=4.11-0.018*LPI _{For}	0.675
	Summer	Y=2.874+0.148*LPI _{Pad} -0.022*ED _{For}	0.881
	Fall	Y=1.409+0.39*PD _{Tea}	0.643
	Winter	Y=3.940+1.666*PD _{Tea} +9.936*LPI _{Res}	0.823

ED total length of all edge segments per hectare for the considered landscape (unit: m/ha), LPI percentage of the landscape in the largest patch (unit: %), LSI landscape shape index, PD number of patches per unit area (number per 100 ha), P_{Land} percentage of landscape types (unit: %)

indicator: percentage of residential areas (P_{Res}) entered the equations. It indicates the landscape configuration indices might be more important than landscape composition for explaining water quality. The landscape metrics can explain approximately 70.5 % (R²) of the variance in the water quality parameters. This result is consistent with previous studies (e.g., Hao et al. 2006), i.e., the contribution of agricultural activities, waste water from livestock and poultry farms, and domestic sewage and solid waste to the total pollution are approximately 70, 20, and 10 %, respectively.

PLAND and LPI of residential areas are entered numerical regression equations for spring and winter; the main reason is that domestic water and daily life solid waste from residential areas become the major contributors for water pollution in spring and winter. Also, the constant in equations for spring and winter is larger than that of summer and fall, which suggests that the water quality is worse in spring and winter than summer and fall. So, pollution control should be paid more attention in spring and winter. In summer and fall regression equations, landscape metrics of tea gardens, paddy lands, and forests are the main factors. In summer and winter, the landscape metrics explained approximately 80.7 % of the variance in the water quality variables, which was higher than that for spring and fall (60.3 %).

The regression equations for NO₃⁻-N suggest that P_{Res}, LPI_{Res}, ED_{Pad}, LPI_{Pad}, and LSI_{For} are entered models. In summer and winter, the landscape metrics can explain up to 71.5 % of the variance in the water quality variables; however, in spring and fall, the R² value decreases to 50.3 %. The paddy lands exhibited

the largest effect out of all of the studied landscape metrics. This finding indicates that NO₃⁻-N pollution is primarily produced in agricultural areas. The results for NH₄⁺-N suggest that P_{Res}, LPI_{Res}, LPI_{Pad}, ED_{For}, and PD_{Tea} should be chosen. The R² value was as high as 85 % in summer and winter, while the regression equations for spring and fall were not as ideal. The findings suggest that not only tea gardens and paddy lands produce large amounts of pollution but also residential areas. TN pollution is always highly correlated with NO₃⁻-N and NH₄⁺-N, i.e., the two main nitrogen forms. The LPI_{For}, ED_{For}, LPI_{Pad}, LPI_{Res}, and PD_{Tea} models exhibit statistically significant in expressing the water quality variables. Moreover, the R² value for summer and winter was higher than that for spring and fall.

Simulating and describing agricultural non-point pollution are very complex tasks that are affected by numerous comprehensive factors. Nevertheless, expanding our landscape ecology knowledge for solving water quality issues will always be an effective and economic approach. In future research, this study and its results will assist in the prediction of water quality in other areas at similar scales. Specifically, by estimating the relationships between the landscape pattern and the water quality variables, environmental managers can obtain more landscape ecological approaches to improve environmental quality.

Discussion and conclusions

With the help of a spatial analysis tool and multivariate statistics, the results of this study demonstrate the

relationships between several landscape metrics and four water quality variables in different seasons in the Jinjing River watershed, China. Comparing with previous studies, some studies just chose the percentage of landscape types or landscape pattern metrics to analyze the relationship between landscape characteristics and water quality, but failed to build the model quantitatively (Chang et al. 2008; Lee et al. 2009; Lowicki 2012; Zhou et al. 2012). While some studies created the regression models of the relationship using stepwise regression analysis, but lacked of analysis from spatial and temporal scale (Amiri and Nakane 2009; Bu et al. 2014; Li et al. 2008; Mehaffey et al. 2005; Uriarte et al. 2011). This study solved the above weakness.

First, this study analyzed the relationships from both spatial and temporal scale. Eighteen sub-watershed zones were delineated and three different buffer areas along the river were drawn. Based on spatial data, landscape metrics were done and analyzed. In consideration of each season had distinctive characteristics and water quality were variable in different seasons, we built the models for each season. These works can promise the results more accuracy.

Second, the study identified a suitable scale for research. Landscape scale is a very important aspect in landscape ecology research. Even the same landscape type may show different ecological functions in the ecological process at the different scales. To determine a suitable landscape scale for this study, a series of buffers with widths of 250, 500, and 750 m on each side of the river were drawn. The results of Pearson's correlation coefficients show that the sub-watershed scale was a suitable scale for this study.

Third, the study recognized the main landscape factors. In the research of landscape pattern and process, different landscape types can be divided into three kinds of landscape: source, sink and flow landscape. If the ecological process were changed, the effect of landscape type may be transformed to one another. Therefore, source, sink, or flow should be defined before modeling. This study identified tea gardens, residential areas, and paddy lands as source landscape, forests as sink landscape, and rivers as flow landscape, and recognized tea gardens, residential areas, paddy lands and forests as the primary landscape characteristics for modeling the relationships using a principal component analysis.

Finally, the study chose proper landscape pattern metrics and created the regression models. A large number of landscape indices were developed to quantify

landscape spatial pattern, but they were highly correlated among them. One problem faced by landscape ecologist was that how to choose them. Based on previous studies (Bu et al. 2014; Lee et al. 2009; Lowicki 2012) and landscape characteristics of the Jinjing River watershed, PLAND, PD, LPI, LSI, ED SHDI, and CONTAG were selected. The results show that landscape composition and configuration indices PLAND, PD, LPI, LSI, and ED entered the equations for different seasons.

This study not only analyzed landscape characteristics and water quality dynamics qualitatively but also expressed their relationships by regression equations quantitatively. The results are critically important for estimating pollution potential and controlling pollution risk. Landscape pattern metrics are more likely to impact water quality and to have a consistent impact over seasons. This study provided managers an ecological and economic approach to improve water quality in the future. We can adjust the future landscape pattern to control water quality. P_{Res} , LPI_{Res} , ED_{Pad} , LPI_{Pad} , and PD_{Tea} have positive relationships with concentration of water pollutants. Some measures, for example, controlling residential area expansion, applying paddy land consolidation, merging small adjacent paddy patches, and reducing the tea garden patch density, could decrease the value of these indicators, thus reducing the water quality risk. Conversely, LPI_{For} , LSI_{For} , and ED_{For} negatively impact water pollutions. Therefore, increasing the size and number of forest patches, and expanding forest edge density should help alleviate pollution of NO_3^- -N, NH_4^+ -N, and TN.

The results of this study help us to better understand the relationship between landscape characteristics and water quality in four seasons and provide useful idea and insights on predict and control water quality for managers. Further research using landscape pattern metrics to clarify the complex nature on the relationships between landscape characteristics and water quality could expand on our results. In addition, due to limitations in data, we examined the relationships between landscape characteristics and water quality in four seasons within 1 year. Validations with other years and geographic locations are needed to optimize the findings of this study. Overall, the following conclusions were attained:

- (1) Landscape characteristics are strongly correlated with the water quality variables in small watersheds in highly intensive agricultural areas; tea

gardens, residential areas, paddy lands, and forests are the primary landscape types contributing to water pollution.

- (2) Buffers with three different widths were drawn to describe the spatial relationship between landscape types and water quality; the sub-watershed level is considered to be a suitable scale.
- (3) The regression models of the relationship between landscape characteristics and water quality during four seasons were created. The results show that both landscape composition and configuration have substantial effects on water quality. In different seasons, various landscape indices are expressed to explain the variance of water quality.
- (4) According to the effects of landscape pattern metrics on water quality, some measures were proposed for managers to predict and control the water quality in the future.

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