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AN ILLUSTRATIVE STUDY ON LOCAL LANDSCAPE AND ITS LONG-TERM CHANGES BASED ON IKONOS AND HISTORICAL AERIAL PHOTO

RUAN Ren-zong[1], Erle C ELLIS[2]

(1. Department of Urban and Resources Sciences, Nanjing University, Nanjing 210093, P. R. China; 2. Department of Geography and Environmental Systems, University of Maryland, Baltimore County, USA)

ABSTRACT: Nowadays, the research works on landscape at fine scales using high-resolution images are uncommon. This research is based on the analysis of the combination of remote sensing data (IKONOS imagery acquired in 2002 and historical aerial photo taken in 1942). In the paper, the ecotopes in Qiujiadou and Xishao villages in Yixing City of Jiangsu Province in 1942 and 2002 were compared and landscape changes as well as the causes of the considerable changes were analyzed. It was found that the ecotope changes were at greater level in some aspects such as water surface and perennial vegetation coverage etc. This study at fine scale is globally significant for the rural areas, especially for the subsistence agricultural land, which occupies larger percentage in the earth. And it analyzes the structure of landscape based on a new landscape classification system—stratifications method.

KEY WORDS: IKONOS; aerial photo; landscape; ecotope

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1 INTRODUCTION

In previous years, people generally used aerial photos for studying the long-term dynamics of landscape (KADMON and HARARI-KREMER, 1999). Recently, successfully launched satellites such as IKONOS2, EROS, QuickBird provided high resolution images that can be used to extract geo-spatial features accurately (PETRIE, 2001). Similar to most of the other satellite sensors, the bandwidths of IKONOS2, which was lanched in 1999, are comparatively broad to ensure adequate signals (multispectral channels: 445–516, 506–595, 632–698, 757–853nm; the panchromatic channel: 450–900nm). Over the past few years, a lot of researches have been done (APLIN *et al.*, 1999; TOUTIN and CHENG, 2000; HOFFMANN *et al.*, 2001; MUMBY and EDWARDS, 2002; WANG and ZHANG, 2002; LEE *et al.*, 2003; ZHANG and WANG, 2003; CARLEER and WOLFF, 2004). However, the landscape research works based on IKONOS are still unusual, and even the long-term landscape investigations based on IKONOS and historical aerial photos are rare. In this paper the long-term changes of landscape have been analyzed between 1942 and 2002.

2 STUDY AREA

Study area is located between Qiujiadou and Xishao villages, in Xushe township of Yixing City, Jiangsu Province (Fig. 1). It covers nearly 40ha with a typical landform of floodplain. This area is separated from urbanized areas and typical development areas such as special government programs. In the study area, villages are constructed on low-lying floodplain land reclaimed from wetlands not far away from Taihu Lake at a range of 2.5 m to 5m above sea level. All terrestrial soils are classified as Hydragric paddy soil by national experts using field profiles with reference to Xushe Township Soil Map①.

3 METHODOLOGY

The methodology of the study comprises of following steps:

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Biography: RUAN Ren-zong (1965–), male, a native of Hefei of Anhui Province, Ph.D. candidate, specialized in application of remote sensing in landscape ecology. E-mail: ruanrenzong@163.com
① Yixing Soil Survey Office, 1986.

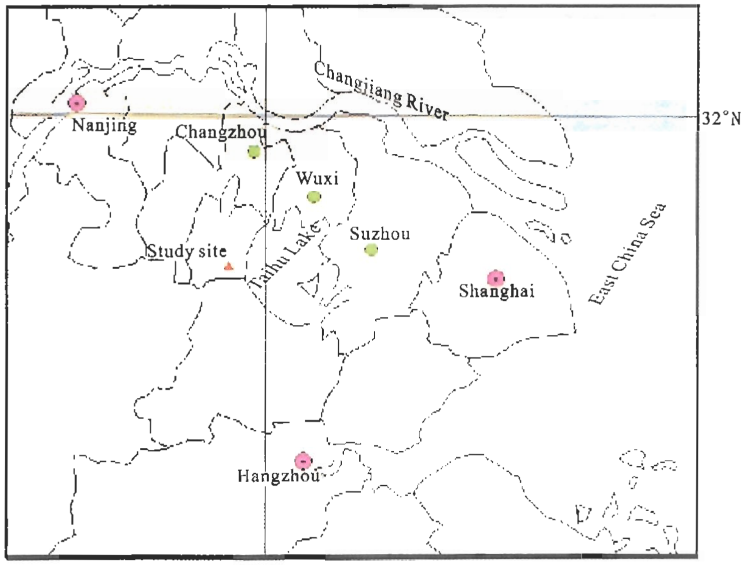

Fig. 1 Study site (red triangle)

(1) Image processing of IKONOS and historical aerial photos. Georeferencing and geometric corrections of IKONOS images were based on the high-precision GPS measurements and the data from Shanghai base station. The georeferencing and geometric corrections of the World War Ⅱ (WW2) aerial photos were carried out based on the georeferenced IKONOS images. The aerial photos were georeferenced to the features visible both on the images and aerial photos such as old buildings and the intersection of two rivers etc.

(2) Image classification and construction of vegetation maps. A hierarchical nomenclature was included in this process and the same used for delineating different classes and class label assignments. Landform, land use, land cover and group are the four levels included.

(3) Ground-truth. Printouts of IKONOS image at the scale of 1:1200 were used for ground verification of the features, which have been interpreted on images. For the mapping of features in the past, the aerial photos taken on September 23, 1942 in the room are interpreted. After completing the ocular interpretation of aerial photos, map tiles were prepared and printed for field verification. Since most of the past features have disappeared or at least changed a lot, the comments given by the old people living in and around the study area were considered for ground-truth. Those old people must be up to the conditions that their age should be greater than 75 (2002 minus 1942, then plus 15) with a clear mind at reviewing time. Since they were already 15 years old in 1942 and lived in the study area, they might remember the old features or at least the parts, living conditions, and production at that time. The interviewing process was conducted in pairs (two old men/women), asking the same questions and letting them to identify the same features several times under several groups. This helps them to make remind each other about old incidents at the same time, and a possible confirmative analysis was done with the help of different answers obtained from different groups.

(4) Data sources. Three scenes of IKONOS(Fig. 2) images acquired on September 27, 2002 were obtained from Space Imaging Co. The historical aerial photo (Fig. 3) dated September 23, 1942 was gathered from US National Archival taken by Japanese aircrafts over the current working site. The flight altitude was about 9989m, and the extent of each aerial photo was about 9km×9km. Land use and soil maps were procured from local land department. The statistical data on socio-economics was obtained from the local township governments.

4 LAND CLASSIFICATIONS

Land in each village is classified into ecotope by using a four-stage classification method, which is called stratification method, based on the hierarchy of landscape. In this method, landscape is classified at landform, land use, land cover, and group. Ecotopes are defined as the smallest homogeneous ecosystem units within landscapes (KLIJIN and UDO DE HAES, 1994). In the present case, ecotopes are recognizable on satellite images, aerial photographs and on the ground, for at least two years in the same location using a standardized classification system. The basic ecosystem factors used

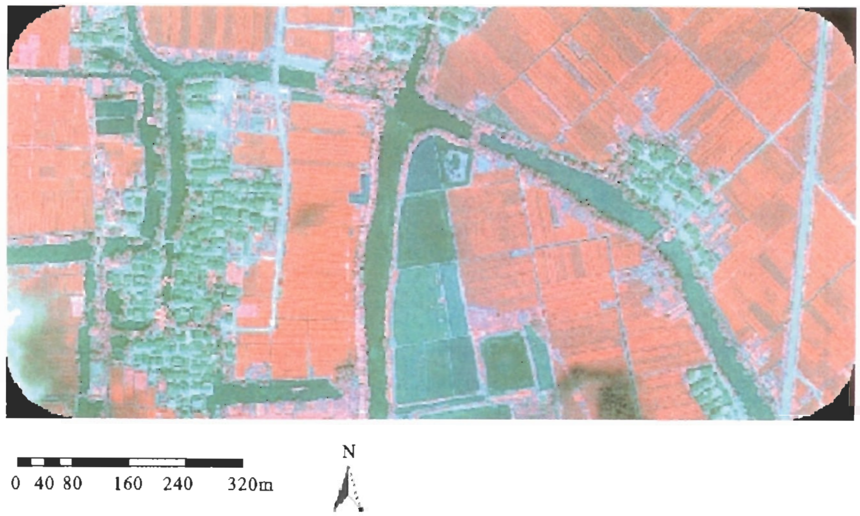

Fig. 2 Study area on original IKONOS image

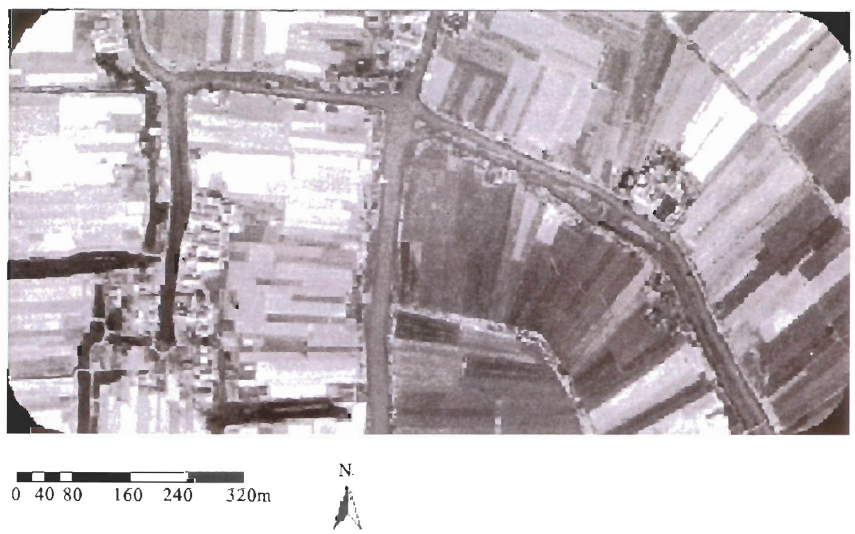

Fig. 3 Study area on WW2 aerial photo

for classification were soil type, sedimentary process, hydrology (periodicity and management), disturbance (type, intensity, and frequency), vegetation cover, and human and animal residence. By design, the higher levels of classification were larger and stable over the time in that area than lower levels (ELLIS *et al.*, 2000).

The definition of landform component in landscape depends on terrain, soil, and hydrological factors (Table 1). Water bodies and wetlands are differentiated by sedimentary process and potential for emergent vegetation, and wetlands can be defined as water bodies having considerable depth of water (>1m) or a seasonal depth of water less than 1m. Margins are those areas nearer to the slope of canals and pond banks, where there is perched water layer of <1m during most of the time in a year. Marsh is a man-made class, representing canals and ponds filled with sediment or trash with a maximum seasonal water depth less than 1m (ELLIS *et al.*, 2000). Ponds and canals are classified into two subclasses based on their scales.

Land use mainly relates to human management. They are differentiated based on enduring human management factors influencing hydrology (irrigation, flooding) and disturbances (construction, cultivation etc.) (ELLIS *et al.*, 2000) (Table 2). Land cover classes are differentiated based on biota, i.e., natural characteristics of the landscape (Table 3).

Group is used to classify consistently observable patterns of landform, land management, vegetation cover that varies a little over the period of few years, usually at least two years (Table 4).

According to the classes of landform, land use, land

Table 1 Landform classes for hierarchical ecotope classification

Code	Name	Description	Soil type	Hydrology	Elevation (m)
TE	Terrestrial	Generic class	Hydragric paddy soil	Saturated	+5 to 0
FP	Floodplain	River floodplain	Hydragric paddy soil	Saturated	+5 to 0
MA	Marsh	Water body depth <1m	Sediment	Seasonally inundated	+5 to −1
PM	Pond margin	Water body depth <1m	Sediment	Seasonally inundated	+5 to −1
CM	Canal margin	Water body depth <1m	Sediment	Seasonally inundated	+5 to −1
PA	Small pond	Water body depth >1m and width <30m	Accumulation	Permanently inundated	<−1
PB	Large pond	Water body depth >1m and width >30m	Accumulation	Permanently inundated	<−1
CA	Small canal	Flowing man-made watercourse with a depth >1m and a width <30m	Sediment	Permanently inundated	<−1
CB	Large canal	Flowing man-made watercourse with a depth >1m and a width >30m	Sediment	Permanently inundated	<−1

Note: Categories from ELLIS *et al*. (2000), some changes have been made

Table 2 Land use classes for hierarchical ecotope classification

Code	Name	Description	Water management	Cultivation
C	Constructed	Built-up area	Sealed or compacted surface	Cleared
P	Paddy	Paddy crops	Seasonal	Annual cropping
A	Aquatic	Aquaculture and aquatic crops	Year-round flooding	Aquatic cropping
I	Irrigated	Irrigated crops	Seasonal flooding	Annual and perennial cropping
R	Rainfed	Rainfed crops	Rare or infrequent low volume watering	Annual and perennial cropping
L	Livestock	Outdoor livestock production	Variable	Grazing
F	Fallow	Not managed for production	Usually none	Minimal, infrequent vegetation harvesting
D	Disturbed	Disturbed or fragmented by human activities	Variable	Variable

Note: Categories from ELLIS *et al*. (2000), some changes have been made

Table 3 Land cover classes for hierarchical ecotope classification

Code	Name	Description	Vegetation
S	Sealed	Impermeable cover/paved/sealed/roofed	Impermeable surface >90% /some vegetation inside greenhouses & buildings/courtyards, including areas with vegetation canopy overhead
E	Bare soil	Bare soil all the year round/usually compacted/disturbed/incapable of supporting annual vegetation	Exposed soil >90% all the year round, including areas with vegetation canopy overhead
A	Annual	Annual & herbaceous vegetation cover	Annual and other herbaceous vegetation (tree & shrub cover <10%) during growing season
M	Mixed	Trees/bushes/shrubs/other woody perennial vegetation	Mixtures of vegetation/bare earth and one or more other cover class either horizontally or vertically
P	Perennial	Mixtures of vegetation cover	Woody vegetation cover (bushes & shrubs)/tree canopy cover >10%
V	Variable	Variable between years to classify, such as seasonal riverbeds	Variable within a year to classify cover
W	Water	Water surface	Some submerged & floating
X	Barren	Permanent rock/snow/ice	Barren land >90%/exposed soil or vegetation <10%

Note: Categories from ELLIS *et al*. (2000), some changes have been made

cover, and group, the classification of ecotopes and their changes in the study area between 1942 and 2002 are listed in Table 5.

5 LONG-TERM MAN-MADE CHANGES

5.1 Change of Landform

According to Table 6, the change of floodplain between 1942 and 2002 was less than 10%. However, the canals have been changed greatly. The number of small canals had increased nearly by 3 folds, while larger canals had decreased a great bit. It was presumed that all the larger canals might have become smaller or changed into other landform classes. In the past, canals were the main transportation ways in study area. At that time, this area was a typical subsistence agriculture region. In winter, the local farmers usually grabbed silt out of canals and used them as fertilizer. But now, the dredging of canals has been done rarely due to extensive use of chemical fertilizers. This gradually narrowed the width of canals. Some of the canals and ponds have been finally become marsh because of sedimentation process, which make marsh area increase greatly. Since the beginning of adjustment in agricultural structure, a lot of paddy

Table 4 Group classes for hierarchical ecotope classification

Code	Group	Group description	Type	Type description
ho01	ho	Housing	01	Single story houses
ho02	ho	Housing	02	Multi-story houses
ib01	ib	Industrial building	01	Small generic factory (area<30m×30m)
ib02	ib	Industrial building	02	Large generic factory (area>30m×30m)
nb01	nb	Non-industrial building	01	Small non-industrial buildings (area<30m×30m), including pump houses, power transfer, etc.
nb02	nb	Non-industrial building	02	Large non-industrial buildings (area>30m×30m), including pump houses, power transfer, etc.
tr01	tr	Transportation	01	Unpaved paths, roads & accesses (width>2m)
tr02	tr	Transportation	02	Paved paths, roads & accesses (width>2m)
tr03	tr	Transportation	03	Railway
ir01	ir	Irrigation	01	Permeable irrigation & drainage ditch (width>2m)
ir02	ir	Irrigation	02	Sealed irrigation & drainage ditch (width>2m)
db01	db	Disturbed area and debris	01	60% of area covered with bare earth
db02	db	Disturbed area and debris	02	60% of area covered with annual vegetation
db03	db	Disturbed area and debris	03	60% of area covered with perennial vegetation
db04	db	Disturbed area and debris	04	Grave, most area covered with perennial vegetation
db05	db	Disturbed area and debris	05	Grave, most area covered with annual vegetation
db06	db	Disturbed area and debris	06	Grave, most area covered with bare soil
ls01	ls	Livestock	01	Small unsealed floor (area<30m×30m)
ls02	ls	Livestock	02	Large unsealed floor (area>30m×30m)
ls03	ls	Livestock	03	Small sealed floor (area<30m×30m)
ls04	ls	Livestock	04	Large sealed floor (area>30m×30m)
aq01	aq	Aquaculture	01	Small-scale generic fresh water fish culture (area<30m×30m)
aq02	aq	Aquaculture	02	Medium-scale generic fresh water fish culture (area is 30m×30m to 1ha)
aq03	aq	Aquaculture	03	Large-scale generic freshwater fish culture (area>1ha)
aq04	aq	Aquaculture	04	Floating aquatic crops
wa01	wa	Water surface	01	Lentil open freshwater, no aquaculture
wa02	wa	Water surface	02	Flowing open fresh water, no aquaculture
ri01	ri	Hydromorphic crops	01	Rice paddy not used for transplant each year
ri02	ri	Hydromorphic crops	02	Rice paddy used for transplant each year
ri03	ri	Hydromorphic crops	03	Non-rice rooted wetland crops
ac01	ac	Annual crops	01	Small-scale intensive annual crops (area<30m×30m)
ac02	ac	Annual crops	02	Large-scale intensive annual crops (area>30m×30m)
dw01	dw	Deciduous woody crops	01	Orchard trees, peaches dominant
dw02	dw	Deciduous woody crops	02	Vineyard
dw03	dw	Deciduous woody crops	03	Mulberry
av01	av	Annual vegetation	01	Weeds, larger patches
av02	av	Annual vegetation	02	Field borders, soybean, broad bean
pv01	pv	Perennial vegetation	01	Brush and weeds
pv02	pv	Perennial vegetation	02	Medium trees, saplings and scrub
pv03	pv	Perennial vegetation	03	Mature trees, closed canopy, mainly deciduous
pv04	pv	Perennial vegetation	04	Public planted trees
tg01	tg	Tall graminoids plant	01	Tall grass
tg02	tg	Tall graminoids plant	02	Bamboo thicket
hv01	hv	Hydryomorphic annual vegetation	01	Rooted, floating leaf and floating vegetation
hv02	hv	Hydryomorphic annual vegetation	02	Floating and submerging vegetation

Note: Categories from ELLIS *et al*. (2000), some changes have been made

and other land have been transformed into aquatic ponds, which make small and large ponds increase greatly.

5.2 Change of Land Use

From Table 7 it can be seen that the reduction of paddy was nearly one fold. The increase of rainfed land was about 6 times. According to the views of old people, in the past the local farmers usually did not planted any vegetables because of hard living conditions as well as undeveloped commerce. Their land was usually borrowed from landlords and temples. Based on the analysis of study area, nearly 75% of the land in Qiujiadou Village and also a part of the study area were owned by the landlords and temples or clan building managers. Landlords and temples owned nearly 85% of the land in

Table 5 Classification of ecotopes and their changes in the study area between 1942 and 2002

Code	Description	Area (m^2)		Change between 1942 and 2002
		1942	2002	
FPCSho01	Single story building	4248	112	−4136
FPCSho02	Multistory building	5404	39956	+34552
FPCSls01	Outdoor livestock	0	348	+348
FPCEtr01	Width >2m, road of bare earth	4044	1629	−2415
FPCStr02	Width >2m, sealed road	0	3752	+3752
FPPAri01	Rice paddy, not for transplanting field	276294	164971	−111323
FPRAac01	Rained dry land, annual crops	80	49764	+49684
FPRPdw03	Mulberry field	7680	0	−7680
CAAWaq01	Small canal for aquaculture	0	2440	+2440
CAAWaq02	Small canal for aquaculture, but the area is large	0	5937	+5937
CAAWaq03	Small canal for aquaculture, long enough for classification into aq03	0	40067	+40067
CAFWwa01	Small and lentic canal, not for fish or other production purpose	0	0	0
CAFWwa02	Small and flowing canal, not for fish or other production purpose	13607	0	−13607
CBFWwa02	Large and flowing canal, for fish or other production purpose	56793	0	−56793
PAAWaq01	Small pond for aquaculture	400	0	−400
PBAWaq02	Large pond for aquaculture	0	20749	+20749
PBAWaq03	Large pond (>1ha) for aquaculture	0	19695	+19695
FPCEir01	Irrigation ditches, not sealed	0	1661	+1661
FPDEdb01	60% of area is covered with bare earth	0	77	+77
FPDAdb02	60% of area is covered with annual vegetation	0	22771	+22771
FPDPdb03	60% area is covered with perennial vegetation	19882	18765	−1117
FPDPdb04	Grave, most area covered with perennial vegetation	6647	0	−6649
FPDAdb05	Grave, most area covered with annual vegetation	4922	0	−4922
MAFAhv01	Rooted, floating leaf and floating vegetation	0	2389	+2389

Table 6 Change of landform (m^2)

	Floodplain	Small canal	Large canal	Marsh	Small pond	Large pond
1942	329200	13607	56793	0	400	0
2002	303807	48444	0	2389	4904	40444
Change	−25393	+34837	−56793	+2389	+4504	+40444

Table 7 Change of land use (m^2)

	Paddy	Rainfed	Constructed	Aquatic	Disturbed	Fallow
1942	276294	7760	13695	400	31451	70400
2002	164971	49764	47458	93792	41614	2389
Change	−111323	+42004	+33763	+93392	+10163	−69011

Xiaoshao Village. After crop harvesting, most of grains have to be given back to the landowners. And hence, farmers did their utmost to increase grain harvest. They have no idea to plant vegetables.

5.3 Change of Land Cover

Table 8 indicates that the change of annual cover was considerably less, but perennial land cover decreased nearly a half. This is only because tree denudation under the stress of population resulted in an increase of sealed area. The sealed area increased by 3 folds. Most of this increase comes from the increase of housings. Moreover, most of housings at present are multistoried. Another cause for the decrease of perennial land cover was the change of grave land cover.

Table 8 Change of land cover (m^2)

	Annual	Perennial	Bare soil	Sealed	Water
1942	281296	34209	4044	9651	70800
2002	239896	18765	3366	44169	93792
Change	−41400	−15444	−678	+34518	+22992

In the past, pines and cypresses surrounded most of graves and the coverage of grave was greater than that of today. The change in water coverage was a little. Although a lot of land has been transformed into fishing ponds because of the adjustment of agriculture, the canals were getting narrower and narrower because of no dredging. So the overall changes of water coverage were less.

5.4 Change of Group

Table 9 indicates that the housing was increased by 3 times. This is because of the improvement of living conditions of people after liberation in 1949 on one hand and the increase of population on the other hand. In Xiaoshao Village, there were only five families in the past. But now, there were as many as 23 families living there. The population has been increased by 4 times.

Hydromorphic crop area was decreased nearly a half, while the area for the annual crops and aquaculture has increased greatly. The decrease of hydromorphic crop

Table 9 Change of group (m^2)

Group	Housing	Hydromorphic crops	Annual crop	Aquaculture	Transportation	Irrigation	Livestock	Hydromorphic annual vegetation	Disturbed area & debris	Mulberry	Fallow water
1942	9651	276294	80	400	4044	0	0	0	31541	7680	70400
2002	40068	164971	49764	93792	93792	1661	348	2389	41614	0	0
Change	+30417	−111323	+49684	+93392	+89748	+1661	+348	+2389	+10073	−7680	−70400

area and the increase of annual cropping and aquaculture area together were almost the same. Since the aquaculture and vegetable plantings were more profitable than rice planting, at present the local farmers are willing to carry on aquaculture and vegetable planting practices. At the same time, the local governments also encourage aquaculture and vegetables plantings along with other special agriculture. It could be estimated that paddy area continued to decrease in the recent years because of the guide of market economy and value regulation.

The area of transportation has been increased greatly. In those days, the canals were main transportation ways, so most of the cargo was transferred in and out with the help of boats. There were only a couple of roads whose width was not greater than 2m. Now, the roads and highways have connected both rural area and towns together. In the past, there was almost no irrigation ditches; most of the land was irrigated by using canals; and there were few people who reared pigs, goats and other livestocks.

There was/is hydromorphic annual vegetation in the past and at present. In the past, wetland was wide spread than today. There was about 20ha of wetland not far away from the study area.

5.5 Ecotope Changes

From Table 5, it can be noticed that single-storied buildings were almost at the edge of disappearance(112m^2) in 2002. The multi-storied buildings were increased greatly about 7 times in the study period. The construction of multi-storied buildings has grown up because of increased population and limited building area. The outdoor livestock has disappeared. Now for the rearing of pigs, outdoor rearing was only a chance phenomenon. The roads of bare soil were reduced by 2 times or more, while the sealed roads have been increased nearly by the same times. The transportation conditions have been improved greatly. Paddy has decreased nearly a half.

In 1942, there was no dryland for annual crops. In 2002, the area of dryland was estimated to be 49 764m^2. Market guide and the local agricultural adjustment encouraged by the local governments might be the reasons for increase of dryland area. The area of mulberry plantation was decreased greatly from 7680m^2 to 0m^2. At present, the cocoon is cheap and difficult to sell. In 1942, the price of concoon was very high, and 0.5kg of cocoon was worth about 500kg of grains. So, farmers tried their best to plant mulberry at that time. The aquaculture area of small canals was 48 444m^2 in 2002. Fish rearing was not widely popular. In the past, the availability of fish was plenty as there were lots of ponds, canals and something alike everywhere, and the organic fertilizers were widely used compared to today. The rivers and canals were clean, without the pollution caused by chemicals and pesticides. Environment itself can support sustainability. In 1942, canals were wider than those in 2002, being almost 30m. The water coverage of canals in 1942 was greater than 2002 and the difference of cover was about 21 956m^2.

The disturbed area, of which more than 60% was covered by annual vegetation, was 22 771m^2 in 2002, with a remarkable change. The disturbed area, of which more than 60% was covered by perennial vegetation was 18 765m^2, while in 1942 the area was 19 882m^2. The decrease was only 1117m^2.

In 1942, the grave area covered with perennial vegetation (6647m^2) was greater, but the area of such kind was 0 in 2002. In 1942, the grave area covered with annual vegetation was 4922m^2, while in 2002 the area was also 0. The grave area covered with annual or perennial vegetation has been decreased greatly because of reformation in burial styles.

In the past, there was no marsh with hydromorphic vegetation either with rooted or floating leaves. In 2002, the area of this kind was 2389m^2. The landform in this area has been changed a little.

6 CONCLUSIONS

At present, China is experiencing great changes not only in cities but also in rural areas. However, the research works on long-term changes using high-resolution images are rare. This paper tried to make an exploration on the long-term man-made changes in rural area in China by using IKONOS images and historical aerial photos. In China, the rural area is greater than urban area. And the change of landscape in Chinese rural area must contribute greatly to the global change. It has been observed that rural areas in China have been greatly changing for the last 60 years.

The application of IKONOS imagery to the research of landscape has a good prospect. It can save a lot of time, field works and money and make a more extensive landscape study possible. From this the researchers can combine high resolution remotely sensed data such as IKONOS and QuickBird imagery into middle and low resolution remotely sensed data such as Landsat TM, ETM, SPOT and MODIS etc. and carry out a more extensive and more precise research on landscape.

Stratification method of landscape has more advantages than the conventional methods and it can reveal more details of landscape at finer level and more precise level. Since landscape unit is a complex of geophysical factors, such as hydrology, botany, land use and land cover, topography and soil, stratification method can extract and synthesize the landscape information more precisely and get a full knowledge of landscape.

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