Monitoring land use and landscape changes caused by migrant resettlement with remote sensing in Region of Three Gorges of Yangtze River

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Abstract: China Three Gorges Water Conservancy Project has imposed a profound impact on the change of land use and landscape patterns after the successful dam in 1997. This paper uses remote sensing techniques to detect land use dynamics and adopts a landscape approach to quantify changes in landscape patterns for two counties which have larger amount of migrants. The results show that 22.9% total region had been changed in one and half a year. Development changed most obviously during this phase; it increased by 4800.8 hm^2, about 626.6%. Arable land in this phase decreased by 18567.9 hm^2, about 27.6%. All these land use changes affected landscape patterns. Patch density increased relatively about 29.5% and contiguity index decreased by 13.9% at landscape level, reflecting landscape more fragmented. The landscape shapes index increased by 17.7% at landscape level, showing the shapes of landscape are more irregular. Particularly, the most remarkable landscape pattern changes occurred on development, orchard, grassland and arable land. The land use change, is not in the good order management, but quite different from the migrant resettlement plan. It is very important to control the scope and the expanding speed of development, afforest and regrass the area where is not suitable for agriculture development in the future.

Key words: land use; landscape pattern analysis; remote sensing; image analysis; Three Gorges of Yangtze River; migrant resettlement
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1 Introduction

The monitoring and assessment of land use and land cover is an extremely important activity for contemporary land management. A large body of current literature suggests that human land use management practices are the most important factor influencing ecosystem structure and functioning at local, regional and global scales[1~3]. Landscape composition and patterns affect key ecological transfer processes that govern the movement or flow of energy, nutrients, water, and biota over time and operate at many scales[4]. O'Neill et al. argued that a landscape approach was practical within current technologies for monitoring environmental quality over large regions and it might represent a less expensive approach than using traditional fine-scaled ground-based surveys[5].

China Three Gorges Water Conservancy Project has both advantage and disadvantage on ecological environment of the Three Gorges. After the construction of the Reservoir, its length will be prolonged 690 km along the Yangtze River, the land area inundated will be 632 km^2, and migrants will be 1200000. Ecological environment of the Three Gorges has been studied since 1980s[6], but the Three Gorge Project has quite long-term and compound effects on ecological environment. After the successful dam of Yangtze River, land use and landscape pattern changed largely due to the settlement of migrants. So measuring the effects of the 17-year settlement of migrants on ecological environment is essential for the sustainable development of the Three Gorges. As we know, monitoring and evaluating the changes of land use and landscape pattern is an important job to measure the condition and changes of ecological environment in the Three Gorges.

In order to investigate the effects of the ongoing land use dynamics and landscape pattern changes, two counties, where the land use has significant changes after the river was dammed in 1997 and the amount of migrant is large, were selected. So the aim of this paper is to detect land use dynamics and quantify changes in landscape patterns between 1998 and 2000. Remote sensing is a powerful tool that can provide information concerning the landscape, such as land

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use and land cover, and the size, form and patterns of features on the surface of the earth, and the temporal dynamics of the landscape. But paradoxically, the direct implementation of remote sensing in landscape research and its application remains relatively scarce[7].

Detection of land use changes is one of the most interesting aspects of the analysis of multi-temporal remote sensing images[8]. Bruzzone et al. proposed a supervised non-parametric technique, based on the "compound classification rule" for minimum error, to detect land cover transitions between two remote sensing images acquired at different times which allows the probabilities of transitions to be estimated directly from the images under investigation[9]. It provides remarkably better detection accuracy than the "post-classification comparison" algorithm, which does not take into account the class dependence existing between two images acquired at different times. In this paper, we also adopted the land use class dependence probabilities into the compound maximum likelihood classifier, and directly made the landscape pattern dynamics map through the multi-date remote sensing classification.

2 Methods

2.1 Study area and data

Fengjie county and Wushan county, locating on Qutang Gorge and Wu Gorge, have beautiful natural landscape. The migrant settlement project covers 18 towns of Fengjie county and 17 towns of Wushan county, about 641010 migrants, 2,436 km^2 land area, elevation ranges from 75 m to 2123 m and annual average rainfall is 1039 mm, the climate type is southeast mild monsoon climate of middle sub-tropic zone. The land use and landscape patterns have changed largely since the migrant project constructed in this region since 1998. The remote sensing data used was Landsat TM5 (path/row 126/28) of 29, September 1998 and Landsat TM7 (path/row 126/38) of 21, February 2000. The whole image size was 2521rows 3451cols, and they were geo-referenced to a 30 × 30 meter Beijing groundcoordinate grid with a nominal geometric precision of 1~1.5 pixels satisfying the multi-date image analysis. Nearest-neighbor method was used for image re-sampling in order to preserve the original digital numbers for classification purpose. According to Chinese land use classification system, we worked out the land use classification system for the Three Gorges region (table 1). A special land use type, Development, was added to the classification system; it refers to the depletion of vegetation and topsoil for the new construction migrant towns, industry and traffic, and primary farmland reclamation, but it was still left barren at the time of the image acquisition. Together with the band473 color composite image, the interpretation characters of land use types were determined (table 1).

Table 1 Land use classification system and remote sensing interpretation characters

Land use type	Interpretation characters
Paddy field	mild blue, relatively homogeneous, leaf form, usually locate on the gentle slope zone of hilly land
Arable land	light blue or red, heterogeneous, spot form, scatter at the both sides of middle mountains or hilly land
Orchard	middle crimson, heterogeneous, large irregular spot form, usually locate on the slope zone of the water system or valley
Forest	scarlet or brown red mixed gray green spot, stripe or flake form, often found on the middle mountains or hilly land
Grassland	brown or gray green, heterogeneous, irregular stripe, round or branch form, distribute on the slope zone of mountains
Development	gray white mixed light blue, large regular or irregular spot form, scatter on the slope zone near rivers and banks of ditches between mountains
Residential area	dark blue, heterogeneous, large spot or spot form with clear edges, locates the slope zone near water system or stormed cracks
Water area	black blue, homogeneous, line or stripe form

2.2 Detection of landscape dynamics by compound remote sensing classification

Let us consider couples of pixels made up of a pixel of the multi-spectral image acquired at time t_1 and a spatially corresponding pixel of the multi-spectral image at time t_2; Let such pixels be characterized by the d-dimensional feature vectors X_1 and X_2, respectively. Let $\Omega = \{\omega_1, \omega_2, \cdots, \omega_l\}$ be the set of possible land use classes at time t_1, and let $V = \{v_1, v_2, \cdots, v_n\}$ be the set of possible land use classes at time t_2. A change in the landscape considered couple of pixels is detected if the two classes ω_i and v_j, to which such pixels are assigned, are different. Assuming the probabilistic dependence between the images at the two times derives only from the dependence of the classes at the two times, and one can write the conditional joint probability:

$$p(X_1, X_2/\omega_i, v_j) = p(X_1/\omega_i)\,p(X_2/v_j) \quad (1)$$

According to the above formula, to perform the compound classification of two multi-temporal remote sensing images, the multi-variate normal distribution model was used to estimate the conditional probabilities $p(X_1/\omega_i)$ and $p(X_2/v_j)$ by the classes train samples each independently. Here, the prior joint probabilities were estimated on the local window region instead of the whole image, because the local statistics in images can differ significantly from global statistics[10], Second, the local statistics can converge faster than the global statistics. The size of the windows was 100 × 100 according to Vanzyl and Burnette and stop the iterative compound classification after eight times[10]. The adaptive prior joint probabilities for center couple pixel were calculated through the following formula:

$$p(\omega_i, v_j) = Num(\omega_i, v_j)/10000 \quad (2)$$

Where, $Num(\omega_i, v_j)$ is the number of couples pixels assigned to class ω_i at t_1 and to class v_j at t_2, 10000 is the number of couples pixels included in the 100×100 size window.

In both times, 17 spectral classes were identified. Once the images were classified, these spectral classes were then amalgamated into the land use class is be listed in table 1. Prior to image classification, a field trip was made in October, 2000 and attention was given to the areas undergone change with the aid of hard-copy images of both times. Training areas were selected by using 1∶50 000 land use maps and the ground data collected during the field trip. Because no other sources map was available in digital form, we used the contextual correction techniques which Groom et al. developed to make improvements to spectral classification[11]. Except that, because no water was stored in the reservoir, so the residential area and water area of 1998 did not change in 2000. In the compound remote sensing classification, the prior joint probabilities of residential area and water area were set to 1.0 separately.

2.3 Landscape metric calculation

In order to assess the landscape pattern on the spatial and temporal domains, we used FRAGSTASTS3.02 software to calculate the landscape metrics for the two times land use map, which include number of patches (NP), patch density (PD), landscape shape index (LSI), largest patch index (LPI), mean patch area (AREA_MN), mean fractal dimension index (FRACT_MN) and contagion (CONTAG) at class and landscape level. We also calculated the shannon diversity index (SHDI) at landscape level.

3 Results

3.1 Land use changes

We evaluated the accuracy of the classification results of the two years on the basis of confusion matrix, according to the investigation ground true data. The total accuracy and kappa coefficients are all over 0.8[12]. Proportional land use extent as total hectares, percent of the region and relative land use change extent and percent are displayed in table 2. The transfer matrix of different land use types of the two years (table 3) demonstrates the direction and extent of change among different land use types. From Table 3, we can see that 22.9% total area has been changed within a half and one year. All land use types except water area changed obviously on area and percentage (table 2). The land use types having most remarkable change were development, orchard, grassland and arable land.

1) Development changed most obviously during this phase, increasing by 4800.8 hm^2, about 626.6% (table 2). The reason is that the speed of construction of migrant towns, industry and primary farmland reclamation was faster after dam. The increased development mainly came from the arable land, orchard, forest and grassland of 1998 separately (table 3). On the other hand, only 20.2% of the development of 1998 transferred to different land use types of 2000 because of the development of 1998 not suitable for different land use; the other reason is that the migrants did not have enough money to reclaim the primary farmland and still waited more input from the government.

2) Orchard increased by 17186.4 hm^2 in this phase, about relative 178.8%, occupying 11.0% of total area in 2000 from 3.9% in 1998 (Table 2). The Three Gorges region is suitable zone for oranges, so migrants strengthened the construction of orange orchards, treated the produce of oranges as the role industry in the economical development.

3) Grassland increased by 7745.9 hm^2 in this phase, about 64.8%. The increased grassland mainly was composed from arable land and forest of 1998 (table 3). The main reason is the construction of ecological environment through the regrass from the arable land and forest degradation.

4) Arable land in this phase decreased by 18567.9 hm^2, about 27.6% (table 2). The decreased part was transfered to 1679.7 hm^2 paddy field, 12397.7 hm^2 orchard, 2867.7 hm^2 forest, 8422.0 hm^2 grassland, 2631.5 hm^2 development, and 118.2 hm^2 residential

area (table 3). There are two reasons for this decrease, one is the construction of ecological environment by aforest and regrass on the steep slope arable land in the middle and upper reaches of the Yangtze River after the large flood in 1998. The other reason is the migrant resettlement and the adjustment of agriculture structure occupied the arable land.

Table 2 Proportional land use extent as total hectares, percent for the region and relative land use change extent and percent (1998 and 2000)

	1998		2000		1998~2000 changes	
	area/hm²	%	area/hm²	%	area/hm²	%
Paddy field	6272.4	2.6	7134.5	2.9	862.1	13.7
Arable land	67354.6	27.6	48786.7	20.0	-18567.9	-27.6
Orchard	9614.0	3.9	26800.4	11.0	17186.4	178.8
Forest	137289.7	56.4	124804.3	51.2	-12485.4	-9.1
Grassland	11962.5	4.9	19708.4	8.1	7745.9	64.8
Development	766.2	0.3	5567.0	2.3	4800.8	626.6
Residential area	1871.0	0.8	2248.9	0.9	377.9	20.2
Water area	8558.7	3.5	8558.7	3.5	0	0

Table 3 Land use classes joint matrix as hectares between 1998 and 2000

		2000							
		Paddy field	Arable land	Orchard	Forest	Grass land	Development	Residential area	Water area
1998	Paddy field	5184.8	0	817.4	0	0	192.2	77.9	0
	Arable land	1679.7	39237.8	12397.7	2867.7	8422.0	2631.5	118.2	0
	Orchard	256.7	2033.4	7126.5	0	0	82.5	115.3	0
	Forest	0	5475.8	5779.9	119666.5	5677.6	636.7	53.1	0
	Grassland	0	1966.7	696.1	2252.3	5592.5	1450.8	4.0	0
	Development	13.3	73.3	62.9	17.7	16.3	573.3	9.4	0
	Residential area	0	0	0	0	0	0	1871.0	0
	Water area	0	0	0	0	0	0	0	8558.7

3.2 Landscape pattern changes

1) Landscape level changes

The calculation results of different landscape metrics at landscape level are displayed in Table 4. We can see that NP and PD, with the resettlement of migrant in the Three Gorges, increased relatively about 29.5% since the Three Gorges dammed successfully on the Yangtze River. It reflects landscape in this region became more fragmented. This also causes the average patch area decreased from 4.605 hm² in 1998 to 3.555 hm² in 2000, about 22.8%. At the same time, it brings about the decrease of LPI, which felle from 15.819 in 1998 to 15.129 in 2000. On the other hand, during this phase, the structure of landscape was more complicated, the LSI rose by 17.7%, which means that the shape of landscape became more irregular. The CONTAG decreased by 13.9%, from 58.016 in 1998 to 49.610 in 2000. It also means the more fragmented. That SHDI rose about 19.7% because the land use types were well-distributed on the Three Gorges region.

Table 4 Landscape metrics and relative change extent and percent for landscape level (1998 and 2000)

		NP	PD	LSI	LPI	AREA_MN	FRAC_MN	CONTAG	SHDI
Landscape level	1998	52909	21.716	111.810	15.819	4.605	1.040	58.016	1.221
	2000	68529	28.128	131.556	15.129	3.555	1.042	49.610	1.462
	Change	15620	6.412	19.746	-0.690	-1.050	0.002	-8.046	0.241
	%	29.5	29.5	17.7	-4.4	-22.8	0.2	-13.9	19.7

2) Land use class level changes

The landscape metrics of different land use types are listed in table 5. According to the table 5, all land use types except the water area changed in varying degrees. The most remarkable changes occurred on development, orchard, grassland and arable land. With the settlement of migrants Development's NP and PD increased by 267% under the condition of the relatively increase by 626.6% on area. So its average area of patch rose to 1.340 hm^2 from 0.667 hm^2 in 1998, its LPI increased by 420.8%, and its CONTAG and FRACT_MN rose slightly; its LSI increased by 181.9%. These changes of the indexes show that the development, under the complicated mountain circumstance, had to suit local conditions and the landscape shape became more complicated. Table 5 showed that the increase of NP and PD of orchard were smaller than that of its area; so its average area of patch also rose to 3.143 hm^2 from 2.323 hm^2 in 1998, its LPI also increased by 182.0%. Its LSI increased by 181.9%, which reflects that the orchard landscape shape also became more complicated. But the increase of NP and PD of grassland were bigger than that of its area, so its average area of patch and CONTAG dropped and its LSI and LPI arose. With the area decrease of arable land, its NP and PD arose, so its LPI decreased by 53.8% and LSI also dropped. All these changes show the arable landscape shape became simpler slightly. According to the upper analysis, the landscape changes of development and orchard were quite different from those of arable land and grassland that became more fragmented.

Table 5 Landscape metrics and relative change extent and percent for land use class (1998 **and** 2000) %

		NP	PD	LSI	LPI	AREA_MN	FRAC_MN	CONTAG
Paddy field	1998	11120	4.564	23.081	0.042	0.564	1.045	0.756
	2000	12838	5.269	25.723	0.037	0.556	1.043	0.757
	Change	1718	0.705	2.642	-0.005	-0.008	-0.002	0.001
	Change percentage %	15.4	15.4	11.4	-11.9	-1.4	-0.2	0.1
Arable land	1998	13754	5.645	78.735	1.337	4.898	1.035	0.885
	2000	16963	6.962	76.111	0.618	2.876	1.042	0.861
	Change	3209	1.317	-2.642	-0.719	-2.022	0.007	-0.024
	Change percentage %	23.3	23.3	-3.3	-53.8	-41.3	0.7	-2.7
Orchard	1998	4105	1.685	17.493	0.155	2.323	1.050	0.883
	2000	8527	3.500	39.713	0.437	3.143	1.047	0.886
	Change	4422	1.815	22.220	0.282	0.820	-0.003	0.003
	Change percentage %	107.8	107.8	127.0	182.0	35.3	-0.3	0.3
Forest	1998	11763	4.828	76.414	15.819	11.673	1.037	0.909
	2000	10599	4.350	69.632	15.129	11.777	1.038	0.919
	Change	-1164	-0.478	-6.782	-0.690	0.104	0.001	0.010
	Change percentage %	-9.9	-9.9	-8.9	-4.4	0.9	0	1.1
Grassland	1998	4422	1.815	19.882	0.176	2.705	1.051	0.890
	2000	8541	3.506	33.840	0.327	2.308	1.047	0.874
	Change	4119	1.691	13.958	0.151	-0.397	-0.004	-0.016
	Change percentage %	93.1	93.1	70.2	85.8	-14.7	-0.4	-1.8
Develop-ment	1998	1132	0.465	5.071	0.024	0.677	1.037	0.799
	2000	4155	1.705	14.294	0.125	1.340	1.047	0.846
	Change	3023	1.24	9.223	0.101	0.663	0.010	0.047
	Change percentage %	267.0	267.0	181.9	420.8	97.9	0.1	5.9
Residential area	1998	4428	1.817	9.250	0.056	0.423	1.034	0.750
	2000	4721	1.938	10.134	0.067	0.476	1.035	0.763
	Change	293	0.121	0.884	0.011	0.053	0.001	0.013
	Change percentage %	6.6	6.6	9.6	19.6	12.5	0	1.7
Water area	1998	2185	0.897	11.671	2.626	3.917	1.039	0.922
	2000	2185	0.897	11.671	2.626	3.917	1.039	0.922
	Change	0	0	0	0	0	0	0

4 Discussion and conclusion

The second phase of the Three Gorges Project was from 1998 to 2003, its main objective was the resettlement of migrant of the local residents, who lived under the conservancy inundating level whose altitude is 135 m, and it was the critical phase. The use of multi-date compound maximum likelihood classification considering the land use class joint prior probability to directly produce the landscape pattern dynamics and land use map has been a success in terms of achieving its original goals. Spot, other high spatial resolution image and the digital ancillary information are considered to improve the monitoring accuracy in the future work. Because of the resettlement of migrants and the construction of ecological environment from September 1998 to February 2000, the land use and landscape pattern of the Three Gorges changed significantly.

1) Since the River was dammed in November 1997, the area of the land occupied by the migrants rose steeply. The development added up to 5567.0 hm^2 in February 2000, which was 1104.8 hm^2 bigger than the area that was planned by the two counties, about 4462 hm^2[13, 14]. This phenomenon results in a waste of land resources, the expansion of development must be controlled, the transfer of development to the other kinds of land use types needed in settling migrants must be quickened. In the land use structure of the two counties, orchard rose largely, occupied 11% of the total land area in 2000, about 5.1% bigger than the quantity planned, which is about 5.9%. This means that migrants put their economical emphasis on orchard. On the other hand, the construction of ecological environment was relatively strengthened. The area for planting forest and grass from arable land is planned 19.3%. From the results of our monitoring, this job has been finished about 86.5%. At the same time, trees were planted on the grassland suitable for forest. According to the plan, 27% grassland was transferred to forest. About 70% job has been finished. The migrants need to plant crops to meet their food requirement, so about 2.3% arable land was planned to reclaim, but the monitoring results was 11.0% much bigger than planned. This part of arable land was mainly transferred from forest and grassland resources, so it caused part forest degraded to grassland. Forest, the biggest in the land use structure of the Three Gorges, was planned to be 55.46% of the total land area, but its real area is 51.2% through monitoring. For the landscape pattern of the region, it had more fragments, more complicate structure and lower contagion. The average patch area of development and orchard was bigger, but that of arable land and grassland was smaller. From the monitoring results, the land use changed, not in the good order management, are quite different from the plan. So plan management and land use control are imperative in the region.

2) The resettlement of migrants resulted in the remarkable change of land use of the region. So this also caused many problems on land use. On one hand, afforest and regrass arable land on the steep slope are needed to improve the ecological environment quality. On the other hand, the soil erosion is aggregated because of reclaiming large quantities of arable land on the steep slope. The scope of development was so large that occupied arable land and resulted in the waste of land resources. At the same time, it occupied forest and grassland resources so that the ecological environment is worse, the region soil erosion area expand to 46.7% of total land area[12]. But the quality of new-built orchard is bad, orchard with low production is about 44.18% of the total area of orchard[12].

According to the problems on land use and ecological environment in the region due to the resettlement of migrants, the following suggestions were gotten:

1) Control the scope and the expanding speed of development, which should occupy arable land or good quality land as less as possible; on the other hand, make full use of the development which has already been exploited to settle the migrants. At the same time, afforest and regrass are not suitable for the development.

2) Quicken afforesting and regrassing. Contour cropping, terrace changing from steep slope and biological hedge, etc, measures are used to lessen the soil erosion in the region that could not afforest and regrass in time. On the other hand, build fields with high and constant production, and change into intensive cultivation. At the same time, stabilize the forest area, quicken the transform of forest with low quality, and plant trees on the grassland suitable for forest, devote major efforts to developing animal husbandry and making use of grassland resources. At last, the ecological management and exploitation in this region should be tackled on the basis of watersheds.

3) Control the scale of migrants and combine the migration with the settlement in other provinces to reduce the pressure on the Three Gorges land resources.

4) Evaluate the land suitability, exploit all kinds of land resources, and enforce the supervision of the execution of land use planning.

5) Make full use of remote sensing techniques, build long-time and constant monitoring cycle, measure the land use and land cover change and the environmental effects, serve the sustainable development of the reservoir region and the upper, middle reaches of the Yangtze River.

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长江三峡库区移民工程土地利用和景观格局变化遥感监测研究

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摘 要: 自1997年中国三峡大坝成功截流以来, 对库区土地利用和景观格局产生复杂影响。该文采用遥感技术和景观格局评价方法对奉节和巫山两个移民大县在1998年到2000年的土地利用变化进行监测研究。在大江截流后一年半时间内, 该区域22.9%土地利用发生了变化, 表明移民安置工作速度显著加快。新开发用地变化最为明显, 增加4800.8 hm^2, 扩展626.6%。而耕地面积则减少了18567.9 hm^2, 下降约27.6%。这些土地利用变化导致区域景观发生了变化。斑块密度增大了29.5%, 连通度下降了13.9%, 表明移民安置导致区域景观进一步破碎化。景观形状指数上升了17.7%, 斑块形状进一步复杂和不规则。研究结果表明土地利用变化并未按照移民安置规划有序进行, 应进一步控制新开发用地扩展速度和范围, 对不适合农业用地的新开发用地及时进行退耕还林草工作。
关键词: 土地利用; 景观格局分析; 遥感技术; 影像分析; 长江三峡库区; 移民安置