ELSEVIER

Available online at www.sciencedirect.com
SciVerse ScienceDirect

Procedia Environmental Sciences 10 (2011) 1698 – 1706

Procedia
Environmental Sciences

2011 3rd International Conference on Environmental Science and Information Application Technology (ESIAT 2011)

Landscape Pattern Analysis and Quality Evaluation in Beijing Hanshiqiao Wetland Nature Reserve

Zhang Weiwei[1], Wu Pengpeng[2], Li Hong[1, *], Sun Danfeng[2] , Zhou Liandi[1]

1Institute of System Comprehensive Development, Beijing Academy of Agriculture and Forest Science, Beijing 100097, China;
2College of Resources and Environmental Sciences, China Agricultural University, Beijing 100193, China
*W.G_Zhang@TOM.com， *corresponding author*

Abstract

Taking the Landsat TM and ASTER images of Hanshiqiao wetland nature reserve in 1988, 1996 and 2004 as data source, based on the landscape types from imagery classification, the reserve landscape pattern and its changes were analyzed, meanwhile, the landscape quality and its changes were evaluated and discussed. Several landscape pattern indices were analyzed, the results indicated that from 1988 to 2004, as the result of natural factors and human disturbances, the landscape structure has been changed, landscape fragmentation has become more and more serious, patches have been tended to regular shape, and connectivity of the natural wetland has been weakened. In addition, the landscape quality was evaluated based on the indicators of pressure, state and response. The results showed that during 1996-2004 periods, the landscape quality for Hanshiqiao wetland nature reserve has degraded obviously, which was mainly influenced by human activities breaking into wetland landscape. Effective wetland management and control is therefore needed to solve the issues of the wetland loss and degradation in Hanshiqiao wetland nature reserve.

Selection and/or peer-review under responsibility of Conference ESIAT2011 Organization Committee.

Keywords: Landscape pattern; Quality evaluation; Hanshiqiao wetland.

Introduction

Wetlands are integral part of the global ecosystem as they can prevent or reduce the severity of flood, feed ground water, and provide unique habitats for flora and fauna [1]. With the development of social economy, human activities (urbanization, deforestation, agriculture reclamation, ect.), as external stress factors, is accelerated the wetland landscape change such as area shrinking, landscape fragmentation and ecological function degradation [2]. This, in turn, influences the regional hydrological environment, climate change, biodiversity and so on [3]. Researches on regional wetland landscape change and quality evaluation come into focus in the study field of landscape ecology and wetland, which help to understand

Selection and/or peer-review under responsibility of Conference ESIAT2011 Organization Committee.
doi:10.1016/j.proenv.2011.09.267

the driving, mechanism and evolution resulting in wetland landscape change, and to offer scientific evidence to landscape planning, resource and ecology environment management as well as protection and restoration of wetland.

The concept of landscape ecology provides an integrated approach and challenge to study the wetland landscape patterns and changes [4]. Quantification of landscape patterns through various landscape indices can be used to describe the characteristics and the fragment of the landscape patterns [5]. Such information, together with other information characterizing wetland status can be applied to evaluate the landscape quality. In this paper, the landscape pattern and quality of the Hanshiqiao wetland was examined with the following objectives: to analyze the wetland landscape pattern's characteristics and its changes, and to quantitatively assess the wetland landscape quality together with the factors reflecting the wetland landscape pressure, wetland liveliness and ecological function.

Study area and methods

Study area

Hanshiqiao wetland nature reserve locates in the midland of Beijing Shunyi district, which belongs to alluvial plain of Chaobaihe River (Fig. 1). The area has a temperate continental monsoonal climate with an annual average temperature of 11.8ºC. Mean annual precipitation in the area is about 566 mm, about 60% of which is in July and August. Hanshiqiao wetland is natural lowland in the downstream of Caijiahe River. Caijiahe River flows across the wetland from the north to south, and then flows into Jianganhe River, a tributary river of Chaobaihe River. As the important reserve of water head site in Chaobaihe watershed, the landscape patterns and its changes and the eco-environment quality in Hanshiqiao wetland would be great of importance to the Chaobaihe and its downstream basin.

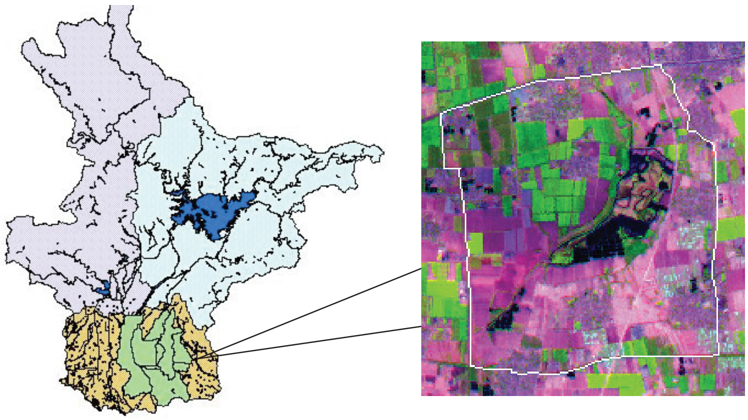

Fig.1 The area of research watershed

Data collection and landscape type classification

The Landsat TM images of the study area in May 1988 and May 1996, and the ASTER images in May 2004 formed the primary spectral data sources for mapping the wetland landscapes of the nature reserve. The satellite images were first geo-referenced with a digitized topographical map at a scale of 1:10000. According to the research purpose and status of the study area, the landscape system of Hanshiqiao wetland nature reserve was divided into three first level types that wetland landscape, agricultural land landscape and building zone landscape and seven second level landscape types (Table 2). Based on the geo-referenced images in three dates, using Erdas Imagine 9.2 software, the images were interpreted by supervised classification, and the landscape type data of Hanshiqiao wetland nature reserve in 1988, 1996 and 2004 were obtained.

Landscape pattern data extraction and analysis

Choices for the appropriate landscape pattern indices are dependent upon the scale of the analyses and the objectives of the study [5,6,7,8,9]. In this study, several indices were employed for the landscape pattern analysis (Table 2, 4, 5, 6). The details of the explanation, calculation and the range of each index can be found in FRAGSTATS METRICS. To assess the changes in landscape patterns over the years, the data have been analyzed by using ArcGIS9.2 and Fragstats3.3.

Landscape quality evaluation

Evaluating indices system. The evaluating indices should have the principles of systematicness, operability, acquirable and comparable. Based on that, we constructed the frame hierarchy of landscape quality evaluating indices (Table 1). The pressure indicator expressed the stress on the wetland landscape of human interference and natural factor, which can make early-warning for wetland eco-environment quality in future. The state indicator could synthetically reflect the wetland vitality and function level of current condition from three aspects of wetland abiotic factors, biological community and ecological function. The response indicator reflected the external performance of wetland landscape degradation under various disturbances. Several landscape pattern indices on the landscape level were took as the response indicator, because they could express the integrity of wetland ecological process and the degradation of wetland landscape structure from landscape level.

As for the study area, some acquirable indices were chose from indices system to participate in the landscape quality evaluation, which also were defined by calculation formula (Table 1). According to the historical literature records and the recollection of local people, the wetland status in 1980s was better than the after years. Hence, taking the wetland status in 1988 as a reference, this study mainly evaluated the landscape quality of the Hanshiqiao wetland nature reserve in 1996 and 2004.

Table1 Landscape evaluating indices system

Index			Definition of index
Pressure		*Wetland occupied	The wetland area occupied by other land/ The original or referenced wetland area
		*Human disturbance index	（Cultivated land + building zone）/ The total area of reserve
		*Wetland drainage intensity	Current open water area of wetland / Original or referenced open water area of wetland
State	Abiotic factors	*Water Function level	The wetland water area which water quality decreased to the Chinese surface drinking water standard limit below / Original or referenced water area of wetland
	Biological community	*Invasion index of exotic species	The amount of exotic invasive plant species / The amount of wetland native plant species
		Dominant species index	
		Waterfowl habitat index	
	Ecological function	*Primary productivity levels	Current primary productivity / Original or referenced primary productivity of wetland
		*Biological diversity index	Wetland habitats within the current species / Wetland original or referenced species

		Water storage	
		Non-point source pollution loading	
Response	Landscape pattern	*Landscape fragmentation degree index	(Current PD at the landscape level – PD before disturbance) / Current PD at the landscape level
		* Landscape shape index	PAFRAC at the landscape level / The theoretical maximums of PAFRAC
		*Patches aggregation degree index	CONTAG at the landscape level
		*Landscape diversity index	SHEI

Note：The index with asterisk (*) were used in this evaluation.

Single factor evaluation and comprehensive assessment method. The measurement value of each index did not linearly show every aspect and hierarchical state level of the wetland landscape quality, so it was not reasonable to take the indices and wetland landscape quality equivalence using simple proportion. Therefore, Logistic growth curve was used to carry on the single index evaluation.

When landscape quality was better with the single index value increased, the formula 1 was used. Otherwise, when landscape quality was worse with the single index value increased, the formula 2 was used [10].

$$P = \frac{1}{1+e^{(a-b\times R)}} \quad (1)$$

$$P = 1 - \frac{1}{1+e^{(a-b\times R)}} \quad (2)$$

Where, P was the evaluation value for each single index, which was a non-dimensional value. R was the measurement value of each single index. The value of *a* and *b* was 4.595and 9.19.

The comprehensive evalution index, which was the integration of all indices, was calculated using formula 3.

$$CEI = \sum_{i=1}^{n} W_i \times P_i \quad (3)$$

Where, *CEI* was the value of comprehensive evalution index, W_i was the weight for index *i*, P_i was the evaluation value for index *i*.

Results and Discussion

Landscape pattern and changes

The changes in the structure of landscape quantity. Table 2 showed the changes in the structure of landscape quantity. Over the 16 years, the areas of landscape changed. From 1988 to 2004, cultivated land was the largest landscape and increased gradually, covering nearly 50% of the nature reserve. The natural wetland, as the second largest landscape, shrank with a great rate. The forest and grass landscape also was the main type, which first decreased (1988-1996) and then increased (1996-2004). The artificial wetland area was small and increased quickly then decreased. The other landscape areas covered the small percent of the study area, but they were gradually increasing, especially building land.

Comparing the landscape transfer characteristics of 1988-1996 and 1996-2004 in the Hanshiqiao wetland nature reserve (Table 3), the conversion from wetland landscapes to other landscape was the main mode, but inverse little. The natural wetland was mainly converted to cultivated land, forest and grass land and artificial wetland from 1988 and 1996, while to cultivated land and forest and grass land from 1996 and 2004. The 60 percent of artificial wetland was transferred to cultivated land, building zone and natural wetland. The other conversion mainly occurred within the agricultural lands, thereinto the conversion from the forest and grass land to cultivated land was most serious.

Table 2 The characteristics of the landscape quantity structure in three years

Landscape types		CA/TA（hm^2）					PLAND（%）		
		1988	1996	2004	88-96 %	96-04 %	1988	1996	2004
Wetland	Natural wetland	536.94	325.08	205.29	-39.46	-36.85	22.70	13.76	8.68
	Artificial wetland	33.39	70.02	61.83	109.70	-11.70	1.41	2.96	2.61
Agricultural land	Forest and grass land	408.24	318.78	362.25	-21.91	13.64	17.26	13.49	15.31
	Cultivated land	1048.8	1134.8	1144.6	8.19	0.86	44.35	48.04	48.38
	Vegetable land	0.00	102.51	127.98		24.85	0.00	4.34	5.41
	dry land	112.59	123.21	156.60	9.43	27.10	4.76	5.22	6.62
Building zone		225.09	288.00	307.26	27.95	6.69	9.52	12.19	12.99
Landscape level		2365.1	2365.4	2365.8			100	100	100

Table 3 Transition matrix of landscape for 1988-1996 and 1996-2004 periods (%)

Perio-ds	Landscape types	Natural wetland	Artificial wetland	Forest and grass land	Cultivated land	Vegetable land	dry land	Buildi ng zone
1988 - 1996	Natural wetland	51.50	8.59	8.09	29.73	0.08	0.12	1.90
	Artificial wetland	19.84	36.14	1.09	19.29	0.82	0.00	22.83
	Forest and grass land	6.60	0.57	25.13	63.15	2.01	0.20	2.34
	Cultivated land	1.39	0.90	15.34	61.29	7.57	7.66	5.84
	Vegetable land	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	dry land	0.00	0.00	4.72	40.08	11.92	36.24	7.04
	Building zone	0.04	0.00	2.86	10.68	0.20	0.36	85.85
1996 - 2004	Natural wetland	58.23	2.76	9.17	27.94	0.81	0.92	0.17
	Artificial wetland	7.60	63.14	2.45	19.59	1.68	3.99	1.55
	Forest and grass land	0.59	0.25	18.61	71.91	3.09	3.40	2.15
	Cultivated land	0.74	0.39	21.58	60.82	4.92	7.15	4.40
	Vegetable land	0.00	0.00	3.19	24.51	43.19	24.87	4.25
	dry land	0.00	0.30	12.61	50.89	6.68	27.52	2.00

Landscape pattern changes. The patch density (PD) of landscape first decreased and then increased suggesting that the degree of landscape fragmentation has been reduced from 1988 to 1996 and then aggravated from 1996 to 2004 in Hanshiqiao wetland nature reserve (Table 4). At the class level, the fragmentation degree for natural wetland has been reduced according to smaller and smaller values for PD from 1988 to 1996, while that for artificial wetland has been aggravated due to the intensification of human activity, with greater and greater values for PD.

Largest patch index (LPI) is a simple measure of dominance. The values for LPI at the landscape level were quite low, suggested that the dominant type was inconspicuous in the landscape. Though it was cultivated land that had greater LPI indices than the other types from 1988 to 2004, the cultivated land was not the dominant species in the Hanshiqiao wetland nature reserve due to the low values of 27.71%, 23.64% and 34.74% for LPI (Table 4).

Table 4 The characteristics of the landscape pattern in three years-1

Landscape types		PD（Number per 100 hectares）			LPI（%）		
		1988	1996	2004	1988	1996	2004
Wetland	Natural wetland	2.33	1.65	1.10	16.98	11.87	8.21
	Artificial wetland	0.47	0.59	0.59	0.35	0.67	1.02
Agricultural land	Forest and grass land	2.45	2.16	3.13	4.74	2.90	4.41
	Cultivated land	2.11	1.78	2.03	27.71	23.64	34.74
	Vegetable land	0.00	1.10	0.97	0.00	0.88	1.16
	dry land	1.18	1.10	1.31	1.38	0.97	2.37
Building zone		0.51	0.51	0.47	1.68	2.72	2.43
Landscape level		9.05	8.89	9.59	27.71	23.64	34.74

Table 5 The characteristics of the landscape pattern in three years-2

Landscape types		PAFRAC			COHESION（%）		
		1988	1996	2004	1988	1996	2004
Wetland	Natural wetland	1.37	1.36	1.28	97.93	97.81	96.99
	Artificial wetland				85.94	88.07	88.84
Agricultural land	Forest and grass land	1.45	1.50	1.43	94.67	93.22	93.52
	Cultivated land	1.40	1.45	1.45	98.66	99.12	99.02
	Vegetable land				0.00	89.26	90.66
	dry land	1.38	1.38	1.40	90.34	90.27	92.54
Building zone					94.29	95.06	95.25
Landscape level		1.37	1.38	1.36	97.56	97.96	97.73

Table 6 The characteristics of the landscape pattern in three years-3

Level	CONTAG（%）			SHDI			SHEI		
	1988	1996	2004	1988	1996	2004	1988	1996	2004
Landscape level	45.28	45.75	46.56	1.43	1.55	1.55	0.80	0.79	0.80

Perimeter-area fractal dimension (PAFRAC) is measure of the complexity of the patch perimeter as compared to a perfect square of circle [11]. It is probably most useful if sample sizes are large (e.g., more than 20), thus PAFRAC indices only for the types which number of patches were more than 20 were calculated in this study. At the landscape level, the values of PAFRAC were 1.37 (1988), 1.38 (1996) and 1.36 (2004), which showed that human activities and natural factors had a certain impact on landscape resulting in the regular shapes. From 1988 to 2004, PAFRAC indices for natural wetland increased gradually, with the values of 1.37, 1.36 and 1.28, respectively, being lower than those of other types (Table 5). The results demonstrated that human activities and natural factors increasingly modified this landscape type with regular shapes.

Patch cohesion index (COHESION) at the class level measures the physical connectedness of the corresponding patch type, however, at the landscape level, the behavior of this metric has not yet been evaluated. Hence, the COHESION only at the class level were been analyzed in this paper. The COHESION of natural wetland and cultivated land were greater than the other types (Table 5), indicating the two landscape types were more physically connected compared to other types. From 1988 to 2004, the value of COHESION for natural wetland and artificial wetland reduced and increased respectively, indicating natural wetland has become less clumped in its distribution, while artificial wetland has become more aggregated. The decreased connectivity of the natural wetland has reduced the exchanges of species, materials and energy among the landscapes, which could accelerate the ecological function degradation of natural wetland.

The Contagion index (CONTAG) described the degree of aggregation for all patch types at the landscape level. The CONTAG indices were relatively low and increased little from 1988 to 2004 (Table 6), indicating that the Hanshiqiao wetland nature reserve was the dense pattern landscape having a variety of elements, and the patch types were disaggregated, which also suggested that the degree of landscape fragmentation was higher.

The Shannon's diversity index (SHDI) is used to measure the patch diversity for a given landscape structure. The SHDI indices were 1.43 (1988), 1.548(1996) and 1.549(2004) (Table 6). This result implied that the patch diversity in the nature reserve was relatively low in that only six or seven landscape types were used in the study. The SHDI index increased from 1988 to 2004 suggested that the richness of the landscape types was increasing and that the composition of the ecosystem was gradually complexity, related to the appearance of vegetable plot in 1996 and 2004. The increase of landscape type diversity in Hanshiqiao wetland nature reserve represented the changes of the wetland ecosystem, having an impact on the functions of the nature reserve.

The Shannon's evenness index (SHEI) measures the extent to which one of a few patch type dominate the landscape structure. Since 1.00 is the maximum value for SHEI, the values of 0.797 (1988), 0.794 (1996) and 0.796 (2004) were relatively high (Table 6), which suggested that a few types (e.g., cultivated land, natural wetland and forest and grass land) dominate the landscape in the Hanshiqiao wetland nature reserve. This was expected in that the three landscape types covered a majority of area ratios in the total nature reserve, respectively.

Driving factors of landscape changes. The driving factors of landscape changes include two aspects of natural and artificial driving factors. For the natural factors, climate-driven change in the hydrological conditions is the key factor causing the changes of the wetland landscape in the nature reserve. As we know, water is key element to maintain its spatial distribution and ecological function for the wetland. As the direct and important supply source, precipitation within the watershed is an essential factor for the wetland landscape change [2]. Over the last decade, the climate of North China generally become warm and dry, especially the Beijing plain in where Hanshiqiao wetland located. The precipitation and runoff volume reduced and became unstable, which may cause the area of natural wetland landscape to shrink, bring the conversion from wetland to terrestrial landscape such as cultivated land and forest and grass land, and eventually influence the whole landscape changes.

Some researches have considered that socio-economics and policies are the major driving forces for land use/cover change [1,12], and human disturbances accelerate the changes of landscape patterns in the wetland [3,5]. In this study for Hanshiqiao wetland nature reserve, we agree with the above-mentioned findings. For the sake of pursuing economic benefit, wetland area has been transformed to agricultural land since the late 1980s. During the 1988-2004 periods, agricultural development and wetland reclamation was promoted as affected by government subsidies for agriculture. Hence, wetland loss in the Hanshiqiao wetland nature reserve can not only be attributed to natural climate and precipitation conditions, but also to direct human agricultural activities. Ultimately, as the result of natural factors and human disturbances, the landscape structure has been changed, landscape fragmentation has become more and more serious, patches have been tended to regular shape, and connectivity of the natural wetland has been weakened. All of them have an important influence on landscape quality.

Landscape quality evaluation and analysis. The natural status of Hanshiqiao wetland has been changed obviously under the interference and pressure from human and natural factors. The percentage of total landscape area comprised by the human activity increased from 69.8% in 1996 to 73.4% in 2004, resulting in the reduction of wetland landscape. The wetland landscape areas in 1996 and 2004 have respectively decreased by 30.8% and 53%, as compared to that in 1988. In the wetland landscape, the open water areas in 1996 and 2004 have respectively decreased by 33% and 45%, as compared to that in 1988 (Table 7). The decreased area of wetland and its open water, the increased area of landscape comprised by the human activity since 1988, indicated that the hydrology in the Hanshiqiao wetland nature reserve gradually decreased and that the human activity processes accelerate, which would result in negative effects on the wetland environmental conditions and the ecological functions of the nature reserve.

Table 7 Landscape quality evaluation of the study area

Index		Weight	1996			2004		
			R	P	CEI	R	P	CEI
Pressure	Wetland occupied	0.136	0.308	0.854	0.556	0.531	0.429	0.533
	Human disturbance index	0.115	0.698	0.140		0.734	0.104	
	Wetland drainage intensity	0.081	0.670	0.827		0.552	0.617	
State	Water Function level	0.125	0.400	0.715		0.143	0.964	
	Invasion index of exotic species	0.089	0.310	0.852		0.219	0.930	
	Primary productivity levels	0.063	0.651	0.800		0.480	0.453	
	Biological diversity index	0.089	0.358	0.213		0.580	0.676	
Response	Landscape fragmentation degree index	0.078	0.995	0.010		0.996	0.010	
	Landscape shape index	0.073	0.381	0.250		0.362	0.220	
	Patches aggregation degree index	0.073	0.457	0.404		0.466	0.422	
	Landscape diversity index	0.078	0.795	0.938		0.796	0.938	

Through the investigation of Hanshiqiao wetland nature reserve, the sewage from Yang town around the wetland had not been treated well all along. In addition, with the intensification of human activities, industrial and agricultural effluent and domestic sewage drained into the rivers lying to the upstream of wetland, resulting in water quality pollution and function of water body degradation. The water quality for 40 and 14 percent of water areas in 1996 and 2004 had been decreased to the Chinese surface drinking water standard limit below, due to the influence of sewage discharge (Table 7). The scarcity of water resources has made a few xerophytes and mesophytes grow and reproduce in large quantities, which caused the invasion of alien species. There were respectively 31 and 21.9 percent of invasive species in 1996 and 2004, changing the composition and structure of native plant community in Hanshiqiao wetland nature reserve. The biological diversity and primary productivity levels of the wetland have varied heavily, as a result of water resources scarcity, sewage discharge and alien species invasion. The amount of hydrophytes in 1996 has obviously reduced by 64.2% compared with that in 1988, and then increased by 2004.

The landscape pattern indices showed the landscape structure of Hanshiqiao wetland nature reserve in 1996 and 2004 has been subject to destroy at a certain extent. The integrality of landscape has been destroyed, with the more and more intense degree of fragmentation. The patch shapes in landscape tended to be regular under the human activities disturbance. The landscape diversity in the nature reserve was relatively low, and there was not obvious dominant landscape type, but a few types (e.g., cultivated land, natural wetland and forest and grass land) that dominated the landscape.

It is observed that the landscape quality for Hanshiqiao wetland nature reserve has degraded obviously. The degradation of the reserve landscape in 1996 and 2004 was mainly influenced by human activities breaking into wetland landscape. In the course of landscape degradation, biological diversity and primary productivity levels of the wetland varied evidently and further aggravated the degradation of the reserve landscape. The integrity and patch shape diversity of the reserve landscape lost seriously, being indicative of high degree of fragmentation and human disturbance. The landscape quality of the study area has declined since 1988, and the quality in 2004 was worse than that in 1996. Combining with the single evaluating index, water environment and biological diversity of wetland in 2004 was preferable to that in

1996, however the disturbance and pressure to wetland from human activities and natural factors in 2004 was greater than that in 1996, which made the landscape quality in 2004 be lower than that in 1996.

Conclusions

In this study, the landscape pattern and its changes in Hanshiqiao wetland nature reserve were firstly analysis using a few landscape pattern indices. And then the landscape quality was evaluated based on the indicators of pressure, state and response. From 1988 to 2004, as the result of natural factors and human disturbances, the landscape structure has been changed, landscape fragmentation has become more and more serious, patches have been tended to regular shape, and connectivity of the natural wetland has been weakened. During 1996-2004 periods, the landscape quality for Hanshiqiao wetland nature reserve has degraded obviously, which was mainly influenced by human activities breaking into wetland landscape. Hence, the management of Hanshiqiao wetland nature reserve must focus on the impacts of human activities on wetland landscape quality in future, so as to achieve effective conservation of the wetland. We believe that the study results can provide foundations for target protection in Hanshiqiao wetland nature reserve.

References

[1] S. Q. Zhang, X. D. Na, B. Kong, Z. M. Wang and H. X. Jiang: Wetland Vol. 29 (2009), p. 302-313
[2] L. Yu, M. L. Min, S. H. Wang and Y. W. Zhao: Procedia Envrionmental Sciences Vol. 2 (2010), p. 1255-1264
[3] D. R. Xiao, B. Tian, K. Tian and Y. Yang: Acta Ecologica Sinica Vol. 30 (2010), p. 27-32
[4] E. J. Gustafson: Ecosystems Vol. 1 (1998), p. 143-156
[5] D. Q. Gu, Y. Z. Zhang, J. Fun and X. L. Zhang: Environ Monit Assess Vol. 124 (2007), p. 361-370
[6] R. L. Graham: Landscape Ecology Vol. 1 (1998), p. 153-162
[7] G. K. Zhang, W. Deng, X. G. Lv, K. S. Song, H. D. Li and H. Y. Zhang: Journal of Natural Resources Vol. 22 (2007), p. 204-210
[8] H. Y. Liu, Z. F. Li: Acta Ecologica Sinica Vol. 28 (2008), p. 9104-9105
[9] J. M. Tang, L. Wang and S. W. Zhang: International of Journal of Remote Sensing Vol. 26 (2005), p. 2259-2280
[10] B. Hu, C. Y. Huang and L. M. Yuan: Water Resources & Hydropower of Northeast China Vol. 22 (2004), p. 46-48
[11] L. R. Iverson: Landscape Ecology Vol. 2 (1988), p. 45-61
[12] X. T. Liu: Scientia Geographica Sinica Vol. 20 (2000), p. 14-19