Front. Biol. China (2006) 4: 455–462
DOI 10.1007/s 11515-006-0062-3

RESEARCH ARTICLE

Landscape pattern and eco-hydrological characteristics at the upstream of Minjiang River, China

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Abstract Based on three scenes of Landsat 5 Thematic Mapper (TM) satellite images acquired on June 26, 1994, 12 land cover types were identified by the supervised classification techniques. The precipitation, runoff, and normalized difference vegetation index (NDVI) data of six catchments were accumulated from April to September in 1992, 1993, and 1995. A new eco-hydrological index, expressed by the difference between precipitation and runoff divided by the product of precipitation and NDVI, was used in this study to represent the eco-hydrological functions of different catchments. The results were: (1) The selected six catchments at the upstream of Minjiang River, China were different in landscape patterns in terms of landscape type and cover. There were higher contagion, lower edge density and diversity index in the Shouxi catchments and lower contagion, higher edge density and diversity index in the Zagunao catchments. (2) Eco-hydrological indexes had remarkable differences among different catchments. The highest eco-hydrological index was found in the Shouxi catchments, which indicated higher precipitation holding capacity of vegetation therein. While the lower eco-hydrological index was found in the Zagunao catchments, which indicated its lower precipitation holding capacity of vegetation. (3) High correlation was detected between the landscape indexes and eco-hydrological indexes. Eco-hydrological index was positively correlated with landscape contagion in contrast with the negative correlation with landscape diversity and edge density.

Keywords precipitation, runoff, landscape pattern, eco-hydrological index

Translated from *Acta Ecologica Sinica*, 2005, 25(4): 691−698 [译自: 生态学报, 2005, 25(4): 691−698]

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1 Introduction

The relationships among vegetation, precipitation, and runoff were important issues in eco-hydrological study (Azzali and Menenti, 2002; Bradford et al., 2003; Zhang, 2003). There are a lot of studies on eco-hydro1ogica1 function of forest at a small scale of a catchments or an ecosystem, while less effort were made at a large scale of a landscape or watershed (Liu et al., 2003). Different vegetation pattern and pattern changes had different hydrological function at the watershed. The study on the different vegetation pattern should be about the vegetation hydrological function at the watershed instead of simply forestry (Liu et al., 2001).

Landscape indices can express landscape pattern characteristics in which there exist three levels of types of patches and landscape that are simple quantitative indexes including landscape composition and space pattern (Wu, 2000). There are some arguments on the real landscapes meaning and worth. Analysis on landscape pattern mainly focuses on structure analyses. At the same time，there are few studies on the relationship between landscape indices and ecological functions, which indicates potential interaction of landscape patterns and landscape processes (Tischendorf, 2001; Li et al., 2004). Normalized difference vegetation index (NDVI) expresses synthetical characteristics of vegetation soil and moisture in a pels. NDVI, as an ecological function index, was applied to the study on the relationship between vegetation and environments (Kondo et al., 1998). The paper analyzed the relationship of landscape pattern and landscape eco-hydrological functions at a watershed based on landscape pattern rainfall runoff, and NDVI.

The accurate vegetation classification of the studied area is the foundation of vegetation pattern analysis. The commonly used vegetation classification system in China is mainly based on physiogram faura composition and habitat attributes (China vegetation map editor committee, 2001), which can reflect vegetation pattern comprehensively and precisely but is time consumable and expensive to make a vegetation survey extensively. Therefore, it was difficult to monitor the vegetation distribution timely at a large scale. The development of Remote Sensing (RS) and Geographic Information Systems (GIS) make it feasible to monitor land cover dynamics timely at a larger scale. Two classification systems, land use and land cover, are widely used in RS imagery processing. Land use classification system emphasizes on the social and economic attributes of land, while land cover classification system on natural attributes of land. In this study, we used land cover classification system rather than land use based classification system (Shi et al., 2000). The reasons are that spatial distribution and temporal dynamics of land cover play an important role in the biological, physical, and chemical cycling of the global system (Sellers et al., 1997), and that the land cover based category system can further divide forests into conifer, broad-leaved, and mixed forest, which makes it convenient to study ecological processes and function of vegetation. Considering that natural vegetation is the dominant landscape type in the Minjiang watershed and that land cover classification system emphasizes on the natural attributes rather than social–economic attributes of land, land cover based vegetation pattern analysis in the Minjiang watershed should be of more scientific significance (Fan and Zhang, 2002; Li et al., 2003).

The upstream of the Minjiang River (UMR) is located at the south-east edge of the Tibetan sub-Alpine, and the topography is characterized by deep valleys and steep slopes. The complicated landscape patterns resulted from land use and land cover change might create different eco-hydro1ogica1 functions at UMR. The study pursues two aims:

(1) To characterize vegetation and landscape patterns, to analyze dynamics of the precipitation, runoff, and NDVI in the different catchments at UMR;

(2) To explore the eco-hydrologica1 responses of the targeted catchments to the corresponding landscape pattern, which infers landscape pattern-function relationship.

2 Backgrounds and methods

2.1 Study area

Located in the transition zone from the Sichuan basin of hilly land to the northwest Sichuan plateau, UMR (30°45′–33°09′N; 102°35′–104°56′E) is a part of the eastern edge of the Qingzang Plateau region with high mountains and deep valleys. Many county-level administration regions (Songpan, Heishui, Li Xian, part of Wenchuan and Mao) are included in UMR. As one of the key branches of Changjiang River, UMR is 337 km in length and 22 900 km^2 in area. Vegetation and soil pattern in UMR show obvious vertical zone feature due to climatic change. Along the elevation gradient from bottom to top, sub tropic, temperate, sub-alpine, and alpine cold climate appear in succession, which lead to the vegetation vertical zone including temperate forest, dry shrub, sub alpine forest, sub alpine meadow, and sub alpine scrub. Vegetation in UMR belongs to the Hengduanshan Mountain region, China, pan-artic flora regional vegetation (Zhang et al., 2003).

2.2 Data source

Based on the three scenes of Landsat 5 Thematic Mapper (TM) satellite images, including path 130 rows 37–39, acquired on June 26, 1994, land cover types were identified with reference to the global positioning system (GPS) points, land use map (1:100 000) in 1990 and GIS coverage for vegetation (1:1 000 000) acquired from the Institute of Botany, Chinese Academy of Science, China. The precipitation/runoff and NDVI data of different catchments were accumulated from April to September in 1992, 1993, and 1995. Spatial surfaces for monthly precipitation were produced based on 51 gauged precipitation points by the thin plate smoothing spline techniques. Annual runoff data in six different watersheds were provided by the Sichuan Bureau of hydrology and water resources, while NDVI were freely acquired form USGS/EROS data center.

2.3 Methods

Watershed boundary of the study area was first created by 1:100 000 topography map and six hydrology station positions (Fig. 1). Six watershed boundaries named Zhenjangguan, Heishui upside, Heishui down, Zagunao upside, Zagunao down, and Shouxi were derived. Twelve land cover types were identified by the supervised classification techniques. Geometric correction, image processing, and edge enhancing of the TM image were conducted by ERDAS software 8.7. Combining with auxiliary interpretation data, GPS ground truth points, and the known land objects, the supervised classification was conducted to produce 12 land cover types based on IGBP standards (Loveland et al., 1999), which were conifer forest, broad-leaved forest, mixed forest, closed shrub, spare shrub-grass, grassland, alpine meadow, cultivated land, urban, snow, barren land, and water body. In addition, based on GPS points and the auxiliary interpretation data, fifty points for each land cover type were selected randomly to assess classification results and the precision was 83.1%.

Landscape pattern of six watersheds were analyzed at landscape type level. By means of Fragstats software, six landscape indices, such as patch density, total edge density, area-weighted fractal dimension shape indices, contagion and connectivity, were calculated (Wu, 2000). With the support of AUNSPLN (Ver. 4.1), monthly precipitation was spatially interpolated to obtain a precipitation map with 51 rain gauges in the Minjiang River and its adjacent regions, on which basis annual precipitation maps were derived from

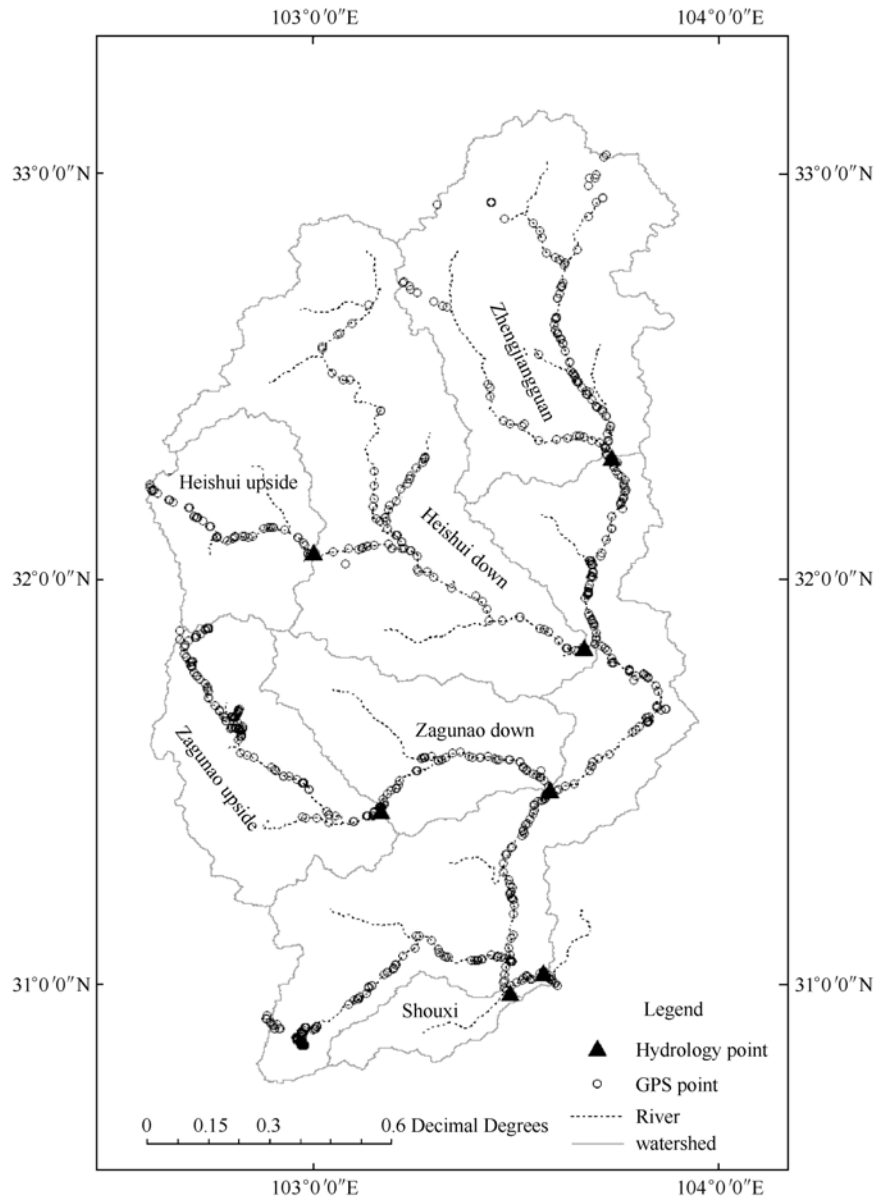


Fig. 1 Position of watershed and the distribution of GPS points

using ARCINFO software (Stoms et al., 2000). Monthly average precipitation map, NDVI map and watershed boundary were overlaid, and average precipitation and NDVI for each watershed were obtained by Arcview software. Runoff depth of different watersheds was calculated by runoff following the format:

$$R = \frac{T \cdot \overline{Q}}{1000F}$$

where $\overline{Q}$ was the average runoff (m^2/s), T is the time of runoff(s), F wais the area of watershed (km^2), R was the depth of runoff (mm).

Different watersheds had different hydrology functions. The difference when precipitation (P) is subtracted runoff (R) means the water-holding ability of different watersheds. On the other hand, the ratio of the difference ($P-R$) divided by precipitation (P) expressed the holding precipitation function of different watersheds. NDVI was an effective index to monitor the change of vegetation and environment. NDVI was not only closely correlated to vegetation growth but also to precipitation change in a long time scale (Kondo et al., 1998; Richard and Pocccard, 1998; Stoms et al., 2000). A new eco-hydrological index (holding water index), which was expressed by the difference of vegetation growth from April to September between precipitation and runoff divided by the product of precipitation and NDVI (see succeeding equation), was used in this study to represent the eco-hydrological functions of different catchments:

$$H = \frac{\sum_{i=4}^{9}(p_i - R_i)}{\sum_{i=4}^{9} p_i \cdot \sum_{i=4}^{9} \mathrm{NDVI}}$$

where P_i was average monthly precipitation (mm) and R_i was the depth of runoff (mm). Holding water index indicated the water holding ability of vegetation of different watershed in the growth season.

3 Results and analysis

3.1 Vegetation distribution of different catchments in UMR

In the Mingjiang valley, the vegetation distribution was composed of forest, shrub lands, grasslands, alpine meadow, and croplands (Table 1). Grassland and alpine meadow (52.06%) was the dominant vegetation in Zhengjiangguan catchments. Forests (conifer, broad leaf forest, Mixed forest) accounted for 89.41% in the Shouxi catchments. Shrub lands and grassland were widely distributed in the Heishui catchments and grassland had higher percentage in Heishui down. Forest and shrub lands were broadly distributed in the Zagunao catchments and forest had higher percentage in Zagunao down.

3.2 Vegetation pattern characteristics of different catchments in UMR

Vegetation pattern in different catchments significantly varied with the adopted landscape metrics (Table 2). Seven popular indices (patch density, edge density, fractal dimension, contagion index, Shannon's diversity index, evenness index, and dominance index) were used to express the vegetation pattern characteristics. Patch density and edge density are indicators of vegetation fragmentation. The bigger the patch density, the more patches in per unit area; and eventually the bigger the fragmentation. Edge density was related to boundary dissecting extent or fragmentation. Shouxi had the lowest relative patch density and edge density (13.53 and 83.63, respectively), which indicated that they were slightly fragmented. Whereas, Zaguonao had relative higher patch density and edge density (27.06 and 148.55, respectively), which meant that they were seriously fragmented.

Table 1 The different land cover in different catchments of UMR

Land cover	Zhenjiangguan		Heishui upside		Heishui down		Zagunao upside		Zagunao down		Shouxi	
	Area /km^2	%	Area /km^2	%	Area /km^2	%	Area /km^2	%	Area /km^2	%	Area /km^2	%
Conifer	580.79	13.00	119.82	7.00	728.78	13.34	299.95	12.23	407.09	19.06	118.89	19.79
Broad leaf	3.39	0.08	4.59	0.27	30.78	0.56	13.74	0.56	21.80	1.02	417.23	69.45
Mixed forest	278.34	6.23	121.00	7.07	430.33	7.88	237.65	9.69	259.18	12.13	1.00	0.17
Closed shrub lands	922.15	20.64	571.73	33.38	1540.4	28.19	793.19	32.33	605.18	28.33	18.35	3.05
Open shrub lands	32.64	0.73	97.76	5.71	288.40	5.28	197.96	8.07	154.61	7.24	7.27	1.21
Grasslands	1970.4	44.11	372.98	21.78	1735.4	31.76	271.28	11.06	240.59	11.26	0.61	0.10
Meadow grasslands	355.27	7.95	303.00	17.69	399.36	7.31	336.83	13.73	303.65	14.22	32.00	5.33
Farm	138.71	3.10	28.90	1.69	204.20	3.74	22.79	0.93	62.68	2.93	0.57	0.10
Urban and built-up	14.42	0.32	2.51	0.15	17.94	0.33	4.28	0.17	9.73	0.46	0.00	0.00
Snow and ice	25.73	0.58	40.21	2.35	15.25	0.28	86.60	3.53	19.48	0.91	0.11	0.02
Barren	138.82	3.11	44.22	2.58	56.21	1.03	142.15	5.79	44.45	2.08	3.98	0.66
Water bodies	6.80	0.15	5.93	0.35	16.46	0.30	46.92	1.19	7.46	0.35	0.73	0.12
Sum	4467.5	100	1712.6		5463.6	100	2453.3	100	2135.8	100	600.75	100

Table 2 Landscape pattern in different catchments of UMR

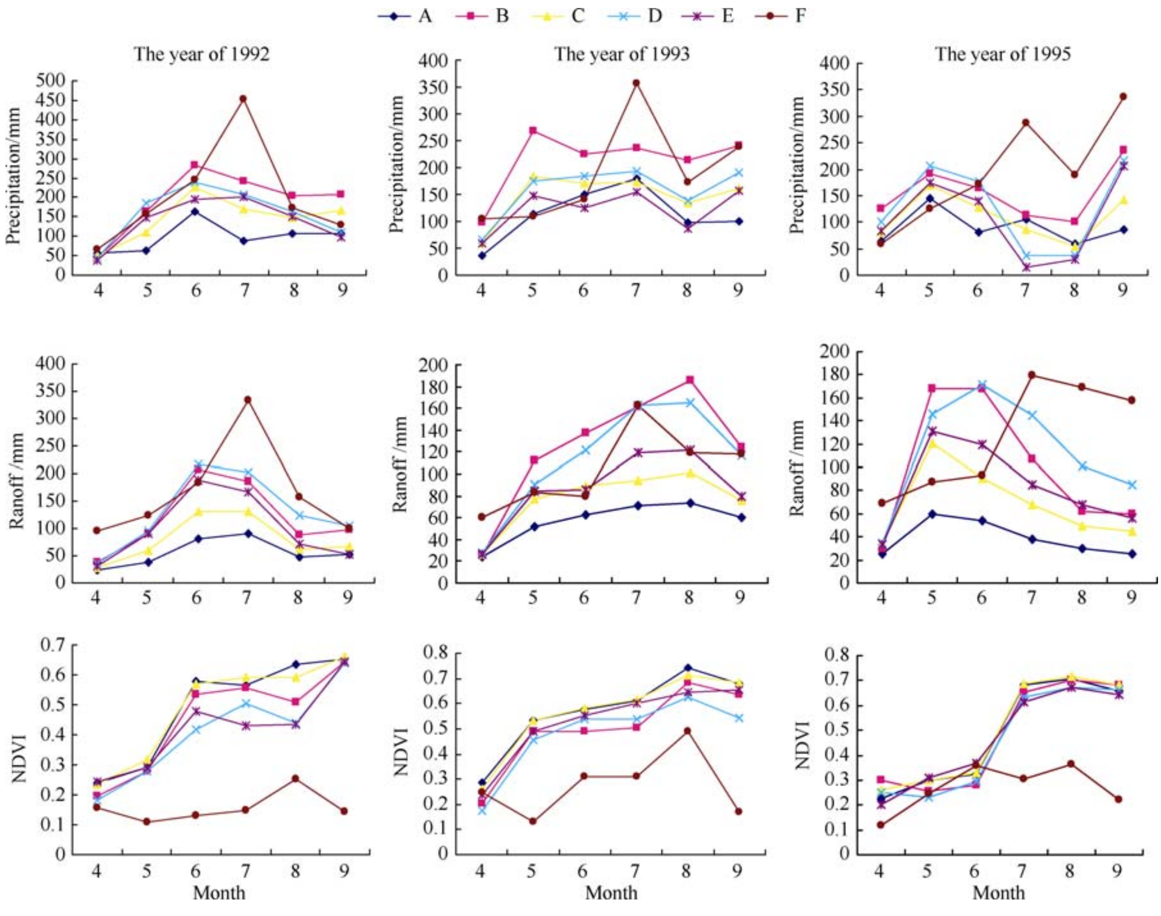
Watershed	Landscape index						
	Patch density	Edge density	Fractal index	Contagion	Diversity index	Evenness index	Dominance index
Zhenjiangguan	20.094	113.185	1.069	55.578	1.647	0.642	0.838
Heishui upside	21.506	126.035	1.070	49.883	1.861	0.726	0.624
Heishui down	20.509	114.425	1.068	51.904	1.811	0.706	0.674
Zagunao upside	26.399	145.652	1.070	44.701	2.034	0.793	0.451
Zagunao down	27.061	148.553	1.068	45.663	1.991	0.776	0.494
Shouxi	13.526	83.628	1.068	71.679	0.959	0.386	1.526

Fractal dimension reflected vegetation complexity and stability, which was positively related to disturbance intensity. The area-perimeters based fractal dimension (1.068–1.070) did not vary much with different landscape types. Contagion showed patch-patch neighborhood relationship and their spatial configuration (landscape connectivity). Contagion showed neighborhoods of different patch types, while connectivity indicated the extent of patches of the same type when they connected. Contagion index showed Shouxi and Zhengjiangguan catchments had higher landscape connectivity than other catchments. The most popular diversity index was Shannon's diversity index (SHDI), a popular measure of diversity in community ecology and based on information theory, was applied here to the landscapes. Evenness index measured the other aspect of landscape diversity (the distribution of area among patch types). The dominance index measured how extensively one or a few land-cover types occurred on the landscape. Higher values of dominance index indicated that the landscape was dominated by a few kinds of land-cover types, while lower values indicated a more equal distribution of land-cover types. Based on diversity, evenness, and dominance index, there were more complex landscape configuration, more equal patches distribution and without dominated land-cover types in Zaguonao catchments. On the other hand, there were dominating land-cover types (mix forest and grassland), unequal patches distribution, and simple landscape configuration in the Shouxi catchments and Zhengjiangguan catchments.

In sum, landscape fragmentation, connectivity, and diversity were remarkably different in the different catchments. Especially, Shouxi catchments had lower fragmentation, lower diversity, and higher connectivity.

3.3 Eco-hydrology characters of the different catchments in UMR

The precipitation, runoff, and NDVI data of the six catchments were accumulated from April to September in 1992, 1993, and 1995 (NDVI data was absent in 1994). The precipitation had different variation in every month and every year. In 1992, the precipitation had a peak value in July in the Shouxi catchments and others in June. The precipitation fluctuated more clearly in 1995 than that in 1992. There were peak values in May and June and low values in July and August. The precipitation was different in each catchment. Zhengjiangguan catchments had lower rainfall while there was higher rainfall in the Shouxi catchments. The runoff had the same characteristic with precipitation. However, it fluctuated more smoothly because



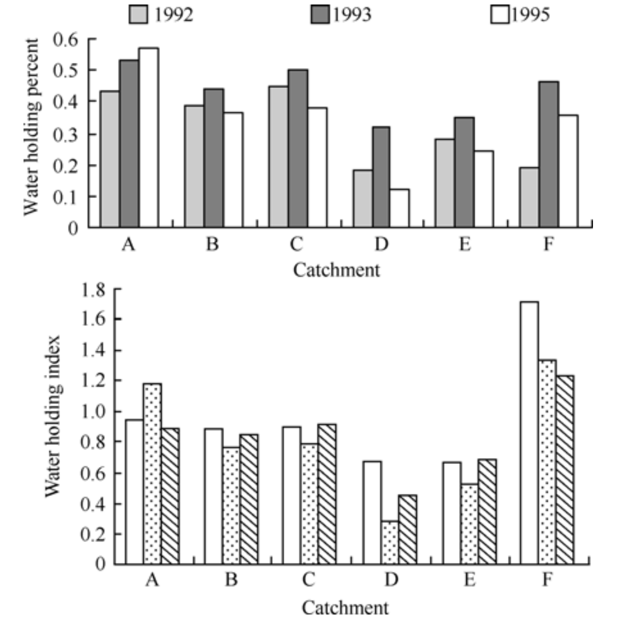
A: Zhenjiangguan; B: Heishui upside; C: Heishui down; D: Zagunao upside; E: Zagunao down; F: Shouxi

Fig. 2 The different precipitation, runoff and NDVI in the different catchments of UMR it lagged for rainfall. NDVI expressed vegetation growth and it had no relation with rainfall and runoff in a short time scale. So, NDVI did not fluctuate like rainfall and runoff. Meanwhile, vegetation growth kept ascending in the growth seasons and had a peak value in August. NDVI of the Shouxi catchments showed a more remarkable drop than that in the other catchments in September. Because a high percentage of broad leaf trees in Shouxi, defoliation reduced NDVI values in September. The change of NDVI reflected the growth of vegetation in the catchments.

Statistical analysis showed NDVI was not positively correlated with precipitation and runoff. Precipitation and runoff were more random and did not follow any rules in a short time scale. However, NDVI was correlated with vegetation growth and changed correspondingly to the variation of the season.

3.4 Relationship between the eco-hydrology characteristics and landscape patterns of the different catchments in UMR

Water-holding percentage was different in each watershed (Fig. 3). Zhenjiangguan catchments had higher percentages than other catchments and Zagunao upside catchments had lower percentages. Based on the water balance law, the difference between the precipitation and runoff expressed evapotranspiration of vegetation and water storage of soil. Water-holding percent is defined as the ratio of the different precipitation, which indirectly highlighted water remaining in each watershed. In this study, water holding index expressed vegetation eco-hydrology function,



A: Zhenjiangguan; B: Heishui upside; C: Heishui down; D: Zagunao upside; E: Zagunao down; F: Shouxi

Fig. 3 Water holding percentage and water holding index in the different years from April to September in the different catchments of UMR

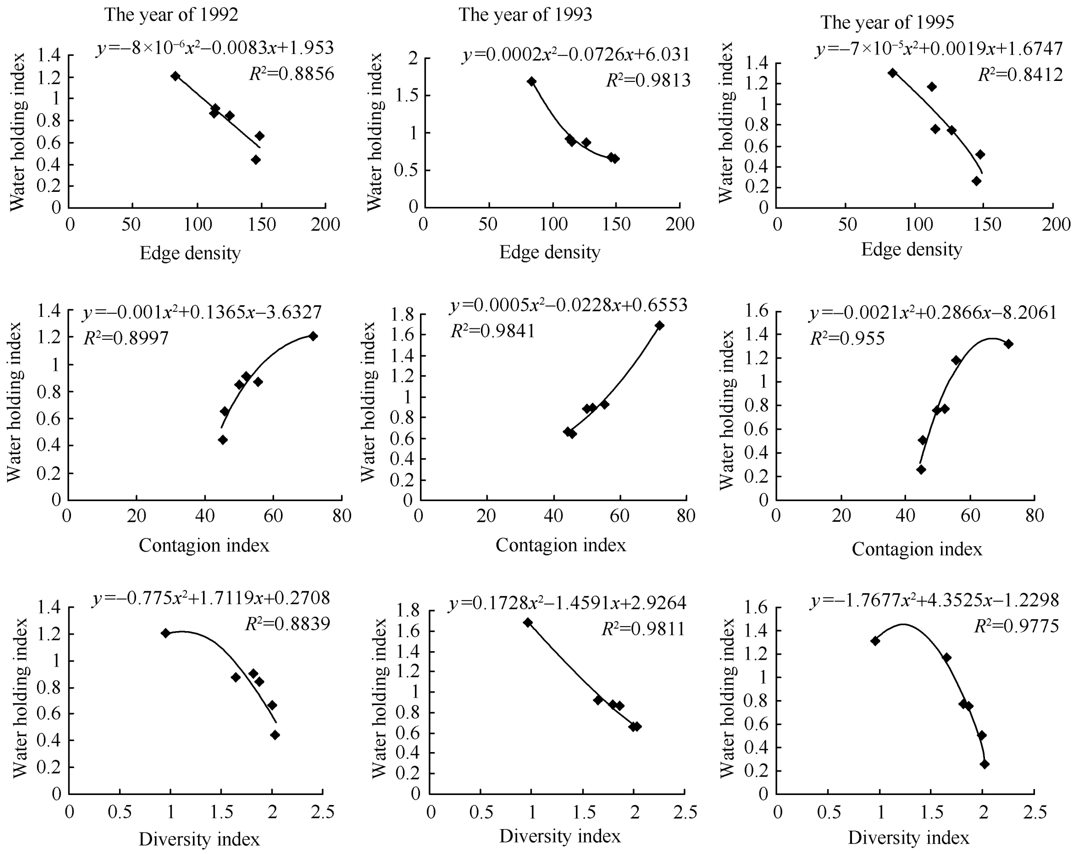


Fig. 4 Relationship between the water holding index and landscape index

which meant water-holding ability per unit NDVI. Water-holding index was also different in each watershed (Fig. 3). The Shouxi catchments had higher percentage than the other catchments and the Zagunao upside catchments had lower percentage. Because vegetation composition and landscape pattern were different in each of the catchments, there were more forest that had more water in the Shouxi catchments and these induced the different vegetation eco-hydrology function among catchments.

Correlation analysis between landscape index and water-holding index was carried out to study the relationship between landscape pattern and eco-hydrology function among six catchments. Edge density index, contagion index, and diversity index were selected to highlight the characteristics of landscape fragmentation, connectivity, and diversity. Results showed higher correlations were found between the landscape index and water holding index in six catchments by SPSS software (Fig. 4). Firstly, it was found that edge density index was negatively correlated with water holding index. Multiple correlation index (R^2) were 0.8856 ($P<0.05$), 0.9813 ($P<0.01$) and 0.8412 ($P<0.01$) in 1992, 1993, and 1995. Edge density index was higher and water holding index was lower in the Zaguonao upside catchments. In contrast, Edge density index was lower and water holding index was higher in the Shouxi catchments. Secondly, contagion index was positively correlated with water holding index and multiple correlation index (R^2) were 0.8997 ($P<0.05$), 0.9841 ($P<0.01$) and 0.955 ($P<0.01$) in 1992, 1993, and 1995. Different patch types were highly aggregated and they had higher water-holding index in the Shouxi catchments. Thirdly, diversity index was negatively correlated with water holding index and multiple correlation index (R^2) were 0.8839 ($P<0.05$), 0.9811 ($P<0.01$) and 0.9775 ($P<0.01$) in 1992, 1993, and 1995. For instance, vegetation types in which richness and landscape composition were complex in the Zaguonao upside catchments. However, vegetation had lower water-holding index.

4 Discussion

NDVI was not positively correlated with the precipitation and runoff. The conclusion was different from other researches (Richard and Pocccard, 1998; Sziliagyi, 2000; Zhang et al., 2003). Because this paper was carried out in short time scales, the precipitation and runoff change were remarkably different and they were more random and did not follow any rules in 1992, 1993, and 1995. However, NDVI was correlated with vegetation growth and showed clear characteristics with seasonal changes. NDVI did not fluctuate correspondingly with rainfall in a short time scale and maybe it was correlated to precipitation in a long time scale.

There were controversies on landscape index selection and index meanings (Tischendorf, 2001; Li et al., 2004). In this paper, landscape indices were selected based on the study by Li et al. (2004). These landscape indices were used in order to avoid redundancies on landscape indices. They were selected to highlight the characteristics of landscape fragmentation, connectivity, and diversity. On the other hand, four other indices were also closely correlated to water holding index. In this paper, three years of data were analyzed because of the difficulty in data matching and lack of enough data. Whether landscape indices were correlated to water holding index in a long time scale or in other watersheds need to be further studied.

The relationship between forests and runoff were studied in a long period of time. More researches were based on two comparison experiments in a small catchments scale (Zhang, 2003). Forest cover change brought eco-hydrology function change at a large scale. The researches on eco-hydrology functions at landscape scale are still absent. A complex mosaic, including forests, shrub lands, grasslands, and denuded lands, was more complicated especially at the Mingjiang Valley. For instance, Zaguonao catchments were a complex of mosaic forests, shrublands, and grasslands with the proportions of 22.48%, 32.33%, and 24.79%, respectively. It was not enough to study the eco-hydrology of forest vegetation. Landscape pattern and landscape composition also played an important role. Based on the research, more forest cover would increase the vegetation connectivity and decrease landscape fragmentation of catchments. Meanwhile, vegetation ability of holding precipitation would improve and runoff would cut down.

Acknowledgements This paper was supported by the National Key Projects for Basic Research of China (No. 2002CB111504), the Outstanding Young Scientist Program of National Natural Science Foundation of China (No. 30125036) and the National Natural Science Foundation of China (No. 30471383).

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