SOCIOECONOMIC DRIVERS OF SPATIO-TEMPORAL LAND USE/LAND COVER CHANGES IN A RAPIDLY URBANIZING AREA OF CHINA, THE SU-XI-CHANG REGION

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Abstract. The rapid economic development resulting from Chinese economic reform has greatly accelerated urbanization and industrialization, thus leading to alterations in the natural landscape. Understanding the extent of these changes is important for regional sustainable land management. An integrated approach with a geographic information system and remote sensing was used to extract land use/land cover (LULC) change information for the Su-Xi-Chang region over the period of 1980 to 2010. To calculate the dimensions of fragmentation and to observe changes in spatial patterns, FRAGSTATS was used. Major drivers were determined through bivariate statistical analysis of socioeconomic data sources. Three change matrices were constructed for detecting LULC changes from 1980 to 1990, 1990 to 2000, and 2000 to 2010. In the study period, farmland, water bodies and wetlands significantly decreased. However, construction land, grassland and woodlands increased considerably. The pattern and composition of the landscape exhibited significant fragmentation for the whole area. Socioeconomic analysis showed that population growth and economic development, urbanization and subsequent construction land expansion, and industrialization were the major socioeconomic drivers of LULC changes. Changes in farmland resulted in decreases in area and production that might impair ecological functions and decrease food production. Therefore, better land use policy would address the consequences of the loss of the natural landscape due to drastic socioeconomic drivers in the region. Further research along these lines should be encouraged, because additional studies will be helpful for the decision makers engaged in planning activities at various levels.
Keywords: *GIS, temporal changes, landscape ecology, urbanization, landscape pattern*

Introduction

A wide range of drivers associated with social, biophysical, environmental, economic and technological factors lead to land use/land cover (LULC) changes in different parts of the world (Beilin et al., 2014; Tian, 2015). The drivers of these changes may be well known, such as demographic change (Salvati et al., 2017), industrial development (Li et

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al., 2010), agricultural expansion (Kibret et al., 2016), urbanization (Deng et al., 2015; Xian and Crane, 2005), global market forces (Temesgen et al., 2013), and climatological change, such as drought and rainfall variability (Amuti and Luo, 2014; Biazin and Sterk, 2013; Luo and Zhang, 2014; Román-Cuesta et al., 2014), or they may also involve interactions of institutional or cultural impacts (Kindu et al., 2015; Sakayarote and Shrestha, 2017). These drivers have triggered drastic LULC conversions by substituting one type of LULC with another. Through these processes, the pattern, structure and function of the natural landscape are inevitably altered (Lambin et al., 2001), thus consequently influencing the global environment (Amuti and Luo, 2014). Particularly, the socioeconomic drivers are more intense than the physical drivers of these processes (Desalegn et al., 2014). Understanding these factors is vital for forecasting future LULC dynamics by using models (Lambin et al., 2001) or for the design of management strategies and policies for the sustainable management of land resources (Mottet et al., 2006; Turner et al., 1993).

Since the launch of economic reform and the opening-up policy in the late 1970s in China, LULC changes have rapidly taken place, and land use patterns are quite spatially variable throughout the country (Hua et al., 2010; Wei and Ye, 2009). Particularly since the beginning of the 21st century, the rapid socioeconomic development has resulted in remarkable changes in the spatio-temporal distributions of LULC and has adversely affected the natural environment (Deng et al., 2015; Yirsaw et al., 2016). However, because of the diversified and complex driving forces in the country, there are substantial arguments about the extent and magnitude of changes in LULC (Xu, 2004). Previous studies have revealed different findings on LULC change drivers in different regions of the country. For instance, Wang et al. (2011) have suggested the expansion of residential areas to cause LULC changes at the expense of agricultural land in northeastern China. Long et al. (2009) have proposed that rapid economic developments are major drivers for the process. Li et al. (2010) have claimed that in the eastern fringe of the Tibetan Plateau of China, the changes have occurred because of climate change and human activities. Kuang et al. (2016) have suggested that the expansion of industrialization is an important factor in LULC change in eastern China. Other studies have indicated that land policy is a major influential driver in LULC changes (Liu et al., 2010b).

Though substantial efforts have been made to identify factors driving LULC changes in different parts of the country, those research findings have revealed that the drivers vary from place to place depending on location-specific factors. Moreover, there is significant disagreement regarding the extent of influence by these drivers of changes, thus making generalizations nearly impossible (Li and Yeh, 2004; Wu et al., 2013). Therefore, any intervention to address drivers of change for sustainable land management must begin with locally specific understanding of the different drivers affecting the LULC. This requirement is especially true for the Su-Xi-Chang region of eastern coastal China, which has a fragile environment where substantial LULC changes have occurred. In the Su-Xi-Chang region, as stated by Zhou et al. (2014), owing to economic development, different conflicts, such as the conflict between land resources and demand for development versus the vulnerability of the coastal area, have arisen. Moreover, Xie et al. (2007) have suggested that both the existence of rapid economic development and the loose and neglected control of land use have put the LULC management of the region at risk. Thus, it is crucial to determine the dynamics of LULC and the main socioeconomic drivers of the change in this fragile environment. This

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information would facilitate measures to arrest and reverse the situation of LULC changes in the region and would improve understanding of the influence of socioeconomic drivers on LULC changes.

Considering these factors, this paper was designed with the following objectives: (1) to characterize land use dynamics and patterns of LULC change across the study area over the past three decades; (2) to determine the major socioeconomic drivers in periods from 1980 to 2010; and (3) to assess the relationship between LULC changes and the major socioeconomic drivers.

Materials and Methods

Study area

Encompassing three municipalities, Suzhou, Wuxi and Changzhou, the Su-Xi-Chang region is located in the Jiangsu Province ($36^0 46'$ – $32^0 04'$N, $119^0 08'$–$121^0 15'$E) in the middle of the Yangtze River Delta Economic zone of east China. It covers a total area of 1.7×10^4 km^2, with an average elevation below 50 meters (*Fig. 1*). The area has a monsoon climate with a mean annual temperature and precipitation of 15.3^{0}C and 1,092 mm, respectively (Long et al., 2009).

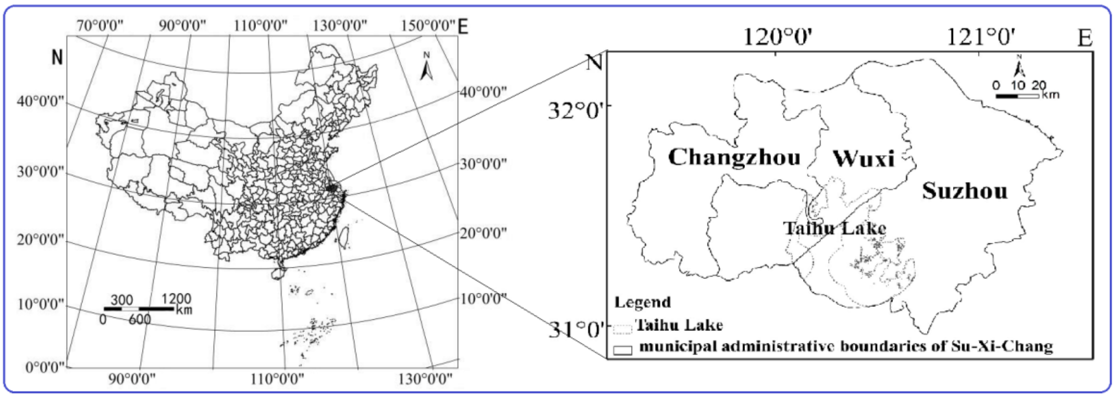

Figure 1. *Location of the study area*

In 2014, the region had a total population of 14.55 million (838/km^2), which was more than 6 times the total population per km^2 (135.5/km^2) of the country in the same year. Similarly, the GDP per capita of the Su-Xi-Chang region (123,325 CNY) was three times more than the GDP per capita of the country in the same period (NBSC, 2014). From the early 1980s, the growth of Shanghai has pushed the region toward rapid urbanization and industrialization (Long et al., 2009). Unprecedented changes in the local economy have taken place in recent decades. On the grounds of diversified cooperative enterprises in the mid-1980s, the region has served as a model for the advancement of rural industrialization (Xie et al., 2007; Tan, 1986). With these changes, the Su-Xi-Chang region has confirmed its position of importance at the national level, and today, it constitutes the Key Economic Zone in Eastern China. However, with the development of economic activities, drastic changes in LULC have been occurring in the region. These changes have prompted concerns and attempts to detect and monitor

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changes in LULC and to assess the main socioeconomic drivers of the changes, in order to attain sustainable land management.

Data source and processing

For time series LULC changes analysis (1980, 1990, 2000 and 2010), the study used vectored data sets with a 30 m spatial resolution from Landsat reflectance products and the DEM of the Computer Network Information Center, Chinese Academy of Science. Additionally, administrative boundaries at the county level were used, which were provided by the Data Sharing Infrastructure of Earth System Science, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Science. MSS and TM images were geometrically corrected using ground control points, with ETM+ images as the master and reference images. To identify the agreement in classification consistency and accuracy, effective classification was conducted by using standard procedures (Liu et al., 2005). Accordingly, as shown in *Table 1,* six land use categories were classified for the four study periods: farmland, construction land, grassland, woodland, water body, and wetland. The ESRI ArcGIS spatial analysis model was applied to measure variation within LULC types. A set of pattern metrics was identified to examine cover change spatial patterns, and FRAGSTATS was used to compute the dimension of fragmentation. In addition, a time series of socioeconomic data on population, industrial output value, agricultural production (crop yield), aquatic products, GDP, agricultural land, and construction land (settlement areas) from 1980 to 2010 was collected from local government offices and statistical year books for the region (Appendix A). These data were used to analyze the potential socioeconomic driving forces triggering LULC changes in the Su-Xi-Chang region.

Methods

Mainly on the basis of classified and gridded land use polygon themes (*Fig. 2*), internal change variations were computed between each consecutive map (from 1980 to 1990, 1990 to 2000 and 2000 to 2010). For each consecutive pair of gridded time series maps, a transition matrix was assembled (*Tables 2, 3 and 4*). Then, for each LULC category *m* in the transition matrix, the conversion between the two periods was computed via the GIS analysis function:

$$\Delta L_m = (r_m - r_{.m})/r_{.m} \times 100 \quad \text{(Eq.1)}$$

where ΔL_m is the change of LULC in row *m,* relative to the previous compared year; $r_{m.}$ is the row total of grid cells for category *m*; and $r_{.m}$ is the column total of grid cells for category *m*.

For exploring the internal conversion between different cover types, we treated the change (decrease or increase) for a cover category in a given year relative to a compared year considering various “loss or gain” conversions. Thus, for any type of “conversion loss to” or “conversion gain from”, the percentage taken by this type in the total “loss or gain” was calculated as:

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$$\begin{cases} R_{loss(m)n} = \dfrac{(r_{nm} - r_{mn})}{(r_{m.} - r_{.m})} \times 100 \quad m \neq n \\ R_{gain(m)n} = \dfrac{(r_{m,n} - r_{n,m})}{(r_{m.} - r_{.m})} \times 100 \quad m \neq n \end{cases} \quad \text{(Eq.2)}$$

where $R_{loss(m)n}$ is the percentage taken by type n in the total "conversion loss" of category row m; $R_{gain(m)n}$ is the percentage taken by n in the total "conversion gain" of category row m; and r_{nm}, and r_{mn} are the individual entries in a change matrix.

Bivariate correlation statistical analysis was performed to assess the relationships between LULC changes and socioeconomic drivers (*Table 6*). Through examining the spatial change patterns, we identified a set of pattern metrics at both the class and landscape levels that capture different dimensions of land fragmentation. Parker et al. (2001) have observed the absence of a site (region) specific typical set of metrics, as a result of variations in the significance of specific metrics significance based on research objectives and study area characteristics. As indicated by (McGarigal et al., 2002), six major landscape metrics at the class level, including patch density (PD), largest patch index (LPI), number of patches (NP), landscape shape index (LSI), area-weighted mean patch fractal dimension (AWMPFD), and interspersion and juxtaposition (IJI); and six at the landscape level, including Shannon's diversity index (SHDI), number of patches (NP), largest patch index (LPI), area-weighted mean patch fractal dimension (AWMPFD), contagion index (CONTAG) and interspersion and juxtaposition (IJI), were selected for this study on the basis of our research objectives and study area characteristics. These indices were calculated using FRAGSTATS, a spatial pattern analysis program for categorical maps (*Table 5*, and *Fig. 3*).

Result and discussion

Spatial patterns of LULC dynamics

Figure 2 shows the spatial pattern of LULC changes for the years 1980, 1990, 2000 and 2010 of the study area. In 1980, farmland and water body were the dominant cover types, and the direction of urban development (collectively termed construction land) was confined to the central part of the three municipalities – Su Zhou, Wu Xi and Chang Zhou of the Su-Xi-Chang region (*Fig. 2*).

However, in 1990, construction land started to replace some of the farmland. The construction land development tended to extend further in the north and northeast directions between 1980 and 1990, when the region embarked on economic reform by developing collective enterprises at the start of the age of rapid urban and industrial development. In the 1980s, township enterprises expanded with the formation of various small towns in the region (Long et al., 2009). After 1990, construction land became more prevalent, and the pace of urbanization and industrialization was considerably accelerated. Particularly at the end of 2010, the area of construction land overtook the area of farmland (*Fig. 2*) and covered more than 29% of the studied landscape (*Table 1*). However, farmlands started to vanish at the same time, because the demand for construction land dramatically increased with socioeconomic development.

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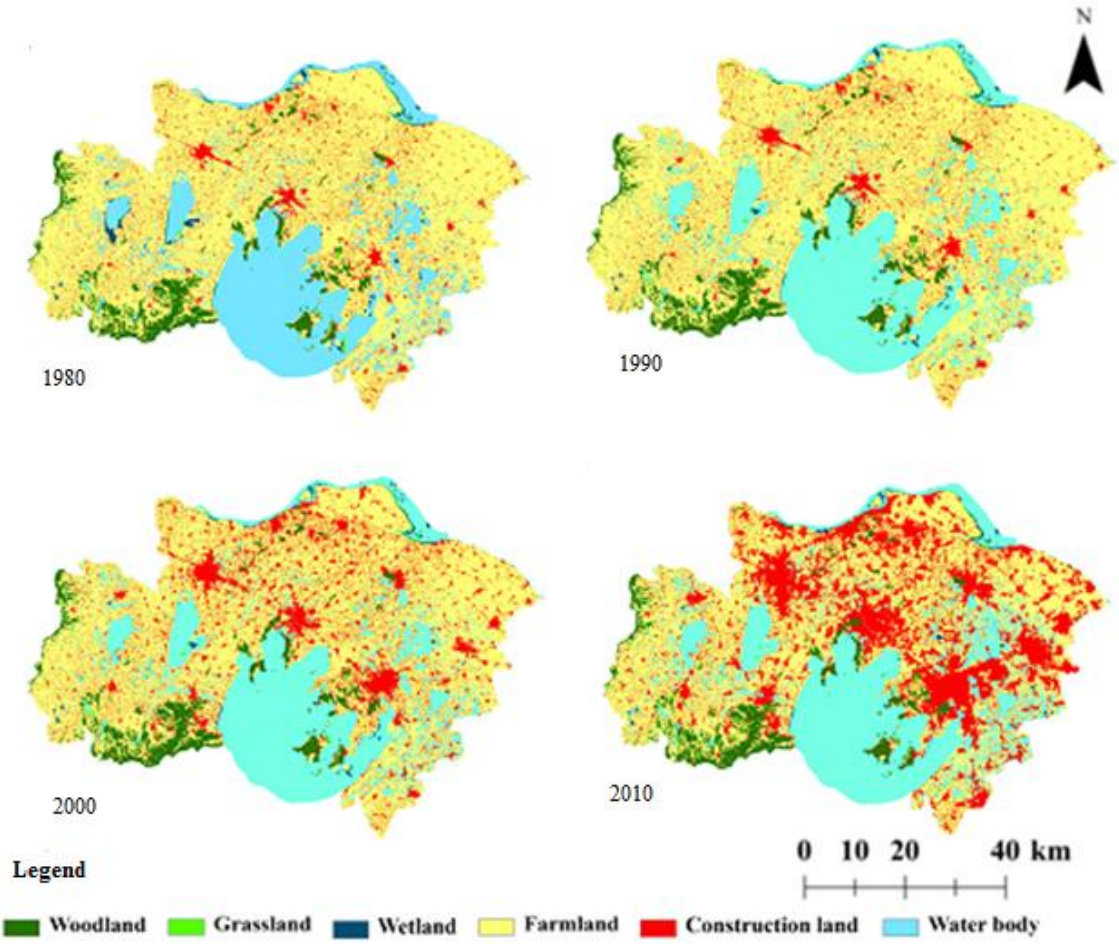

Figure 2. *LULC maps of the Su-Xi-Chang region for the years 1980, 1990, 2000 and 2010*

Table 1. *Temporal patterns of LULC changes of the Su-Xi-Chang region*

LULC type	1980		1990		2000		2010		Change (1980 – 2010)	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Total	%
Farmland	977,687	56.04	922,383	52.87	864,338	49.54	647,986	37.14	-329,701	-33.71
Woodland	114,796	6.58	116,890	6.78	117,154	6.72	119,831	6.87	5,035	4.37
Grassland	1919	0.11	1745	0.11	1592	0.09	2203	0.13	284	14.81
Water body	514,839	29.51	516,757	29.61	499,309	28.62	485,055	27.8	-29,784	-5.79
Wetland	7153	0.41	5059	0.31	3672	0.21	3454	0.20	-3,699	-51.71
Construction land	126659	7.26	181,790	10.32	258,559	14.82	486,095	27.86	359,436	284.81
Total	1,744,624	100	1,744,624	100	1,744,624	100	1,744,624	100	-	-

Analysis of temporal LULC changes

The general tendency of change in LULC during the thirty-year period is indicated in *Table 1*. On the basis of the land use transition matrix, the comprehensive dynamics among different LULC types is shown in *Tables 2, 3 and 4*. With 56% coverage of the study area, farmland was the dominant cover type in 1980, followed by water body

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(30%). In the same period, construction land covered only 7% of the studied landscape (*Table 1*). In 1990, farmland decreased to 53% and water body was slightly balanced (30%), and both are the dominant LULC types. However, construction land increased by 3.2% of the preceding period, covering more than 10% of the total study area during this period (*Table 1*).

From 1980 to 1990, construction land, woodland, and water body enlarged by 3.4%, 0.2%, and 4%, respectively. In contrast, farmland, grassland, and wetland decreased by 1.3%, 9.6%, and 39%, respectively (*Table 2*). In this period, farmland was the main contributor to an increase in the areas of woodland, water body, and construction land by allowing for 27%, 48%, and 79% of the increase in their total area, respectively (*Table 2*). In this period, the grain for green development policy, expansion of artificial ponds for fish production, and urban expansion were the main reasons for the large amount of farmland conversion.

Table 2. *LULC conversion matrix from 1980 to 1990 (ha)*

								Change 1990	
Land use type	FL	WOL	GL	WB	WL	CL	Sum 1990	Total	%
Farmland (FL)	922,011	106	10	110	94	263	922,383	-55,304	-5.71
Woodland (WOL)	591	114,656	204	2	6	2	116,890	2,094	1.79
Grassland (GL)	396	13	1648	9	12	1	1745	-174	-9.01
Water body (WB)	9386	10	52	514,449	2830	3	516,757	1918	0.39
Wetland (WL)	1098	0	4	154	4181	13	5059	-2,094	-29.31
Construction land (CL)	44205	11	1	15	30	126477	181,790	5,513	4.35
Sum 1980	977,687	114,796	1919	514,839	7153	126659	1,744,624	-	-

From 1990 to 2000 farmland, grassland, and wetland continued decreasing by more than 6%, 8%, and 27% respectively. In addition to these three LULC categories water bodies started to decrease with more than 3% of its total area of the base year in the same period; however, woodland, and construction land expanded by 0.3%, and 42%, respectively (*Table 3*). In this period, the diminishing of farmland contributed 100%, and 5% to the expansion of construction land, and woodland, respectively (*Table 3*). In the period between 2000 and 2010, a comparable LULC change pattern was found, in which construction land continued to increase at an alarming rate, and was followed by grassland and woodland. The decreasing farmland area caused an increase in the areas of construction land, woodland, and grassland by 76%, 93%, and 100%, respectively (*Table 4*). In addition, a reduction in wetland area contributed 4% toward the expansion of construction land in the same period (*Table 4*). Thus, as lands supporting construction land expansion became scarce, wetlands the target for construction development. Our result supports the findings of Wang et al. (2011), who have found that the expansion of construction land in the West Songneu Plain of China led to the shrinking and fragmentation of swamplands. Similarly, Yuan Zhang (2010) has described the same phenomenon in the Yinchuan Plain of China.

Considering the LULC conversion matrix from 1980 to 2010, there was considerable growth in construction land over the other LULC types; remarkably, this growth far exceeded the amount of land converted from construction land to other LULC types.

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The results (*Tables 2, 3 and 4*) showed that over the study period, the loss of farmland strongly contributed to the newly emerging construction land, and was followed by wetland and water bodies, respectively. Thus, driven by robust socioeconomic factors, the ongoing growth in construction land was responsible for a large decline in the farmlands, wetlands and water bodies in the region.

Table 3. *LULC conversion matrix from 1990 to 2000 (ha)*

Land use type	FL	WOL	GL	WB	WL	CL	Sum 2000	Change 2000	
								Total (ha)	%
Farmland (FL)	828,938	198	0	2	1	1331	864,338	-58,045	−6.29
Woodland (WOL)	185	113,840	0	0	0	1	117,154	264	0.23
Grassland (GL)	6	58	1695	155	0	1	1592	-153	−8.77
Water body (WB)	8763	34	6	516,032	185	221	499,309	-17448	−3.38
Wetland (WL)	1	0	3	0	4856	110	3672	-1387	−27.42
Construction land (CL)	84,490	2760	41	620	17	180,126	258,559	76769	42.23
Sum 1990	922,383	116,890	1745	516,757	5059	181,790	1,744,624	-	-

Table 4. *LULC conversion matrix from 2000 to 2010 (ha)*

Land use type	FL	WOL	GL	WB	WL	CL	Sum 2010	Change 2010	
								Total (ha)	%
Farmland (FL)	646,970	703	23	96	18	6205	647,986	-216,352	−25.02
Woodland (WOL)	2593	111,390	16	50	0	109	119,831	2,677	2.27
Grassland (GL)	1124	2226	1274	58	1	155	2203	611	38.38
Water body (WB)	33,412	457	185	487,479	67	2456	485,055	-14,254	−2.85
Wetland (WL)	186	35	0	1498	3492	554	3454	-218	−5.93
Construction land (CL)	179,952	2343	94	10,128	94	249,044	486,095	227,536	88.01
Sum 2000	864,338	117,154	1592	499,309	3672	258,559	1,744,624	-	−

Analysis of landscape metrics

The overall trends of LULC fragmentation at both class (*Table 5*) and landscape (*Fig. 3*) levels were considered. The detailed descriptions of landscape metrics used in this study are given in Appendix B. As shown in *Table 5*, the landscape change for farmland and wetland at the class level indicated a consistent increase in the number of patches (NP) that enhanced the corresponding patch density during the study period. For farmland, NP increased from 357 in 1980 to 383 in 1990 and to 539 and 812 in 2000 and 2010, respectively, thus indicating that the spatial heterogeneity of this class increased with increasing disturbance over time. A similar pattern was found in the wetland category, as evidenced by increased patch density (PD) (*Table 5*). This result suggested that in recent decades, increasing human pressure has led to the fragmentation of both farmland and wetland LULC categories. The largest patch index (LPI) for both farmland and wetland showed a declining trend throughout the study period, owing to the intensification of construction land. For instance, the LPI for the wetland category

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decreased from 10.12% in 1980 to 2.04% in 2010. Likewise, the LPI for farmland decreased from 38.7% in 1980 to 27.5% in 2010 (*Table 5*). Furthermore, interspersion and juxtaposition (IJI) indicated identical configurations for both LULC types, thus indicating that the patch types of these LULC categories were more scattered.

Apart from farmland and wetland, and except for construction land, the rest of the LULC types showed irregular stability with variable values. However, as observed in the LULC change analysis (*Tables 2, 3, 4; and Fig. 2*), construction land has rapidly replaced farmland in the Su-Xi-Chang region. The NP for construction land was 10,510 in 1980, decreased to 10,252 in 1990 and increased to 10,835 in 2000, but in 2010, markedly decreased to 7641. The rapid urban development between 1990 and 2000 might have resulted in the large NP in 2000. The PD values also showed that the construction land became denser over time, a result also confirmed by its IJI values, which kept increasing, thus indicating that the construction land category has a continuous and clumped pattern.

Table 5. *Landscape metrics changes according to patch class level in the Su-Xi-Chang region*

Class	Year	NP	PD	LSI	LPI	AWMPFD	IJI
Farmland	1980	357	0.0205	69.0205	38.7074	1.1	62.2521
	1990	383	0.022	75.9841	34.2572	1.02	61.1539
	2000	539	0.031	93.1932	30.2799	1.21	56.0708
	2010	812	0.0467	103.8536	27.4821	1.26	56.7936
Woodland	1980	609	0.0363	38.8551	1.4845	1.26	41.071
	1990	641	0.035	38.5286	1.4822	1.23	41.2144
	2000	631	0.0369	39.9257	1.4601	1.06	50.6993
	2010	640	0.0368	40.9147	11.4319	1.02	60.4878
Grassland	1980	141	0.009	19.184	0.0385	1.23	88.902
	1990	156	0.0081	18.8301	0.0215	1.03	89.8603
	2000	152	0.009	19.5546	0.0214	1.01	93.1942
	2010	157	0.0145	24.5787	10.0182	1.02	92.6445
Water body	1980	2447	0.1407	40.8143	17.835	1.25	41.1412
	1990	2201	0.1265	39.4735	16.1191	1.2	39.6078
	2000	2548	0.1465	42.6489	15.187	1.26	43.7562
	2010	2534	0.1457	47.0361	14.477	1.16	47.2235
Wetland	1980	219	0.0126	42.3869	10.1173	1.08	61.3066
	1990	225	0.0143	52.7915	8.054	1.05	61.0185
	2000	238	0.0145	68.0608	5.0451	1.14	62.1501
	2010	287	0.0152	75.2681	2.0428	1.23	70.0982
Construction land	1980	10510	0.6043	138.6259	10.3137	1.2	14.5744
	1990	10252	0.5895	135.9465	20.3498	1.26	14.7907
	2000	10835	0.623	132.7572	26.7967	1.06	20.3902
	2010	7641	0.4393	97.3106	33.3579	1.05	29.8143

NP = number of patches; PD = patch density; LSI = landscape shape index; LPI = largest patch index; AWMPFD = area-weighted mean patch fractal dimension; and IJI = interspersion and juxtaposition.

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To designate the characteristic features of the fragmentation of LULC at the landscape level and to evaluate the extent of human pressure causing changes on landscape structure, the NP, LPI, AWMPFD, IJI, Shannon's diversity index (SHDI), and contagion index (CONTAG) were computed by using FRAGSTATS, and the results are presented in *Fig. 3*. The opposite magnitudes between LPI and NP at the landscape level (*Fig. 3a, and b*) indicated high landscape fragmentation. Thus increasing human activities in the region have caused a dispersed landscape structure. In addition, the continuously increasing value of AWMPFD indicated clear fragmentation of LULC at the landscape level (*Fig. 3c*). A continuous decline in values of SHDI indicated that the landscape was unevenly distributed and subjected to less patch types. The SHDI decreased from 1.2608 in 1980 to 1.1382 in 1990, and from 1.0377 in 2000 to 1.0352 in 2010 (*Fig. 3d*), possibly as a result of urban landscape dominance. The CONTAG value was lower in 1990 than in 1980. However, the values again became higher after 2000, thus suggesting a more contiguous and homogenous pattern. The analysis showed that the intensification of human activities in the study area has caused landscape fragmentation, thereby leading to the loss of the function of a natural landscape.

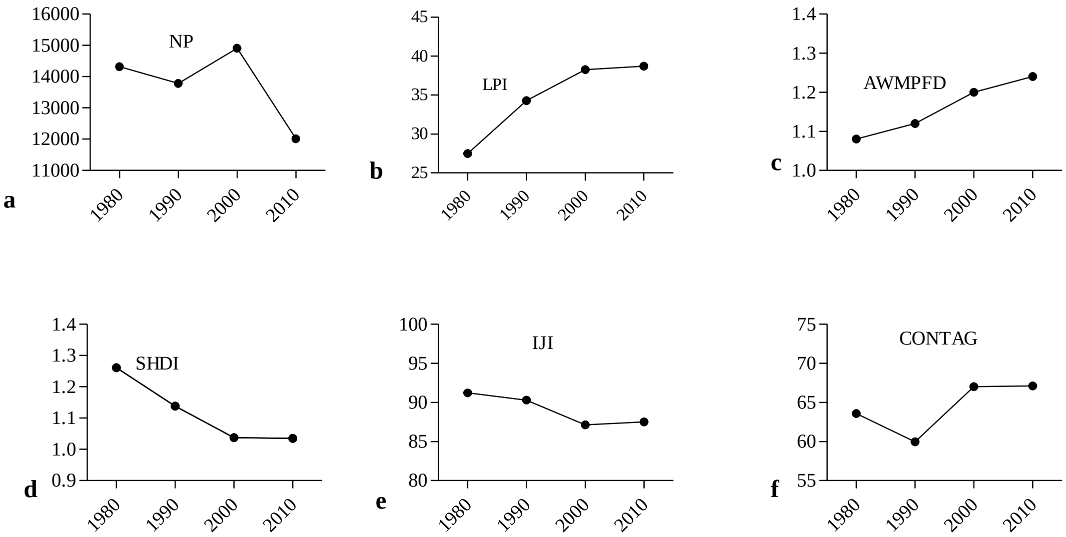

Figure 3. *Changes in number of patches (NP), largest patch index (LPI), area-weighted mean patch fractal dimension (AWMPFD), Shannon's (SHDI), interspersion and juxtaposition (IJI) and contagion index (CONTAG) at the landscape level*

Analysis of major socioeconomic drivers

Combinations of various socioeconomic factors have induced LULC changes in the Su-Xi-Chang region. *Table 6* depicts the relationships among these different socioeconomic variables and LULC changes. In addition, Appendix A shows the various socioeconomic variables considered in this study along with their detailed values over the past thirty-years. The overall results of our statistical analysis showed that over the past three decades, population growth and economic development, urbanization and subsequent construction land expansion, and rapid industrialization were the major drivers of LULC changes in the Su-Xi-Chang region.

Population growth and economic development

The total population of the Su-Xi-Chang region was approximately 11 million in 1980, and suddenly increased to 13 million within a decade in 1990, with an annual growth rate of 8.6%. In 2000, the population rose to 13.5 million, and in 2010, it reached 14.5 million. In 2014, the population reached more than 15.2 million (NBSC, 2015). After population growth, LULC changes in the region became aggravated over time (*Table 1*). Different authors, particularly those in developing countries, have suggested that increased population growth causes LULC changes (Garedew et al., 2009; Kamusoko and Aniya, 2007).

Our results showed that the relationship between the growth in population and construction land was positively correlated ($r = 0.631$), and the values were significantly different ($P<0.05$). This result suggested that the increase in population also caused the increase in construction land expansion (*Table 6*), possibly because of an increase in settlement demand, for which large parts of agricultural lands were changed to residential areas, both in rural and urban zones. This possibility was confirmed by the inverse relationship between population growth and agricultural land (*Table 6*). Furthermore, the negative correlation between these two factors may suggest the importance of population growth in the LULC changes occurring in the region. This result is consistent with findings from Priess et al. (2007) in Indonesia and Kidane et al. (2012) in Ethiopia, which have shown that increases in population growth lead to agricultural land loss. Because Su-Xi-Chang is a potential region for agricultural production, a large part of this region is still in the agricultural sector. To meet the demands of the growing population by producing high production from limited land resources, large areas of agricultural land were converted into alternative productive land use practices, such as fishponds for fish farming, as evidenced by the strong positive relationship between the growth of population and increase in aquatic products (*Table 6; Fig. 4*).

Table 6. *Correlation coefficients between different socioeconomic variables*

	Population	Industrial output	Agricultural production	Aquatic products	GDP	Agricultural land	Construction land
Population	1	.407*	-.307	.479**	.405*	-.447*	.631*
Industrial output		1	-.882**	.715**	.999**	-.979**	.976**
Agricultural production			1	-.704**	-.867**	.880**	-.905**
Aquatic products				1	.706**	-.826**	.815**
GDP					1	-.973**	.971**
Agricultural land						1	-.982**
Construction land							1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

In addition to population growth, economic development showed a positive correlation ($r = 0.971$) with construction land, and the relationship was highly significant ($P<0.01$) (*Table 6*). Thus, an increase in economic development also caused an increase in

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construction land expansion. This result is in line with findings from Tang et al. (2014) in Harbin, Northeast China, which have indicated that economic development can cause LULC changes that significantly affect the functions of a natural landscape. Given the advantage of its location, being in a coastal area of the country, the economy of the Su-Xi-Chang region showed an upward trajectory (*Fig. 4a*), and currently, the region plays a vital role in the Chinese economy. This observation also accounted for the rapid expansion of urban and industrial lands that led to LULC change. Hence, our results showed that in general, the growth of the population and economic developments were the principal causal factors of changes in the LULC of the study area.

Industrialization

In the study period, industrialization in the Su-Xi-Chang region explosively increased after the rapid rise in the total industrial output value (*Fig. 4a*), which also caused major LULC changes. An all-around rapid industrialization and urbanization occurred in the region since 2000, owing to a higher consumption of land for industrialization than for urbanization. During this period, to support the manufacturing expansion, less attention was given to agricultural land. As a result, urban associated industrialization became an essential driving force of LULC changes, thereby decreasing the arable land category. Rural industrialization has been reported to contribute to construction land expansions in China (Lin and Ho, 2003). This phenomenon also occurred in the Su-Xi-Chang region, as evidenced by the strong positive correlation between construction land and the industrial output value (r = 0.976) with a significant difference of P<0.01.

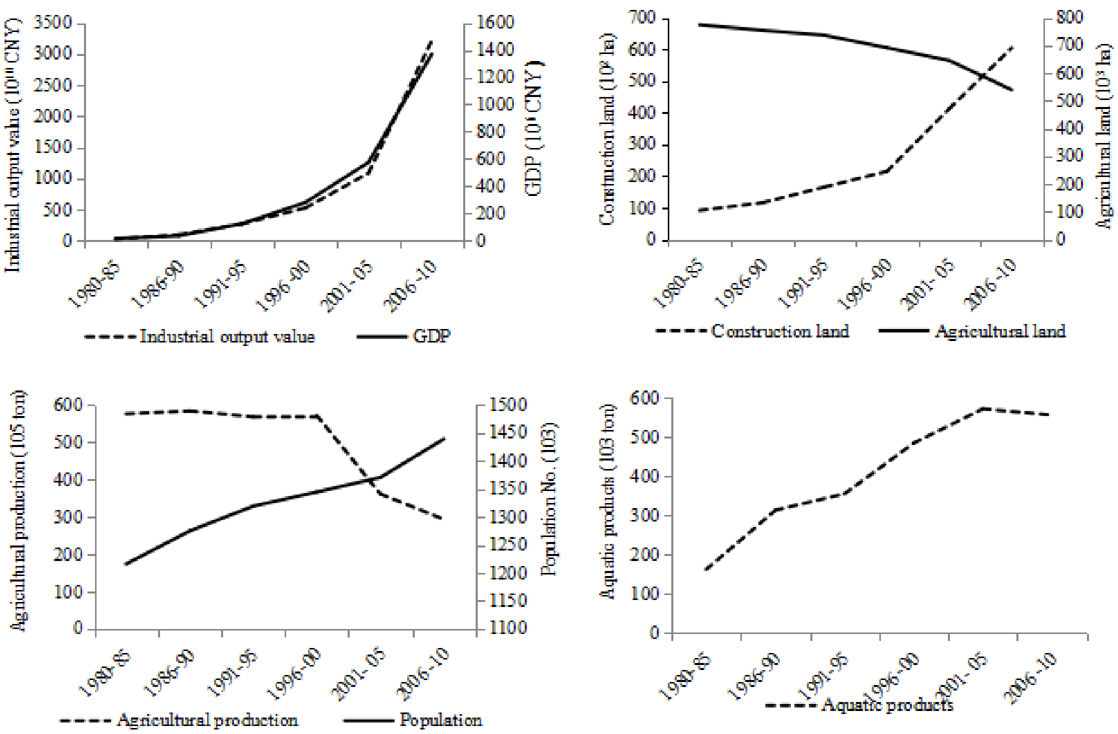

Figure 4. *Trends in different socioeconomic variables from 1980 to 2010 in the Su-Xi-Chang region*

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As indicated in *Table 6*, there was a strong positive correlation between aquatic products and the industrial output value (r = 0.715) and between GDP and the industrial output value (r = 0.999), both of which exhibited significant differences (P<0.01). These findings suggested that increases in both aquatic products and GDP contributed to the increase in industrial output. This finding may have been due to an increase in the row material supply from increased aquatic products, as well as to an increase in GDP, which enhanced the output values of industries. However, the industrial output value was negatively correlated with agricultural production (r = -0.882) and agricultural land (r = -0.979), and the relationships were highly significant (P<0.01), thus indicating the effect of industrialization from the massive conversion of agricultural land into market oriented land use. Put another way, the results indicated that industrialization has cursorily caused substantial loss of agricultural land, to the benefit of market oriented farming and non-agricultural development.

In addition, owing to economic prosperity, particularly by the middle of the 1980s, the region provided a model for the development of rural industries. This model also describes when the Township and Village Enterprises (TVEs) thrived after rapid growth of the rural economy in southern Jiangsu (Long et al., 2009). Since then, the growth of TVEs and the development of an export-oriented economy have fundamentally transformed the industrial pattern of the region. As a result, the total industrial output value markedly increased (*Fig. 4a*). These manifestations played roles in LULC changes, as evidenced by the strong inverse relationship between industrial output values and the loss in agricultural land (*Table 6*).

Urbanization and subsequent construction land expansion

Rapid urbanization was stimulated after the Chinese economic reform of the 1970s, particularly around the beginning of the 1990s, and urbanization was accelerated to a great extent as the centrally planned economy shifted to a socialist market. This shift led to construction land expansion (Xu, 2004; Liu et al., 2005) and subsequently to the loss of agricultural land in China (Kuang et al., 2016). In the Su-Xi-Chang region, the area of construction land, mainly owing to urbanization, increased from 126,659 ha in 1980 to 181,790 ha in 1990, with an annual growth rate of 4.35% (*Table 1*). In 2000, it attained a total area of 258,559 ha, and in 2010, it increased by 227,536 ha more than that in the former period, in which farmland contributed 76% of the amplification (*Table 4*). These changes were evidenced by the strong inverse relationship between construction land and agricultural land (*Table 6; Fig. 4b*). In the past three decades, notably, construction land increased by 359,436 ha, amounting to 284.81% of the area in 1980, during which it covered merely 7% of the total landscape, which rose to 27.86% in 2010 (*Table 1*).

The results showed that areas of 79%, 100%, and 76% enlargement in construction land from 1980 to1990, 1990 to 2000, and 2000 to 2010, respectively, were contributed by farmland (*Tables 2, 3, and 4*). As (Liu et al., 2008) have described, this type of occupation mostly occurred in the developed areas, especially in the main grain production zone of the coastal regions, thus leading to simultaneous decreases in both the area and production of agricultural land (*Fig. 4b and c*). Particularly, the decrease in production occurred because the productive lands occupied by construction land and crop cultivation were forced to be located in less productive areas. This scenario can be seen in *Table 6,* which shows the negative relationship between agricultural production

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and construction land (r = -0.905) as well as agricultural land and construction land (r = -0.982), with a highly significant correlation ($P<0.01$).

The occurrence of various development activities in the region also played vital roles in the construction land expansion, which was followed by a decrease in agricultural land (*Fig. 4b*). For instance, the construction of a special development zone, the ETDZ, in Kunshan City of the Su-Xi-Chang region originated in 1985 (Long et al., 2007). It was approximately 375 ha before it was chosen as one of the state development zones. After a decade, its planning area increased by more than 500%, and it attained a total area of 2000 ha. Correspondingly, the advent of TVEs to increase farmers' non-agricultural income by promoting the structural adjustment and institutional innovation made a vital contribution to the process of expanding construction land, thus resulting in conversion of large areas of agricultural land for rural village construction. Thus, urbanization and the subsequent expansion of construction land was generally one of the most important factors in LULC change in the studied landscape.

Conclusion

We examined the spatio-temporal dynamics of LULC changes, major socioeconomic drivers, and the relationship between changes in LULC and their drivers in the Su-Xi-Chang region over the course of 1980 to 2010. Significant changes in LULC were found in the region, whereby construction land dramatically increased largely at the expense of farmland. From 1980 to 1990, diminishing farmland was more important for the newly emerged construction land, as well as for the enlargement of water bodies and woodland, than the other cover types. In the same period, dwindling wetland contributed to construction land and water body increases next to farmland. Similar trends of conversion occurred in the periods from 1990 to 2000 and 2000 to 2010, except for variations in the spatial extent of changes among the different categories. In addition, changes in landscape patterns and composition exhibited increased the fragmentation of farmland and wetlands. However, the construction land category became aggregated and complex, thereby resulting in the high fragmentation of other LULC categories.

Population growth and economic development, urbanization and subsequent construction land expansion, and industrialization were found to be the major change drivers. The growth of population over time increased the demand for residential areas, and hence, large areas of farmland were converted for settlement construction. Furthermore, to achieve more economic benefits from their farmland, farmers practiced profit oriented farming systems, particularly by converting their farmland into artificial ponds for fish production. Similarly, the rapid industrialization consumed large areas of farmland. In general, the marked expansion of construction land is mainly accountable for the 33% decrease in farmland in the past three decades.

Given the current trends of socioeconomic drivers in the Su-Xi-Chang region, increasing pressure on LULC is causing an alarming change in farmland, water bodies, and wetland. The change in farmland involves decreases in both area and production and may impair the ecological functions that support the human dominated environment and result in a decline in food production. Therefore, policies to achieve long term sustainable development must address the effects of these drivers on LULC changes. Moreover, further research along these lines should be encouraged because additional studies will be helpful for the decision makers engaged in planning activities at various levels in the region.

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APPENDIX

Appendix A. *The various annual series of socioeconomic data of the Su-Xi-Chang region over the past 30 years used for this study*

Year	Population ($\times 10^3$)	Ind. Output (10^9 CNY)	Agri. Pro ($\times 10^5$ ton)	Aqu. Pro ($\times 10^3$ ton)	GDP ($\times 10^6$ CNY)	Agri. Land ($\times 10^3$ ha)	Cons. Land ($\times 10^2$ ha)
1980	1191.44	210	540.39	120.66	9.9	781.36	80.9
1981	1204.55	230	487.42	125.586	10.61	779.85	80.5
1982	1217.34	240	610.62	152.132	11.44	777.6	90.6
1983	1222.89	280	604.22	151.164	12.85	776.88	96
1984	1225.95	360	676.13	185.776	16.61	772.91	99.7
1985	1233.93	510	538.77	231.141	22.14	765.55	105.1
1986	1245.57	600	602.55	278.718	15.42	760.86	108.6
1987	1260.22	750	565.21	303.477	29.71	757.58	111.9
1988	1275.2	990	581.32	318.259	38.1	753.8	117

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1989	1290.68	1110	570.34	322.999	40.86	752.77	120.5
1990	1303.58	1230	601.95	337.012	45.75	751.26	124.2
1991	1307.97	1330	576.96	324.575	52.21	750.16	137.9
1992	1312.36	1440	551.97	312.139	80.81	749.06	154.1
1993	1319.36	2410	591.95	348.315	119.02	737.88	173.2
1994	1325.14	3570	567.72	372.112	164.04	729.06	180.4
1995	1331.19	4740	552.64	412.938	202.85	720.83	188.5
1996	1335.75	4720	578.81	452.861	229.51	712.54	201.8
1997	1342.48	4870	603.88	464.161	255.05	691.36	207.8
1998	1346.51	5010	608.56	476.479	279.29	688.08	215.5
1999	1348.31	5460	542.7	501.561	301.77	685.19	222.1
2000	1349.34	6070	525.57	521.389	331.79	684.36	231.3
2001	1354.26	7090	457.19	558.672	376.18	681.59	330.9
2002	1357.95	7750	391.9	577.017	437.51	673.68	378.1
2003	1365.68	9490	365.51	588.776	553.64	652.28	416.4
2004	1379.73	12,520	288.01	575.635	680.28	638.65	454.6
2005	1395.01	17,380	305.06	553.112	825.52	587.86	487.5
2006	1411.78	21,600	283.81	567.64	979.66	575.32	507.1
2007	1428.55	27,230	307.16	562.868	1164.33	546.83	531
2008	1443.55	33,960	261.91	550.901	1380.5	536.62	633.3
2009	1452.69	37,590	306.51	557.026	1525.19	531.74	661
2010	1458.76	40,530	307.63	535.986	1806.71	513.35	696.9

NB: Ind. output = Industrial output value; Agri. Pro = Agricultural production; Aqu.pro = Aquatic products; Agri. Land = Agricultural land; Cons. Land = Construction land (in this particular case it stands for residential area).
(**Sources**; Statistical year books and different surveys deployed in different time by the governmental offices of the region).

Appendix B. *Landscape metrics selected for this study and their description*

Acronym	Name (units)	Description	Justification
NP	Number of patches	Total number of patches in the landscape	Fragmentation
PD	Patch density (per 100 ha)	Number of patches per unit area	Fragmentation
LSI	Landscape shape index	The landscape boundary and total edge within the landscape divided by the total area, adjusted by a constant for a square standard	Aggregation

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LPI	Largest patch index (%)	Area of the largest patch in each class, represents percent of the total landscape area	Dominance
SHDI	Shannon’s diversity index	SHDI equals minus the sum, measure of diversity. Approaches 0 when there is no diversity, increases with number of patch types.	Diversity
IJI	Interspersion and juxtaposition index (%)	Intermixing of patches of different types, based on patch adjacencies. Increases to 100 as the patch type becomes increasingly interspersed with other patch type.	Fragmentation
CONTAG	0 < CONTAG ≤ 100 Contagion index (%)	Approaches 0 when the patch types are maximally disaggregated and interspersed. Approaches 100 when the landscape consists of a single patch.	Fragmentation
AWMPFD	Area-weighted mean patch fractal dimension	Shape complexity weighted by the area of patches	Fragmentation

Adapted from McGarigal et al. (2002).

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