Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 15	No. 2	pp. 377-384	2016

Original Research Paper

Analysis of Urban Wetland Changes and their Driving Forces based on RS and GIS: A Case Study in the Longfeng Wetland Natural Reserve, China

Xuewei Wu*(***), Wenfeng Gong† and Yaming Xu***
*College of Geodesy and Geomatics, Wuhan University, Hubei, P. R. China
**College of Hydraulic and Electrical Engineering, Heilongjiang University, P. R. China
***College of Civil Engineering, Northeast Forestry University, Hei Longjiang, P.R.China
†Corresponding author: Wenfeng Gong

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 22-05-2015
Accepted: 21-06-2015

Key Words:
Urban wetland
Geo-information image analysis theory (GIAT)
Urbanization
Longfeng wetland natural reserve

ABSTRACT

Spatial distribution characteristics and dynamic changes over 21 years in Longfeng wetland in Daqing city, China, were analysed using remote sensing and geographic information systems. Landsat TM images were used as the main data source. Based on geo-information image analysis theory, the spatiotemporal change of land use cover was obtained, and the spatial and temporal evolution mechanisms were revealed. This study provides a method to study the driving forces of urban wetland degeneration, and it could aid in developing protective measures for wetland in rapidly urbanizing regions. The results indicated that the swamp land composed the landscape matrix and exhibited a trend of decreasing area over time, whereas the built-up land exhibited an increasing trend. Cropland and wetland were the main sources of land-use change. The stable model accounted for the largest area, swamp-swamp-swamp was its largest area change mode. The repeated model accounted for the least area, as the cropland-unused land-cropland represented the largest area change in this model. Both natural factors and human activities have made an impact on wetland degeneration, but human activities were the main driving force for the spatiotemporal evolution of land use cover pattern.

INTRODUCTION

Urban ecosystems are severely influenced by human activities, and their development is an inevitable trend in human societies (Li et al. 2003). Urban wetland is an important part of the urban ecosystem, and it is considered to be the optimal use of terrestrial ecosystems because of its multiple irreplaceable ecosystem service functions (Gao et al. 2005). However, in recent years, with economic development and the acceleration of the urbanization process, there has been a fundamental change in urban land-use patterns (Zhang et al. 2007). In addition to urban expansion, the discharge of effluent from industry and agriculture combined with domestic sewage has increased and changed the natural elements of the original landscape. These changes threaten to shrink the urban wetland area, increase pollution, decrease biological diversity, aggravate landscape fragmentation (Faulkner 2004, Zhang et al. 2007, Zheng et at. 2008, Zheng et al. 2009), decrease urban wetland habitats and could even lead to a dramatic transformation of the surrounding natural environment (Ren et al. 2011, Antrop 2000). The urban wetland loss has greatly reduced support capabilities for the urban economy and socially sustainable development of the wetlands (Gao et al. 2005), has triggered many ecological problems, and has had a dramatic impact on the region's natural environment (Peng et al. 2011). Therefore, the conflict between environmental protection, economic development and urban sprawl is inevitable in the process of urbanization (Peng et al. 2011). Research in China has been mainly concentrated in large cities, such as Guangzhou, Beijing and Shenzhen (Gu 1999, Liu & Wu 2000, Weng 2002). However, the northeast city of Daqing has experienced rapid economic development and contains a rare large wetland area (Wang et al. 2005). Few studies on urbanization and the dynamic changes of wetland have been conducted in Daqing, and very little work has investigated the relationship among natural, economic and social characteristics (Zeng et al. 2010).

Geo-information image analysis theory (GIAT) is a complex spatial and temporal analysis methodology (Chen 2001, Fu 2002, Li & Zhuang 2001) and is able to combine the "map which expresses unit space features" with the "spectrum of the development's initiation and process" (Zhang et al. 2010). Remote sensing (RS) and geographic information systems (GIS) were then combined to produce a time series information map (Li et al. 2002). This paper used GIS and RS technology by employing Landsat TM images as data sources, adding topographic maps and related socio-economic statistical data with information mapping theory, to compound

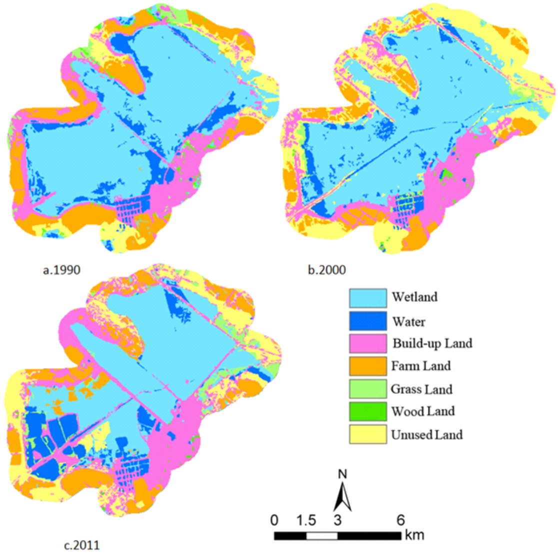

Fig. 1: Land use patterns from 1990 to 2011.

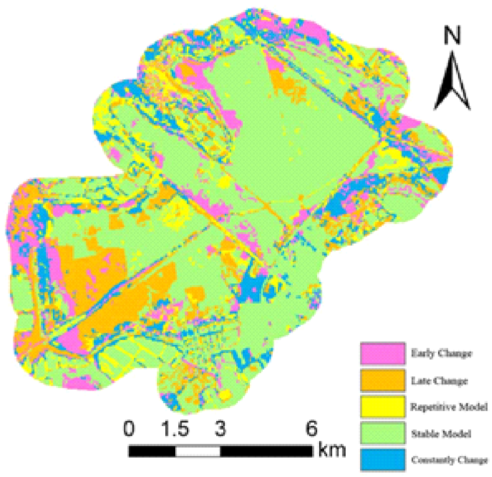

Fig. 2: Synthesis pattern of 1990 to 2011.

the land-use change map in different periods. We quantitatively revealed the spatiotemporal evolution rule of land-use patterns under an urbanization background over 21 years in Longfeng wetland. The driving forces of the land use alterations were analysed and discussed concerning the protection, restoration and reconstruction arrangements in this region. A theoretical basis was provided by using time series remote sensing dynamic monitoring data and scientific management to provide technical support for further research on regional sustainable development.

METHODS

Study sites: Daqing city is a resource-based city with oil exploration and development (Dong & Zang 2011), a typical result of northeast China's rapid urbanization process, and the Longfeng Wetland Nature Reserve is located in Longfeng district of Daqing city. The rapidly degenerating wetland is a geographic microcosm of urbanized wetland in Northeast China, spanning the coordinates of 46°28'~ 46°33' N, 124°15'~ 125°07' E, and it officially became a provincial nature reserve in 2003. It is a typical urban wetland area with a temperate continental monsoon climate with four distinct seasons and large seasonal temperature differences. Winter (November to February) is long, cold and dry, but summer is short, hot and rainy. Rains occur primarily in July and August, with seasonal variation in spring and autumn. The temperature changes rapidly, and the annual average temperature is 4.5°C, the extreme maximum temperature is 39.8°C, and the extreme minimum temperature is -39.2°C. The average annual rainfall is 435 mm, and the annual evaporation is 160.3 mm, with evaporation being much greater than precipitation. Geomorphic units within the study area are mostly swamp, lake and low-lying plain, and pools and swamps crisscross the area. The plain terrain is an alluvial formation by the Nen River, Wuyu'er River and Shuangyang River, and the soil is composed of meadow soil and boggy soil, with the boggy soil accounting for approximately 80 percent of the total area in the Nature Reserve. The natural vegetation is mainly composed of meadow grassland, lowland salt meadow and marsh.

Data collection and processing: The main data used in this paper are a Landsat TM remote sensing image obtained on September 13, 1990, a Landsat ETM+ image from September 20, 2000, and a Landsat TM image from September 16, 2011. We also used a 1:50000 topographic map, a boundary vector map of the Natural Reserve, parts of land use maps in 1988 and 2005, field survey data between August and September in 2011 and Statistical Yearbook data from 1990 to 2011.

By using ERDAS IMAGE 9.2 and the 1:50000 topographic map as a geo-reference, we geometrically rectified the three remote sensing images. The spatial location error was within a pixel. The growth process was completed in the Natural Reserve with an average vector boundary distance of 1 km, which was then subtracted from the TM images. A maximum likelihood method of supervised classification was applied to each remote sensing image, with relevant land use data and field survey data employed in the process. A relevant classification analysis was then achieved by applying data from the neighbourhood and elimination analyses. Sample data obtained with a GPS field survey and images provided by Google Earth were used to verify classification accuracy. Accuracy levels of 88.7%, 91.5% and

89.6% were achieved for each image, reaching the accuracy requirements. Land-use type was designated according to the China land use classification criteria and the actual conditions of the study area. Land-use type was divided into seven categories: wetland, water, built-up land, cropland, grassland, woodland and unused land.

Map information on land-use change: The land use type was recoded in ArcGIS 9.3. The class code was represented by applying a simple numerical system as 1, 2, 3 ... and 7, and the data were stored in grid format. With the spatial analyst module, algebraic calculations were used to produce the land-use change maps for different time units. Each polygon attribute code was calculated and recorded in the conversion process from 1990 to 2011 and then integrated into space attribute process integration map units. The formula is as follows:

$$T_{(90-11)} = t_{90} * 100 + t_{00} * 10 + t_{11} \quad ...(1)$$

Where, t_{90}, t_{00} and t_{11} were the land-use types of 1990, 2000 and 2011, respectively, and $T_{(90-11)}$ was the synthetic map unit.

RESULTS

Overall land-use change characteristics: Based on ArcGIS 9.3, we obtained the land use map of the study area (Fig. 1) and analysed its general structural features. Changes in various land-use types within the region can be observed in Table 1. Wetland occupied 49.12%, 45.33% and 44.92% of the landscape in 1990, 2000 and 2011, respectively, constituting nearly half of the landscape matrix landscape. However, wetland exhibited a trend of decreasing area over time, with a total loss of 23.23 km^2 from 1990 to 2011. The built-up land occupied 16.21%, 16.46% and 23.24% of the landscape, respectively, exhibiting an increasing trend for 21 years. The land was primarily converted from cropland and wetland, and built-up land peaked from 2000 to 2010, reaching 8.28 km^2. A development strategy of "moving eastward and expanding northward" created a boom in urban population growth in Daqing city after 2000. Accelerated urbanization increased the urban land area and squeezed the wetland areas to make room for urban roads and other infrastructures. Serious damage to wetland resources brought concern, as the natural environment suffered great repercussions from urbanization. Rising pressure to recognize and protect ecological resources inspired the establishment of a provincial natural reserve in 2003, altering the pace of wetland encroachment by introducing protection measures for wetland resources. Cropland took up a certain percentage of land, first decreasing in area and then increasing. The decrease in cropland area was larger than the subsequent area increase. Water and grassland area experienced a trend similar to cropland, while woodland occupied a smaller area and even appeared to decrease in area. Unused land initially increased by 16.33 km^2 and then decreased by 7.34 km^2. Unused land largely originated from abandoned farmland and degraded wetland, due to the weakness of farming systems and the awareness of environmental protection. Furthermore, the climate and environmental conditions in Daqing city seriously affected wetland degradation, thereby increasing the area of unused land. However, because of the establishment of the Natural Reserve, increased protection intensity has resulted in reduced wetland impacts and even the introduction of ecological environmental restoration measures focused on returning farmland to wetland and grassland. Protective measures also slowed the degradation rate of soil and sand, thus decreasing the deterioration of the natural environment.

Changes in land-use pattern: The regional land-use pattern map above was based on the GIAT from 1990 to 2000 to 2011. The land-use change patterns were categorized into five models, namely :

1) The early change model, which exhibited changes only from 1990 to 2000. 2) The late change model, which exhibited changes only from 2000 to 2011. 3) The repetitive model, which exhibited changes only in 2000. 4) The stable model, which exhibited no changes in all three periods. 5) The constantly changing model, which exhibited changes from 1990 to 2000 to 2011 (Wang 2009, Gong et al. 2012).

With the ArcGIS9.3 spatial analysis module and the analysis of the three land use overlays, we produced the land-use change maps. Map algebra operations were applied to obtain the spatiotemporal evolution rule of land use status and its changing process. To synthesize the patterns from 1990 to 2011 (Fig. 2), changing patterns of 236 land polygons were generated, and various types of map unit statistics were recorded in Table 2. It shows the following results:

1. The stable model occupied the largest area, with 50.71 percent of the land area. The area with the most significant change was "swamp → swamp → swamp": mainly distributed in the core area, indicating that swamp was the main land-use type of the Longfeng Nature Reserve, which is dominated by salt marsh and some lake swamp.

2. The late change model area occupied 19.66 km^2, with "swamp → swamp → built-up land" as the largest area change mode, accounting for 27.06% of the total area. This result indicates that with the population increasing and urbanization accelerating in Daqing city, land development and utilization resulted in the continual development of the surrounding wetland. Wetland changes occurred as a result of settlement, land mining and transportation development. Roads and railways that occupied the Natural Reserve were divided into four sections (Wang et al. 2005). The process

of urbanization continued to accelerate the shrinking of wetland area and the resultant reduction of hygrophilous vegetation, thus causing a gradual degradation of wetland function. Unreasonable encroachment of wetland and pressure on regional wetlands still exists in this area. Rapid economic development and the acceleration of urbanization progress, as related to wetland protection, will be a challenge in the future.

3. "Water → swamp → swamp" was the largest change area of the early change model, which covered an area of 4.21 km^2. A shortage of local surface water and the exploitation of a large number of groundwater resources by agricultural and industrial production resulted in a decline of the wetland water level (Wang et al. 2005). Reduction in the water area caused several lakes to shrink or even completely dry up. The changes in wetlands resulted in "water → swamp → swamp meadow → meadow steppe" (Liu 1997), and part of the region was converted directly from wet marsh to salt marsh as a result of salinization from development.

4. The continuous change model covered 14.46 km^2, with its largest change areas being "cropland → unused land → built-up land" and "cropland → unused land (saline-alkali soil)". The fragility of the natural environment and the continual decline of climatic conditions, combined with overuse impacts, such as overgrazing, estrepement, oilfield development, turf and solonetz harvesting, affected arable lands through resulting salinization and desertification. Thus, human factors were dominant in the process of land-use change. "Unused land → built-up land" conversion was induced through the rapid development of the oil industry and the resultant rising social economy in Daqing city. Population and urbanization processes were increasing rapidly, and the rate of regional urban construction and road construction grew to match the ensuing needs. The urban unused land began to be used for transformation and utilization, indicating that competition between humans and land use was still severe. The "swamp → unused land → built-up land" mode was the second largest area change pattern, which was 1.44 km^2.

5. The repeated model, with only 11.21 km^2, was the smallest, and "cropland → unused land → cropland" was its largest area change pattern. Human impact was the dominant factor driving the spatiotemporal evolution of the land use; "cropland → unused land (saline-alkali soil)" resulted from low-level local farming techniques and little focus on farming effects and land management to support long-term agriculture. The land was abandoned when the fertility declined, leaving degraded saline-alkali soil. The "unused land → cropland" mode demonstrated that with the continuous development of economy and society, combined with rapid expansion of agriculture and animal husbandry skills (Gong et al. 2010), regional environmental reconstruction activities continually increased, thus strengthening the development and use of unused land. In short, "cropland → unused land → cropland" was primarily due to the impetus of regional economic development, and to a certain extent, it reflected the complexity of the mechanisms driving the spatiotemporal evolution of land use.

Driving mechanism analysis: Many factors have affected the wetland change in the Longfeng Natural Reserve. Natural, societal and economic factors interact on spatial and temporal scales. Varying modes of action affect the scope and intensity of the spatiotemporal evolution on land use, resulting in a complex unpredictability of wetland change (Li et al. 2005). This paper synthesized natural and human factors to understand the main driving factors of wetland change, with concentrated focus on human factors.

Natural causes: Since the 1970s, the temperatures of Daqing city have exhibited an upward trend. According to meteorological records, the average annual temperature in 2002 increased by 3.4°C since 1945, but the annual precipitation showed a downward trend. Within the major wetlands and surrounding areas in Daqing city, precipitation, runoff, evaporation, their spatial and temporal distributions, and other aspects of land cover change, especially in the upstream areas (Wang et al. 2005), have changed the distribution of surface water resources. Moreover, a large amount of groundwater was exploited by industry and agriculture, resulting in declining of groundwater levels in some areas. Lowering groundwater levels formed groundwater depression cones (Wang et al. 2005), which shrank the lakes and gradually reduced the water levels. Wetlands, deprived of water, morphed into meadow and salt marshes, aggravating the degree of land desertification and increasing soil salinization. Additionally, petroleum pollutants that were generated from industrial production continually aggregated into the Longfeng wetland with sewage outfall and other surface runoff (Hu et al. 2010). The poor drainage of the Longfeng wetland area, due to the closed flow zone of the Anda district (Hu et al. 2010), increased the effects of non-point source pollution, such as sewage, pesticides and fertilizers, and accelerated the contamination level of the wetland. Eutrophication resulted in a sharp deterioration in water quality, and wetland areas diminished as ecological functions were gradually lost. The water quality of several parts in the Natural Reserve was tested and found to be a very low Class V quality standard (Hu et al. 2010). The long-term evolution of natural processes combined with short-term processes produce a passive integration effect for the ecological situation of the Longfeng wetland (Wang et al. 2005).

Table 1. Construction characteristics of land-use types from 1990 to 2011.

Land-use type	1990		2000		2011	
	area/km²	proportion/%	area/km²	proportion/%	area/km²	proportion/%
Wetland	60.00	49.12	55.37	45.33	44.92	36.77
Water	11.48	9.40	7.80	6.39	11.38	9.32
Built-up land	19.80	16.21	20.11	16.46	28.39	23.24
Cropland	18.81	15.40	11.43	9.36	15.48	12.67
Grassland	2.12	1.74	1.88	1.54	4.07	3.33
Woodland	1.25	1.02	0.54	0.44	0.23	0.20
Unused land	8.69	7.11	25.02	20.48	17.68	14.47

Table 2: The analysis of land-use change patterns in the study region from 1990 to 2011.

Land-use change pattern	area/km²	proportion /%	Number of units	largest area change mode	area /km²
Early change	14.88	12.18	34	Water-swamp-swamp	4.21
Late change	19.66	16.09	31	Swamp-swamp-built-up land	5.32
Repetitive model	11.21	9.18	31	Cropland-unused land-cropland	2.41
Stable model	61.94	50.71	7	Swamp-swamp-swamp	35.78
Constantly change	14.46	11.84	133	Cropland-unused land-built-up land	1.76

Human factors: Population growth, urbanization and industrialization prompted significant and indisputable wetland change (Yang et al. 2009). Population growth and urbanization acceleration brought a certain potential threat to the ecological security of Longfeng wetland. Socio-economic factors were the main driving forces of land-use change, and they were significantly greater than the natural factors at small spatial and temporal scales (Yang et al. 2009). Based on the analysis of the Statistical Yearbook data in Longfeng district, this paper revealed the mechanisms of the man-land relationship evolution rule in Longfeng wetland.

1. Economic development factor: The urban land-use change generated by economic development primarily occurred through industrial restructuring changes (Peng et al. 2011). The Statistical Yearbook data analysis showed that from 1990 to 2011, the annual regional GDP increased from 1.04 billion yuan to 108.14 billion yuan. Primary industry increased from 0.09 billion yuan to 1.6 billion yuan; secondary industry increased from 0.36 billion yuan to 58.03 billion yuan; and tertiary industry increased from 0.59 billion yuan to 48.51 billion yuan (Fig. 3). The second and third industry growth rates were much larger than the primary industry growth rate. Three major phases of urban construction have occurred since the Daqing oilfield discovery in 1959. Following the 1990s, the urbanization process was much more rapid, particularly in the recent years, with the implementation of the strategic goal of constructing a high-tech northern city (Hu et al.2011). Further urban acceleration vastly increased demand for land, resulting in a reduction of agricultural land. Agricultural labour forces were moved into secondary and tertiary industries, thus enhancing the speed of growth. Additionally, the rapid development of the tertiary industry increased urban construction and expanded the land urbanization trend. Reclamation farming in wetlands and the construction of a breeding base received some economic return but led to the sharp decline of natural resources in the Natural Reserve and the surrounding areas, further damaging the environment. Following the establishment of the Natural Reserve in 2003, wetland resources obtained some protection, and the speed of wetland loss slowed. Coordination between the Wetland Natural Reserve and the development of the surrounding regional economy was vital to strengthening the wetland resource protection in the future.

2. The population factor: Demographic factors are vital socio-economic indicators for human factors. The population in Longfeng district increased from 137,800 to 185,700 from 1990 to 2010. The total population increased by 47,900, and the urban population increased from 110,700 to 167,400 (Fig. 4). The rural population decreased from 27,100 to 18,300, mainly due to rapid economic development in the Longfeng district and a large number of farmers moving into the city to work in secondary and tertiary industries. As the population grew, demands for the construction of urban residential (Peng et al. 2011), business and industrial structures also grew (Fig. 5). Additionally, Daqing city was becoming a new mining city, with petroleum and petrochemical sites built on swamp and grassland (Zang et al. 2007). The ex-

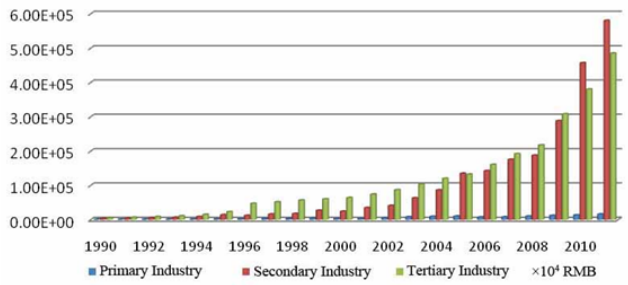

Fig. 3: GDP of Longfeng District (1990-2011).

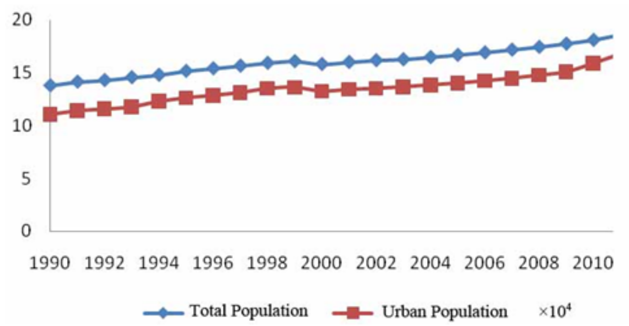

Fig. 4: Population variation of Longfeng district (1990-2010).

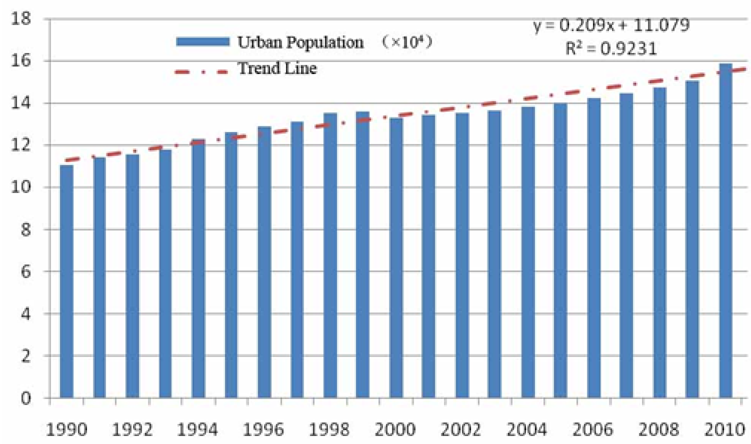

Fig. 5: Urban population changes of Longfeng wetland (1990-2010).

pansion of the city, the concentration of the population, and the expansion and acceleration of urban construction and land conversion resulted in increasing land use pressure in Longfeng district and the subsequent development and utilization of wetland resources. The relationship between the wetlands (rivers, lakes and ponds) and the urbanization process must address adverse effects on wetlands, including those from industry and other human factors, while considering sustainability enhancements within the Longfeng Wetland Nature Reserve.

3. The policy factor: The policy factor may act as an incentive mechanism or a constraint mechanism (Peng et al.2011). A land-use type designated under a specific environment policy and economic system impacts the development of the social economy, transportation, conservation and other aspects. There is an increasing pressure on the entire wetland ecosystem under accelerating urbanization due to Daqing city's strategic objective of constructing a high-tech north modern city and the implementation of the urban development strategy of "movement eastward and expansion northward" (Hu et al. 2011). Adjustments to the land-use policies for agriculture, forestry and animal husbandry should be introduced gradually, with more attention focused on positive ecological policy and converting farmland to forest and grass. Protection of lake and wetland resources should be improved through coordinating ecological needs with development needs. Coordination will enhance regional ecological balance and function, thereby attaining maximum ecological, social and economic benefits.

RESULTS AND DISCUSSION

Based on remote sensing images in various periods, with the assistance of RS, GIS and GIAT, quantitative information were acquired and analysed with the space-time evolution model of land use from 1990 to 2011 in the Longfeng Wetlan Natural Reserve of Daqing city. Driving factors of accelerated urbanization were discussed, basic data and suggestions were provided for future wetland protection in the accelerated urbanizing areas.

Swamps occupied the largest proportion of land and constituted the landscape matrix of land-use patterns. Swamps exhibited a trend of decreasing area over time, whereas, built-up land exhibited an increasing trend. Farmland and wetland were the main sources of conversion. Cropland area, water and grass area initially decreased in area but then increased, whereas unused land first increased in area and then decreased.

The stable pattern occupied the largest area, and the largest area change mode was "swamp → swamp → swamp," which was mainly distributed in the core area. The repeated model was the smallest change pattern and only occupied 11.21 km^2. "Cropland → unused land → cropland" was the largest area change mode of the repeated change pattern. The complexity of the mechanisms driving the space-time evolution of land use was reflected in these patterns. "Unused land → cropland → built-up land" was the largest area change mode of continuous change pattern, followed by "cropland → unused land (saline-alkali soil)". The fragility of the natural environment and the constantly deteriorating weather conditions, combined with human factors, played a leading role in this land-use change pattern.

The rapid degradation of the Longfeng wetland Natural Reserve is a microcosm of wetland degradation in the urbanized areas of Northeast China. The rapid development of the oil industry and the resulting social economy, accompanied by an increasing population since 2000, were the main drivers of urban land expansion in Longfeng district. Wetlands were threatened, damaged and devastated as urban roads and other infrastructures were built in and around them. Ecological safety pressures began to flourish with the establishment of Natural Reserve in 2003. The Natural Reserve provides a level of wetland damage control, but additional attention should be paid to correctly coordinate wetland reserve protection with surrounding economic development to strengthen the wetland resource reserve zone in the future.

ACKNOWLEDGEMENTS

Financial support for this paper was kindly provided by the Scientific and Technological Cooperation Projects of Heilongjiang Province,China (HZ201315), Natural Scientific Foundation of Heilongjiang Province (Grant No. D201410), Natural Science Foundation of Heilongjiang Province, Department Education Commission (Grant No. 12531513). We want to provide our gratitude to the editors and the anonymous reviewers.

REFERENCES

Antrop, M. 2000. Background concepts for integrated landscape analysis. Agric. Ecosyst. Environ., 77: 17-28.

Cao, X., Zhai, Q. and Guo, Z. 2005. Ecosystem services of urban wetland and its conservation. Res. Soil Water Conserv., 12:145-148.

Chen, S. 2001. Exploration Research on Geoscience TUPU. Beijing: Commercial Press.

Dong, J. and Zang S 2011. Driving force mechanism of urban land use changes in Daqing city, Northeast China. Geogr. Res., 30: 1121-1128.

Faulkner, S. 2004. Urbanization impacts on the structure and function of forested wetlands. Urban Ecosyst., 7: 89-106.

Fu, S. 2002. Remote Sensing Subject Analysis and Geoscience TUPU. Beijing: Science Press.

Gong, W., Yuan, L. and Fan, W. 2010. Temporal-spatial evolution of landscape elements in Zhalong wetland based on RS and GIS. Res. Soil Water Conserv., 17: 190-195.

Gong, W., Yuan, L. and Fan, W. 2012. Dynamic change and prediction of land use in Harbin city based on CA-Markov model. Trans. Chin. Soc. Agric. Eng., 28: 216-222.

Gu, C. 1999. Study on phenomena and mechanism of land use/cover change in Beijing. J. Nat. Resour., 14: 307-312.

Huang, X. 2008. Remote sensing and GIS-based analysis on temporal-spatial evolution of urban land use change: A case study of Changsha. Thesis, China University of Geosciences.

Hu, Y., Da, L., Xu, D., Ma, L., Yinyou, J. and Dulin, S. 2010. Current analysis on water quality and prevention of pollution about Daqing Longfeng Wetland Natural Reserve. Territory & Natural Resources Study, 5: 53-54. doi: 10.3969/j.issn.1003-7853. 2010.05.023

Hu, Y., Da, L., Xu, D., Miao, D., Ding, C. and Zhu, N. 2011. Change in landscape pattern of urban-lake wetland in Daqing City during rapid urbanization. J. Northeast For. Univ., 39: 75-78. doi: 10.3969/j.issn.1000-5382.2011.01.024.

Li, J. and Zhuang, D. 2001. Theories and systems of geo-spatial data integration. Prog. Geogr., 20: 137-145.

Li, X., Fang, C., Huang, J. and Mao, H. 2003. The urban land use transformations and associated effects on eco-environment in northwest China arid region: A case study in Hexi region, Gansu province. Quat. Sci., 23: 280-290.

Li, X., Peng, W. and Cao, T. 2002. The analysis of development of Shunyi County in Beijing from TUPU of remote sensing information. Geoinf. Sci., 4: 55-60.

Li, Q., Yu, X. and Li, J. 2005. Analysis on wetland use change in Zhangdu watershed, Hubei province. Resources and Environment in the Yangtze Basin, 14: 600-604.

Liu, S. and Wu, C. 2000. A GIS-based model of urban land use growth in Beijing. Acta. Geogr. Sin., 55: 407-416.

Liu, X. 1997. The wetland resources and its sustainable utilization on the Songnen-Sanjiang plain. Geogr. Sci., 17: 451-460.

Peng, Y., He, B., Huang, S., Chen, G. and Han, J. 2011. Analysis of urban land expansion and its driving forces in Beibei District, Chongqing Municipality. Resour. Sci., 33: 704-711.

Ren, Y., Li, F., Li, J. and Ren, Y. 2011. The function of Harbin Songbei urban wetland. Environ. Sci. Manag., 36: 94-97.

Wang, C. 2009. Research on land use changes evaluation and optimization supported by eco-environment information atlas-spatial analysis technique in Songnen Plain. PhD Thesis, Jilin University.

Wang, J., Liu, X. and Chen, J. 2005. Study on the ecological characters of wetland degradation and the wetlands conservation measures in Daqing City. Wetland Sci., 2: 143-148.

Weng, Q.H. 2002. Land use change analysis in Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling. Environ. Manag., 64: 273-284.

Yang, Z., Wu, C. and Liu, Y. 2009. Evaluation of frangibility of wetland in rapidly urbanized areas: A case study of Hangzhou Bay Wetland. Resour. Sci., 31: 243-249.

Zang, S., Ji, S., Li, Y. and Feng, Z. 2007. Atlas analysis of land use/cover change process in a resource-based city. J. Beijing For. Univ., 29: 232-237.

Zeng, H., Gao, Q. and Chen, X. et al. 2010. Changes of the wetland landscape in Shenzhen City from 1988 to 2007 and the driving force analysis. Acta. Ecol. Sin., 30: 2706-2714.

Zhang, G., Deng, W., Zhang, H., Song, K. and Li, H. 2010. The TUPU analysis of land use pattern in Xinkai River Basin. Acta. Geogr. Sin., 65: 1111-11120.

Zhang, M., Shi, T. and Wang H. 2007. Change of wetland landscape in Kaifeng City and its landscape conservation. Res. Soil Water Conserv., 14: 198-201.

Zhang, S., Wang, Z. and Zhang, J. 2007. Analysis of landscape ecological features on watershed wetland and application of landscape characteristic index: Illustrated with Yanshan River watershed and Xixi wetland in Hangzhou. J. Zhejiang Univ. Eng. Sci., 41: 1053-1060.

Zheng, X., Li, C., Huang, G. and Yang, Z. 2008. Research progress in effects of urbanization on wetland ecosystem in watershed. Wetland Sci., 6: 87-95.

Zheng, Z., Li, H., Zhou, Z., Xu, Y. and Teng, M. Landscape changes of Wuhan wetlands in 1978-2007 with the process of urbanization. Chin. J. Ecol., 28: 1619-1623.