Sustainable Development Research; Vol. 7, No. 2; 2025
ISSN 2690-9898 E-ISSN 2690-9901
https://doi.org/10.30560/sdr.v7n2p109

Study on Land Use Change and Its Impacts in the Nanming River Basin

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Received: May 2, 2025 Accepted: June 6, 2025 Online Published: June 10, 2025

Abstract

Land use significantly affects river basin water quality directly and indirectly through landscape pattern changes. This study analyzed land use changes in the Nanming River Basin in 2000, 2010, and 2020, calculating landscape pattern indices for different buffer zones in 2010 and correlating them with water quality data. Key findings: From 2000 to 2020, grassland area decreased while artificial surfaces expanded, with landscape fragmentation declining as buffer scales increased. Upper reaches had better water quality than lower reaches, though both sections showed significant nitrogen pollution. Higher proportions of cropland and artificial surfaces correlated with worse pollution, while grassland and forest land strongly inhibited pollutants. Reduced landscape fragmentation benefited water quality, and more standardized artificial surface shapes had stronger positive effects.

Keywords: land use, landscape index, correlation analysis

1. Introduction

1.1 Research Background and Significance

1.1.1 Research Background

Land and water resources are indispensable materials for human survival. With the continuous advancement of industrialization and urbanization, the rationality of land use structure directly constrains regional ecological environments and economic development[1]. Guiyang City, as the main city within the Nanming River Basin, significantly impacts the water quality of the Nanming River through its development. In 2021, Guiyang City announced the implementation of a five-year "Strengthening the Provincial Capital" action plan, aiming to establish Guiyang as a city with higher primacy and greater influence. Consequently, its permanent urban population will further increase, urbanization will accelerate, and the land landscape pattern will undergo corresponding changes. Therefore, to alleviate the human-land conflicts caused by population growth, this study takes the Nanming River Basin as the research area and applies the principles and methods of landscape ecology to analyze the impact of landscape patterns on water quality at a spatial scale, emphasizing the importance of land-water interactions.

1.1.2 Research Significance

By analyzing the temporal characteristics of land use change, the spatial variations of landscape patterns at different scales, and the characteristics and seasonal spatial variations of water quality parameters in the Nanming River Basin, this study reveals the intrinsic characteristics of land use development within the basin. While promoting the scientific planning, orderly management, and protection of water quality, it seeks coordinated human-land development approaches and provides a reliable scientific basis for water quality governance in the Nanming River Basin.

1.2 Research Status at Home and Abroad

1.2.1 Domestic Research Status

With the continuous advancement of science and technology, land use-related technologies have matured. Among them, land use classification research based on 3S technology (Remote Sensing, GIS, GPS) has become a fundamental approach. The integration of 3S technology provides convenience for solving many problems in land use. Deng Yangqiong (2020) proposed that the effective use of 3S technology plays a vital role in land resource planning development. Applying this technology to land use change monitoring can effectively save manpower and material resources, compensate for the shortcomings of traditional monitoring techniques, and enable better management and control of land resources, thereby improving China's land resource management level[2]. With changing times, the research field of land use and its changes continues to expand, and research methods are constantly updated. In recent years, the impact of watershed land use and its changes on water quality has become a research hotspot both domestically and internationally. However, conclusions about the impact of land use on water quality often vary depending on the research methods used. Hu Hebing (2013) employed redundancy analysis (RDA), analytical selection, RS, and GIS technologies to explore the changing characteristics of watershed land use patterns, river water environmental quality characteristics, the influence of watershed land use patterns, and land use intensity on water environmental quality. The study concluded that increased land use intensity leads to river water quality deterioration[3].

1.2.2 Foreign Research Status

Since the 1970s, the impact of land use on water quality has received continuous attention. Allan (2004) reported that land use/cover changes caused by human activities, such as urbanization and deforestation within watersheds, have widely led to water degradation, soil erosion, habitat destruction, and other environmental problems[4]. Consequently, many studies focus on assessing the relationship between land use and water quality. However, Cole et al. (2016) reported that such assessments are complex and difficult because human activities and other influencing factors may operate at different spatial scales, and their combined effects make it challenging to evaluate the impact of individual factors[5]. Furthermore, Ding et al. (2016) reported that the diversity of landscape pattern indicators, especially hierarchical indicators for each land use type, are not fully considered in assessments[6]. Previous studies have shown that analyzing the relationship between landscape patterns and water quality changes using the principles and methods of landscape ecology is effective. Li et al. (2020) reported that landscape patterns significantly impact water quality, and this impact depends on seasonal spatial bases, different landscape pattern indicators, and water quality parameters[7]. Zhang et al. (2019) reported that the impact of landscape patterns on water quality varies with spatial scale. Considering the role of spatial scale in the relationship between watershed landscape patterns and water quality helps protect and improve water quality when planning landscape patterns[8].

2. Overview of the Study Area

2.1 Physical Geographical Conditions

The Nanming River is one of the important rivers in Guizhou Province, located in central Guizhou between 26°11′20″N ~ 26°54′20″N and 106°27′40″E ~ 107°03′10″E. It is the source river of the Qingshui River, part of the Wujiang River system, and a first-level tributary of the Yangtze River. It originates in Linka Township, Pingba County, Guizhou Province, and flows through Huaxi District, Nanming District, Yunyan District, Wudang District, Baiyun District, and Guanshanhu District of Guiyang City.

The total watershed area of the study area is 2371.29 km². Major tributaries include the Xiao Huanghe, Shixi River, Xiao Chehe, Guancheng River, and Madi River. Key small and medium-sized reservoirs built within the basin include the Hongfeng Lake and Baihua Lake, two important water replenishment sources. The study area is located in a subtropical plateau monsoon humid climate zone, with an average annual temperature of 15.3°C. The average temperature of the hottest month is above 22°C, while the coldest month averages below 5°C but above 0°C. Under the perennial influence of the westerlies, it features abundant rainfall and a mild climate.

3. Data and Methodology

3.1 Data Sources

The land use data for this study are sourced from GlobeLand30 (globallandcover.com/def...). Landsat-TM remote sensing images from 2000, 2010, and 2020 with a spatial resolution of 30m were selected as the research objects. Additionally, extensive literature was referenced to ensure the accuracy of land use data in the study area. Based on the three-period land use data, ArcGIS software was used to classify the research data according to the GlobeLand30 classification system standards, resulting in 6 land use types: cropland, forest, grassland, water, Urban, and unused land. Four land use types in the classification system were not involved in this study area.

3.2 Research Methods

First, ArcGIS software was used to analyze and compare changes in different land use types across the three periods (2000, 2010, 2020) based on land use data. Second, buffer analysis was performed on the land use data. Previous research by Shi et al. (2017) reported that urban land shows a higher positive correlation with water quality degradation at smaller scales compared to larger scales[9]. Therefore, based on the 2010 land use data of the Nanming River Basin, ArcGIS software was used to conduct buffer analysis at different scales to compare changes in land use types across different buffers(Fig.1). Riverine buffer zones with widths of 100m, 200m, 300m, and 500m were created on both sides of the river channel, centered on basin sampling points. Third, based on the principles and methods of landscape ecology, the Fragstats landscape analysis software was used to analyze the landscape pattern indices of land use types at different scales and across the entire basin for the Nanming River Basin in 2010. Finally, SPSS software was used to conduct a correlation analysis between the 2010 land use data, landscape pattern indices, and water quality parameters.

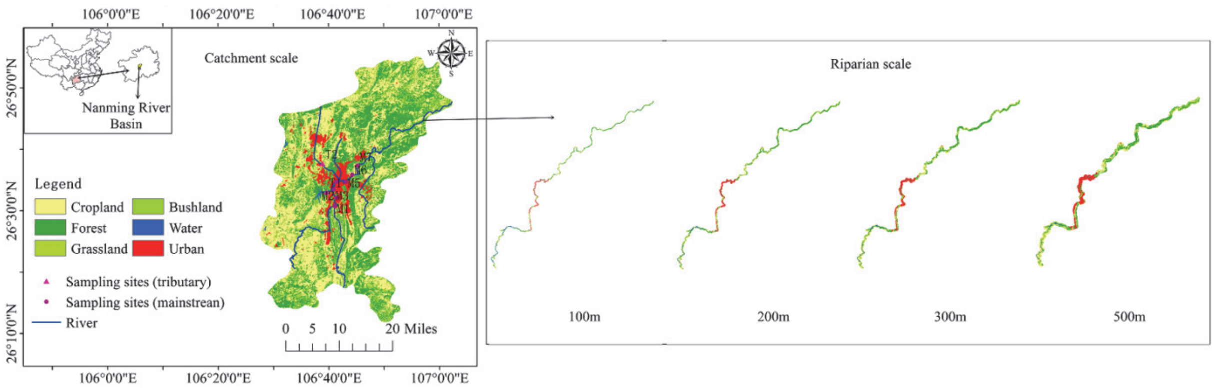

Figure 1. Distribution of sampling points and schematic diagram of riparian buffer zone

4. Results and Analysis

4.1 Watershed Land Use Characteristics

4.1.1 Overall Watershed Land Use Status

The land use status of the Nanming River Basin in 2000, 2010, and 2020 (Fig.2) shows that cropland and forest, as the dominant land use types in the study area, are mainly distributed in the southwest and northeast regions, respectively. The most significant change is observed in Urban, which is concentrated in the central part of the study area and shows a trend of outward expansion from 2000 to 2020. The distribution of grassland, Bushland, and water is less pronounced.

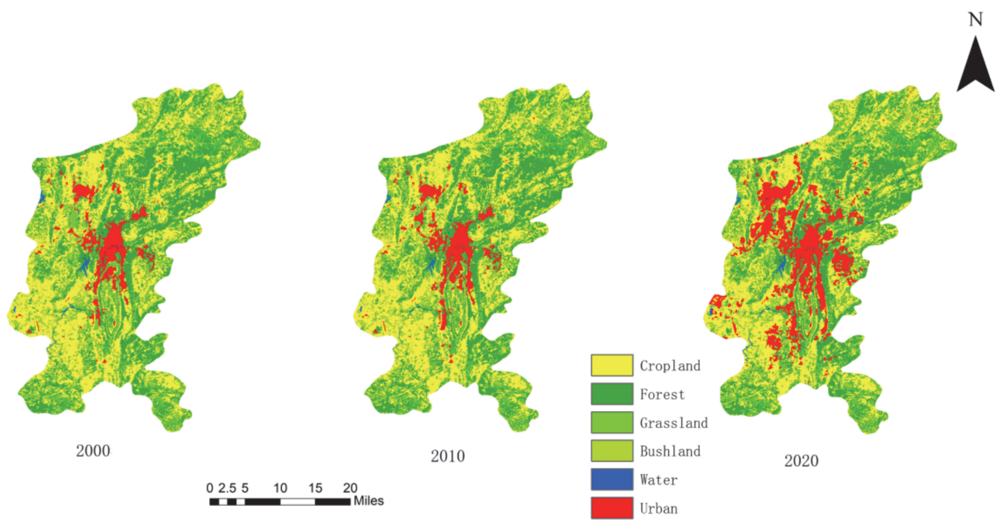

Figure 2. Land Use Distribution in the Nanming River Basin (2000, 2010, and 2020)

Among the various land use types in the Nanming River Basin, the three types with the widest area distribution are cropland, forest, and grassland, while water have the smallest distribution area (Fig.3). Both cropland and forest showed slight increases between 2000 and 2010. Reasons for this increase include: 1) the official implementation of the national Grain for Green Program regulations starting in early 2003; 2) the Guizhou provincial government's efforts to meet farmers' food demands; and 3) certain achievements in rocky desertification control. However, since 2014, with the development of Gui'an New Area and the continuous advancement of urbanization in Guiyang, cropland and forest showed a significant decrease by 2020, declining by 114.92 km² and 24.02 km², respectively. Over the two decades from 2000 to 2020, grassland showed a slight but continuous downward trend. By 2020, it had decreased by 34.26 km², indicating relatively stable utilization efficiency compared to other land types. water and Bushland, due to their smaller distribution areas, showed no significant changes. Among the six land use types, only Urban showed a significant increasing trend, expanding by 180.56 km² from 2000 to 2020, indicating that human land utilization is primarily reflected in construction activities.

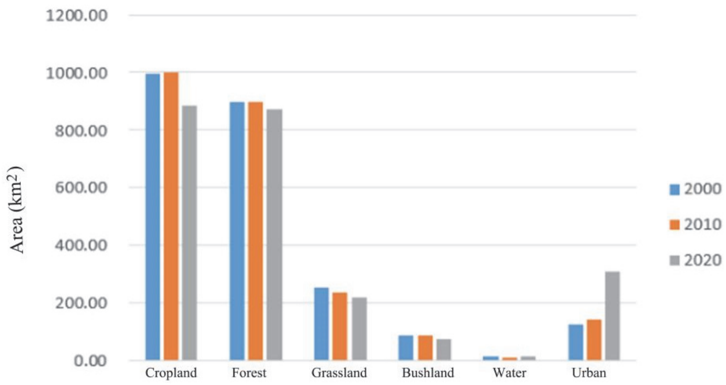

Figure 3. Land Use Area Distribution in the Nanming River Basin (2000, 2010, and 2020)

Table 4.1 shows that land use changes in the Nanming River Basin are mainly characterized by the continuous increase in Urban. This is due to rapid economic development and population agglomeration, leading to increasing demand for urban land and the gradual expansion of urban areas. Compared to the period from 2000 to 2010, the increase from 2010 to 2020 was larger (119%), indicating rapid urbanization and economic development in the study area over the past decade. However, this also reflects a series of unreasonable land use phenomena accompanying the urbanization process during this period.

Table 1. Proportion Changes of Land Use Types in the Nanming River Basin (2000, 2010, and 2020)

Year / Land Use Type	**2000**	**2010**	**2020**
Cropland	41.99%	42.13%	37.29%
Forest,	37.78%	37.86%	36.85%
Grassland	10.64%	9.91%	9.20%
Bushland	3.62%	3.71%	3.13%
Water	0.62%	0.47%	0.58%
Urban	5.34%	5.91%	12.95%

4.1.2 Land Use Overview in Buffer Zones

Fig.4 shows the changes in land use types within different buffer scales along the Nanming River in 2010. The proportions of cropland, forest, Bushland, and Urban increased with the enlargement of the buffer scale, reaching their maximum values within the 500m buffer zone. Grassland and water showed the opposite trend, reaching their maximum proportions within the 100m buffer zone. Cropland and forest are the dominant land use types across all buffer zones, while Bushland and water have relatively low coverage (<15%).

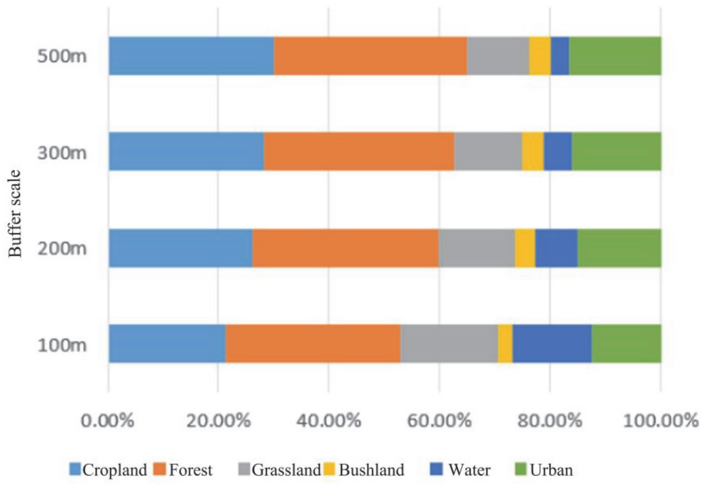

Figure 4. Changes in Land Use Types within Buffer Zones of the Nanming River Basin (2010)

4.2 Watershed Landscape Pattern Characteristics

4.2.1 Landscape Pattern Indices

Landscape pattern indices can fully reflect the composition and distribution characteristics of regional landscape types, benefiting the improvement of the ecological environment in the study area. They are a common quantitative research method in landscape ecology. Referring to relevant research results[10], this study selected five landscape indices: Patch Density (PD), Edge Density (ED), Aggregation Index (AI), Largest Patch Index (LPI), and Landscape Shape Index (LSI) to reflect landscape connectivity, fragmentation, and complexity. Descriptions of the landscape indices are shown in Table 2.

Table 2. Description of Landscape Indices

Index Name	Definition
Patch Density (PD)	Degree of landscape fragmentation
Edge Density (ED)	Degree to which the landscape is divided by edges
Aggregation Index (AI)	Connectivity between landscape patches
Largest Patch Index (LPI)	Ratio of the area of the largest patch to the total landscape area
Landscape Shape Index (LSI)	Complexity of the shapes of patches constituting the landscape

4.2.2 Analysis of Landscape Pattern Indices at Multiple Scales

Watershed landscape pattern indices exhibit significant differences across different buffer scales. The results (Fig.5) show that the Patch Density (PD) and Edge Density (ED) for all land use types decrease as the scale increases, indicating that the degree of landscape segmentation and fragmentation decreases as the buffer scale expands. The Aggregation Index (AI) increases with the scale, indicating that the degree of aggregation between patches strengthens as the scale gradually expands. Changes in the Largest Patch Index (LPI) reflect the direction and intensity of human activities[11]. The LPI of Urban increases from small to large scales, indicating that the overall influence of the Urban landscape increases as the buffer scale expands. The LPI of cropland, grassland, and forest showed no regular trend. The LSI of grassland increases from small to large scales, indicating that the complexity of the grassland landscape increases as the buffer scale expands. The LSI of cropland, forest, and Urban showed no regular trend.

a. Patch Density b. Edge Density c.Aggregation Index

d. Largest Patch Index e. Shape Index

Figure 5. Landscape Pattern Indices for Four Riverine Buffer Scales and Watershed Scale in the Nanming River Basin

4.3 Correlation Analysis between Land Landscape Patterns and River Water Quality

4.3.1 Water Quality Status of the Nanming Basin

This study extracted water quality indicators for the Nanming River in 2010 from the literature[12], including 5-day Biochemical Oxygen Demand (BOD_5), Total Nitrogen (TN), Chemical Oxygen Demand (CODcr), Total Phosphorus (TP), and Ammonia Nitrogen (NH_4^+-N) (Table 3). The data show that the CODcr, BOD_5, TN, NH_4^+-N, and TP values for the downstream Xinzhuang section were higher than those for the upstream Huaxi section in all periods, indicating more severe pollution in the Xinzhuang section compared to the Huaxi section. Seasonally, the water quality in the Xinzhuang section was significantly worse during the dry season than during the normal and wet seasons. This is because reduced precipitation in the dry season decreases surface runoff into the river, weakening the river's dilution and self-purification capacity and increasing the average concentration of pollutants in the water body. In the Huaxi section, TN was higher during the wet and normal seasons than during the dry season, while other water quality indices were worse during the dry season than during the wet and normal seasons. This suggests that nitrogen pollution in water is more severe during periods of intense agricultural activity, consistent with the finding that upstream areas are predominantly cropland.

Table 3. Water Quality Monitoring Results for the Nanming River Basin (2010)

Water Quality Indicator (mg/L)	Huaxi Section			Xinzhuang Section		
	Normal Season	Wet Season	Dry Season	Normal Season	Wet Season	Dry Season
ρ(CODcr)	12.00	10.00	7.00	35.40	30.30	67.00
ρ(BOD_5)	1.00	2.00	2.00	9.30	10.40	11.00
ρ(TN)	3.43	2.98	2.04	5.40	10.30	19.20

ρ(NH_4^+-N)	0.33	0.19	0.33	4.34	2.77	5.57
ρ(TP)	0.01	0.02	0.03	0.85	0.43	0.87

Referring to the "Environmental Quality Standards for Surface Water" (GB3838-2002), it was found that BOD_5, NH_4^+-N, and TP in the Huaxi section met National Class I or II surface water environmental quality standards during all three periods. However, in the Xinzhuang section, BOD_5 during the normal season met National Class V standards, while BOD_5 during the other two periods, TP during all three periods, and NH_4^+-N far exceeded national standards. This indicates that the Xinzhuang section, located downstream in the city, suffers from much higher pollution levels than the upstream Huaxi section. Notably, TN levels in both the Huaxi and Xinzhuang sections during the normal, wet, and dry seasons were far higher than national standards, indicating significant nutrient pollution with abundant organic and inorganic nitrogen in the river.

4.3.2 Correlation between Land Use Percentage and River Water Quality

The correlation coefficient between water quality indicators and the percentage of land use types describes the relationship between water quality and land use type changes. A correlation coefficient greater than 0 indicates a positive correlation, meaning changes in land use type exacerbate increases in water pollution indices[13]; conversely, it indicates a negative correlation. Correlation analysis was performed between the proportions of various land use types and the concentrations of river CODcr, BOD_5, TN, TP, and NH_4^+-N. The results are shown in Table 4. The table shows that as the buffer zone expands, the average water pollutant concentration is positively correlated with cropland and Urban, and negatively correlated with forest and grassland.

Table 4. Correlation between Land Use Percentages and Water Quality at Different Buffer Scales

Indicator	Cropland	Woodland	Grassland	Urban
ρ(CODcr)	0.949	-0.945	-0.938	0.934
ρ(BOD_5)	0.950	-0.953	-0.960	0.963
ρ(TN)	0.919	-0.914	-0.905	0.900
ρ(NH_4^+-N)	0.203	-0.216	-0.237	0.248
ρ(TP)	0.979	-0.976	-0.971	0.969

* p<0.05 (2-tailed), Significant correlation
** p<0.01 (2-tailed), Significant correlation

4.3.3 Correlation between Landscape Pattern Indices and River Water Quality**

Correlation analysis between various landscape pattern indices and river water quality parameters (Table 5) showed that the Edge Density (ED) and Patch Density (PD) for all land use types were negatively correlated with all water quality indicators. The Landscape Shape Index (LSI), except for Urban, was positively correlated with all water quality indicators. Among them, forest showed significant correlations with river BOD_5, NH_4^+-N, and TP average concentrations. In the Largest Patch Index (LPI), cropland and forest were positively correlated with river TN. Other indices were correlated with various water quality parameters, among which grassland showed significant correlations with all water quality indicators.

Table 5. Correlation between Landscape Pattern Indices and River Water Quality

Index		ρ(CODcr)	ρ(BOD_5)	ρ(TN)	ρ(NH_4^+-N)	ρ(TP)
Edge Density (ED)	Cropland	-0.453	-0.673	-0.225	-0.577	-0.598
	Forest,	-0.468	-0.685	-0.241	-0.590	-0.611
	Grassland	-0.492	-0.704	-0.271	-0.610	-0.631
	Urban	-0.471	-0.687	-0.251	-0.589	-0.611
Patch Density (PD)	Cropland	-0.416	-0.640	-0.195	-0.536	-0.560
	Forest,	-0.465	-0.682	-0.243	-0.584	-0.606
	Grassland	-0.469	-0.685	-0.247	-0.588	-0.610
	Urban	-0.272	-0.503	-0.077	-0.378	-0.409

5. Conclusions

5.1 Impact of Land Use on River Water Quality

Land use types and their spatial distribution influence water pollution status[14], and there is usually a correlation between them. However, different land use methods have varying impacts on water quality. Previous research[15] indicates that during rainfall, surface pollutants enter water with surface runoff. During this process, pollutants may be deposited, absorbed, and re-released as water flows through different types of land use.

This study shows that among single land use types, forest and grassland have positive effects on river water, benefiting water quality optimization. Conversely, cropland and Urban exacerbate water pollutants, negatively affecting river water quality parameters. Extensive grassland distribution intercepts pollution, effectively reducing nutrient salts and organic matter content in rivers, acting as a "sink" for water quality[16]. forest also acts as a sink for water pollutants. As it absorbs surface runoff, it also absorbs most of the pollutants within the runoff, resulting in better water quality in areas with higher proportions of forest. Urban has a negative effect on water quality because the continuous hardening of urban surfaces during urbanization reduces water infiltration, increases surface runoff, and allows large amounts of surface pollutants to enter water without purification, leading to river water quality deterioration. Cropland also negatively impacts water quality, acting as a "source" of pollutants. Human agricultural activities increase nitrogen, phosphorus, and other nutrients in the soil, thereby increasing nutrient content in rivers and causing water eutrophication.

Therefore, in summary, larger proportions of cropland and Urban correlate with higher concentrations of water pollutants and more severe water pollution; conversely, larger proportions of grassland and forest inhibit river pollutants more effectively, leading to better river water quality.

5.2 Impact of Landscape Pattern on River Water Quality

Previous studies have found that landscape indices help explain the load of dissolved substances and sediments in water. Establishing links between landscape indices and river pollutant concentration indices allows the prediction of water quality changes[17]. Watershed geographic indicators also show significant correlations with certain physicochemical parameters, partly due to the combined influence of topography and land use[18]. Landscape patterns significantly impact water quality, and this impact depends on seasonal spatial bases, different landscape pattern indicators, and water quality parameters. Changes in landscape patterns depend on human activities. Increased landscape pattern aggregation, slightly weakened heterogeneity, reduced fragmentation, and relatively unchanged diversity and evenness indicate strong human influence on landscape patterns[19].

This study shows that Edge Density (ED) and Patch Density (PD) are negatively correlated with various water quality indicators, indicating that reduced landscape fragmentation of land use types positively impacts water quality. This suggests that more concentrated patches of land use types are more conducive to water quality protection. The Largest Patch Index (LPI) of grassland showed significant correlation with all water quality indicators, consistent with the above research. As the buffer scale expands, grassland decreases, negatively impacting river water quality. This also proves the "sink" effect of grassland in absorbing pollutants. Small land use patches have lower interception and absorption capacity for non-point source pollutants, making it easier for pollutants to enter water. The Landscape Shape Index (LSI) of Urban is negatively correlated with water quality, indicating that more regular and simpler shapes of the Urban landscape enhance its positive effect on water quality.

5.3 Recommendations

forest has a clear positive effect on water quality[20], consistent with the findings of this study. Therefore, larger areas of forest play a more active role in protecting water quality by effectively absorbing large amounts of pollutants. The study also found negative correlations between grassland and CODcr, BOD_5, TN, TP, and NH_4^+-N, indicating that expanding the proportion of grassland area within the basin positively impacts water quality by inhibiting increases in river pollutants. Urban and cropland negatively impact water quality, showing positive correlations with CODcr, BOD_5, TN, TP, and NH_4^+-N at various scales. This indicates that expanding the proportion of Urban and cropland leads to deteriorating river water quality. Therefore, based on the above research, the following suggestions are proposed for the development of the Nanming River Basin:

(1)Reduce the negative environmental impacts of urbanization, optimize regional land use patterns, enhance urban agglomeration, and prevent unreasonable outward expansion of urban areas.

(2)Strengthen greening construction within buffer zones, especially within the 500m buffer zone, to improve the purification capacity of grassland and forest for water.

(3)Enhance the capacity of Guiyang's underground drainage pipelines, strengthen environmental protection education, and raise pollution discharge standards for various enterprises in the Xinzhuang section.

(4)Promote the modernization of agriculture in the Nanming River Basin, upgrading from a single agricultural system to a compound agricultural system to reduce the use of various fertilizers.

(5)Improve water quality by adopting better landscape planning, such as enhancing patch connectivity and aggregation, reducing patch boundary complexity, and decreasing landscape fragmentation.

6. Limitations and Prospects

Studying the relationship between land use/landscape patterns and river water quality within watersheds has been a hotspot but also a challenge. Over time, research areas, methods, and theories constantly evolve due to various factors. This study analyzed the relationship between land use types, landscape patterns, and river water quality at buffer zone scales in the Nanming River Basin, setting different buffer distances to compare specific changes in this relationship. Certain research results were obtained. Considering that river water quality is also influenced by other factors, coupled with data collection constraints, limited access to materials, and the author's own capabilities, the research content is relatively basic and insufficiently comprehensive. More systematic and scientific in-depth research is needed:

The study area is relatively small, with limited distribution of different landscape types. Changes in river water quality are not only influenced by single landscape types but are also not confined to the landscape patterns within the watershed. They are also affected by point source pollution, topographic characteristics, and natural disasters. In this study, due to the small scale and insufficient number of monitoring points, the collected water quality data struggles to reflect the true water quality status. For the Xinzhuang and Huaxi river sections, the large distance between the two monitoring points and their differing industrial distributions limit the overall significance of the watershed water quality study. Urban only indirectly reflects the impact of point source pollution on the river. Therefore, future research should improve relevant information within the basin during long-term monitoring to further discuss and reveal the relationship between land use/landscape patterns and river water quality.

During the process of delineating the watershed boundaries, the small size of the basin prevented comprehensive delineation using hydrological analysis methods. Using administrative divisions to determine the watershed boundaries was hampered by time-lagged administrative data that did not match the current actual administrative situation. This resulted in a final study area smaller than the actual watershed, preventing a full watershed analysis of land use and landscape patterns.

Due to a lack of water quality statistics, only one period of water quality correlation analysis was conducted. The absence of a time series comparison prevents a comprehensive analysis of water quality changes in the basin and thus hinders discussion on the impact of landscape patterns on water quality across different periods. Only through long-term monitoring of the river water environment and the water quality status within the study area can the dynamic patterns of both be analyzed.

Acknowledgements

This research was supported by the National Natural Science Foundation of China (grant number: 42261056) and Guizhou Province Basic Research Program (Qiankehejichu-zk[2025]mianshang256).

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