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Original Research Paper

Eco-Environmental Quality Evaluation and Dynamic Ecological Patterns for Songhua River Watershed in Harbin Section, China

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ABSTRACT

Analyses of land use change (LUC) is fundamental to the understanding of economical development, social contradiction and environmental problems, therefore, in this paper, the Songhua River watershed was selected as a case study area for quantitative evaluation of eco-environment quality. Technologies of RS (remote sensing), GIS (geographic information system), the analytic hierarchy process (AHP) methods, and other statistical methods were employed to implement. The results shown that during the recent decade, more than 87% of the total land area in the study area was dominated by agriculture, forestry, animal husbandry production; the areas of foreland and water body were increased, while others decreased .The eco-environment response to LUC displayed spatial distribution, it can be concluded that the excellent eco-environment quality, with the stable ecosystem, was mainly located in mountain region covering a larger vegetation, the poor and bad level of eco-environment quality associated with plain region that is dominated by the greater extent of human activities. The change of eco-environment quality grades in the study area was mainly associated with LUC. The social economic indicators were not integrated into that ecological model, thereby, in the course of economic development, more attention should be paid to this aspect in future studies in order to better coordinate the relationship between economical development and ecological processes.

INTRODUCTION

Land use change (LUC), as the complex process interaction between natural environment evolution and human activities on different temporal and spatial scales, is among the most important alterations of the Earth's land surface (Lambin & Geist 2001), and has become the great sensitivity to the changes of environmental elements (Peng et al. 2012). Therefore, as an important part and one of the main reasons of the global environmental change (Chen et al. 2003), LUC can affect climate, biogeochemistry and biological diversity profoundly (Hao & Ren 2009). Moreover, among the many concerns about global environmental change today (Pelorosso et al. 2009), there is an increasing awareness of the importance of issues involved in LUC over time.

With the rapid development of science and technology and the explosive growth of population (Yan et al. 2007), human activity increasingly plays an important role in changing the land cover and land use throughout the world, meanwhile, it has brought a series of severe disasters and retracted eco-environment quality that concerned many problems, such as global climate change, food security, land degradation and biodiversity (Vitousek et al. 1997, Xie et al. 2006, Xie et al. 2012, Xie et al. 2013). It is very clear that land use change not only changed the conditions of the land cover, but also produced many influences during the ecological processes (Turner 1989), especially in regional climate, soil, and water quantity and quality (Guo et al. 1999,

Generally, watershed areas are perceived as large and described only in the context of rivers or large lake (Davies et al. 2008, And this region can be taken as a completely natural geographical unit (Dou et al. 2008), the occurring and development of natural processes can be directly restricted with the regional LUC of watershed, such as hydrological processes, water chemical process, biological process, etc. (Xie et al. 2013). However, with the effects of traditional concept, rapid population growth and other factors (Dou et al. 2008), the conservancy construction activities in this region were constantly developed and taken, which promoted the development of agriculture and animal husbandry. On the other hand, it made the adverse effects on ecological environment, especially on deforestation, cultivation on steep slopes (Wang et al. 2004), the land use frequently change in conditions, soil and water loss gradually aggravate year by year, ecological environment constantly deteriorate, and at last seriously restricted the regional social and economic sustainable development. However, some quantitative studies mainly focused on the impact of LUC on single environmental factors, e.g., atmospheric environment, soil environment, water environment, biodiversity, etc. (Shi et al. 2008, Chen et al. 2006, Zhang et al. 2007), while the social factors were rarely mentioned, such as human activities impacts.

Recently, remote sensing (RS) and geographic information system (GIS) had been used as powerful tools for geo-environmental evaluation in support of LUC (Wang et al. 2008). As the major grain producing areas of Heilongjiang Province, Songhua River watershed became the more typical region in the dynamics change of resources and environment. In order to immediately obtain accurate environmental information and monitor dynamic ecological changes in this region, based on RS and GIS technology, taking the Songhua River watershed in Harbin section as a case study region, LUC in the study area during the recent decade was analysed, the regional ecological environment was quantitatively evaluated from the natural environment and social factors, then the eco-environment quality responses to LUC were calculated and evaluated, which reveal the driving mechanism of LUC, on this basis, to explore the evolution of the regional ecological environment and spatial differentiation process, and then to provide the scientific support on restoration and reconstruction for ecological environments and the sustainable development for land use. Meanwhile, this study results made the important significance on soil and water loss control, eco-environment protection, and black soil ecological safety erosion planning of northeast region in China.

MATERIALS AND METHODS

Study area: The study area, Songhua River (Harbin section), is located in south-central of Heilongjiang Province, lies between 37°33' to 37°60' N and 125°40' to 129°33' E, with approximately an area of 28906 km^2. The eastern region of the study area is hilly and western is plain, the general trend of hypsography in this study area is from higher in eastern region to lower in western region, the annual average temperature is 215~410°C, the average annual frost-free period is 110~150 d, annual precipitation is 400~600 mm, annual accumulated temperature is 2500~3100°C. This area is suitable for the development of agricultural production and as an important grain production base with fertile land, vast territory and relatively smaller population.

Image process and interpretation: The ground controls (GCPs) were selected from the topographic map at scale of 1:50 0 00, the geometric correction of Landsat TM image in 1996a and Landsat ETM + image in 2005a were carried out in ERDAS IMAGINE 9.2 software by using polynomial model, and the geometric correction of resultant root mean square error was generally less than 0.5 pixel, then the false colour composites were got from bands 5, 4 and 3 as red, green and blue, respectively. The Landsat TM (ETM+) images were masked by study boundary. Using the Chinese land classification system (2001) as a standard in this paper, the images were classified in supervised classification method in ERDAS IMAGINE 9.2 with support for the land use present situation and the field survey data with GPS. The spatial topological relation of land use was built and land use database was generated. The land use was divided into 6 types: cropland (paddy and upland), forestland (forestland, shrub land, open woodland), grassland, water bodies (rivers, lakes, ponds and reservoirs), built-up land (urban and rural residential land mines and other construction sites) and unused land (sand swamps, etc.).

Eco-environment evaluation unit: Based on DEM in the study area, supported by spatial analyst and Geostatistical Analyst module of ArcGIS, the Songhua River watershed was divided into 5 km × 5 km with equally spaced sampling methods (Yue et al. 2006, Yue et al. 2007), to obtain eco-environment comprehensive evaluation unit and to evaluate and count the eco-environment quality of each study zone. On this basis, the eco-environmental quality of whole study region was acquired by using the cringing interpolation method from each evaluation zone in ArcGIS software.

Construction of evaluation index: Eco-environment system was the complex one with multi-subjects and multi-levels (Li et al. 2008). It was composed of natural factors and human factors, which was important and essential to select appropriate factors for eco-environmental evaluation (Xiong et al. 2007). In this paper, with the characteristics of the regional ecological environment and the capacity of environmental information of Songhua River watershed, there are five factors to be considered in terms of the nature, agricultural and human environment, such as biological abundance, vegetation cover, land degradation, water network density and human activities factors, so as to evaluate the eco-environment in this region synthetically. It is obvious that each factor had a different role in eco-environmental evaluation in this paper with land degradation and vegetation cover may be more important in promoting eco-environmental situation, while the others also did in influencing the eco-environmental quality. Using ArcGIS 10, each factor was calculated and stored in raster data with resolution 30m × 30 m.

Evaluation methods processing: Due to great differences and different units among values of different evaluation factors, it was difficult to evaluate the eco-environmental status using these factors indirectly (Li et al. 2008). In order to maintain comparability among the data of each factor (Ma 1998), we used the standardized methods to deal with these factors for eco-environment evaluation. The standardized equation was as follows.

$$Y_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \times 10 \qquad ...(1)$$

Where, Y_i represents the standardized value *i* factor, varying from 0 to 10, X_i represents the measured value *i* factor, and X_{min} and X_{max} represent minimum and maximum value *i* factor, respectively.

The weight of each factor was determined with AHP according to the expert advice (Li et al. 2008). AHP was a systematic analysing evaluation method to treat the complex and multi-index system quantitatively. Due to its ability of assigning proper weights to various factors of complex systems, eco-environment system was suitable to employ AHP (Li et al. 2008). In the research, using ArcGIS software, based on the Delphi expert advices, the AHP method was applied to determine the weight of each factor (Dorey 2000). The eco-environment model for eco-environment quality (*EEQ*) in Songhua River was synthetically evaluated; the equation of *EEQ* was as follows.

$$EEQ = \sum Y_i \times w_i \qquad ...(2)$$

Where, *EEQ* is the synthetic index of eco-environment quality, *Y* is the value of each index, *w* is the weight of each index. *EEQ* = 0.25 × biological abundance index + 0.25 × vegetation cover index + 0.25 × Water network density index + 0.15 × (1-land degradation index) + 0.1 × Human impact index.

RESULTS AND ANALYSIS

Land use change analysis: Analysing land use data of two periods in Fig. 1 and Table 1, more than 87% of the total land area in the study area was dominated by forestland, cropland and grassland. It is obviously indicated that the land use characteristics of this study region were major on agriculture, forestry, and animal husbandry production in some way. The areas of forestland and water bodies were increased, with the annual change rate of 1.314% and 3.068%, respectively. The increasing area for water was attributed to the seasonal precipitation effects in 2005a, while forestland was due to the implementation of natural forest protection project, Songhua River comprehensive ecological environment management and other ecological restoration projects. The annual change rate of cropland, grassland, built-up land and unused land was (-)1.356%, (-) 5.308%, (-) 1.568% and (-) 0.085%, respectively. The decreasing of cropland area was maximum in the aspect of area and speed, which accounted for 1230.21km^2 during the recent decade, followed by grassland and unused land, while the built-up land decreased the least. One case for cropland reduction was attributing to the policies for cropland returning forestland in a large extent, in addition to, another important reason was that some parts of cropland were inundated by Songhua River.

Spatial analysis of EEQ: First of all, supported by the spatial analyst module of ArcGIS 10 and software Static 6.0 for Windows, the eco-environmental quality evaluation could be calculated and graded as five levels: excellent, good, general, poor and bad. As shown in Table 2 and Fig. 2, the excellent eco-environment quality, accounting for 0.33% in 1996a and 6.38% in 2005a respectively, was mainly located

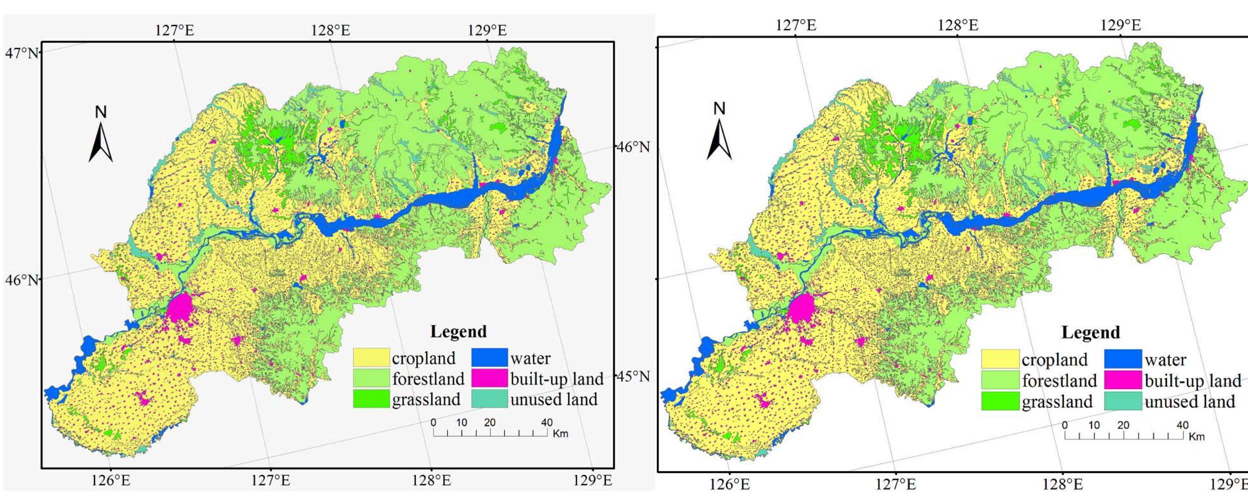

Fig. 1: Land use distribution map of different periods (1996a, 2005a).

Table 1: Change in area of different land use types and their dynamic extent.

Land use types	1996a		2005a		1996-2005a	
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Change	Annual change (%)
Forestland	13240.332	45.805	14632.191	50.62	1391.859	1.314
Cropland	11338.605	39.226	10108.4	34.97	-1230.21	-1.356
Grassland	1018.935	3.525	586.282	2.028	-432.653	-5.308
Water	1489.529	5.153	1855.164	6.418	365.635	3.068
Built-up land	1125.047	3.892	1117.404	3.866	-7.643	-0.085
Unused land	693.597	2.399	606.604	2.098	-86.993	-1.568

Table 2: Change in area of eco-environmental status and their dynamic degrees.

Eco-environment	1996		2005		1996-2005	
types	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Change	Change extent
Bad	2687.18	9.3	1375.51	4.76	-1311.67	-0.49
Poor	9909.29	34.28	8715.15	30.15	-1194.14	-0.12
General	7471.69	25.85	8972.85	31.04	1501.16	0.20
Good	8742.89	30.25	7997.27	27.67	-745.62	-0.09
Excellent	95.01	0.33	1845.28	6.38	1750.27	18.42

Table 3: Classification of land eco-environmental status change degree.

Grade	Slightly worse	Basically unchanged	Slightly changed for better	Basically changed for better
Change value	$-1 \leq \Delta EEQ < 0$	$0 \leq \Delta EEQ < 1$	$1 \leq \Delta EEQ < 2$	$2 \leq \Delta EEQ < 3$

Table 4: The change of land eco-environmental grades.

Change types	Slightly worse	Basically unchanged	Slightly changed for better	Basically changed for better
Area (km^2)	126.68	22596.54	5666.57	516.27
Proportion (%)	0.44	78.17	19.60	1.79

in the southern and northern part of the study area, where there were mountain regions, forestland occupied by a large proportion with good vegetation cover, the less intensity of human disturbance, and the slight land degradation. Besides, ecological diversity was abundant, and the ecosystem was stable.

Secondly, the good eco-environment quality covered much larger area, which accounted for 30.25% and 27.67% respectively, and there was a decrease of area up to 745.62 km^2 in recent decade. It was the reason that there were much more forestland, unused land, water body, as well as some cropland and fairly good vegetation cover. In addition, some of this region was destroyed by human activities in certain extent, the transition from forestland to cropland was the main land use conversion trajectory. In a world, in some key regions, the policies for returning farmland to forests would be taken and implemented so as to strengthen the rational land use of the optimal allocation pattern in future.

Thirdly, the eco-environment quality in western region was with general level, covering 25.85% and 31.04% respectively, where there was the transitional zone for hilly and plain regions, most of cropland, some of forestland and grassland, and the vegetation cover, in general. Besides, there was some disturbance of human activities, while with the general ecosystem, the transition of land use was mainly from forestland to grassland and to cropland. Therefore, the improvement of the eco-environment could be promoted by managing of the grassland and abandoned farmland.

Fourthly, the poor eco-environment accounted for 34.28% and 30.15% respectively. The fact is that there was the plain region with most cropland, water body and some unused (wetlands), as well as more rural residents. Additionally, the greater population growth and rapid urbanization impacted the greater demand for cropland in this region. And then it was obvious that the transition from wetland and grassland to cropland, the structure of land use was unreasonable for the too heavy pressure on land, the fast growth of population, the rapid development of urbanization and agriculture restructuring; these were the direct cause for the eco-environment quality.

Finally, the bad eco-environment, it appeared in the northeastern and southwest of the study region, accounting for 9.3% and 4.76% respectively. There were more cropland

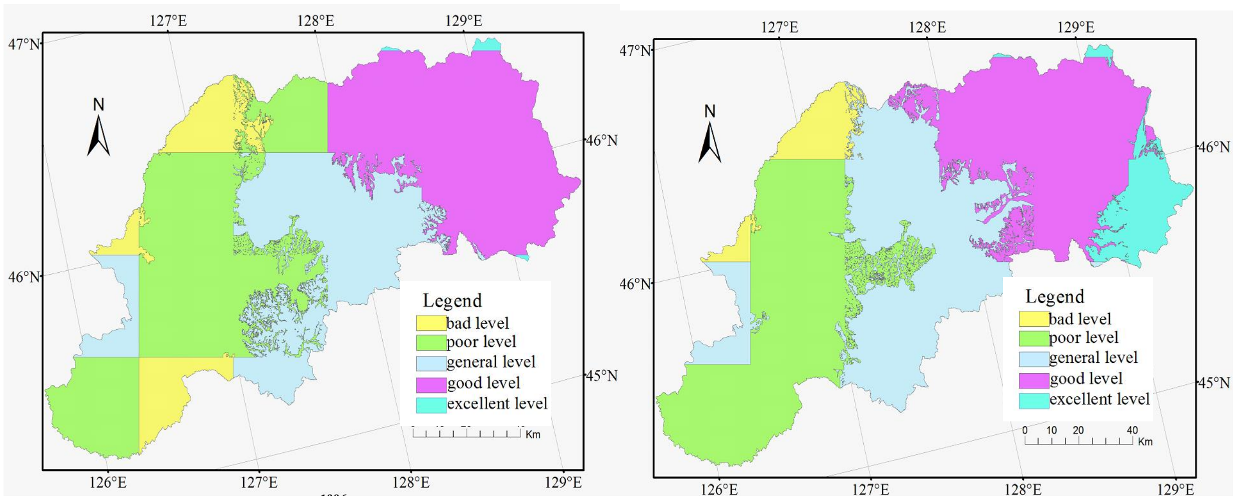

Fig. 2: Distribution map in area of ecodevelopment quality (1996a, 2005a).

and rural residents in this region with lower vegetation cover. The intensity change from cropland to built-up land was very obvious, and there was unreasonable land use phenomenon, such as overgrazing grassland and deforestation. The more disturbances of human activities not only made the eco-environment much severe, but also accelerated the contradiction between human and the natural environment.

Dynamic analysis of EEQ: The two different evaluation maps were overlaid with the support for ArcGIS 10, and on the basis to detect the *EEQ* changes, according to the change situation of eco-environment quality, the *EEQ* was divided into four levels: slightly worse, basically unchanged, slightly and basically changed for better (Table 3). In the meantime, the change classification distribution map of eco-environment situation of land use was generated as shown in Fig. 2.

From the Table 4 and Fig. 2, it was clear that the better tendency of the eco-environment took on from 1996a to 2005a, the basically and slightly changed for better up to 21.39% of the whole area, which was composed of the mountains, hilly region, and most of cropland and forestland. The implementation of Natural Forest Protection Project, Songhua River ecological environment management, the ecological restoration projects, and the major trend of land use of transition from cropland to forestland, these were the necessary conditions for improving the eco-environment.

Therefore, we have been implementing the proactive adjustment policies on the agriculture, reinforcing the supervision and management of the forestry in order to stop the irrationally exploiting activities, and properly coordinating the contradiction between humans and the land for utilizing rationally the resources of land use, so as to form a relatively stable ecological structure and ecological functions.

The basically unchanged zone accounted for 78.17% of the whole area, which was absolutely occupied with the plain and mountains. That was also the main region for human living and agricultural production, with the large proportion of cropland and forestland. So, we considered that it was important to reasonably strengthen the optimal allocation of the land use pattern for the purpose of gradually improving and forming the good black soil ecosystem.

Moreover, the slightly worse zone was mainly distributed in the junction between plain and hilly. With the fragile regional eco-environment and the relatively frequent disturbance of human activities, the soil erosion in this region often happened. That would be the focus on finding the solution for soil erosion in future.

Hence, in the course of economic development, according to local conditions to create a water conservation forest, timber, etc., we must continue to implement the "Grain for Green" policy, which could achieve rational land use and promote regional sustainable development.

CONCLUSIONS

By combining AHP method with ArcGIS 10, the study approached the research on the current condition of eco-environmental quality of Songhua River watershed in Harbin section, located in northeast China. The results showed that the region was mainly dominated by agriculture, forestry and animal husbandry production, and the summed areas were more than 87% of the total area. The area of forestland and water increased, while others decreased, forestland increased most, on the contrary for cropland.

The excellence of eco-environment quality, with the stable ecosystem, was mainly located in mountain region and forestland occupied a larger proportion, the good level of eco-environment quality was major in hilly region, the poor and bad level of eco-environment associate with plain region with the greater extent of human activities.

Utilizing AHP method in this paper, the ecological evaluation model could easily use the spatial analysis module in GIS to obtain the assessment results of Songhua River section in Harbin section, while due to limited data and technical problems, the social economic indicators were not integrated into that ecological model, thereby, in the course of economic development, more attention should be paid to this aspect in future studies in order to better coordinate the relationship between economical development and ecological processes.

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