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Correlation Analysis of Landscape Pattern and Water Quality in Baiyangdian Watershed

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Abstract

Water quality is sensitive to changes in landscape patterns in a watershed, particularly during urbanization. Using GIS tools, the landscape pattern index method was proposed to compare the landscape patterns of Baiyangdian Watershed in 2002 and 2007, determine the transformation rules of landscape essential factors, and analyze the correlation between the changes of landscape patterns and water quality in Baiyangdian Watershed. The study shows that 1) the degree of fragmentation of man-made landscape is decreasing and that of the natural landscape is increasing in the watershed during its urbanization; 2) Construction land and farmland are the dominant factors leading to river pollution in most cases, while a higher percentage of forest cover contributes to improved water quality. Furthermore, other physical and social factors were analyzed that may influence the relationship between water quality patterns of land use in the study area.

Key words: Landscape pattern; Water quality; Correlation; Baiyangdian; Watershed

1. Introduction

There is a growing demand for landscape-level freshwater monitoring and assessment methods [1, 2]. Freshwater research and management efforts could be greatly enhanced by a better understanding of the relationship between landscape-scale factors and water quality indicators [3]. Changes in the landscape pattern (land use/cover) are particularly sensitive to the effects of urbanization because they receive and

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transport water and materials from across watersheds, resulting changes in runoff as well as the quality of receiving water [4-6]. Water quality is affected by both point source and non-point source pollution [7]. Point source pollution has been fairly controlled thus non-point source pollution has become the main factors of water pollution, while the impact on non-point sources caused by landscape pattern change is very significant [8, 9]. It is possible to study the quality of river water using the landscape pattern. The use of landscape metrics in particular provides the ability to quantify land use pattern relatively quickly and easily. It also represents the spatial heterogeneity of a given landscape, and different patterns are observable at different scales [10].

Analyses using GIS in combination with other techniques for studying the relationship between landscape patterns and water quality are becoming more popular but have resulted in mixed conclusions [11-15]. Allan found that suspended sediment concentrations measured during low flows were higher in areas of greater agriculture [16]. Johns showed that landscape metrics consistently explained high amounts of variation in nitrogen yields to streams (65 to 86% of the total variation) [17]. In a similar study in the same region, Roth found that large-scale land use is the most effective predictor of biological community conditions [18]. Landscape metrics respond to a series of landscape features, while also mapping the social and economic conditions of the watershed. Water quality is affected by the landscape pattern of the basin while also greatly influenced by policy [19]. However, few studies analyze both the compositional attributes and spatial distributions (landscape metrics) of the land cover in order to link them with the water quality at the same time [20].

In this paper, the correlation between landscape pattern and water quality in Baiyangdian watershed was analyzed. The representative indicators of landscape pattern and water quality were selected and the land use data and water quality monitoring data of 2002 and 2007 were used. The landscape pattern change and water quality change within five years were illustrated. This study may provide a theoretical basis for land use management and landscape pattern control.

2. Materials and Methods

2.1. Study area

Baiyangdian Watershed is located in the piedmont plains east of Taihang mountain, in central Hebei Province of China, with E113 ° 40 '~ 116 ° 20', N 38 ° 10 '~ 40 ° 00'. It has a basin area of 31,200 km^2, running across multiple cities, including Baoding city, which has a basin area of 22,100 km^2 covering 70.8% of the total basin area. Water from the Baiyangdian Watershed mainly comes from the Daqinghe Drainage, which has north, south and central branches fanning out through the whole basin, and imports water eastward into the basin. The basin terrain gradually slopes from northwest to southeast, divided into western mountains, hills, piedmont plain, alluvial plain, and swamp. The basin has a semi-arid, temperate continental monsoon climate. It has an average temperature of 7.3~12.7˚C and receives a mean annual precipitation of 564 mm, with 80% of the precipitation coming in July and August.

2.2. Spatial data and analysis

Considering the basin scale, this study chose TM remote sensing image data, which included 2002 and 2007 in two parts, with image resolution of 30m*30m. After the pre-treatment including geometric correction, image stitching and image interception in ENVI4.4, the data were imported into the professional object-oriented remote sensing interpretation software ----Definiens Developer 7.0. Then information was extracted by using the man-machine interactive interpretation method which contains both the adjacent combination classification and manual classification. With the information combined within the context of case study area, the landscape types are classified into 8 landscapes: woodland, farmland, construction land, reed land, river, beach, lake, barren land (see Fig.1).

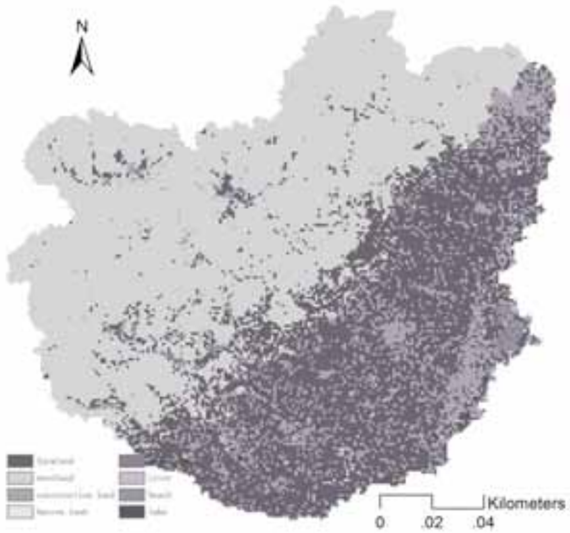

Fig. 1. Land-use map of Baiyangdian Watershed in 2007

2.3. Subwatershed delineation

With a 1:250,000 digital elevation model (DEM) and supported by ArcGIS9.2 platform, subwatersheds were delineated through the following steps: first, the depressions of the DEM data were filled with the Fill tool in the hydrological module (Hydrology); second, the flow direction and accumulation were computed; third, different thresholds were set to extract the stream network, and determined a reasonable threshold of 1700 through comparison between the result and river system map, which could generate the nearest approach to the actual river system; fourth, Point Delineation, Batch Watershed Delineation and Batch Subwatershed Delineation tools were used in the hydrological analysis expanding module (Arc Hydro Tools) to divide each subwatershed.

This research focused on the relationship between the landscape pattern and water quality in Baiyangdian Watershed. In addition, water sampling sites in mountain areas with minor human disturbance were selected for use as background values in the analysis. The sample area should cover the whole range of this basin, thus water sampling sites upstream that are closest to the lake were selected as points to divide the subwatersheds, which included seven sub-basins: Zhulong River basin, Juma River basin, Tang River basin, Fu River basin, Basha River basin, Dashi River basin (see Fig. 2).

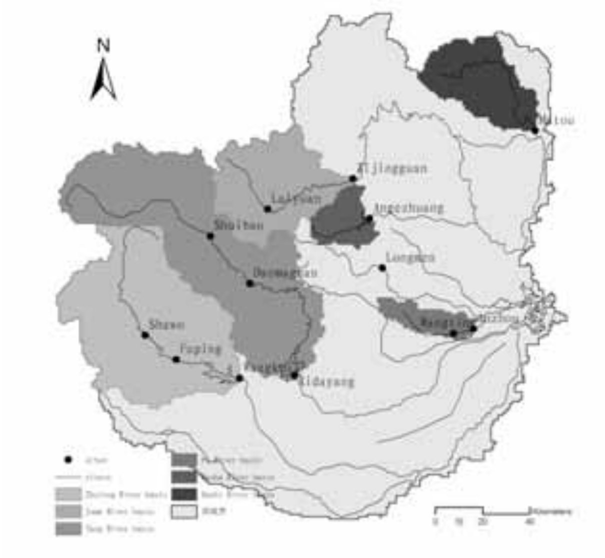

Fig. 2. Subwatershed delineation

2.4. Landscape pattern indices

Landscape pattern indices can be divided into three types: the level of plaque index (patch), plaque type level index (class) and the landscape level index (land). As the research required, we selected appropriate indices in the three levels. Selected indicators of landscape pattern indices and its ecological significance are shown in Table 1.

Table 1. Landscape pattern indices and its ecological significance

landscape pattern indices	ecological significance
Patches Density(PD)	Reflects the degree of landscape fragmentation and landscape spatial heterogeneity, the size of this value positively correlates with landscape fragmentation
Number of Patches (NP)	Describes landscape heterogeneity, size and its value positively correlates with landscape fragmentation
Shannon's Diversity Index (SHDI)	Reflects the number of landscape elements and the changes in the proportion of it, landscape types abundant and the degree of fragmentation positively correlate with its value
Shannon Evenness Index (SHEI)	Reflects the landscape types in the landscape of the uniform distribution and its value positively correlates with the distribution uniformity
Percentage of Landscape (PLAND)	Reflects the percentage of the landscape type
Landscape Shape Index (LSI)	Reflects the complexity of the landscape patches, the greater the value the more complexity

2.5. Water quality parameters selection

By calculating the contamination contribution of each monitoring section, we selected the larger ones as water quality parameters. Larger contamination contribution means that this section has major impact on water pollution, thus it is more appropriate to be applied in the correlation analysis. The synthetic pollution index was calculated using the following equations:

$$P_r = \sum_{i=1}^{n} P_i \quad (1)$$

$$P_i = \frac{C_i}{C_{io}} \quad (2)$$

Where P_r is the synthetic pollution index, P_i is the pollution index of pollutant i, C_i is measured concentration of pollutant i, C_{i0} is evaluation criteria of pollutant i. The criteria used in monitoring sections are from the corresponding standards in the "Surface Water Quality Standard" (GB3838-2002) based on "Functional Zoning of Surface Water Environment of Hebei Province". Evaluation indices used in this study include ammonia nitrogen (NH_3-N), total phosphorus (TP), chemical oxygen demand (COD), permanganate index ($KMnO_4$), dissolved oxygen (DO), and synthetic pollution index (Pr).

2.6. Correlation Analysis

Pearson's (parametric) correlation coefficient matrix was adopted to do bivariate analysis of water quality parameters and landscape pattern indices in the multivariate statistical analysis software PASW statistic 18. Correlations between the land cover (i.e. compositional attribute (%) and spatial distribution or landscape metrics), and water quality were determined. The two-sided test method was chosen for significance test. Only the coefficientswhere $p<0.05$ were analyzed in this study.

3. Results and discussion

3.1. Watershed landscape pattern

In 2002 and 2007, woodland landscape occupied 51.70% and 52.16%, respectively, as a dominant landscape type, farmland landscape is the secondary type, occupying 27.82% and 32.00%, respectively; the next is construction land landscape with 11.65% and 13.38%, respectively. Construction land and farmland always have the greatest amount of patches, the largest patch density and the most complex landscape shape out of all the landscape types.

Fig. 3 characterized the changes of landscape pattern structure from 2002-2007. Between 2002 and 2007, farmland, woodland, construction land, and rivers have increased 4.18%, 0.46%, 1.78%, and 0.32% respectively. Unused land, reed land, and beach decreased 6.55%, 0.10%, and 0.09% respectively, due to a large area of unused land turning into farmland (see Fig. 3a, PLAND reflecting the percentage of the landscape type). Patches Number (NP) and Patches Density (PD) had the same trend, the values of construction land, woodland, and farmland landscape pattern significantly increased while those of unused land decreased, the overall level increased significantly (see Fig. 3b & 3c, NP describing landscape heterogeneity, PD reflecting the degree of landscape fragmentation and landscape spatial heterogeneity). Landscape Shape Index (LSI) showed a different trend, the level of unused land landscape was significantly reduced, although the levels of other landscape types increased, the overall level was still significantly decreased (see Fig. 3d, LSI reflecting the complexity of the landscape patches).

From 2002 to 2007 watershed landscape pattern changed significantly, its diversity index and evenness index were both reduced, indicating that the type of watershed landscape was decreased and homogeneity of landscape pattern was reduced, while the watershed landscape complexity increased. Large-scale development and utilization have combined the new construction land and farmland with the existing lands, contributing to a reduction of landscape fragmentation level. The decrease of unused land and the uneven increase of other landscape types led to a slight reduction of diversity index. The whole basin's landscape fragmentation has been increased, especially in construction land landscape and woodland landscape. The former was directly influenced by human activities, while the latter was due to the development and utilization that damaged the woodland landscape integration.

3.2. Relationship between landscape pattern and water quality

The northwestern mountainous region was selected to have a pre-correlation analysis, where areas suffering minor human disturbance and four sub-basins were involved: the Zhulong River basin, Juma River, Tang River basin, and Bai River basin. It turned out that areas with minor human interruption have a better significant level of correlation than the whole basin does. Most of water quality indexes (i.e. NH_3-N, TP, COD, $KMnO_4$, and the synthetic pollution index Pr) showed a significant positive correlation with the percentage of construction land landscape, and a significant negative correlation with the percentage of woodland landscape. Only DO, in contrast, did not. NP and PD of farmland had a significant positive correlation with NH_3-N, TP, $KMnO_4$, and COD respectively, and showed a significant negative correlation with DO.

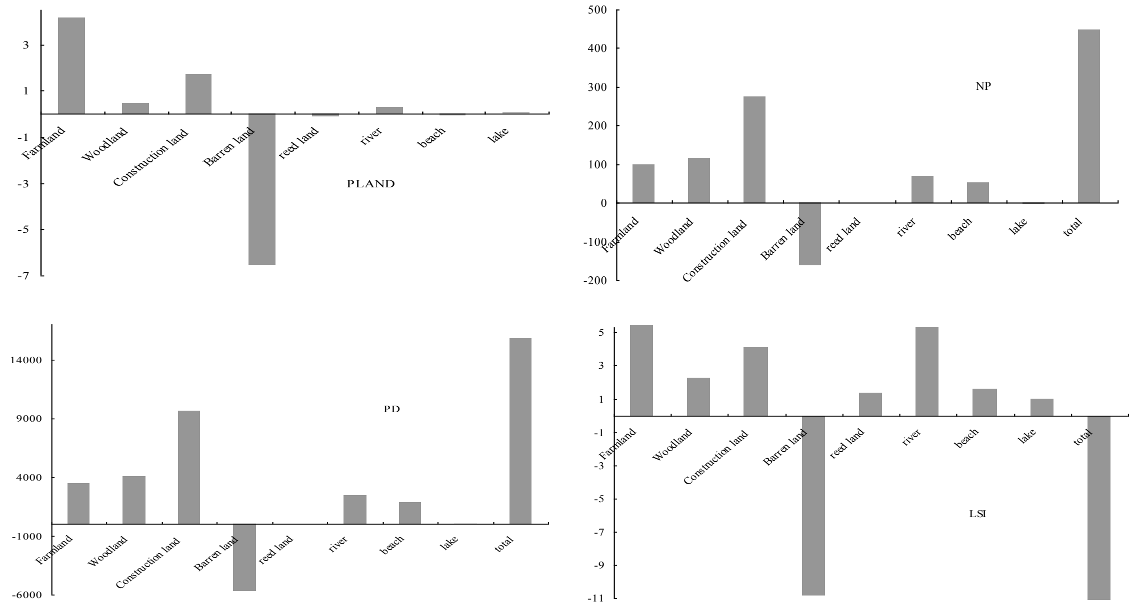

Fig. 3. Baiyangdian watershed landscape pattern changes in 2002-2007(a) PLAND; (b) NP; (c) PD; (d) LSI

Table 2 and Table 3 showed the significant correlations between water quality characteristics and landscape pattern in the whole basin in 2002 and 2007. In 2002, $KMnO_4$ showed a significant positive correlation to the percentage of farmland and construction land, a significant negative correlation to the percentage of woodland landscape, and a significant positive correlation to LSI, NP, and PD of construction land and LSI of farmland. Overall, $KMnO_4$ was significantly positively correlated with the LSI of the entire basin. In 2007, $KMnO_4$ was significantly positively correlated with the percentage of farmland, construction land, and unused land, significantly negatively correlated with the percentage of woodland. It showed a significant positive correlation to NP and PD of the unused land and SHDI and SHEI of the entire basin. TP, NH_3-N and P presented similar correlations with $KMnO_4$ and DO showed an opposite result. In conclusions, higher fragmentation level leads to more serious water pollution due to high fragmentation landscape susceptibility to more pollutants. Comparatively, the correlation in 2007 was more significant than in 2002.

The greater percentage of human-made landscape types (i.e. construction land and farmland), the worse the water quality in the watershed is. Contrary conclusion may be drawn for natural landscape types (i.e. woodland). High PD and NP values of unused land means high degree of fragmentation, which leads to worse water quality due to increasing soil erosion and garbage piling up. Greater SHEI and SHDI values, representing greater spatial heterogeneity and higher degree of fragmentation, lead to worse water quality in a watershed occupying large area of woodland because high fragmentation means destruction of the forest and damage to the water conservation and purification functions.

However, water quality deterioration would be stopped with more investment put into comprehensive water pollution control in a watershed. In recent years, positive efforts have been made on water and soil conservation, non-point source pollution control, and development of wastewater treatment plants in Baiyangdian Watershed. Water quality of the main rivers including Juma River, Tang River, Zhulong River has been improved to meet the grade III standard, and four surface water reservoirs (i.e. Xidayang, Angezhuang, Wangkuai and Longmen) were improved to grade II standard.

Table 2. Correlations calculated between water quality and landscape indices of 2002

Items		NH_3-N	NO_3-N	$KMnO_4$	DO	Pr
PLAND	Farmland	-0.129	0.021	**0.938****	-0.032	-0.043
	Woodland	0.220	-0.017	**-0.858****	-0.048	0.160
	Construction land	-0.174	0.145	**0.927****	0.000	-0.061
LSI	Farmland	-0.161	0.324	**0.766***	0.028	-0.035
	Construction land	-0.040	0.399	**0.849****	-0.170	0.112
Construction land	NP	-0.122	0.312	**0.898****	-0.087	0.019
	PD	-0.096	0.251	**0.904****	-0.117	0.026
LSI		-0.351	0.138	0.686*	0.226	-0.289

Table 3. Correlations calculated between water quality and landscape indices of 2007

Items		NH_3-N	TP	$KMnO_4$	DO	Pr
PLAND	Farmland	**0.885****	**0.845****	**0.812***	-0.554	**0.843****
	Woodland	**-0.940****	**-0.910****	**-0.877****	0.655	**-0.908****
	Construction land	**0.901****	**0.876****	**0.813***	-0.618	**0.872****
	Barren land	**0.820***	**0.774***	**0.764***	-0.456	**0.777***

LSI	Farmland	-0.640	-0.653	-0.726*	0.581	**-0.676***
	Barren land	**0.835****	**0.789***	**0.742***	-0.495	**0.784***
Barren land	NP	**0.835****	**0.789***	**0.742***	-0.495	**0.784***
	PD	**0.673***	0.636	**0.721***	-0.426	0.656
SHDI		**0.850****	**0.870****	**0.779***	**-0.865****	**0.853****
SHEI		**0.933****	**0.941****	**0.864****	**-0.869****	**0.927****

*indicates significance at $p < 0.05$，** indicates significance at $p < 0.01$

Conclusions

This paper has presented a method to analyze relationships between landscape pattern and water quality in an identified watershed context. Combined with GIS tools, this method employed both the landscape index and correlation analysis to make a comprehensive analysis of water quality indicators and landscape pattern indices. The Baiyangdian watershed was selected as a study area, and DEM data, land use data, and water quality monitoring data in 2002 and 2007 were used for correlation analysis. In general, human-made landscape in developed regions have a lower degree of fragmentation, which neutralizes negative impacts on water quality due to the increasing degree of landscape fragmentation caused by human-made landscape invading the natural landscape. Landscape fragmentation and landscape complexity have major impacts on water quality, especially in areas with minor human disturbance. Water quality is very sensitive to landscape type in a watershed. The case study shows that the increasing percentages of farmland and construction land are the main reason for water quality deterioration, while the increasing percentage of woodland plays a positive role to improve water quality in Baiyangdian Watershed.

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