Stoch Environ Res Risk Assess (2014) 28:783–799
DOI 10.1007/s00477-012-0623-8

ORIGINAL PAPER

Economic development, urban expansion, and sustainable development in Shanghai

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Published online: 22 August 2012

Abstract Studies of urbanization effects in Chinese cities from the aspect of the coupled development of economy and environment are rare due to data limitations. This paper studied Shanghai's fast urban expansion and examined the dynamic relationship between economic growth and environment consequences at the district level. We extracted data on urban built-up area and land surface temperature from remote sensing images. We analyzed the patterns of urban expansion and land use change and explained the dynamic relationship between economic development and environment conditions. We attributed the uneven economic development and environmental change in districts of Shanghai to four main institutional factors: (1) the role of the government, (2) the multi-level urban planning system, (3) land market reform, and (4) the economic restructuring.

Keywords Urban expansion · Environmental change · Economic restructuring · Sustainable development · Shanghai · China

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1 Introduction

Chinese cities have grown rapidly and experienced drastic spatial restructuring in the last three decades since the economic reform began (Ma 2004; Luo and Wei 2009). The blistering speed and the massive scope of urban spatial reconfiguration are unprecedented. Rapid urban expansion and the dramatic changes in urban landscapes in China have had considerable impacts on the economy and environment. Environmental degradation and economic inequality are major concerns which have attracted the attention of researchers since the early 1990s (Fan et al. 2009; Ma 2004; Wei 2002).

A substantial body of research has emerged concerning the driving forces of urban growth in Chinese cities (Wei and Li 2002; Zhao 2009; Fan et al. 2009; Liu et al. 2011), including Shanghai (Yue et al. 2008; Han et al. 2009). Among the various causes of urban expansion, the extensive literature on urban China has identified that strengthening market forces and the transformed role of local governments in planning have been primarily responsible for the expansion of Chinese cities (Friedman 2005; Logan 2002, 2008; Wu et al. 2007). In Shanghai, Han et al. (2009) used remote sensing and multivariate regression to evaluate land use change; they concluded that population, economy and transportation are the primary spatial determinants of the city's expansion from 1979 to 2000.

Several studies have focused on the ecological and environmental impacts of China's urban expansion (Ren et al. 2003; Zhao et al. 2006; Lu et al. 2010; Xia et al. 2011). Rapid spatial expansion in China has led to the massive conversion of forests, farmland, grassland and wetlands into urban built-up areas, resulting in degradation of the environment (Chen 2007a; Cheng and Masser 2003; Krushelnicki and Bell 1989; Zhao 2009). Among the consequences of the hasty destruction of rural landscapes are diminished evapotranspiration, accelerated surface runoff, increased storage and transfer of sensible heat, and decreased air and water quality (Owen et al. 1998; Goward 1981; Yue et al. 2007; Wilson et al. 2003).

Researchers have used remote sensing and geographic information system (GIS) technologies to derive urban expansion and land-use change data, and to analyze the environmental effects on green space, urban heat islands (UHIs), and air and water quality in Chinese cities (Chen and Pian 1997; Chen et al. 2002; Ren et al. 2003; Ji et al. 2006; Zhao et al. 2006; Yue et al. 2007; Zhang et al. 2010). These studies reveal that different urban expansion scales and patterns can have different effects on urban environment. For instance, Ren et al. (2003) used a regression model to explore the relationship between water quality and land use in Shanghai, and concluded that close to 94 % of the variability in water quality is explained by the pattern of industrial land use. Zhao et al. (2006) found that the impacts of the urbanization process on air and water quality, local climate, and biodiversity in Shanghai varied among urban, suburban, and rural areas. Yue et al. (2008) also found that Shanghai's UHI has grown along with the city's territory, but its intensity has weakened in the urban central area. In recent years new approaches have come into play in the assessment of the environmental effects of urbanization, including the ecosystem health concept (Wang et al. 2009) and an urban environmental entropy model (Wang et al. 2011).

There is growing interest in investigating the linkages between economic development, urban expansion and environmental costs in North American and European cities (Arrow et al. 1995; Grossman and Krueger 1995; Costantini and Monni 2008) and recently in Chinese cities as well (Kahn 2006). Cross-country regressions show a significant relationship between economic growth and environmental degradation, in the form of an "inverted-U" shape; i.e., as income goes up there is an increasing environmental degradation up to a point, after which environmental quality improves (Arrow et al. 1995). Nevertheless, institutions and polices matter greatly in determining a sustainable development path for a city (Costantini and Monni 2008; Arrow et al. 1995), especially in transitional China (Zhao et al. 2006; Jiang and Li 2007; Han et al. 2007). Camagni et al. (2002) conducted an empirical study on the relationships between different patterns of urban expansion and specific environmental costs in Europe, and found that higher environmental impacts were associated with low densities and sprawling development. Jiang and Li (2007) and Han et al. (2007) explored the inverted-U-shaped relationship between economic development and environmental pollution level in the context of rapid urbanization in two Chinese cities: Suzhou and Chongqing. These studies all support the conclusion that managing the tradeoffs between urbanization and environmental protection is a major challenge for policy-makers, especially in rapidly urbanizing China (Zhao et al. 2006).

While these existing studies have examined the relationship between urban expansion and environmental costs by comparing different cities and countries, little attention has been paid to the spatial pattern this relationship produces within a city. Exceptions to this generalization include Wilson et al. (2003) who used a zoning method to analyze urban environment change spatially, and Yue et al. (2010) who introduced a spatial gradient method to reveal urban landscape differentiation from the center to peripheral subcenters. Yet past research on cities seldom has used administrative units at the intraurban level. To address this gap in the literature, we assess the extent of urban expansion and changing types of land use in Shanghai and evaluate how these processes affect the environment at the district level. Although the lowest administrative level in a city, the district government can make decisions affecting the spatial distribution of industries, population, and environmental protection, thus directly influences the spatial configuration of the district. This study therefore has policy implications at the most fundamental level. We obtained economic statistic data from publications and the website of Shanghai Statistical Bureau and derived detailed environmental data from remote sensing images and in situ monitoring.

This paper is organized as follows. In Sect. 2, we introduce the data and methodology. In Sect. 3, we outline the process of urban development and describe the different economic growth patterns in various parts of Shanghai. In Sect. 4, we present findings on urban expansion and land use conversion. In Sect. 5, we explore the spatial changes in land use at the district level, analyze the temporal and spatial variation of the urban thermal environment, and detail the spatial differentiation of urban air pollution. In Sect. 6, we discuss how government, urban planning, land market forces, and economic restructuring drive the spatial differentiation in Shanghai. In the final section, we present our conclusions based on the research and discuss some policy implications.

2 Data and methodology

2.1 Data

We have employed a variety of data to conduct an analysis of urban expansion and environmental change in districts of Shanghai, such as land use and land cover data, demographic census data, GDP, local revenue, and environmental data such as air pollution index (API), based on in situ monitoring, and land surface temperature (LST) data, based on remote sensing images.

Since obtaining accurate data on urban land use types, urban built-up areas, and environmental variables is difficult, we have relied on remote sensing images to conduct land use classification, and used GIS to extract urban built-up areas and LST. We derived urban land use, urban expansion and urban thermal radiation information via two types of remote sensing images, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite image data (October 2009, resolution: 15 m) and Landsat TM/ETM+ images (2000 and 2008, resolution: 30 m).

We collected district level socioeconomic data from the Statistical Bureau of Shanghai and various district governments. We obtained API data, used by Chinese cities to report real-time air pollution conditions, from daily reports on air quality by the Shanghai Municipal Environmental Protection Bureau (SMEPB). API is a composite index based on the levels of five atmospheric pollutants measured by in situ monitoring: sulfur dioxide (SO_2), nitrogen dioxide (NO_2), suspended particulates (PM_{10}), carbon monoxide (CO), and ozone (O_3), measured at the monitoring stations in each district (API). As for the daily data and the calculation of API, please refer to the websites of SMEPB[1] for details.

2.2 Identifying built-up areas and land use classifications

To identify the built-up areas of Shanghai main city, we mainly rely on historical land use maps and Landsat images. The existing historical land use maps, referring to the built-up area boundaries of main city, were provided by Professor Mei Anxin from the Geography Department at East China Normal University. The specific built-up land patterns in the whole Shanghai city were interpreted from Landsat images. The Landsat 7 ETM+ images and Landsat 5 TM images (centered at about 31.446°N, 121.536°E) were acquired on June 14, 2000 and April 13, 2008, respectively. The acquisition dates had clear atmospheric conditions. The images, acquired from USGS, were corrected for radiometric and geometrical distortions to a quality level of 1G before their delivery. However, since each image had homogeneous atmospheric conditions, atmospheric corrections were not performed. The images were re-sampled by using the nearest neighbor algorithm with a pixel size of 60 m by 60 m. The root mean-square error was found to be less than 0.5 pixels. Based on different spectral responses of urban built-up land and non-urban land, we employed an object-oriented classification with the help of ENVI 4.7 platform to derive the urban built-up land.

Land use data were culled from the existing land use maps (2002), produced using aerial photo and satellite image interpretation techniques and combined with field surveys by a research group in East China Normal University. The land use data of 2009 were generated from ASTER data. When we conducted several separate supervised classifications for land use types, the existing 2002 class map and high-resolution images from Google Earth were used as interpretation keys. We also conducted sampling to assess the accuracy of our classification by selecting 60 sample points for each land use type. We consider our classification accurate as the overall kappa value of our land use classification has reached 0.8452.

2.3 LSTs calculation

Deriving LST is a more complicated procedure, so we used the following steps: (1) convert digital number (DN) to "at sensor radiance"; (2) convert the spectral radiance to the radiant surface temperature; (3) correct the radiant surface temperature for emissivity to obtain the LST. First, we converted DNs in each band of the Level 1G ETM+ images to physical measurements of "at sensor radiance" (L_λ) by using the following DN to radiance conversion equation:

$$L_\lambda = \text{gain} \times \text{DN} + \text{offset} \tag{3}$$

where L_λ is the "at sensor radiance," gain is the slope of the radiance/DN conversion function, DN is the digital number of a given pixel, and offset is the intercept of the radiance/DN conversion function (Landsat Project Science Office 2002). Gain and offset values are supplied in the metadata accompanying each ETM+ image. We used ERDAS Imagine 9.3 to process imageries and implement all equations used in this paper through its map algebra functions, including the conversion from DN to radiance.

The spectral radiance of ETM+ Band 6 image can then be converted to a physically useful variable, the effective at-satellite temperature of the viewed earth-atmosphere system, under the assumption of unity emissivity and using pre-launch calibration constants supplied by Landsat Project Science Office (2002) as the following equation:

$$T_B = K2/(\ln(K1/L_\lambda + 1)) \tag{4}$$

where T_B is the radiant surface temperature (K), $K2$ is the calibration constant 2 (1,282.71), $K1$ is calibration constant 1 (666.09), and L_λ is the spectral radiance of thermal band pixels (Landsat Project Science Office 2002).

The T_B values obtained above are referenced to a black body and they need corrections for spectral emissivity (ε) of the land cover. The emissivity of a surface is determined by factors such as content, chemical composition, structure, and roughness. Therefore, almost all techniques measuring the emissivity of ground objects from passive sensor data require land cover classification. We classified the land cover into vegetated areas and non-vegetated areas and corrected the emissivity accordingly. Vegetated areas were given a value of 0.95 and non-vegetated areas 0.92 for ε (Nichol 1994). Meanwhile, emissivity is a function of

[1] http://www.sepb.gov.cn/; http://www.xmems.org.cn/hjkp/about_api.htm.

wavelength, therefore often referred as spectral emissivity (Weng et al. 2004). The LSTs corrected for emissivity can be computed by using the following equation (Artis and Carnahan 1982):

$$\mathrm{LST} = \frac{T_B}{1 + (\lambda \times T_B/\rho)\ln\varepsilon} \tag{5}$$

where λ is the wavelength of emitted radiance (for which the peak response and the average of the limiting wavelengths ($\lambda = 11.5$ µm) will be used), $\rho = h \times c/\sigma$ (1.438×10^{-2} mK), where h is Planck's constant (6.626×10^{-34} J s), c is the velocity of light (2.998×10^{8} m s^{-1}), and σ is the Boltzmann constant (1.38×10^{-23} J K^{-1}) (Landsat Project Science Office 2002).

3 Shanghai: urban development and spatial restructuring

With a registered population of 18.6 million and total area of 6,340.5 km^2 in 2008, Shanghai is located on the east coast of China at latitude 31°14′ and longitude 121°29′ (Fig. 1), at the tip of the Lower Yangtze River Delta. Shanghai has been the most important location for China's economic development since it became a treaty port after the Opium War in the middle of the nineteenth century. Relying on its hinterland of the Yangtze River Delta, Shanghai has remained China's economic center for over a century, leading in manufacturing, commerce, and international trade. During the socialist period (1949–1978), the city focused on developing manufacturing capacity while the amenities of urban life were neglected. In this period most urban development and economic activities were concentrated in the Puxi area (west of Huangpu River). Since the economic reform in 1978, especially since the establishment of the Pudong New Area (east of Huangpu River), Shanghai has experienced unprecedented economic growth and rapid urban expansion; the level of urbanization has increased significantly from 59.0 % in 1978 to 88.6 % in 2008.

Shanghai city governed 18 districts and 1 county before 2009. Since the administrative division has changed little since 2009, we still used the system of 19 spatial units to maintain consistency. We divided Shanghai's districts and county into four different zones, according to their land use/land cover characteristics, such as percentage of urban built-up area and the level of urbanization. Zone I is composed of nine districts in the urban core, Huangpu, Luwan, Jing'an, Xuhui, Changning, Zhabei, Putuo, Hongkou and Yangpu, where nearly 100 % of the land cover consists of urban built-up areas. These nine districts, together with Nanshi (now part of Huangpu district), Wusong (currently Baoshan), and Minhang, were the original 12 districts of Shanghai's urban area in the 1980s. Zone II includes five districts around the urban core of Zone I, Pudong, Baoshan, Minhang, Jiading and Songjiang; each district possesses some, but not significant, areas of agricultural or open land. In 1992, Pudong New Area was set up and Jiading County was changed to Jiading district. Zone III refers to the four exurban districts south of Zones I and II, namely, Jinshan, Qingpu, Nanhui and Fengxian. They were converted from counties to urban districts successively at various times from 1993 to 2001, and most of the lands in these districts are agricultural or open land. Due to the special characteristics of Chongming Island as an ecological and environmental reserve for Shanghai, we designated Chongming as Zone IV.

After the establishment of Pudong New Area, Shanghai's economy took off, reflected by much higher growth rates of GDP and GDP per capita. Although the economy of Shanghai as a whole has grown rapidly in recent decades, GDP per capita of 2000 and 2008 at district level (Fig. 2) indicate that there are significant differences in levels and rates of economic development among districts. We calculated the coefficients of variation (C_V) for GDP per capita among districts in 2000 and 2008 respectively. The C_V of GDP per capita in 2000 is 0.38, while in 2008 it increased to 0.48. Referring to the Fig. 2, the difference of GDP per capita across districts was much bigger in 2008 than that in 2000, especially the difference between emerging manufacturing districts in Zone II and the other zones. The change of C_V reveals that the expansion of urban land, caused by uneven growth and relocation of manufacturing and population, has contributed unevenly to the economic development of areas in Shanghai. It also indicates that the increasing differentiation among spatial units is more likely caused by various economic structures, either manufacturing or producer service oriented. For instance, all emerging manufacturing districts have enjoyed faster economic growth, such as Pudong, Jiading, Minhang and Songjiang in Zone II. While for districts in Zone I, some experienced high-level development, such as Jing'an and Luwan as they successfully upgraded their economic structure towards producer services and commerce, others, such as Putuo, Zhabei, Yangpu, Hongkou, had limited growth as they struggled to identify new economic activities after their manufacturing units had been relocated to suburbs.

4 Urban expansion and land use change

4.1 Urban land expansion

Shanghai has expanded its urban built-up area since the 1940s, with the main city increasing 18 times from 76 km^2 in 1947 to 1,462 km^2 in 2008 (Fig. 3). While annual land expansion ratios were below 6.0 km^2 before 1984, they dramatically spiked to over 100 km^2 for the period of

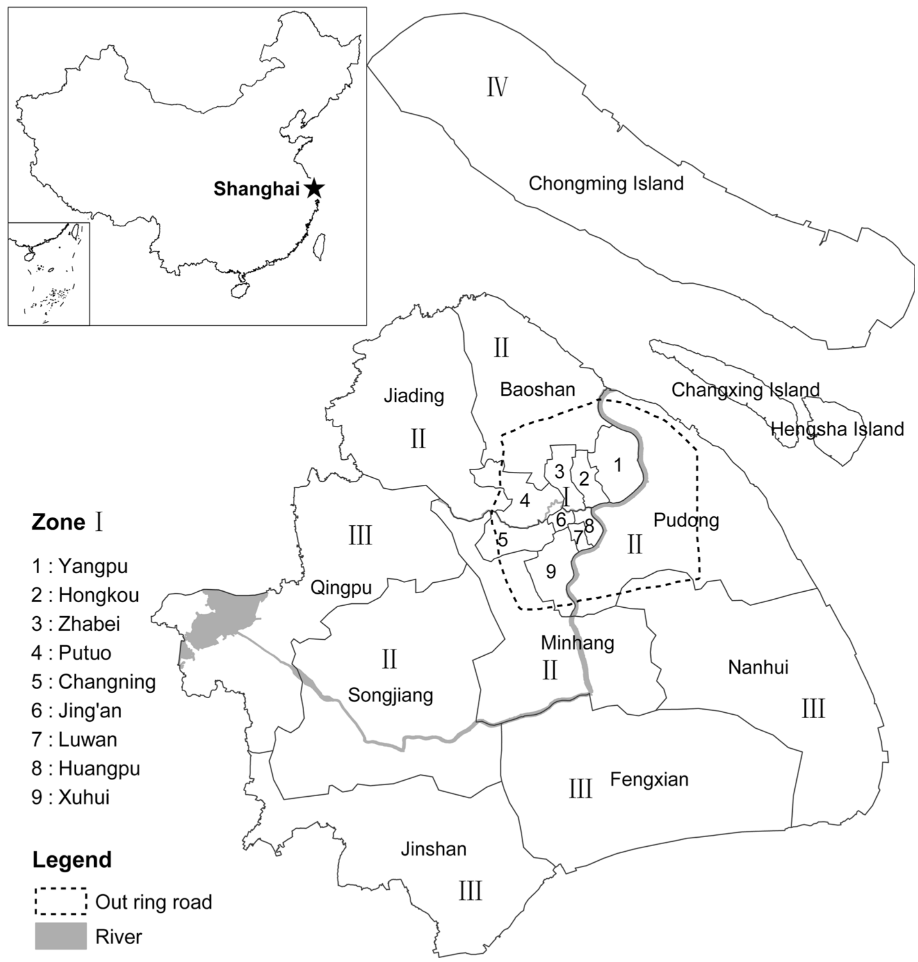

Fig. 1 Location and administrative divisions of Shanghai

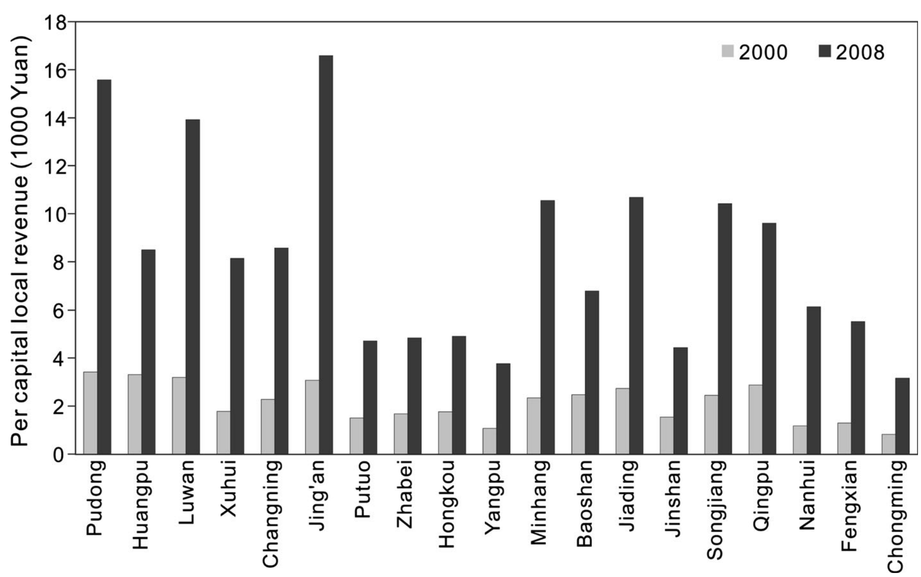

Fig. 2 Change of per capita income at the district level

2002–2008. As illustrated in Fig. 3, from 2002 to 2008, the city expanded 751.38 km^2 within a short span of 6 years, due to the development along the paths connecting the main urban core and the satellite towns. While before 1996 the city mainly expanded along a northeast–southwest axis, Shanghai has mainly developed towards northwest,

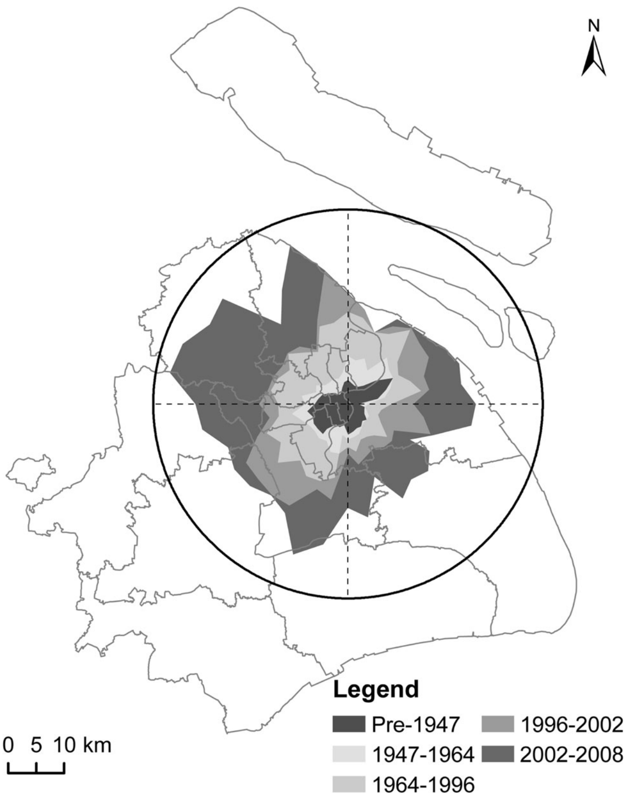

Fig. 3 Urban expansion area and direction of the main city 1947–2008

southwest and east since 1996 as districts in Zone II, such as Pudong New Area, Jiading and Minhang, became new industrial centers of Shanghai. The urban expansion is fueled by industry and residents relocating from the urban core to suburban areas, as well as new industrial zones setting up on the urban fringe to attract investment and migrant workers.

4.2 Change of urban land use types

We consider that land use/cover characteristics may have contributed significantly to spatial patterns of economic activity and environmental conditions in Shanghai (Fig. 4), especially in terms of affecting the range and intensity of air pollution and UHI. We investigated land use type change in the rapidly expanding main city. The land use maps were interpreted from remotely sensed images, 2002 and 2009 (Table 1). Following the government policy of industrial relocation, urban industrial land decreased and vegetation cover increased. This transformation occurred when much of the original urban industrial land in the inner city was converted to vegetation cover during urban renewal projects, as the Shanghai municipal government used planting more vegetation as a promising mitigation measure against environmental degradation. From 2002 to 2009, many industrial enterprises were relocated to suburban areas from the main city. The share of industrial land decreased from 17.32 to 11.14 %, while green space and residential land had a considerable increase, whose shares rose from 4.15 and 22.17 % to 11.46 and 33.38 % respectively. Most arable land was converted to residential land as a result of the policy of commodity housing development, especially in the western and northern suburbs.

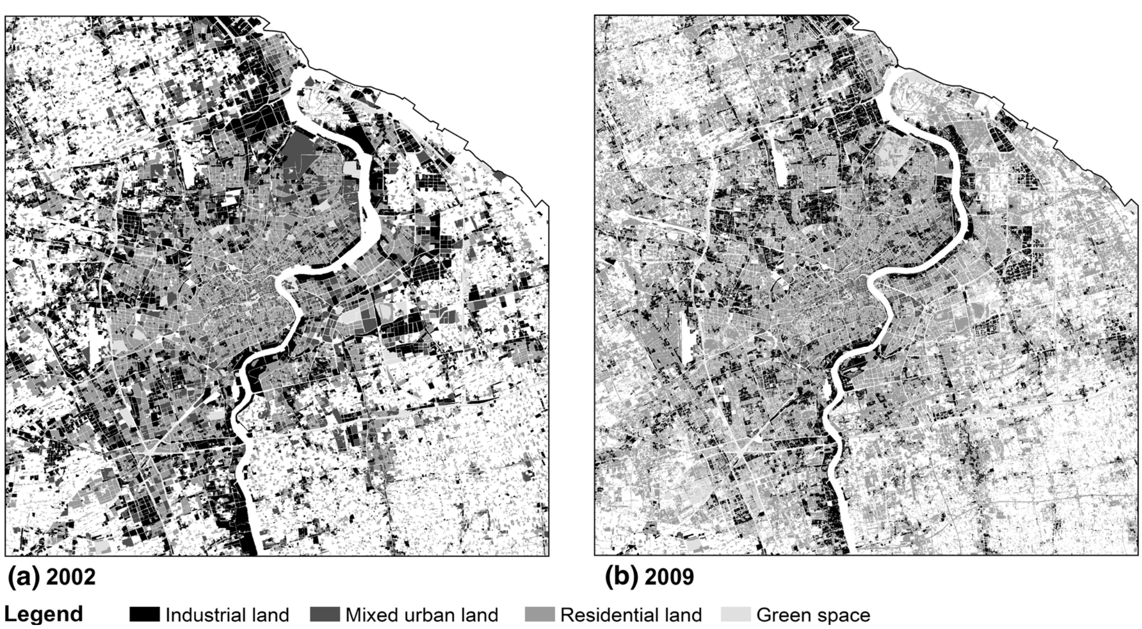

Fig. 4 Land use change in the main city from 2000 to 2009

Table 1 Land use change in the main city from 2000 to 2009

Land use types	2000		2009		Change ratio (%)
	Area (km^2)	Share (%)	Area (km^2)	Share (%)	
Mixed	153.98	9.83	51.08	3.26	−66.83
Residential	347.48	22.17	523.1	33.38	50.54
Industrial	271.39	17.32	174.53	11.14	−35.69
Transportation	127.54	8.14	108.13	6.9	−15.22
Green space	65.08	4.15	179.62	11.46	176.00
Arable	490.17	31.28	423.63	27.03	−13.57
Water	111.36	7.11	106.91	6.82	−4.00

5 Urban expansion and environmental change

5.1 Impacts of urban expansion on land use change

Figure 5 shows a more accurate picture of urban built-up land expansion at the district level from 2000 to 2008 when Shanghai experienced the fastest urban expansion. Although districts in Zone I had limited room for urban built-up area expansion (over 95 % of the land was already built-up area), districts in Zones II and III and Chongming (Zone IV) all experienced substantial gain in urban built-up land. The most impressive expansions happened in Zone II. For instance, the area of built-up land increased by 155.41 km^2 in Jiading, and by 122.46 km^2 in Pudong during the short span of 8 years. The ratio of built-up land increased from 19.08 to 52.95 % in Jiading, from 38.19 to 61.62 % in Pudong, and from 48.68 to 85.99 % in Baoshan (Table 2). Additionally, in Zone I, which did not have room for expansion of built-up area, the districts underwent dramatic urban renewal and economic restructuring (Yue et al. 2006, 2009).

As a significant consequence of urbanization, land use change is not only considered an important environmental effect of urban expansion, but also the economic manifestation of urbanization; for example, green land increase can be considered an environmental improvement, and manufacturing land change can be explained as industrial restructuring. We calculated the main land use change for the whole Shanghai city proper in Table 3.

For industrial land, nine districts in Zone I all exhibited a decreasing trend, the total amount decreased from 55.79 km^2 in 2002 to 39.84 km^2 in 2009; while the other three zones all had an increasing trend, especially in the emerging manufacturing areas, such as Zone II which increased from 218.95 to 270.88 km^2. For residential and commercial land, except for Zone IV (Chongming County), where the residential land had a large decline due to a rural housing demolition policy, the other zones all experienced vast growth, while there was a reverse trend in the arable land change. With respect to green space, except for Chongming Island (Zone IV) reclaiming land from the sea, Zones I and II tended to increase, while Zone III was still decreasing (Table 3).

Fig. 5 Urban built-up area expansions at the district level, 2000–2008

Table 2 Expansion of urban built-up area of Zones II, III, and IV

Zone	District	Area (km^2)	BUA 2000		BUA 2008		Increased BUA	
			Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)
II	Pudong	522.75	199.65	38.19	322.12	61.62	122.46	23.43
	Minhang	371.68	137.94	37.11	232.8	62.63	94.87	25.52
	Jiading	458.8	87.52	19.08	242.93	52.95	155.41	33.87
	Baoshan	270.99	131.91	48.68	217.91	80.41	85.99	31.74
III	Songjiang	604.71	92.71	15.33	204.11	33.75	111.4	18.42
	Nanhui	687.66	81.6	11.87	179.77	26.14	98.17	14.28
	Fengxian	687.39	52.37	7.62	141.6	20.60	89.23	12.98
	Jinshan	586.05	42.59	7.27	104.75	17.87	62.16	10.61
	Qingpu	675.54	70.4	10.42	164.84	24.40	94.44	13.98
IV	Chongming	1,185.49	29.7	2.51	59.62	5.03	29.92	2.52

BUA means built-up-area

Source Calculated by the authors based on Fig. 5

Table 3 Main land use change of the four zones (km^2)

Zone	Industrial		Residential and commercial		Arable		Ecological	
	2002	2009	2002	2009	2002	2009	2002	2009
Zone I	55.79	39.84	100.92	169.77	9.95	1.45	22.00	26.69
Zone II	218.95	270.88	322.93	618.93	912.53	570.11	167.86	208.77
Zone III	103.05	252.06	384.07	553.48	2,297.10	1,994.58	356.39	346.97
Zone IV	9.55	11.56	121.03	79.51	966.18	998.63	44.66	73.54

Source Derived from existing land use data (2002) and ASTER images (2009). Ecological land includes green land and water body

5.2 Urban thermal environment change

We examined the pattern of the urban thermal environment at the district level. In order to compare the urban thermal environment between two different dates, we normalized the LST data of 2000 and 2008 by subtracting the global mean of each image. Figure 6 indicates that the UHI had a considerable expansion over this time period. In 2000, the main body of the UHI was distributed within the outer ring road, i.e., in Zone I. By 2008, except for Chongming, Shanghai's UHI had expanded to every district. Nevertheless, the intensity of the heat island in the urban core declined, especially in districts such as Huangpu, Jing'an, and Luwan.

The urban thermal environment underwent a drastic change at the district level from 2000 to 2008 (Fig. 7). In 2008, if we classified all areas with a LST 4 °C above the global average temperature at the same time, i.e., the mean LST of Shanghai, as the heat island, then all nine districts in Zone I were within the boundary of UHI; however, if we classified all area with a LST 2 °C above the global average temperature, then the UHI expands to all districts in Zone II. In terms of the thermal dynamic, the temperature declined from 2000 to 2008 for districts in Zone I, while the temperature increased considerably for all districts in Zones II and III, particularly Baoshan, Jiading, Minhang and Songjiang. Chongming district is the only one with the improved thermal environment in a suburban area.

Our findings disclose a distinct relationship of UHI dynamics and economic development for districts in Shanghai (Fig. 8). UHI, represented by LST, is influenced by physical characteristics of land surface and human socioeconomic activities, such as the establishment of new factories and population agglomeration. Therefore, the dynamic of Shanghai's UHI intensity has a close relationship with economic restructuring, especially the relocation of manufacturing (Yue et al. 2008).

In Fig. 8, the *X* axis represents the increase of income per capita, and the *Y* axis denotes the increase of the UHI intensity. A value greater than zero for *Y* refers to the increased intensity of UHI, namely the thermal environment tending to worsen; in contrast, a value less than zero for *Y* refers to the decreased intensity of UHI, namely the thermal environment getting better. The *Y* axis meets the *X* axis when *X* equals to 5,000 Yuan per person, dividing the 19 districts into two groups. The scatter plot thus is divided into four parts by the two axes. Five districts in the lower right corner, all belonging to Zone 1 (urban core),

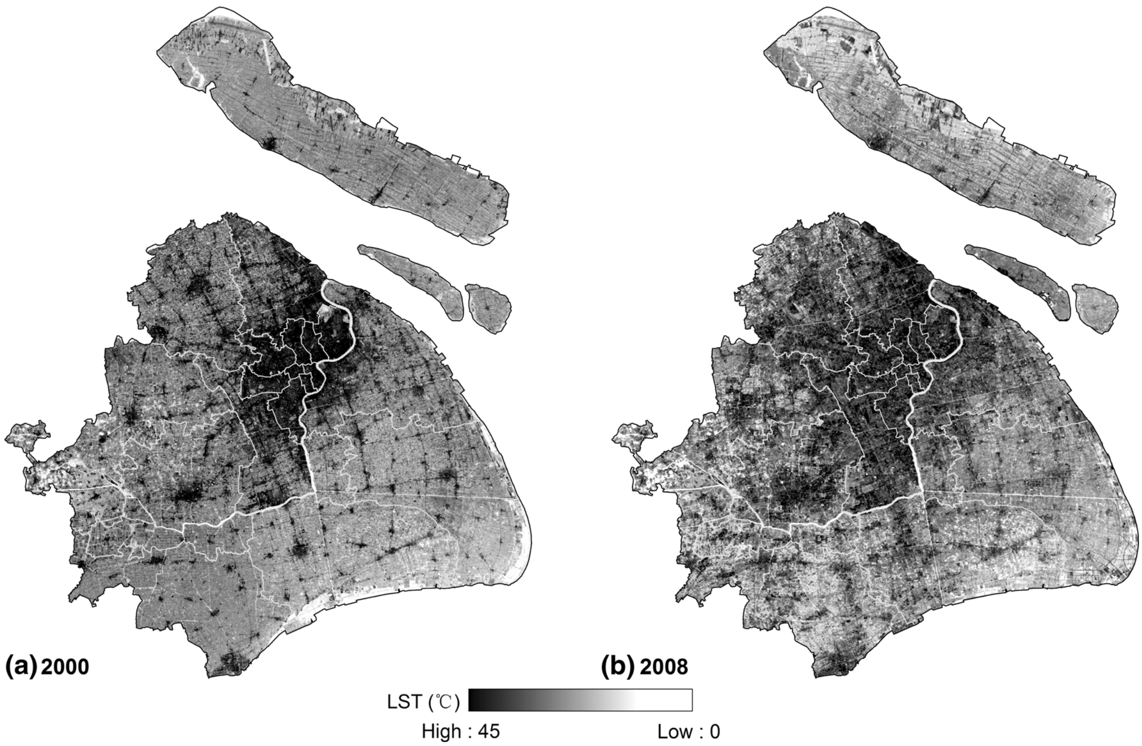

Fig. 6 LST after normalization

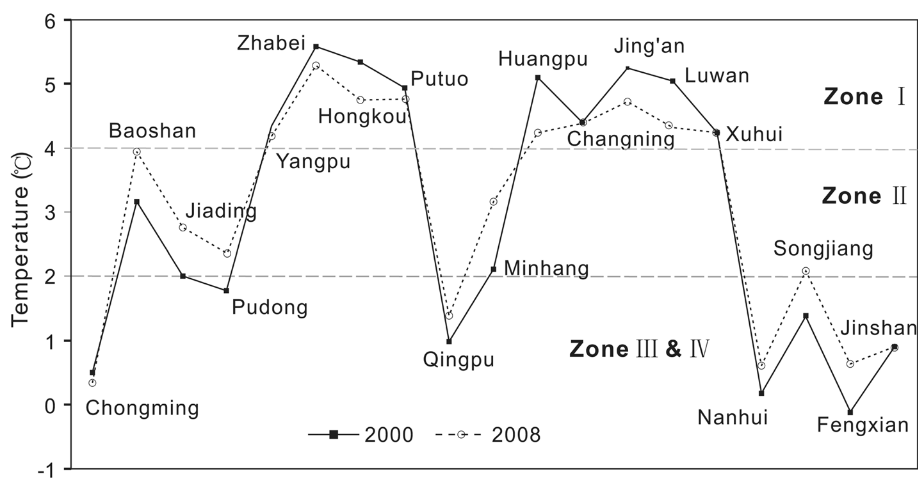

Fig. 7 Temperature contrast after normalizing

fared well in economic development and improved their environment conditions, especially Luwan and Jing'an, which, despite the relocation of their manufacturing enterprises, achieved successful economic restructuring. Five districts in the upper right corner realized fast economic growth but suffered from a deteriorating urban environment. Except for Qingpu, four of these five districts are located in Zone II. These districts possess many national and municipal level industrial zones and contributed more than 50 % of the total industrial output of Shanghai in 2008 (Shanghai Bureau of Statistics 2001, 2009).

Four districts in the upper left corner are Baoshan in Zone II and Fengxian, Nanhui and Jinshan in Zone III. Their economy grew slower than the city's average and their environment deteriorated from 2000 to 2008. Baoshan district is an old industrial area dominated by a huge state-owned enterprise (SOE), a steel mill, and several SOEs in the ship-building industry. It struggled to achieve both economic efficiency and environmental sustainability in the 2000s. The other three districts also were locations dominated by heavy industry. Although all three districts are located outside the urban area, their thermal environment became much worse, except Jinshan. Districts in the

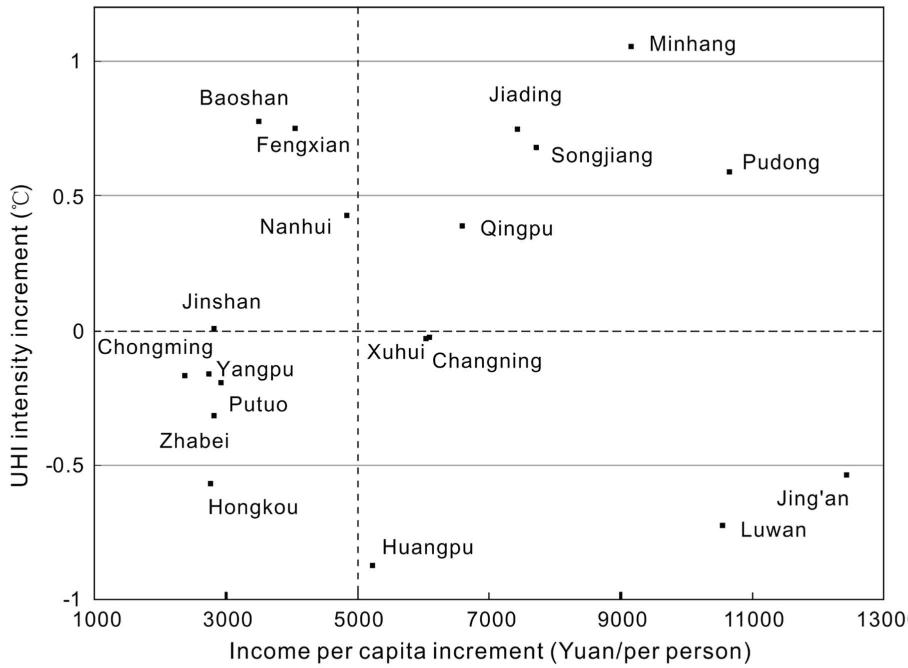

Fig. 8 UHI intensity and the economy of the districts in Shanghai, 2000–2008

lower left corner had slower economic growth but experienced improvements in their urban environments. Four districts in Zone I, i.e., Yangpu, Putuo, Zhabei, and Hongkou, and Chongming in Zone IV belong to this group. Due to the reallocation of manufacturing enterprises and urban renewal, the urban environment in Yangpu, Putuo, Zhabei, and Hongkou, improved remarkably. However, these districts were not able to upgrade their economic structure as other inner city districts, leading to the slower economic growth. Chongming grew its economy much more slowly than other parts of Shanghai because the island has almost no manufacturing and is dominated by agricultural activities. Its environment improved further as the government began to turn Chongming into an ecotourism preserve.

5.3 Air quality

Shanghai's air quality has improved in the last decade, as is indicated by the decreasing value of PM_{10}, SO_2, NO_2, and the increasing number of days with good air quality. Whereas in 1997 the average concentrations of SO_2, NO_2 and PM_{10} were 0.068, 0.105 and 0.231 mg/m^3, respectively; these figures declined to 0.055, 0.054 and 0.088 mg/m^3 respectively in 2007. The ratio of days with good air quality per year also increased from 80.8 % in 2000 to 89.9 % in 2007.

However, the disparity in air quality between districts is pronounced (Fig. 9). For instance, Huangpu, Xuhui, and Jing'an in Zone I have relatively more days with good air quality, while Baoshan, Putuo and Yangpu, which lie in the outer sphere of the urban core, have fewer days with good air quality. Baoshan, Jiading, Minhang and Songjiang in Zone II have made considerable improvements, although Baoshan was far behind other districts. Pudong also had a high ratio of days with good air quality and improvement despite being located in Zone II.

Using the API as an indicator of environmental quality, while keeping GDP per capita as an indicator of the level of economic development, we further investigated the relationship between the economy and environment at the district level with a scatter plot of the districts in Shanghai (Fig. 10).

Our analysis shows that the pollution level increased first, then decreased as the level of economic development rose (Fig. 10). Based on the relationship between economic development and environmental conditions in different districts in Shanghai we did a regression analysis. The regression curve of API and per capita income follows the inverted-U-shaped relationship, though the correlation coefficient was only 0.47 (Fig. 10). This confirms the findings of other researches of Chinese cities (Han et al. 2007; Su et al. 2009), demonstrating that as the economy develops, a spatial unit's environmental condition usually deteriorates first, then improves after reaching a turning point, following a course of "treatment after pollution." Figure 10 illustrates that the turning point for Shanghai's districts is RMB 6,800 Yuan (US$1,000) per capita. For districts with more than RMB 6,800 Yuan GDP per capita, the higher the level of economic development, the better

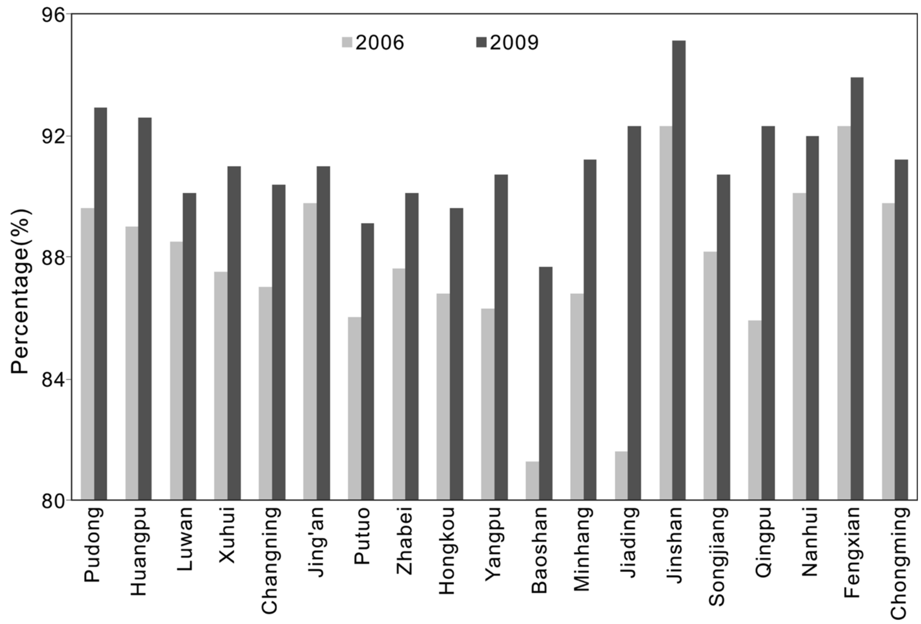

Fig. 9 Days with good air quality at the district level (%)

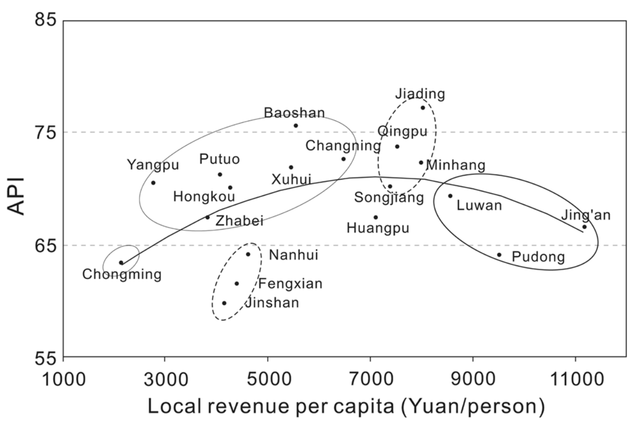

Fig. 10 Relationship between average API and GDP per capita

the environmental conditions are for the district. For districts with less than RMB 6,800 Yuan GDP per capita, the lower the level of economic development, the better environmental conditions are, indicating the economy grows at a cost of environmental quality.

Figure 10 illustrates that districts of Shanghai can be grouped into different clusters (here we use ovals) based on their economic development level and environmental conditions. The solid line oval at the lower right corner includes Jing'an, Luwan, and Pudong, which reached high levels of economic development and environmental quality, serving as role models for districts in the old urban core of Zone I and rising manufacturing districts in Zone II, respectively. Jing'an and Luwan, located at the CBD of Zone I, upgraded their industrial structure to producer oriented services; Pudong, located in Zone II, leapt forward to financial services and high-tech industries directly from agricultural activities.

The dashed line oval at the top right corner represents the rising manufacturing centers with the worst environment conditions in Zones II and III, including Jiading, Qingpu, Minhang and Songjiang. The solid line oval at the top left corner includes districts in Zones I and II that were not so successful in both economic restructuring and the improvement of environmental conditions (Yangpu, Putuo, Hongkou, Zhabei, Xuhui, Changning, and Baoshan); those in Zone I were struggling to identify new economic engines as their manufacturing enterprises were relocated, while Baoshan had to deal with the inefficiency of state-owned heavy industry. The dashed line oval at lower left corner represents those districts in Zone III, i.e., Nanhui, Fengxian and Jinshan. In the initial phase of industrialization, their environment was not as polluted as those districts in the black circle. Nevertheless, they mostly likely will follow the steps of the districts in the black circle closely as they accelerate their industrialization.

Finally, with few manufacturing activities, Chongming distinguishes itself as a spatial unit with good environment conditions but extremely low levels of economic development. We expect activities that utilize its ecological resources and tourism, in addition to organic agriculture, will boost its economy without significant impacts on its environment.

6 Discussion: driving forces of urban expansion and environmental change

Our analysis not only deals with rapid urban expansion, a phenomenon quite usual for contemporary Chinese cities, but also assesses the uneven sustainability of development in different districts of Shanghai. Following our research framework, in this section we examine the role of the local government, the land market, and economic restructuring in Shanghai's urban expansion and land use change.

6.1 The role of the government

Government at different levels has been involved actively in Shanghai's urban transformation and spatial differentiation. The central government is mainly involved in overseeing the Pudong New Area and national level development zones that offer preferential policies for foreign investment, including concessions with respect to income taxes, customs duties, and taxes for equipment, vehicles, and building materials. Overall FDI has grown rapidly from US\$3 million in 1981 to US\$10.08 billion in 2008. FDI poured both into manufacturing, including the automotive, electronics, telecommunication equipment, and chemicals industries, and tertiary sectors such as finance, banking, real estate, and other services (Wei et al. 2006).

In Shanghai the real estate sector has become one of the largest areas to absorb FDI; in 2007 12.15 % of the city's FDI was invested in real estate. Yet the spatial distribution of FDI is highly uneven. Pudong New Area, Jiading, and Minhang led in FDI due to investment in manufacturing and central districts such as Jing'an, Luwan, and Xuhui also scored high in attracting FDI in producer services. In contrast, districts such as Putuo and Zhabei seem unable to attract as much FDI as other central districts (Fig. 11). This uneven development pattern is partly explained in terms of the location of government-sponsored, FDI-oriented development zones, which are the largest land development projects in Shanghai.

Governments have also played a major role in reshaping the urban landscape through a large number of major infrastructure projects. The World Expo 2010 was the archetypical case. The Expo, which covered 5.28 km^2 on both banks of the Huangpu River, drew more than \$48 billion investment. The project involved moving 18,000 families and 272 factories, including the Jiang Nan Shipyard, which employed 10,000 workers, and Pugang Iron and Steel Company, which occupied more than 2 km^2 of land. Six new subway lines were opened between 2008 and 2010, and the Expo attracted more than 73 million visitors. In addition to the metro lines, a large number of major infrastructure projects, such as Yangshan Harbor phase I, the Pudong Airport phase II, and Chongming linkage were constructed.

The World Expo 2010 affected Shanghai's urban transformation mainly in the following three aspects. First, Shanghai used the opportunity to upgrade its industrial structure and boost the development of trade, and tourism, and services. Second, by replacing heavily polluting factories with international trade, tourism, culture, education and other service industries and by relocating many residents, the World Expo 2010 promoted the renewal of the central city and brought a new round of real estate development. Third, the improved urban infrastructure speeded Shanghai's suburbanization of industries and population.[2]

6.2 The multi-level urban planning system

It needs to be emphasized that a multi-level urban planning system has played a significant role in reshaping and restructuring the economic and environmental patterns of the city. So far, most of the development has followed the direction of Shanghai's master plans, and new developments have to be constantly checked against the plans of the government, such as comprehensive plans, infrastructure plans, as well as urban core renovation plans.

First, the government has designed a comprehensive plan dubbed "1966", which covers the central city, 9 satellite cities, 60 new towns, and 600 key settlements. The central city, with a 660 km^2 area lying in the current main urban area within the outer ring road, is planned to accommodate 10 million people, with population density held below 15,000 persons/km^2. The nine satellite cities, namely, Baoshan, Jiading-Anting, Qingpu, Songjiang, Minhang, Fengxian, Jinhan, Lingang and Chongming, together will accommodate a population of 5.4 million. The 60 new towns, each with a unique feature, will accommodate populations of 3 million in total. Finally the 600 key settlements, serving as Shanghai's basic living units in suburban areas, are designed to accommodate populations of 5,000 each. The basis for the "1966" urban-town network has been established and it will continue to influence the economic and residential patterns in various districts.

Second, the municipal government has invested heavily in urban infrastructure. However, the investment in infrastructure has not been evenly distributed, which has led to uneven development, as districts that received heavier investment tend to be more favorable locations for economic enterprises and residential projects. For instance, over the short period of 1986–1990, Shanghai invested 22.5 billion Yuan in infrastructure improvement, seven times the total of the previous three decades. One noted example was the opening of the Shanghai Metro System in 1995, which is the longest urban rapid transit network in Asia and the third longest in the world. Sites around metro stations are highly sought after. As most of the metro stations are located in districts of Zone I and Pudong New Area, it is no surprise to see higher land prices in these districts. Nevertheless, as the number of metro lines increased and lines extended over time, there has been a trend of decentralization reflected by the decline of population in the central

[2] http://www.iges.or.jp/en/ue/pdf/activity03/BAQ_IGES_Pa.pdf.

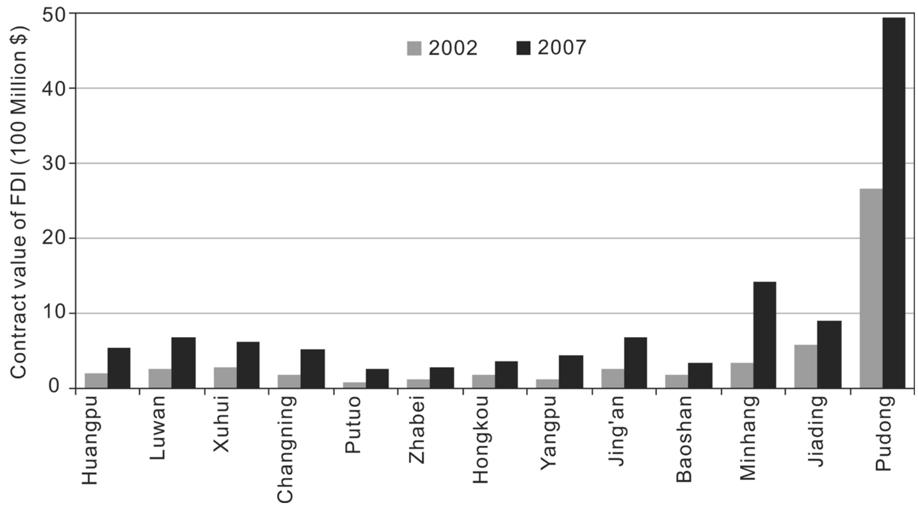

Fig. 11 The uneven distribution of FDI at districts of Zones I and II

area from 2000 to 2008, thus reducing heavy congestion in the urban core and a mitigation of traffic pollution.

Third, Shanghai's urban planning has put its emphasis on the renovation of the old city, significantly improving the environmental conditions of districts in Zone I. The Shanghai municipal government launched the "365 urban renovation project" in 1992, planning to reconstruct old buildings with a total area of 3,650,000 m^2. By 2000, it finished the reconstruction of an old urban area of 3,800,000 m^2, having demolished run-down buildings over an area of more than 4,000,000 m^2 and relocated 1,000,000 residents. Most communities that benefited from reconstruction are located in Huangpu, Luwan, Jing'an, Xuhui, Hongkou and Yangpu districts. The government also converted more than 10 % of the area in the old downtown to parks or green spaces, leading to a considerable increase of green space and the improvement of environmental quality in the urban core (Table 3) (Yue et al. 2007).

6.3 Land market reform and urban land use

Land market reform and the establishment of land and housing markets have introduced market mechanisms and fueled land development. Before the land market reform, in contrast to capitalist cities land was owned by the state, which allocated land to work units (*Danwei*) through administrative methods without any market involvement. In the initial years (from 1979 to 1986), some coastal cities, especially Guangzhou and Shenzhen, began to experiment with paid use of urban land, charging foreign investors for using state-owned land, to address the problem of limited capital in infrastructure construction. Later, the state legalized initial land experiments in the constitution and other national laws. Shanghai was one of the six cities proposed by the State Council to experiment with the transfer of land use rights for payment in September 1987. By 1990, 28 cities and 19 counties had experimented with the paid transfer of land use rights (Wu et al. 2007).

In the 1980s, Shanghai developed its own system of land leasing by following Hong Kong's operational procedure, introducing a series of local regulations regarding land leases. For instance, on November 29, 1987, it approved "the Regulation for the Transfer of Land Use Rights in Shanghai," which laid down the rights and responsibilities of investors, and the procedures to obtain land use rights. The regulation also set the standard fee levels for land use, with land in the central commercial area charged at US$12/$m^2$ in 1987 and US$20/$m^2$ in 1991, and land in rural areas was charged as low as US$0.06/$m^2$ in 1991 (Chen 2007b).

It has been recognized that many urban problems characteristic of Chinese cities, such as urban sprawl, loss of arable land, social discontent due to demolition, forced relocation, and ruthless land acquisition, can all be contributed to the rise of the land market, as land has become an important revenue source for the local state. Shanghai is no exception. From 2003 to 2008, a total land area of 33,539.86 m^2 was leased from the Shanghai government. This large amount of land has fueled rapid urban expansion in recent years, as investors can lease large tracts of land at cheap prices along the urban periphery. At the same time, developers lease land in the city core at higher prices, to ensure profit from redevelopment, and most of the land is converted to high-end residential projects or commercial and financial complexes, making them unaffordable for the original residents. Thus, due to locational differences of the districts, land value and land income differ significantly.

After 20 years of land market reform, land prices overall have increased significantly, making Shanghai one of the most expensive cities in China. The land transfer fee of Shanghai increased from 24.8 billion RMB in 2005 to 102.4 billion RMB in 2009, leading all Chinese cities. The spatial distribution of land prices is grossly uneven.

Table 4 Land transfers in Shanghai, 2005

District	Count	Average price (Yuan/m^2)
Huangpu	4	126,731
Luwan	1	66,762
Jing'an	3	81,614
Xuhui	19	34,422
Hongkou	15	37,111
Yangpu	24	15,917
Zhabei	19	35,347
Changning	12	30,366
Putuo	21	17,363
Pudong	49	15,350
Jiading	3	9,265
Minhang	29	6,342
Baoshan	67	6,209
Songjiang	45	4,462
Nanhui	45	3,873
Fengxian	45	3,190
Jinshan	28	2,701
Qingpu	4	975
Chongming	20	1,464

Source The land transfer data was collected from the website of Bureau of Planning and Land Recourse Management in Shanghai

In 2005, four parcels of land were leased from the district government of Huangpu for an average price of 126,731 Yuan/m^2, while four parcels in Qingpu leased for an average of 975 Yuan/m^2, approximately 0.77 % of the Huangpu price. The land price decreased dramatically from the core area to the periphery and the suburban area. The average price in each district of Zone I was more than 15,500 Yuan/m^2 which was higher than the most expensive district in the rest of the zones (Table 4).

Differences in land value are reflected in the disparity among average housing prices (Fig. 12). Housing prices across Shanghai have increased significantly from 2002 to 2008. While prices were generally higher in districts of Zone I in 2002 compared to spatial units of other zones, some of them rose astonishingly high in 2008, such as Huangpu, Changning, Hong Kou, Luwan, and Jing'an.

6.4 Economic restructuring, relocation and industrial land use

Shanghai's urban development and spatial differentiation have been directly shaped by economic restructuring. The relocation of traditional manufacturing to the urban periphery, the rise of high-tech manufacturing in development zones, and the growth of producer services in both new and old centers of the city have all been in part driven by the inflow of global capital.

While Shanghai has been the largest manufacturing base in China for over a century, it now has started a journey to transform itself into a global city focused on high-tech manufacturing and producer services, as well as commercial sectors. For instance, in the 1960s and 1970s, secondary and tertiary industries contributed to 70 and 20 %, respectively, of Shanghai's GDP, while the figures had changed to 45.5 and 53.7 % by 2008. Relying on the vast hinterland of the Yangtze River Delta, Shanghai aims to establish itself as the economic and financial center of East Asia, competing with other cities in the region such as Tokyo, Seoul, Hong Kong, and Taipei.

This economic restructuring, however, has varying implications for different districts in Shanghai. At the beginning of the market reform, Shanghai's main economic activities, i.e., manufacturing, were located mostly in the central districts of Zone I. However, in 2008, districts in Zones II and III, i.e., Pudong New Area, Nanhui, Minhang, Jiading, Baoshan, and Jinshan, led in industrial output. By then most districts in Zone I had very little industrial output and tertiary industry accounted more than 90.0 % of their GDP, especially Huangpu, Luwan, Hongkou, Jing'an, and Changning.

The spatial locations of Shanghai's major industrial zones further confirm this uneven pattern (Fig. 13). Most industrial zones, especially manufacturing ones with high levels of pollution, are located in the districts of Zone II. Industries from Zone I were relocated and set up new factories in Zones II and III, causing the environmental quality of districts in Zones II and III to further deteriorate. Currently Zone I has only one state-level development zone (Shanghai Caohejing Hi-tech Park) in Xuhui district, and one municipal-level development in Changning district. The relocation of manufacturing activities from densely populated districts in Zone I has helped to improve the environmental conditions in these districts. For example, the Hetian community in Zhabei district used to be a heavily polluted area due to the chemical industry. Since the relocation of seven plants, along with 1,700 households, Hetian's environment has improved dramatically.[3]

In contrast, districts in Zones II and III have experienced a pollution expansion with the development of manufacturing activities. With three industrial bases, three state-level development zones, and six municipal level development zones, districts in Zone II contributed to over 60 % of Shanghai's total manufacturing output. Excepting Pudong New Area, where the economic structure is characterized by low-pollution and high-value added, high-tech manufacturing, and financial services, other districts have experienced environmental degradation. Similarly, districts in Zone III experienced aggravated environmental

[3] http://www.shtong.gov.cn/node2/node2245/node73963/node73969/node74016/node74046/userobject1ai88852.html.

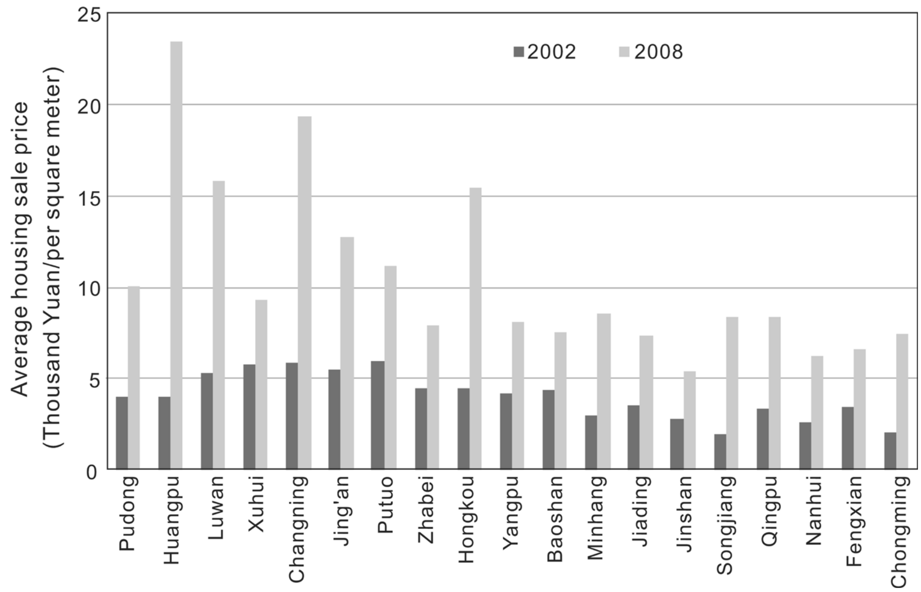

Fig. 12 Contrast of average housing sale price at the district level

pollution as they emerged as new manufacturing bases for Shanghai. Industrial relocation/location can be considered as a major driving force for the expansion of the boundary of the UHI and the declined UHI intensity in the urban core of Shanghai.

It should be noted that the new industrial zones have been strategically planned so that each will specialize in a specific industry. For example, Jiading is focusing on the automobile industry, Baoshan on the steel industry, Minhang on the aerospace industry, Songjiang on machine tools and light industry, Jinshan on petrochemicals, and Pudong on high-tech manufacturing and financial services. In this regard, the distinct development path of Pudong deserves special attention. While some outer districts proceeded along a classical development path from agriculture to industry, and then on to service industries, the Pudong New Area was converted directly from agriculture to high-tech manufacturing and the tertiary sector (especially financial services). Thus, thanks to its role as centerpiece in Shanghai's plan to become the economic and financial center of East Asia, Pudong has partly by-passed the environmental degradation experienced in other districts.

7 Conclusion and implications

This paper studied Shanghai's urban expansion and examined the inter-related economic-environmental evolution of Shanghai at the district level. In combination with other socioeconomic data, we analyzed urban expansion patterns and explained the inter-relationship between economic development and environmental conditions.

We identified different articulations of the relationship between economic development and environmental conditions in different districts within the overarching context of rapid urban expansion. Further we elaborated on a sustainable development model of urban expansion that focuses on the dynamic relationship of economic restructuring and environmental amelioration. Some districts have upgraded their industrial structure to be producer service oriented, thus achieving higher income and lower pollution, such as some districts in Zone I, including Jing'an, Luwan, and Pudong most notably in Zone II. Jiading and Minhang, as Shanghai's current manufacturing centers, are experiencing low environmental quality as an expense for their improved economic conditions. However, some districts in Zone I have succeeded neither in economic restructuring nor in improving environmental conditions. Finally, most districts in Zone III, i.e., Nanhui, Fengxian and Jinshan, still have good environmental quality, as their industrialization has not reached the intensity of other districts.

The land market, economic restructuring, and government have played important roles in Shanghai's urban development. First, the market has induced spatial differentiation and affected the co-evolution of the economy and environment. Due to the relocation of manufacturing from the urban core and the allocation of investment in developing zones, on the one hand, and the proliferation of producer services in both new and old city centers on the other, economic restructuring has had different consequences for different parts of Shanghai. Moreover, the plans and actions of the government have been spatially uneven, which has further differentiated the economic development and environmental conditions of different parts of Shanghai.

Despite its severe environmental problems, Shanghai has also experienced major economic development. Managing the tradeoffs between urbanization and environmental

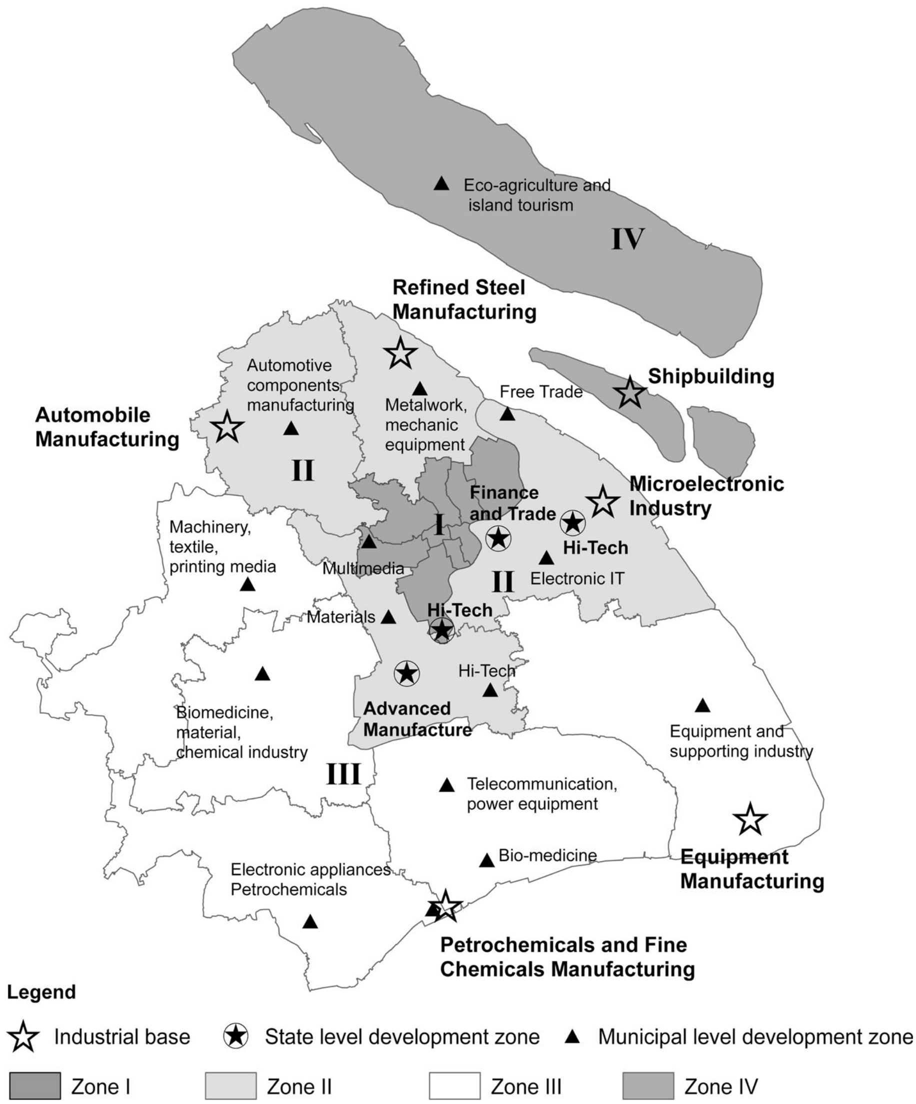

Fig. 13 Location and type of the main industrial zones in Shanghai

protection will be a major challenge for Chinese policy-makers. As many Chinese cities have experienced economic growth and environmental deterioration along with rapid urban expansion, we expect that they may follow Shanghai's past and current footsteps in attempting to achieve sustainable development. We hope the findings from this paper can provide some fresh insights to planners and policy-makers of cities that are pursuing an economically and environmentally sustainable mode of development.

Acknowledgements We would like to acknowledge the funding of Zhejiang Provincial Natural Science Foundation of China (Y5110009), the National Aeronautics and Space Administration (NASA)'s Land Cover and Land Use Program through the grant to Michigan State University (NNX09AI32G), Zhi-Jiang Young Scholars Program through Zhejiang Philosophy and Social Science Planning Project (11ZJQN042YB), Qian-Jiang Talent Program (2011C), the Fundamental Research Funds for the Central Universities (2012X ZZX012), and Lincoln Institute of Land Policy (CYW010511). We would also like to thank Huiqing Huang and Yong Liu for their helps with data processing.

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