Landscape change under the surface water allocation in Ejina oasis, northwestern China

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***Abstract*—Exploring the relationships, which are strictly influenced by water resource conditions, between oasis landscape pattern and hydro-ecological process in arid area, becomes the hot topic and difficult challenge in arid landscape ecology and one of the most important issues in arid areas ecological protection and reconstruction. The Heihe river basin, as the ^{2}nd longest inland river basin, is located in the northwest arid regions of China. During the past few decades before 2001, increasing local population and social-economic development in the upper reaches of Heihe river basin have consumed surface water resource enormously. Consequently, a lot of serious ecological and environmental problems were occurred in the Ejina natural oasis, which is in lower reaches of Heihe river basin. Especially, the Ejina natural oasis was in face of disappearing in the world with no surface water provided from the upper reaches for continuous several years around 2001. From the beginning of 2001, appropriate amount of surface water has been allotted to Ejina oasis from the upper reaches by the Chinese government every year to prevent the rigorously ecological crisis continuing and retrieve the environment restoring. Based on field investigation, remote sensing, and GIS technologies, Ejina natural oasis landscape spatial pattern and its dynamic change in different temporal and spatial scale before and after surface water allotted (1987~2001~2009) were analyzed in this paper. Three Landsat TM/ETM+ images in 1987, 2001 and 2009 were collected to analysis the characteristics of oasis landscape spatial pattern dynamics over the past few decades. The main results show that: before and after water resource allocated, the area of oasis classes decreased during 1987-2001 and increased during 2001-2009, but simultaneously the desert classes changed to an inverse direction; the landscape diversity and ecological stability for Ejina oasis after water allocated was much higher than before water allocated.**

***Key words*—Landscape spatial pattern change, APACK, surface water allotting, Ejina natural oasis, Northwestern China.**

I. INTRODUCTION

With the development of sciences and technologies and the rapid increasing world populations, the degree of human activities are getting more and more serious, and the influences of mankind has become the key factor to drive modern landscape change in the earth [1,2]. Integrating the aspects of human activity into the research fields of landscape ecology also became one of the most important challenges and issues in modern earth sciences. As an interdisciplinary subject of geography, ecology, biology and related environmental sciences subjects, landscape ecology is the science of studying landscape pattern (i.e. spatial structure), landscape process (i.e. ecological function) and the dynamics of landscape pattern and process over time driving by physical elements and human activities. As the hot topics on interpreting the relationship between landscape pattern and ecological process in landscape ecology, studies on the characteristics of landscape dynamic changes could well reveal the mechanism of landscape evolvement, evaluate ecosystem service function and simulate the trend of ecological process [3,4,5]. In arid regions on the earth, water resource is the elemental driving force for all ecological processes. Meanwhile, water is also one of the most active factors in arid environments. Owing extremely uneven distributing of water resource in spatial scale, two kinds of quite different landscapes of oasis and desert could exist synchronously in arid environments. As the special synthesis of man and nature, oasis landscape is not only the main area of human activities, but also the most ecologically sensitive area, especially influenced by water factor. Therefore, the dynamics of oasis landscape are obviously affected by the local conditions of water resources. This study will focus on the analysis of landscape spatial pattern changes for Ejina natural oasis landscape under the policy of the surface water allocation in Heihe river basin. The Heihe river is the ^{2}nd longest arid inland river in China. During the past few decades, especially before 2000, increasing local populations and social-economic development resulted in sharp reduce of water resource. Consequently, a lot of serious ecological and environmental problems occurred throughout the watershed. Especially for the Ejina natural oasis, which is in lower

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reaches of Heihe river basin, and it was dying because of no water resource distributed from the upper reaches for several years [6]. To prevent the ecological crisis from continuing and retrieve the environment recovering, Bureau of Heihe River Basin Water Resource Management was established directly by Chinese Central Government in 1999. Since 2000, appropriate amount of water resource have been allocated to Ejina natural oasis from the upper reaches of Heihe river basin by the bureau. Till 2009, almost ten years has passed, what has happened for Ejina natural oasis? How did human activities influence the ecological effects in Heihe river basin? And what's the relationship between natural oasis landscape pattern dynamics and hydro-ecological processes in human-dominated watershed? All above questions could be answered by investigating this area. This area could definitely provide an ideal site to facilitate interdisciplinary research on the relationship between water and water-related natural systems and human society. Therefore, this study will aim at the landscape spatial pattern changes which have been extensively modified by human activities, interpret the relationship between human activity (that is program of surface water allocation launched by government) and the ecological response of the natural environment (that is natural oasis landscape dynamics).

II. MATERIALS AND METHODS

A. Study area

The Heihe river is rising from the southern Qilian Mountains, Tibet plateau and is flowing northward to Juyan lakes in Ejina oasis (Fig. 1). The overall length and watershed area of Heihe river is about 821 kilometer and 143,000 square kilometer respectively. Before 2001, especially during 1980s~2000, owing to the uneven surface water distribution over the entire watershed, the whole Heihe river basin was facing increasing environmental problems and ecological degradation. Especially for the area of the lower reaches of Heihe river basin, the Ejina natural oasis is at the edge of disappearing. The study area of Ejina oasis is a natural oasis with about 30,000 square kilometer located in lower reaches of Heihe river basin. It has a typical continental climate with about 40 millimeter annual precipitation and about 3,500 millimeter annual evaporation. So it is a typical arid region with high evaporation and little rainfall. There are two major branches of Heihe river in Ejina oasis, one is the West Ejina river flowing to West Juyan Lake and the other is the East Ejina river flowing to East Juyan Lake.

Facing degradation and desertification of Ejina oasis, the Chinese government had carried out a strategy of surface water allocation in the Heihe river watershed. An official department of Heihe Watershed Management Bureau was established in 1999. The Bureau launched the first water allocation in 2000, the core Ejina oasis was irrigated for the first time in 2001. And the East Juyan Lake and West Juyan Lake were firstly filled in 2002 and 2003 respectively. Since August, 2004, till present, East Juyan Lake has gained and maintained about 40 square kilometer water area. Before and after the surface water was allocated from the upper reaches of Heihe river, the local ecological conditions, especially for the water resources, were quiet different.

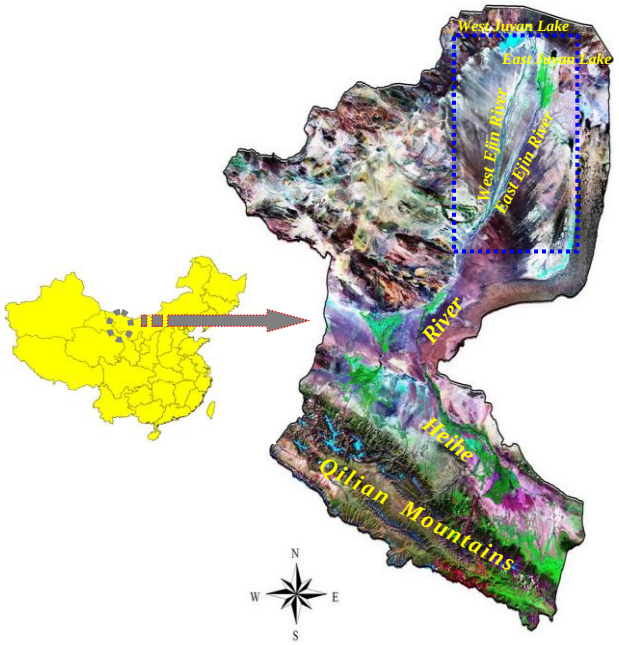

Fig. 1. The location of the Ejina oasis in lower reaches of Heihe river basin, northwestern China

B. Data source

Three Landsat TM/ETM+ images in 1987, 2001 and 2009 were collected to analyze the characteristics of oasis landscape spatial pattern dynamics over the past few decades. In addition, the statistical annual runoff data (1987~2009) prepared by Water Conservation Bureau of Ejina Banner were collected to explore the relationship between the oasis landscape pattern change and annual surface water allocation quantity.

C. Landscape pattern analysis

Based on remote sensing images, three landscape types and ten landscape classes were classified as the dominate land use type: oasis landscape (dominated by riparian forest, riparian shrub, water, saline and urban area), desert landscape (dominated by desert shrub, desert grassland, Gobi and sand) and others (i.e. hills and dried lake) (Table I). The spatial pattern analysis was performed based on the landscape maps in 1987, 2001 and 2009 using the APACK software package. APACK is a program that can calculate statistics of landscape spatial pattern from raster data. Basic area measures and some selected landscape indices such as Average area per patch (AA), Contagion (CO), Dominance (DO), Edge density (ED), Shannon-Weaver diversity (SWD) and Shannon-Weaver Evenness (SWE) were calculated, and landscape spatial pattern changes from 1987 to 2009 were analyzed.

III. RESULTS AND DISCUSSION

A. Statistical analysis of landscape types

Table II is the statistics about the area and the percentage of different landscape class in Ejina oasis during past 20 years.

TABLE I. LANDSCAPE CLASSIFICATION SYSTEM IN EJIN OASIS

Landscape types	Landscape classes	Description
Oasis	Riparian forest	Mixed forest of *Populus euphratica* Olive, *Elaeagnus angustifolia* L. and *Tamarix ramosissima* Ledeb, 60% ≦ canopy density ≦ 80%
	Riparian shrub	*Tamarix ramosissima* Ledeb, *Sophora alopecuroides* L., *Haloxylon ammodendron* (C.A.Mey.) *Bunge and Phragmites australis* (Cav.) Trin. ex Steud, 50% ≦ vegetation coverage ≦ 80%
	Water	River, lake, reservoir, wetland and hydraulic structure
	Saline	Saline and alkaline land
	Urban	Ejina county and artificial hills
Desert	Desert shrub	*Tamarix ramosissima* Ledeb, *Phragmites australis* (Cav.) Trin. ex Steud, *Achnatherum splendens* (Trin.) Nevski, *Glycyrrhiza glabra* L., *Sophora alopecuroides* L.,30% ≦ vegetation coverage ≦ 50%
	Desert grassland	*Lycium ruthenicum* Murr., *Nitraria tangutorum* Bobr., *Alhagi pseudalhagi* Desv., *Karelinia caspica* (Pall.) Less., *Reaumuria soongorica* (Pall.) Maxim., vegetation coverage ≦ 30%
	Gobi	Gobi desert
	Sand	Moving sand dunes
Others	Hill	Low erosion hills
	Dried lake	Dried West Juyan Lake

TABLE II. STATISTICS OF EJINA OASIS LANDSCAPE DURING 1987~2009 (HM^2)

Class	Landscape Type	1987a		2001a		2009a	
		Area	*%*	*Area*	*%*	*Area*	*%*
1	Riparian forest	35418.42	2.11	19473.48	1.16	36671.76	2.19
2	Riparian shrub	42938.19	2.56	57978.99	3.46	55188.72	3.29
3	Desert shrub	73758.24	4.40	92848.50	5.54	76019.31	4.54
4	Desert grassland	216189.45	12.90	184730.76	11.03	220225.77	13.14
5	Water	2661.84	0.16	194.85	0.01	15616.71	0.93
6	Saline	1272.60	0.08	225.36	0.01	191.43	0.01
7	Urban	522.00	0.03	698.67	0.04	1354.23	0.08
8	Gobi	1255743.09	74.95	1265445.45	75.53	1217945.34	72.69
9	Sand	11442.06	0.68	18391.50	1.10	17253.63	1.03
10	Hill	3852.63	0.23	3852.63	0.23	3852.63	0.23
11	Dried lake	31649.40	1.89	31649.40	1.89	31173.39	1.86

From this table we can see: the landscape of Gobi is the first primary class in this area covering over 70% of the total area; and the desert vegetation (i.e. Desert shrub and Desert grassland) is the second dominate class covering about 17% of the entire landscape; the area of the oasis vegetation (i.e. Riparian forest and Riparian shrub) is only taking up about 5% of the total area; the water area is very small and only covering less than 1% of the total area.

Table III shows the statistics of changing area and ratio for Ejina oasis landscape from 1987 to 2009. Two stages were made for comparison. The first one is from 1987-2001 and the second one is from 2001-2009. For the first stage, one of the obvious change is from the oasis vegetation types, the riparian forest reduced by about 45%, but the riparian shrub expanded by about 35%; And for the desert vegetation types, the area of desert shrub increased by about 26% but the area of desert grassland shrank by about 15%; The water area reduced by more than 90%. But for the class of Gobi and sand, though they had only 0.77% and 60.74% increasing ratio respectively, their absolute areas increased about 9,700 and 6,900 square hectometer accordingly, these changes were huge for Ejina oasis during 1987 to 2001.

TABLE III. CHANGING AREA AND RATIO OF EJINA OASIS DURING 1987~2009 (HM^2)

Class	Landscape Type	1987-2001		2001-2009	
		Change	*%*	*Change*	*%*
1	Riparian forest	-15944.94	-45.02	17198.28	88.32
2	Riparian shrub	15040.80	35.03	-2790.27	-4.81
3	Desert shrub	19090.26	25.88	-16829.19	-18.13
4	Desert grassland	-31458.69	-14.55	35495.01	19.21
5	Water	-2466.99	-92.68	15421.86	7914.73
6	Saline	-1047.24	-82.29	-33.93	-15.06
7	Urban	176.67	33.84	655.56	93.83
8	Gobi	9702.36	0.77	-47500.11	-3.75
9	Sand	6949.44	60.74	-1137.87	-6.19
10	Hill	0.00	0.00	0.00	0.00
11	Dried lake	0.00	0.00	-476.01	-1.50

And for the second stage from 2001 to 2009, it seems that all the changes were in an opposite direction compared with the changes in the first stage. First, oasis vegetation of riparian forest expanded almost 90% from 2001 to 2009. Second, water area increased by nearly 8,000 times. For the other oasis vegetation of riparian shrub, it had a little reduction by about 5%. And for the desert vegetation, desert shrub reduced by about 18% and desert grassland increased by about 19%. But, similarly, for the classes of Gobi and sand, though they only had about 4% and 6% decrease respectively, the absolute decrease area were about 47,500 and 1,138 square hectometer respectively. It was also great changes for Ejina oasis during this period.

Figure 2 is a histogram of landscape change ratio for Ejina oasis during 1987 to 2009 (Fig. 2). From this figure, we can obviously find that, except for the classes of decreasing saline and increasing urban, all other classes were changing in opposite direction during 1987-2001 and 2001-2009.

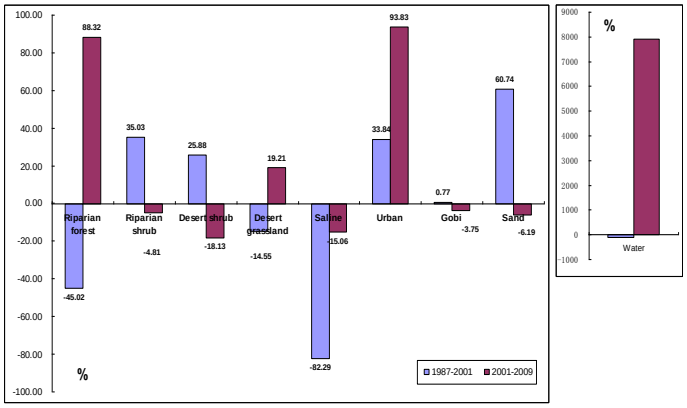

Fig. 2. Landscape change ratio of Ejina oasis during 1987~2009

B. Landscape spatial pattern change

Figure 3 shows how Ejina natural oasis landscape pattern was changing on spatial scale (Fig. 3). Among these changes, two of them should be noticed, one is the change from all other classes to oasis vegetation (riparian forest and riparian

shrub), and the other is the change from all other classes to Gobi and sand, because these landscape classes are the key elements and sensitive indicators of ecological conditions for Ejina oasis. So we can make some general judgment from these two periods of landscape changes: Firstly, landscape changes from other classes to Gobi during 1987 to 2001 was greater than changes to oasis vegetation. Secondly, landscape changes from other classes to oasis vegetation during 2001 to 2009 was greater than changes to Gobi. Thirdly, changes to sand during 2001~2009 was obviously less than that during 1987~2001. Finally, landscape change spread all over the Ejina oasis, but mainly along the riparian zones of West and East Ejina river.

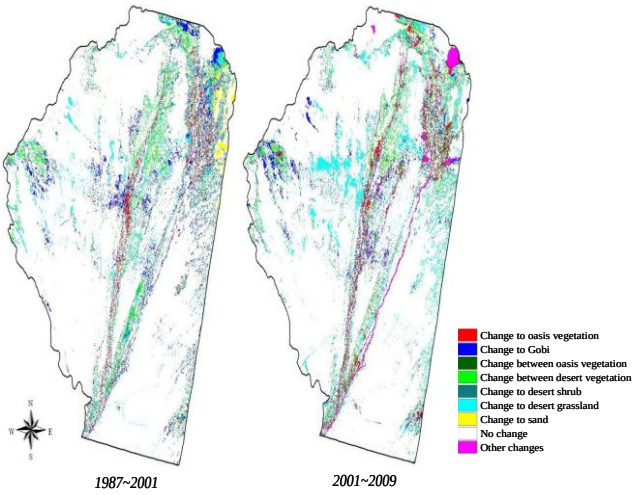

Fig. 3. Landscape spatial pattern change for Ejina oasis during 1987~2009

C. *Landscape metrics analysis*

Table IV and Fig. 4 show the statistics of landscape indices changes. From this table and figure we can see that all the landscape indices were also changing in an opposite direction for two different periods. Among these changes, the indices of Average patch area, Contagion and Dominance were increasing during 1987~2001 but were decreasing during 2001 to 2009. And the opposite changes could be observed from Edge density, Shannon-Weaver diversity and Shannon-Weaver Evenness. All these changes show that before and after 2001, the landscape diversity and the landscape stability for Ejina oasis were quite different. Before 2001, the landscape diversity and landscape ecological stability became degraded, but after 2001, they got improved.

D. *General analysis of relationship between landscape change and surface water allocation*

Generally, all landscape changes have two kinds of driving forces, nature elements and human activities. Based on our previous research results, the hydrological factors are the most key driving force for the Ejina oasis landscape change, including surface water resource and ground water table [8]. The ground water table is mostly influenced by the surface runoff water. And the surface runoff water resource is finally influenced by human activities, such as increasing population, social and economic development, and water resource management. According to the statistical annual runoff data (1987~2009), the water resource management especially for the surface water allocation is the crucial factor for Ejina oasis landscape change during the past 20 years.

TABLE IV. STATISTICS OF LANDSCAPE INDICES CHANGE FOR EJINA OAISIS DURING 1987~2009

Landscape index	1987	2001	2009	1987~2001	%	2001~2009	%
AA (hm2)	53.76	61.37	55.22	7.61	14.16	-6.15	-10.02
CO	2.77	2.83	2.71	0.05	1.88	-0.12	-4.25
DO	1.46	1.47	1.38	0.01	0.48	-0.09	-6.33
ED (m/hm2)	41.38	35.58	37.59	-5.80	-14.01	2.01	5.64
SWD	0.94	0.93	1.02	-0.01	-0.64	0.09	10.02
SWE	0.40	0.39	0.43	0.01	-0.77	0.04	10.08

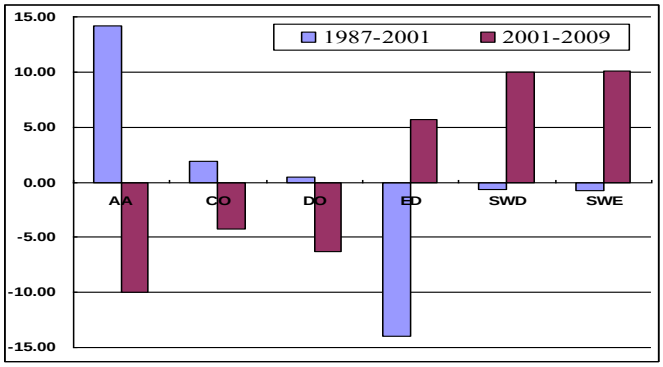

Fig. 4. Landscape indices change for Ejina oasis during 1987~2009

IV. CONCLUSIONS

Before and after water allocated in Ejina oasis, the classes of oasis landscape type decreased during 1987-2001 and increased during 2001-2009, but at the same time, the classes of desert landscape type changed to an inverse direction. Moreover, landscape diversity and ecological stability for Ejina oasis after water allocated was much higher than before water allocated. And finally, Ejina oasis landscape spatial pattern changes were generally related to surface runoff water allocation in the whole Heihe river basin.

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