ELSEVIER

Journal of Environmental Management 83 (2007) 351–364

Journal of Environmental Management

www.elsevier.com/locate/jenvman

Socio-economic driving forces of land-use change in Kunshan, the Yangtze River Delta economic area of China

Hualou Long[a,b,*], Guoping Tang[c], Xiubin Li[a], Gerhard K. Heilig[b]

[a]*Institute of Geographic Sciences and Natural Resources Research (IGSNRR), Chinese Academy of Sciences, 11A Datun Road, Anwai, Beijing 100101, PR China*

[b]*International Institute for Applied Systems Analysis (IIASA), A-2361 Laxenburg, Austria*

[c]*Department of Geography, University of Oregon, OR 97403, USA*

Received 9 May 2005; received in revised form 3 April 2006; accepted 7 April 2006
Available online 5 July 2006

Abstract

This paper analyzes characteristics, major driving forces and alternative management measures of land-use change in Kunshan, Jiangsu province, China. The study used remote sensing (RS) maps and socio-economic data. Based on RS-derived maps, two change matrices were constructed for detecting land-use change between 1987 and 1994, and between 1994 and 2000 through pixel-to-pixel comparisons. The outcomes indicated that paddy fields, dryland, and forested land moderately decreased by 8.2%, 29% and 2.6% from 1987 to 1994, and by 4.1%, 7.6% and 8% from 1994 to 2000, respectively. In contrast, the following increased greatly from 1987 to 1994: artificial ponds by 48%, urban settlements by 87.6%, rural settlements by 41.1%, and construction land by 511.8%. From 1994 to 2000, these land covers increased by 3.6%, 28.1%, 23.4% and 47.1%, respectively. For the whole area, fragmentation of land cover was very significant. In addition, socio-economic data were used to analyze major driving forces triggering land-use change through bivariate analysis. The results indicated that industrialization, urbanization, population growth, and China's economic reform measures are four major driving forces contributing to land-use change in Kunshan. Finally, we introduced some possible management measures such as urban growth boundary (UGB) and incentive-based policies. We pointed out that, given the rapidity of the observed changes, it is critical that additional studies be undertaken to evaluate these suggested policies, focusing on what their effects might be in this region, and how these might be implemented.

Keywords: Land-use change; Driving forces; Urbanization; Land management measures; The Yangtze River Delta; China

1. Introduction

Since China initiated economic reforms and an open-door policy in 1978, tremendous land-use change has occurred in many coastal regions of China such as the Yangtze River Delta region (Xu, 2004) and Pearl River Delta region (Weng, 2002; Seto and Kaufmann, 2003; Li and Yeh, 2004). In these regions, the conversion of cultivated land to non-agricultural land has been considered a major feature of land-use change (Li, 1999; Yang and Li, 2000). The fragmentation of cultivated land can be also observed due to construction on land of the countryside (Lin and Ho, 2003; Long and Li, 2005). In addition, the adoption of market principles has resulted in the internal restructuring of agricultural land use from traditional paddy production to more diversified agricultural activities such as growing cash crops, fruits and aquaculture (Heilig, 1999; Li and Yeh, 2004). The accelerated industrialization and urbanization following economic reforms and population increases have greatly affected land-use change through the increase of built-up areas and urban sprawl (Wu et al., 2004). With the continuous growth of China's economy, massive farmland loss for the benefit of market farming and non-agricultural

*Corresponding author. Institute of Geographic Sciences and Natural Resources Research (IGSNRR), Chinese Academy of Sciences, 11A Datun Road, Anwai, Beijing 100101, PR China. Tel.: +86 10 64889297; fax: +86 10 64854230.

E-mail addresses: longhl@igsnrr.ac.cn (H. Long), lixb@igsnrr.ac.cn (X. Li).

0301-4797/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2006.04.003

development may occur without appropriate planning and management of existing land resources in these regions.

Both remote sensing (RS) and geographic information systems (GIS) have been widely applied and recognized as powerful and effective tools in detecting the spatio-temporal dynamics of land use and land cover (LULC) (Fazal, 2000; Hathout, 2002; Herold et al., 2003; Mapedza et al., 2003; Alphan, 2003; Nagendra et al., 2004; Wang et al., 2005). RS can provide researchers with valuable multi-temporal data for monitoring land-use patterns and processes (Lambin et al., 2001; Yildirim et al., 2002), and GIS techniques make possible the analysis and mapping of these patterns (Imbernon, 1999; Zhang et al., 2002). One can develop spatially explicit time series of land-use change based on RS (Moglen and Beighley, 2002; Poyatos et al., 2003; Himiyama, 1998). The widely used approach of change detection enables us to discover the structural variation among different land-cover patterns (Chen et al., 2003; Walker, 2003; Liu et al., 2003a). In addition, statistical analysis such as correlation analysis (Shoshany and Goldshleger, 2002; Hietel et al., 2004; Krausmann et al., 2003), multi-variate analysis (Kaufmann and Seto, 2001; Aspinall, 2004), and econometric models (Burgi and Turner, 2002; Lo and Yang, 2002; Seto and Kaufmann, 2003; Veldkamp and Verburg, 2004) are used to diagnose land-use change based on time series socio-economic data. These time series analyses of land-use change and the identification of driving forces responsible for these changes are significant not only for the sustainable management of land resources, but also for the projection of future land-use trajectories (Kelly, 2003; Giri et al., 2003; Alig et al., 2004).

Recently, issues related to LULC change have attracted interest among a wide variety of researchers, ranging from those who favor modeling spatial and temporal patterns of land conversion to those who try to understand causes and consequences of land-use change (Muller and Middleton, 1994; Brown et al., 2000; Irwin and Geoghegan, 2001; Veldkamp and Lambin, 2001; Burgi et al., 2004). Although industrialization, urbanization, and population growth have been considered the most common forces contributing to land-use change on a global scale, there is no consensus concerning the factors contributing to land-use change in China's coastal regions. For example, rural housing development may have contributed greatly to the loss of agricultural land (Xu, 2004), and large-scale investments in industrial development, rather than local land users, may be a major factor in causing urban land-use change (Seto and Kaufmann, 2003). In addition, there is considerable debate on the extent and magnitude of Chinese rural land-use change since the onset of reforms in 1978 (Xu, 2004), largely because of the complexity of land-use change regarding its process, dynamic, and driving forces (Theobald, 2001; Burgi and Turner, 2002; Lambin et al., 2003). Therefore, Verburg and Veldkamp (2001) have stated that a single research approach does not suffice for a complete analysis of land-use change. Instead, a combination of multiple approaches is necessary for land-use change research (Lambin et al., 2000; Cai, 2001; Long, 2003).

In this paper, our main objectives are to explore the characteristics of land-use change in Kunshan and its major driving forces through combining RS-derived LULC maps and socio-economic data. Using historical LULC data, we first reclassified the LULC types in the three RS-based maps into eight categories, and then converted these reclassified maps into raster format with a spatial resolution of 200×200 m. Based on these maps, two change matrices were constructed for detecting land-use change between 1987 and 1994, and between 1994 and 2000 through pixel-to-pixel comparisons. In addition, socio-economic data were used to analyze major driving forces triggering land-use change in Kunshan through bivariate analysis. Finally, we suggested some possible management measures that are crucial for future sustainable utilization and management of its existing land resources, e.g. managing urban growth and protecting cultivated land.

2. Materials and methods

2.1. Study area

Our study area, Kunshan, is located inside the Yangtze River Delta economic area (YRDEA), one of the fastest growing regions in China (Fig. 1). It ranges from 120°09′04″E to 120°48′21″E, and from 31°06′34″N to 31°32′36″N. There are three of the biggest cities in China around Kunshan: Shanghai (to the east), Nanjing (to the west and the capital of Jiangsu province), and Hangzhou (to the south and the capital of Zhejiang province). Kunshan covers about 928 km^2 with average elevation below 50 m. The northern subtropical monsoon climate dominates Kunshan year-round, with mean daily temperature of 15.3 °C, mean annual rainfall of 1060 mm, and mean annual non-frost period of 299 days, all of which are beneficial for agricultural production.

Kunshan is unique because of its high population density and agricultural intensity. Kunshan's population has been increasing by an annual rate of 0.23% since the early 1980s. With a total population of about 600 thousand, the population density in Kunshan was up to 646 persons/km^2 in 2002, which was much higher than the average population density (131 persons/km^2) of China at the same period. Of the total population, 53% were engaged in farming, providing much of the labor force to produce commercial grains in the south part of Jiangsu province. The gross grain output in Kunshan, an important grain production base of China's Jiangsu province, amounted to 283 000 tons in 2000 (Jiangsu Statistical Bureau (JSB), 2001).

The growth of Shanghai, the most important industrial, commercial, and financial center of China, and the prosperity of Nanjing and Hangzhou, have pushed Kunshan into the industrial age since the early 1980s. In 1984, Kunshan was defined as one of the open cities and counties by the State Council of China, largely because of

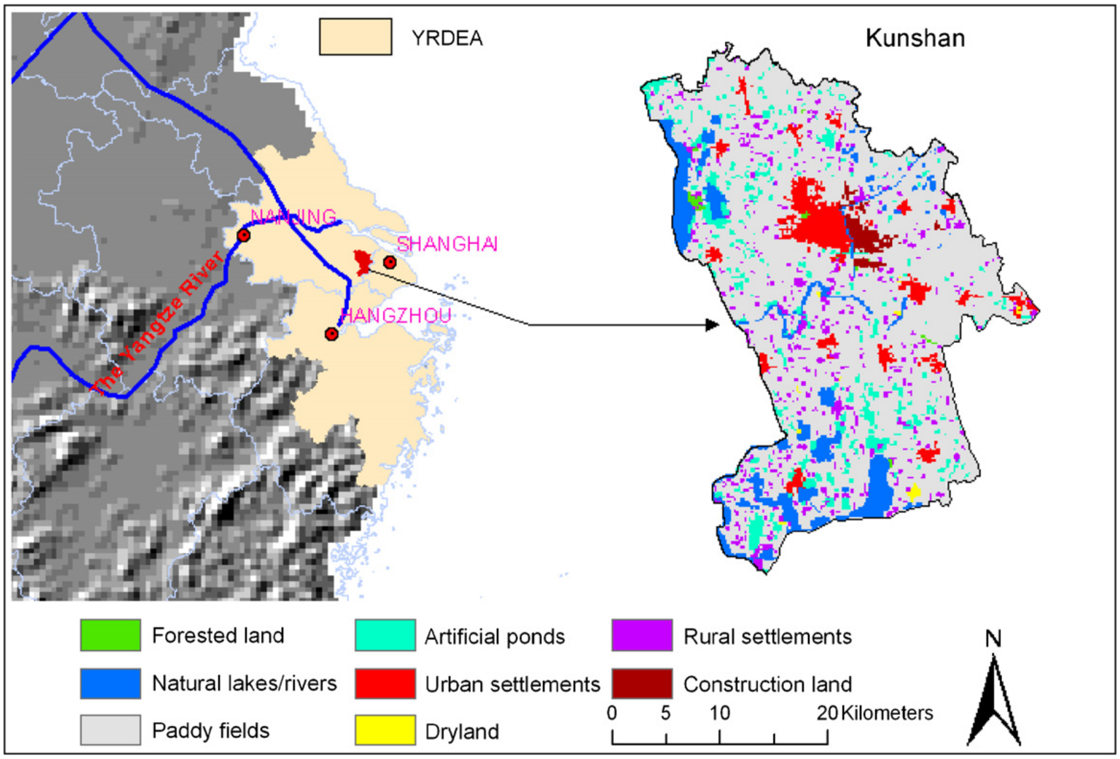

Fig. 1. The study area Kunshan in the Yangtze River Delta economic area (YRDEA).

certain policies established by Kunshan local government, such as devoting major efforts to developing township and village enterprises (TVEs). Because of the special geographic location, Kunshan has been booming since 1984. At present, Kunshan is famous for its economic and technological development zone (ETDZ), one of the most successful development zones in China (Long et al., 2000; Long and Meng, 2004). In 2000, Kunshan's gross domestic product (GDP) per capita amounted to 33 936 yuan (1 US$ $\approx$8.28 yuan), and 59 861 yuan per capita for gross output value of industry, which was much higher than the average gross output value (6768 yuan) of industry in China at the same period. The average agricultural net income in Kunshan was 5616 yuan per capita, and the average government revenue reached a record of 2162 yuan per capita in Jiangsu province (JSB, 2001).

However, with the growth of population and economic activities, land use in Kunshan has changed dramatically as evidenced by the continuous decline of cultivated land. In 1994, the total area of cultivated land in Kunshan was around 48 828 ha. By the end of 2002, it had decreased to 45 883 ha, a decline of 6% in 8 years. The ongoing land-use change in Kunshan is not only a serious challenge to the local government, but can be also seen as a model of land-use change in rapidly developing regions of China.

2.2. Data sources and processing

The analysis of land-use change in Kunshan is based on three LULC maps at a 1:100 000 scale. These maps were derived from historical Landsat thematic mapper (TM) satellite images, which were acquired on 18 May 1987, 29 June 1994, and 4 May 2000, respectively, by the Institute of RS Applications, the Chinese Academy of Sciences. An efficient classification system was drafted and an effective research team was organized to work on remote sensed data through human–machine interactive interpretation to guarantee classification consistency and accuracy. Land-use maps, classified into six first levels and 25 second levels of land-use categories in total, were drawn based on the Landsat TM data (Liu et al., 2003b). After geometrical image correction and geo-referencing, the average location errors were estimated at less than 50 m (about two pixels). An out-door survey and random sample check (covering a line survey of 70 000 km and 13 300 patches) verified that the average interpretation accuracies for land-use/land-cover were 92.9% and 97.6% for land-use change interpretation (Liu et al., 2003b).

There were six major LULC types (cultivated land, woodland, grassland, water body, unused land, and rural and urban settlements), and 25 sub-categories in the original LULC datasets. However, based on ground survey, it was found that grassland and unused land do not exist in Kunshan. Therefore, we reclassified the original LULC types into eight classes: paddy fields, dryland, forested land, lakes and rivers, artificial ponds for fishing and other domestic purposes, urban settlements, rural settlements, and construction land mainly for mining and transportation. Then, we measured the variations among the eight different LULC types by converting the three

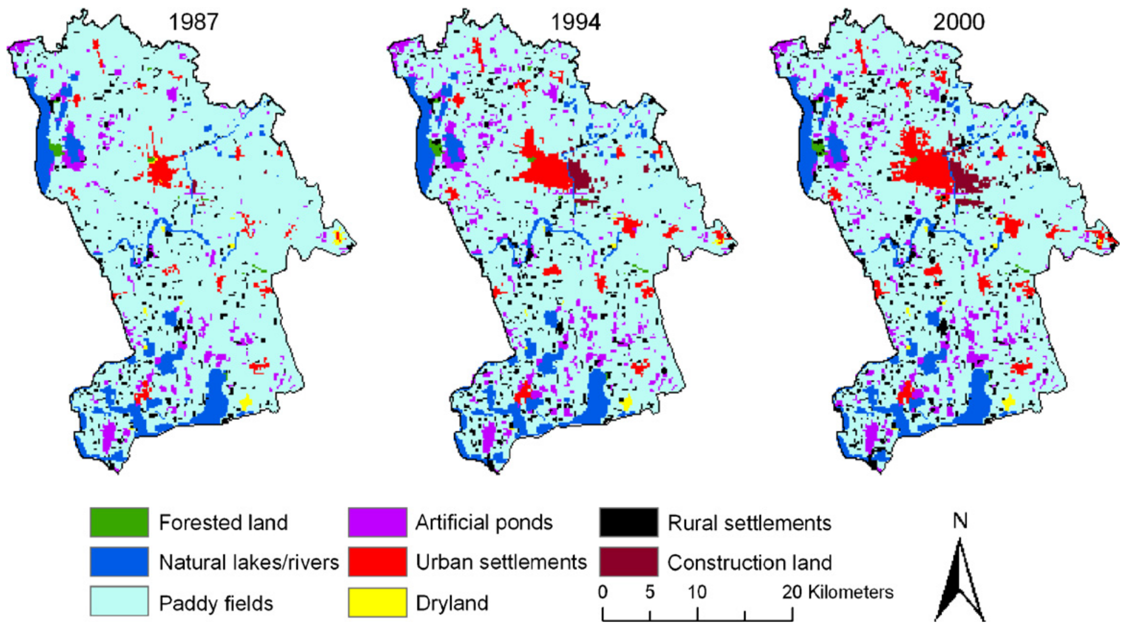

Fig. 2. Reclassified and gridded LULC types in 1987, 1994, and 2000 in Kunshan.

LULC vector format maps into raster format with a spatial resolution of 200×200 m (the minimum area of land covers in Kunshan is around $0.04\,km^2$) using ESRI's ArcGIS spatial analyst module. Fig. 2 illustrates the three gridded and reclassified LULC maps in 1987, 1994, and 2000 in Kunshan.

Because of the shortage of published annual time-series data of LULC in Kunshan, socio-economic data were collected from the local government (Table 1). These socio-economic data include time-series data on population, industry, agriculture (crop yield and agricultural land), fisheries (aquatic products), residential areas per capita, and construction land (here mainly used for mining and transportation) in the whole region between 1989 and 2000. Historical socio-economic data before 1989 were not available. These data were used to analyze potential driving forces resulting in land-use change in Kunshan.

2.3. Methods

The three reclassified and gridded LULC maps (Fig. 2) were mainly used to detect the internal variations of LULC in Kunshan between two different periods: from 1987 to 1994, and from 1994 to 2000. For each pair of gridded datasets, a change matrix was constructed. Then, for each LULC category i in a change matrix A, the change between the two periods was calculated according to the following equation:

$$\mathrm{CH}_i = (p_{i.} - p_{.i})/p_{.i} \times 100, \quad (1)$$

where CH_i is the change of LULC in row i relative to the previous compared year; $p_{i.}$ is the row total of grid cells for category i; $p_{.i}$ is the column total of grid cells for category i.

For exploring the internal conversion between different LULC types, which took place between the two compared periods, we treated the change (decrease or increase) of a LULC type in a given year relative to the compared year as a result of several "loss or gain" conversions. Thus, for each LULC type we calculated the percentage of "conversion loss to" or "conversion gain from," in relation to the total "loss or gain" conversion of a LULC type according to

$$\begin{cases} P_{\mathrm{loss}(i),j} = (p_{j,i} - p_{i,j})/(p_{i.} - p_{.i}) \times 100 & i \neq j, \\ P_{\mathrm{gain}(i),j} = (p_{i,j} - p_{j,i})/(p_{i.} - p_{.i}) \times 100 & i \neq j, \end{cases} \quad (2)$$

where $P_{\mathrm{loss}(i),j}$ is the percentage taken by type j in the total "conversion loss" of category row i; $P_{\mathrm{gain}(i),j}$ is the percentage taken by type j in the total "conversion gain" of category row i; $p_{i,j}$, and $p_{j,i}$ is the individual entry in a change matrix A.

Our initial research showed that the decrease and fragmentation of paddy fields is the most significant feature of land-use change in Kunshan. Paddy fields account for more than 92% of local agricultural land. Therefore, considering the limitation of only 3 years of LULC data (derived from remotely sensed images), we used the annual series of agricultural land data to explore the possible driving forces contributing to land-use change in Kunshan. Several bivariate statistical analyses were made to explore the correlations between different socio-economic variables (Table 1).

3. Results

3.1. Characteristics of land-use change in Kunshan

Land use has changed greatly over the period from 1987 to 2000 in Kunshan. From 1987 to 1994, paddy fields, dryland, and forested land decreased by 8.2%, 29%, and

2.6%, respectively. In contrast, artificial ponds, urban settlements, rural settlements and construction land increased by 48%, 87.6%, 41.1%, and 511.8%, respectively, in the same period (Table 2). These trends continued in the period from 1994 to 2000. By the end of 2000, paddy fields, dryland and forested land had decreased by 4.1%, 7.6%, and 8%, respectively, relative to 1994. Artificial ponds, urban settlements, rural settlements, and construction land had expanded by 3.6%, 28.1%, 23.4%, and 47.1%, respectively, in the same period (Table 3). The areas of natural lakes and rivers were relatively stable within these two periods. To a large extent, land-use change from 1987 to 2000 was characterized by a serious replacement of paddy fields with artificial ponds, urban and rural settlements, and construction land.

In addition to LULC change, we also analyzed changes in *fragmentation* of land in Kunshan between 1987 and 2000. Although many indices are available for assessment of spatial patterns, e.g. fragmentation, in landscape ecology (Sleeman et al., 2005), we simply used patch counts and average patch area to measure the fragmentation of LULC in Kunshan. Table 4 shows the changes in different LULC patches from 1987 to 1994, and from 1994 to 2000 in Kunshan. These data were calculated based on the three reclassified vector maps of LULC in Kunshan. In 1987, the total number of patches of LULC was 583. By 1994, they had increased to 714, and by 2000 the number was 869. As a result, the average area of each patch shrunk from 159.2 ha in 1987 to 130.0 ha in 1994 and further to 106.8 ha in 2000. We found that the fragmentation of LULC in Kunshan was mainly due to the expansion of rural settlements and artificial ponds. In 1987, there were 155 patches of artificial ponds; by 2000, the number of fishponds had increased to 269 (an increase of 73.5%). Likewise, rural settlements increased sharply from 290 in 1987, to 326 in 1994, and to 446 in 2000. Over the whole period between 1987 and 2000, the fragmentation of paddy fields was the most distinct trend. In 1987, there were only

Table 1
Annual series socio-economic data in Kunshan over the period from 1989 to 2000

Year	Population	Industrial output value (10 000 yuan)	Crop yield (ton)	Aquatic products (ton)	Residential areas per capita (m^2)	Agricultural land (ha)	Construction land (ha)
1989	554,500	108,956	485,757	22,350	39.9	78,001.4	—
1990	564,610	113,640	473,569	23,511	40	77,899.4	—
1991	568,430	150,218	466,697	23,333	42	77,664.7	—
1992	572,051	245,564	464,466	27,236	48	71,888.1	—
1993	575,519	348,724	421,078	36,691	42.2	70,937.9	—
1994	578,269	454,567	429,153	40,270	43.4	69,479.3	2819.04
1995	580,504	580,085	433,122	45,500	45.5	68,741.2	2871.31
1996	583,364	685,578	457,048	54,228	48	68,339.5	2931.63
1997	585,155	763,534	441,275	58,780	53	67,672.4	2963.73
1998	587,509	868,949	374,626	67,115	58.2	66,695.0	3070.93
1999	588,865	1,006,483	353,946	56,000	62.77	66,423.1	3069.49
2000	594,592	1,192,328	283,236	60,000	61.2	66,147.8	3109.64

Data sources: the data of residential areas and construction land are from Kunshan Land Administration Bureau; other data are from Socio-Economic Yearbook of Kunshan in 2000, provided by People's Government of Kunshan City. Construction land data are not available for years prior to 1994. Agricultural land here is mainly composed of paddy fields and dryland.

Table 2
Change matrix of each compared LULC type in 1987 and 1994, and its changes in 1994

LULC type in 1994	LULC type in 1987									Changes in 1994 (%)
	PF	DL	FL	LR	AP	US	RS	CL	Total	
PF	17152	0	0	0	1	0	0	0	17153	−8.2
DL	0	66	0	0	0	0	0	0	66	−29
FL	0	0	75	0	0	0	0	0	75	−2.6
LR	80	0	0	1922	0	0	0	0	2002	4.1
AP	495	0	0	0	1028	0	0	0	1523	48
US	460	27	0	0	0	556	0	0	1043	87.6
RS	327	0	2	1	0	0	803	0	1133	41.1
CL	174	0	0	0	0	0	0	34	208	511.8
Total	18688	93	77	1923	1029	556	803	34	23203	

Note: PF = paddy fields, DL = dryland, FL = forested land, LR = lakes and rivers, AP = artificial ponds, US = urban settlements, RS = rural settlements, CL = construction land.

Table 3
Change matrix of each compared LULC type in 1994 and 2000, and its changes in 2000

LULC type in 2000	LULC type in 1994									Changes in 2000 (%)
	PF	DL	FL	LR	AP	US	RS	CL	Total	
PF	16454	3	0	0	0	0	0	0	16457	−4.1
DL	0	61	0	0	0	0	0	0	61	−7.6
FL	0	0	69	0	0	0	0	0	69	−8
LR	0	0	0	1998	0	0	0	0	1998	−0.2
AP	63	0	0	0	1515	0	0	0	1578	3.6
US	288	0	0	0	5	1043	0	0	1336	28.1
RS	253	2	3	4	3	0	1133	0	1398	23.4
CL	95	0	3	0	0	0	0	208	306	47.1
Total	17153	66	75	2002	1523	1043	1133	208	23203	

Note: PF = paddy fields, DL = dryland, FL = forested land, LR = lakes and rivers, AP = artificial ponds, US = urban settlements, RS = rural settlements, CL = construction land.

Table 4
Changes of LULC patches from 1987 to 1994, and to 2000

LULC type	Patch counts			Minimum area (ha)			Maximum area (ha)			Average area (ha)		
	87	94	00	87	94	00	87	94	00	87	94	00
PF	16	9	31	1.36	0.36	0.36	73788.5	67714.4	64791.4	4662.2	7604.0	2122.0
DL	13	9	9	5.13	7.95	7.95	133.0	115.3	115.3	29.2	31.0	27.6
FL	11	11	11	4.07	4.07	4.07	131.3	119.7	106.3	27.3	26.2	24.0
LR	43	60	60	0.05	0.05	0.05	1619.6	1619.6	1619.6	179.7	134.1	133.8
AP	155	267	269	0.14	0.14	0.14	348.3	348.3	348.3	27.2	23.2	23.9
US	37	18	34	1.96	47.55	1.55	875.0	1891.7	2540.7	59.5	231.6	155.9
RS	290	326	446	0.09	0.12	0.12	69.3	82.8	108.3	11.0	13.9	12.3
CL	18	14	9	0.98	6.38	3.37	36.3	510.1	759.5	8.5	58.2	133.7
Total	583	714	869							159.2	130.0	106.8

Note: PF = paddy fields, DL = dryland, FL = forested land, LR = lakes and rivers, AP = artificial ponds, US = urban settlements, RS = rural settlements, CL = construction land.

16 patches of paddy fields and the average area was 4662.2 ha. However, by 2000, the number of paddy fields had increased to 31 and the average area had decreased to 2122 ha (a decrease of roughly 50%).

The accelerating urbanization process may increase the degree of fragmentation and structural complexity of LULC (Jenerette and Wu, 2001). Table 5 presents the urbanization-related land-use change in Kunshan from 1987 to 1994. During this period, the increase of artificial ponds, urban settlements, rural settlements and construction land accounted for 32.2%, 30%, 20.5%, and 11.3% of the decrease of paddy fields, respectively. From 1987 to 1994, the reduction of dryland was completely due to urban settlements expansion (100%). Rural settlements expansion (100%) accounted for all of the shrinking of forested land in the same period. However, the expansion of artificial ponds, urban and rural settlements, and construction land between 1987 and 1994, occurred mainly at the expense of paddy fields, which accounted for 100.2%, 94.5%, 99.1% and 100.0% of changes in artificial ponds, urban settlements, rural settlements, and construction land, respectively.

Over the period from 1994 to 2000, the trend of internal structural variability of LULC in Kunshan was similar to the period before. The decrease of paddy fields was caused mainly by the expansion of urban settlements, rural settlements, construction land, and artificial ponds. Similarly, the expansion of rural settlements and increase of construction land were two main factors in the decline of forested land. Although the expansion of artificial ponds, urban settlements, rural settlements, and construction land may have taken up some part of previous ponds and forested land, most of these changes occurred on paddy fields, which accounted for 114.5%, 98.3%, 95.5%, and 96.9% of the increases of these LULC types, respectively (Table 6).

3.2. *Major driving forces of land-use change in Kunshan*

The relationships between different variables in Table 1 are illustrated by Fig. 3 and Table 7. Our statistical analysis suggested that rapid industrialization and urbanization, population growth, and economic reforms in China are

Table 5
Internal conversions between LULC types from 1987 to 1994 and the percentages taken by corresponding types in such loss or gain conversions

LULC type	Loss or gain in 1994	Type (1)	Percent (%)	Type (2)	Percent (%)	Type (3)	Percent (%)	Type (4)	Percent (%)
PF^-	−8.2%	AP	32.2	US	30.0	RS	20.5	CL	11.3
DL^-	−29.0%	US	100.0						
FL^-	−2.6%	RS	100.0						
LR^+	4.1%	PF	101.3*						
AP^+	48.0%	PF	100.2*						
US^+	87.6%	PF	94.5	DL	5.5				
RS^+	41.1%	PF	99.1	FL	0.6	LR	0.3		
CL^+	511.8%	PF	100.0						

Note: $^-$ conversion loss to, $^+$ conversion gain from, * "conversion loss" occurred even the net change was "conversion gain."
PF = paddy fields, DL = dryland, FL = forested land, LR = lakes and rivers, AP = artificial ponds, US = urban settlements, RS = rural settlements, CL = construction land.

Table 6
Internal conversions between LULC types from 1994 to 2000 and the percentages taken by corresponding types in such loss or gain conversions

LULC type	Loss or gain in 2000	Type (1)	Percent (%)	Type (2)	Percent (%)	Type (3)	Percent (%)	Type (4)	Percent (%)
PF^-	−4.1%	US	41.4	RS	36.4	CL	13.6	AP	9.1
DL^-	−7.6%	PF	60.0	RS	40.0				
FL^-	−8.0%	RS	50.0	CL	50.0				
LR^-	−0.2%	RS	100.0						
AP^+	3.6%	PF	114.5*						
US^+	28.1%	PF	98.3	AP	1.7				
RS^+	23.4%	PF	95.5	LR	1.5	FL	1.1	AP	1.1
CL^+	47.1%	PF	96.9	FL	3.1				

Note: $^-$ conversion loss to, $^+$ conversion gain from, * "conversion loss" occurred even the net change was "conversion gain."PF = paddy fields, DL = dryland, FL = forested land, LR = lakes and rivers, AP = artificial ponds, US = urban settlements, RS = rural settlements, CL = construction land.

four major correlates of land-use change in Kunshan over the period from 1989 to 2000.

3.2.1. Industrialization

According to the analyses by the World Bank (1992) and Verburg et al. (1999), the major land-use change is caused by the increasing demand for non-agricultural land because of urban and manufacturing development. Urban-related industrialization is well known to be one of the most important driving forces of land-use changes in China (Zhou and Fischer, 1999; Wu et al., 2004), and it plays an important role in reducing the quantity of arable land (Chen, 1999). It also may alter the internal structure of LULC in a region (Chavez, 2004). In Kunshan, industrialization increased from 1989 to 2000, as evidenced by the fast increase in the total industrial output value (Table 1). Apparently, rapid industrialization in Kunshan is a very significant factor of land-use change. First, as Lin and Ho (2003) pointed out, the expansion of construction land is largely a result of *rural* industrialization in China. This also occurred in Kunshan, which can be illustrated by the strong positive relationship between industrial output value and construction land (Fig. 3).

In addition, industrialization in Kunshan has apparently triggered massive farmland loss for the benefits of market-oriented farming and non-agricultural development. According to Fig. 3, there was a strong positive relationship between industrial output value and aquatic products; and also between industrial output value and residential areas per capita. For the former, the correlation coefficient was 0.94 and for the latter it was 0.92 (Table 7). However, there was a strong negative relationship between industrial output value and crop yield (coefficient = −0.87). The negative relationship indicates that industrialization in Kunshan has triggered a large amount of cultivated land to be converted into market-oriented land used for built-up areas. For example, construction land (mainly used for mining and transportation) increased from 1987 to 1994 by 511.8%, which was totally (100%) at the expense of paddy fields (Table 5). Likewise, it increased by 47.1% from 1994 to 2000, of which 96.9% was reallocated from what was formerly paddy fields (Table 6).

The economic reforms in China encouraged the development of household and township enterprises, which gave rise to a booming rural industry of TVEs in Kunshan. The increase in TVEs can be seen as a spatial and temporal

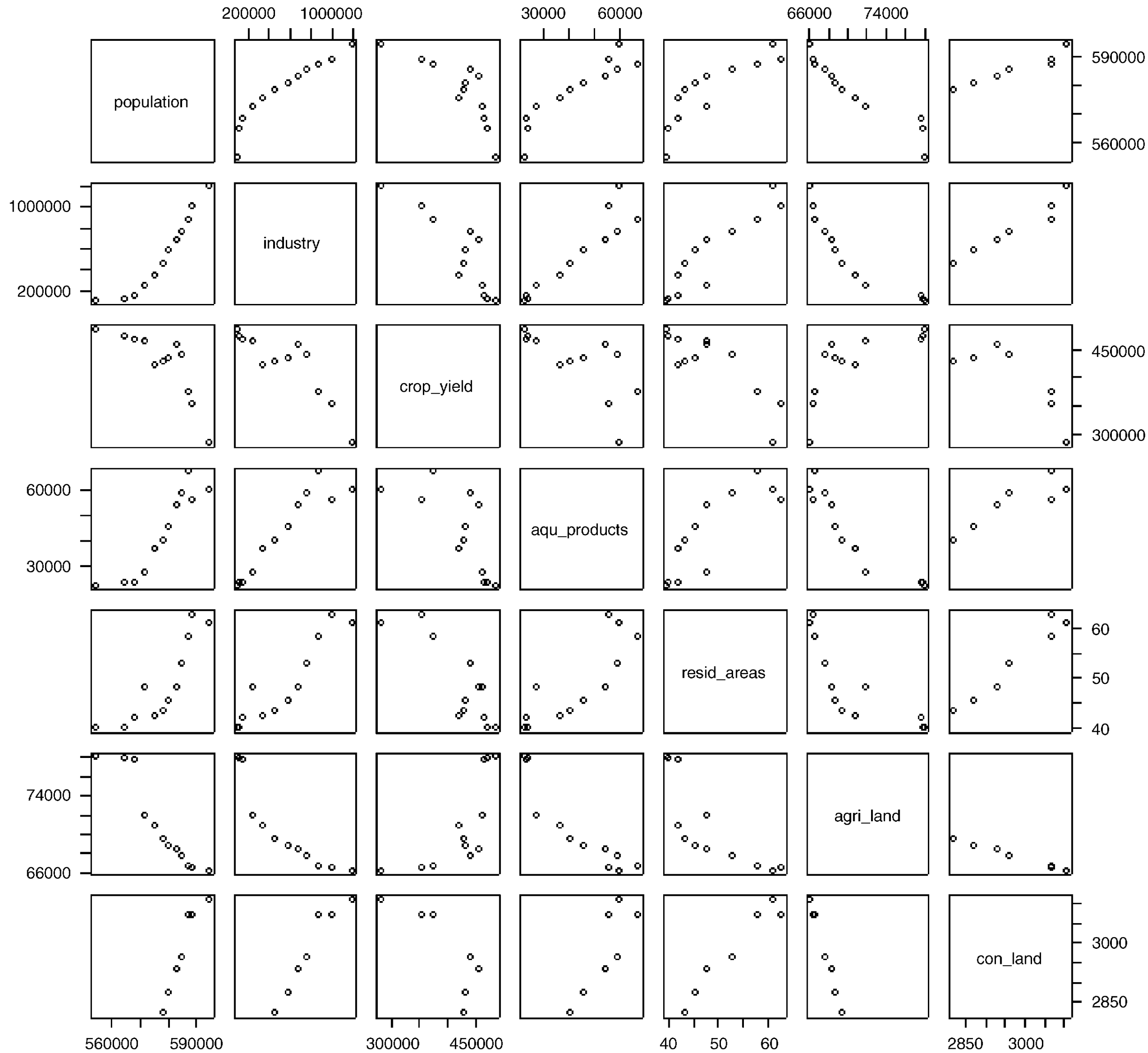

Fig. 3. Bivariate plot matrix for variables: population, industrial output value, crop yield, aquatic products, residential areas per capita, agricultural land, and construction land.

Table 7
Correlation coefficients between different socio-economic variables

	Population	Industry	Crop yield	Aqu_products	Residential areas	Agri_land
Population	1.00	0.94	−0.81	0.92	0.85	−0.94
Industry		1.00	−0.87	0.94	0.92	−0.90
Crop yield			1.00	−0.71	−0.84	0.72
Aqu_products				1.00	0.83	−0.92
Residential areas					1.00	−0.80
Agri_land						1.00

Note: industry = industrial output value, aqu_products = aquatic products, residential areas = residential areas per capita, agri_land = agricultural land. Due to missing construction land data before 1994, the calculation of coefficients does not count it here.

extension of urban industrialization (Zhou and Fischer, 1999). In Kunshan, the impact of rapid rural development on land-use changes mainly resulted from the development of TVEs and rural housing. The growth of TVEs and the development of an export-oriented economy have transformed the industrial pattern of Kunshan radically since the early 1980s. For example, the shares of agriculture, industry and other professions (mainly service and trade) in GDP were 44.2%, 42.3%, and 13.5%, respectively, in 1980; however, they were 5.6%, 59.4%, and 35.0%, respectively,

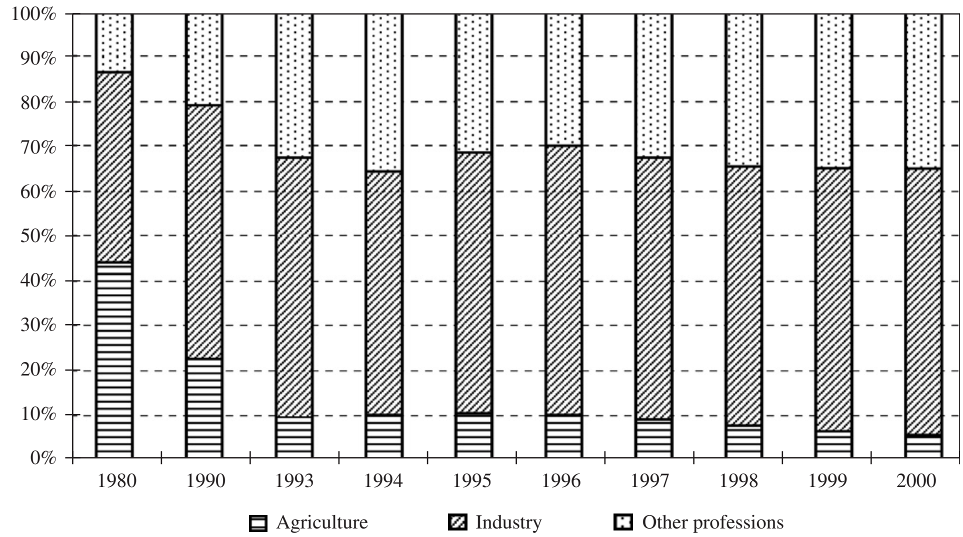

Fig. 4. Change of the shares of agriculture, industry, and other professions (In China, agriculture is also called primary industry (including farming, forestry, animal husbandry and fishery), industry called secondary industry (including mining and quarrying, manufacturing, production and supply of electricity, water and gas, and construction), and other professions called tertiary industry (all other industries not included in primary or secondary industry)) in Kunshan's GDP from 1980 to 2000. *Source*: Data for 1980 and 1990 are from Liu, 1995; Data for 1993–2000 are from JSB, 1994–2001.

in 2000 (Fig. 4). The output value of TVEs in Kunshan amounted to 1.97 million yuan in 1994, which was equivalent to 78.22% of the local total output value of industry.[1] With the development of industry and service trade, farmers' income increased quickly, and it resulted in a fast development of rural housing. Between 1987 and 1994, the area used for rural housing increased by about 110 ha in Kunshan.[2]

3.2.2. Urbanization

Urbanization greatly contributed to the loss of agricultural land in China (Zhang et al., 2000; Xu, 2004; Liu et al., 2005), and is generally seen as one of the most important factors of land-use change (Heilig 1997; Ho and Lin, 2004). In China, two forms of urbanization have occurred: the growth of cities following urban economic development and population concentration, and rural urbanization based on the growth of smaller towns in rural areas (Cui and Ma, 1999). In Kunshan, the first trend was typical. The direct result of urbanization was the reduction of agricultural land by increasing urban settlements. The area of urban settlements in Kunshan increased by 87.6% from 1987 to 1994, and 28.1% from 1994 to 2000 (Tables 2 and 3). Compared to the average area (59.5 ha) of urban settlements in 1987, it was enlarged greatly to 231.6 ha in 1994 and 155.9 ha in 2000 (Table 4).

The construction of a special development zone has also played a very important role in Kunshan's urbanization. The Kunshan development zone originated in 1985 with an area of 375 ha, and was officially named the ETDZ in 1987 with the area expanded to 618 ha. In 1992, ETDZ was designated as one of the state development zones in China, and its planning area was enlarged to 2000 ha (Long and Meng, 2004). The construction and development of ETDZ consolidated the role of Kunshan's urban area (the biggest red coverage in Fig. 2) as an urban center (Liu, 1995). ETDZ has been the most active area of economic growth in Kunshan, which clearly accelerated Kunshan's urbanization. From 1987 to 1994, Kunshan's urban settlements increased by 87.6% (Table 2). In this period, about 1948 ha of cultivated land (2.46% of paddy fields and 29.0% of dryland) were converted into urban settlements. Although the speed of Kunshan's urbanization decelerated from 1994 to 2000, urban settlements still increased by 1172 ha (Table 3). Most of this expansion was at the expense of paddy fields. This certainly happened in Kunshan as shown by the continuous decline in agricultural land and crop yield (Fig. 5).

3.2.3. Population growth and economic reforms

Rapid industrialization and urbanization are often correlated with the increase of population size for the same periods (Fischer et al., 1997; Jenerette and Wu, 2001; Heilig, 1996). Population growth has long been considered a major factor leading to land-use change (Lin and Ho, 2003; Tanrivermis, 2003). In Kunshan, the population increased from 1989 to 2000 (Fig. 6). This increase was strongly correlated with industrial output value (coefficient = 0.94, Table 7). With the increase of population, per capita residential areas also grew (Fig. 6). As a result, large parts of farmland were converted for constructing (rural) settlements. The strong inverse relationship (Fig. 3; coefficient = −0.94, Table 7) between

[1] People's Government of Kunshan City, 2002. Socio-Economic Yearbook of Kunshan in 2000.

[2] Kunshan Land Administration Bureau, 1995. Study on the Practices of Land Use and Conservation in Kunshan City.

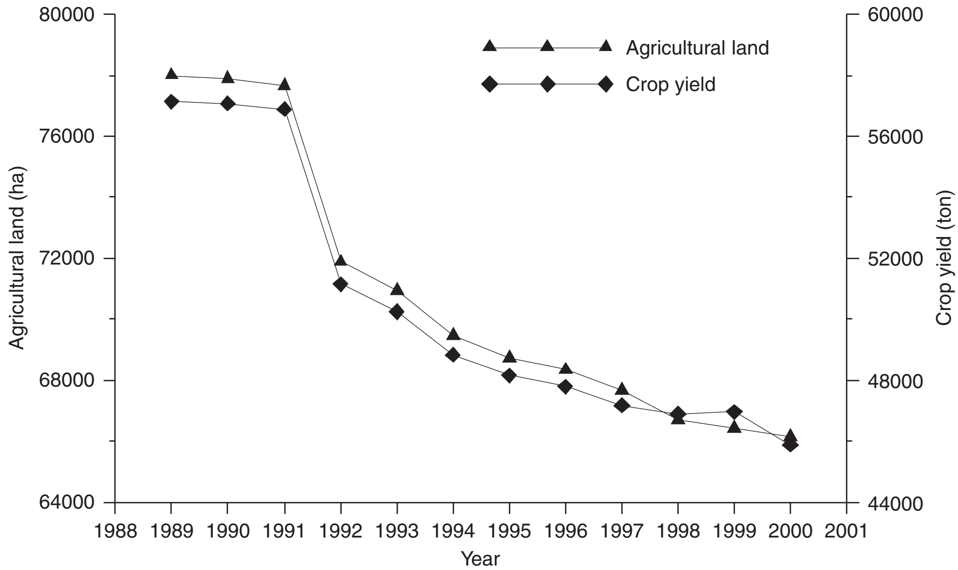

Fig. 5. Changes of agricultural land and crop yield in Kunshan from 1989 to 2000.

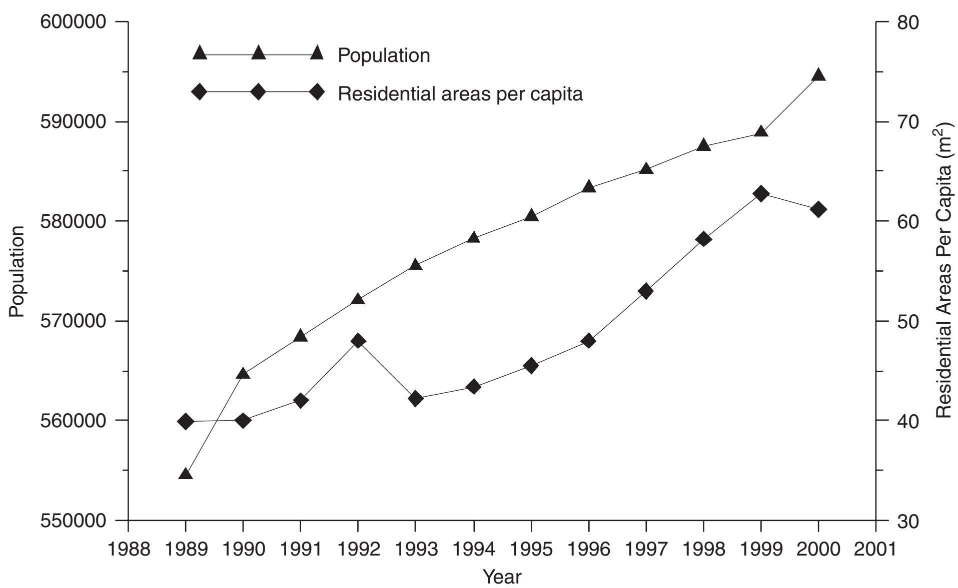

Fig. 6. Changes of population and residential areas per capita in Kunshan from 1989 to 2000.

population growth and agricultural land decline suggests that demographic factors may be important for land-use change in Kunshan. In the Yangtze River Delta, it is typical that a large population is still in the agricultural sector. In order to meet the demands of the growing population, a large amount of paddy fields were converted to fishponds, which allow much higher productivity production (Table 8). This can be illustrated by the strong positive relationship between the growth of population and the increase of aquatic products (coefficient = 0.92, Table 7).

China's economic reforms also played an important role in the transformation of Kunshan's land use. In the 1980s, China's government launched the Household Production Responsibility System (HPRS). Under the new rural economic system, farmers became more profit-oriented. As a result, a large proportion of paddy fields have been withdrawn from crop cultivation for other uses such as fishponds and orchards, largely because these production activities generate higher income (Cai, 2000). From Table 8, it can be seen that the average net economic return was 116 200 yuan/ha from constructing urban settlements, 14 970 yuan/ha from fishponds, but only 5535 yuan/ha from crop cultivation. Compared with cultivated land, fishponds are much more profitable.

Table 8
Economic assessment of land-use change in Kunshan

Land-use type	Net economic return (1000 yuan/ha/year)	Land-use change (ha)		Total economic value (million yuan)
		1987–1994	1994–2000	
Urban settlements	116.20[a]	+1948	+1172	+362.54
Fishpond[b]	14.97[c]	+1980	+220	+32.93
Cultivated land	5.535[c]	−6248	−2804	−50.10

Data source:
[a]Wu and Guo (1994).
[b]According to authors' reconnaissance survey, during this time, almost all artificial ponds converted from cultivated land were used for raising fish.
[c]National Office of the Regional Planning for Agricultural Resources, 1997. "Analysis and assessment of the 10-year change of China's agricultural resources, 1986–1995."

4. Discussion

Urban sprawl is defined as dispersed and inefficient urban growth and characterized as relatively low-density, non-contiguous, automobile-dependent, and residential and non-residential development that consumes relatively large amounts of farmland and natural areas (Burchell et al., 1998; Fazal, 2000; Hasse and Lathrop, 2003). From Fig. 2, it can be seen that the urban growth of Kunshan is such a kind of sprawl. Urban sprawl is increasingly considered a significant and growing problem that entails a wide range of social and environmental costs (Bengston et al., 2004). Urban sprawl in Kunshan leads to the inefficient utilization of land resources. In addition, the serious loss of cultivated land hampered the development of local agriculture, and also affected future development (Long and Meng, 2004). Addressing the growing concern about the social and environmental costs of sprawling development patterns, more effective policies will be required to manage urban growth and protect cultivated land.

The concept of an urban growth boundary (UGB) has played an important role in the well-ordered growth of the urban area in Oregon State, US (Pendall et al., 2002). An UGB is not a physical space but a dividing line drawn around an urban area to separate it from surrounding rural areas. Areas outside the boundary are zoned for rural use. Usually, an UGB is drawn to accommodate expected growth for some period of time, and is periodically reassessed and expanded as needed. Delineating an UGB can let the public know where urbanization or industrialization should occur, where farm and forest should be preserved, and where infrastructure should be developed. An UGB will minimize urbanization of cultivated land and thereby stop urban sprawl. Also, it is good for minimizing public service costs and avoiding the loss of farmland. Innovative incentive-based policies are also necessary to manage urban growth and protect cultivated land, so as to reduce the social and environmental costs of sprawling development patterns. Incentive-based policies such as development impact fees, location efficient mortgages, and infill and redevelopment incentives are widely adopted and proved to be practical (Bengston et al., 2004; Ding, 2003).

The loss of valuable agricultural land due to rapid urban sprawl has caught the attention of the Central Government. The State Council promulgated the Regulations for the Protection of Basic Agricultural Land on July 4, 1994, and the Protection Rules of Basic Farmland[3] on December 27, 1998. The two laws both focus on the protection of basic agricultural land (Tan et al., 2005). Usually, local governments implement the policies from the Central Government in a modified way to get more benefits. This usually results in the excessive loss of agricultural land and serious fragmentation of land use, especially in most coastal regions of China (Li and Yeh, 2004). As with any public policy instrument, the specific details of how growth management is implemented—rather than the general type of policy—are critical in determining effectiveness and impacts (Bengston et al., 2004). The impact of urban containment policies depends largely on their implementation (Pendall et al., 2002).

The data in Table 8 shows that the land-use change in Kunshan was mainly the outcome of market forces, i.e., land-use types were being converted from relatively low value use to higher value use. However, little attention has been paid to the social and environmental costs of these market mechanisms. Introducing the idea of UGB and incentive-based policies such as development impact fees, location efficient mortgages, and infill and redevelopment incentives may be helpful for Kunshan local government to stem the tide of urban sprawl, and to reduce the social and environmental costs of sprawling development patterns. Given the rapidity of the observed changes, it is critical that additional studies be undertaken to evaluate these alternative policies such as UGB and incentive-based policies, focusing on what their effects might be in this region and how these might be implemented.

[3]Basic farmland consists of (Ding, 2003): (1) agricultural production bases (such as crops, cotton, edible oils, and other high quality agricultural products) approved by government; (2) farmland with high productivity and a good irrigation system and that has been exploited; (3) vegetation production bases for large and middle cities; and (4) experimental fields for science and educational purposes.

5. Conclusions

Land-use change in Kunshan can be characterized by three major trends: First, the non-agricultural land (urban and rural settlements, construction land, and artificial ponds) increased substantially from 1987 to 2000, thus causing agricultural land especially paddy fields to decrease continuously. Second, a fragmentation of LULC in Kunshan was evident over the period from 1987 to 2000, especially for the paddy fields. Third, the conversion of paddy fields in Kunshan was a very serious issue. The expansion of urban and rural settlements, artificial ponds and construction land was almost completely at the expense of paddy fields. Compared to the area in 1987, paddy fields in Kunshan decreased by about 8924 ha (or 11.9%) in 2000.

Industrialization, urbanization, population growth, and China's economic reforms are four major driving forces contributing to land-use change in Kunshan. The rapid industrialization in Kunshan increased the demand for non-agricultural land, which diminished cultivated land and the resulting crop production. The industrialization pushed forward the development of TVEs, which led the expansion of rural housing areas. The direct outcome of urbanization in Kunshan was the expansion of urban settlement areas and construction land. Urban settlements in Kunshan increased by 87.6% from 1987 to 1994, and by 28.1% from 1994 to 2000. Most of these increases occurred at the cost of paddy fields. Population growth further increased the demand for rural housing land. The adoption of HPRS and introduction of profit-oriented farming led to the conversion of cropland into more profitable forms of production, such as fishponds.

In contemporary China, local governments are emerging as major players in translating the land policy established by Chinese Central Government into local patterns of land use (Skinner et al., 2001). The concept of an UGB and incentive-based policies such as development impact fees, location efficient mortgages, and infill and redevelopment incentives may be helpful for local government to stem the tide of urban sprawl. Given the rapidity of the observed changes, it is critical that additional studies be undertaken to evaluate these alternative policies, focusing on what their effects might be in this region and how these might be implemented.

Acknowledgements

This work is supported by the funding from the National Natural Science Foundation of China (Grant no. 40201001 and 40271010) and Program of Excellent Young Scientists of the Ministry of Land and Resources of China. This project was mainly carried out at the IIASA Research Activity on Sustainable Rural Development (SRD). One of the authors, Hualou Long, is grateful to China–US Sustainable Land Use Training Program. The insightful and constructive comments of three anonymous reviewers are appreciated.

References

Alig, R.J., Kline, J.D., Lichtenstein, M., 2004. Urbanization on the US landscape: looking ahead in the 21st century. Landscape and Urban Planning 69, 219–234.

Alphan, H., 2003. Land-use change and urbanization of Adana, Turkey. Land Degradation and Development 14, 575–586.

Aspinall, R., 2004. Modelling land use change with generalized linear models—a multi-model analysis of change between 1860 and 2000 in Gallatin Valley, Montana. Journal of Environmental Management 72, 91–103.

Bengston, D.N., Fletcher, J.O., Nelson, K.C., 2004. Public policies for managing urban growth and protecting open space: policy instruments and lessons learned in the United States. Landscape and Urban Planning 69, 271–286.

Brown, D.G., Pijanowski, B.C., Duh, J.D., 2000. Modeling the relationships between land use and land cover on private lands in the Upper Midwest, USA. Journal of Environmental Management 59, 247–263.

Burchell, R.W., Shad, N.A., Listokin, D., Phillips, H., Downs, A., Seskin, S., Davis, J.S., Moore, T., Helton, D., Gall, M., 1998. The Costs of Sprawl—Revisited. Report 39. Transit Cooperative Research Program, Transportation Research Board, National Research Council. National Academy Press, Washington, DC.

Burgi, M., Turner, M.G., 2002. Factors and processes shaping land cover and land cover changes along the Wisconsin River. Ecosystems 5, 184–201.

Burgi, M., Hersperger, A.M., Schneeberger, N., 2004. Driving forces of landscape change—current and new directions. Landscape Ecology 19, 857–868.

Cai, Y.L., 2000. Problems of farmland conservation in the rapid growth of China's economy. Resources Science 22, 24–28 (in Chinese).

Cai, Y.L., 2001. A study on land-use/cover change: the need for a new integrated approach. Geographical Research 20, 645–652 (in Chinese).

Chavez, J., 2004. Localized effects of globalization: the case of Ciudad Juarez, Chihuahua, Mexico. Urban Geography 25, 120–138.

Chen, B.M., 1999. The existing state, future change trends in land-use and food production capacities in China. Ambio 28, 682–686.

Chen, J., Gong, P., He, C.Y., Pu, R.L., Shi, P.J., 2003. Land-use/land-cover change detection using improved change-vector analysis. Photogrammetric Engineering and Remote Sensing 69, 369–379.

Cui, G., Ma, L.J.C., 1999. Urbanization from below in China: its development and mechanisms. Acta Geographica Sinica 54, 106–115 (in Chinese).

Ding, C., 2003. Land policy reform in China: assessment and prospects. Land Use Policy 20, 109–120.

Fazal, S., 2000. Urban expansion and loss of agricultural land—a GIS based study of Saharanpur City, India. Environment and Urbanization 12, 133–149.

Fischer, G., Heilig, G.K., Young, A., Vlek, P., Heilig, G., Tinker, B., 1997. Population momentum and the demand on land and water resources. Philosophical Transactions of the Royal Society of London Series B—Biological Sciences 352, 869–889.

Giri, C., Defourny, P., Shrestha, S., 2003. Land cover characterization and mapping of continental Southeast Asia using multi-resolution satellite sensor data. International Journal of Remote Sensing 24, 4181–4196.

Hasse, J.E., Lathrop, R.G., 2003. Land resource impact indicators of urban sprawl. Applied Geography 23, 159–175.

Hathout, S., 2002. The use of GIS for monitoring and predicting urban growth in East and West St Paul, Winnipeg, Manitoba, Canada. Journal of Environmental Management 66, 229–238.

Heilig, G.K., 1996. Who is changing the land? Lifestyles, population, and global land-use change. In: Ramphal, S., Sinding, S.W. (Eds.), Population Growth and Environmental Issues. Westport, London (Praeger), pp. 109–128.

Heilig, G.K., 1997. Anthropogenic factors in land-use change in China. Population and Development Review 23, 139–168.

Heilig, G.K., 1999. China Food: Can China Feed Itself? International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Herold, M., Goldstein, N.C., Clarke, K.C., 2003. The spatiotemporal form of urban growth: measurement, analysis and modeling. Remote Sensing of Environment 86, 286–302.

Hietel, E., Waldhardt, R., Otte, A., 2004. Analysing land-cover changes in relation to environmental variables in Hesse, Germany. Landscape Ecology 19, 473–489.

Himiyama, Y., 1998. Land use cover changes in Japan: from the past to the future. Hydrological Processes 12, 1995–2001.

Ho, S.P.S., Lin, G.C.S., 2004. Non-agricultural land use in post-reform China. China Quarterly 179, 758–781.

Imbernon, J., 1999. Pattern and development of land-use changes in the Kenyan highlands since the 1950s. Agriculture Ecosystems and Environment 76, 67–73.

Irwin, E.G., Geoghegan, J., 2001. Theory, data, methods: developing spatially explicit economic models of land use change. Agriculture Ecosystems and Environment 85, 7–23.

Jenerette, G.D., Wu, J.G., 2001. Analysis and simulation of land-use change in the central Arizona-Phoenix region, USA. Landscape Ecology 16, 611–626.

Jiangsu Statistical Bureau (JSB), 1994–2001. Jiangsu Statistical Yearbook. Chinese Statistical Publishing House, Beijing (in Chinese).

Kaufmann, R.K., Seto, K.C., 2001. Change detection, accuracy, and bias in a sequential analysis of Landsat imagery in the Pearl River Delta, China: econometric techniques. Agriculture Ecosystems and Environment 85, 95–105.

Kelly, P.F., 2003. Urbanization and the politics of land in the Manila region. Annals of the American Academy of Political and Social Science 590, 170–187.

Krausmann, F., Haberl, H., Schulz, N.B., Erb, K.H., Darge, E., Gaube, V., 2003. Land-use change and socio-economic metabolism in Austria—Part I: driving forces of land-use change: 1950–1995. Land Use Policy 20, 1–20.

Lambin, E.F., Rounsevell, M.D.A., Geist, H.J., 2000. Are agricultural land-use models able to predict changes in land-use intensity? Agriculture Ecosystems and Environment 82, 321–331.

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X.B., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skanes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel, C., Xu, J., 2001. The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change—Human and Policy Dimensions 11, 261–269.

Lambin, E.F., Geist, H.J., Lepers, E., 2003. Dynamics of land-use and land-cover change in tropical regions. Annual Review of Environment and Resources 28, 205–241.

Li, X.B., 1999. Change of arable land area in China during the past 20 years and its policy implications. Journal of Natural Resources 14, 329–333 (in Chinese).

Li, X., Yeh, A.G.O., 2004. Analyzing spatial restructuring of land use patterns in a fast growing region using remote sensing and GIS. Landscape and Urban Planning 69, 335–354.

Lin, G.C.S., Ho, S.P.S., 2003. China's land resources and land-use change: insights from the 1996 land survey. Land Use Policy 20, 87–107.

Liu, W. (Ed.), 1995. The Spring up and Sustainable Development of Kunshan City, China. Science Press, Beijing (Chapters 6–8, in Chinese).

Liu, Y.S., Gao, J., Yang, Y.F., 2003a. A holistic approach towards assessment of severity of land degradation along the Greatwall in northern Shaanxi province, China. Environmental Monitoring and Assessment 82, 187–202.

Liu, J.Y., Liu, M.L., Zhuang, D.F., Zhang, Z.X., Deng, X.Z., 2003b. Study on spatial pattern of land-use change in China during 1995–2000. Sciences in China (Series D) 46, 373–378.

Liu, J.Y., Zhan, J.Y., Deng, X.Z., 2005. Spatio-temporal patterns and driving forces of urban land expansion in China during the economic reform era. Ambio 34, 450–455.

Lo, C.P., Yang, X.J., 2002. Drivers of land-use/land-cover changes and dynamic modeling for the Atlanta, Georgia Metropolitan Area. Photogrammetric Engineering and Remote Sensing 68, 1073–1082.

Long, H.L., 2003. Land use transition: a new integrated approach of land-use/cover change study. Geography and Geo-information Science 19, 87–90 (in Chinese).

Long, H.L., Li, X.B., 2005. Rural housing land transition in transect of the Yangtze River. Acta Geographica Sinica 60, 179–188 (in Chinese).

Long, H.L., Meng, J.J., 2004. Optimal Allocation of Land Resources in China's Development Zones. Jilin People's Press, Changchun (Chapters 1–2, in Chinese).

Long, H.L., Cai, Y.L., Wan, J., 2000. Sustainability evaluation of land use in development zones: the case of Kunshan. Acta Geographica Sinica 55, 719–728 (in Chinese).

Mapedza, E., Wright, J., Fawcett, R., 2003. An investigation of land cover change in Mafungautsi Forest, Zimbabwe, using GIS and participatory mapping. Applied Geography 23, 1–21.

Moglen, G.E., Beighley, R.E., 2002. Spatially explicit hydrologic modeling of land use change. Journal of the American Water Resources Association 38, 241–253.

Muller, M.R., Middleton, J., 1994. A Markov model of land-use change dynamics in the Niagara Region, Ontario, Canada. Landscape Ecology 9, 151–157.

Nagendra, H., Munroe, D.K., Southworth, J., 2004. From pattern to process: landscape fragmentation and the analysis of land use/land cover change. Agriculture Ecosystems and Environment 101, 111–115.

Pendall, R., Martin, J., Fulton, W., 2002. Holding the line: urban containment in the United States. Discussion Paper. Center on Urban and Metropolitan Policy, The Brookings Institution, Washington, DC (http://www.brook.edu/dybdocroot/es/urban/publications/pendallfultoncontainment.pdf).

Poyatos, R., Latron, J., Liorens, P., 2003. Land use and land cover change after agricultural abandonment—the case of a Mediterranean Mountain Area (Catalan Pre-Pyrenees). Mountain Research and Development 23, 362–368.

Seto, K.C., Kaufmann, R.K., 2003. Modeling the drivers of urban land use change in the Pearl River Delta, China: integrating remote sensing with socio-economic data. Land Economics 79, 106–121.

Shoshany, M., Goldshleger, N., 2002. Land-use and population density changes in Israel—1950 to 1990: analysis of regional and local trends. Land Use Policy 19, 123–133.

Skinner, M.W., Kuhn, R.G., Joseph, A.E., 2001. Agricultural land protection in China: a case study of local governance in Zhejiang Province. Land Use Policy 18, 329–340.

Sleeman, J.C., Kendrick, G.A., Boggs, G.S., Hegge, B.J., 2005. Measuring fragmentation of seagrass landscapes: which indices are most appropriate for detecting change? Marine and Freshwater Research 56, 851–864.

Tan, M.H., Li, X.B., Xie, H., Lu, C.H., 2005. Urban land expansion and arable land loss in China—a case study of Beijing–Tianjin–Hebei region. Land Use Policy 22, 187–196.

Tanrivermis, H., 2003. Agricultural land use change and sustainable use of land resources in the mediterranean region of Turkey. Journal of Arid Environments 54, 553–564.

Theobald, D.M., 2001. Land-use dynamics beyond the American urban fringes. Geographical Review 91, 544–564.

Veldkamp, A., Lambin, E.F., 2001. Predicting land-use change. Agriculture Ecosystems and Environment 85, 1–6.

Veldkamp, A., Verburg, P.H., 2004. Modelling land use change and environmental impact. Journal of Environmental Management 72, 1–3.

Verburg, P.H., Veldkamp, A., 2001. The role of spatially explicit models in land-use change research: a case study for cropping patterns in China. Agriculture Ecosystems and Environment 85, 177–190.

Verburg, P.H., Veldkamp, A., Fresco, L.O., 1999. Simulation of changes in the spatial pattern of land use in China. Applied Geography 19, 211–233.

Walker, R., 2003. Mapping process to pattern in the landscape change of the Amazonian frontier. Annals of the Association of American Geographers 93, 376–398.

Wang, Y.Q., Tobey, J., Bonynge, G., Nugrandad, J., Makota, V., Ngusaru, A., Traber, M., 2005. Involving geospatial information in the analysis of land-cover change along the Tanzania coast. Coastal Management 33, 87–99.

Weng, Q.H., 2002. Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modelling. Journal of Environmental Management 64, 273–284.

World Bank, 1992. Indonesia: agricultural transformation challenges and opportunities. Report No. 1054-IND, Washington.

Wu, C., Guo, H., 1994. Land Use in China. Science Press, Beijing (Chapters 6–7, in Chinese).

Wu, L.X., Sun, B., Zhou, S.L., Huang, S.E., Zhao, Q.G., 2004. A new fusion technique of remote sensing images for land use/cover. Pedosphere 14, 187–194.

Xu, W., 2004. The changing dynamics of land-use change in rural China: a case study of Yuhang, Zhejiang Province. Environment and Planning A 36, 1595–1615.

Yang, H., Li, X.B., 2000. Cultivated land and food supply in China. Land Use Policy 17, 73–88.

Yildirim, H., Ozel, M.E., Divan, N.J., Akca, A., 2002. Satellite monitoring of land cover/land use change over 15 years and its impact on the environment in Gebze/Kocaeli—Turkey. Turkish Journal of Agriculture and Forestry 26, 161–170.

Zhang, B.P., Yao, Y.H., Cheng, W.M., Zhou, C.H., Lu, Z., Chen, X.D., 2002. Human-induced changes to biodiversity and alpine pastureland in the Bayanbulak Region of the East Tianshan Mountains. Mountain Research and Development 22, 1–7.

Zhang, Y.L., Li, X.B., Fu, X.F., Xie, G.D., Zheng, D., 2000. Urban land use change in Lhasa. Acta Geographica Sinica 55, 395–406 (in Chinese).

Zhou, Y., Fischer, G., 1999. Cultivated land-use change in the east region of China. IIASA Interim Report IR-99-055, Laxenburg.