Impacts of Land Use on Water Quality of Inflowing Rivers to Erhai Lake Across Different Spatiotemporal Scales: Postprint

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Abstract

The relationship between land use and water quality of inflow rivers exhibits spatiotemporal variations. Taking the western inflow rivers of Erhai Lake and their small watersheds as the study area, this study employed integrated spatial analysis and mathematical statistical methods to explore the relationship between the two with respect to spatial scale and temporal variation. The results indicate that: across the four selected scales of small watershed, 30m riparian buffer zone, 60m riparian buffer zone, and 90m riparian buffer zone, the land use types that significantly influenced inflow river water quality were construction land and vegetation (including forest land and grassland), with the small watershed scale having the greatest influence, followed by the 30m riparian buffer zone. At the small watershed scale, the percentage area of construction land was positively correlated with COD and TP concentrations in inflow rivers, while the percentage area of vegetation was negatively correlated with NH4+-N concentration; the primary water quality indicators responding to land use were TN and TP, with adjusted regression coefficients of 0.624 and 0.579, respectively. Seasonal correlation analysis revealed that the regression relationships between construction land and COD, NH4+-N, TP were stronger in the rainy season than in the dry season, and those between vegetation and COD, TP were also stronger in the rainy season; during the rainy season, changes in construction land and vegetation area caused faster changes in COD concentration. In watershed management, Baihe Creek and Zhonghe Creek, which have low vegetation coverage and high construction land proportion, should be prioritized for enhanced land use control during the rainy season, with increased vegetation coverage and rational development of construction land.

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Full Text

Preamble

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Impact of Land Use on the Water Quality of Inflow Rivers to Erhai Lake at Different Temporal and Spatial Scales

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Abstract

Relationships between land use and water quality of rivers flowing into lakes vary spatially and temporally. This study investigated these variations in the western inflow rivers and their subcatchments in the Erhai Lake basin using spatial analysis and mathematical statistical methods. The results indicated that the land use types significantly influencing river water quality were construction land and vegetation land at four spatial scales (subcatchment, and 30 m, 60 m, and 90 m riparian buffer zones). Vegetation land included forest, grassland, and shrub land. The greatest impact occurred at the subcatchment scale, followed by the 30 m riparian buffer zone. At the subcatchment scale, the percentage of construction land was positively correlated with COD and TP concentrations of the inflow rivers, while the percentage of vegetation land was negatively correlated with NH -N concentration. The main water quality indexes corresponding to land use were TN and TP, with adjusted regression coefficients of 0.624 and 0.579, respectively. Seasonal correlation analysis suggested that the regression relationships between construction land and COD, NH -N, and TP concentrations during the wet season were stronger than those in the dry season, and the regression relationships between vegetation land and COD and TP concentrations were also stronger during the wet season than those in the dry season. COD concentration change caused by variation in construction land and vegetation land occurred more rapidly during the wet season than in the dry season. During basin management, particular attention should be paid to land use control during the wet season for the Baihe and Zhonghe Rivers, whose watersheds have a lower proportion of vegetation land and a higher proportion of construc-

tion land. Vegetation coverage should be increased, whereas the effects of land development should be studied adequately before implementation.

Keywords: temporal and spatial scales; land use; inflow river; redundancy analysis

Introduction

Unreasonable human activities lead to changes in land use, which in turn affects many aspects of human life. The impact of land use change on surface water environments is a key focus in the field. Inflow rivers serve as important channels for external sources flowing into lakes and are significant sources of water resource replenishment, with their water quality and quantity changes directly affecting lake water environmental quality. Research on the relationship between land use and inflow rivers is crucial for watershed water environmental protection and land development utilization. As a product of human activities, land use affects river ecological environments by altering hydrological cycles and nutrient migration and transformation processes in watersheds. Inflow rivers, as important components of ecological landscapes, have been the subject of numerous studies investigating the spatiotemporal differences in their relationships with land use.

Previous research has produced varying conclusions regarding the optimal spatial scale for land use-water quality relationships. Silva and Williams conducted a comparative study of water quality and land use relationships across watershed and buffer zone scales in Canadian basins, finding that land use types had more significant impacts on water quality at the watershed scale. Tudesque et al. studied the relationship between land use patterns and water quality across multiple spatial scales in the Adour-Garonne basin in France, reaching similar conclusions. Ding et al. investigated the relationships among land use, water quality, and algae in the Dongjiang River basin, while Shen and Zhou studied land use-water quality relationships across full watershed, subwatershed, and three buffer zone scales in the Beiyun River basin, concluding that land use patterns had more significant impacts on river water quality at buffer zone scales compared to full watershed scales. Other studies have reached opposite conclusions, highlighting that these relationships are influenced by spatial scale and temporal variation.

Seasonal effects on land use-water quality relationships have also been examined. Prathumratana et al. demonstrated that the impact of land use on river water quality is closely related to seasonal changes, with variations in rainfall, temperature, and agricultural activities across seasons affecting these relationships. Research methods have included traditional approaches such as correlation analysis, multiple regression analysis, and more recently developed geographic information technologies and models. Although numerous studies have advanced this field, influenced by watershed characteristics, human disturbance intensity, and data precision, some aspects remain unresolved, such as the optimal or strongest spatial scale for land use-water quality relationships, which has not reached a unified conclusion.

Erhai Lake, the second largest plateau freshwater lake in Yunnan Province, forms the foundation for sustainable socioeconomic development in Dali Prefecture and Yunnan Province. However, with socioeconomic development and population growth in the watershed, land development and utilization have intensified, leading to declining water quality. The western region of Erhai serves as the core area for inflow rivers, providing important clean water sources for the lake. Due to its superior geographic environment and abundant water resources, it has become a central area of human activity in the watershed, with prominent issues of high-density human activity and intensive land development. Environmental pollution dominated by non-point source pollution is becoming increasingly severe, affecting inflow river water quality and threatening the Erhai water environment. Therefore, balancing land development and water environmental protection is an important challenge currently facing the region and is key to improving regional river water quality, ensuring clean water flows into Erhai, and promoting watershed economic development. Against this background, and building on previous research, this study employs mathematical statistics and spatial analysis methods to investigate how inflow river water quality varies with land use spatial scales and seasonal effects, aiming to provide references for local water environmental protection and land development utilization.

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1 Study Area Overview

The study area is located in the western part of the Erhai Lake basin in Dali City, Dali Bai Autonomous Prefecture, Yunnan Province, covering 336.9 km^2 (33% of the Erhai basin). The climate is characterized as typical low-latitude subtropical plateau monsoon, with a multi-year average temperature of 15.1°C and average rainfall of 1048 mm. The wet and dry seasons are distinct, with 88.7% of annual precipitation occurring during the wet season (May–October). The geographic coordinates are 99°58 -100°14 E, 25°35 -25°56 N.

The study area has a developed water system with abundant water resources, consisting of 18 mountain streams perpendicular to Erhai Lake, collectively known as the "Cangshan Eighteen Streams," which constitute important sources of clean water replenishment for the lake. Originating from the Cangshan Mountains, these streams flow through the Dali Dam area with dense human activity, irrigating vast farmlands before finally entering Erhai Lake. The average annual surface runoff is 2.339 billion m^3, accounting for 24.7% of Erhai's water resources. As the main water source and core inflow channels for Erhai, water quality and quantity changes in the Cangshan Eighteen Streams directly affect Erhai' s water environmental quality. Among these, 14 rivers were selected for this study based on the finding that 4 streams remain dry most of the year. Monitoring frequency was monthly, with monitoring points located at the inflow mouths of each subcatchment. Two years of data (2014–2015) were obtained from the Dali Prefecture Environmental Monitoring Station and Erhai Lake Research Center, with sampling and analysis methods following national standards.

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2 Data Sources

Water quality data comprised four representative indicators: COD, NH -N, TN, and TP. Remote sensing imagery data were from ZY-3 satellite imagery captured in 2014 with 2.36 m resolution. Based on investigation showing relatively slow land use change, the 2014 remote sensing imagery data could reflect the land use structure characteristics for the period around 2015. DEM data were ASTER GDEM 30 m resolution elevation data obtained from the Chinese Academy of Sciences Computer Network Information Center.

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3 Methods

3.1 Spatial Analysis

Based on remote sensing imagery and referring to the latest land classification standard "Current Land Use Classification," unsupervised classification was used for land use classification, corrected using the second national land survey results of the Erhai basin as reference. Land use was divided into five types: construction land, agricultural land, vegetation land, water bodies, and other land. Vegetation included forest land and grassland, which were combined into one category due to the large forest area and small grassland area in the study area. Other land included special-use land, natural reserve land, and scenic facility land.

Watershed delineation was performed using hydrological analysis tools in ArcGIS 10.1 (ESRI). Currently, riparian zone delineation types are mainly rectangular and circular. Given that the study area rivers are narrow mountain streams and considering regional land use spatial distribution characteristics, rectangular buffers were adopted along rivers extending 30 m, 60 m, and 90 m to both banks—a method commonly used in river studies.

3.2 Statistical Analysis

SPSS 19 software was used for river water quality characteristic analysis. Before analysis, data normality tests were conducted using double-tailed asymptotic probability tests, with all P-values greater than the given significance level of 0.05, indicating normal distribution. Based on this, descriptive statistical analysis was used to analyze water quality data for the 14 inflow rivers after outlier removal and screening.

Redundancy analysis (RDA) was performed on the Canoco 4.5 platform to analyze correlations between land use and inflow river water quality. Detrended correspondence analysis (DCA) was first used to determine water quality change characteristics. With the maximum gradient value of sorting axes found to be less than 3, the commonly used linear sorting model RDA was selected. At a significance level of 0.05, stepwise multiple regression analysis was used to establish response relationships between inflow river water quality and land use, with entry and removal probabilities set at 0.05 and 0.10, respectively.

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4 Results

4.1 Characteristics of Inflow River Water Quality and Land Use in the Study Area

After outlier removal and screening, descriptive statistics were used to analyze variation characteristics of water quality data for the 14 inflow rivers. At a significance level of 0.05, the results showed: COD ranged from 0.20-57 mg/L (mean 18.99 mg/L), NH -N from 0.01-11.79 mg/L, TN from 0.01-3.34 mg/L, and TP from 0.01-0.45 mg/L.

Descriptive statistics of inflow river water quality

Spatial statistical analysis of land use characteristics in the subcatchments of the 14 inflow rivers at different spatial scales revealed that the study area land use types were dominated by vegetation, agricultural land, and construction land. At the subcatchment scale, vegetation was the dominant land type (66% average), followed by construction land. At riparian buffer zone scales, vegetation and agricultural land had the highest proportions. The area percentages of various land use types differed across spatial scales: vegetation area percentage was lower in riparian buffer zones than at subcatchment scale, while construction land and agricultural land area percentages decreased with increasing buffer zone width, being higher in riparian buffer zones than at watershed scale. Water body and other land area percentages were also higher in riparian buffer zones than at subcatchment scale.

4.2 Relationship Between Land Use and Inflow River Water Quality

Redundancy analysis was used to investigate relationships between land use area percentages and inflow river water quality at different spatial scales, testing the explanatory power of land use for water quality variation to identify the spatial scale with the greatest impact. The spatial scale ranking of land use type impacts on river water quality was: subcatchment $>$ 30 m riparian buffer $>$ 60 m riparian buffer $>$ 90 m riparian buffer. At the subcatchment scale, land use area percentage explained 47.4% of water quality variation—the highest among all scales—making it the spatial scale with the strongest impact on river water quality.

Total variance explained by the ordination axis

The explained variance of different land use types on river water quality at various spatial scales is shown in Figure 5. Overall, the land types with highest explanatory power for river water quality were construction land and vegetation. At the subcatchment scale, partial Monte Carlo permutation tests showed $P < 0.05$ for these two types, indicating significant impacts. While agricultural land was not a significant factor in redundancy analysis, it appeared as a main factor affecting TN concentration in regression equations.

[Figure 4: see original paper] Redundancy analysis between land use and inflow river water quality

4.3 Response Relationship of Inflow River Water Quality to Land Use

Based on the identified optimal spatial scale, stepwise multiple regression was used to establish response equations of inflow river water quality to land use at subcatchment scale. Multiple stepwise regression results were generally consistent with redundancy analysis. Construction land and vegetation, as the main factors affecting river water quality, appeared in regression equations for most indicators. Construction land area percentage was positively correlated with COD and TP concentrations, while vegetation area percentage was negatively correlated with NH -N concentration. Agricultural land and other land area percentages also appeared in some regression equations.

The regression equations showed that water quality indicators responding strongly to land use were TN and TP, with adjusted R^2 values of 0.624 and 0.579, respectively.

Response of inflow river water quality to land use types

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5 Seasonal Association Between Land Use and Inflow River Water Quality

The relationship between land use and inflow river water quality is significantly influenced by rainfall and runoff. Based on rainfall characteristics in the study area, river water quality data for the 14 subcatchments were classified by season into wet season (May–October) and dry season, with average values calculated for each hydrological season. Seasonal association analysis revealed differences in relationships between the main affecting land types (construction land and vegetation) and water quality indicators. Overall, regression coefficients (R^2) for both land types with water quality indicators were higher in the wet season than in the dry season.

Construction land area percentage showed positive correlations with COD, NH - N, and TP, with regression coefficients higher in the wet season. Vegetation area percentage showed negative correlations with COD and TP, also with higher regression coefficients in the wet season. Regression equation slopes indicated that COD concentration changed faster with variations in construction land and vegetation area during the wet season, consistent with RDA results.

[Figure 6: see original paper] Seasonal association analysis between construction land and water quality
[Figure 7: see original paper] Seasonal association analysis between vegetation and water quality

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6 Discussion

6.1 Scale Effects of Land Use and Inflow River Water Quality Relationship

While scale effects in land use-water quality relationships are well established, no unified conclusion exists regarding the optimal spatial scale. This study used redundancy analysis to investigate spatial effects, finding that the relationship varied with spatial scale. The subcatchment scale explained the highest proportion of water quality variation (47.4%), making it the spatial scale with the strongest impact on inflow river water quality. This conclusion differs from some previous studies that found buffer zone scales more significant, but is consistent with others that identified watershed scales as optimal.

The subcatchment scale' s dominance in this study is closely related to the high vegetation coverage (66%) in the study area. The significant relationship between this dominant, single land type and water quality resulted in high total explanatory power. At riparian buffer scales, agricultural land and construction land jointly constituted dominant types, creating complex land composition with varied effects on water quality, resulting in lower explanatory power. Riparian zones remain crucial as the final barrier preventing pollutant migration into rivers, and their ecological functions should be protected.

6.2 Response Relationship of Inflow River Water Quality to Land Use

Quantitative studies on land use-water quality relationships have employed diverse methods. This study established response equations based on mathematical statistical analysis. Construction land area percentage was positively correlated with COD and TP, while vegetation area percentage was negatively correlated with NH -N. These findings align with previous research. Construction land, as an intensive human activity area, increases impervious surfaces, leading to concentrated pollutant discharge and increased organic matter and phosphorus loss under runoff scouring. Vegetation acts as a pollutant sink, with its area percentage negatively correlated with nutrient concentrations.

The Baihe and Zhonghe Rivers, where construction land area percentages exceed 40% and vegetation area percentages are below 30%, should be prioritized as key management areas.

6.3 Seasonal Effects on Land Use and Inflow River Water Quality Relationships

As an important component of non-point source research, the land use-water quality relationship is closely related to rainfall and runoff. Seasonal effect studies have produced varying conclusions. This study found seasonal differences, with stronger regression relationships in the wet season for both construction land and vegetation with water quality indicators. This occurs because land use affects inflow river water quality by altering surface hydrological cycles and pollutant migration pathways, with runoff scouring having greater influence during the wet season when more pollutants are washed into rivers. Therefore, land use management should particularly restrict construction land expansion during the wet season while ensuring vegetation protection. More data should be obtained in future studies to better reveal seasonal effects.

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7 Conclusions

In the selected subcatchments, construction land and vegetation were the main land types affecting river water quality across four spatial scales. The subcatchment scale was identified as the strongest spatial scale, followed by buffer zones. At this strongest scale, land use explained up to 47.4% of water quality variation, with construction land and vegetation explaining 40.7% and 24.8%, respectively.

Construction land area percentage was positively correlated with COD and TP concentrations, with adjusted regression coefficients of 0.624 and 0.579, respectively. Vegetation area percentage was negatively correlated with NH -N concentration. The water quality indicators responding most strongly to land use were TN and TP.

Seasonal analysis showed that regression relationships between construction land area percentage and COD, NH -N, TP, as well as between vegetation area percentage and COD, TP, were stronger in the wet season than in the dry season. COD concentration changed faster with construction land and vegetation area variations during the wet season.

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Note: Figure translations are in progress. See original paper for figures.