Monitoring land use dynamics for ecological degradation assessment in the rim zone of North China using MODIS and Land TM data

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Abstract: Within North China there is a special rim zone characterized with a mixture of crop farming and herd grazing. Due to intensive land use for cropping and grazing, natural ecosystems in this semi-arid zone have been seriously destroyed in the past decades. Several strong sandstorms in recent years swept through the zone to invade into Beijing the capital of China and other big cities in North China. It has been commonly agreed that the sandstorms are the direct results of landscape ecological destroy in Northwest China, Inner Mongolia and Mongolia Plateau. The ecological degradation and desertification are the core issues concerned from both inside and outside China especially Japan and Korea. In order to monitor the ecosystem development and its dynamics in the zone and in the Northwest China Plateau for possible programs of environmental improvement, many academic efforts have been on the way toward the zone. The current study at our lab is part of the efforts in China. The objective of the study is to monitor the land use changes in last twenty years in the rim zone. ArcInfo GIS has been used as tool to establish a spatial database for the social-economic and natural conditions of the zone. Remote sensing (RS) data especially MODIS and Land TM images have been used for land use mapping. Integrating GIS with RS techniques, we analyze the land use dynamics of the zone, which has above 200 counties spreading in Qinghai, Gansu, Shaanxi. Shanxi, Hebei, Inner Mongolia, Liaoning, Jilin, and Heilongjiang provinces. The zone can be divided into three sub-regions for detailed examination: the east, the middle and the west. The result indicates that farmland in the zone expands 3.12% from1985 to 2000, while rangeland as a contrast reduces 3.44% during the period. On the other hand, the occupied area of settlements (villages and towns) increases up to 11.61%. All these imply that intensive anthropogenic activities have been the forces driving the landscape ecosystem in the zone to change dramatically in the recent decades. It is very urgent to administrate crop farming and herd grazing for a sustainable development in the zone where ecosystem has been very fragile.

Keywords: land use, rim zone, semi-arid region, landscape ecology, crop farming, herd grazing, geoinformatics, remote sensing.

Ⅰ. INTRODUCTION

Environmentally and climatologically, the Earth is a system. Changes of environments and landscapes in one part of the Earth will have some effects on the others. To understand the changes of the giant system in the last decades and their potential impacts on mankind in the next future, many efforts have been devoted to study the environment and terrestrial ecosystem of the Earth system [1]. Geographically North China is very important in governing the global system and its dynamics. The rim zone within North China is agriculturally characterized with a mixture of crop farming and herd grazing. In the south of the rim zone is so-called agricultural region of China, feeding the Chinese and breeding the Chinese culture. Outside the rim zone is so-called grassland pasture region with nomads in the past, who have been settled down in recent decades. Due to intensive land use for cropping and grazing, natural ecosystems in this semi-arid zone have been seriously destroyed in the past decades. Several strong sandstorms in recent years swept through the zone to invade into Beijing the capital of China and other big cities in North China [2][3]. The impacts of the sandstorms were not only limited within China but also extended into the northeast Asia. It has been commonly agreed that the sandstorms are the direct results of landscape ecological destroy in Northwest China, Inner Mongolia and Mongolia Plateau [2]. Due to its importance of geographical location as the juncture between North China and the Northwest China Plateau, the rim zone has attracted many concerns from scientific, political and public circles. The ecological degradation and desertification are the core issues in these concerns from both inside and outside China especially Japan and Korea.

In order to monitor the ecosystem development and its dynamics in the zone for possible programs of environmental improvement, many academic efforts have been on the way toward the zone. The current study at our lab is part of the efforts in China. The objective of the study is to monitor the changes of land use and land cover in last twenty years in the rim zone. Emphases are given to the changes of farmland for cropping and grassland pasture for cattle grazing.

Ⅱ. METHODOLOGY

A. The rim zone and its situation

The rim zone is a transaction region in North China. The feature of agriculturally transforming from cropping into pasture grazing makes the zone very unique not only in China but also throughout the world. Annual precipitation of the zone is usually around 200mm. There are total 200 counties and banners (local administrative unit of China) in the zone,

with a territory of 707000 km^2. Geographically the rim zone can be divided into three sub-zones: the east, the middle and the west. The east sub-zone is consisted of 47 counties and banners, mainly locating in west Liaoning, north Hebei, west Jilin, west Heilongjiang and east Inner Mongolia. The middle sub-zone has 96 counties and banners, spatially distributing in south Inner Mongolia, north Hebei, north Shanxi, north Shaanxi and east Gansu. The west sub-zone has 57 counties and banners, mainly in west Shaanxi, south Gansu, east Qinghai and south Ningxia.

Population of the rim zone is totally about 60 million, with a density of 85 person/km^2. Among the population, above ¾ (46 million) reside in rural villages as farmers or herders. Total output of rural economy was RMB¥194.6 (US$23.7) billion in 1995 and RMB¥214.3 billion in 2000, with an annual growth of 1.67%, which is much lower than the annual growth of entire China (7%). Annual net income of rural resident in the zone is very low: only RMB¥408 (US$51) per capita in 1995 and RMB¥1141 per capita in 2000. The net income level is only about haft of entire China average. Rural poverty of the rim zone has long been well known in China. Poor living conditions and few ways for better life make rural farmers in the rim zone to focus their attention on the land. Consequently the increase of land use intensity in the zone has aggravated the serious environmental and ecosystem degradation.

B. Remote sensing data and image processing

In the study, we mainly use Landsat TM images together with MODIS data as the data sources for identification of each type of land use and land cover in the rim zone. About 50 TM images are used, acquired in two years: 1985 and 1999. Since land cover change is defined as the change of specific type of land cover in a time period, the detection of such change through interpretation of remote sensing images is simply to identify the type of land cover in the two years for comparison of its change in area and quality. To match the geographical location of the images into a specific coordinate system, we select Albert conic projection for geometric correction, which can be done through georeferencing with a number of control points. In each image we obtain 20-40 control points for geometric correction. Polynomial model with order of 2 is selected as geometric correction model. Nearest neighboring method is used to resample the pixel values for the output file.

C. Types of land use/covers for image interpretation

The system developed by Liu [4] is used in the study as the types of land use and land cover. The system is consisted of 6 types: farmland, forestland, grassland, water body, urban and roads, and others. Farmland is defined as the cropping land for such field crops as rice, wheat, maize, sorghum, potatoes and so on. Farmland in China is generally consisted of two sub-types: water farmland mainly for paddy rice and dry farmland for wheat, corn, etc. Forestland is the land with arboreal trees and woodland is the land with shrubs and low trees. Grassland is mainly covered with various grasses. In our study, we further divided grassland into three sub-types: sparse grassland with low grass cover rate, moderate grassland with moderate grass cover rate and dense grassland with high grass cover rate. The type of urban and roads is mainly composed of three sub-types in our region: towns, villages and roads. Though Liu [4] divided water body into several sub-types such as channels, lakes, ponds, and so on, we only use them as one type in the study because our region is a semi-arid region with very few water body areas. Among the type of others, we identify several sub-types according to the special features of land cover in the rim zone: gobi, sandy land, salty land, wetland, bare soil and bare rock. Gobi is an important landscape in west China, defined as the land covered dominantly with small stones or rock particles with diameter of 2-10cm. Except wetland, these sub-types of other land covers represent a negative direction of landscape ecosystem development.

III. RESULTS AND ANALYSIS

A. Changes of land uses in the rim zone

Our monitoring results (table 1) indicate that land uses in the rim zone had experienced dramatic changes in last two decades. One obvious feature is the expansion of farmland. The cultivated land area increases 6682 km^2 between 1985 and 1999, accounting for 3.12% cultivated land area in mid-1980s. Expansion of cultivated land is actually in cost of grassland, which has shown a similar percentage of decrease during the period. In 1985 the zone had about 31525.28 km^2 of grassland but the type of land use dropped to 301152.1km^2 in 1999, with a decrease rate of 3.44% (table 1). Another feature revealed in table 1 is the rapid expansion of towns and villages. This implies that pressure of population has made the occupation of man-made settlement steadily expanding to meet the essential living demands of local people. As a cost, the area of wetland and water bodies is in disappearing. The increase of forestland is the only one encouraging feature favorable to ecosystem sustainability in the rim zone. This increase in forestland is probably due to the campaigns of re-foresting the landscape in the region to harness the desertification and environmental degradation.

Table 1. Changes of land uses in the rim zone since mid-1980s.

Land use	Area in 1985 km^2	Area in 1999 km^2	Change in %
Farmland	214133.4	220815.4	3.12
Forestland	119665.8	121739.6	1.70
Grassland	311525.3	301152.1	-3.44
Water and wetland	10799.8	10298.2	-4.87
Towns and villages	12716.3	14386.6	11.61
Others	38438.5	38887.9	1.16

Tables 2 and 3 shows land use changes in two typical administrative units of the zone: table 2 for Tolon County and table 3 for the Left Kolchin Rear Banner. More detailed classification of land uses have been employed for the monitoring in the two units. In Tolon County, the most obvious change is the bare soil. This type of land cover was only 5.3km^2 in 1985, while it expanded into 20.3km^2 in 1999, with an increase of 2.8 times. Sharp changes can also be seen in woodland, sandy land and wetland. The increase of woodland in this county is 1.4 times between 1985 and 1999. This increase is probably attributed to degradation of

forestland into woodland in the evolution of local ecosystem. As shown in table 2, forestland decreases from 312.2km^2 in 1985 to 218.1km^2 in 1999, with a reduction of 94km^2, which is larger than the increase of woodland area (72km^2) during the period. Of course, the efforts to forest the landscape may also have some positive contributions to the increase of woodland. With regarding to ecosystem degradation, the expansion of sparse grassland is exactly attributed to the reduction of moderate grassland. During this period, sparse grassland increased about 30km^2, while moderate grassland decreases 339 km^2. Since the increase of sparse grassland is much smaller than the decrease of moderate grassland. The degradation of grassland ecosystem is even more severe. This implies that only small part of the moderate grassland degrades into sparse grassland. Most degrade into sandy land or bare soil. Quality of the landscape is also not optimistic in the county. The salty land expanded above 10 times during the period. In 1985 the county only had about 25km^2 of salty land. However, this type of land cover has expanded to 287km^2, with an increase of 10.67 times. The disappearance of many wetland areas also confirms the severe degradation of landscape environment and ecosystem in the county. The sharp changes in main types of land cover in the county have reached the level of threatening the sustainability of landscape environment ecosystem.

Table 2. Changes of land uses in Tolon County.

Types of land use	Area in 1985 km^2	Area in 1999 km^2	Change in %
Towns	4.1	5.4	32.62
Rural villages	28.7	31.1	8.49
Sparse grassland	257.2	287.1	11.65
Moderate grassland	965.3	626.1	-35.13
Dense grassland	558.0	408.5	-26.79
Woodland	50.7	122.9	142.74
Forestland	312.2	218.1	-30.16
Dry farmland	1020.9	970.7	-4.91
Bare soil	5.3	20.3	281.27
Sandy land	172.5	346.0	100.59
Water bodies	6.7	8.5	27.30
Wetland	157.1	11.6	-92.62
Salty land	24.8	286.9	1067.11

Table 3. Changes of land uses in Left Kolchin Rear Banner

Types of land use	Area in 1985 km^2	Area in 1999 km^2	Change in %
Towns	6.7	8.5	27.85
Rural villages	173.6	221.6	27.65
Sparse grassland	295.7	190.1	-35.70
Moderate grassland	4803.4	4435.0	-7.67
Dense grassland	1863.1	2010.0	7.89
Woodland	75.0	106.8	42.32
Forestland	332.5	180.6	-45.70
Dry farmland	1415.4	1619.1	14.39
Bare soil	0.5	0.5	0.00
Sandy land	1112.4	1170.6	5.24
Water bodies	226.5	233.7	3.17
Wetland	665.0	779.4	17.20
Salty land	328.9	340.6	3.56

As a contrast to the severe degradation, the change of land use and land cover in Left Kolchin Rear Banner since mid-1980s is much better in terms of environmental development and ecosystem evolution (table 3) though some similar degradations can also been seen in the Banner. The land use/cover change limits to below 50% in all types between 1985 and 1999, while the change in Tolon reaches to above 10 times for salty land and 2.8 times for bare soil. According to our monitoring results, the Banner has quite stable bare soil area during the period. Only 0.5km^2 of bare soil can be identified on the images of the Banner in 1985 and this area keeps unchanged in 1999. One interesting feature in land use/cover change in the Banner is probably the expansion of dry farmland. In 1985 this type of land cover was 1415km^2. It increases to 1619km^2 in 1999, with an increase of 203km^2. This increase may be contributed by the reduction of sparse grassland and moderate grassland. The two types of grassland reduces 105km^2 and 368km^2 respectively during the period. This means that the pressure of population in the Banner has forced many grasslands be reclaimed into cropping land. The expansion of farmland is accompanied with increase of rural village areas. During the period, area of rural villages increases 48km^2, with a rate of 27.65%. Such expansion of cultivated land may not be an encouraging direction of environmental development and ecosystem evolution in the Banner where rainfall is only about 200mm and the landscape is a typical semi-arid region.

B. Land use change in the three sub-zones

Table 4 compares the land use change of the three sub-zones since mid-1980s. Farmland in China includes two types: water farmland and dry farmland. During the period, water farmland in the rim zone experienced a reduction of area. Totally the area reduced 131km^2, with a rate of 4.52%. This is mainly contributed by the sharp reduction in the middle sub-zone, which has a reduction of 322km^2 during the period. The reduction in the west sub-zone is only 5.5km^2, with a rate of 2.23% (table 4). Spatial distribution of water farmland in the middle sub-zone is mainly along the Yellow River valley. The sharp reduction of water farmland during the period may be the direct results of water shortage in the region. Yellow River is the second important river in China. However, in recent two decades the river has been facing severe problem of over use of its limited water resources, which has made the river to break its flow in lower reaches to the sea by several times. The farmland for paddy rice is one of the reasons leading to over use of the river's limited water resources. Facing the shortage of water supply, many farmlands for paddy rice in the rime zone, where the environment is not suitable for paddy rice planting, have been changed into dry farmland for such crops as wheat, sunflower and sugar beet. However, the east sub-zone still has an increase of water farmland area during the period. This probably is due to the relatively sufficient water resources in the sub-zone along the Daqinganling Mountains.

Another factor that may be important in shaping the direction of ecosystem evolution is reclamation of grassland and forestland/woodland into farmland. During the period between 1985 and 1999 the area of dry farmland in the rim zone increases 6813km^2, with an increase rate of 3.24%. Dry farmland expands more in the east sub-zone than in the middle

sub-zone or the west sub-zone. The east sub-zone has an increase of about 6% during the period and it is below 2% in both middle and west sub-zones. Together with water farmland, we can conclude that reclamation in the east sub-zone is much more severe than that in the middle and the west sub-zones. Examination of grassland area changes in the three sub-zones enables us to touch the scenario of intensive reclamation in the rim zone and makes us to concern the sustainable development of grassland ecosystem in the zone.

Table 4. Land use change rate in the three sub-zones

Land use type	East (%)	Middle (%)	West (%)
Water farmland	10.16	-43.64	-2.23
Dry farmland	5.96	1.63	1.70
Forestland	99.70	251.30	102.31
Woodland	5.31	-5.84	0.32
Sparse grassland	-19.76	6.96	0.47
Moderate grassland	-8.07	-2.98	-3.57
Dense grassland	0.97	-17.38	1.64
Water bodies	-16.20	19.68	8.79
Wetland	-1.87	-4.78	-0.67
Towns	12.22	23.79	14.43
Villages	9.94	15.67	8.17
Roads	48.04	46.41	12.26
Sandy land	1.79	6.18	-7.94
Gobi	36.54	0	23.43
Bare soil	50.32	-36.32	1.29
Bare rock	-8.9	23.58	-2.93
Salty land	-1.5	2.15	-2.75
Others	-17.72	0	-8.08

All three types of grassland have experienced a decrease in area during the period between 1985 and 1999 (table 4). The reduction rate of both moderate and high cover rate grasslands is high up to 4-5%, which is higher than the increase rate of dry farmland. Total decrease of grassland in the rim zone reaches the magnitude of 10372km^2. Analyzing the table 4, we find that the decrease of grassland can be associated with the expansion of such types of land use/cover as dry farmland, village, sandy land, and bare surfaces. Since grassland represents the dominant natural ecosystem in the rim zone, the reduction of its areas reflects the severe status of current ecological conditions for sustainable development of the fragile economic system. Therefore, ideology of sustainable development and ecosystem conservation must be emphasized in planning local economic development.

In the east zone, both sparse and moderate grasslands have shown a dramatic drop of areas. Only dense grassland shows slight increase. However, the increase is much smaller than the decrease. As indicated in table 4, the areas of sparse and moderate grasslands have a decrease of 6395km^2, with a rate of 11.05% (the decrease rate for sparse grassland is 19.76%).

Another scenario of grassland degradation can be observed in the middle and the west sub-zones. Remarkable deduction of grassland area can be seen in the types of dense and moderate grasslands, while the area of sparse grassland has a change of increase during the period. In 1985 the middle sub-zone had areas of 24945km^2 and 49611km^2 respectively that can be classified as dense and moderate grassland. The areas dropped toward 20612km^2 and 48133km^2 respectively in 1999. Thus the area decrease is 1478km^2 and 4336km^2 respectively for the two types of grassland, with a rate of 3% and 17%. The sharp decrease of dense grassland in the middle sub-zone confirms the argument of severe ecological degradation currently existing in the grassland landscape of the zone. Similar environmental degradation can also be seen in the west sub-zone, as shown in table 4, though the severity is not as big as that in the middle sub-zone.

Ⅳ. CONCLUSION

Integration of remote sensing with GIS techniques is employed in the study to detect the changes of land use/cover in the rim zone within North China in recent two decades. One obvious feature is that farmland increases steadily while the grassland decreases accordingly. This is due to the reclamation of grassland for cropping. During 1985-1999, farmland in the rim zone increased 6682 km^2, with an increase rate of 3.12%. As a contrast, grassland decreased 10373 km^2 during the period, with a rate of 3.44%. Therefore, it can be concluded that the expansion of cropping in the zone is in cost of grassland shrinking. Climatologically the zone is a semi-arid environment, hence unfavorable for extensive cropping especially paddy rice planting. However, the east part of the zone has an increase of water farmland by up to 10%. Grassland ecosystem and semi-arid environment has been remarkably destroyed under the intensive and unreasonable use of the limited natural endeavors in the rim zone. Fortunately the environmental degradation in the zone has been highly concerned in China. Some actions such as returning farmland into its original grassland and forestland have been on the way to release the degradation in the zone.

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