Landscape Ecol Eng
DOI 10.1007/s11355-011-0174-z

SPECIAL FEATURE: ORIGINAL PAPER

Landscape change and sustainable development in Yangtze River Basin, China

Variations in air quality during rapid urbanization in Shanghai, China

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Received: 17 August 2009 / Revised: 17 May 2011 / Accepted: 11 July 2011

Abstract Shanghai is the largest commercial and industrial city of China, but air quality issues have hindered its development in becoming a "global city." This study used monitoring data on SO_2, NO_x, acid rain pH, dustfall, and total suspended particles (TSP) from the Shanghai Environmental Monitoring Center to evaluate and analyze the air quality in urban, suburban, and rural areas during the period 1983–2005. The results showed that the spatial pattern of air parameters was determined by the level of urbanization; thus, the higher the level of urbanization, the worse the air quality. On the whole, the atmospheric environment of the three spatial regions improved gradually because of economical growth and environmental protection since the 1990s. For the entire region of Shanghai, the relationship between the integrated air quality index and gross domestic product (GDP) per capita was an N-shaped environmental Kuznets curve (EKC) due to decreasing air quality in suburban and rural areas this century. Thus, environmental controls should be increased in Shanghai, especially in developing suburban and rural areas during rapid urbanization.

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Keywords Variations · Air quality · Urbanization · Shanghai

Introduction

In a span of more than two decades since the 1980s, China has emerged as the world's fourth largest economy. It now ranks third among trading nations, accounting for more than 6% of world trade; it is one of the leading industrial engines of the global economy (World Bank 2006). However, a World Bank report indicates that economic losses caused by environmental pollution in China range from 3% to 8% of gross domestic product (GDP) (World Bank 1997). Air pollution is one of the country's biggest environmental problems. China has become one of the countries most severely affected by acid rain, with a quarter of its regions affected (Jerrett et al. 2005). In 2004, results from routine monitoring of 360 cities in China revealed that the air quality of nearly 70% of urban areas did not meet national ambient air quality standards, and that nearly 75% of urban residents were regularly exposed to air considered unsuitable for inhabited areas (Shao et al. 2006).

As China's economic center and with annual GDP increase of almost 10% due to reform and opening policies, Shanghai's population increased from 10.9 million in 1978 to 13.6 million in 2005 (Shanghai Statistical Bureau 1984–2006). Greater Shanghai's urbanization level was 84.5% in 2005, while that for the nation stood at only 43.0%. With this dramatic economic development and the accompanying population increase, problems of air pollution have become severe and are obstacles to sustainable development.

Many published studies focus on the air problems of urban areas, because of their special importance and challenges (Sengupta et al. 1996; Gargava and Aggarwal

Published online: 19 August 2011

1996; Collett et al. 1997; Fenger 1999; Ma et al. 2004; Xu et al. 2005; Vardoulakis et al. 2005; Singh et al. 2005). Some research compares air quality in different spatial regions, such as urban, suburban, and rural areas (Putaud et al. 2004; Harrison et al. 2004; Ziska et al. 2004; Hueglin et al. 2005; Luhar et al. 2006), or residential, industrial, and agricultural regions (Garg et al. 1995). On the temporal scale, some scholars study daily or seasonal variations of air parameters, with periods of monitoring data limited to 1–2 years (Wilson et al. 2006; Huang and Zhang 2006; He et al. 2006). Changes in the atmospheric environment have also been studied on both the temporal scale and by spatial region (So and Wang 2003; Sun et al. 2004), but the time periods of these studies have been limited to a few recent years. For Shanghai, many papers have discussed the impacts of air pollution on human health (Tao et al. 1992; Kan and Chen 2004; Li et al. 2004). Others deal mainly with the various sources of atmospheric pollutants (Shu et al. 2001; Li et al. 2003), and air pollution as a consequence of rapid urban expansion (Zhao et al. 2006).

It is well known that there are tight relationships between environment quality and economic growth. The environmental Kuznets curve (EKC) (Grossman and Krueger 1991) hypothesizes that the relationship between per capita income and emission of wastes has an inverted U-shape, and this curve can be modified by environmental policies. For Shanghai, many policies to reduce air pollution have been implemented since the 1990s, which was also a period of fast urban expansion. The trend of air quality as a function of these two opposite effects remains unclear. In this study, we (1) analyze variations of the atmospheric environment in three distinct regions, urban, suburban, and rural, in Shanghai from 1983 to 2005, and (2) determine the relationship between air quality and economic development to understand how urban expansion and environmental policies act on trends in air quality. The study may provide material to aid sustainable development of the atmospheric environment in developing cities worldwide.

Methods

Study area

Shanghai is located on the eastern coast of China, south of the Changjiang (Yangtze) River Estuary, at 31°14′N and 121°29′E (Fig. 1). The total municipal area is 6,340.5 km^2. It has a subtropical monsoon climate with four distinct seasons. The average temperature is 18.1°C with 1,158.1 mm rainfall and 104 sunny days.

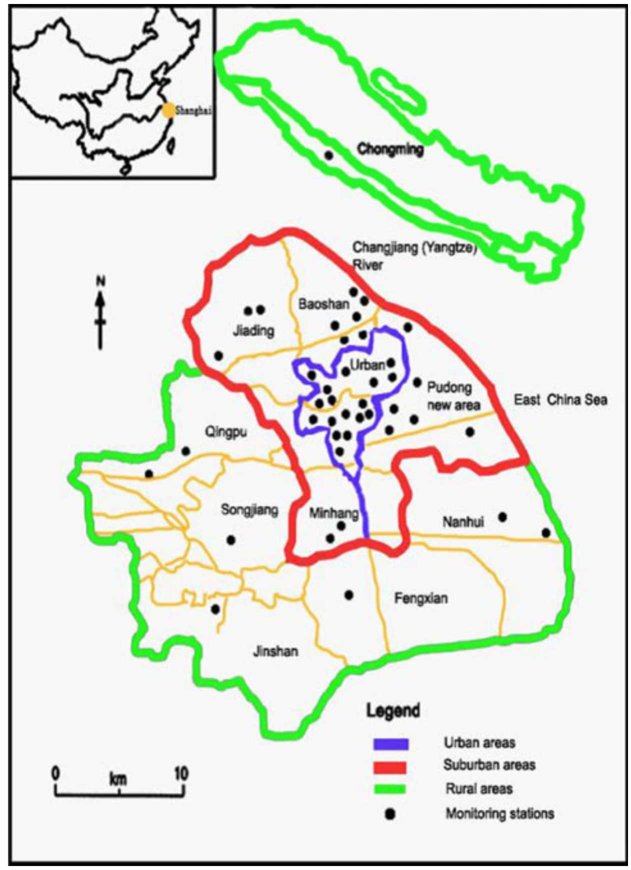

Fig. 1 Locations of Shanghai administrative areas and monitoring stations

Administrative territories of Shanghai are redivided continually, but the urban areas remain unchanged. The administrative territory of suburban areas expanded from four districts in 1992 to nine districts in 2005, while its total area increased from 1,624.2 to 4,865.6 km^2. The administrative territory of rural areas, whose total area was 4426.8 km^2 in 1992, shrank from six counties to one in 2005, with total area of just 1185.5 km^2. To date, only Chongming is a rural area, but the other five administrative areas, which are Nanhui, Fengxian, Songjiang, Jinshan, and Qingpu, still contain substantial rural land and a number of rural residents who continue to farm for their livelihood. Thus, in this study, to characterize regional and temporal variations of air quality, Shanghai was divided into three distinct regions: urban, suburban, and rural, based on the administrative divisions of 1992. The central urban area includes 10 districts, adjoined by four suburban areas. Five rural divisions are more distant (Fig. 1). General descriptions of the three regions are presented in Table 1. The division of spatial regions shows that the process of urbanization starts from the center of city, then gradually spreads to the suburban and rural areas.

Table 1 General description of urban, suburban, and rural areas in 2005

Region	District	Area (km^2)	Population density (per km^2)
Urban areas	Huangpu, Nanshi, Luwan, Xuhui, Changning, Jing'an, Putuo, Zhabei, Hongkou, Yangpu	289.4	21,283
Suburban areas	Pudong New Area, Minhang, Baoshan, Jiading	1,624.2	2,469
Rural areas	Nanhui, Fengxian, Songjiang, Jinshan, Qingpu, Chongming	4,426.8	775

Source: Shanghai Statistical Bureau, 1983–2006

Table 2 General monitoring method, sampling instrument, sampling height, and analytical instrument of monitoring parameters

Parameter	Monitoring method	Sampling instrument	Height of sampling point (m)	Analytical instrument
SO_2	Manual	Continuous constant-temperature sampling instrument	5–15	Spectrophotometer
	Automatic	SO_2 monitoring instrument	12–21	SO_2 monitoring instrument
NO_x	Manual	Continuous constant-temperature sampling instrument	5–15	Spectrophotometer
	Automatic	NO_x monitoring instrument	12–21	NO_x monitoring instrument
Acid rain	Manual	Rainfall collector	5–15	Acidimeter
Dustfall	Manual	Integration barrel	5–15	
Total suspended particicular	Manual	Total suspended particicular sampling instrument	5–15	Balance

Source: Shanghai Environmental Protection Bureau 1984–2006

Data source

Systematic monitoring on atmospheric environment in Shanghai was started in 1983. Thus, the study covers the period 1983–2005. To reflect variations of air quality synthetically on spatial and temporal scales, five representative parameters including sulfur dioxide (SO_2), nitrogen oxide (NO_x), acid rain pH, dustfall, and total suspended particles (TSP) were selected based on the indices of the ambient air quality standard of China or Shanghai. The yearly average data in this study were provided by the Shanghai Environmental Monitoring Center (Shanghai Environmental Protection Bureau 1984–2006), and are scientifically valid. The general monitoring methods, sampling instruments, sampling height, and analytical instruments are presented in Table 2, and 42 (17 in urban area, 17 in suburban area, and 8 in rural area) monitoring stations are indicated in Fig. 1.

SO_2, NO_x, acid rain pH, and dustfall were the conventional monitoring items during a period of 23 years. Because the equipment necessary for actual monitoring work was not available earlier, TSP was only monitored from 1989. Their data on temporal scales are not available from 1983 to 1988 and 1990, respectively.

Air quality evaluation

To evaluate overall air quality, we use an integrated air quality index, which is an alternative Nemerow index and reflects both maximum and average values of concentrations of pollutants relative to their objective air quality standard (Liu et al. 2007):

$$\overline{P} = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{C_{oi}}\,(i = 1, 2, \ldots, n), \quad (1)$$

$$X = \max\left(\frac{C_1}{C_{o1}}, \frac{C_2}{C_{o2}}, \ldots, \frac{C_n}{C_{on}}\right), \quad (2)$$

$$I = \sqrt{X \times \overline{P}}, \quad (3)$$

where C_i/C_{oi} is the air quality index relating the observed concentration C_i of pollutant i with its objective air quality standard concentration C_{oi}; n is the number of monitoring parameters, in this research $n = 5$; $\overline{P}$ is the average of the five air quality indices; X is the maximum value of the five air quality indices; I is the integrated air quality index. The higher the integrated air quality index, the worse the air quality.

This index was first proposed in 1979 (Yao 1979) and has been widely used for air quality evaluation in China.

Table 3 Values of air pollutant standard concentration for three grades

Pollutant	Data time	Grade			Concentration unit
		Grade I	Grade II	Grade III	
SO_2	Yearly average	0.02	0.06	0.10	mg/m^3
NO_x	Yearly average	0.05	0.05	0.10	mg/m^3
TSP	Yearly average	0.08	0.20	0.30	mg/m^3
Dustfall[a]	Monthly average	10.0			ton/km^2
Acid rain pH[a]	Yearly average	≤5.6			/

Sources: Ambient Air Quality Standard of China (State Environmental Protection Administration 1996)

[a] Ambient Air Quality Standard of Shanghai reported on Environmental Quality of Shanghai 1983–2005 (Shanghai Environmental Protection Bureau, 1984–2006). *TSP* total suspended particles. The air pollutant standard concentrations of grade I are used to assess air quality in natural or special protected area. Grade II is used in residential, cultural, general industrial, and rural areas. Grade III is used in special industrial areas

The only difference between the Nemerow index and our index is the calculation of I, which is the root mean square (RMS) of X and P for the former and the geometric mean (GM) of X and P for the latter. Both methods have the function of reflecting the contribution of the maximum and average values of concentrations of pollutants to the air quality. Although the RMS value is equal to or slightly larger than the GM for the same data, this will not influence the air quality comparison over time and across space in our research when using the same method.

The objective air quality standard C_{oi} was obtained from the Ambient Air Quality Standard of China (State Environmental Protection Administration 1996) and the Ambient Air Quality Standard of Shanghai reported on Environmental Quality of Shanghai (Shanghai Environmental Protection Bureau 1984–2006). For acid rain pH and dustfall, we chose the Shanghai standard to define C_{oi} due to the lack of a national standard. For the other parameters, the grade II standard in the national standard was chosen for C_{oi} (details in Table 3).

The integrated air quality index was calculated for each monitoring station from 1983 to 2005. The integrated air quality indices for urban, suburban, and rural areas were calculated using the average values of monitoring stations in each area. The mean value of all monitoring stations in Shanghai was calculated as an integrated pollution index for Shanghai.

Economic framework

To understand the relationship between air quality and economic development, we determined the variation trend of the integrated air quality index with economic growth. We introduced the economic dimension into our analyses by using the per capita GDP to indicate the level of economic growth (Liu et al. 2007; Wang et al. 2008). Polynomial formulas were used to fit the curve between GDP per capita and integrated air quality index.

The most widely applied description of the polynomial fit to the curve between GDP per capita and integrated air quality index is an inverse U-shaped curve according to the hypothesis of the environmental Kuznets curve (EKC) (Grossman and Krueger 1991). This describes a process in which environmental quality first decreases due to fast economic development with lower nature resource utilization ratio, then increases due to pollution treatment and improving management under sustainable economic development; this process is called “pollution first, treatment after” (Wang et al. 2008). However, there are other kinds of relationships, namely the monotone-increasing, U-shaped (Robert et al. 1998) and N-shaped curves (Bruyn and Opschoor 1997; Fried and Getzner 2003). The N-shaped curve is an extension of the inverse U-shaped, reflecting a tendency for environmental quality to decrease again. The monotone-increasing, U-shaped curve is considered to be a short-time segment of an inverse U-shaped or N-shaped curve.

As GDP per capita data were only available for the whole City of Shanghai (Table 4), the relationship between integrated air quality index and GDP per capita could only be developed at the whole city level. However, the ordination of GDP per capita was the same with time series in 1983–2005, so we can interpret the air quality variation along the economic dimension by analyzing the trend in air quality over time for urban, suburban, and rural areas.

Results

Temporal variations of five air parameters in three distinct regions

From 1983 to 2005, the actual monitoring concentrations of SO_2, NO_x, dustfall, and TSP were the highest for urban areas, followed by suburban areas, then rural areas except for acid rain pH (Fig. 2). The results also showed that SO_2

Table 4 GDP per capita (in 1985 purchasing power parity, US$) and the integrated air quality index of Shanghai from 1983 to 2005

Year	GDP per capita (US$)	Integrated air quality index			
		Urban	Suburban	Rural	Shanghai City
1983	1,007.82	1.50	0.69	0.70	1.32
1984	1,108.50	1.40	0.65	0.66	1.23
1985	1,311.22	1.53	0.62	0.63	1.29
1986	1,363.27	1.56	1.02	0.66	1.29
1987	1,495.24	1.51	1.10	0.70	1.29
1988	1,755.44	1.48	1.09	0.72	1.30
1989	1,867.01	1.64	1.23	0.77	1.45
1990	2,010.20	1.55	1.36	0.75	1.41
1991	2,365.65	1.66	1.31	0.77	1.40
1992	2,942.86	1.50	1.32	0.73	1.32
1993	3,979.59	1.37	1.00	0.62	1.14
1994	5,171.43	1.33	1.08	0.63	1.11
1995	6,442.86	1.23	1.02	0.69	1.05
1996	7,576.53	1.37	0.92	0.70	1.03
1997	8,758.50	1.53	0.85	0.68	1.06
1998	9,605.44	1.42	0.83	0.65	1.00
1999	10,477.89	1.33	0.74	0.65	0.98
2000	11,750.68	1.23	0.73	0.64	0.96
2001	12,714.97	1.24	0.77	0.63	0.82
2002	13,825.17	0.92	0.73	0.66	0.91
2003	15,890.48	0.94	0.73	0.60	0.92
2004	18,811.90	1.03	0.85	0.64	1.01
2005	22,956.46	1.00	0.81	0.62	1.00

and dustfall in urban areas decreased gradually from 1986 to 2002. However, SO_2 in suburban and rural areas was below the average for the whole period from 1983 to 2005. Only in urban areas did concentrations of NO_x increase substantially. The actual monitoring concentrations of TSP in urban and suburban areas dropped gradually between 1989 and 2000. Acid rain pH mostly varied between 4.5 and 5.5 (Fig. 2).

Compared against values of air pollutant standard concentrations for China or Shanghai, we found that the SO_2 and NO_x concentrations of rural areas between 1983 and 2005 were lower than the grade I air pollutant standard concentration, and acid rain pH was lower than the yearly average value of air pollutant standard concentration for Shanghai. Thus, acid rain pH of urban, suburban, and rural areas was not better than the Shanghai standard due to the harmful effects of low pH. The acid rain pH of rural areas was better than the Shanghai standard in 1989 and 1990, which suggests that the air pollutant concentration of the rural areas was better than those of suburban and urban areas. The SO_2 concentration of urban areas after 1998 and TSP concentration of urban areas after 1999 did not exceed the grade II values. However, the NO_x concentration of urban areas from 1986 to now exceeded grade II, though the values declined from 1997 to 2003. We also found that the SO_2 concentration of urban and suburban areas, and the NO_x concentration of suburban areas displayed a relatively fast upwards trend from 2002 to now (Fig. 2).

Temporal variations of integrated air quality index in three distinct regions

According to the integrated air quality index, we found that the air quality of the urban areas was the worst, followed by suburban areas, then rural areas (Fig. 3a–c). Figure 3a shows that the integrated air quality index for urban areas increased in the first period of the 1980s and then decreased in the early period of the 1990s. With respect to suburban areas, the index increased in the first period of the 1980s, but decreased in the early of 1990s, and then increased in the early 2000s. The integrated index of rural area displayed a relatively stable trend (Fig. 3b, c). The annual variations in suburban areas showed an N-shaped curve, while urban areas displayed an inverted U-shaped curve reflecting a developing phase of “pollution first, treatment after” in urban areas.

Relationship between integrated air quality index and economic development

As shown in Wang et al. (2008), the average level of urbanization for urban areas was 100% based on the three censuses of China of 1982, 1990, and 2000. The average urbanization levels for suburban were 31.7%, 44.0%, and 58.9% in 1982, 1990, and 2000, respectively. The average urbanization levels for rural areas were 10.0%, 14.0%, and 29.8% in 1982, 1990, and 2000, respectively. In these years, the order of urbanization levels was urban > suburban > rural areas. The levels of urbanization of suburban and rural areas displayed an increased trend, indicating that air quality negatively correlated with the level of urbanization on the spatial scale.

For the entire region of Shanghai, the growth of GDP per capita and the integrated air quality index were related by an N-shaped curve (Fig. 4). The integrated air quality index increased before GDP per capita reached about US $2365.65 in 1991 (in 1985 purchasing power parity), and then the index decreased. Nevertheless, when the GDP per capita reached US $13,825.2 in 2002 (in 1985 purchasing power parity), the integrated air quality index again showed a tendency to increase (Fig. 4; Table 4).

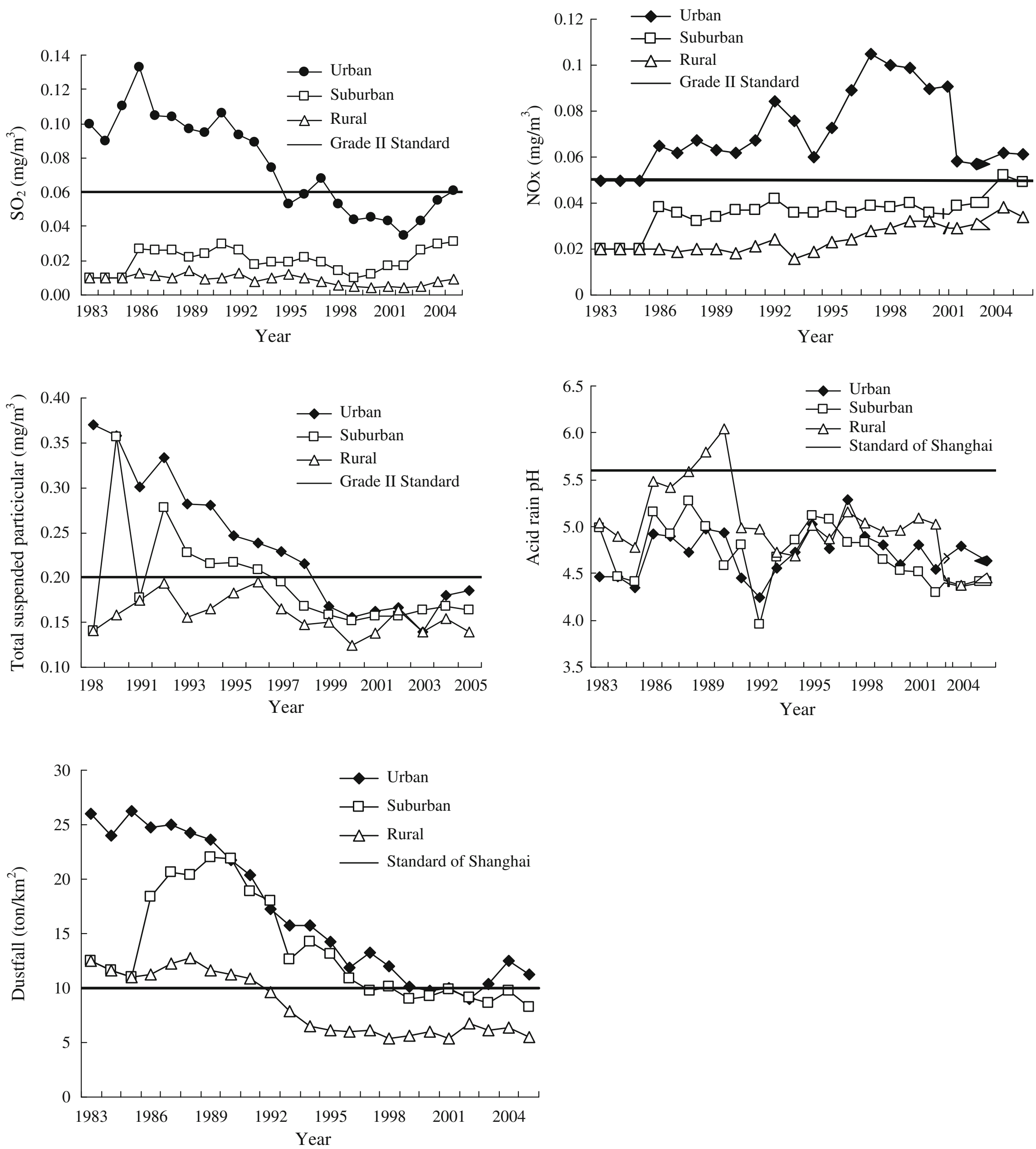

Fig. 2 Variations of five air parameters (SO_2, NO_x, TSP, acid rain pH, and dustfall) from 1983 to 2005

Discussion

The spatiotemporal pattern of air quality: combination of urbanization and environmental policies

Along the urban–rural gradient, there was distinct difference of air quality in Shanghai from 1983 to 2005. The integrated index and most pollutants showed an increasing tendency from rural to urban. Study in Switzerland also showed that the SO_2, NO_2, and particulate material (PM) of any size fraction were greatest in urban areas, while suburban areas had intermediate levels and rural areas had the lowest levels (Monn et al. 1999). Berry and Colls (1990) indicated that there was a weak trend for increasing CO_2 and SO_2 towards the city during the winter. In Philadelphia, SO_2 was an order of magnitude greater in the city center than in suburban areas and the countryside, because more pollutants were emitted in the city and concentrated in the city center due to centripetal air movement into the urban heat island (Feddema and Meieriding 1987).

Shanghai's air pollution mainly stems from three sources: (1) Industrial emissions: the industrial emissions of

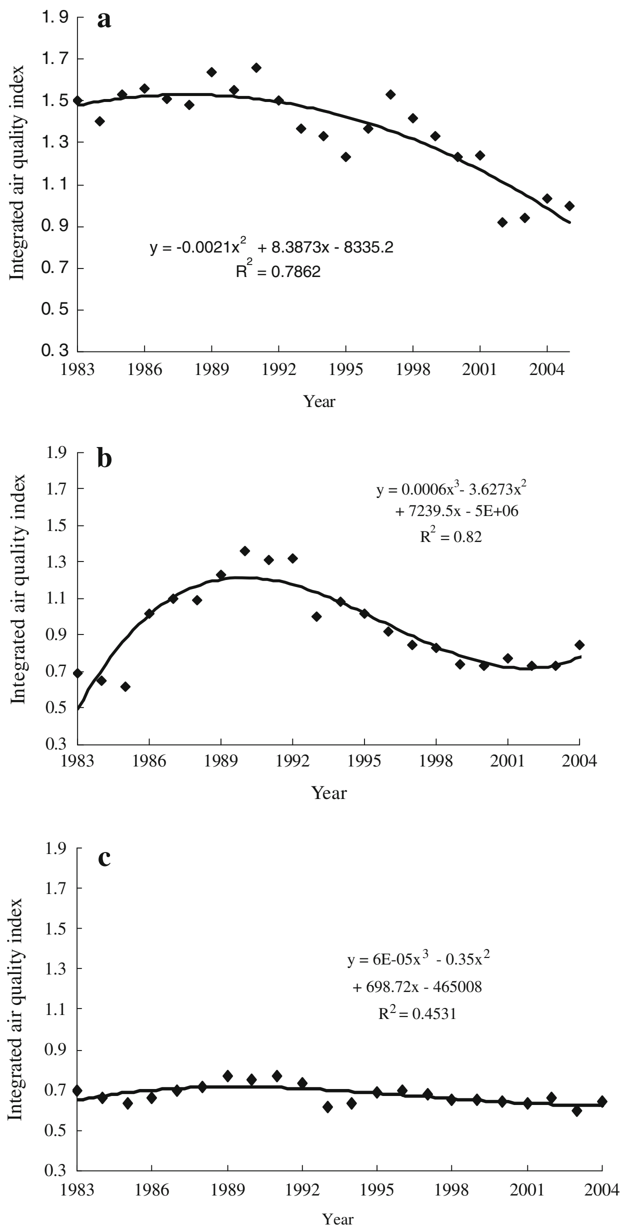

Fig. 3 Polynomial fit of annual variations in different distinct regions: **a** urban areas, **b** suburban areas, and **c** rural areas

total exhaust gas increased from 86.6% in 1991 to 93.2% in 2005 (Shanghai Statistical Bureau 1984–2006). The process of urbanization is closely related with industrialization. Urban planning has been primarily driven by industry distribution rather than optimizing the multiple functions that a normal city would usually have (Wu 1999). (2) High population density: the urbanization level can be measured by population growth in a developing city. Most of the resident and floating populations gather in urban areas. Because of the high population density, taxicabs, passenger vans, and buses often appear in urban centers to provide for

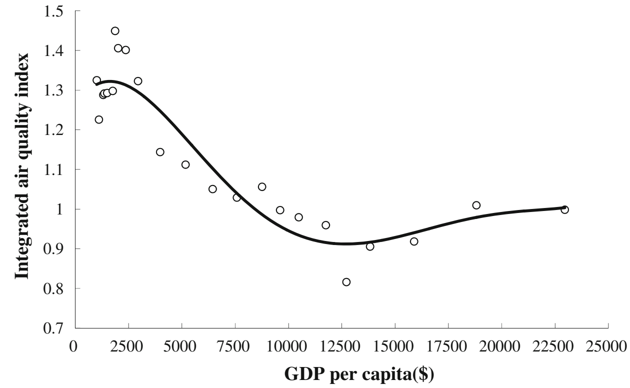

Fig. 4 Relationship between GDP per capita and integrated air quality index in Shanghai, 1983–2005 (in 1985 purchasing power parity, US$)

the transportation needs of the population (Energy Information Administration 2000). These vehicles are the primary source of air pollution in China's major cities, responsible for 50–60% of air pollution (Weisbrod 1999). In 1999, motor vehicles accounted for 56% of total NO_x emissions in downtown Shanghai (Huang et al. 2001). (3) Special land uses: special land uses such as many-storied buildings, armored concrete construction, and low fractional coverage by green areas are generally found in the parts of Shanghai with high urbanization levels. If crops in suburban and rural areas are counted as green plants, the spatial difference would be even greater.

The results for the integrated air quality index reflect that Shanghai experienced a development process of "pollution first, treatment after," similar to that in most cities in developed countries (Krupa and Legge 1995; Fenger 1999). At a high cost in terms of environmental degradation, after 1978, Shanghai entered its fast development phase. Industrial emissions, population density, and special land uses were the main reasons for the increase of the integrated air quality index between 1983 and 1991. Fast economic development forced the government to take measures for the protection of the environment, and air quality improved after 1991. Three reasons could be conducive to this shift: (1) Environmental investment rose from US $0.26 billion in 1991 to US $33,614.88 billion in 2005 (in 1985 purchasing power parity), reaching 3.07% of the GDP of Shanghai (Shanghai Statistical Bureau 1984–2006). (2) Since the late 1980s, the conditions of the infrastructure have been further improved; for example, between 1978 and 2005, the fractional coverage by green areas to whole land increased from 8.2% to 37% (Shanghai Census Bureau 2005). Green area of urban gardens reached 288.65 km^2 in 2005, 37.9 times the value in 1978. (3) By adjusting the industrial structure, increasing the rate of residential coal-gas use and secondary energy use, establishing dust control areas, strengthening the management of construction areas, and constituting the Three-Year Environmental Action Plans (2000–2002, 2003–2005, and 2006–2008), the atmospheric environment in Shanghai was gradually improved in the early 1990s. However, the integrated air quality index showed an increasing trend in suburban areas after 2002, which suggests that pollution in suburban areas is starting to increase, which might be a significant future problem in suburban areas if the situation continues in the same trend. In particular, the NO_x density in suburban areas in recent years became 0.05 mg/m^3, which exceeds the environmental standards value. The main reason may be that the increasing urbanization level leads to an increasing number of motor vehicles, combined with air flow shaped by the urban heat island effect (Zhao et al. 2006).

N-shaped EKC: a characteristic for a region under fast urban expansion

Our results showed that the relationship between integrated air quality index and economic development in Shanghai exhibits an N-shaped curve. This result is inconsistent with the common environmental Kuznets curve (EKC) proposed by many scholars, such as Grossman and Krueger (1991), Panayotou (1997), de Bruyn et al. (1998), Sun (1999), and Taskin and Zaim (2001), indicating that pollution levels may exhibit an inverse U-shaped curve with respect to per capita income. According to the analysis by Grossman and Krueger (1995) and other scholars of data collected from different countries and regions, air quality deteriorates when GDP per capita reaches US $5,000–8,000 (in 1985 purchasing power parity, the same lower) (Zhao et al. 2005). Beyond this economic level, environmental quality will gradually improve. However, in our research, when GDP per capita reached about US $2365.65 for the entire region of Shanghai in 1991, atmospheric environment was already exhibiting improvement. This economic level at which environmental quality started to improve is lower than the range of US $5,000–8,000 (Zhao et al. 2005). In a study of temporal variation of surface water quality in Shanghai, Wang et al. (2008) pointed out that the relationship between the integrated water quality index and GDP per capital was inverse U-shaped with a turning point of US $6442.9 in 1995, which is larger and earlier than the turning point in our research. It is known that policies can change the shape of the EKC by forcing it to become flatter or making the turning point come earlier (Forms and Boyce 1998). In China, the first environmental problem in urban areas attracting attention was air pollution (Ke et al. 2002), before water pollution. So, in Shanghai, a series of initiatives were implemented to ameliorate air pollution, earlier than activities for water pollution control.

Nevertheless, when GDP per capita reached US $13,825.2 in 2002, the integrated air quality index again showed a tendency to increase. After 2001, the integrated air quality index of urban and suburban areas showed an increasing trend (Fig. 3), mostly contributed by increasing SO_2 and NO_x (Fig. 4). Also, an increasing trend of the integrated water quality index was observed in rural areas of Shanghai after 2000 (Wang et al. 2008). These results suggest that the increasing trend this century can mainly be attributed to the fast economic development in suburban and rural areas, especially increasing numbers of motor vehicles and industry (Zhao et al. 2006). Besides, the population density in suburban areas increased from 1,407 person/km^2 in 1983 to 2,469 person/km^2 in 2005, while the density in urban areas began to decrease after 1994 (Wang et al. 2008). This high population density brought more consumption-related pollutants, causing greater environmental pressure in suburban areas.

The N-type EKC has not only been found for Shanghai. It was also observed in Beijing by analysis of the emission load of SO_2 from 1986 to 2006 (Mu 2008). Shen and Xu (2000) noted that the relationship between GDP per capita and environmental pressure was an N-type EKC from 1981 to 1998 in Zhejiang Province. All these regions are under fast urban expansion with high economic growth rate (Zhao et al. 2006). So, we consider that the N-type EKC cloud be a trait for regions under fast urban expansion in China, because in such regions, the growth rate of environmental investment is slower than the rate of economic growth, and most environmental efforts focus on pollution treatment in urbanized areas while fewer activities are applied to prevent pollution in suburban and rural areas which face fast urbanization. Therefore, this research suggests that decision-makers and city officials should be more aware of the risk of environment degradation in suburban and rural areas facing fast urban expansion in Shanghai, and throughout China.

Conclusions

In this study, long-term, systematic atmospheric environmental monitoring data from 1983 to 2005 were used to evaluate the air quality in urban, suburban, and rural areas of Greater Shanghai. As a whole region, the relationship between environmental quality and economic development exhibits an N-shaped curve, which was considered to be the result of fast urbanization in suburban and rural areas.

The Shanghai Municipal Government has set itself the goal of making Shanghai a global city, but environmental degradation has been a stumbling block during the period of economic development. More measures should be taken to improve air quality: changing the mode of economic growth, promoting energy diversification, controlling the number of vehicles according to road capacity, prohibiting use of vehicles that do not meet exhaust requirements, controlling the distribution of enterprises, and learning from the lessons of urban areas and other developed countries.

Acknowledgments We would like to thank the anonymous reviewers and managing editor for constructive comments and suggestions. This research was supported by the National Natural Science Foundation of China (40971041), the Science and Technology Ministry of China "11th five-year" Key Science and Technology Supported Project (2008BAJ10B04), and Tokyo University of Information Sciences, which is funded by Ministry of Education, Culture, Sports, Science, and Technology (MEXT) support program S0801024.

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