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Spatio-temporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization

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ABSTRACT

Analyzing spatio-temporal characteristics of land use change is essential for understanding and assessing ecological consequence of urbanization. More importantly, such analysis can provide basic information for appropriate decision-making. By integrating historical high spatial-resolution SPOT images and spatial metrics, this study explored the spatio-temporal dynamics and evolution of land use change and landscape pattern in response to the rapid urbanization process of a booming-developing city in China from 1996 to 2006. Accurate and consistent land use change information was first extracted by the change detection method proposed in this study. The changes of landscape pattern were then analyzed using a series of spatial metrics which were derived from FRAGSTATS software. The results indicated that the rapid urbanization process has brought about enormous land use changes and urban growth at an unprecedented scale and rate and, consequently, given rise to substantial impacts on the landscape pattern. Findings further revealed that cropland and water were the major land use types developed for urban sprawl. Meanwhile, the landscape pattern underwent fundamental transition from agricultural-land-use dominant landscape to urban-land-use dominant landscape spanning the 10 years. The results not only confirmed the applicability and effectiveness of the combined method of remote sensing and metrics, but also revealed notable spatio-temporal features of land use change and landscape pattern dynamics throughout the different time periods (1996–2000, 2000–2003 and 2003–2006).

1. Introduction

Urbanization has been a universal and important social and economic phenomenon taking place all around the world. This process, with no sign of slowing down, may be the most powerful and visible anthropogenic force that has brought about fundamental changes in land use and landscape pattern around the globe. Rapid urbanization, especially in the developing world, will continue to be one of the crucial issues of global change in the 21st century affecting the human dimensions (Sui and Zeng, 2001). This has resulted in an unprecedented scale and rate of urban expansion in China over the last two decades. According to the prediction of Construction Department of the central government, China's urbanization level will reach 50% with an urban population of 1.5 billion by the end of 2020 (Tian et al., 2005). However, rapid urbanization and exploitation of natural resources have given rise to significant impacts on ecosystem structure, function and dynamics which has made urban as a fragile region. This is particularly the case in the economic-developed regions where dramatic urban expansion and land use change have induced serious environmental issues threatening urban sustainable development (Yeh and Li, 1999; Weng, 2001; Ji et al., 2001; Li and Yeh, 2004; Chen et al., 2005; Xiao et al., 2006; Liu et al., 2007). Accurate and timely information on the status and trends of urban ecosystem, therefore, has attracted increasing attention from local communities and policy decision makers alike. Unfortunately, due to the lack of basic knowledge and timely information of the urbanization process and its long-term ecological impacts, people have not been able to assess and analyze consistently, much less to manage and restore, the urban ecosystems in both urban cores and suburban fringes.

Remote sensing represents a major, though still under-used, source of urban information by providing spatially consistent coverage of large areas with both high spatial detail and temporal frequency, including historical time series (Jensen and Cowen, 1999; Donnay et al., 2001). With increased availability and improved quality of multi-spatial and multi-temporal remote sensing data as well as new analytical techniques, it is now possible to

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monitor and analyze urban expansion and land use change in a timely and cost-effective way (Yang et al., 2003). However, there are some technical challenges in retrieving accurate information of urban expansion and land use changes. A major difficulty in urban remote sensing analysis is caused by the high heterogeneity and complexity of the urban environment in terms of its spatial and spectral characteristics. A successful implementation of remote sensing requires adequate consideration and understanding of these specific urban landscape characteristics in order to fully explore the capabilities and limitation of remote sensing data and to evaluate appropriate image analysis techniques (Herold et al., 2005). Cowen and Jensen (1998) outlined the relationship between selected urban/suburban attributes and the remote sensing resolutions required to provide such adequate information. Among these issues, the most important technical concern has been the pursuit of finer spatial resolutions of image pixels (Lo, 1986; Curran and Williamson, 1986; Atkinson and Curran, 1997; Yang and Lo, 2002; Lu et al., 2004). It was suggested that remote sensing data with a spatial resolution of 0.5–10 m IFOV are required to determine adequately the high frequency detail which characterizes the urban scene (Welch, 1982). In addition to resolution requirement of remote sensing data, image analysis methods are also very important technical barriers for its urban applications. Land use change detection method is as, even more, crucial to urban application as is the choice of remote sensing data. Developing an improved understanding of how to match applications and change detection methods is still confronted with several challenges. Despite many factors affecting the selection of suitable change detection methods, image differencing, principal component analysis (PCA) and post-classification are, in practice, the most commonly used methods and usually demonstrate better performance compared with other methods (Collins and Woodcock, 1996; Yuan and Elvidge, 1998; Lu et al., 2004; Jensen, 2005).

Much less known than remote sensing, spatial metrics can be a useful tool for objectively quantifying the structure and pattern of an urban environment directly from thematic maps, e.g. from remote sensing mapping products (Herold et al., 2005). Spatial metrics are commonly used in landscape ecology, known as landscape metrics. Changes of landscape pattern can be detected and described by the landscape metrics, which quantify and categorize complex landscape into identifiable patterns and reveal some ecosystem properties that are not directly observable (Antrop and Van Eetvelde, 2000; Turner et al., 2001; Weng, 2007). Recently there has been an increasing interest in applying spatial metrics techniques in urban environments because of their use in bringing out the spatial component in urban structure and in the dynamics of change and growth process (Zhou, 2000; Sui and Zeng, 2001; Apan et al., 2002; Luck and Wu, 2002; Li and Yeh, 2004; Dietzel et al., 2005; Porter-Bolland et al., 2007). Furthermore, spatial metrics have the potential for more detailed analyses of the spatio-temporal patterns of urban change, and the interpretation and assessment of urbanization process. Undoubtedly, the combined application of remote sensing and spatial metrics can provide more spatially consistent and detailed information about urban structure and change, and consequently, allowing for improved representations and understanding of both the heterogeneous characteristics of urban areas and of the impacts of urban development on the surrounding environment.

As a case study in Hangzhou City, one of the most rapidly developing cities in China, this paper explores the spatio-temporal dynamics, and evolution of land use and landscape pattern in response to the rapid urbanization process by integrating remote sensing technology and spatial metrics. Bearing in mind the importance of accurate and consistent land use change information over a long-term, and finer resolution of remote sensing data in concert with the urban properties, this study proposes a feasible and cost-effective land use change detection method by adopting a time series analysis of high spatial-resolution SPOT imagery spanning the last 10 years (1996–2006). Specifically, this study focuses on analysis of the spatio-temporal dynamics of land use change, a comprehensive examination of landscape pattern from a comprehensive point of view and making preliminarily exploration of the influence of urban development on these changes. The overall objective of this study is to improve the understanding of the effects of urbanization on landscape patterns and provide the basic information for identifying the potential ecological impacts and appropriate decision-making towards urban sustainable development.

2. Materials and methods

2.1. Study area

Hangzhou is the capital of Zhejiang province, on China's east coast and forms the south wing of the Yangtze River Delta forming the largest economic concentration region in China (Fig. 1). The city has been internationally renowned for its attractive scenery, richness in the Chinese history and divers culture spanning back more than 2000 years. It is also a vigorous and economically competitive city and has become a very important part within the Metropolitan Shanghai Economic Zone in China. Hangzhou started economic reform in the mid-1980s which has resulted in an almost immediate inflow of foreign and domestic investment. Since then the city has been among the top five most economically competitive cities in mainland China and awarded as the Best Chinese Destination for Investment by the World Bank. Its gross domestic product (GDP) increased rapidly from 4.57 billion RMB in 1996 to 27.38 billion in 2006, in concert with a population increase from 1.67 million to 4.14 million. Concomitant with significant economic development and industrialization, and tremendous immigration, the city has witnessed a rapid urbanization process and experienced fundamental land use change in the latest decade. To a large extent, Hangzhou represents of a typical urbanization process that is taking place in economic-developed regions throughout China.

2.2. Remote sensing data selection

It has been argued that remote sensing data for urban applications must meet certain requirements, among which finer spatial resolution is the most important one. Because of the advantages of repetitive data acquisition, its synoptic, long-term historical archives, high spatial-resolution, and stable quality, SPOT series of satellites have become a major data sources and extensively used in urban remote sensing analysis (Jensen et al., 1995; Weber and Hirsch, 1991; Donnay et al., 2001; Chen et al., 2003; Rogan and Chen, 2004; Weber and Puissant, 2003). However, owing to data-related issues such as historical data availability, quality, costs and even data distribution, it is substantially difficult to repetitively obtain long-term historical SPOT imagery over urban area in China. Therefore, only four scenes cloud-free SPOT images during the study period (1996–2006) were acquired and used in this study. Table 1 documents characteristics of the multi-temporal data series. Other data used in this study mainly include: (1) land use map derived from the National Detailed Land-use Inventory for 1996; (2) scanned color-composition aerial photograph for 2000; (3) digital orthorectified map (DOM, 2003, 1:10000 scale) and IKONOS image for 2003; (4) QUICKBIRD image for 2006; and (5) field survey data carried out in 2003 and 2006, respectively, including GPS positioning, recent photographs and interview of farmers about the land use history.

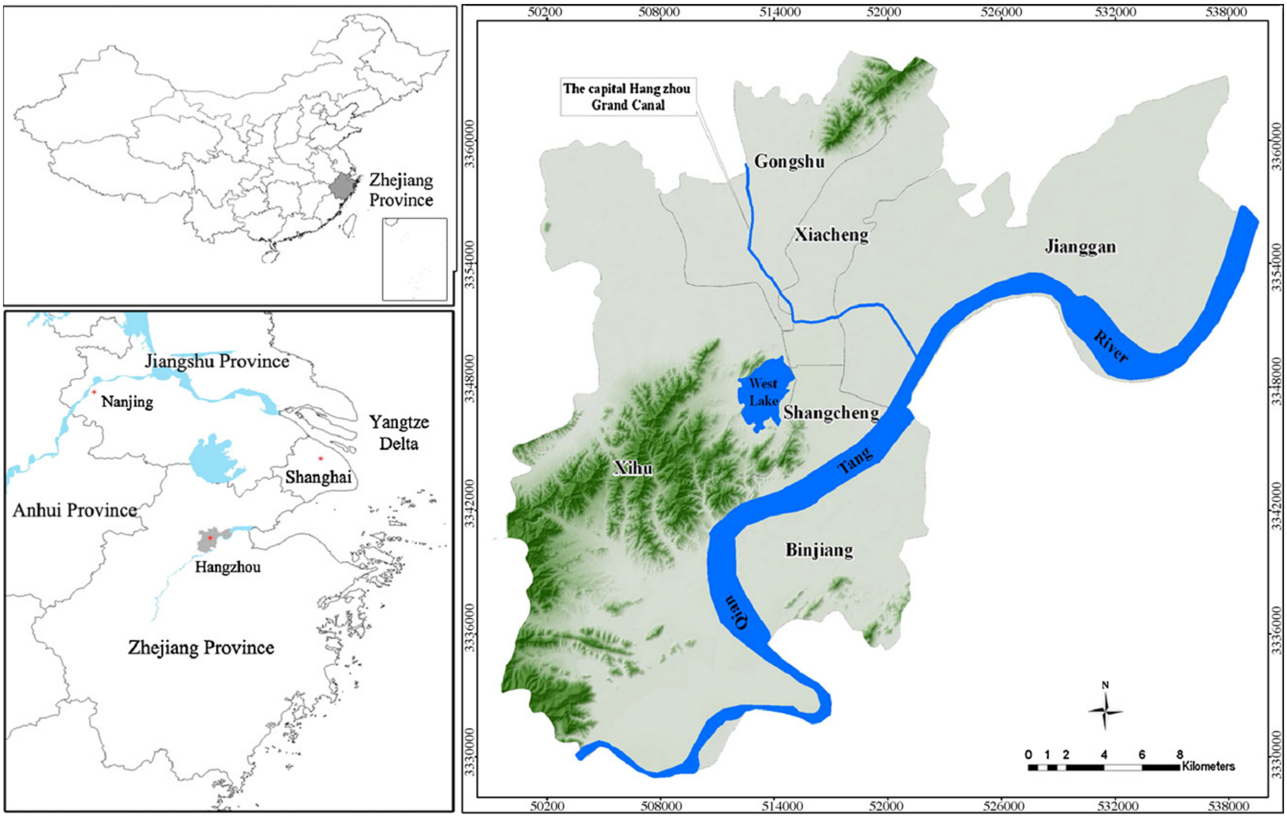

Fig. 1. Location of study area.

2.3. Land use change detection method

The method integrating PCA and hybrid classification to extract urban land use change information is illustrated in Fig. 2. It can be divided into four sections as a whole: data pre-processing, land use change enhancement and extraction, accuracy assessment, and decomposition for individual land use map. In the data pre-processing part, precise geometric corrections including image-to-image rectification and registration are the most important steps. To remove geometric distortion especially in mountainous areas and to be consistent with other spatial data, a rigorous orthorectification method based on collinearity equation was performed on all four SPOT images in order to finish image-to-image rectification and registration simultaneously. Digital elevation model (DEM) with 25 m interval, sensor position information and DOM were used as ancillary data in the correction model. This process was finished adopting the Image Geometric Correction Module in ERDAS 8.7 software. In general, atmospheric or radiometric correction is an important pre-processing step for multi-temporal change detection (Lu et al., 2004). A relative normalization based on the assumption of a simple linear relationship among images across time and the dominance of stable features in the scene is an alternative and commonly used whenever in suit absolute surface radiances are not required (Song et al., 2001; Jensen, 2005). A pilot research on relative radiometric normalization using regression equation and pseudo-invariant features (including flat road, urban area and deep water) was adopted to normalize the intensities of bands of multi-date data to the 2006 SPOT-5 image. The detailed description of radiometric normalization method can be found in literatures (Collins and Woodcock, 1996; Jensen, 2005). However, results indicate that there are no significant effects of radiometric normalization on the accuracies of multi-temporal change detection using the proposed PCA-base method in this study. In addition, these four SPOT images were purchased from SPOT Image Company (appointed by CNES as sole commercial operator of the SPOT satellites) with 1A pre-processing level which has processes the data to a much higher degree of radiometric quality than the raw data (SPOT Image Inc., 2005). Because of these reasons, radiometric normalization was not implemented in this study.

After pre-processing, a method integrating PCA and hybrid classification was adopted to detect multi-temporal urban land use change. In this study, PCA was first performed on multi-temporal composite imagery from two consecutive dates, respectively, to enhance the change information. Subsequently, the PCA-enhanced images were first classified using unsupervised classification (adopting ISODATA technique) to yield unlabeled cluster maps which were mainly utilized to identify “change” and “non-change” pixels and provide basic set of training classes for further supervised

Table 1
Characteristics of the multi-temporal data series.

Acquisition date	Sensor	Spectral mode	Spectral resolution (μm)	Spatial resolution (m)
2006-12-21	SPOT-5	XS	0.50–0.90	10
			0.61–0.68	
			0.78–0.89	
			1.58–1.75	20
2003-03-06	SPOT-5	XS	0.50–0.90	
			0.61–0.68	10
			0.78–0.89	
			1.58–1.75	20
2000-03-29	SPOT-2	XS	0.50–0.90	
			0.61–0.68	20
			0.78–0.89	
1996-04-22	SPOT-3	PAN	0.51–0.73	10

XS, multispectral mode; PAN, panchromatic mode.

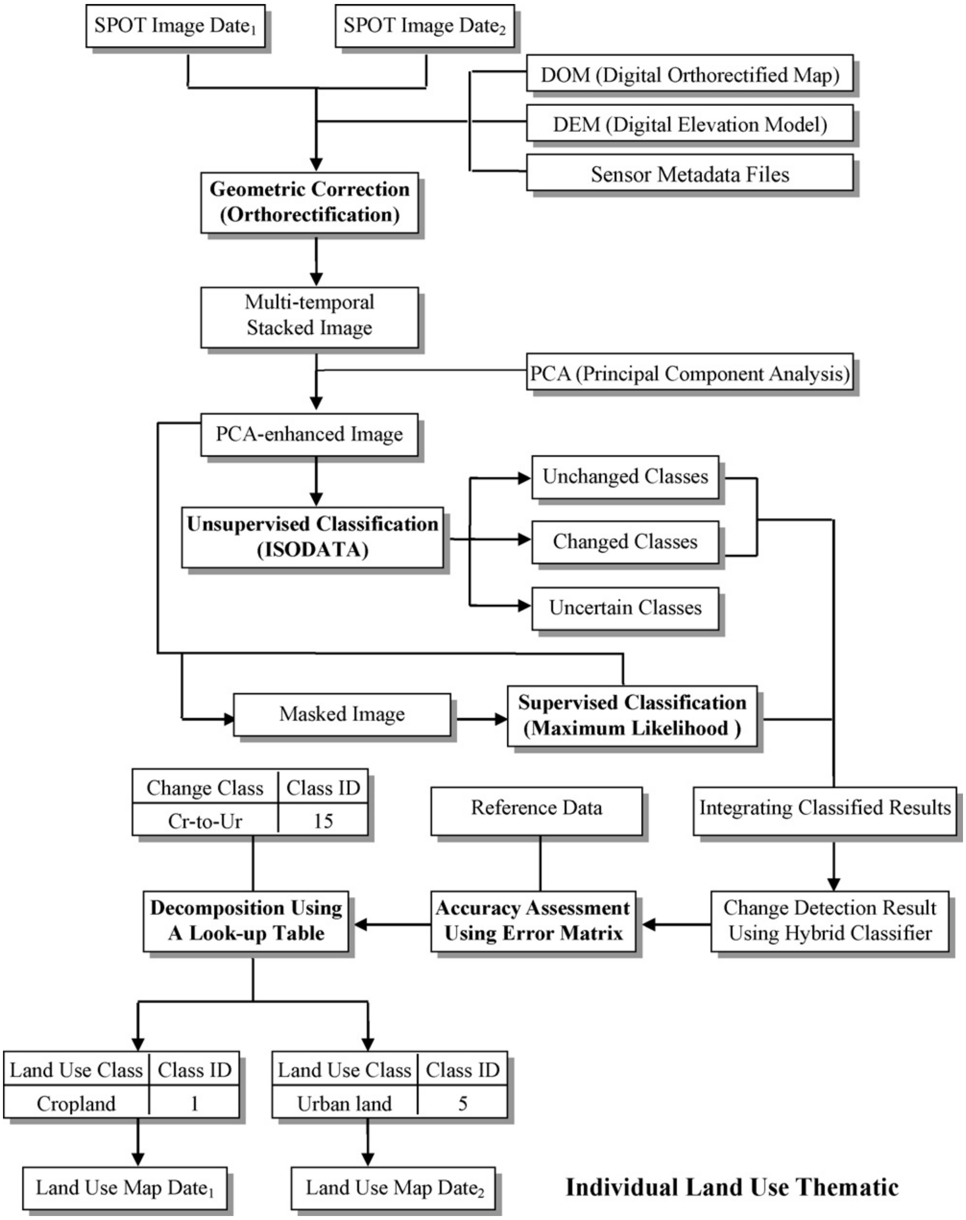

Fig. 2. Flow chart of the proposed PCA-based land use change detection methodology.

classification as well. To interpret and label these clusters, the original image in false color composite, the clustered maps and ancillary data were displayed side by side and then spatially linked together on the computer monitor screen. All these clusters were examined and assigned into three categories: obvious changed classes, unchanged classes (such as cropland and urban land), and unidentified classes. Then, taking unidentified classes as mask template, multi-temporal PCA-enhanced images were masked to remove the obvious changed and unchanged pixels, respectively. The maximum likelihood (ML) supervised classification was then implemented on the masked images with the same ancillary reference date as unsupervised classification. After that, the results derived from unsupervised and supervised classifications were integrated to achieve "from-to" land use change maps of three time periods. For this project, the main goal is to explore the spatial-temporal dynamics of land use and landscape pattern in response to rapid urbanization process from 1996 to 2006. A modified version of the Anderson land use/cover classification system with hybrid levels I and II categories was adopted in this study (Anderson et al., 1976; Jensen, 2005). There are five major land use classes of interest and then great efforts and special emphasis are placed on detecting the conversation from no-urban land, especially agricultural land to urban land. In this classification scheme, urban land refers to developed land including low-intensity residential; high-intensity residential; commercial, industrial and transportation land. Total 12 classes were detected and identified in this study and depicted as the following: cropland (Cr); orchard (Or); forest (Fo); water (Wa); urban land (Ur); cropland to urban land (Cr-to-Ur); orchard to urban land (Or-to-Ur); water to urban land (Wa-to-Ur); forest to urban (Fo-to-Ur); cropland to water (Cr-to-Wa); crop to orchard (Cr-to-Or); forest to orchard (Fo-to-Or). Finally, a quantitative accuracy assessment method based on error matrices derived from land use change maps and reference data sets was conducted (Congalton, 1991; Foody, 2002). The related assessment elements include overall accuracy, producer's accuracy, user's accuracy and Kappa coefficient. Previous studies provided the meanings and methods of calculation for these elements (Congalton, 1991; Foody, 2002). A total of 930 reference points were selected to calculate the change detection accuracy in this study. In order to confirm the performance and effectiveness of the proposed PCA-based method as compared with the conventional methods, the commonly used post-classification was also adopted in this study. In post-classification change detection two images from different dates are independently classified and labeled. The area of change is then extracted through the direct comparison of the classification results (Lu et al., 2004; Jensen, 2005).

Although actual "change/non-change" and "from-to" has been identified and extracted, it is necessary to decompose the change detection results to achieve independent land use thematic maps for each date. Hereby, land use change maps were respectively decomposed into two separate thematic images which contained land use class of pre-date and after-date according to a look-up table which can be used to construct the land use conversion matrix (Fig. 2). An important aspect that needs to be noted here is that two land use maps were derived for the same date. For example, decomposing 2003–2006 and 2000–2003 change maps will simultaneously result in 2003 land use map. To address this problem, separate thematic land use maps of the repeating years (2000 and 2003) was determined to be the ones decomposed from the bi-temporal change detection results of 2000–2003 and 2003–2006 which exhibited higher accuracies.

2.4. Derivation of spatial metrics

Different representations of space have led to a variety of spatial metrics for the description of spatial structure and pattern. The basis of these metrics calculations is a thematic map representing a landscape comprising of spatial patches categorized in different patch classes (Herold et al., 2005). Calculations of spatial metrics were performed using the public domain software FRAGSTATS version 3.3 (McGarigal et al., 2002). This public domain program was developed in the mid-1990s and has been continuously improved and widely used in many studies. While FRAGSTATS provides a large number of spatial metrics, a specific subset of them was specifically selected for this study which is described in Table 2.

Table 2
Spatial metrics selected in this study (adopted from McGarigal et al. (2002)).

Metrics	Abbreviation	Description	Unit
Number of patches	NP	Total number of patches in the landscape	None
Patch density	PD	The number of patches of per 100 ha	Number per 100 ha
Edge density	ED	The sum of the lengths of all edge segments in the landscape, divided by the total landscape area, multiplied by 1000	Meters per hectare
Largest patch index	LPI	The proportion of total are occupied by the largest patch of a patch type	Percent
Mean patch size	MPS	The area occupied by a particular patch type divided by the number of patches of that type	Square meter
Landscape shape index	LSI	The total length of edge in the landscape divided by the minimum total length of edge possible	None
Shannon's diversity index	SHDI	Equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion	None
Shannon's evenness index	SHEI	A measurement of patch diversity, which is determined by the distribution of different types of patch in landscape	None

3. Results and discussions

3.1. Land use change detection

Accuracy assessment results indicated that land use changes have been accurately identified and extracted using the PCA-based method during three periods, confirmed by the reasonable and approving overall accuracies and Kappa indices (Table 3). All the overall accuracies clearly exceed the minimum standard of 85 percent stipulated by the USGS classification scheme (Anderson et al., 1976). Furthermore, comparison from Table 3 shows that the PCA-base method even outperformed the post-classification according to the accuracy assessment and confirms its effectiveness for land use change detection.

3.2. Spatio-temporal dynamics and evolution of land use change from 1996 to 2006

Hangzhou has witnessed rapid urbanization which has brought on fundamental land use change during the last 10 years. From land use conversion matrix (Table 4), the area that underwent change was 19720.25 ha. This represents 27.40% of the total land, at an annual rate of 2.74%. The conversions between urban land, cropland and water were the major change types that compromised of 92.38% of the total changes. Accordingly, urban land has altogether increased by 17088.83 ha or 141.14% in area, while cropland has decreased by 16294.47 ha or 48.64% in area. Other obvious changes were the declines in water (2289.72 ha, representing 3.32%) and forest (621.25 ha, representing 4.77%). However, a net increase of 202 ha or 10.05% was found in orchard land. Findings further indicated that cropland and water had the highest figure for land changes and were the major land resources which were encroached by urbanization. The conversion from cropland and water to urban land constituted about 71.06 and 11.61% of the total change, respectively. Of the 17088.83 ha increase in urban land, 82% resulted from cropland and 13.40% from water. As a historical and tourist city, Hangzhou has long retained a high level of economical development which has allowed it to be listed at the top of the most developed regions in China. With the advantage of cultural, historical, geographical and natural conditions and a

Table 3
Accuracy assessment of the proposed method and post-classification.

Time period	Method	Overall accuracy (%)	Kappa coefficient
1996–2000	Proposed method	88.39	0.87
	Post-classification	86.56	0.85
2000–2003	Proposed method	90.43	0.89
	Post-classification	87.10	0.86
2003–2006	Proposed method	92.58	0.92
	Post-classification	90.11	0.89

Table 4
Land use conversion matrix from 1996 to 2006 (in hectares).

1996	2006					1996 Total
	Cropland	Orchard	Forest	Water	Urban land	
Cropland	17205.53	366.17		1914.61	14013.69	33500.00
Orchard		1496.00			514.81	2010.81
Forest		350.64	12408.79		270.61	13030.04
Water				9020.91	2289.72	11310.63
Urban land					12108.09	12108.09
2006 Total	17205.53	2212.81	12408.79	10935.52	29196.92	71959.57

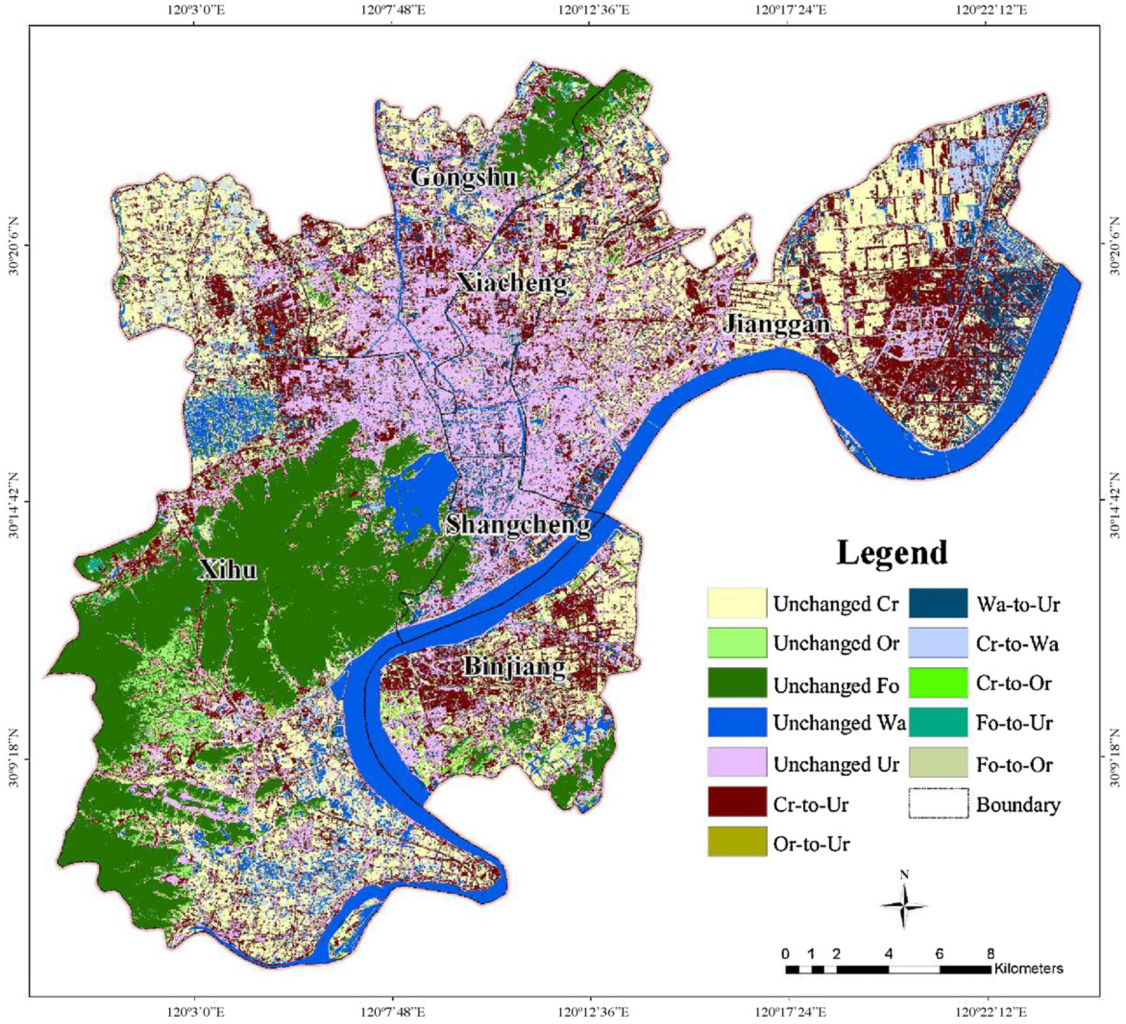

Fig. 3. Spatial occurrence of land use changes, 1996–2006.

Table 5
Measuring land use changes in different administrative districts.

Periods	Indexes	Districts					
		GS	XC	JG	SC	BJ	XH
1996–2006	Area (ha)	1989.19	1427.31	6751.96	551.79	2514.33	6470.65
	Intensity (%)	28.95	29.59	35.54	20.79	34.38	20.73
1996–2000	Area (ha)	891.27	647.47	2978.08	335.78	845.79	2875.24
	Intensity (%)	12.96	13.40	15.67	12.61	11.55	9.21
2000–2003	Area (ha)	777.51	508.80	2702.78	138.71	1115.35	2663.79
	Intensity (%)	11.30	10.53	14.22	5.19	15.24	8.53
2003–2006	Area (ha)	391.24	302.20	1348.26	81.60	583.62	1132.34
	Intensity (%)	5.69	6.25	7.09	3.05	7.97	3.63

GX: Gongsu; XC: Xiangcheng; JG: Jianggan; SC: Shangcheng; BJ: Binjiang; XH: Xihu.

conductive investment environment, the city has attracted a large number of investors and migrants from other parts of the country as well as from overseas (Deng et al., 2008). Concomitant with rapid urban and economic development, a vast number of non-urban lands, especially the cropland which is suitable for urban construction and near the city center or major transport routes have been developed for urban sprawl, such as real estate, the Economic and Technological Development Zone (ETDZ), and the new University or Industry Parks. Surprisingly, the rampant urbanization process also depleted a large number of wetlands, streams and pools in peri-urban area. These dramatic land use changes can have significant impacts on urban ecosystem and environment. Rapid urbanization and exploitation of natural resources have led to substantial alterations of physical environment far beyond city limits, resulting in soil degradation, deforestation, environmental pollution, habitat destruction, biodiversity loss, hydrological alteration and climatic change which have made urban area as a fragile region (Yeh and Li, 1999; Weng, 2001; Allan, 2004; Chen, 2007). In addition, spatial variations in land use changes were also identified among the administrative districts within the city. The areal extent and spatial occurrence of land use changes are clearly showed in Fig. 3. It was further indicated from Table 5 that in percentage terms, the most intensive land change occurred in Jianggan district (35.54% of its administrative area), followed by Binjiang district (34.38%), Xiacheng district (29.59%), Gongshu district (28.95%), Shangcheng district (20.79%) and Xihu district (20.73%). However, in terms of absolute area, the largest land change took place in Jianggan (6751.96 ha) and Xihu (6470.65 ha) districts which accounted for 67.10% of total change over the past 10 years.

Urban development and resultant land use change in Hangzhou went through three periods of time during the 1996–2006. The first period of 1996–2000 experienced remarkable land use changes on a rapid scale. The conversion matrix (Table 6) indicates that 11.91% of the total area (8573.64 ha) experienced changes during the first 4 years. The annual growth rate reached 2.98% which was above the average of 10 years. There was an increase of 6721.97 ha in urban land occupying 78.40% of the total land use change among which 78.49 and 16.88% resulted from cropland and water, respectively. Since the mid-1980s, Hangzhou has made great efforts to provide hospitable economic environment which has resulted in an almost immediate inflow of foreign and domestic investment in manufacturing sector. Consequently, huge tracts of land were leveled and developed to build ETDZ and Industry Parks. At the same time, land reform after 1987 re-introduced land values in China which has gradually created a property market and increased the need of housing construction. Moreover, the administrative adjustment implemented in 1996 when six surrounding towns were merged into Hangzhou city proper by force further promoted a dramatic land use change, especially urban growth. The increase in administrative area relieved pressure of the limited land resource for urban expansion. Unfortunately, these newly merged lands were quickly depleted by the urbanization process. With respect to spatial pattern (Fig. 4 and Table 5), Jianggan (2978.08 ha) and Xihu (2875.24 ha) districts held the biggest change dimensions which all together accounted for about 68.30% of the total changes. They were followed by Gongshu (891.27 ha) and Binjiang (845.79 ha). The most intensive land use change in percentage took place in Jianggan (15.67%), followed by Xiacheng (13.40%), Gongshu (12.96%), Binjiang (11.55%) and Shangcheng (9.21%) districts.

In the second period of 2000–2003, conspicuous land use changes took place at a larger scale than before. The conversion matrix (Table 7) showed that 10.99% (7906.91 ha) of the land underwent changes spanning 3 years with an annual growth rate of 3.66%, which is far more than the 10 years average. A total of 6890.34 ha of land was converted into urban land accounting for about 87.14% of the total land change with almost all resulted from cropland (93.69%). The GDP of Hangzhou in 2003 was RMB 209.977 billion, which was a 15.2% increase over the previous year. Under the background of rapid economic development and urbanization, a vast number of lands were urgently needed to extend the area of ETDZ and Industry Parks. In addition, the property boom and land speculation greatly contributed to the proliferation of land change during this phase. As for the spatial occurrence of land use changes, it can be deduced from Table 5 that in absolute land areas, the largest land use change occurred in Jianggan (2702.78 ha), Xihu (2663.79 ha) and Binjiang (1115.35 ha) districts that made up of almost 82% of the total change. They were followed by Gongshu (777.51 ha), Xiacheng (508.80 ha) and Shangcheng (138.71 ha) districts. However, in terms of percentage growth, the greatest land use changes occurred in Binjiang district (15.24%), followed by Jianggan (14.22%), Gongshu (11.30%), Xiacheng (10.53), Xihu (8.53%) and Shangcheng (5.19%) districts (Fig. 5 and Table 5). Under the planning strategy of Development Over Qiantang River initiated by the Hangzhou government in 2000, Binjiang district had become the main focus for investment and construction which led to the most intensive land use change with a significant increase from 9.86% (1996–2000) to 15.24% (2000–2003).

In the third period of 2003–2006, the scale of land use change significantly decreased compared to that of the first two periods. It was found from the conversion matrix (Table 8) that 3839.23 ha or 5.43% of the total land experienced change, only about half of that in 2000–2003 period. Up to 2003, Hangzhou had a total of 16480.55 ha (22.9%) of land change and an urban growth of 13612.31 ha (112.42%). The figure was much greater than what was prescribed by the official ‘Development Planning for 1996–2006’. Restrained by the strict implementation of the ‘Ordinance for the Protection of Primary Agricultural Land’ constituted by State Council and the National Macro-control Policy, land resources for further urban expansion was significantly limited. Although sudden diminishment was identified in the change scale, the pace of rapid urbanization does not show any sign of ceasing. There is still an increment in urban land which mainly resulted from cropland (51.16%) and water (40.49%). Spatially speaking, Jianggan (1348.26 ha) and Xihu (1132.34 ha) districts had, all the same, the largest land change, followed by Binjiang district (583.63 ha), composing of altogether 79.83% of the total change (Fig. 6 and Table 5). However, Binjiang (7.97%) and Jianggan (7.09%) districts still hold the greatest changes where intensive land use change will continue for a long time in the future along with the new urban centers under construction. Other districts, however, experienced decreasing rate of change after the peak during 2000–2003 period mostly due to the significant limitations imposed on the supply of land. Hence, along with the rapid economic development and urbanization, a reasonable utilization and effective protection of land resource have become a great challenge confronting the urban planning and decision-making departments.

It is noteworthy that land use change types such as cropland-to-orchard and cropland-to-water identified in this study were most significantly related to the agricultural restructuring policy and market promotion. This was carried out because of better economic values from breeding aquatics and planting seeding tree compared to that of grain. In fact, these kinds of changes were also, to some extent, stimulated by the rapid urbanization process. Further more, some inter-change types throughout the three phases, such as cropland–water–urban and cropland–orchard–urban, were also detected and mapped in this study, which can explain why the accumulative total change area (20319.78 ha) of three individual periods was slightly greater than the figure (19720.25 ha) from entire period of 1996–2006. This suggests that change detection using multi-temporal data can lead to more detailed land use dynamic information and even inter-transition than the traditional bi-temporal data does.

Table 6
Land use conversion matrix from 1996 to 2000 (in hectares).

1996	2000					1996 Total
	Cropland	Orchard	Forest	Water	Urban Land	
Cropland	26819.05	76.87		1328.17	5275.91	33500.00
Orchard		1699.67			311.14	2010.81
Forest		446.63	12583.41			13030.04
Water				10175.71	1134.92	11310.63
Urban land					12108.09	12108.09
2000 Total	26819.05	2223.17	12583.41	11503.88	18830.06	71959.57

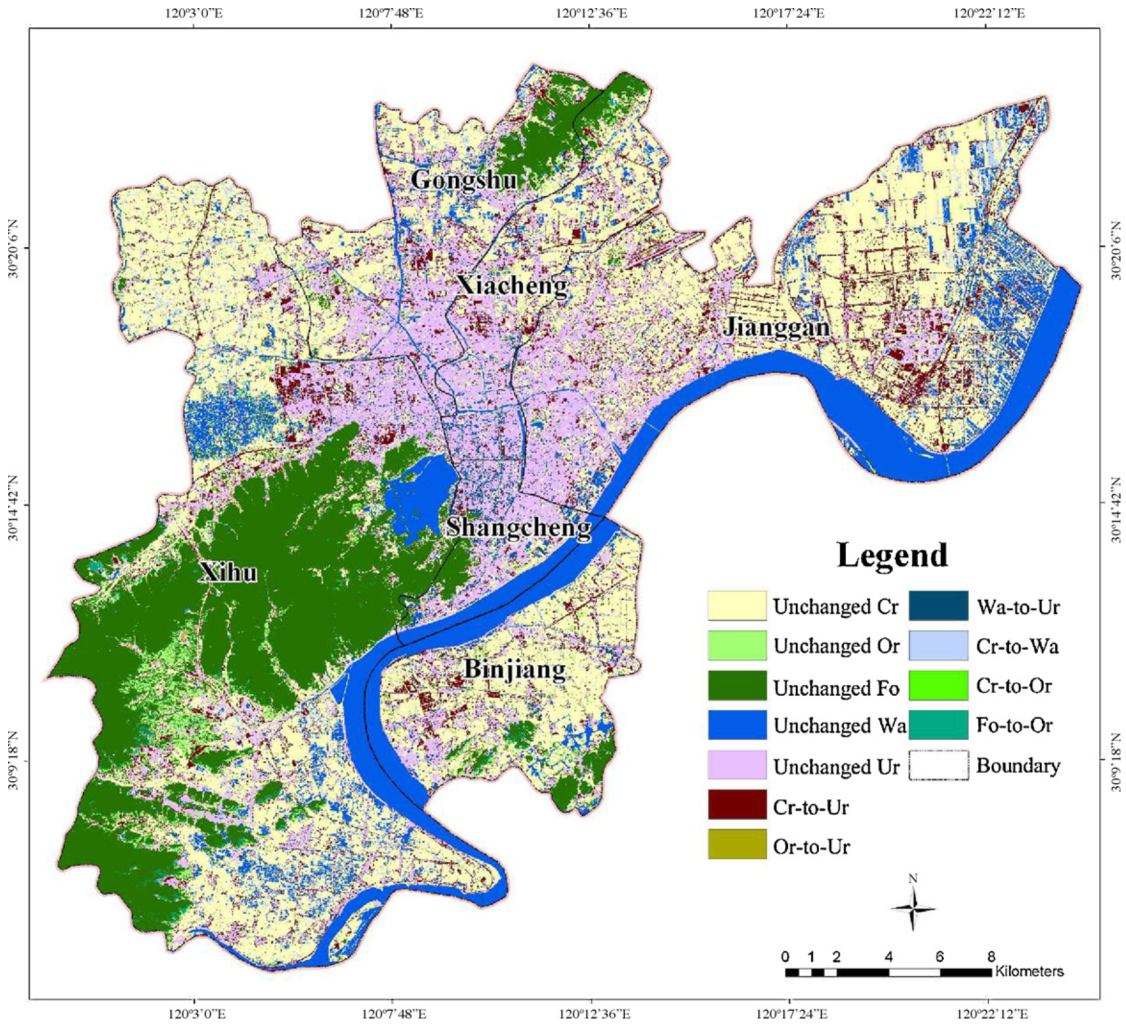

Fig. 4. Spatial occurrence of land use changes, 1996–2000.

Table 7
Land use conversion matrix from 2000 to 2003 (in hectares).

2000	2003					2000 Total
	Cropland	Orchard	Forest	Water	Urban Land	
Cropland	19347.00	314.34		702.23	6455.48	26819.05
Orchard		2064.49			158.68	2223.17
Forest			12532.83		50.58	12583.41
Water				11278.28	225.60	11503.88
Urban Land					18830.06	18830.06
2003 Total	19347.00	2378.83	12532.83	11980.51	25720.40	71959.57

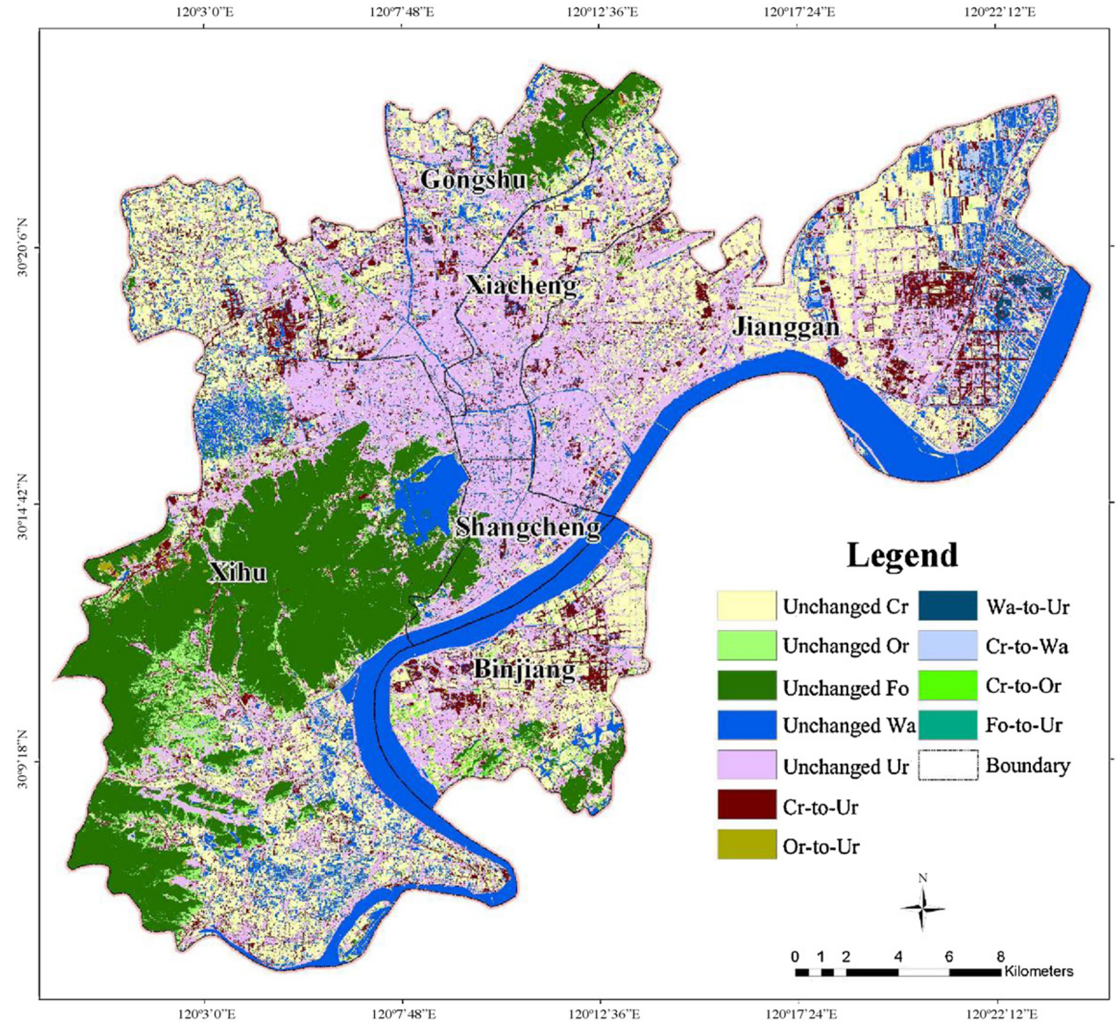

Fig. 5. Spatial occurrence of land use changes, 2000–2003.

3.3. Landscape pattern analysis in response to rapid urbanization process

The dramatic land use change stimulated by rapid urbanization in Hangzhou had resulted in fundamental change of landscape pattern. The agricultural-land-use dominant landscape was gradually converted into urban-land-use dominant landscape. It can be seen from Fig. 7 that the percentage area of cropland landscape decreased greatly from 46.55 to 23.91% of the total and, on the contrast, the percentage of urban landscape increased sharply from 16.83 to 40.57% during the same time period. From 1996 to 2003, the diversity metric increased constantly indicating that the landscape composition became more even and land use types were more equally distributed. This trend was confirmed by the increase in the evenness index (Fig. 8). Although the total number of land use types remained constant, their respective proportion and spatial composition were, however, changing throughout the study periods. Along with rapid urbanization, the predominant agricultural landscape was progressively substituted by an urban landscape, creating a more heterogeneous and complicated landscape as evidenced by the increase of SHDI and LSI indexes. While, the landscape exhibited an even composition indicated by the increase of SHEI index in which land use types were more equally distributed. The results are consistent with the conclusion that in urban areas, the proportion of different land use types is more even than in rural landscapes (Weng, 2007). In contrast, the subsequent slight decline in Shannon's diversity index (SHDI) and Shannon's evenness index (SHEI) between 2003 and 2006 reflected the fact that the continual

Table 8
Land use conversion matrix from 2003 to 2006 (in hectares).

2003	2006					2003 Total
	Cropland	Orchard	Forest	Water	Urban Land	
Cropland	17205.53			362.71	1778.76	19347.00
Orchard		2212.81			166.02	2378.83
Forest			12408.79		124.04	12532.83
Water				10572.81	1407.70	11980.51
Urban land					25720.40	25720.40
2006 Total	17205.53	2212.81	12408.79	10935.52	29196.92	71959.57

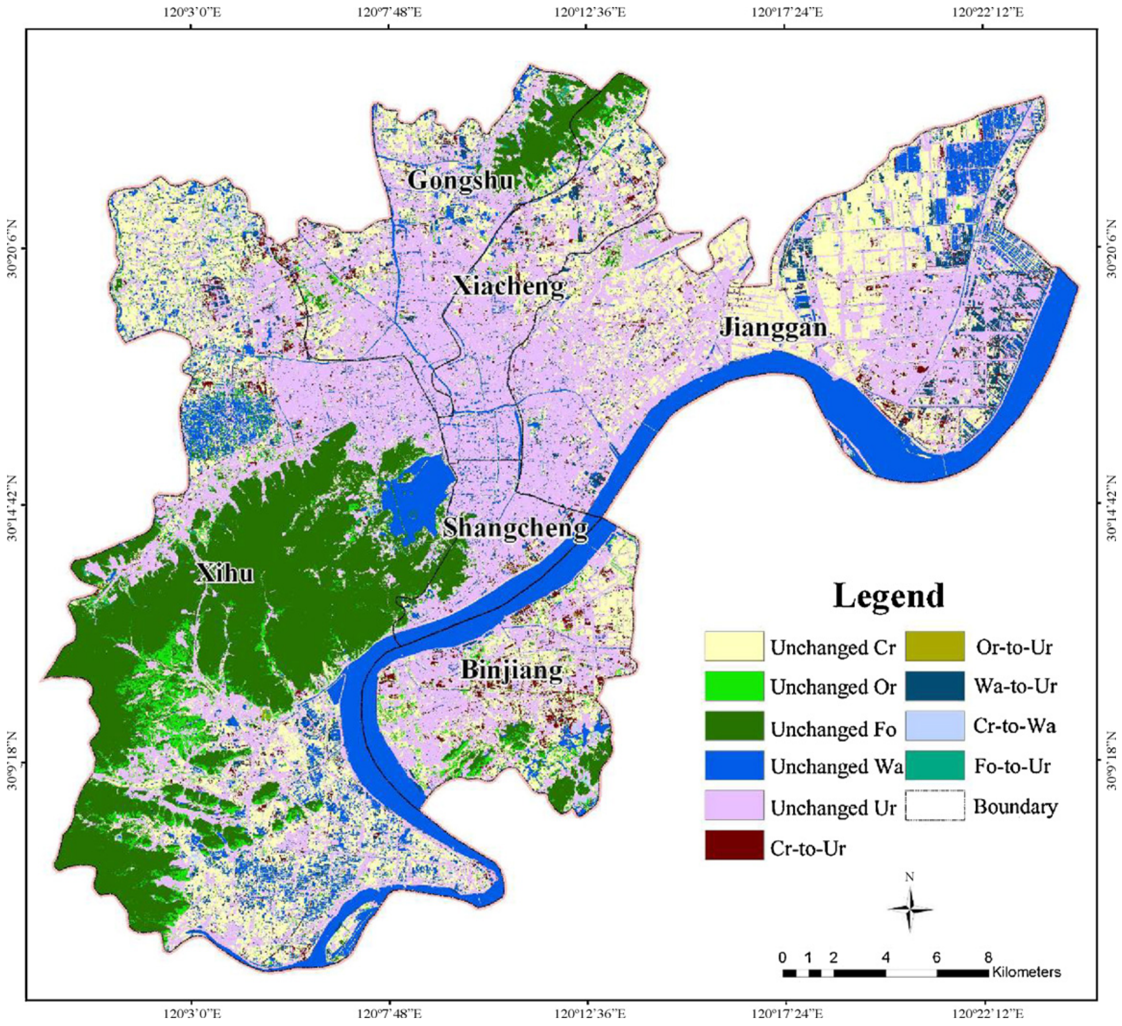

Fig. 6. Spatial occurrence of land use changes, 2003–2006.

increase in urban land use curtailed the heterogeneity and made landscape uneven again.

In 1996 Hangzhou comprised of a rural landscape with minor, but increasing urban land development. The massive construction of ETDZ and Industry Park had initially formed a dispersed landscape pattern which was indicated by the peak values of patch number and patch density in 1996. Driven by the 'Urban Planning for 1996–2010' and administrative re-adjustment for city boundaries constituted by the local government, Hangzhou witnessed a rapid urban sprawl and land use change at an unprecedented speed. The significant decreases in number of patches (NP) and patch density (PD) up to 2003 exhibited compact sprawl and "dense-onion" urban development pattern which were attributable to the considerable reconstruction of historical urban central area and peri-urbanization process (Fig. 8). The "dense-onion" model describes the growth of cities as successive allocation of new layer development around existing urban centers (Herold et al., 2003). Most of land development was focused on the regions between the sprawled and fragmented urban areas, where large numbers of cropland and water were encroached into urban land to form compact patches. Subsequently, the areas of diffuse sprawl were connected to urban development cores. This trend was confirmed by the continual increase of largest patch index and mean patch size through the time period (Fig. 8).

After the rush of land development during the time periods between 1996–2000 and 2000–2003, intensive urban sprawl slowed down significantly as evidently indicated by the abrupt drops in the rate and amount of changed land use between 2003 and 2006, due to improved management and planning activities. Whereas, urban growth was still on the rise and initially exhibited a diffuse pattern. The allocation of urban land included both the development of new individual urban unites, as reflected by the slightly increases in NP and PD, and the sprawl of the historical urban development cores, as indicated by the constantly increasing largest patch index (LPI). Furthermore, over the time period 1996–2000, the edge density (ED) and landscape shape index (LSI)

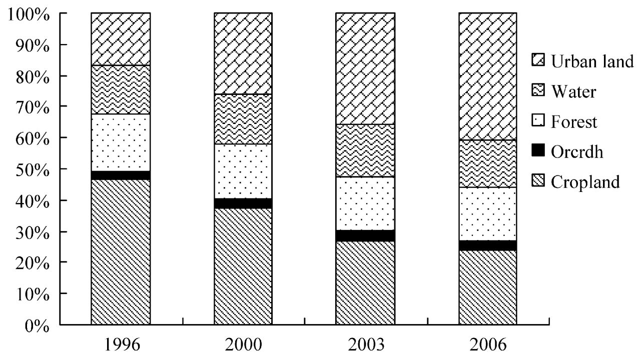

Fig. 7. Dynamics of land use pattern, 1996–2006.

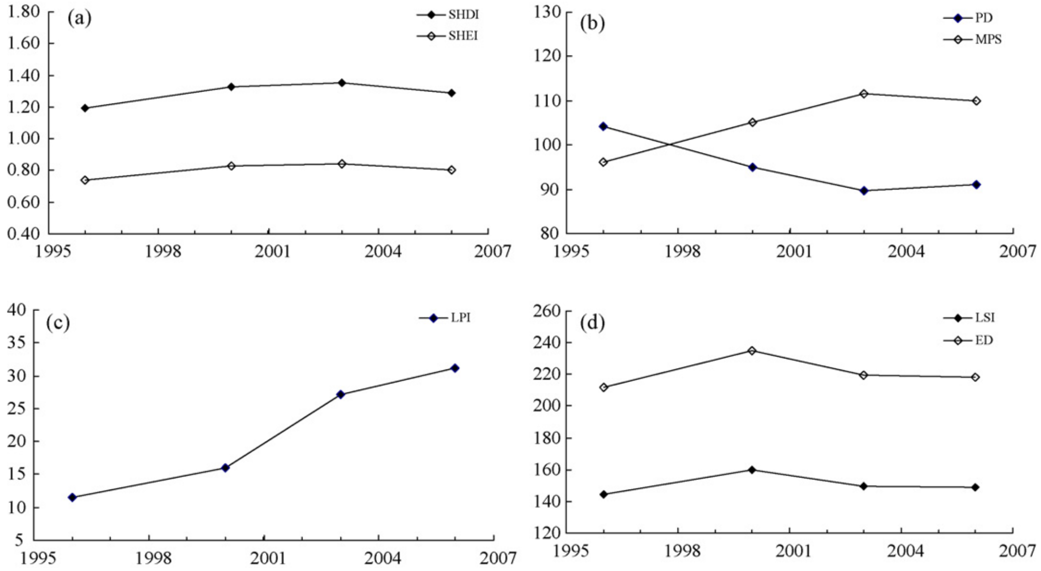

Fig. 8. Changes in spatial metrics selected in this study.

increased acutely and reached their peak values in 2000, when there was an abrupt drop in NP and PD (Fig. 8). This can be explained by the fact that the development cores grew together to form larger but more complicated patches and, in the meantime, the most significant land use changes during the period 1996–2000 also produced many smaller and fragmented patches, especially cropland patches. Concomitant with rapid urbanization process, space in between the individual and fragmented patches was further urbanized and enveloped on each other while NP and PD metrics gradually declined until 2006 (Fig. 8).

4. Conclusion

Understanding the urban growth and change brought on by urbanization is critical to those who study urban dynamics and manage land resources and provide services in these rapidly changing environments (Yang and Lo, 2002). Due to widespread availability, frequency of coverage and improved quality, remote sensing has become the major source extensively used in monitoring land use change and urban expansion. Finer spatial resolution of image has been deemed as the single most important issue in urban remote sensing analysis. Critical in the descriptive analysis of urban structure and its changes are the spatial metrics adopted from landscape ecology that can be used objectively to quantify the structure and pattern of an urban environment from thematic maps (Herold et al., 2005).

This study integrated remote sensing and spatial metrics to analyze the spatio-temporal dynamics and evolution of land use change and landscape pattern as a result of rapid urbanization process in the past 10 years. This process has brought about conspicuous land use changes and urban growth at an unprecedented scale and rate, and consequently given rise to substantial impacts on the landscape pattern. A total of 19720.25 ha or 27.40% of the total land has undergone change, of which 88.66% occurred in the transformation from no-urban to urban land. The results also revealed that cropland and water were the major resources that were converted for urban development. Most of the converted lands were developed for the real estate, ETDZ, and new University or Industry Parks. Rapid urbanization and exploitation of natural resources will exert significant impacts on urban ecosystem and environment. Spatially, it was indicated that most of land use changes occurred in Jianggan and Xihu districts which attributed to 67.10% of the total change. The land use pattern underwent fundamental transition from agricultural-land-use dominant landscape to urban-land-use dominant landscape. Temporally, rapid urbanization and notable land use change dynamics in Hangzhou went through three periods, 1996–2000, 2000–2003 and 2003–2006. The fist two periods witnessed remarkable land use change at a stepped-up rate until it reached 13612.31 ha or 112.42% in urban land conversion from 1996 to 2003. In the meantime, the landscape comprised a more heterogeneous and complex, but even composition suggesting land use types were more equally distributed. Urban development exhibited a compact sprawl and “dense-onion” pattern through this time period. After the development peak in 2003, land use change and urban growth were constrained by stricter planning and management efforts. In the following 2003–2006 period, only 3839.23 ha or 5.43% of the total land experienced changes, about half of that from 2000 to 2003. Although there was a steep decline in the rate of urbanization, additional 3476.52 ha were converted in the following period from 2003 to 2006. In spite of the strict land planning and management policies, urbanization and land development continues. Although there was a steep decline in the rate of urbanization, additional 3476.52 ha were converted in the following period from 2003 to 2006.

This study also highlighted some important issues associated with the use of remote sensing and spatial metrics. The selection or development of suitable methodology and utilization of satellite data with finer spatial resolution remains an attractive and promising orientation in urban application of remote sensing. Because the absolute values of spatial metrics are dependent on imagery spatial resolution, extent of the study area, and level of detail in landscape classification, any change in these factors may affect the metrics and therefore interpretation of results from different urban regions (Herold et al., 2003). Future analysis may be focusing on a smaller landscape scale (administrative district) and test on a class-level to further improve understanding of the variation in intra-urban and different land use types.

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