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H. H. Ho
State University of New York at New Paltz


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Eco-health evaluation for the Shanghai metropolitan area during the recent industrial transformation (1990–2003)

Hao Zhang[a,*], Xiangrong Wang[a], Hon H. Ho[b], Yi Yong[a]

[a]Department of Environmental Sciences and Engineering, Fudan University, 220 Handan Road, Shanghai 200433, China
[b]Department of Biology, State University of New York at New Paltz, 75 S. Manheim Blvd., Suite 9, New Paltz, NY 12561, USA

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Abstract

Shanghai is a cosmopolitan city and one of the most important economic centers in China, but is saddled with serious environmental problems resulting from a recent industrial transformation. This paper examines the interactive relationships between economic growth, eco-efficiency of urban metabolism, and environmental performance of the Shanghai metropolitan area since the 1990s using 15 indicators. This study has revealed an enhanced eco-efficiency of water and energy use as well as an improved overall environmental quality in the central urban districts of Shanghai. Both TGDP (total GDP) and GDP per capita increased rapidly at the annual rate of 16.28% and 15.91%, respectively. In contrast, energy consumed per 10 000 RMB YUAN GDP (ECG), water consumed per 10 000 RMB YUAN GDP (WCG), wastewater discharged per 10 000 RMB YUAN GDP (WWDG), and waste gases emitted per 10 000 RMB YUAN GDP (WGEG) decreased at the annual rate of 9.34%, 10.69%, 14.57%, and 8.52%, respectively. The rapid decline in ECG, WCG, WWDG, and WGEG indicates an enhanced eco-efficiency of urban metabolism. However, uncontrolled emission of wastes from domestic instead of industrial sources adversely affected the overall environmental quality. In addition, suburban areas have undergone rapid economic growth at the cost of human health deterioration, as measured by mortalities and relative mortality ratios of three major diseases (tumor, respiratory disease, and trauma/toxicosis). With Shanghai serving as the "locomotive" driving the economy of the Yangtze River Basin, effective pollution control policies and a network of regional coordination are urgently needed in the globalization and ecological security of the entire area.

Keywords: Shanghai metropolitan area; China; Environment; Sustainable development; The Yangtze River Basin

1. Introduction

Shanghai has historically been an important economic center to China though its character has changed over time. In the 1920s–1930s, Shanghai was well known as the largest financial center in the Far East (Shen, 1994). Shanghai remained important, but its significance shifted. In particular, during the period of 1949–1978, it was transformed into China's most important industrial city, which negatively degraded Shanghai's economy and environment. Even after a national strategy of 'opening the door to the world and economic reforming' was launched in 1978, this city remained relatively unchanged. At that time, Shanghai's economic development lagged behind cities in the Pearl River Delta. A new era, however, began in 1990 when the Chinese Central Government declared that the Pudong New Area would be open to international investment. Since then, the Shanghai municipal government put forward the 21st Century Renaissance Strategic Plan, aiming at developing the city into an international economic, financial, and trade center to drive the economic growth of the Yangtze River Basin (Wu, 2000).

During the last decade, vast foreign and domestic investments, high quality labor and huge market demands

*Corresponding author. Tel.: +86 21 55664052; fax: +86 21 65643343.
E-mail address: zhokzhok@163.com (H. Zhang).

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have greatly contributed to Shanghai's success in meeting its goals. As a result, it has now become a successful globalizing city, with approximately 13 million permanent residents by the end of 2003 (Shanghai Municipal Statistics Bureau, 2004). In addition, propelled by the recent urbanization of the Shanghai metropolitan area, which consists of central urban districts and rapidly urbanizing suburban districts, the city has become the powerful "economic locomotive" of the Yangtze River Basin. However, with the rapid urban sprawl and intense population pressure, local residents were subject to heavy air pollution, urban heat island, water shortage, and land subsidence. Thus, Shanghai is also one of the mega cities within China's eastern coastal economic zones with severe environmental problems.

In 2000, the Shanghai municipal government announced a Development Blueprint for the next century, aiming at establishing an international eco-megalopolis with a healthy environment by 2020. Local authorities have since made many efforts to reinforce integrated urban environmental development. For example, as part of achieving the targets set for the coming 2010 EXPO in Shanghai, many traditional industrial polluters within Shanghai's central urban districts were forced to adopt more technologically advanced and eco-friendly techniques; otherwise, they were closed or moved. Simultaneously, urban green spaces spread steadily, and the smoke and dust control areas expanded gradually. The urban region of Shanghai (the current central urban districts after district rezoning in 1999) benefited greatly from enhanced environmental quality during the past decade (Yuan and James, 2002). However, the over-dense urban population, historically irrational urban planning and industrial layout resulted in problems achieving the recent urban regeneration and the overall environmental improvement. The local population was subject to severe air pollution, urban heat island, and water shortage. Hence, if judged in an ecological sense, this city is still far less green and healthy than other large cities such as London, Paris, Stockholm, and Shenzhen.

Previous studies of Shanghai's specific environmental situation, such as the urban heat island, air pollution and non-point agricultural pollution are abundant. However, comprehensive studies evaluating the overall environmental quality and its impact on human health during the rapid development stage are relatively scarce, except for some sporadic papers on human health (Jin et al., 1999; Tao et al., 1999; Ye et al., 1999; Peng et al., 2002; Kan et al., 2004; Kan and Chen, 2004; Liu et al., 2004). A better understanding of the environmental performance of Shanghai during the rapid urbanization is essential for making rational decisions to improve the quality of the environment. Thereby, the objectives of this study focused on (1) analyzing interactive relationships between economic growth and the eco-efficiency of energy and water metabolism and the environmental performance of rapid urbanization in Shanghai and (2) examining the dynamics of the overall environmental situation and the response of the local population health to the environmental during 1990–2003.

2. Materials and methods

2.1. Data collection

The socio-economic data for this study were extracted from several official publications, such as the China Statistical Yearbook (National Bureau of Statistics of China, 1991–2004) and the Shanghai Statistical Yearbook (Shanghai Municipal Statistics Bureau, 1991–2004). Environmental data were extracted from the Shanghai Environmental Bulletin (1990–2003) as well as the 10th five-year planning task for Shanghai environmental protection (2001–2005), both of which were issued by the Shanghai Environmental Protection Bureau (SEPB). Data on water resources were obtained from the Water Resource Bulletin (1998–2003), which was issued by the Shanghai Water Affairs Bureau (SWAB). Moreover, unpublished data provided by SEPB and SWAB were used to verify the accuracy of official published data during the same period.

2.2. Data interpretation

Human health condition is very important to maintain a sustainable human-dominated ecosystem. Although natural ecosystem health can be measured by vigor, organization, and resilience (Costanza, 1992; Rapport, 1992; Rapport et al., 1998), it is still difficult to compile complex indicators to evaluate the human-dominated ecosystem, due to the complicated interaction of natural and socio-economic systems. Until now, there were few case studies assessing the urban health of China's large cities such as Beijing, Shanghai, Guangzhou, and Ningbo (Guo et al., 2002; Hu et al., 2005; Zeng et al., 2005). Moreover, the indicator systems in these studies were complicated, so they could not readily be adopted to evaluate Shanghai. As shown in recent studies, some simple but well designed indicators in relation to eco-efficiency worked better when used to examine the relation between human health and ecological risk (Newman 1999; DeSimone and Popoff, 1997; Warren-Rhodes and Koenig, 2001; Yuan and James, 2002).

The scientific criteria for the improved indicator selection used in this study include the following features:

- *Simplicity*: Simple and effective indicator systems were used, thereby overcoming the difficulties of prior studies in selecting and constructing complicated indicators.
- *Validity*: It is the foundation of providing the valid data. Hence, aside from the published data sources, unpublished data authorized by the relevant administrative agencies such as SEPB and SWAB were used.
- *Comparability*: In order to explore the data and related information on local and national scales, comparable variables were used to draw the conclusions.

- *Integrity*: In addition to routine socio-economic indicators, indicators of urban metabolism, mortalities, and relative mortality ratios of major diseases of population on local and national scales were considered.

The following 15 indicators in 3 categories were selected to evaluate the eco-health of the Shanghai metropolitan area:

(1) *Population and economic output*: Population and economic output are the driving forces of social development. However, because of the pressure on resource consumption, they can also adversely affect the environment. Herein, three indicators were adopted:

TPOP: Total population (in units of million).
TGDP: Total gross domestic production (in units of 100 million RMB YUAN).
GDP per capita: In units of RMB YUAN.

(2) *Intensity and eco-efficiency of urban metabolism*: Urban metabolism is increasingly used to understand the intensity and eco-efficiency of human-dominated ecosystems as well as its impacts on the environment (Warren-Rhodes and Koenig, 2001; Yan and Huang, 2003; Yu and Huang, 2005). Urban metabolism is defined by the amount of water and energy consumption as well as the impacts on the environment by the emission of pollutants. Herein, six indicators were employed for measurement of intensity and eco-efficiency of urban metabolism.

TWW: total wastewater discharged annually (in units of ton).
TWG: total waste gases emitted annually (in units of m^3).
ECG: energy consumed per 10 000 RMB YUAN GDP, unit of which is converted to tons of standard coal energy.
WCG: water consumed per 10 000 RMB YUAN GDP (in units of ton).
WWDG: wastewater discharged per 10 000 RMB YUAN GDP (in units of ton).
WGEG: waste gases emitted per 10 000 RMB YUAN GDP (in units of m^3).

(3) *Health response of population to the environment*: To a certain extent, human health serves as a reliable indicator of the environment (Li et al., 2000; Azin et al., 2001). Age-adjusted mortalities and relative mortality ratios of major diseases were used to measure overall human health relative to the environment.
RMR_{Sh}: Relative mortality ratios of major diseases (detailed description was shown in Section 3.4), indicating the potential response of population health to the environment on a local scale. For the major diseases, the formula is presented below:
$RMR_{Sh} = SUB_{Death}/CD_{Death}$, where SUB_{death} is the age-adjusted mortality per 100 000 suburban individuals in Shanghai; and CD_{death} is the age-adjusted mortality per 100 000 individuals in central districts of Shanghai.
RMR_{Aver}: Relative mortality ratios of the major diseases (detailed description was shown in Section 3.4), indicating the potential response of population health to the environment on a national scale. For the major diseases, the formula is presented below:
$RMR_{Aver} = RURAL_{Death}/URBAN_{Death}$, where $RURAL_{death}$ is the age-adjusted mortality per 100 000 rural individuals on a national scale; and $URBAN_{death}$ is the age-adjusted mortality per 100 000 urban individuals on a national scale.

2.3. Statistical analysis

Statistical analysis was performed by using the DPS 5.12 statistical package (Tang and Feng, 1997, 2002). Descriptive statistics were employed, and all the data showed normal or nearly normal distribution using the normality test. Since the scatterplots proved to be superior to the linear model in curve estimation and examining relationship between the parameters of economic growth and urban metabolism, a nonlinear regression was adopted. Also, the Spearman rank correlation was used as a nonparametric alternative to the nonlinear regression in exploring the relationship between the parameters.

Furthermore, one-way analysis of variance (ANOVA) was carried out to examine whether there were significant differences among CD_{death}, SUB_{death}, $URBAN_{death}$, and $RURAL_{death}$. Also, unpaired *t*-test was employed to examine whether there existed significant difference between RMR_{Sh} and RMR_{Aver}.

3. Results and discussion

3.1. Economic growth and urban metabolism

Figs. 1 and 2 show different trends of total waste gas emission and total wastewater discharge over the study period. The best-fit curves of total wastewater discharge and TGDP clearly indicate enhanced efficiency of water metabolism, as evidenced by the decreased total wastewater discharge and increased TGDP. Table 1 shows the wastewater discharge and atmospheric pollutant emission during the same period. Although the annual growth rate of local permanent population was only 0.32%, the total pollutant emission from domestic sources greatly increased. Since 1996, the quantity of the industrial wastewater decreased gradually, whereas the quantity of domestic sewage increased steadily and completely surpassed the former. The percentage of total waste gases emissions from domestic sources rapidly decreased from 15.43% in 1990

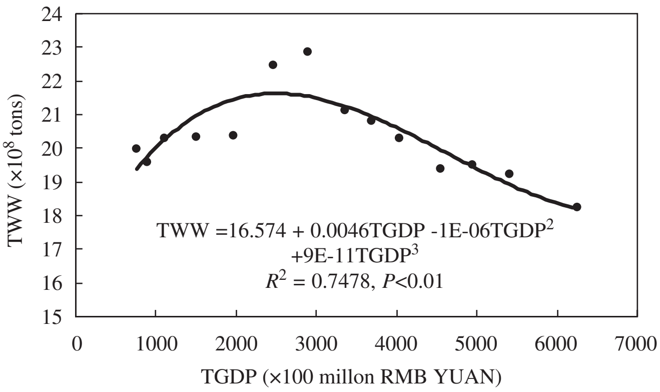

Fig. 1. Nonlinear regression between TGDP and TWW in Shanghai over the study period.

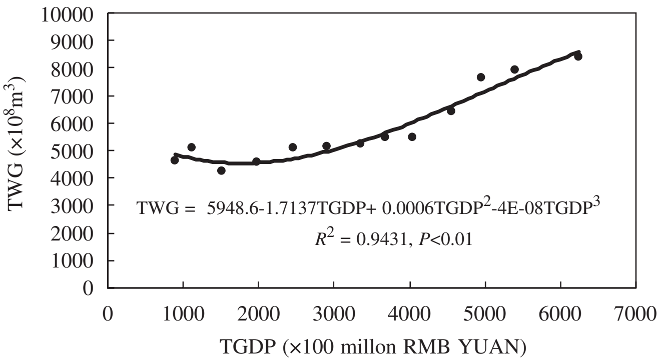

Fig. 2. Nonlinear regression between TGDP and TWG in Shanghai over the study period.

to 7.59% in 2003. However, the percentage of smoke and dust emission increased from 31.85% in 1991 to 56.93% in 2003. Simultaneously, the percentage of SO_2 emission from domestic sources increased from 29.32% in 1991 to 30.94% in 2003 with fluctuating rebounds. The total SO_2 emission is still higher than 0.4 million tons each year, which was the target of the 10th five-year planning task force for local environmental protection (2001–2005).

On the other hand, the intensity and eco-efficiency of urban metabolism measured by ECG, WCG, WWDG, and WGEG show encouraging results, though the total waste gases emissions (TWG) and total wastewater discharge (TWW) still remained at high levels. As shown in Table 2, the consumption of water and energy, as well as the emission of wastes, significantly decreased. During 1990–2003, both TGDP and GDP per capita increased rapidly at an annual rate of 16.28% and 15.91%,

Table 2
Spearman rank correlation coefficient of parameters of economic growth and urban metabolism

	TGDP	GDP per capita	ECG	WCG	WWDG	WGEG
TGDP	1.000					
GDP per capita	1.000**	1.000				
ECG	−1.000**	−1.000**	1.000			
WCG	−0.996**	−0.996**	0.996**	1.000		
WWDG	−1.000**	−1.000**	1.000**	0.996**	1.000	
WGEG	−0.943**	−0.943**	0.943**	0.938**	0.943**	1.000

Note: ** means correlation is significant at the 0.01 level (two-tailed).

Table 1
Description of annual wastewater discharge and atmospheric pollutants emissions in Shanghai during 1990–2003

Year	Population (million)	Waste water discharge ($\times 10^8$ ton)			Waste gases emissions ($\times 10^8$ m^3)			Components of major atmospheric pollutants					
								Smoke and dust emissions ($\times 10^4$ ton)			SO_2 emission ($\times 10^4$ ton)		
		Total	Industrial sources	Domestic sources	Total	Industrial sources	Domestic sources	Total	Industrial sources	Domestic sources	Total	Industrial sources	Domestic sources
1990	12.83	19.99	13.32	6.67	–	–	–	–	–	–	–	–	–
1991	12.87	19.58	13.25	6.33	4617	4000	617	21.54	14.68	6.86	47.92	33.87	14.05
1992	12.89	20.28	13.70	6.58	5110	4418	692	22.5	14.81	7.69	51.36	35.62	15.74
1993	12.94	20.32	12.81	7.51	4230	3859	371	18.93	14.80	4.13	44.12	35.67	8.45
1994	12.98	20.37	11.81	8.56	4577	4184	393	18.45	14.08	4.37	45.19	36.24	8.95
1995	13.01	22.45	11.61	10.84	5096	4625	471	20.78	13.33	7.45	53.41	38.15	15.26
1996	13.04	22.85	11.41	11.44	5132	4757	375	15.78	14.77	1.01	51.0	43.30	7.70
1997	13.05	21.1	9.99	11.11	5249	4755	494	17.08	13.38	3.70	50.85	43.62	7.23
1998	13.06	20.81	9.00	11.81	5492	4912	580	15.63	10.74	4.89	48.89	39.09	9.80
1999	13.13	20.28	8.52	11.76	5480	4947	533	13.57	9.00	4.57	40.31	31.09	9.22
2000	13.21	19.37	7.25	12.12	6398	5755	643	14.12	8.32	5.80	46.49	32.68	13.81
2001	13.27	19.5	6.8	12.7	7620	6964	656	13.52	6.23	7.29	47.26	30.00	17.26
2002	13.34	19.21	6.49	12.72	7902	7440	462	10.74	5.60	5.14	44.66	32.49	12.17
2003	13.41	18.22	6.11	12.11	8391	7799	592	11.54	4.97	6.57	43.54	30.07	13.47

Note: – means data not available.

respectively. In contrast, ECG, WCG, WWDG, and WGEG decreased rapidly at an annual rate of 9.34%, 10.69%, 14.57%, and 8.52%, respectively. Since the 1990s, emerging industries such as real estate, information technology, automobile manufacturing, banking, and import-export trading have dominated the economy of Shanghai. WCG significantly decreased from 686 ton in 1993 to 238 ton in 2000, though local WCG was nearly 10.6, 3.0, and 2.8 times that of Japan, Korea, and the United States, respectively (Zhu and Qin, 2003). The recent transformation from heavy to light industries and service business might contribute to the enhanced eco-efficiency and declined intensity of water and energy metabolism.

In summary, during the robust economic growth since 1990, the eco-efficiency in urban metabolism improved as demonstrated by the economic productivity, water and energy consumption as well as wastes emitted. However, uncontrolled emission of waste from domestic, rather than industrial sources, adversely affected the overall environmental quality.

3.2. Environmental quality trends

3.2.1. Air pollution

Currently, atmospheric environmental quality in central urban districts is tending to improve steadily, as evidenced by the decreased annual average concentration of three common air pollutants SO_2, TSP, and NO_2. During 1996–2003 the annual average concentrations of these three air pollutants in central districts continued to decrease, and therefore air quality improved from category III (worse) to category II (better), as measured by China's ambient air quality standard (GB 3095-1996) (SEPA and GAQSIQ, 1996). However, the annual average concentrations of these three air pollutants in suburban districts increased and were close to those in central urban districts. In 2003, the concentrations of inhalable particulates (PM_{10}) in suburban districts and central urban districts were 0.096 and 0.097 mg/m^3, respectively. In addition, a preliminary study by our group (unpublished data) also showed the increasing trend of fine particulates ($PM_{2.5}$) concentrations with the rapidly increasing number of automobiles in Shanghai. The air pollution with fine particles could be a very serious problem in this mega city. Thus, in general, the suburban air environmental quality tended to get worse since coal–petroleum mixture instead of pure coal burning contributed to the air pollution. Furthermore, according to the 10th five-year planning task for local environmental protection (2001–2005), during 1996–2000 the annual average concentration of NO_2 in Shanghai was much lower than those of international mega cities such as New York, Los Angeles, Chicago, and London. However, the annual average concentrations of SO_2 and PM_{10} in Shanghai were nearly two or three-fold those of other international mega cities. In addition, with the recent urban sprawl, dramatic changes in land use and land cover, and the rapid development of industrial parks, more than 86% of the local population live in highly urbanized and rapid urbanizing areas, which are polluted with industrial and traffic emissions. As a result, the risk of human health deterioration due to air pollution is becoming much higher (Zhang and Wang, 2003).

3.2.2. Water pollution

Within the urban area of Shanghai, pollution of the main rivers was characterized by organic pollutants, which can be mainly measured by dissolved oxygen (DO), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonia–nitrogen (NH_3–N), total manganese (as Mn^{2+}), etc. According to China's environmental quality standards for surface water (GB 3838-2002) (SEPA and GAQSIQ, 2002), the overall water quality levels of the local main rivers were ranked in order of increasing pollution levels: Category II, Category III, Category IV, Category V, and Category Worst (Fig. 3). The Category II water and Category III water are potable; Category IV water is acceptable for industrial use and recreational activities; Category V water is only acceptable for agricultural irrigation; and Category Worst water is unsuitable for any use. The percentage of river length with various water quality levels within the main river systems of Shanghai fluctuated at the monitoring sites during 1997–2003. Fig. 5 shows the site-monitored rivers with different water quality levels in Shanghai during 1997–2003. The percentage of water with quality levels better than Category III seemed to steadily increase, but this situation only existed in remote islands and at the estuary of the Yangtze River. Within the central urban districts and most of the suburban areas, where comprehensive treatments and ecological rehabilitation were carried out, the percentage of water with Categories IV and V levels tended to decrease. However, the percentage

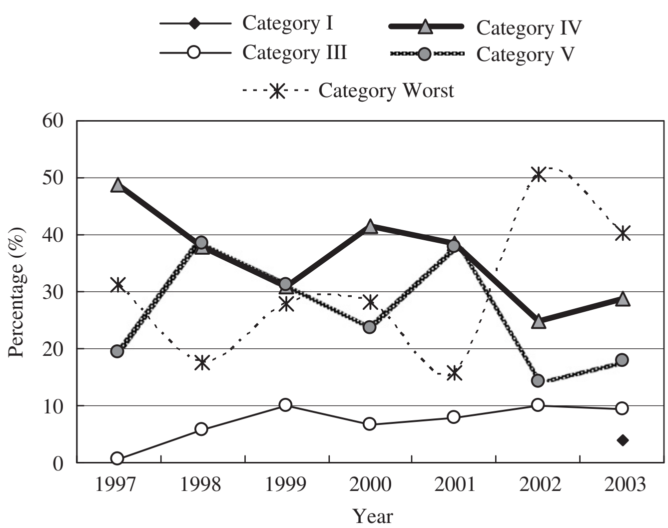

Fig. 3. The percentage of the site-monitored rivers with different water quality levels in Shanghai during 1997–2003.

of Category Worst water tended to increase and consequently indicated a very pronounced deterioration in the water quality.

3.2.3. Noise level

The regional environmental noise data were collected from the municipal noise monitoring network within the city of Shanghai. Fig. 4 showed, in general, that both the regional environmental noise and the traffic noise decreased slightly over the study period. The environmental noise levels at both daytime and nighttime showed corresponding dynamic trends and tended to decrease with the yearly expansion of certificated noise-controlled areas. According to China's Standard of Environmental Noise of Urban Area (GB 3096-93) (SEPA and GAQSIQ, 1993), noise levels are divided into five levels similar to those for water quality as described above. Since 1996 the environmental noise levels at both daytime and nighttime have been lower than Category II for the mixed zone of residence, commerce, and industry, where the acceptable daytime and nighttime maximum values were 60 dB(A) and 50 dB(A), respectively. However, the traffic noise levels at daytime and nighttime showed somewhat different trends due to the recent rapid increase of automobiles. Hence, the average traffic flow per hour during daytime increased from 889 in 1992 to 2268 in 2003, and the average traffic flow per hour during nighttime increased from 202 in 1992 to 1082 in 2003. Due to the strict traffic management policy, heavy trucks were allowed to enter the main road systems only at nighttime. Consequently, since 1998 the traffic noise level at daytime has been lower than Category IV for the zones neighboring the main traffic roads, where the acceptable daytime noise level was at the maximum value of 70 dB(A). In contrast, the nighttime traffic noise level was much higher than the maximum value of 55 dB(A) over the study period.

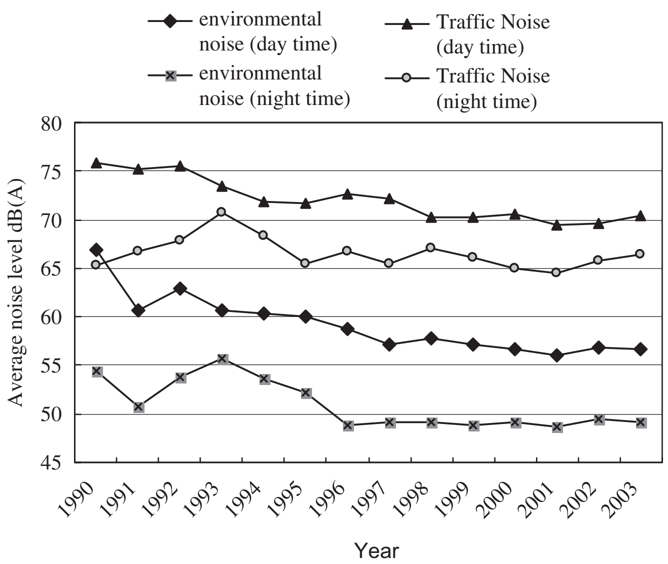

Fig. 4. Dynamics of environmental noise and transportation noise in Shanghai during 1990–2003.

3.3. Citizens' complaints about environmental issues

Based on further analysis of unpublished data provided by SEPB, there was a large variation in citizens' complaints about environmental issues during 1990–2003 (Table 3). Although there were some breaks in keeping records during the study period and some data were unavailable, complaints about air pollution and noise disturbance still accounted for an annual average of 26.16% and 35.02%, respectively, of the total complaints. Complaints about water pollution varied annually but took third place, and recent complaints about smoke from restaurant cooking oil smells and other smoke disturbance took fourth place.

Citizens have long expressed dissatisfaction of air quality and inadequate green space through various channels including TV, radio, newspaper, and direct complaints to government agencies. In brief, there was a slow but steady improvement in the environment in Shanghai during this rapid economic growth period. Also, public awareness about the local environment and the demand for better environmental quality became stronger than before. Increasing public concerns of environmental quality seemed to prompt the authorities into action. Consequently, the proportion of complaints about comprehensive environmental issues, including breaches of duty in environmental management, approvals of environmentally damaging construction projects, inappropriate planning, damage to green space, and poor sanitary conditions decreased dramatically from 64.80% in 1997 to 5.40% in 2003. Taking urban green space as an example, For a long time there has been criticism that citizens cannot enjoy clear air and adequate urban green space, so it is also one of the frequent focuses. Fortunately, with the substantial economic growth the authorities started to solve the problems. As a result, the urban green space coverage increased rapidly from 12.4% in 1990 to 35.2% in 2003. During the same period, the urban green space area increased from 3570 to 24426 ha.

3.4. Human health assessment

Figs. 5 and 6 and Table 4 compare death rates from major diseases of urban residents on local and national scales during 1990–2003. Because of the complex statistical sources and the disease classification system, the causes of the major diseases as well as mortality rate of the population measured on local and national scales were somewhat different. In addition, due to the recent incorporation of suburban counties and districts into the Shanghai metropolitan area in 1999, the traditional boundary between urban and rural areas was replaced with a new boundary between the central and the suburban districts. Thus, for the sake of data comparison on different scales, only the mortalities of three common diseases

Table 3
Citizens' complaints about the major environmental issues during 1990–2003

Year	Air pollution (%)	Noise disturbance (%)	Water pollution (%)	Solid waste (%)	Electromagnetic radiation (%)	Cooking oil and smoke disturbance (%)	Comprehensive environmental issues (%)
1990	–	–	–	–	–	–	–
1991	24.58	43.96	–	–	–	–	–
1992	30.90	45.00	–	–	–	–	–
1993	26.30	46.60	–	–	–	–	–
1994	27.30	42.60	–	–	–	–	–
1995	25.20	25.60	–	–	–	–	–
1996	14.10	13.80	–	–	–	–	64.80
1997	13.29	18.23	32.07	1.88	–	–	31.73
1998	29.30	23.50	–	–	–	–	–
1999	30.40	27.40	12.30	1.60	–	–	13.60
2000	32.40	42.50	–	–	–	–	–
2001	–	–	–	–	–	–	–
2002	27.80	46.50	15.10	0.80	1.80	4.60	3.40
2003	32.30	44.60	10.40	0.60	2.50	4.20	5.40

Note: – means data unavailable.

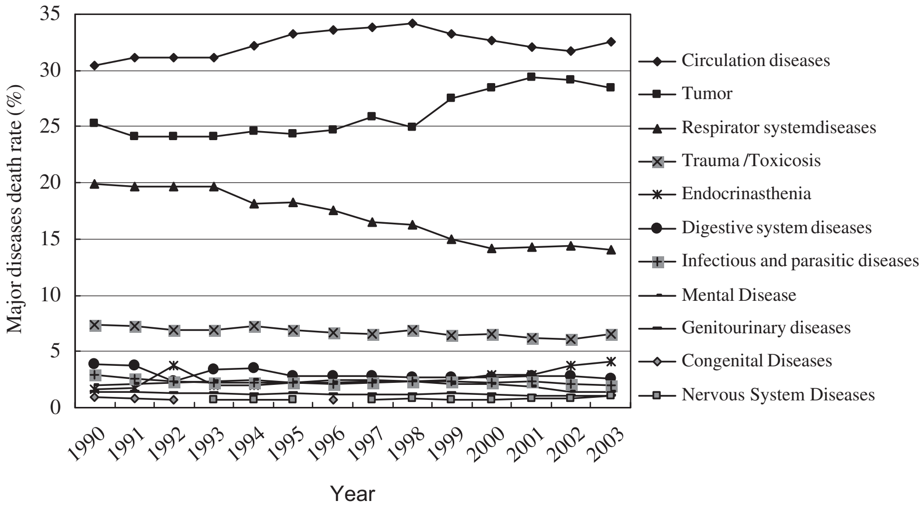

Fig. 5. Mortality rates of the major diseases of urban residents in Shanghai during 1990–2003.

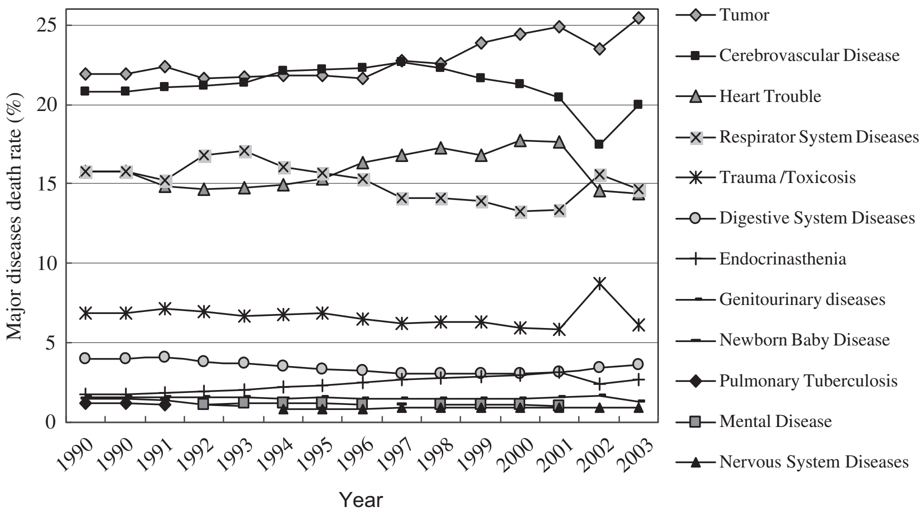

Fig. 6. Mortality rates of the major diseases of China's urban residents during 1990–2003.

Table 4
Mortalities of three major diseases on local and national scales during 1990–1999

Cause of death	Indicator	Range	Mean ±S.E.
Tumor	CD_{death}	25.09–27.67	26.247 ± 0.308^a
	$URBAN_{death}$	21.66–22.71	22.220 ± 0.222^b
	SUB_{death}	21.60–25.40	22.996 ± 0.367^b
	$RURAL_{death}$	16.11–18.40	16.877 ± 0.227^c
Respiratory diseases	CD_{death}	11.67–16.91	15.019 ± 0.489^a
	$URBAN_{death}$	13.89–17.05	15.402 ± 0.354^a
	SUB_{death}	21.83–28.37	26.149 ± 0.646^b
	$RURAL_{death}$	22.04–26.57	24.785 ± 0.492^b
Trauma/toxicosis	CD_{death}	5.92–6.84	6.433 ± 0.081^a
	$URBAN_{death}$	6.18–7.12	6.655 ± 0.103^a
	SUB_{death}	7.63–8.70	8.280 ± 0.102^b
	$RURAL_{death}$	10.65–12.04	11.325 ± 0.145^c

Note: Column with different letters indicates significantly different at $p<0.05$.

(tumor, respiratory diseases, and trauma/toxicosis) during 1990–1999 were available for further analysis.

As shown in Table 4, the mortality due to tumor ranked highest in the urban residents of Shanghai (CD_{death}), followed by that of the suburban residents (SUB_{death}) and the urban residents ($URBAN_{death}$) on a national scale. Clearly, the mortality of the rural residents on a national scale ($RURAL_{death}$) was significantly lower (one-way ANOVA, $F_{3,36} = 182.95$, $P<0.01$). For respiratory diseases, there was no significant difference between CD_{death} and $URBAN_{death}$, so did SUB_{death} and $RURAL_{death}$, but SUB_{death} and $RURAL_{death}$ were significantly higher than CD_{death} and $URBAN_{death}$ (one-way ANOVA, $F_{3,36} = 138.251$, $P<0.01$). For trauma/toxicosis, RURAL-death ranked higher than SUBdeath. In contrast, CD_{death} and $URBAN_{death}$ were significantly lower than $RURAL_{death}$ and SUB_{death} (one-way ANOVA, $F_{3,36} = 416.66$, $P<0.01$).

Relative mortality ratios (RMRs) of three major diseases show the differences on local and national scales. For tumor, RMR_{Sh} (0.874 ± 0.007) was significantly higher than RMR_{Aver} (0.760 ± 0.007) (*t*-test, df = 18, $t = 11.5027$, $P<0.01$). For respiratory diseases, RMR_{Sh} (1.753 ± 0.055) was significantly higher than RMR_{Aver} (1.611 ± 0.014) (*t*-test, df = 18, $t = 2.5072$, $P = 0.022$). Whereas for trauma/toxicosis, RMR_{Sh} (1.288 ± 0.021) was significantly lower than RMR_{Aver} (1.707 ± 0.033) (*t*-test, df = 18, $t = -10.6937$, $P<0.01$). The above analyses suggest that the residents in Shanghai benefited from substantial economic growth, advanced scientific and technological developments, and superb healthcare system. The population's life expectancy in Shanghai was much higher than the national average. It was reported that the average death rate of the urban population in Shanghai was lower than that of China (Takano et al., 2002). However, the seeming long life expectancy is offset by the health deterioration in urban and rural populations due to massive emission of pollutants during the past decade (Li et al., 2000). For example, recent epidemiologic research showed that life-style changes and environmental exposure affected the rates of cancers in local population. In particular, there were substantial increases in cancers of the brain and nervous system, kidney, pancreas, prostate, endometrium, and female breast during 1972–1999 (Liu et al., 2004).

4. Conclusions

In this paper, we examined the interactive relationships between economic growth, eco-efficiency of urban metabolism, and environmental performance of Shanghai since the 1990s. Analysis of socio-economic and monitoring data, measured by the economic productivity, water and energy use as well as waste emissions, has shown the enhanced eco-efficiency of water and energy use as well as the improved overall environment quality in Shanghai during the latest industrial transformation period. Based on our findings, we concluded that the enhanced eco-efficiency of urban metabolism was characterized with the rapid decline in ECG, WCG, WWDG, and WGEG. These may partly help explain the improvement of the overall environment quality in Shanghai during the latest industrial transformation period.

However, during the process of shaping a globalizing metropolis with an excellent investment environment, current environmental policies have focused strictly on cutting pollutant emissions in the central urban districts, with some industries emitting heavy pollutants being moved to the suburban areas. Since the 1990s, many industrial polluters within the central districts were forced to close or move to suburban areas. Waste from domestic rather than industrial sources now impact the overall environmental quality. Accordingly, we encourage policy makers to effectively engage and inform the public concerning environmental impacts of their daily life. On the other hand, due to the irrational industrial layouts and the urban pollutants transfer, the suburban areas have undergone rapid economic growth at the cost of public health. Moreover, some local enterprises, which fail to reach compulsory environmental standards set by SEPA, will try to relocate to neighboring provinces with poor economic growth. Hence, the authorities must implement the integrated treatments and management policies to prevent wide spread of the pollutants.

In summary, Shanghai's case study may provide the beneficial experiences for other cities in China and even for metropolises in developing countries. However, an excessively dense population, massive resource consumption, and large quantity of pollutant emission have greatly impaired this city's capacity to meet the challenge presented by international competition and sustainable environment. Therefore, in the context of globalization and ecological security, it is important to point out that rational urban planning, effective pollution control policies and mutual regional coordination frameworks are urgent to achieve sustainable development not only for Shanghai but for the whole Yangtze River Basin.

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