Report

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Impact of Impoldering and Lake Restoration on Land-cover Changes in Dongting Lake Area, Central Yangtze

Human activities can have a remarkable effect on land-cover patterns over time. This study characterized long-term (1930s–1998) land-cover changes in Dongting Lake area in the Central Yangtze River, China, by digitalizing historical topographical maps for the 1930s and 1950s and interpreting satellite remote sensing data for 1978, 1989, and 1998. The study indicates that land-cover patterns in Dongting Lake area have been greatly altered by impoldering and subsequent lake restoration activities in the past 70 years. There are two distinct periods of change characterized by impoldering (1930s-1978) and lake restoration (1978-1998). In the former period, cropland increased sharply at the cost of a drop in other land-cover types, which had resulted in significant negative consequences, while the pattern of land-cover changes reversed in the later period.

INTRODUCTION

Human activities have directly altered between one-third and one-half of the earth's land surface (1, 2). One of the most pervasive modes of anthropogenic change has been the land transformation from natural ecosystems to agricultural lands (3). Most current agricultural lands occupy former primary forests, grasslands, and wetlands (4). Historically, impoldering (a special type of land conversion that encroaches on lakes and their associated wetlands through the construction of dikes for agricultural purposes) is a major human activity to support growing human population in the Central Yangtze River, China, which was accelerated during the period from the early 1950s through the end of the 1970s (5). This land reclamation has greatly altered land-cover patterns in this area. For example, in Dongting Lake area in Central Yangtze, the increased arable land by impoldering amounted to 1.8×10^5 ha (~ 45% of lake size in the 1950s) from the early 1950s to the end of the 1970s (6), resulting in substantial negative consequences, including increased flooding and crop losses, as well as a reduction in biodiversity (7). These negative consequences and a growing awareness of the importance of wetlands motivated the establishment of policies to protect and restore lakes and associated wetlands. The Chinese government enacted a policy to prohibit impoldering at the end of the 1970s. At the same time, cost-benefit estimates also made local people unwilling to repair inundated dyke breaches. Therefore, as a reverse of impoldering, this type of lake restoration, such as opening dyke breaches and abandoning inundated polders, could also alter regional land-cover and riparian landscapes in a relatively short period.

Despite the increasing recognition of the impacts of these two reverse human-induced land transformations, there is a lack of adequate data on historical land-cover information, which is imperative to address the impact of human activities on land-cover changes, since the present distribution of land-cover reflects complex patterns of anthropogenic land conversion.

In this study, we used an approach integrating satellite remote sensing data with historical topographical maps to reconstruct historical land-cover changes of the Dongting Lake area, Central Yangtze, China, and to understand the changes of land-cover resulting from impoldering and subsequent lake restoration, then to relate these changes to contemporary socioeconomic factors and policies.

We focused our study on Dongting Lake area for the periods from the 1930s to 1998 for the following two reasons: *i)* this region has good quality historical topographical maps with detailed land-cover information; *ii)* as one of the largest lakes in the Central Yangtze, this area experienced extensive impoldering before the end of 1970s, and subsequent lake restoration after the end of 1970s, resulting in tangible changes to the lake itself, as well as changes in regional land-cover patterns.

METHODS

Study Area

The Dongting Lake area is situated at the southern part of the Yangtze River's middle reaches, Hunan Province (Fig. 1). The area comprises 13 cities and 14 national agriculture zones, with an area of 23 947 km^2 (111°12'–113°44'E, 28°17'–29°57'N). The area has a subtropical climate, with an annual sunlight range of 1757–1832 hrs, precipitation 1200–1400 mm, and annual mean temperature 16.4–17.0 °C (8). The area harbors approximately 1300 plant species and a wide variety of threatened fish, birds, and mammals. The lake area is recognized as a globally important area for freshwater aquatic biodiversity, particularly with respect to its unique fish fauna, and especially as a habitat for the critically endangered Yangtze Dolphin or Baiji (*Lipotes vexillifer*). The region has also been one of the global 200 conservation priority ecoregions proposed by World Wide Fund For Nature due to its valuable and exclusive biodiversity (9). In addition, the area serves other significant functions, including water sup-

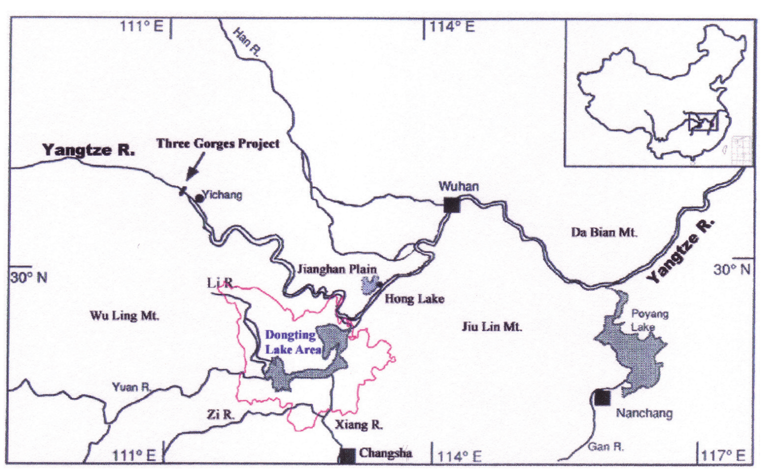

Figure 1. Map of the study area.

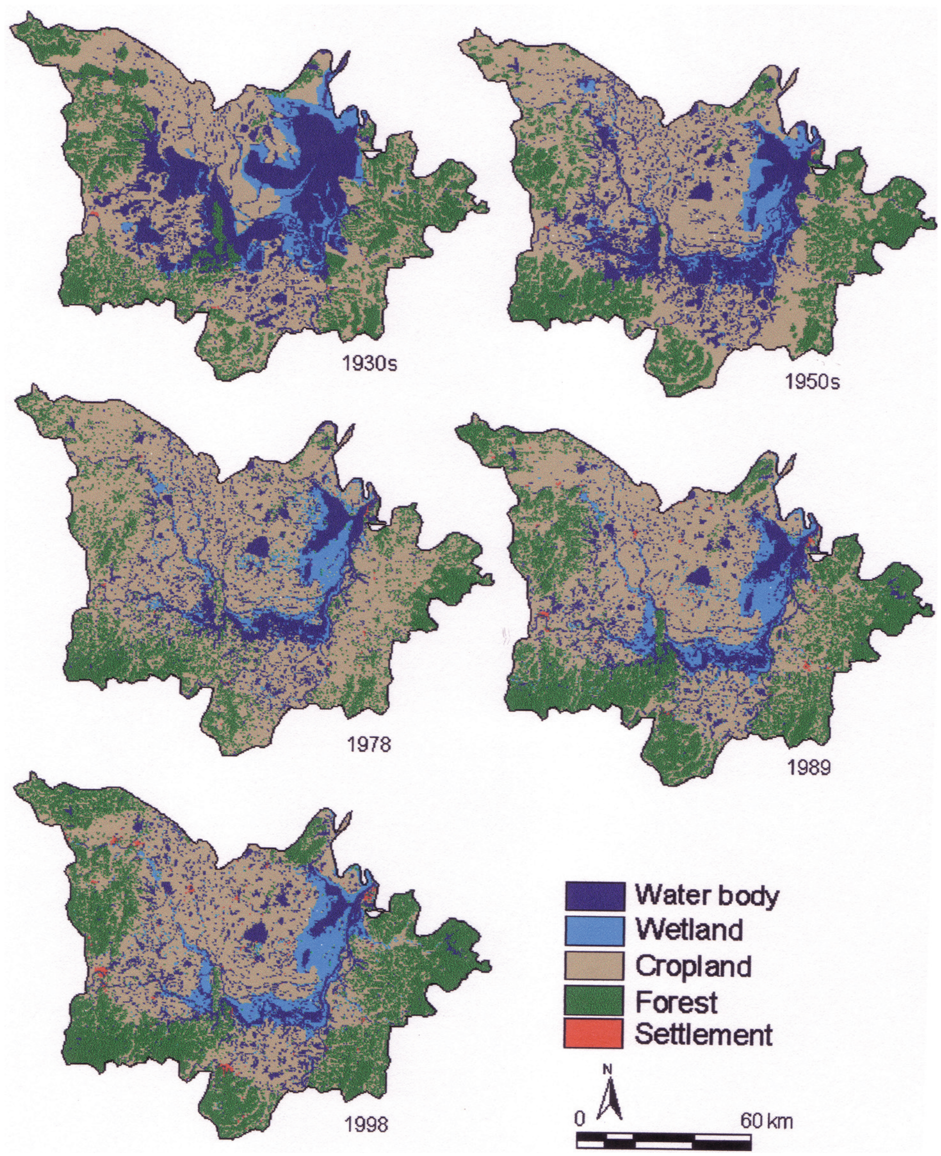

Figure 2. Land-cover types of the study area in the 1930s, 1950s, 1978, 1989 and 1998.

ply, flood mitigation, wastewater treatment, and transportation. However, the regional environment of Dongting Lake area has been greatly altered by human activities in past decades, threatening biodiversity and undermining its socioeconomic benefits.

Data and Methods

The historical topographical maps in the 1930s and 1950s, as well as Landsat satellite images from 1978, 1989, and 1998 were used to acquire long-term land-cover information of the study area (10). The image processing software Erdas 8.4 was used to classify the land-cover types of remotely sensed data in 1978, 1989, and 1998. To provide consistency, the Landsat data were interpreted using similar band combinations with RGB (MSS bands 6, 7, 5 and TM bands 4, 5, 3). All images were georeferenced according to 1:50 000 topographical maps, and the TM images (30 m by 30 m) were degraded and resampled to a resolution of 80 m by 80 m. The images from each year were then classified using the maximum likelihood method (11). The land-covers were grouped into five types: waterbody, wetland, cropland, forest, and settlement (Table 1). Several initial field surveys were conducted before Landsat images were interpreted.

All the historical topographical maps in the 1930s and 1950s were converted to digital images at 600 dots per inch, giving a ground resolution of approximately 10 m. These topographical maps contain 40–55 land-cover types. According to the classification standard described in Table 1, we reclassified them into five types first through visual interpretation, then traced the boundary of each patch of these five types using a GIS software, Founder drawing 5.5, and transferred vector maps of these land-cover maps into ArcView GIS software to resample to a resolution of 80 m by 80 m to make them comparable with remotely sensed data.

The accuracy of the classifications was assessed by verifying general land-cover delineation using topographical maps and vegetation maps or based on field survey information and interviews with local residents. The resulting overall classification accuracy of three classified images in 1978, 1989, and 1998 was 81%, 86%, and 89%, respectively. The historical topographical maps possessed detailed information on land-covers, and since we reclassified them into five land-cover types, the classified historical data should be more precise than the remotely sensed data.

Based on the classified products (Fig. 2), the land-cover changes under the impact of human activities over the past 70 years were analyzed using ArcView GIS 3.2 program. Through overlaying five classification maps generated from the historical data and satellite imageries, the percentage of each type of land-cover which had been converted to another land-use type, and the contribution of such land transition type to other types of land-cover between two neighboring periods were computed. The type and extent of the dominant land-cover change in the past 70 years were generated to analyze land-cover change processes.

RESULTS AND DISCUSSION

Land-cover Changes

The data analysis indicates that extensive impoldering before the end of the 1970s and subsequent lake restoration from impoldering in the recent 20 years in Central Yangtze significantly altered

Table 1. Description for land use/cover categories in Dongting Lake area.

Land use/cover categories	General description
Waterbody	Rivers, lakes, channels, and ponds for aquaculture
Wetland	Floodplain and wetland vegetation, in some cases mixed with natural and artificial forests and shrubs
Cropland	Dry fields, paddy fields and other arable land
Forest	Area covered conifers, broadleaved trees, shrubs and herbs
Settlement	Urban areas and transportation mains

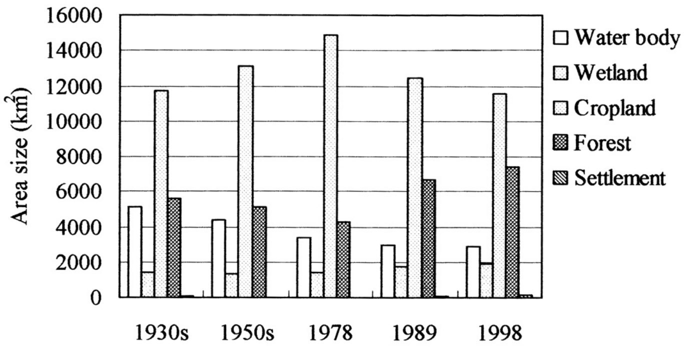

Figure 3. Area of different land-covers: Five periods.

the land-cover patterns in Dongting Lake area. As indicated by Figures 2 and 3, the waterbody area decreased by 2156.8 km^2 during the 1930s to 1998, which was 42.5% of the original waterbody area in the 1930s. Of which 13.7%, 19.1%, 8.6%, and 1.1% was decreased for the periods of the 1930s–1950s, the 1950s–1978, 1978–1989, and 1989–1998. Wetlands decreased from 1432.7 km^2 in the 1930s to 1317.5 km^2 in the 1950s, then increased by 605.8 km^2 from the 1950s to 1998, of which 43.8 km^2, 399.9 km^2, and 162.1 km^2 was increased for the periods of the 1950s–1978, 1978–1989, and 1989–1998, respectively. Impoldering had been a major agricultural activity in this area historically (5). However, the impoldering in the early 20th century was small-scale and frequent, generally occupying perennially and seasonally flooded wetlands. This land reclamation practice accelerated during the period from the early 1950s through the end of the 1970s, and 15 national farms were established, which occupied both Dongting Lake and the wetlands around the lake, in order to meet the demand for rapidly increasing food production (12). Therefore, the decrease in the waterbody reached a maximum between 1950 and 1978. While the wetland area greatly decreased during the period of the 1930s and 1950s.

Human population growth can be considered an ultimate cause of many land-use changes (2, 13). Human population in Dongting Lake area increased by 23.2%, 43.0%, 16.3%, and 8.1% for the periods of the 1930s–1950s, the 1950s–1978, 1978–1989, and 1989–1998 (14, 15). This increase in human population enhanced the need of land for food production, so impoldering, which coincided with that of the rapidly increased human population in the lake area, occurred before 1978 and greatly affected the land-cover patterns of this area. These land-cover changes resulted in ecologically negative consequences. For example, waterbird species, such as geese and ducks in Dongting Lake area declined from 31 at the end of the 1950s to 20 in the early 1990s (16, 17). Following this pattern of waterbody and wetland change, the cropland area increased significantly, by 26.8% from the 1930s to 1978, then decreased by 22.5% up to 1998.

In contrast, the area of forest decreased from 5638.7 km^2 in the 1930s to 4257.1 km^2 in 1978, then continuously increased to 7389.7 km^2 by 1998. This pattern of forest change was closely related to forest policy and the socioeconomic situation during different time periods. Since the establishment of a new social system in 1949, the rapidly increasing population and economic development resulted in increased forest exploitation across China, including in the Dongting Lake area (18). Since the 1980s, however, the Chinese government has implemented several ecological restoration projects and natural forest protection programs to increase forest coverage (19). The Rivers Protection Forest Program has led to an increase in forest cover in Dongting Lake area in the most recent 20 years.

Because the settlement was composed by the mixed pixels in the remotely-sensed data, and the percentage of this land-cover type was small, the area of settlement in classified images was often smaller than its actual size, so we did not further analyze the change in settlement area. However, the settlement change in the past 70 years showed the process of urbanization in this region.

Because the present distribution of land-cover reflects complex patterns of historical land conversion, a transition matrix (Table 2) was calculated to help understand the land-cover change processes (what kinds of land-cover change in the early period led to the land-cover pattern of some period, and how the land-cover changes in this period caused the formation of land-cover in the later period) and the change rate among land types between two periods.

Table 2. Land-cover transition and contribution rate (%) between the 1930s–1998.

Land-cover	Waterbody		Wetland		Cropland		Forest		Settlement	
	a	(b) %	a	(b) %	a	(b) %	a	(b) %	a	(b) %
					1950s					
1930s										
Waterbody	40.3	(46.7)	16.0	(45.7)	40.5	(15.7)	3.1	(3.1)	0.1	(22.4)
Wetland	27.4	(11.2)	17.7	(19.3)	52.5	(8.8)	2.4	(0.7)	0.0	(0.0)
Cropland	13.5	(36.2)	5.1	(31.2)	62.1	(55.7)	19.2	(41.9)	0.1	(62.7)
Forest	4.4	(5.7)	0.9	(3.8)	45.5	(19.6)	49.2	(54.0)	0.0	(11.9)
Settlement	10.9	(0.2)	1.7	(0.1)	26.9	(0.3)	29.9	(0.4)	30.6	(3.0)
					1978					
1950s										
Waterbody	46.5	(59.8)	11.4	(36.7)	38.3	(11.3)	3.7	(3.8)	0.1	(17.0)
Wetland	19.2	(7.4)	44.5	(43.1)	34.5	(3.1)	1.7	(0.5)	0.1	(2.5)
Cropland	7.8	(29.9)	2.1	(20.0)	77.7	(68.4)	12.2	(37.7)	0.2	(58.4)
Forest	1.9	(2.9)	0.1	(0.2)	49.9	(17.2)	48.1	(58.0)	0.1	(9.7)
Settlement	23.1	(0.1)	0.7	(0.0)	36.2	(0.0)	4.3	(0.0)	35.7	(12.3)
					1989					
1978										
Waterbody	53.4	(61.2)	12.9	(24.9)	27.7	(7.6)	5.5	(2.8)	0.6	(18.4)
Wetland	12.6	(5.8)	61.9	(47.9)	23.8	(2.6)	1.4	(0.3)	0.3	(3.6)
Cropland	5.8	(29.2)	3.0	(25.0)	67.7	(81.2)	23.1	(51.3)	0.4	(58.7)
Forest	2.4	(3.4)	0.9	(2.2)	25.1	(8.6)	71.5	(45.5)	0.2	(8.4)
Settlement	19.1	(0.3)	3.0	(0.1)	21.7	(0.1)	15.8	(0.1)	40.4	(10.9)
					1998					
1989										
Waterbody	59.3	(60.4)	12.3	(18.9)	23.5	(6.1)	3.9	(1.6)	1.0	(17.0)
Wetland	9.9	(6.0)	70.6	(64.7)	16.1	(2.5)	2.9	(0.7)	0.6	(5.6)
Cropland	6.7	(28.7)	2.1	(13.7)	74.2	(79.9)	16.3	(27.4)	0.6	(41.8)
Forest	2.0	(4.6)	0.7	(2.4)	19.4	(11.3)	77.5	(70.2)	0.3	(12.9)
Settlement	11.4	(0.4)	5.2	(0.3)	22.3	(0.3)	11.5	(0.2)	49.6	(22.7)

a Transition rate is the percentage of the area of transition type from one land cover to another to the area of certain land cover in the beginning period.
b Contribution rate is the percentage of the area of transition type from one land cover to another to the area of different another land cover in the end period.

The decrease in the waterbody between the 1930s and 1950s was primarily caused by the transformation from waterbody to cropland and from waterbody to wetland, with transition rates of 40.5% and 16.0%, respectively. However, concurrent conversions of cropland to waterbody and wetland to waterbody counteracted the decease in the waterbodies to some extent, contributing to the waterbody area in the 1950s at rates of 36.2% and

11.2%, respectively. The decrease in wetland during this period was primarily caused by the land transformation from wetland to cropland, at a transition rate of 59.5%. The land-cover change types from waterbody, wetland and forest to cropland caused the increase in the area of cropland in the 1950s, and the contribution rate was 15.7%, 6.5%, and 19.6%, respectively. The forest retention rate was 47.4%, almost entirely resulting from the change from forest to cropland (transition rate 45.5%).

In the period 1950–1978, the highest transition rate was for forest to cropland (i.e. 48.1%), and the contribution rate of this type of land-cover change to the cropland area in 1978 was 17.2%, indicating that 17.2% of the cropland in 1978 was reclaimed from forest in the 1950s. Waterbody and wetland area further decreased primarily by changing to cropland. During this period the decrease in total waterbody and wetland areas reached its zenith, due to the acceleration of impoldering from the early 1950s to the end of the 1970s. Concurrently, 15 national farms were heavily reclaimed in Dongting Lake area combining with lake management and schistosome prevention (7, 12).

The decrease in the area of cropland during the period of 1978 and 1998 was a result of the land transformation from cropland to waterbody, wetland and forest. The contribution rate of these types to waterbody, wetland, and forest in 1989 and 1998 was 29.2%, 25.0% and 51.3%; 28.7%, 13.7% and 27.4%, respectively. These land transformation processes were in accordance with the lake restoration and forest protection programs in the most recent 20 years.

Croplands hold the higher retention rate (transition rate from one land-cover type to the same one) during all four periods, since cropland was the dominant land-cover type in the study area.

Dominant Land-cover Changes during the Past 70 Years

Through analyzing dominant land-cover change processes (the percentage of the change amount equal to or more than 1% of the total study area) in the past 70 years, the impact of impoldering and subsequent lake restoration from impoldering on the land-cover and landscape patterns in Dongting Lake area can be better understood (Table 3). The percentage of unchanged amount of cropland, forest and waterbody to the total study area across all five study periods (numbered as 33333, 44444 and 11111) was 14.8%, 5.5% and 2.6%, respectively, indicating that large-scale land-cover changes had occurred.

Almost all the dominant land-cover transition processes were related to cropland since cropland was the main land-cover type in the study area. Most significant among the change processes was a conversion of 21.2% of the 1930s waterbody area to cropland by the 1950s, and maintained as cropland to 1998 (13333). Similarly, 11.3% of the waterbody area did not change between the 1930s and the 1950s, but was converted to cropland by 1978 (11333). These two major changes account for 4.5% and 2.4% of the total study area, respectively. Additionally, 2.3% of the total area was converted from waterbody in the 1950s to cropland since 1978 (31333). Of the 1930s wetland area, 35.5% was reclaimed for cropland by 1998 (23333), which occupied the 2.1% of the total Dongting Lake area.

The abovementioned land-cover change processes led directly to the reduction of Dongting Lake and its wetlands in the last 70 years, all of which resulted from impoldering activities before the end of the 1970s. While the land-cover change process of the cropland in 1978 to waterbody in 1998 (31311) showed that lake restoration in the recent 20 years decelerated the decline in the size of waterbody.

The transitions between cropland and forest in the past 70 years are also obvious (Table 3). These land-cover change processes directly relate to forestry management policies and socioeconomic factors in different periods, namely, the reclamation of forests to cropland before 1978, followed by restoration back to forests (i.e. 44344).

CONCLUSIONS

The study suggests that land-cover patterns in Dongting Lake area were greatly altered by the impoldering and subsequent lake restoration activities during the past 70 years, thus presenting two distinct periods caused by impoldering (1930–1978) and by lake restoration (1978–1998).

The impoldering implemented before the end of the 1970s significantly increased cropland while reducing waterbody, wetland, and forest coverage, especially causing the shrinkage of the total area of the waterbody and wetlands in Dongting Lake area. Because there are few historical land-cover maps in China, we do not have direct means by which to validate and compare with our findings. However, we found these changes were coincident with a rapid decrease in the lakes in Central Yangtze. The surface area of Dongting lake was 4350 km^2 in 1949 and was still the largest freshwater area; however, it decreased to 2740 km^2 by 1977, becoming the second largest freshwater area in China. In Jianghan Plain in Central Yangtze, the number of the lakes with ≥ 1 km^2 declined to 326 in the early 1980s from 1066 in the early 1950s, and the surface area of the lakes decreased by about 6000 km^2 (20).

The changes in land-cover types in the study area varied less in the period from the 1930s to the 1950s than from the 1950s to 1978, indicating that the impact of impoldering on the land-cover patterns in the latter period is more than in the former. It was noted that the growth rate of the human population in Dongting Lake area during the period of the 1950s–1978 was 1.9 times that in the 1930s–1950s, (14, 15), placing a high demand on agricultural lands.

During the period 1978–1998, under the condition of lake restoration and reforestation policy, a large amount of cropland was restored to waterbodies, wetlands, and forests. This process varied more from 1978 to 1989 than from the 1989 to 1998. A study on land conversion between 1987–1998 in Honghu lake area, Central Yangtze, gave similar results (21).

Table 3. The area and percentage of dominant land-cover transition types in the past 70 years.

Dominant transition type[c]	Area size (km^2)	Percentage of total area (%)	Percentage of the beginning land-cover (%)
33333	3546.2	14.8	30.2
44444	1196.9	5.0	21.2
13333	1077.6	4.5	21.2
34444	766.6	3.2	6.5
43333	759.5	3.2	13.5
11111	630.8	2.6	12.4
33334	602.1	2.5	5.1
33344	590.6	2.5	5.0
11333	574.7	2.4	11.3
44344	580.9	2.4	10.3
34344	578.7	2.4	4.9
31333	550.8	2.3	4.7
23333	508.4	2.1	35.5
43344	459.2	1.9	8.1
12222	356.6	1.5	24.9
33444	352.8	1.5	3.0
33343	333.6	1.4	2.8
43334	320.8	1.3	5.7
43444	311.0	1.3	5.5
31311	270.0	1.1	2.3
44334	243.8	1.0	4.3

[c] Dominant land-cover transition types are those occupying equal or more than 1% to the percentage of total study area; 1, 2, 3 and 4 represents the land-cover type of waterbody, wetland, cropland and forest, respectively.

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Table Imagery data of Landsat-MSS and Landsat-TM used in this study.

Landsat type	The path No.	Period
Landsat-MSS:	132-40	16 October, 1978
	133-39	17 October; 1978
	133-40	17 October, 1978
Landsat-TM:	123-40	4 December, 1989
	124-39	10 February, 1989
	124-40	10 February, 1989
	123-40	12 February, 1998
	124-39	20 December, 1998
	124-40	20 December, 1998

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