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Landscape Effects of Land Consolidation Projects in Central China —A Case Study of Tianmen City, Hubei Province

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Abstract: The goal of land consolidation in China is still to develop agricultural production. The study of landscape effects of land consolidation projects (LCPs) faces many difficulties because of the lack of government's interest and data. This paper, taking Tianmen City of Hubei Province in Central China as an example, presents a methodology for analyzing landscape effects of LCPs by GIS and Fragstats3.3. It describes landscape effects with indexes of Patch Density (PD), Largest Patch Index (LPI), Landscape Shape Index (LSI), Interspersion and Juxtaposition Index (IJI), Aggregation Index (AI), and Shannon's Diversity Index (SHDI), showing more regular shape, simpler structure and less habitat diversity after LCPs. It computes ten landscape indexes of four categories of patches including Cultivated Land, Road, Water Channel, and River and Pond. The indexes show that 1) cultivated land becomes more fragmental in patch area, less irregular in patch shape and more concentrated in block; 2) the transport capacity of roads and irrigation and drainage capacity of water channels have been improved; 3) the landscape change of river and pond can be summarized as decreasing scale, more regular shape, reducing connectivity and diversity of the class. LCPs can facilitate agricultural production as well as protect cultivated land and food security. However, it is doubted that the increase of cultivated land from LCPs results from the reducing in landscape diversity of water area.
Keywords: land consolidation; landscape effect; TianmenTown

1 Introduction

Land consolidation is a worldwide phenomenon. A shift in goals of land consolidation policies can be seen from initial agricultural production to rural development in many developed countries (Crecente et al., 2002). After World War Ⅱ, Germany and the Netherlands made some earlier attempts considering food scarcity. In the 1960s and the 1970s, most European countries set up land consolidation programs. With growing concern over environmental degradation in the 1980s, the goals of land consolidation began shifting from single agricultural production towards multiple purposes, including sustainable development of rural areas, environment protection and landscape values (Van Huylenbroeck et al., 1996). Evaluation for land consolidation has also been the subject of study for some authors who have considered economic, social and environmental factors as variables (Van Huylenbroeck et al., 1996; Coelho et al., 1996; Crecente et al., 2002). Landscape analysis can be regarded as one approach of environmental evaluation, which describes changes in landscape structure influenced by land consolidation with several indices and the use of GIS (Bonfanti et al., 1997).

Because of the unique history and reality of cultivated land use in China, land consolidation is still at the phase of agricultural goals. Landscape effects of land consolidation are just beginning to attract attentions. In the late 1970s and the early 1980s, household responsibility system (HRS) replaced the less efficient commune system. Although the HRS had greatly improved agricultural productivity in the early years (Lin, 1992), it had resulted in many problems, such as land fragment, declining of area per household from 0.61ha in 1986 to

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0.53ha in 1999 (Tan et al., 2006), and lack of long-term investment in land (Wu et al., 2005). Since the middle 1990s, the Chinese government has implemented a series of policies to maintain the area of cultivated land for food security, and land consolidation is one of the most important programs. From 1999 to 2004, more than 67×10^9 yuan (RMB) had been invested in land consolidation programs by the government (The Ministry of Land and Resources P. R. C., 2000–2005). Because of the problems originating in HRS and pressure to protect cultivated land and food supply, much attention has been paid to the agricultural goal of land consolidation, i.e., improving productivity, while its environmental impact has generally been neglected. Moreover, studies on the environmental impact of land consolidation have many difficulties in China because of the fact that most LCPs are just the beginning and few of them have been completed more than 3 years. Accordingly, Chinese researchers mainly focused on the evaluation of economical and social variables of LCPs (Zhang and Chen, 2002; Liu and Zhou, 2003; Zhang and Chen, 2003; Zhang and Yang, 2005; Wang et al., 2005; Wang et al., 2006), and there are few researches on environmental variables by landscape analysis (Li et al., 2006; Yang et al., 2005).

Bearing this context in mind, this paper, taking Tianmen City of Hubei Province in Central China as a case, presents a methodology for the landscape analysis of the effects of LCPs. Landscape indexes of the landscape mosaic as a whole and each patch type (class) in the mosaic are compared, so as to analyze the landscape effects of LCPs and propose some general suggestions.

2 Study Area

The study area is located in Tianmen City (30°23′–30°54′23″N, 112°35′11″–113°27′30″E) of Hubei Province in Central China (Fig. 1), which is a typical hilly landscape and rich in water resources, with an average annual precipitation of 1108mm. It is adjacent to rivers both in the south and the north, and there are Great Zhangjia Lake, Shijia Lake and other water systems around it. The soil is mainly yellow-brown soil and paddy soil. In 2003, it had a population of 37,780, a total land area of 1241.15ha, and a cultivated land area of 722.90ha. The average net income per capita for recent five year was 3205 yuan (RMB). The study area has been influenced by different types of land improvement works, such as agricultural production structure adjustment, reclamation and land consolidation, which have different impacts on the landscape.

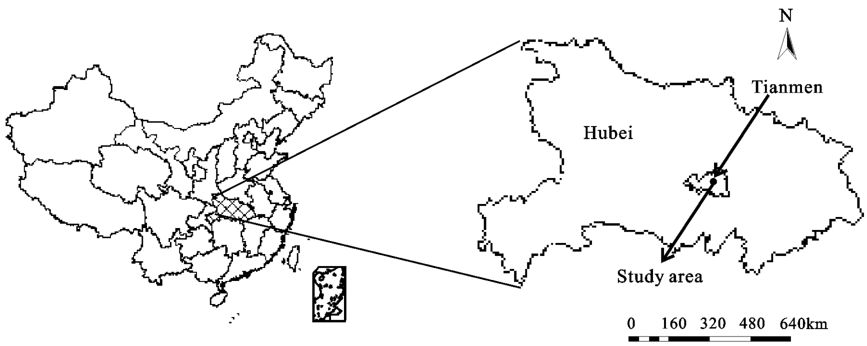

Fig. 1 Sketch of location of study area

The LCP of Tianmen City was sponsored by Land Consolidation Center of Hubei Province in 2003. It was planned and designed by a professional working team from the center and Land Resource Management Department of Huazhong Agriculture University in 2004, and was put into force in 2006. According to the national standards for LCPs plan, land use types in LCPs Plan are mainly the cultivated land (including slope cultivated land and level cultivated land), water channel and irrigation facilities land, and roads land. Specially, the case is located in Jianghan Plain, where there are many rivers and water ponds, so rivers and ponds are also important land use types. Some areas with scattering households in the study area are out of LCPs because of rules of national standards.

3 Data and Methods

3.1 Data

The direct data for landscape analysis were obtained from Current Land Use Map (made by Land Consolidation Center of Hubei Province in 2003) and Map of Land Consolidation Plan (made by Land Consolidation Center of Hubei Province and Land Resources Management Department of Huazhong Agriculture University in 2004) of the study area, both with a scale of 1∶4000. The first map gives the land use information before LCP, and the second map gives the information after LCP. The most common software to plan and design land consolidation projects in China is AutoCAD, so it was also used in Tianmen case. Frastas3.3, which is a spatial pattern analysis program for categorical maps, was applied to analyzing the landscape effect. Therefore, data of arc-grid were needed to meet Fragstas3.3.

3.2 Methods

A landscape is usually composed of many elements, which are known as patch, corridor and matrix. Patch is the basic element or unit that makes up a landscape. Corridor is a linear landscape element that can be defined on the basis of structure or function. In land consolidation area, the landscape changes are mainly caused by four kinds of work: readjusting cultivation land blocks and ponds, building water channel systems and irrigation facilities, constructing road systems, and planting trees beside main roads. The methods of landscape effects analysis of land consolidation can be summarized as follows.

3.2.1 Definition of patches and corridors

Considering landscape features of land consolidation area, roads (width≥2m) and water channels (width≥2m) are defined as corridors. Cultivated land blocks surrounded by corridors are defined as one class of patches, and rivers and ponds as another class of patches. Roads and water channels with a width less than 2m are defined as parts of cultivated land blocks, while tree-protecting roads with a width less than 2m as roads.

3.2.2 Reclassification of land use units

To focus on the main types of landscapes, as well as to meet the need of GIS data accuracy, small land use unites with point distribution are defined as patches or corridors and then reclassified as four unites of cultivated land block (L), road (R), water channel (W), and river and pond (P) (Table 1).

Table 1 Landscape re-classification of all land use units

Old class	Definition	New class
Level cultivated land block	Patch	Cultivated land block (L)
Road within 2m	Patch	Cultivated land block (L)
Water channel within 2m	Patch	Cultivated land block (L)
River	Patch	River and pond (P)
Pond	Patch	River and pond (P)
Water pump	Patch	River and pond (P)
Road beyond 2m	Corridor	Road (R)
Tree-protecting road	Corridor	Road (R)
Simple bridge	Corridor	Road (R)
Water channel beyond 2m	Corridor	Water channel (W)
Culvert	Corridor	Water channel (W)
Water fall	Corridor	Water channel (W)
Water inlet sluice	Corridor	Water channel (W)
Water diversion sluice	Corridor	Water channel (W)

3.2.3 Selection of landscape indexes

Several landscape variables are considered, including area and density, shape, contagion and interspersion and diversity. These variables are the bases of indexes which describe the function of landscape structure. Specific landscape indexes and index ranges are listed in Table 2.

Table 2 Landscape indexes and definitions

Matrix type	Index	Range
Area and density	Percentage of Landscape (PLAND)	0≤PLAND≤ 100
	Patch Density (PD)	PD>0, constrained by cell size
	Largest Patch Index (LPI)	0<LPI≤100
	Area_Mean (Area_MN)	without limit
Shape	Landscape Shape Index (LSI)	LSI≥1, without limit
	Shape_Mean (Shape_MN)	without limit
Contagion and interspersion	Interspersion and Juxtaposition Index (IJI)	0<IJI≤100
	Aggregation Index (AI)	0≤AI≤100
	Patch Cohesion Index (COHESION)	0≤COHESION<100
Diversity	Shannon's Diversity Index (SHDI)	SHDI≥0, without limit

Note: Ranges of indexes come from help file of software Fragstas3.3

4 Results and Analyses

Two groups of matrices have been computed: the landscape mosaic as a whole (Table 3) and each patch type (class) in the mosaic (Table 4).

4.1 Diversity of landscape as a whole

Diversity of landscape as a whole can be described by indexes of PD, LPI, LSI, IJI, AI, and SHDI. The slight change of PD is the result of the increase in roads and water channels and decrease in cultivated land blocks and ponds. LSI decreased from 32.4178 to 30.6173, indicating that the landscape shape became more regular, which facilitates agricultural production but reduces contact area between patches and impedes flows of energy and materials. Along with increase in AI (from 86.8112 to 91.3845), IJI decreased from 89.8112 to 81.3845 and SHDI decreased from 0.4901 to 0.4774 (Table 3), which show that landscape structure of the whole area got simpler after LCP. It will reduce the diversity of habitats and accelerate dissemination of plant diseases and insect pests.

Table 3 Landscape diversity indexes of whole study area

Index	PD	LPI	LSI	IJI	AI	SHDI
Before LCP	179.8176	26.7215	32.4187	89.8112	86.8112	0.4901
After LCP	183.9896	26.7155	30.6173	81.3845	91.3845	0.4774

Table 4 Landscape indexes at class level in study area

	L		R		P		W	
	Before LCP	After LCP	Before LCP	After LCP	Before LCP	After LCP	Before LCP	After LCP
PLAND	19.5424	19.0214	2.0261	4.1977	5.8340	2.0737	3.3568	6.3320
PD	20.2496	30.5669	20.3166	26.5800	31.3801	28.9721	23.8033	91.9002
LPI	1.2913	0.5139	0.5663	0.5450	0.4516	0.5750	0.2275	0.8870
Area_MN	0.9651	0.6223	0.0997	0.1579	0.1859	0.2716	0.1410	0.0689
LSI	24.2629	17.1294	52.7618	54.8088	65.1372	45.4758	59.6356	34.5578
Shape_MN	1.6415	1.3160	2.0000	3.0463	3.4737	2.5927	2.7302	1.4711
IJI	59.6285	93.6847	58.0180	81.1471	62.5490	82.3737	76.7985	87.3904
AI	95.2703	98.0910	81.0885	81.3757	94.8123	69.6277	83.3683	93.1045
COHESION	89.1447	87.7009	88.7426	97.9375	97.6030	91.5499	87.6574	97.3570

Notes: L: cultivated land block; P: river and pond; R: Road; W: water channel

4.2 Cultivated land block

Different from the viewpoints of previous studies, the indexes of cultivated land block show following characteristics in this study (Fig. 2): 1) More fragmental in area. PLAND changed little, while PD increased from 20.2496 to 30.5669, and LPI decreased from 1.2913 to 0.5139 as well as Area_MN from 0.9651 to 0.6223. 2) Less irregular in shape. LSI decreased from 24.2629 to 17.1294 and there was some decrease in Shape_MN. 3) More concentrated in block. IJI increases sharply, from 59.6285 to 93.6847, and AI increased from 95.2703 to 98.0910 (Table 4).

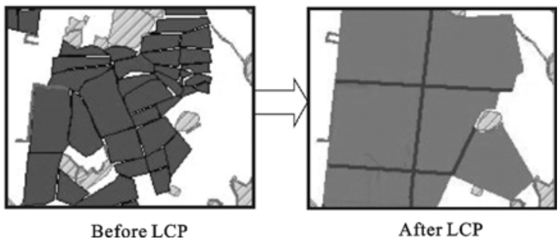

Fig. 2 Landscape change example of cultivated land block

There is a notable question that the more fragment and diversity showed by those indexes are different from the fact. As have mentioned above, only those land blocks surrounded by roads and water channels with a width more than 2m are defined as patches of "cultivated land blocks". In fact, because of the backward of basic facilities of cultivated land, just a few roads and water channels are more than 2m before LCP. According to the definition rule, many actually exist blocks that made by roads and water channels less than 2m could not be defined as one cultivated land block, but a part of cultivated land block. Therefore, the area scale of blocks before LCP had been exaggerated. However, it can be sure that the cultivated land blocks have become less irregular, and decrease of COHESION index was a result of land consolidation.

4.3 Road

Roads are corridors in the study area, which are flows of energy, mineral nutrients, and/or species. Due to the building of roads in land consolidation project, PLAND of roads landscape increased from 2.0261 to 4.1977, so as the PD from 20.3166 to 26.5800. Because of the network layout of roads, AI and COHESION have improved. The LPI decreased slightly from 0.5663 to 0.5450, and the LSI increased from 52.7618 to 54.8088 (Table 4).

The transport capacity of roads has been improved by land consolidation (Fig. 3), which helps material and energy flow within the landscape area, and facilitates the agricultural production.

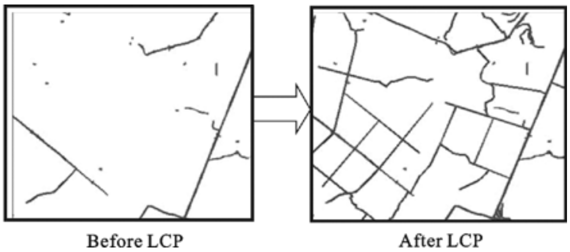

Fig. 3 Landscape change example of road

4.4 Water channel

Water channel is another kind of corridors of landscape. One of the most important goals of land consolidation is to better the water channels system, so as to improve the capacity of water resources use in farmland (Fig. 4). PLAND of water channels increased from 3.3568 to 6.3320, PD from 23.8033 to 91.9002. Just like the road system, network layout of water channel makes the AI and COHESION improve. There still some differences between roads and water channel. The LPI of roads decreases while water channel's LPI increased from 0.2275 to 0.8870, the LSI of road increases while water channel's LSI decreased from 59.6356 to 34.5578 (Table 4).

These indexes show that the irrigation and drainage capacity of water channels have been improved by land consolidation. It will help to promote the rate of water resources use and reduce production cost.

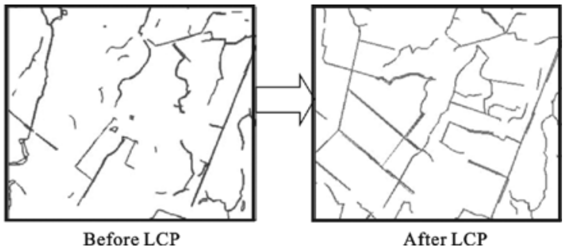

Fig. 4 Landscape change example of water channel

4.5 River and pond

River and pond is another kind of patches that compose the water system. Aiming to increase cultivated land area and improve cohesion of road and water channel network, some small ponds have been changed into cultivated land. As a result, PLAND decreased from 5.8340 to 2.0737, but LPI and Area_MN increased from 0.4516 and 0.1859 to 0.5750 and 0.2716. LSI decreased from 65.1372 to 45.4758, and Shape_MN decreased from 3.4737 to 2.5927 (Table 4). It indicates that the shape of river and ponds became more regular through human activities. However, COHESION reduced (from 97.6030 to 91.5499) after land consolidation, so does AI (Table 4). The landscape change of this class can be summarized as decreasing scale, more regular shape, reducing connectivity and diversity of landscape class from a certain point of view (Fig. 5). The river had little change comparing with the pond before and after LCP, so the paper focuses on pond (Fig. 5).

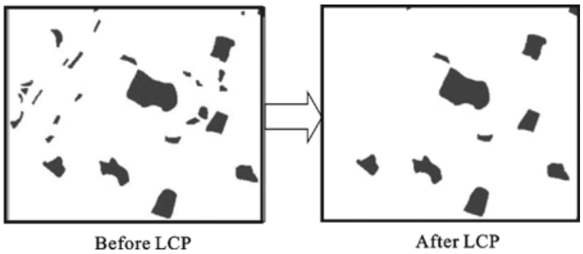

Fig. 5 Landscape change example of pond

Small ponds scattering in cultivated land, which played an important role in ecological system, are a typical landscape in Jianghan Plain, where there exist many rivers and water bodies. However, it is estimated by surveying typical LCPs that about 16%–65% of increased cultivated land originated from ponds occupied. The way is questionable to increase cultivated land at the cost of loss of landscape diversity of water system.

5 Conclusions and Discussion

Because of the unique history and reality of cultivated land use, China's land consolidation is still at the phase to raise food production capability. Landscape effects of land consolidation are just beginning to attract attention. This paper, taking Tianmen City of Hubei Province in Central China as an example, presents a methodology for analyzing landscape effects of LCPs.

Viewing landscape as a whole, the landscape structure becomes simpler after LCP. Classified landscapes show the following characteristics: 1) Cultivated land blocks became more fragmental in patch area, less irregular in patch shape and more concentrated in block. 2) The transport capacity of roads and irrigation drainage capacity of water channels had been improved by land consolidation, which helps material and energy flows within the landscape area. 3) The landscape change of river & ponds can be summarized as decreasing scale, more regular shape, reducing connectivity and diversity of landscape class from a certain point of view.

The Tianmen case is a typical LCP in Jianghan Plain, which is one of the main food-producing regions in China. The first and most important goal of land consolidation in this region is to raise food production capability. A simple and effective method is increasing arable land, roads and drainage area from ponds occupied, which is the common land use change by land consolidation in Jianghan Plain. From the case we can see that landscape effects are mainly positive and little negative, and LCP can facilitate agricultural production as well as protect cultivated land and food security. However, it is questionable that the increase of arable land is at the cost of losing water area.

It should be pointed out that landscape analysis is a kind of location pattern research, which should be achieved through much work on comprehensive mapping and image processing. Therefore, difference of dot-per-inch will impact study results.

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