# Relationship between Landscape Pattern and Environmental Indices in Ebinur Lake Wetland National Natural Reserve

Fei Zhang [1,2,*], Yushanjiang Ayinuer [1,2], Hsiang-te Kung [3] and Ping Shi [4]
[1] *Key Laboratory of Smart City and Environmental Modeling of Higher Education Institute, College of Resources and Environment Sciences, Xinjiang University, Urumqi, 830046, PR China;*
[2] *Key Laboratory of Oasis Ecology, Xinjiang University, Urumqi 830046, China;*
[3] *Department of Earth Sciences, The University of Memphis, Memphis, TN 38152, USA;*
[4] *School of Foreign Languages, Jining Medical University, Jining, Shandong 272067 Urumqi, 830046, PR China.*
*Email: zhangfei3s@163.com*

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Abstract: The study of spatial-temporal changes of the landscape is important in revealing the mechanisms and laws of landscape succession, and to search the relationship between human activities and the environment. This paper presents a research of land use/cover change (LUCC) from 1998 to 2006 and from 2006 to 2014; it also simulates and forecasts land use/cover types of Ebinur Lake Wetland National Nature Reserve (ELWNNR) by using the CA-Markov model. The purposes of this study were determined to the characteristics of landscape patterns in different altitudes. Results showed that: (1) LUCC was “three plus three minus” in ELWNNR. The bared lakebed and desert obviously expanded; land use/cover dynamic degree was 9.5% from 1998 to 2006 for bared lakebed; and 34.1% from 2006 to 2014 for desert. The transform area of land use/cover type would smaller from 2022 to 2030; (2) There were significant correlations between environment quality indices and the landscape indicators; the composition and spatial structure of the landscape affected the spatial distribution of environment quality indices; (3) The $R^2$ of multiple linear stepwise regression model of environmental quality indices and landscape indices in the study area was 0.7, which suggested significant correlation between these two indices. It proved that it is feasible to estimate the environmental quality indices of the study area by landscape indices. The quantified effects of landscape structure variations on this index helped to better understand the effects of land use on it and they are important for policy making and land use planning.

## 1 INTRODUCTION

Land use/cover change (LUCC) is one of the most important consequences of global change; the impact of LUCC on the watershed’s water cycle has always been an essential part in the study about global change and hydrology (Xia et al., 2006). Establishing a simulating model is an effective and reliable measure to describe, explain and reappearance of LUCC in the past, as well as forecast LUCC in the future to formulate countermeasures (Han et al., 2011; Veldkamp et al., 2001). The study of LUCC is of great significance for understanding the stability of environment and the sustainable utilization of water and land resources (Wang et al., 2015; Chen et al., 2015; Tsai et al., 2015). Reasonable land use/cover-landscape changes can produce favorable environmental effects, while excessive reclamation of ecosystems can lead to a series of environmental problems, such as desertification, vegetation degradation, reduction of water area and so on (Brun et al., 2015; Hansen et al., 2007; Ye et al., 2015). Therefore, the environmental effects, which are caused by land use/cover-landscape changes, have become an important topic in this field. Furthermore, the application of statistics (Moghadam et al., 2015; Zhao et al., 2015), GIS and RS technology (Chen et al., 2015), landscape ecology models (Wang et al.,



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2009; Zeng., 2014; Paroissien., 2015) provide the practical and theoretical framework.

The landscape pattern indices are objectively used to evaluate the environment, because it is easy to obtain and almost undisturbed by human factors. Currently, the academic circles are mainly focus on the changes in land use/cover-landscape patterns and the effects of natural factors on environment (Camacho et al., 2015; Vadrevu et al., 2015; Conrad et al., 2015; Bing et al., 2015; Terra., 2014); meanwhile there is less research on the correlation analysis, which is based on landscape pattern and environment quality. The ELWNNR is the most representative wetland desert in China. Affected by geography, climate and human activities, this ecosystem is fragile; water and soil resources are scarce, and the unreasonable distribution of landscape patterns and human interference have caused a series of negative environmental effect on ecology (Lu et al., 2014). Consequently, research based on the regional landscape pattern will be crucial for monitoring the indicators and implementing managing strategies for sustainable development. Therefore, the purpose of the study is to: i) analyze the current and future changes in land use/cover in ELWNNR; ii) quantitatively study the relationship between land use/cover patterns and the environment to provide theoretical support for conservation purposes and sustainable development of agriculture in the region.

## 2 MATERIAL AND METHODS

### 2.1 Study Area

The study area has a total surface of about 2670.85 $km^2$ (Figure 1). This region represents the lowest depression and water-salt collection center in the western Junggar basin. It is in the hinterland of the Eurasian continent and integrates wetlands and deserts, representing one of the key areas in that basin (Xie et al., 2010). The average annual temperature of the ELWNNR is 8°C, characterized by low rainfall, and greater evaporation than precipitation. With the typical temperate and arid continental climate, the ELWNNR is a typical ecologically fragile zone. The lake area is rich in habitat types and is one of the few concentrated areas of desert species in the inland desert (Wang et al., 2015). At present, the environment of the region has been seriously damaged and the balance of ecosystems has been seriously affected.

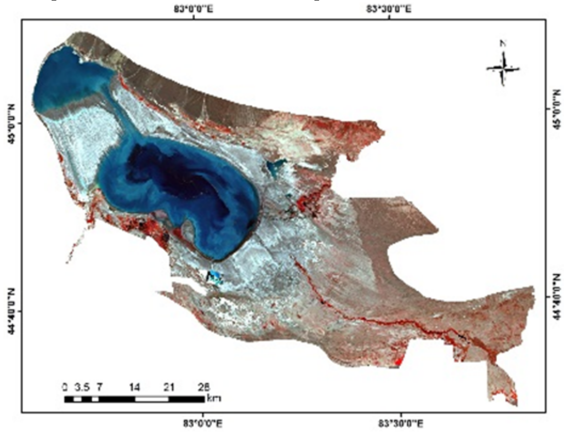


Figure 1: Location map of ELWNNR.

### 2.2 Data Acquisition and Methods

Landsat 7 TM and Landsat OLI images from the ELWNNR were used in this study, that were acquired in September 1998, July 2006 and September 2014 (data from the U.S. Geological Survey, URL: http://earthexplorer.usgs.gov/website). The track number of the satellite images is 146/29. Images were pre-processed, performing geometric correction, radiation correction and image enhancement under the support of ENVI 5.1 software. Then, remote sensing images were clipped to center in the study area. Supervised classification and visual interpretation were used to classify each of the land use/cover types, that were divided into six categories: water body, forest grassland, dry lake bed, saline alkali land, desert, and others. Then, that classification was verified by combining a topographic map, a DEM and Google Earth. The land use/cover classification map was developed for the three years 1998, 2006 and 2014 and the overall accuracy of the three remote sensing images were above 89%.

### 2.3 The Dynamic Simulation of Land Use/Cover Types

In this study, the classified images from 1998, 2006 and 2014 were selected in this study as input into the model to calculate matrices of conversion areas and conversion probabilities. A transition areas matrix expresses the total area (in cells) expected to be changed in the next time. Also, a transition probability matrix determines the probability of a pixel in a land use class to change into another class during that time. The prediction of future land use changes can be calculated based on conditional probability formula by using the following equation:

$$S(t+1) = P_{ij} \times S(t)$$

$$P_{ij} = \begin{bmatrix} P11 & P12 & P1n \\ P21 & P22 & P2n \\ P31 & P32 & P3n \end{bmatrix}$$

and $$\left(0 \le P_{ij} < 1 \; and \; \sum_{j=1}^{N} P_{ij} = 1, j = 1,2,3,\ldots,n\right) \tag{1}$$

Where S(t) is the state of the system at time t; S(t + 1) is the state of the system at time (t + 1); Pij is the matrix of transition probability in a state (Al-sharif and Pradhan, 2013). The output of CA–Markov algorithm is the predicted land cover map for mentioned future year.

## 2.4 Dynamic Degree of LUCC

The rate of LUCC is an important index to reflect the intensity of regional land use change. A dynamic degree indicates the stability of the land use type and is represented in percentage. Land use dynamic models are usually divided into both single and comprehensive degree. The single land use dynamic can be formulated as follows:

$$k = \frac{A_{t2} - A_{t1}}{A_{t1}} \times \frac{1}{t_2 - t_1} \times 100\% \tag{2}$$

Where k represents the dynamic degree of a certain land use and % is the unit, At1 and At2 represent the area of various land use types at the beginning of the and the end of the study; t1and t2 are the initial and final stages of the change.

## 2.5 The Selection and Calculation of Landscape Indices in ELWNNR

Landscape indices are widely used in the analysis of many landscape patterns. It can provide a lot of information as well as it can reflect the characteristics of its composition and spatial configuration (Wu, 2007). In this research, Frag stats 4.2 were used to compute landscape pattern indices in the study area, PLAND (Landscape types' percentage), PD (patch fragmentation), mean patch size (MPS), Largest Patch Index (LPI), ED (edge density), area - weighted mean patch highest-resolution dimension (AWMPFD), COHESION (plaque connection degree), AI (aggregation degree of plaques) were selected on the class level to assist with the exploration of the landscape characteristics in this study; meanwhile, number of patches (NP), ED (edge density), Landscape Shape Index, (LSI), Largest Patch Index (LPI), COHESION (plaque connection degree), AI (aggregation degree of plaques) and SHDI (Shannon diversity Index), CONTAG (spreading Index) were selected on the landscape level to obtain the differences among the landscape metrics in the different land use/cover classifications for the entire ELWNNR. The concepts, calculation methods and ecological significance of these indices were summarized by Wu (2007).

## 2.6 Environment Quality Indices

The overall status of a regional environmental quality is comprehensively the total area environment quality indices Et (Liu et al., 2003); it is obtained by considering the area ratio of each land use/cover type and the weighted sum of relative ecosystem service values; its expression is:

$$E_t = \sum_{i=1}^{n} A_i C_i / TA \tag{3}$$

Where Ai is the land use/cover type area of Class i in the study period T; Ci is the service value of the relative ecosystem of land use/cover type of Class i; n is the number of land use/cover types in the study area; TA is the total area of the region.

# 3 RESULTS AND ANALYSIS

## 3.1 Spatio-Temporal Change of Land Use/Cover Pattern in Ebinur Lake

The most significant change can be observed in the water area. According to the statistical annual book from 1998 to 2006, the precipitation has increased (Figure 2). In 2004, the government implemented the increase water project of the Ebinur Lake, which eventually led to the increase of the water body from 1998 to 2006 (Bai, 2010). However, the extension of the area occupied by water, showed a decreased from 2006 to 2014. This fact was partly due to the massive reclamation of land and the rapid increase of the cultivated land. Meanwhile, Bortala, Jinghe and Kuitun rivers were used for irrigation and resulted in the decrease of water in Ebinur Lake and increase of bared lake bed. Furthermore, the desert is expanding as a consequence.

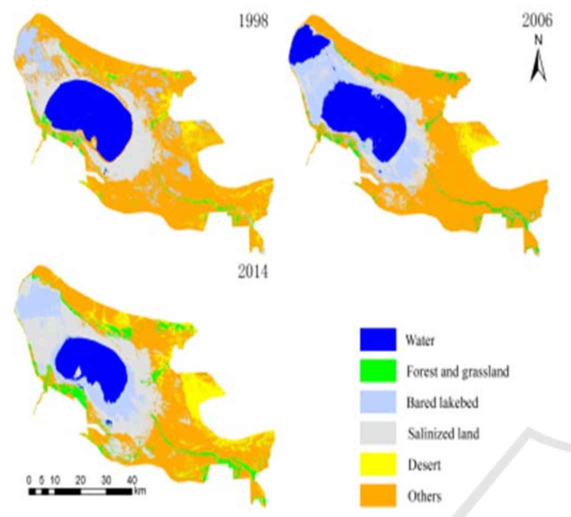


Figure 2: Land use/cover of ELWNNR in 1998, 2006 and 2014.

From 1998 to 2006, the area of salinized land, desert and others has decreased mainly by the land use/cover passive attitudes (-5.8% and -4.0%, respectively) (Figure 3). The government carried out a water increase project of Ebinur Lake in 2004 and the area of water body increased and the area of dry lake bed decreased as a consequence. Compared with 2004, the area of bared lakebed increased and the area of water body decreased in 2006. However, compared with 1998, the area of water body and dry lake bed expanded to a certain extent, because of artificial water increase project. Therefore, forest, grassland, bared bed, and water body showed an expansion. Until 2014, the bared lakebed, water body, and other land species showed a decreasing trend. However, forest, grassland, salinized land, and desert are constantly expanding, in which the dynamic degree of desert is 34.1%. From 2014 to 2022, the bared lakebed, water body, and other areas show a trend to decrease in extension. The bared lakebed had a drastic decrease (-5.2%). The area of forest, grassland, salinized land, and desert increased instead; meanwhile the dynamic degree of forest and grassland was 5.2%. In 2030, these changes were expected to be limited (Figure 3).

The overall LUCC in the ELWNNR showed to distinct trends (Figure 3): the increase of forest, grassland, saline land and desert, and the decrease of dry lake bed, water body, and other lands. After the establishment of the ELWNNR, human activities have been relatively reduced and natural grasslands have been restored; it is mainly attributed to the national implementation of projects, such as returning farmland to forests, returning pasture to grassland, and recognizing the importance of the environment. However, the water area of Ebinur Lake continues to shrink, because of an increase in cultivated land and a large amount of water resources used for irrigation; consequently, resulting the desertification and salinization of bare lake-bed. Meanwhile, the strong wind in Alashankou has accelerated the expansion of saline land. Therefore, it is urgent to manage the saline land in the western part of ELWNNR.

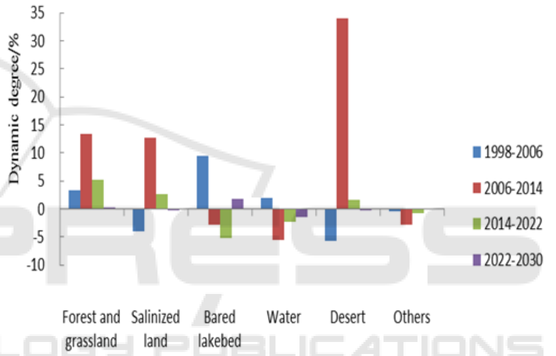


Figure 3: Dynamic degree of land use/cover types of the ELWNNR from1998 to 2030.

## 3.2 The Correlation Analysis between Landscape Indices and Environmental Quality Indices

The correlation between landscape indices and environmental quality indices based on class level and landscape level were shown in Figure 4 and Table 1. From the landscape level, the environment quality indices of forest-grassland are positively correlated with landscape type percentage, patch fragmentation, maximum patch indices, boundary density, area weighted average patch fractal dimension, and patch connectivity. However, there was a significant and negative correlation between environment quality indices of forest-grassland with the average patch area, indicating that the effect of forest and grass land on the environment was higher than other land use/cover types.

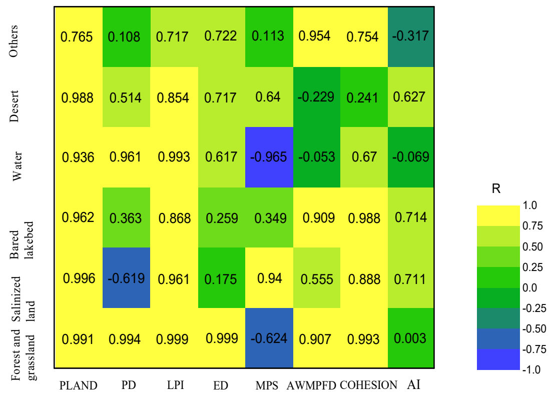


Figure 4: Pearson correlation coefficients between environment quality indices and landscape pattern indices on class level.

The environmental quality indices of the salinized land were positively correlated with the percentage of landscape type, the maximum patch indices, the average patch area and the patch connectivity; and it was negatively correlated with the patch fragmentation. The environmental quality indices of the bared lakebed have a positive correlation with the percentage of landscape types, the maximum patch indices, the area-weighted average plaque fractal dimension, and the patch connectivity. The large amount of cultivated land area rapidly increased due to the human demand for crops and the use of water from Boltara, Jinghe and Kuitun Rivers. As a result, the lake surface shrank, and the area of bared lakebed increased. Therefore, it should pay attention to the protection of forest grassland and the prevention and control of salinized land.

At the landscape level, the environmental quality indices were negatively correlated with the number of patches, boundary density, landscape shape index and Shannon diversity index. There is a significant and high positive correlation among patch index, patch connectivity, plaque aggregation and spread index.

Since the regional environmental quality indices were influenced by the spatial pattern of landscape pattern indices, multivariate correlation analysis (Table 2) was performed based on single factor analysis. Key landscape indices were pointed among numerous landscape indices that affect the environmental quality indices. The $R^2$ value of multiple linear stepwise regression model of environmental quality indices and landscape indices ($p<0.05$) was greater than 0.7, indicating that the value of landscape indices and the value of environmental quality indices in the study area were significantly correlated. Landscape indices can be then used to estimate the environmental quality indices of the study area.

Table 1: Pearson correlation coefficients between environment quality indices and landscape pattern indices on class level.

| Environment indices | Landscape pattern indices | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | NP | LPI | ED | LSI | CONTAG | COHESION | SHDI | AI |
| （E） | -0.96 | 0.78 | -0.911 | -0.911 | 0.91 | 0.667 | -0.792 | 0.909 |

Table 2: Relationship between landscape indices and environment quality indices.

| Environment Indices | Landscape pattern indices | Regression equation | $R^2$ | RMSE | Sig. |
|---|---|---|---|---|---|
| $E_{\text{Forest and grassland}}$ | PLAND, LPI | $E_{\text{Forest and grassland}}$ =-0.913PLAND+2.146LPI-4.323 | 0.888 | 0.0027 | 0.032 |
| $E_{\text{Salinized land}}$ | PLAND, PD | $E_{\text{Salinized land}}$ =2.344PLAND-0.374PD-13.557 | 0.797 | 0.0676 | 0.035 |
| $E_{\text{Bared lakebed}}$ | LPI, AI | $E_{\text{Bared lakebed}}$ =0.037LPI+0.128AI-1.082 | 0.76 | 0.3 | 0.01 |
| $E_{\text{Water}}$ | LPI, AI | $E_{\text{Water}}$ =2.02LPI-56.687AI+252.918 | 0.83 | 0.053 | 0.04 |
| $E_{\text{Desert}}$ | PLAND, ED | $E_{\text{Desert}}$ =2.234PLAND+0.007ED-13.181 | 0.78 | 0.08 | 0.001 |
| $E_{\text{Others}}$ | COHESION, AI | $E_{\text{Others}}$ =257.226COHESION-2.774AI-1176.746 | 0.793 | 0.0767 | 0.028 |

# 4 DISCUSSION AND CONCLUSIONS

The CA-Markov model has always been a common model for predicting LUCC. The CA model has a strong capability in simulating the spatial-temporal characteristics of complex systems. That is why it has been extensively used as a spatially dynamic model in LULC research (Adhikari and Southworth 2012). This model can be understood as a dynamic and relatively simple spatial system, in which the state of each cell of the matrix depends on the previous state of the cells enclosed inside a defined neighbourhood, in accordance with a set of transition rules. Therefore, the CA model is capable enough to predict the spatial distribution of the LULC pattern and its dynamics because it adds the spatial properties of LULC. Because human factors are the most important reason for LUCC, the simulated results of CA-Markov model are highly uncertain. Therefore, we will try to explore new methods and make the results practical in future studies. The CA-Markov model effectively combined the advantages of the Markov model and the CA model, improving the simulation accuracy. This research built a CA model spatial filter of 5 pixels×5 pixels, but it did not compare spatial filters of different sizes. Therefore, future research could be focused on the effect of spatial resolution.

This study can reflect the LUCC of the ELWNNR in 1998-2014 and is closely related to the landscape pattern and environment situation, which can be used to provide reference for environment protection in the ELWNNR. Results show that regional landscape pattern and environment change are key component to develop policies in the ELWNNR and control environmental pollution. The environment should improve CONTAG, SHDI and CONNECT indices at the landscape and class levels, but affect CONNECT, NP, PD, and ED indices. The entire study is based on remote sensing interpretation and requires accurate data that should be further improved in subsequent studies.

Based on Landsat TM, in 1998 and 2006, and Landsat OLI remote sensing images, from 2014, this research studies current and future changes of land use/cover-landscape patterns and establishes a quantitative expression of landscape pattern and environmental quality indices. We can conclude that: (1) The LUCC in the ELWNNR shows a trend with “three increases and three decreases” in the descriptor indices used in this study. From 1998 to 2006, the expansion of dry lake bed was notorious. In 2014, the desert continued to expand, with a dynamic degree of 34.1%. From 2014 to 2022, the dry lake bed, water bodies, and other areas have a trend to decrease. By 2030, the land use/cover type conversion area will be smaller. (2) The landscape indices and the environmental quality indices in the study area are significantly correlated, proving that the composition of the landscape and the spatial structure of the land use have a great impact on the regional environmental quality and the landscape indices can be used to estimate the environmental quality.

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