URBAN EXPANSION IN A DEVELOPED COASTAL REGION, CHINA

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ABSTRACT

With rapid urban expansion and modernization, sustainable land use on limited land resources has become a critical issue for local environment and socioeconomic development. The objectives of this study were to quantify urban or built-up changes and to attempt to identify socioeconomic drivers. Landsat TM/ETM+ images taken in 1985, 1993 and 2001 were used to map land use/cover changes. A stratified unsupervised classification technique was implemented in conjunction with visual interpretation. Using a modified Anderson's I/II/III-level classification scheme, an overall classification accuracy of 90% in level I was achieved. Dramatic increase in urban or built-up areas has quadrupled from 1985 to 2001. Over 90% of this newly expanded built-up area was originally paddy fields or other croplands. Socioeconomic factors, such as gross domestic product, urban population, and financial expenditure, were all highly correlated with the expansion of the urban or built-up areas. Based on the degree of urban sprawl and socioeconomic factors, cities and towns were further divided into six subgroups, which may help decision makers improve land uses for the region.
Keywords*:* Coastal region; Urban expansion; Driving factors

INTRODUCTION

In recent years, both LUCC and IGU-LUCC highlighted the significance of case studies of land use/cover changes to understand the pattern and process. China, as one of the fastest growing and developing countries, has been experiencing a rapid urban growth over the last several decades, especially since the implementation of the economic reform and opening-up policy in 1978 (Longley, 2002). This dramatic change in land use is typical and representative in East Asia and therefore a study on the driving forces of urban expansion could have global implications.

The use of satellite remote sensing has proven to be a good technique for detecting and monitoring urban sprowl land use transformation. There have been many land use change studies using TM (Lorenzo-Garcia and Hoffer, 1993; Stefanov et al., 2001) and ETM+ (Vogelmann et al., 2001) images. At a regional scale, many studies produced results promising enough to use Landsat data for mapping land use (Wilkie and Finn, 1996; Reese et al., 2002; Wu et al., 2001). The relatively high spatial resolution and regular revisit time by the Landsat satellites result in high-quality data that have many advantages in urban expansion detection.

Many coastal regions in China are confronted with pressing problems of scarce land resources and increasing population (Shi et al., 2002). The coastal region exploration strategy in China, first started in the 1980s, promoted urban expansion in the coastal cities, which has attracted many international experts (Heilig, 1997; Verburg et al., 1999; Hubacek and Sun, 2001). For example, urban land expansion and arable land loss in Pearl River Delta and Beijing-Tianjin-Hebei region were studied by Yeh and Li (1999), Weng (2002) and Tan et al. (2005), respectively. As one of the three most important economically developed areas along the coastal region in China, Yangtze River Delta experienced quite different forms of economic development and urban expansion patterns than did the rest of the country, but, little attention was paid to land use change dynamics in towns within the Yangtze River Delta region. Due to industrialization and the relaxation of regional land use policies, the Yangtze River Delta has had the highest economic development rate among these three regions in the past twenty years. Furthermore, this rapid and unrestricted urban expansion has resulted in the loss of valuable but scarce lands, such as the three-rotation paddy fields. Therefore, understanding urban expansion and their drivers in this Yangtze River Delta region is imperative for developing policies that generate sustainable growth.

Multi-temporal Landsat images of the Zhejiang coastal region, about half the size of the Yangtze River Delta, were used to quantify land use changes within this region, which were analyzed with socioeconomic and demographic data with an attempt to identify major driving factors. The specific objective of this study is to detect urban sprawl and identify driving forces, with the goal of providing improved understanding of land use patterns and processes of the region for sustainable land use and economic development.

STUDY AREA

The study area is located within the Yangtze River Delta near the southeast coast of China. To its north is Shanghai, the biggest city in China. It lies between 27°12'～31°30' N and 119°42'～122°06' E and covers 3,409,500 ha. With a subtropical monsoon marine climate, the area has plenty of rainfall. Average annual temperature is above 18°C while the mean precipitation is between 1000 and 2000mm with an average relative humidity of 88%.

Since the adoption of the economic reform and open door policy in 1978, Zhejiang has become one of the provinces experiencing the highest growth rates in economy, with a 13.1% average annual gross domestic product (GDP) increase. Twenty six (26) towns (Table 1) in this coastal region are the most developed areas within the province, and they occupy 30% of the entire lands in Zhejiang province. Its population is 26.65 million, more than half of the provincial total population. The GDP, RMB 612.1 billion is about 79% of the total with a GDP per capita of RMB 22,964, about 1.4 times of the province (16,838). According to Statistical Yearbook of Zhejiang (2004), the area of cropland per capita in Zhejiang in 2003 was 0.0347 ha.，1/3 of the China's average (0.095 ha.), 1/6 of the world's average value. Hence, it is of great significance to understand the urban sprawl dynamics and the driving forces in this highly populated and well developed coastal region.

Table 1. Names and abbreviations of counties/cities in the study region

name	ab.	Name	ab.	Name	ab.	name	ab.
cangnanxian	CN	Jiaojiangshi	JJ	Sanmengxian	SM	yinxian	YX
cixishi	CX	Linhaishi	LH	Shangyushi	SY	yongjiaxian	YJ
fenghuashi	FH	Ningboshi	NB	Shaoxingshi	SXS	yueqingshi	YQ
hainingshi	HN	ninghaixian	NH	Shaoxinxian	SXX	yuhuanxian	YH
haiyanxian	HAY	pinghushi	PH	Wenlingshi	WL	yuyaoshi	YY
hangzhoushi	HZ	pingyangxian	PY	Wenzhoushi	WZ		
huangyanxian	HY	ruianshi	RA	Xiangshanxian	XS		

METHODS

Satellite Data and Preprocessing

Four Landsat TM/ETM+ scenes were needed to cover the entire study area, and three time periods (1985, 1993, and 2001) with an 8-year interval (Table 2) were available for the land use change analysis. There were few clear days in the study area because of the monsoon climate nature of the region, which makes it difficult to obtain clouds-free images within the same year. For the lack of cloud-free data in 1985 and 1993, images from 1986 and 1994 were used to substitute them respectively.

Each TM/ETM+ scene was geo-referenced to the Universal Transverse Mercator Zone 51 North coordinate system. The longitude of the central meridian is 123^{o}E. The ancillary datasets were also geo-referenced to the same coordinate system. Each image was calibrated by the Dark Set-Bright Set Normalization method (Yuan and Elvidge, 1996). Compared with other atmospheric correction methods, this one was deemed able to better build up NDVI and enhance the spectral properties. These images were further geometrically corrected using a 1:50000 scale topographic map to less than 1/2 pixel root mean square error (RMSE), and were then resampled to 30-m pixels using the cubic convolution method.

Table 2. Landsat TM/ETM+ images used in the study*

Path/Row	Date 1	Date 2	Date 3
118/039	November 20, 1985	March 31, 1993	March 13, 2001
118/040	November 20, 1985	March 31, 1993	March 13, 2001
118/041	January 7, 1986	March 31, 1993	March 13, 2001
119/039	November 11, 1985	June 29, 1994	March 3, 2001

* The images for both Date 1 and Date 2 were from TM while for Date 3 were by ETM+ sensor.

Image Classification

Anderson's classification system (Anderson et al., 1976) was employed in this study. The level III, agriculture category, was adjusted according to the characteristics of the study area. Paddy fields and other croplands are the two most common cropland types in the area, so they were categorized up to the third level. Paddy fields refer to the fields used for rice or lotus production, which requires water submergence during the growing season. Other cropland was also called "other croplands" in this study, where non-hydrophytes such as cotton, wheat, potato, and melon, etc. are grown. In addition, dry lakebeds and beaches at estuary were difficult to separate spectrally and therefore they were grouped into a single barren land category (Table 3).

Table 3. A modified land use classification scheme

Level	Level	Level
100 Urban or built-up		
200 Agriculture	210 Cropland	211 Paddy field
		212 Other croplands
	220 Orchards, tea garden	
400 Forest land	410 Evergreen forest	
	430 Mixed forest	
500 Water		
700 Barren land	710 Dry lake beds or beaches	
	730 Sand and gravel other than beaches	

Erdas Imagine and ArcGIS software were used in image classification. As we know, the same processing method will produce different levels of classification accuracy when used on images of different regions or on images of the same region that were acquired at different times (Johnson and Kasischke, 1998). In recent LULC studies, substantial efforts have been made to improve classification methods, including hybrid classification (Benediksson et al., 1997; Steele, 2000). In this study, unsupervised classification and visual interpretation were used to achieve a better Anderson's III-level classification.

First, the 2001 Landsat images were classified using a unsupervised classification (Maximum Likelyhood method) into 255 classes and then these classes were merged into nine final classes (Table 2). Classification accuracy was assessed using reference data for 512 randomly selected points by confirming land use classification results with ground detection. Due to many changes that have occurred since 1985, the land use in these three phases were resurveyed by asking native farmers or officers concerned.

The 1985 and 1993 images were fused into a single twelve-band image. The image was divided according to nine land uses in 2001, then the nine images were classified using the same method into 100 classes, and then these classes were merged into nine final classes.

Accuracy Assessment

Error matrices were generated separately for land use maps in three different years. The overall accuracy of the land use classification at Anderson Level I is above 90%, which at Level II or Level III nearly reaches 85% (Table 4). Clearly, these data met the minimum standard of 85% stipulated by the USGS classification scheme (Anderson et al., 1976，Lucas et al., 1994). In these categories, urban or built-up and forest have the highest classification accuracies. It is difficult to distinguish paddy field from other croplands in remote sensing images because different crops and planting systems produce similar photogrammatic imagery. Due to their overlapping locations and similar reflection spectrum, orchards and tea gardens have relatively lower classification accuracy. It is also easy to confuse beaches and sand and gravel because of their high reflection rate. For the past 20 years, the main trend of land use change in the study area has been the conversion of other land use into urban or built-up. Consequently, change of urban or built-up and their driving factors are the focus in the present study. Meanwhile, a satisfied classification accuracy for urban or built-up is sufficient for analysis of their change.

Table 4. Accuracy assessment of Anderson level I and level II, III

	Level I	Producers Accuracy	Users Accuracy	Level II or III	Producers Accuracy	Users Accuracy
	100	90.38%	88.68%			
	200	89.02%	88.51%	211	80.21%	87.50%
				212	80.00%	78.43%
				220	77.78%	60.00%
1985	400	92.35%	93.89%	410	92.98%	89.83%
				430	81.16%	90.32%
	500	78.00%	88.64%			
	700	92.59%	81.97%	710	85.19%	74.19%
				730	85.19%	76.67%
	Totals	89.65%			84.38%	
	100	88.89%	90.57%			
	200	93.41%	89.66%	211	86.81%	89.77%
				212	91.30%	82.35%
				220	83.33%	71.43%
1993	400	91.94%	95.00%	410	85.83%	87.29%
				430	77.27%	82.26%
	500	86.96%	90.91%			
	700	91.53%	88.52%	710	78.13%	80.65%
				730	81.48%	73.33%
	Totals	91.60%			84.96%	
	100	92.31%	90.57%			
	200	89.41%	87.36%	211	90.00%	92.05%
				212	93.18%	80.39%
				220	72.22%	74.29%
2001	400	92.78%	92.78%	410	86.84%	83.90%
				430	81.82%	87.10%
	500	83.33%	90.91%			
	700	90.32%	91.80%	710	78.79%	83.87%
				730	72.41%	70.00%
	Totals	90.43%			85.16%	

RESULTS

The Sources and Distribution of Urban Sprawl

The land use and urban extension of Zhejiang coastal area in 1985, 1993 and 2001 were mapped (Figure1, Figure 2 and Figure 3). The great majority of new urban or built-up lands originated from cropland, beaches, water and forest. A total of 196,783 ha cropland was transferred into urban or built-up from 1985 to 2001, which occupy 6.34% of the entire study area, and is 15.24% of the whole cropland in 1985, or 67.39% of the total urban or built-up in 2001. Furthermore, because of a strong spatial dependency on land use changes, a high proportion of land use conversion from cropland into new urban land occurred near urban areas. A similar result was reported by Li and Yeh (2004) about land use change in the Pearl River Delta of South China. These change dynamics can be explained in three aspects. Firstly, city expansion and rural urbanization cause the loss of cropland in the suburbs. Secondly, thriving town and village-township enterprises occupy a large amount of cropland in rural areas. Thirdly, the state infrastructure, such as airports, ports and highways now occupy certain amounts of former cropland.

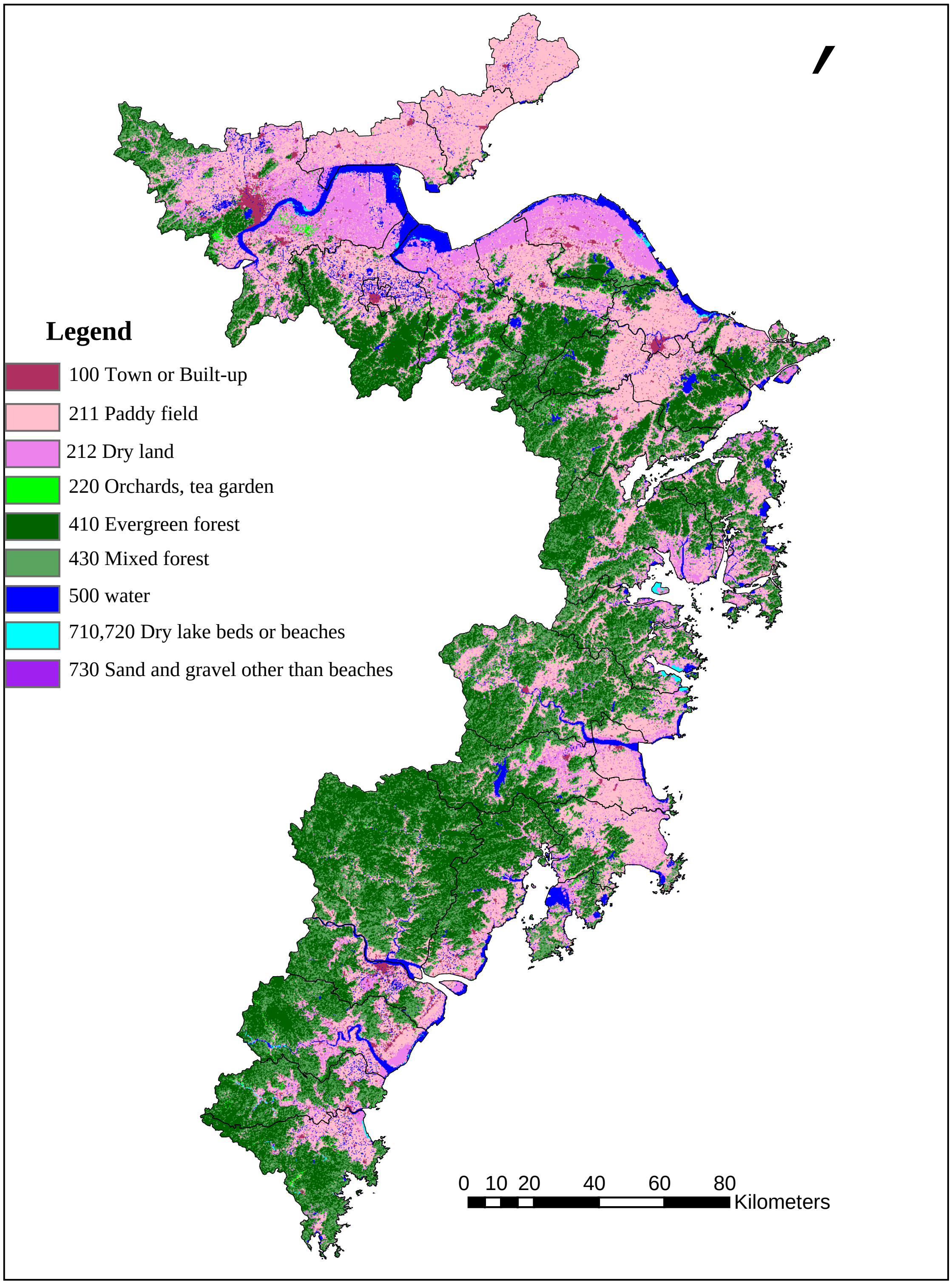

Figure 1. Land use map of Zhejiang province coastal region in 1985

During the study period, 7,858 ha of forest (0.51% of the total area of forest in the study area in 1985) was transferred into urban or built-up from 1985 to 2001 because of mining, and construction of reservoir dams, ports and airports. Otherwise, 5,505 ha of water (3.46% of the total area of water in the study area in 1985) and 1,123 ha of beaches (15.07% of the total area of beaches in the study area in 1985) were converted into urban or built-up land. The change process has mainly taken place after 1993. It is ascribed to many reclamation projects, which enclosed the water body along river banks and beaches to form ponds, which were further reclaimed into paddy field and other croplands, and finally transferred into urban or built-up land. For example, the expansion of Beilun port in NB (planned to be built as the largest port in China) covers a large area of enclosed water and beach land, and also occupies a certain amount of agriculture and forest land.

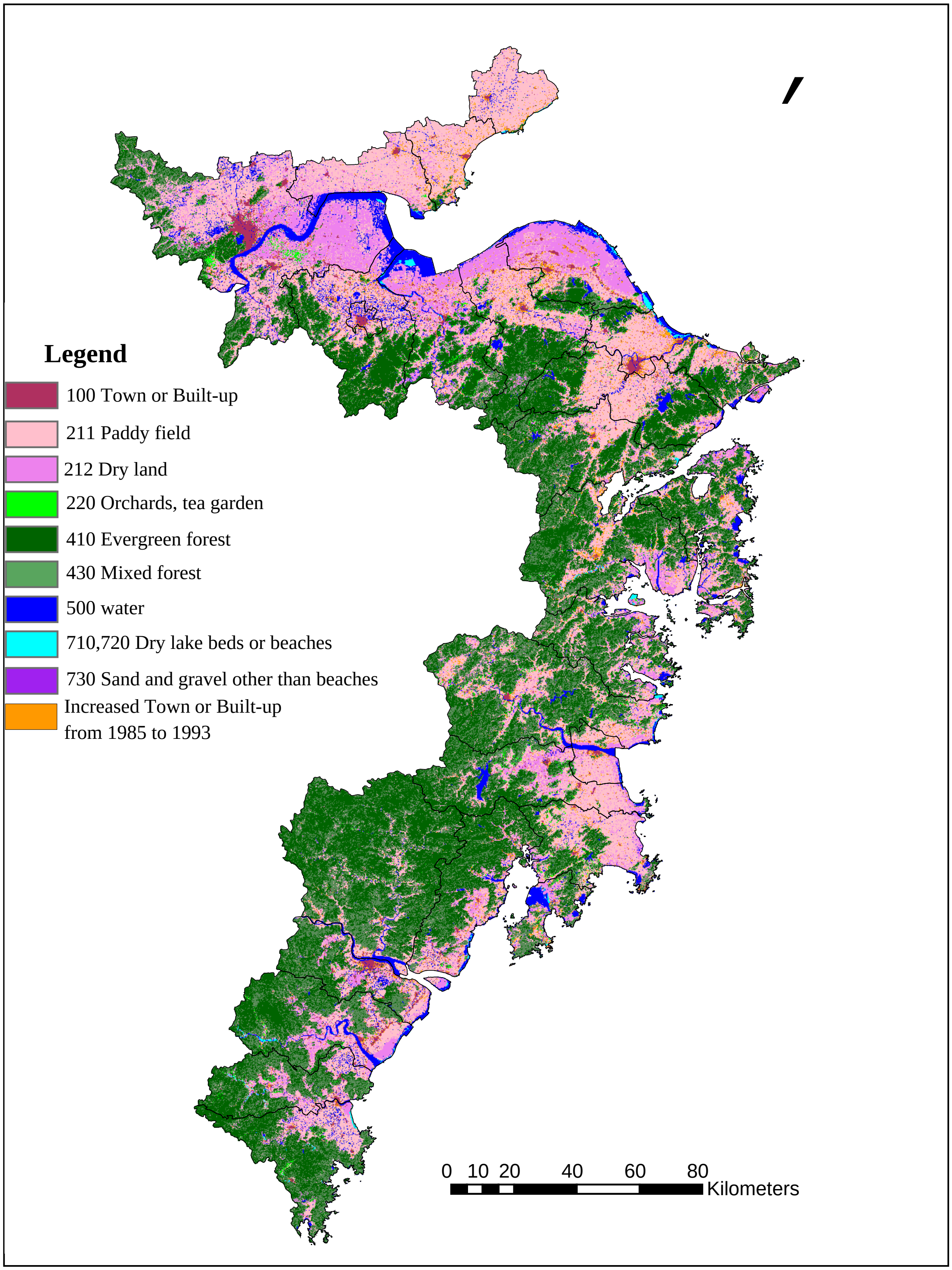

Figure 2. Land use map of Zhejiang province coastal region in 1993.

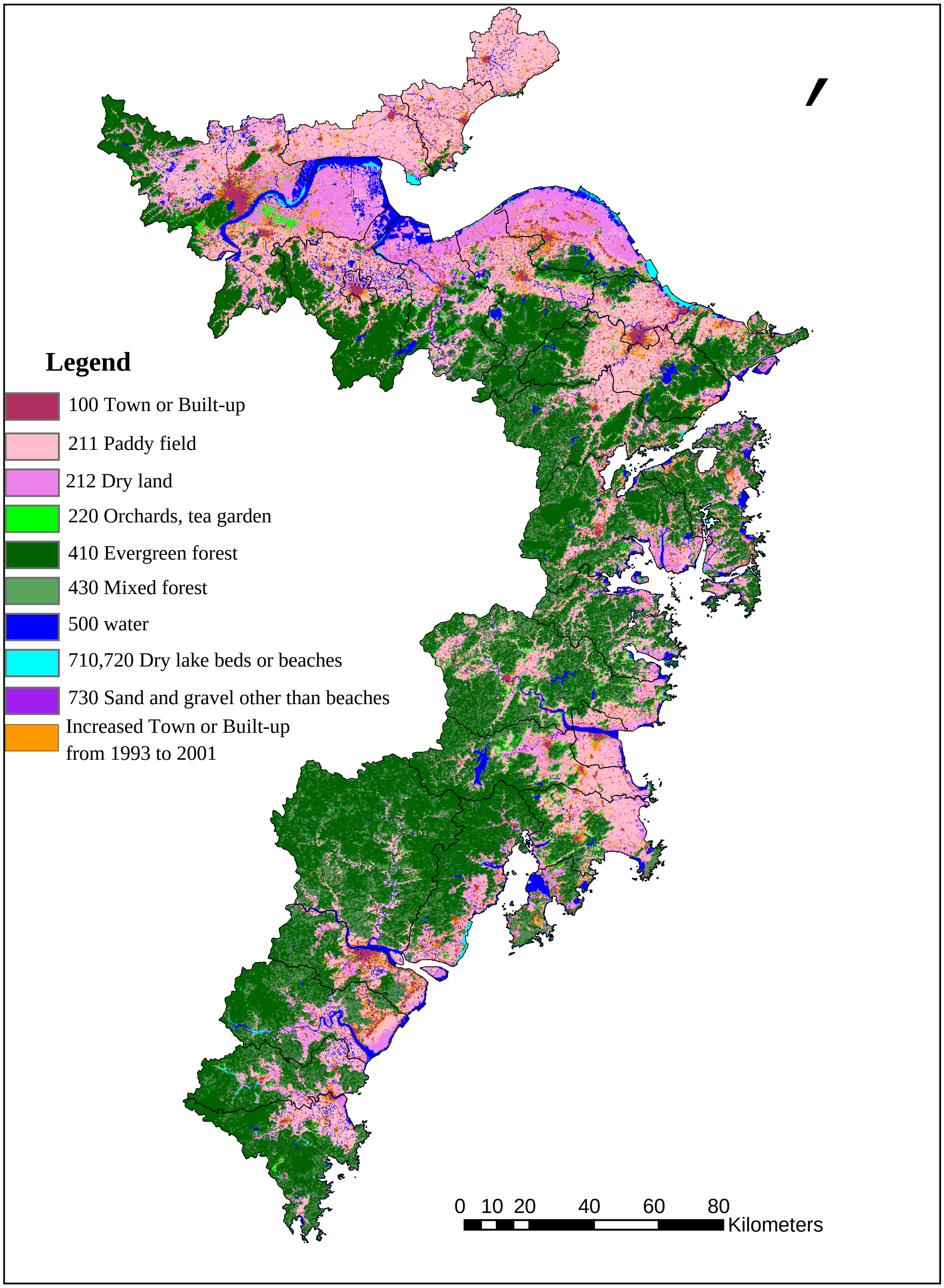

Figure 2. Land use map of Zhejiang province coastal region in 1993.

In the past 20 years, the economy in this area developed rapidly so the urban or built-up radically changes.

However, because of their different biophysical characteristics and socioeconomic conditions, these towns have different urban expansion modes (Figure 4). HZ has the most dramatic extension, but SXS has the least.

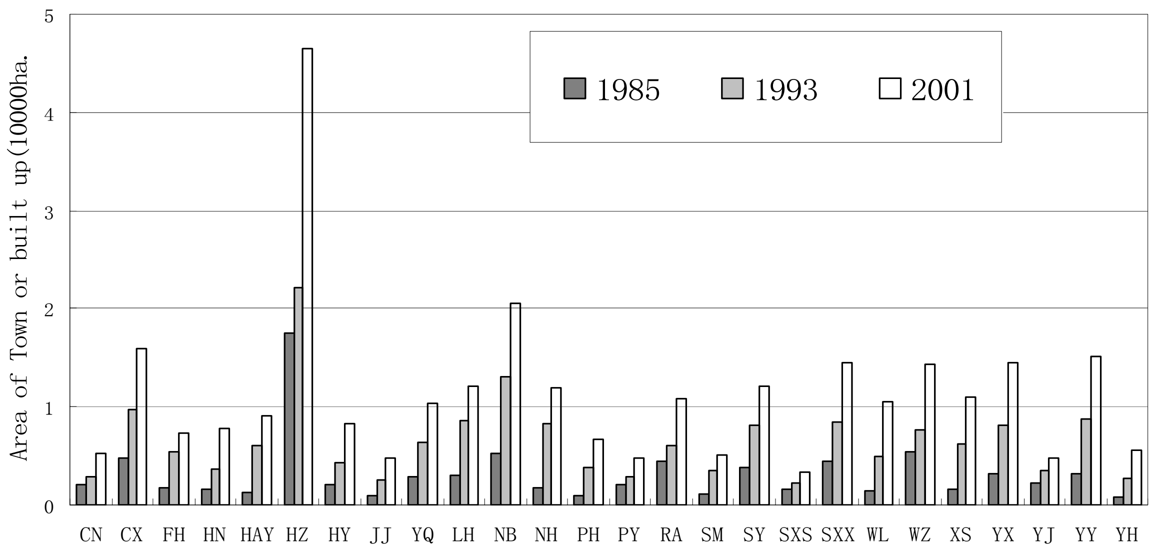

Figure 4. Urban or built-up areas of 26 towns in 1985, 1993 and 2001

The Speed of Urban or Built-Up Expansion

The proceeding analysis shows that the magnitude and spatial patterns of urban extension among all 26 towns in the study area are uneven. According to the increased percentage (P) value of urban or built-up area, all towns can be divided into three groups (Figure 5). In the first group, the P value is 0％-100％; the second, 100%-200%; the third, 200%-370%. In the Figure 4, these towns with different color fills represent different changing speed before and after the year 1993.

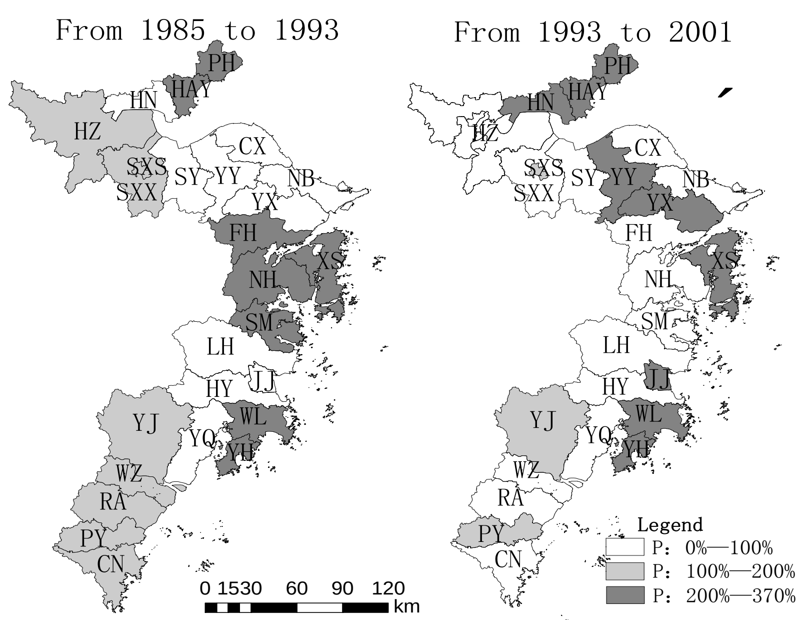

Figure 5. Urban expansion of 26 towns from 1985 to 1993, and from 1993 to 2001.

The black area, which includes XS, WL, YH, PH and HAY, show towns that are experiencing the most rapid expansion, so they were categorized into the third group. HN, YY, YX, JJ also have a relatively high changing speed, so they were transferred from the second group into the third group after 1993. FH, HN and SM belonged to the third group before 1993, but afterward were dropped into the second group because of their decelerated expansion rate.

CX, NB, SY, HY, LH and YQ maintained their expansion speeds between 100% and 200%. HZ, SXX, WZ, RA and CN ranked in the first group before 1993, then slowed down and were recategorized to the second group. YJ, SXS and PY were positioned in the first group with their relatively slow expansion rates.

Drivers of Urban Sprawl

To distinguish different modes and drivers of urban sprawl, cluster analysis is performed with data of principal urban or built-up changes and driving forces. Five major categories changed into urban or built-up are picked out in this analysis (Table 5).

Table 5. The major categories changed into urban or built-up and their percentage

The category which changed into Urban or built-up	From 1985 to 1993	From 1993 to 2001	From 1985 to 2001
paddy field	8.65%	9.19%	17.02%
other croplands	2.71%	9.11%	11.17%
Mixed forest	*	0.81%	0.80
water	*	2.69%	3.46%
Dry lake beds or beaches	2.42%	18.10%	15.07%

Note: the percentage refers to the ratio between the area of this category changed into urban or built-up and the total area of this category before the change. * indicates the omitted category with percentage less than 0.5%.

Only statistics in 1993 and 2001 are used due to the lack of proper statistics in 1985(many statistics did not be collected or collected by different ways). Principal component analysis (PCA) and relationship with urban or built-up analysis were performed with 26 socioeconomic variables in order to choose several representative ones. Twenty six socioeconomic variables from Statistical Year Book of Zhejiang (1986, 1994 and 2002) were used in the PCA analysis: (1) Per Capita GDP; (2) Gross Domestic Product; (3) Primary Industry; (4) Secondary Industry; (5) Tertiary Industry; (6) Gross Output Value of Industry; (7) Local Financial Revenue; (8) Local Financial Expenditure; (9) Saving Deposits of Urban and Rural Residents; (10) Capital Construction; (11) Investment in Fixed Assets; (12) Number of Enterprises; (13) Real Estate Development; (14) Residential area; (15) Residential construction area; (16) Total Output Value of Agriculture; (17) Farming; (18) Planting; (19) Forestry; (20) Animal Husbandry; (21) Fishery; (22) Electricity Consumed in Rural Areas; (23) Total Power of Agricultural Machinery; (24) Consumption of Chemical Fertilizers (pure); (25) Total Population; and (26) Total Employed Persons in Agriculture.

Seven variables with contribution rates higher than 0.7 in the former three principal components and their correlation coefficient reaching significant levels are selected (Table 6). Financial expenditure represents expenditure on infrastructure during the urban sprawl; Industry products denote the products in various industrial sectors; and GDP reflects the overall economic situation of each town. These variables are economic drivers. Residential construction area, which indicates the government's decision to extend residence, is a social driver. The population represents demographic driver. All the drivers mentioned above are closely related to the urban or built-up expansion.

Table 6. The selection of social and economic factors

Driving factors	Correlation coefficients with Urban or built-up	Contribution coefficient （component）
Secondary Industry	0.903	0.818（2）
Gross Domestic Product	0.898	0.841（2）
Tertiary Industry	0.876	0.720（2）
Primary Industry	0.828	0.871（1）
Flovr Space Under Construction	0.825	0.729（2）
Financial Expenditure	0.819	0.738（3）
Total Population	0.783	0.859（1）

n=52 $r_{0.01}$=0.5974 Cumulative contribution ratio>85%

Cluster analysis is implemented with the five land use change variables and seven socioeconomic variables. If the average distance between clusters is set at 2.0, the 24 towns can be divided into 6 clusters (two towns, HY and JJ are excluded due to their administrative division change) (Figure 6). The selected socioeconomic variables have significantly positive relationship with the urban or built-up increase. But each cluster presents different features.

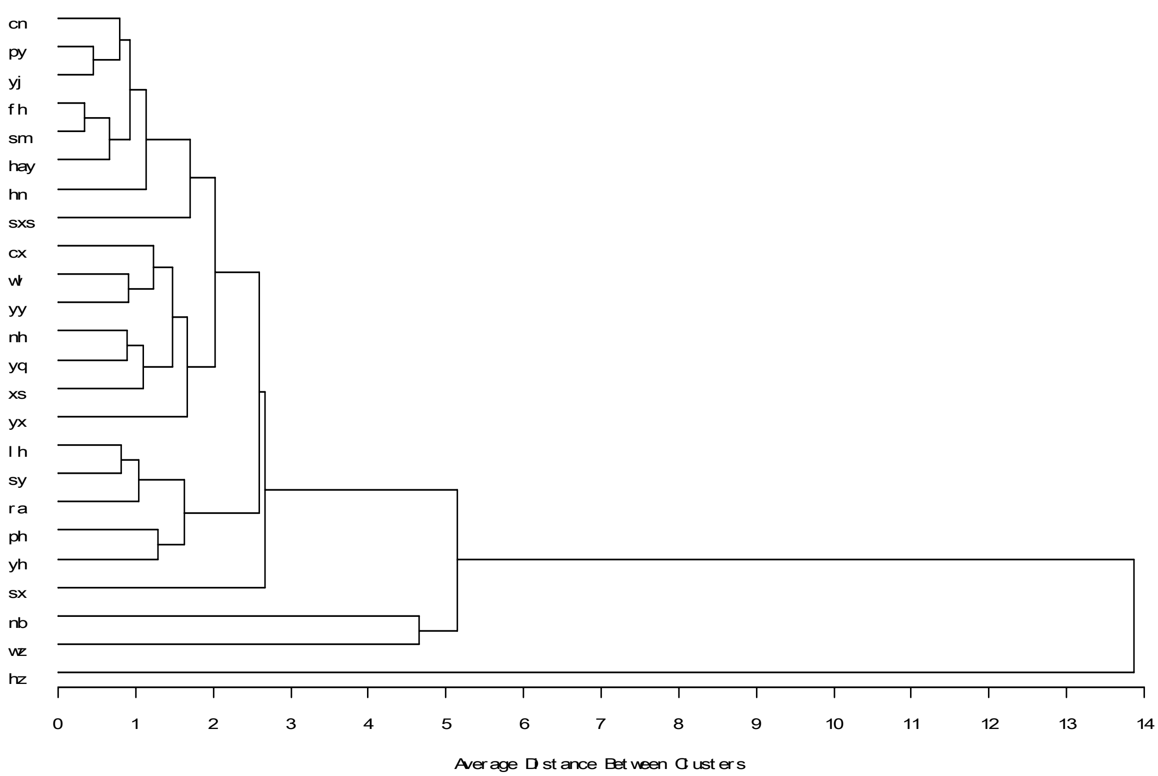

Figure 6. The cluster tree map by Urban built-up expansion areas and driving factors.

The first cluster has eight towns, that is, CN, PY, YJ, FH, SM, HAY, HN and SXS. These towns have the smallest urban expansion area and relatively slower economic development. The principal land uses changed into urban or built-up include paddy field and other croplands and a small amount of reclamation area. The second cluster includes seven towns, namely CX, WL, YY, NH, YQ, XS and YX. In this cluster the urban or built-up expansion area is larger than that in the first cluster, and the economic development is faster. The rapid economic growth played a noticeable role of spurring the growth of urban land. The sources of expansion in this cluster are similar to that of the first cluster.

The third cluster comprises five towns, namely SY, LH, PH, RA and YH. In these five towns a large area of beaches are reclaimed and converted into urban or built-up. In terms of driving factors, the increase of economy and population is slower than that in the second cluster. But the residential construction area increases quickly, which indicates that the government's policy or social factor plays an important role in the urban expansion. SXX in the fourth cluster has very large urban expansion area. The economy has been developing at a normal speed, but the secondary industry, such as manufacturing, car, textile industries, has been increasing rapidly, much more rapidly than the primary (agriculture) and the tertiary industry. So, industrialization is the major driver in this group.

NB and WZ belong to the fifth cluster. The growth of urban or built-up land is at a very large scale, along with the rapidly increasing economy, population and residential construction area. NB owns a longer coastline than WZ, so a large area of beaches in NB is developed into urban built-up land. Meanwhile, the tertiary industry increases more rapidly than the first industry and the second cluster industry in NB. In other words, the development of the tertiary industry, such as tourism, transportation and service, pushes forward the expansion of urban built-up land. HZ is in the sixth cluster. As the capital and the largest city in Zhejiang Province, it has the largest urban expansion area among the 24 towns with its rapidly increasing economy and population. During the eight-year period of 1993-2001, its population increased by 1.23 million. In the fifth and sixth cluster, therefore, economy, society and population contribute equally to the expansion of urban land.

SUMMARY

During the period 1983-2001, rapid urban sprawl has taken place in Zhejiang Province due to accelerated industrialization and urbanization. Spatially, urban land expansion was uneven in different parts of the costal region in Zhejiang Province. Temporally, land use development has not stabilized, and the two study periods of time (1985-1993 and 1993-2001) had different transition styles.

The mix of driving forces of urban expansion varies in time and space, across scales (Lambin and Geist, 2002). In this area, economy, society and population are the major driving forces for urban expansion. With the rapid development of society and economy, urbanization, industrialization and population increase lead to the loss of valuable arable land by the encroachment of urban buildup. Because of their different biophysical characters and socioeconomic situations, these towns have different styles and drivers of urban sprawl. In general, the places experiencing higher growth rates in economy and population have higher expansion rates. In some places, the expansion is mainly caused by industrial structure adjustment and the development of the third industry; in some places, the development of the second industry caused by industrialization plays a leading role; in some places, social factors or government decisions are the principal drivers; and in other places, all the factors mentioned are equally significant.

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