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Analysis of arable land loss and its impact on rural sustainability in Southern Jiangsu Province of China

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ABSTRACT

Rapid urbanization and industrialization in southern Jiangsu Province have consumed a huge amount of arable land. Through comparative analysis of land cover maps derived from TM images in 1990, 2000 and 2006, we identified the trend of arable land loss. It is found that most arable land is lost to urbanization and rural settlements development. Urban settlements, rural settlements, and industrial park-mine-transport land increased, respectively, by 87 997 ha (174.65%), 81 041 ha (104.52%), and 12 692 ha (397.99%) from 1990 to 2006. Most of the source (e.g., change from) land covers are rice paddy fields and dryland. These two covers contributed to newly urbanized areas by 37.12% and 73.52% during 1990–2000, and 46.39% and 38.86% during 2000–2006. However, the loss of arable land is weakly correlated with ecological service value, per capita net income of farmers, but positively with grain yield for some counties. Most areas in the study site have a low arable land depletion rate and a high potential for sustainable development. More attention should be directed at those counties that have a high depletion rate but a low potential for sustainable development. Rural settlements should be controlled and rationalized through legislative measures to achieve harmonious development between urban and rural areas, and sustainable development for rural areas with a minimal impact on the ecoenvironment.

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1. Introduction

With rapid economic development and population growth, urbanization is taking place at an unprecedented pace around the world, especially in developing countries such as China (Liu et al., 2008). As a result of rapid urbanization China is experiencing a drastic loss of arable land (Xu et al., 2000; Gao et al., 2006; Ding et al., 2007). The disappearance of arable land is especially pronounced in southern Jiangsu Province in the Yangtze River Delta. Here industrialization and urbanization have left a lasting imprint on rural land use and the socioeconomic system, and profoundly altered sustainability of rural development (Liu, 2007). It is very important to study the loss of arable land in order to effectively protect it.

So far a large number of studies have been carried out to examine land use changes in rapidly urbanizing areas (Wu et al., 2006; Quan et al., 2007). Remote sensing is one of the most important information sources for deriving land cover information.

Methods have been developed to detect conversion of arable land to urban land from Landsat TM and SPOT images (Chen et al., 2003). Urban expansion and spatial restructuring of land use patterns in the Pearl River Delta of South China have been analyzed by Li and Yeh (2004). Xu et al. (2000) characterized land cover types and land cover changes in Fuqing City in 1991, 1994 and 1996 from Landsat TM images. The factors responsible for causing land use changes have also been identified (MacLeod and Moller, 2006; Rasul et al., 2004). The main driving forces behind the changes are identified as rapid economic development and construction of transportation infrastructure (Xu et al., 2000). Seto and Kaufmann (2003) attempted to determine the socioeconomic driving forces behind urban land use change in the Pearl River Delta, China through estimated econometric models.

Once land cover changes are identified, it is possible to examine their spatiotemporal variations. For instance, Wang et al. (2001) analyzed the spatiotemporal characteristics of land use and land cover change. They concluded that cultivated land, water area, built-up or non-arable land area were on increase while forest and grassland decreased. Twumasi and Merem (2005) examined arable land loss in central Mississippi at the county level between 1987 and 2002. Liu and Li (2006) studied regional disparity in the changes of agricultural land use in China with a focus on land use

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intensity and arable land abandonment. Long et al. (2009) studied the spatiotemporal dynamic patterns of farmland and rural settlements in the Su-Xi-Chang region.

These studies are limited in that they focus on the changes themselves, even though the impact of these changes on the environment has been assessed. Most studies concentrated on land use change in general, but not on arable land. The issue of sustainability of the observed changes in land use has attracted little attention from researchers except Yeh and Li (1998). They developed a sustainable land development model to ensure equity between productivity and efficiency in land use.

This study goes one step further by linking the detected changes in land cover to sustainable development. Through elucidating the trend of arable land loss and its spatial pattern, this paper explores the impact of land use change on the ecoenvironment and sustainable rural development in southern Jiangsu Province. The specific aims are: (1) To determine the spatiotemporal pattern of arable land resources at different times; (2) To quantitatively evaluate the rate and scale of arable land loss, and its sustainability; and (3) To assess the impact of arable land loss on sustainable rural development from the perspectives of ecological service value, per capita net income of farmers, and grain yield. The spatiotemporal differentiation of arable land change can be used to evaluate the trend of arable land loss and its impact on the sustainability of rural development. The information generated from this study is essential to making sound development plans in order to achieve sustainable development.

2. Study area

Southern Jiangsu Province is located in the middle of the Yangtze River Delta (Fig. 1). It covers about 1.76 million ha with an average elevation below 50 m. The northern subtropical monsoon climate dominates this region year round, with a mean annual temperature of 17.5 °C, a mean annual rainfall of 1055 mm, all of which are beneficial for agricultural production. Vegetation in this area includes evergreen and deciduous broadleaf trees and their mixture. Soils are of the yellow and brown loam type, with the latter being distributed in hilly and terraced terrain. This area is one of the fastest economic growth regions in eastern China. With a geographic proximity to the most industrialized city of Shanghai, this region is renowned for its export-oriented, mostly high-tech manufacturing industry.

This region has a long history of development dating back to the late 1970s. It embarked on economic reform by developing collective enterprises. In the 1980s township enterprises mushroomed with the establishment of numerous small towns. Since the mid-1990s the pace of industrialization and urbanization was considerably quickened. Consequently, urban population rose to 14.29 million (JSB, 2007) with a density of 809 persons/km² by 2006. Corresponding to this growth was a reduction in arable land. Arable land per farmer averaged less than 335 m² while over 1.5 million farmers have moved out of farming. If not properly managed, the current trend of arable land loss will threaten sustainable rural development in the future.

3. Research method

3.1. Land use classification and data processing

Land use maps were derived from TM images recorded in 1990, 2000 and 2006 through on-screen digitization (Liu et al., 2005a,b; Long et al., 2007). Ten land use types, namely paddy fields, dryland, forest land, grassland, lakes and rivers, fish ponds, urban settlements, rural settlements, fallow land, and industrial park-mine-transport land, were identified and delineated in each map. In order to reveal the spatiotemporal characteristics of land use change and the trend of arable land depletion, the land use maps were overlaid with each other in the GIS environment. Two land cover change maps between the three study periods were generated. They were statistically analyzed and presented in a tabular form to show the general characteristics of land cover changes. All those land cover patches that have changed their identity during the detection period were extracted. The covers containing these patches were then rasterized at a grid size of 100 m by 100 m using the ArcGIS spatial analyst module. The changes among the ten land cover types within each grid were then statistically analyzed. The dominant type of land cover change in each grid was considered the land cover change within this grid in visualizing land cover changes. The entire process is illustrated in Fig. 2.

3.2. Trend of arable land resources depletion

Resources depletion refers to diminishment in quantity or degradation in quality of resources as a consequence of overuse or use for other purposes. Depletion of rural resources refers to

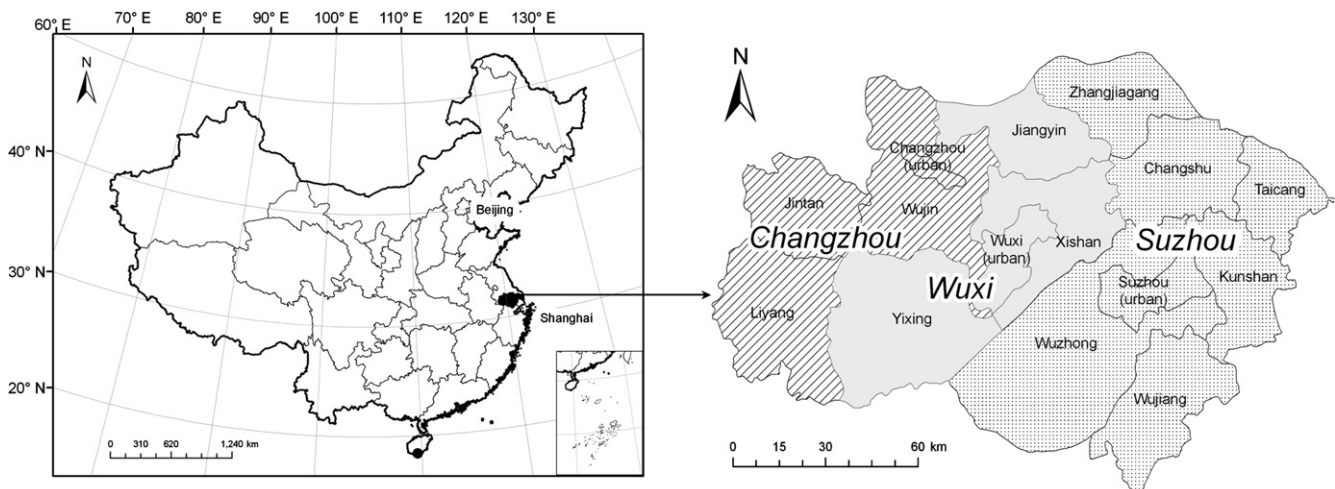


Fig. 1. Location of southern Jiangsu Province (Su-Xi-Chang region).

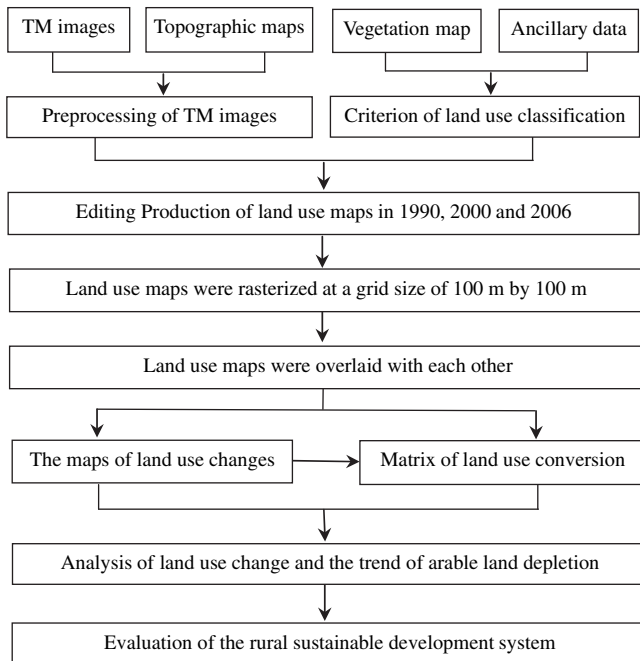


Fig. 2. Flowchart illustrating the procedure of methodology in this study.

reduction in resources abundance and lowering of their quality in the development process due to conversion to other uses in rural areas. This process destabilizes and debilitates self-development of the rural regional system as excessive depletion leads to a large population of landless farmers who cannot be easily reemployed. In the worst scenario it can cause the collapse of the rural development system.

Arable land is the most fundamental resource in the rural development system. Without this resource, it is impossible to guarantee both agricultural production and non-agricultural development. Food security, farmers' income, and ecoenvironment improvement all depends on the sustainable use of arable land resource. The depletion of rural arable land resource is calculated from the changes in the existent conditions of arable land resource as:

$$S = \frac{B_{t+1} - B_t}{B_t} \times \frac{1}{T} \times 100\% \quad (1)$$

where T stands for the duration of the study period; B_t and B_{t+1} refer to the quantity (expressed as percentage of the total land) of arable land at the beginning and end of the study period. $S < 0$ means that arable land resource is in a state of depletion. The larger the absolute value of S , the more intensively arable land has been depleted. $S \geq 0$ means just the opposite.

3.3. Index of rural sustainable development

The rural development system comprises three subsystems of rural ecosystem, economic subsystem, and production subsystem. The state of the rural sustainable development system is depicted by three key factors: ecological service value, per capita net income of farmers, and grain yield. Hindrance of either of them will negatively impact the sustainability of the entire rural development system. Sustainability of the entire rural system is guaranteed only when the three subsystems are proportionally developed. Therefore, the index of rural sustainable development state is constructed as:

$$P = \sqrt{(A^2 + B^2 + C^2)} / 3 \quad (2)$$

where P refers to the sustainability index of the rural development system; A stands for the sustainability index of the rural economic subsystem, measured against per capita net income of farmers; B refers to the sustainability index of the rural production subsystem that is measured against grain yield; and C means the sustainability index of the rural ecosystem calculated from the ecological service value (Costanza et al., 1997; Xie et al., 2008). These data were collected from the statistical yearbook of Suzhou, Wuxi and Changzhou. The values of A , B and C were standardized to [0,1] before being plugged into the above equation.

4. Research results and analysis

4.1. Arable land change during 1990–2000

The land change matrix has a dimension of n ($n = 10$ in this study), the total number of land cover types. The cell value at k_{ij} indicates the total amount of areal change for a given land cover from type i (row) to type j (column) during the temporal interval of k to $k + 1$, where both i and j vary from 1 to n . As shown in Table 1, the most dramatic change took place to industrial park-mine-transport land that has the highest increase of 149.61%. Urban settlements and rural settlements gained 48 880 ha and 48 095 ha, or at a rate of 97.01% and 62.03%, respectively. In contrast to these increases is the decrease in arable land by 108 654 ha in total. In particular, paddy fields decreased by 86 474 ha (8.93%). The lost paddy fields were used for rural settlements (42 199 ha), urban settlements (32 106 ha), and fish ponds (9398 ha). Dryland lost 22 180 ha, of which 16 308 ha were used as urban areas and 4553 ha for rural settlements development.

A comparatively higher proportion of paddy fields than dryland was lost to rural settlements. Construction of rural dwellings over paddy fields took place in the form of lateral expansion from existing villages while dryland further away from existing villages are not favored for such development. Rice paddies are much more productive than dryland. This relativity is indicative of the chaotic and inefficient use of precious arable land resources on the one hand. On the other, it will have severe implications for food security.

Fig. 3 highlights the spatial distribution of changes from paddy fields and dryland to other covers, such as urban use and rural settlements. Spatially, the change from arable land to rural settlements development took place extensively on a massive scale. These changes are located at the periphery of towns and along roads in a linear pattern. In rural Changzhou and Jiangyin, newly developed rural settlements occur in dense clusters. The pace of arable land conversion to towns and non-agricultural covers is related closely to the level of urbanization. A circle of newly urbanized areas is formed along the outer zone of existing towns or cities. The conversion of arable land to industrial park-mine-transport land and other uses took place on a small-scale only. They are located in rural areas not far from an existing city.

4.2. Arable land change during 2000–2006

A similar trend in land use change persisted during 2000–2006 (Table 2). It can be summarized as an increase in industrial parks and mines (7921 ha or 99.51%), urban settlements (39 117 ha or 39.41%), and rural settlements (32 946 ha or 26%). Overall, arable land decreased by 73 831 ha, or an annual rate of 12 305 ha, noticeably lower than that over the previous period, but twice

Table 1

Matrix of land use change between arable land and other uses during 1990–2000 (ha).

1990	2000											Change rate/%
	PF	DL	FL	GL	LR	AP	US	RS	CL	UL	sum	
PF ^a	880624	83	64	10	681	9398	32106	42199	3025	8	968198	−8.93
DL	362	91563	118			339	16308	4553	747		113990	−19.46
FL	30	124	94207	11		163	201	1121	895	42	96794	−2.46
GL				4103		15	21	53	41		4233	1.61
LR	20			177	358577	624	16	49	95		359558	−0.08
AP	651	37				86767	149	232	10		87846	10.78
US	11	2	1				50365	5			50384	97.01
RS	26	1	24			10	56	77417			77534	62.03
CL							42		3147		3189	149.61
UL										682	682	7.33
sum	881724	91810	94414	4301	359258	97316	99264	125629	7960	732	1762408	

^a PF – paddy fields; DL – dryland; FL – forest land; GL – grassland; LR – lakes and rivers; AP – artificial ponds; US – urban settlements; RS – rural settlements; CL – industrial park-mine-transport; UL – unused land.

higher than the national average. A total of 70 164 ha paddy fields were lost during this period. The rate of loss is 11 694 ha for arable land. Nearly all paddy fields (99.5%) were converted to rural settlements at 35 186 ha, and urban areas at 34 632 ha. The remaining is used for fish ponds at 4478 ha, and industrial parks and mines at 3419 ha. Dryland lost a total of 3667 ha to industrial park-mine-transport (2777 ha), urban settlements (1821 ha) and rural settlements (1408 ha).

In comparison with the previous period, the rate of change has been reduced. However, the trend of arable land loss still continues. More paddy fields than dryland have been converted to rural settlements and urban settlements. Rural settlements consumed more paddy fields than urban settlements. In addition, paddy fields have also been converted to forest (1909 ha) and grassland (370 ha), but not dryland. This pattern of change does not represent the most

efficient use of precious arable land. Dryland should be converted to forest and grassland as it yields a lower return than paddy fields.

The spatial distribution pattern of cover change from arable land to rural settlements during 2000–2006 is characterized by a high concentration on a large scale that is further away from existing towns and cities. This pattern indicates that development of rural settlements tends to follow the village-like pattern. There is a high concentration of such newly urbanized villages in Wuxi and rural southeastern Suzhou. Besides, there is also a high concentration of rural settlements along the Shanghai–Nanjing expressway in a belt shape. The conversion from arable land to towns takes the form of a lump or cluster mainly in South Changzhou, Jiangyin and southern Suzhou. The suburb districts of Changshu, Zhangjiagang and Taicang all have a higher concentration of newly constructed industrial parks and mines that have been converted from arable land (Fig. 4).

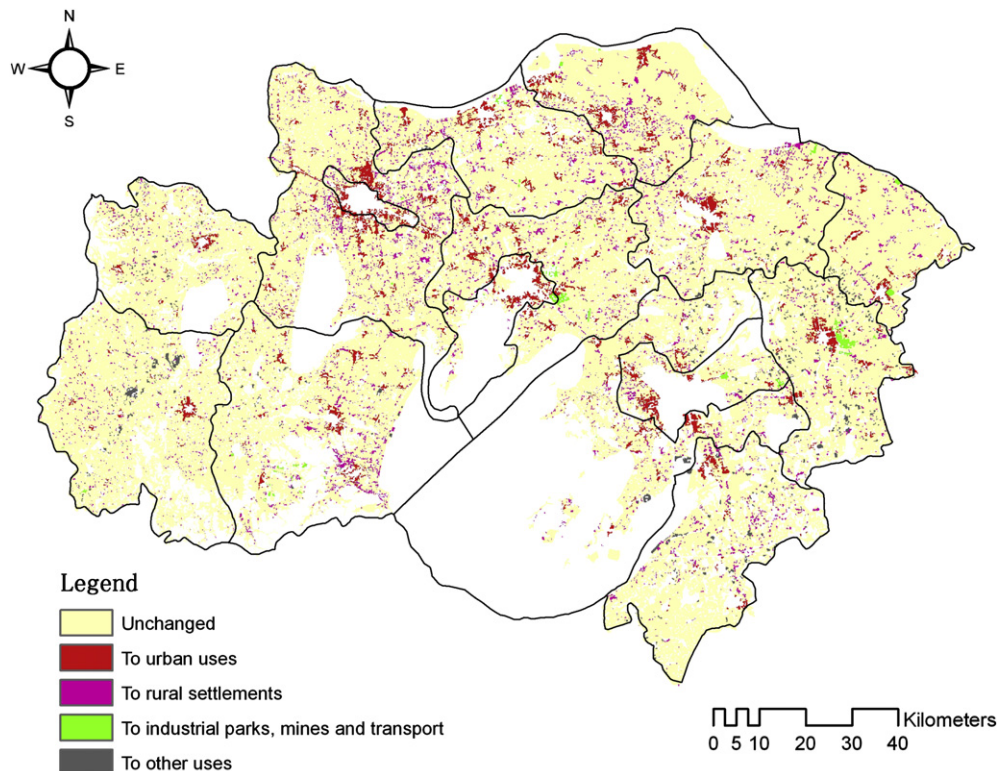
**Fig. 3.** Conversion of arable land to other major covers in southern Jiangsu Province during 1990–2000.

Table 2

Matrix of land use change between arable land and other uses during 2000–2006 (ha).

2000	2006											Change rate/%
	PF	DL	FL	GL	LR	AP	US	RS	CL	UL	sum	
PF ^a	801132	106	1909	370	282	4478	34632	35186	3419	210	881724	–7.96
DL	32	85665			76	31	1821	1408	2777		91810	–3.99
FL	472	517	91304		65	123	270	777	240	646	94414	0.77
GL			83	3993		15	29	17	164		4301	23.58
LR	581	30	560	740	351487	3615	232	1508	492	13	359258	–1.97
AP	3638	302	1137	49	250	87334	617	3299	689	1	97316	–1.00
US	2086	396	17	105	3	40	96615		2		99264	39.41
RS	3158	1122	108	52		669	3965	116361	161	33	125629	26.22
CL	48					6			7906		7960	99.51
UL	413	5	23	6		35	200	19	31		732	23.36
sum	811560	88143	95141	5315	352163	96346	138381	158575	15881	903	1762408	

^a PF – paddy fields; DL – dryland; FL – forest land; GL – grassland; LR – lakes and rivers; AP – artificial ponds; US – urban settlements; RS – rural settlements; CL – industrial park-mine-transport; UL – unused land.

4.3. Contribution of arable land to rural settlements areas

From 1990 to 2006, arable land decreased by 182 485 ha at an annual rate of 11 405 ha, in contrast to the huge increase in urban areas (87 997 ha) and rural settlements (81 041 ha). Of such a decrease, 156 638 ha were paddy fields and 25 748 ha dryland. Conversion from paddy fields to urban settlements rose by 37.12% and 46.39% during 1990–2000 and 2000–2006, respectively. The pace of conversion for rural settlements is much higher at 48.77% during 1990–2000 and 45.65% during 2000–2006. Their net rate of increase is 174.65% and 104.52%, respectively. The increase in rural settlements is contributed by the loss of paddy fields as high as 87.69% and 97.21% during 1990–2000 and 2000–2006, respectively (Table 3). The expansion of rural settlements occurred mainly at the expense of arable land (Long et al., 2009), as evidenced by more

than 92% of the gain in rural settlements from arable land. The drastic increase directly reflects the chaotic state of rural settlements development, and haphazard and inefficient allocation of arable land resources. The reasons for the varying paces of land cover change during the two periods are strategic adjustment in restructuring the agrarian economy in the first period, and an increased income level that quickened the pace of rural settlements development during the second period.

The largest conversion of paddy fields to rural settlements among all the changes indicates lack of governance in rationally allocating land resources to maximize the return from the land. Arable land reduction is profoundly affected by urban settlements and rural dwellings. These changes have reduced the amount of arable land, and fragmented rice paddy fields and dryland, both being counterproductive to improving land productivity

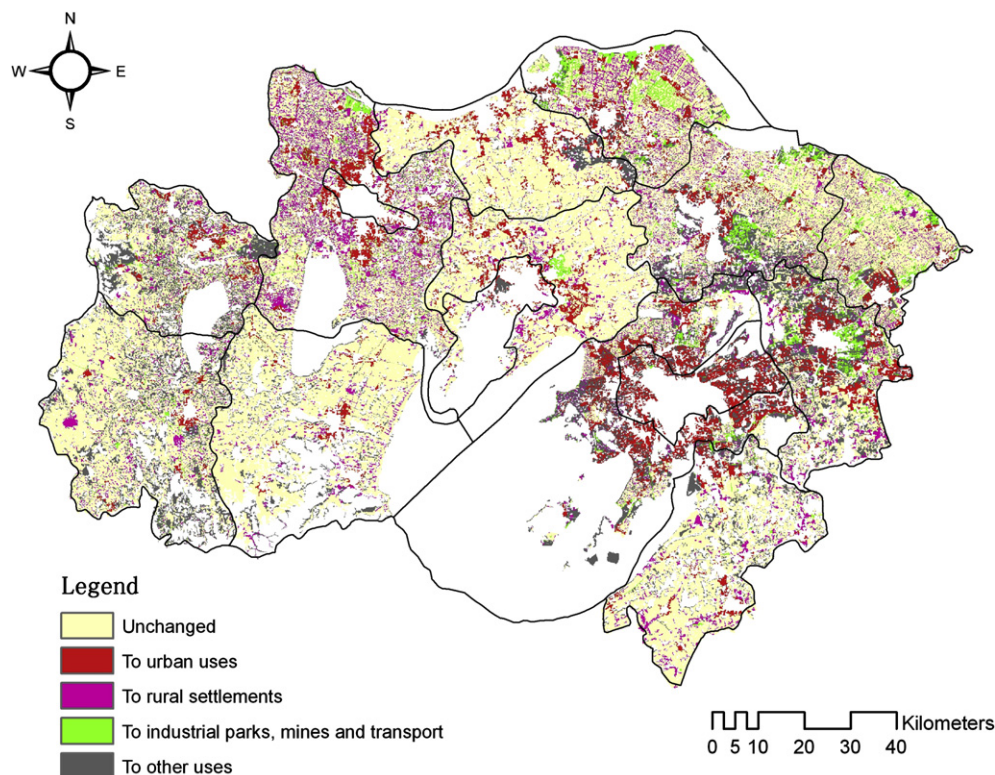


Fig. 4. Conversion of arable land to other major covers in southern Jiangsu Province during 2000–2006.

Table 3Absolute (ha) and relative (%) changes in paddy fields, dryland and rural settlements in relation to changes of other covers during 1990–2000 and 2000–2006^a.

Land use type	1990–2000						2000–2006					
	Paddy fields		Dryland		Rural settlements		Paddy fields		Dryland		Rural settlements	
	area	%	area	%	area	%	area	%	area	%	area	%
PF ^b			279	1.26	42173	87.69			–74	–2.02	32028	97.21
DL	–279	–0.32			4552	9.46	74	0.11			286	0.87
FL	34	0.04	–6	–0.03	1097	2.28	1437	2.05	–517	–14.1	669	2.03
GL	10	0.01	0	0.00	53	0.11	370	0.53	0	0.00	–35	–0.11
LR	661	0.76	0	0.00	49	0.10	–299	–0.43	46	1.25	1508	4.58
AP	8747	10.12	302	1.36	222	0.46	840	1.2	–271	–7.39	2630	7.98
US	32095	37.12	16306	73.52	–51	–0.11	32546	46.39	1425	38.86	–3965	–12.03
RS	42173	48.77	4552	20.52			32028	45.65	286	7.8		
CL	3025	3.50	747	3.37	0	0.00	3371	4.8	2777	75.73	–161	–0.49
UL	8	0.01	0	0.00	0	0.00	–203	–0.29	–5	–0.14	–14	–0.04
sum	86474	100.00	22180	100.00	48095	100.00	70164	100.00	3667	100.00	32946	100.00

^a Absolute changes are detected directly from land cover overlay analysis. Relative change is derived from the ratio of the observed change to the total change.^b PF – paddy fields; DL – dryland; FL – forest land; GL – grassland; LR – lakes and rivers; AP – artificial ponds; US – urban settlements; RS – rural settlements; CL – industrial park-mine-transport; UL – unused land.

(i.e., inability to construct an efficient irrigation system). The drastic reduction in arable land is worsened by the accelerated pace of urbanization. To a large degree, the massive conversion of arable land to rural settlements is attributed to the disorganized spatial distribution of existing residential areas that are widely scattered and excessively expansive.

4.4. Impact of arable land loss on the rural system

As shown in Table 4, all counties/municipalities lost arable land during the study period. The most serious loss took place in Suzhou (urban), Wuxi, Changzhou, and Kunshan. They all have an S value below –65%. These areas are characterized by a high degree of urbanization already. By comparison, Yixing has the smallest loss of only 7.1%. In general, the loss is rather high with nine having a value above 40%. Of the 15 areas, seven have a negative change in ecological service value, implying that they have a higher degree of urbanization. Of the eight areas that have an increased ecological service value, the highest is 42 for Kunshan, followed by Jintang (39.7) and Liyang (34.6). During the study period, all farmers have their income increased by a minimum of 627.2% for Kunshan. However, the pace of increase is rather narrow, ranging from 627.2% to 927% for Wujing. Associated with the loss of arable land is reduced grain yield. All 15 areas have a decreased grain yield by

a minimum of 2.4% for Liyang. However, such a low value is an exception rather than the norm. In fact, only two areas have a decrease below 20%, and the number rises to three for a decrease <30%. The highest decrease occurred to Zhangjiagang at 91.1%.

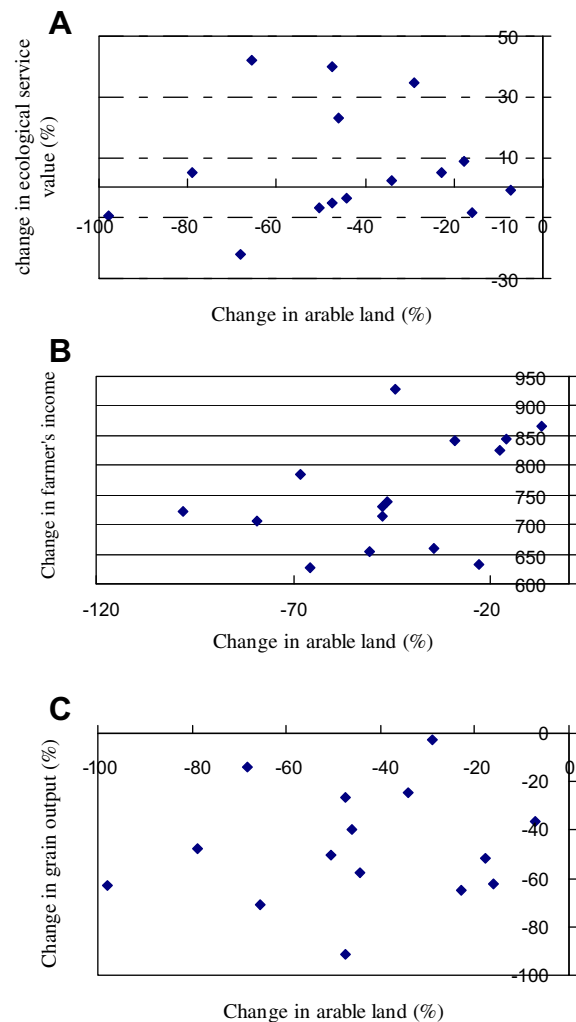


Fig. 5. Relationship between changes in arable land (%) and changes in ecological service value (A), per capita net income of farmers (B), and grain yield (C). All are expressed as percentages.

Table 4

Loss of arable land and change in ecological service value, per capita net income of farmers, and grain yield during 1990–2006 by region (unit: %).

County/city	Loss of arable land	Ecological service value	Farmers' income	Grain yield
Wuxi (urban)	–50.5	–6.6	654.9	–50.3
Jiangyin	–17.7	8.6	824.5	–51.8
Yixing	–7.1	–1.1	865.6	–36.6
Xishan	–16.0	–8.2	844.7	–62.0
Changzhou (urban)	–68.1	–21.8	784.9	–14.1
Jintang	–47.5	39.7	714.7	–26.7
Liyang	–29.0	34.6	842.6	–2.4
Wujing	–44.2	–3.5	927.0	–57.9
Suzhou (urban)	–97.8	–9.1	723.3	–62.7
Changshu	–46.1	23.1	738.0	–39.5
Zhangjiagang	–47.5	–5.1	729.2	–91.1
Taichang	–34.1	2.3	658.6	–24.3
Kunshan	–65.6	42.0	627.2	–70.9
Wujiang	–22.9	4.8	631.9	–64.6
Wuzhong	–79.0	4.8	706.5	–47.4

Fig. 5 illustrates the relationship between the percentage of arable land loss and the changes in three indices of the rural system development. There is no statistically meaningful relationship between change in arable land and ecological service value (Fig. 5A). Changes in ecological service value caused by arable land loss vary with the end use. Some changes (e.g., from arable land to forest and grassland) bring the most benefits to the ecosystem, but other changes (e.g., from arable land to ponds) do not. The change to urban settlements degrades ecological service value as the land is not used for agricultural purposes, such as afforestation and grassland.

There is no definite relationship between per capita net income of farmers and arable land loss (Fig. 5B). This suggests that farmers do not rely on cultivation of grains as their main source of income. Grain cultivation makes up only a small portion of the total income. Most of their income is derived from the secondary sector and township enterprises. Thus, arable land changes will not reduce farmers' income. In reality, it may also be possible for their income to rise. For instance, if arable land is converted to fish ponds, it can generate more return. In this case the reduction in arable land may actually lead to an increase in per capita income for farmers, though a negative impact on food security. During 1990–2006, 13 862 ha of paddy fields were converted to fish ponds. Since 2000 fish ponds contributed 10.73% towards the loss of rice paddy fields. Such a new land use can improve the ecoenvironment, diversify economic activities, and increase farmers' income.

In general, there is a negative relationship between reduced arable land and grain production (Fig. 5C). However, the overall relationship is not very close because some of the lost arable land may not be used solely for growing rice. For instance, it could be used for cultivating cash crops such as fruits and vegetables, especially for those in close proximity to urban and peri-urban areas. Besides, arable land includes both paddy fields and dryland. Dryland has a lower productivity than paddy fields. Indiscriminant

treatment of the two kinds of land may obscure the relationship. Another factor is the increased land productivity owing to the use of high-yield grain species.

All the collected data about ecological service value, per capita net income of farmers, and grain yield were standardized, together with the standardized state of arable land loss S . The sustainability index P of rural development system was derived from the index value of the three subsystems using Equation (2). The plot of standardized S versus P falls into four categories: I – low loss and low sustainability; II – low loss and high sustainability; III – high loss and low sustainability; IV – high loss and high sustainability. There are seven counties in category II but only two in category IV. This indicates that the region in general has a low land resources depletion ratio but still have a high potential for development. However, six counties have a low potential for development. Particular attention should be paid to them and to the protection of the ecoenvironment.

Fig. 6 shows that five of the seven areas in category II are located in the west while two are located in the east. Four category I areas are distributed in central north and southeast. The two category III areas are located in Suzhou (urban) and Wuzhong. The two category IV areas are located in Kunshan and Changzhou (urban). In general, the western half of the area has a more sound development potential with a high potential for further development than its eastern half counterpart. The northern portion tends to have a low loss of arable land. Spatially, there is a continuity among all areas. Namely, if one area has a large potential for development, its neighboring counties are likely to have a large potential as well, and vice versa.

4.5. Implications for land use planning

Rapid industrialization and urbanization in southern Jiangsu Province is achieved at the expense of arable land loss, especially



Fig. 6. Spatial distribution of arable land depletion versus sustainability of rural system development by area.

highly productive rice paddies. The disproportionate increase in rural settlements is indicative of ineffective planning and control in rural areas. Therefore, it is essential to strengthen land use planning and rationalize land allocation for various uses in order to optimize land use efficiency and to improve the region's ecoenvironment. The accomplishment of sustainable rural development requires urgent spatial adjustment, administrative adjustment, and industry adjustment. For instance, small-scale, widely scattered villages should be integrated to curtail unabridged development of rural settlements. Small villages should be amalgamated so as to upgrade the scale and organization of villages and towns. Rural township enterprises that are energy-hungry and energy-inefficient, heavy polluters, and have a low productivity should be phased out. Better management and control of land resources require new legal and institutional regulations that must be defined in terms of multiple uses of agricultural land and strict conservation of prime agricultural land. The enactment of a scientific land use plan can protect arable land without compromising farmers' rights.

5. Conclusions

Southern Jiangsu Province experienced a heavy loss of arable land. During 1990–2006 the amount of arable land lost to urban settlements totaled 182 485 ha. Urban settlements, rural settlements and industry-mine-transport land gained, respectively, by 87 997 ha (174.65%), 81 041 ha (104.52%), and 12 692 ha (397.99%), mostly from rice paddy fields and dryland. They contributed to newly urbanized areas by 37.12% and 73.52% during 1990–2000, and 46.39% and 38.86% during 2000–2006, respectively. During 1990–2006 rice paddy fields contributed 92% towards the increase in rural settlements, and 97% during 2000–2006. Therefore, most of the residential areas are developed over rice paddies. This land cover change indicates a lack of coordinated planning and control between urban and rural development.

All areas in the region experienced a loss in arable land at a variable rate ranging from –7.1% to –97.8%, against an increase of 627.2–927% in per capita net income of farmers, and a reduction in grain yield. However, the observed loss in arable land does not bear any close relationship with changes in ecological service value, per capita net income of farmers, and grain yield. Of the four types of development models, seven fall into category II and two in category IV. It is concluded that sustainable rural development in this region requires a tighter control of arable land resources through legislative measures. Development between urban and rural areas needs to be coordinated to improve land use efficiency and to minimize destruction to the region's ecoenvironment.

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