

LANDSCAPE PATTERN CHANGE AND ASSOCIATED ENVIRONMENTAL IMPLICATIONS IN HAIHE RIVER BASIN, CHINA

Yusheng Shi^{a, b}, Jiying Xiao^c, Yanjun Shen^{a*}

^aCenter for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences. 286. Huaizhong Rd., Shijiazhuang 050021, China; - yjshen@sjziam.ac.cn Tel: +86-311-8582-5464

^bGraduate School of Chinese Academy of Sciences. Beijing, 100049, China

^cSchool of Environmental Science and Engineering, Hebei University of Science and Technology. 70. East Yuhua Rd., Shijiazhuang 050018, China.

Commission IV, WG IV/4

KEY WORDS: Landscape Change, Remote Sensing and GIS, Landscape Metrics, Haihe River Basin, Environmental Effects

ABSTRACT:

Quantifying landscape pattern and its change is essential for the monitoring and assessment of ecological consequences of land use change and human interference. The changing characteristics of landscape structure in the Haihe River Basin (HRB), China, during 1990 to 2000 were detected by using satellite remote sensing based land use data. Key landscape indices were selected to characterize the landscape patterns. The results showed that from 1990 to 2000, the landscape within the study area has undertaken a complicated transformation in landscape structure and composition. A notable decrease in cropland mainly due to conversion to built-up land. Spatial distribution of different patches became more separated and the patch types became more disaggregated. Additionally, we found that both Shannon's diversity index and Shannon's evenness index increased during the periods, manifesting the landscapes in the study area became more fragmented and heterogeneous under intensive exploitation and reconstruction of landscape by human beings. The environmental effects of landscape change were also discussed.

1. INTRODUCTION

Landscape structure and composition develops continuously in space and time. These developments are attributable to the complex interaction between natural environment and human activities, resulting in the change of the stability of individual elements in the landscape system and the spatial structure of landscape (Xiao et al., 1990). Investigating landscape structure and its change is a prerequisite to the study of ecosystem functions and processes, sustainable resources management, and effective land use planning (Matsushita, et al., 2006). The research on regional landscape change has been one of the hot topics in this field, which attracts general interests of the geographers and ecologists worldwide (Forman and Godron, 1986; Dong, et al., 2007). Landscape and environmental changes are interrelated and interact on each other. Studying on landscape change and associated environment takes quantitative analysis of landscape change as preexisting. The methods of quantitative analysis of landscape pattern structure and its change based on landscape metrics have been widely adopted by landscape ecology researchers (Herold, et al., 2003; Olsen, 2007).

Haihe River Basin (HRB), which suffered intense human interference and decreasingly deteriorating environment, has been an important commodity grain base and ecology conservation base in north China and holds an increasingly important social and economic position. A severe lack of water resources, integrated with tremendous landscape change jeopardized the ecosystem stabilization, structure and function. Accordingly, the study on landscape changes in this area can improve our understanding of the interrelationships among landscape structure, natural environment, and human activities, and help to define the magnitude and direction of landscape changes caused by human interfering activities, and thus

provide an important scientific basis for the sustainable development of the region (Lu, et al., 2003). The main issue is the interpretation of the magnitude and pattern of change and its effects on the regional ecological processes and patterns. There have been some academic researches on landscape change in provinces Beijing, Tianjin, and Hebei according to administrative boundary, almost all of which focused on the urbanization process (e.g. Xiao, et al., 2006), but few reports on landscape change analysis at the basin scale based on remote sensing (RS) and geographical information system (GIS).

Therefore, our objectives of the present study are: (1) to characterize the land use change in the Haihe River Basin, China; (2) to quantify the changes in landscape pattern in HRB; and (3) to evaluate the effects of landscape pattern changes on environment.

2. MATERIALS AND METHODS

2.1 Study Area

Haihe River Basin is located between 35°~43°N and 112°~120°E. It neighbors the Inner Mongolia Plateau in the north, and Yellow River is the borderline in the south. It faces the Bohai Sea to the east and borders Shanxi Plateau in the west (Figure 1). It has a typical warm to temperate, semi-humid and semiarid, continental monsoon climate, and well-defined seasons. The Haihe River Basin, with an area of 318,000 square kilometers, involves primarily Hebei Province and two huge municipalities, Beijing and Tianjin. Other four Provinces, such as Inner Mongol, Shanxi, Henan, and Shandong, partially fall into the Basin. Haihe River Basin is one of the most developed regions in China. About 10 percent of the China's population, 15 percent of nation's industrial and 10 percent of the total

agricultural productions are produced in this region, which produces some 30 percent of wheat and 20 percent of corn of the nation. In recent years, HRB is facing to severe shortage of water resources. Water shortage has become a bottleneck to sustainable development of the economy and grain production. It is expected the water demand in future decades will continue to increase and the water predicament will become more seriously, in response to worsening quality of ecology and environment, soil erosion and wetland shrinkage and water pollution.

Accompanied with significant economic growth in the last decade, HRB experienced a series of great changes in land use and land cover during this period due to intensive human-induced activities, including intensive exploitation of land resources. So the matter of evaluating the eco-environment and keeping sound circles in HRB is crucial in order to achieve the sustainable development of basin's society and economy.



Figure 1. The location of Haihe River Basin in mainland China

2.2 Data and Methods

The spatio-temporal analysis of the landscape change was conducted in a systematic process. First of all, the classification maps (1990 and 2000) were merged and reclassified into six main land use classes (Table 1) (Liu, et al., 2005; Xie, et al., 2007). Second, spatial and temporal changes as well as transition of landscape types were analyzed with GIS. Lastly, Changes of landscape pattern can be detected and measured by landscape metrics which quantified and categorized complex landscapes into identifiable patterns and revealed some ecosystem properties (composition, fragmentation, configuration) that were not directly observable (Weng, 2007). The landscape pattern metrics we selected covered patch density (PD), mean patch size (MPS), area-weighted mean patch fractal dimension (AWMPFD), mean nearest-neighbors distance (MNN), interspersion and juxtaposition index (IJI), contagion index (CONTAG), Shannon's diversity index (SHDI), and Shannon's evenness index (SHEI) (McGarigal et al., 2002a).

| Land use/cover classes | description |
|------------------------|--|
| Cropland | Paddy field, dry land. |
| Woodland | Forest, shrubs, woods, others. |
| Grassland | Dense grass, moderate grass, sparse grass. |
| Water body | Stream and river, lakes, ponds and reservoir, perpetual ice and snow, beach and shore, bottomland. |
| Built-up land | Urban built-up, rural settlements, others. |
| Unused land | Sandy land, gobi, salina, swampland, bare soil, bare rock, others. |

Table 1. Land use/cover classes descriptions (Liu, et al., 2005)

3. RESULTS

3.1 Land Use Change across Haihe River Basin

Figure 2 showed the land use maps of HRB in 1990 and 2000 classified based on Landsat TM data (Liu, et al., 2005). Overall, in the mountainous region at the northern part, woodland was the dominant land use/cover type, while grassland with woodland mosaic saw the major land use classes in western and northwestern mountain areas. In the plain areas of HRB, the dominant land use/cover type was cropland, which constituted the landscape matrix of HRB, with built-up land interspersing among it. Water body occupied the least part of land cover type, which distributed mainly in the mountainous regions as reservoirs and rivers, and ponds along the coastal areas.

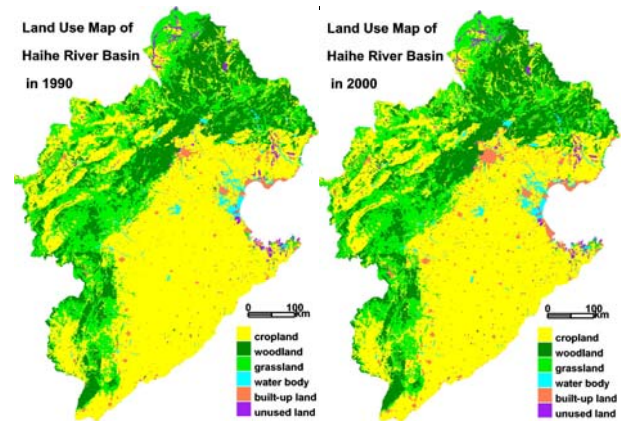


Figure 2. Land use maps of HRB in 1990 and 2000

Table 2 indicated that detected land use/cover changes from 1990 to 2000 (Table 2). The increase of built-up land accounted for the most obvious and drastic transformation in the study area with a net gain of 381934.75 ha, this significant increase was traced to the conversion from cropland, which experienced the most drastic decrease by 341417.73 ha (Figure 3), of which, 97.0% were converted into built-up land, with a slight loss turning into woodland and water body. This fact revealed that rapid urban expansion took place during 1990 and 2000. The rapid urban development was manifested by occupying a large amount of cropland. Grassland also saw a significant change with a net loss of 48483.32 ha, even though 28837.3 ha of woodland were changed to grassland. Noticeably, water

areas, which were originated from cropland, expanded by 38975.67 ha mainly due to the large amount of cultivation of aquiculture in the lower reach of the basin apart from the construction of reservoirs, While, woodland and unused land decreased dramatically by 28469.74 ha and 2541.86 ha, respectively. According to the above statistics, the observed most predominant transformation focused on the conversion from cropland to built-up land, which is a reflection of urbanization process. It is known that the expansion of urban land is primarily related to population growth and urban population increase in particular (Xie et al., 2007). Therefore, human modified landscape witnessed noticeable increase in the basin, resulting in more heterogeneous and fragmented landscape.

3.2 Changes of Landscape Metrics

The landscape became more heterogeneous mainly due to fragmentation. Table 3 compared the landscape metrics in 1990 and 2000 at landscape level. The data of PD, MPS, and LPI indicated that the Basin had undergone considerable fragmentation during the study period. The increase of PD suggested the break up of landscape into smaller parcels. While MPS was also indicative of the landscape fragmentation: it had decreased dramatically from 1990 to 2000. Furthermore, the LPI supported this view, which had decreased from 22.13% to 21.61%. Additionally, both SHDI and SHEI witnessed noticeable increase during the periods, indicating the landscape in the study area became more fragmented and heterogeneous (Apan, et al., 2000).

| 1990 | 2000 | | | | | | |
|---------------|----------|----------|-----------|------------|--------------|-----------|----------|
| | Cropland | Woodland | Grassland | Water body | Buildup land | Bare land | Total |
| Cropland | 14 895.7 | 21.8 | 7.9 | 38.4 | 331.1 | 5.7 | 15 300.6 |
| Woodland | 27.5 | 6140.6 | 28.8 | 0.3 | 3.9 | 0 | 6 201.1 |
| Grassland | 41.3 | 14.4 | 6 339.8 | 6.3 | 17.1 | 12.8 | 6 431.7 |
| Water body | 15.1 | 0.8 | 1.1 | 885.3 | 3.6 | 0.3 | 906.2 |
| Build-up land | 0.2 | 0.2 | 0.0 | 0.9 | 2 554.2 | 0 | 2 555.5 |
| Bare land | 16.3 | 0.0 | 7.9 | 2.3 | 10.6 | 412.8 | 449.9 |
| Total | 14 996.1 | 6 177.8 | 6 385.5 | 933.5 | 2 920.5 | 431.6 | 31 845.0 |

Table 2. Land use transition matrix of Haihe River Basin (Unit: $\times 10^3$ ha)

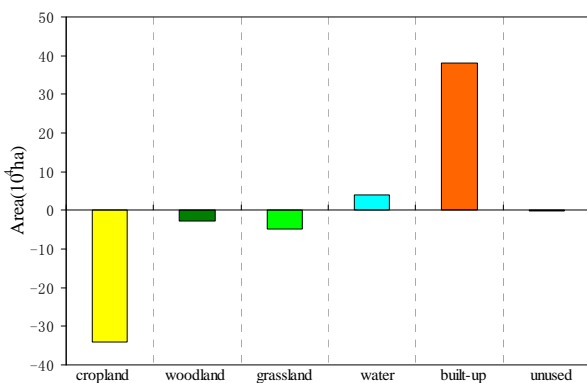


Figure 3. Net changes of six classes land use between 1990 and 2000

Other landscape features, such as landscape configuration, saw less significant changes during the study periods. The MNN showed a slight decrease, which revealed that the patches in 2000 were less isolated than the 1990 patches, and that inter-patch connectivity had enhanced. However, because the number of patches had increased significantly, this did not necessarily mean the spatial distribution of the same patch type had become more assembled. The decrease of MNN was, in fact, attributed to the fragmentation of previously larger patches. Meanwhile, The IJI of the whole landscape increased from 1990 to 2000, indicating more uniform landscape configuration and diversity landscape in the Basin. Still, this value also manifested that patches were well interspersed in the landscape or equally adjacent to all other patch types. This was also in accordance with CONTAG, which became smaller during the two periods, showing that spatial distribution of different

patches became more separated and the patch types became more disaggregated. However, the shape of patches in the study area changed slightly from 1990 to 2000. The AWMPFD, which is a descriptive of landscape shape, was observed to slightly increase from 1.18 to 1.19 during the study period, representing the shape of the landscape became more irregular and complex.

| Index | 1990 | 2000 | Index | 1990 | 2000 |
|-------|---------|---------|--------|-------|-------|
| PD | 0.01 | 0.02 | CONTAG | 58.57 | 57.31 |
| MPS | 4548.15 | 4270.08 | AWMPFD | 1.18 | 1.19 |
| IJI | 63.95 | 66.05 | SHDI | 1.17 | 1.2 |
| MNN | 3466.85 | 3355.11 | SHEI | 0.65 | 0.67 |

Table 3. Comparison of landscape metrics between 1990 and 2000 in Haihe River Basin at landscape level

4. DISCUSSION AND CONCLUSIONS

4.1 Urbanization is the Main Driving Forces of Landscape Pattern Change

This paper analyzed landscape pattern change at the basin scale with the help of GIS analysis and landscape metrics in the HRB during the period of 1990-2000. One of the most significant characteristics of landscape type change in HRB was the fragmentation of the landscape (increasing patch density and decreasing mean patch area and largest patch index), especially for cropland (Table 2) whose dominance had decreased. Key metrics indicated that the landscape had become more

complicated within the 10-year study period, with irregular shapes. The increase of SHDI and SHEI manifested the landscape became more fragmented and heterogeneous under intensive exploitation and reconstruction of landscape by human beings. The most drastic change of landscape type was the transformation from cropland to built-up land, which reflected the urbanization process and contributed the most part of the landscape pattern change.

With significant economic development in the past twenty years, China experienced a fast urbanization. In HRB, built-up land had increasingly expanded and encroached upon cropland. Still, due to the convenient transportation, for example, Jing-Guang Railway (Beijing-Guangzhou), Jing-Zhu highway (Beijing-Zhuhai), and Jing-Jin-Tang highway (Beijing-Tianjin-Tangu), which facilitated the transport to the capital of China, urbanization occurred at an unprecedented fast rate in the HRB during the past 10 years. Simultaneously, advanced infrastructure accelerated this process, in response to apparent increase of fragmentation. Our results of landscape analysis showed this enormous human-induced effect on landscape change. For example, built-up land expanded rapidly across the landscape, resulting in the rapid disappearance of cropland.

4.2 Environmental effects of landscape pattern change

The most intractable ecological problem in the HRB has been the shortage of fresh water, because of the high speed of the economic development, the drying climate, and deterioration of the water resources system, major water problem are encountered in this region. Changes of land use and cover alter the atmosphere-land surface relationship; urbanization accelerates the utility of deep layer underground water with an observed ground subsidence at a marvelous rate. Over-exploited and exhausted groundwater has become a pressing problem we must deal with. Pumping water for irrigation in pursue of the grain production resulted in a rapid decline in water tables (Yang and Zehnder, 2001; Shen, 2003), dramatically altering the regional water cycle. The lack of water resources not only hinders the development of national economy, but also leads to severe environmental problems, especially for HRB. The ecological problems of land degradation and wetland shrinkage are very serious. Presently many rivers have dried up, lost their functions of fishery, recreation, recharging groundwater, etc. Lacking of water resources combined with the reduction of cropland challenged the food security of this region (Shen, 2003; Liu, 2005); besides, another big environmental problem in the study area is the pollution of surface water (and groundwater), which leads to notable declining in the quality of the ecology and environment.

Landscape metrics coupled with GIS have proved useful in monitoring the dramatic landscape changes that have taken place in the HRB, still provided comprehensive information on the direction, quantity of landscape changes as a result of land use. The results of the land use matrix and landscape metrics at the regional scale manifested that the landscape structure and composition changed greatly, resulting in more fragmented and more irregular shape primarily due to the conversion from cropland to built-up land under intensive human interference. In this work, we analyzed the landscape metrics at the basin scale and got a general perspective on the whole landscape change of the Basin. Specifically, such metrics only provide us an overview, failing in determining the actual location that experienced the largest and contributing change. Therefore, detecting the exact position that witnessed the change and

accurately investigating the causes that contributed to this change are our next research purpose.

REFERENCES

- Apan, A., Raine, S., Paterson, M., 2000. Quantifying landscape fragmentation in the Lockyer Valley Catchment, Queensland: 1973-1997. *presented at AURISA 2000-The 28th Annual Conference of AURISA Hyatt Coolum Resort, Coolum QLD, 20-24 November 2000.*
- Dong, X., Liu, L., Wang, J., Shi, J., Pan, J., 2007. Analysis of the landscape change at River Basin scale based on SPOT and TM fusion remote sensing images: a case study of the Weigou River Basin on the Chinese Loess Plateau. *Int J Earth Sci (Geol Rundsch)*, DOI 10.1007/s00531-007-0271-2.
- Forman, R.T.T., Godron, M., 1986. *Landscape Ecology*. Wiley, New York.
- Herold, M., Goldstein, N., Clarke, K., 2003. The spatiotemporal form of urban growth: measurement, analysis and modeling. *Remote Sensing of Environment*, 86, 286-302.
- Liu, J., Liu, M., Tian, H., Zhuang, D., Zhang, Z., Zhang, W., Tang, X., Deng, X., 2005. Spatial and temporal patterns of China's cropland during 1990-2000: An analysis based on Landsat TM data. *Remote Sensing of Environment*, 98, 442-456.
- Lu, L., Li, X., Cheng G., 2003. Landscape evolution in the middle Heihe River Basin of north-west China during the last decade. *Journal of Arid Environments*, 53, 395-408.
- Matsushita, B., Xu, M., Fukushima, T., 2006. Characterizing the changes in landscape structure in the lake Kasumigaura Basin, Japan using a high-quality GIS dataset. *Landscape and urban planning*, 78, 241-250.
- McGarigal, K., Cushman, S.A., Neel, M.C., Ene, E., 2002a. FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps. Computer Software Program Produced by the Authors at the University of Massachusetts, Amherst. Available at the following website: www.umass.edu/landeco/research/fragstats/fragstats.html.
- Olsen, L., Dale, V., Foster, T., 2007. Landscape pattern as indicators of ecological change at Fort Benning, Georgia, USA. *Landscape and Urban Planning*, 79, 137-149.
- Shen, Y., Xiao, J., Kondoh, A., Tateishi, R., 2003. Influence of land use and land cover change due to urbanization on hydrological environments: a case study of Shijiazhuang, China. [A]. In: *Proceedings of the CReS International Symposium on Remote Sensing: Monitoring of Environmental Change in Asia*[C]. Chiba, Japan, 2003. 25-28.
- Weng, Y., 2007. Spatiotemporal changes of landscape pattern in response to urbanization. *Landscape and urban planning*, 81, 341-353.
- Xiao, D., Zhao, Y., Sun, Z., Zhang, H., 1990. Study on the variation of landscape pattern in the west suburbs of Shenyang. *Chinese Journal of Applied Ecology*, 1: 75-84 (in Chinese).
- Xiao, J., Shen, Y., Ge, J., Tateishi, R., Tang, C., Liang, Y.,

Huang, Z., 2006. Evaluating urban expansion and land use change in Shijiazhuang, China, by Using GIS and remote sensing. *Landscape and urban planning*, 75, 69-80.

Xie, Y., Fang, C., Lin, G., Gong, H., Qiao, B., 2007. Tempo-spatial patterns of land use changes and urban development in globalizing China: a study of Beijing. *Sensors*, 7, 2881-2907.

Yang, H., Zehnder, A., 2001. China's regional water security and implications for grain supply and trade. *Environment and planning A*, 33, 79-95, 2001.

ACKNOWLEDGEMENTS

This research is supported by the Knowledge Innovation Program of the Chinese Academy of Sciences, Grant NO. KZCX1-YW-08-03-07.

