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Temporal variations of surface water quality in urban, suburban and rural areas during rapid urbanization in Shanghai, China

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An integrated pollution index documents the deterioration of water quality in greater Shanghai, recently most serious in rural sections.

Abstract

As the economic and financial center of China, Shanghai has experienced an extensive urban expansion since the early 1980s, with an attendant cost in environmental degradation. We use an integrated pollution index to study the temporal variations of surface water quality in urban, suburban and rural areas between 1982 and 2005. Data on monitored cross-sections were collected from the Shanghai Environmental Monitoring Center. The results indicated that the spatial pattern of surface water quality was determined by the level of urbanization. Surface water qualities in urban and suburban areas were improved by strengthening the environmental policies and management, but were worsening in rural areas. The relationship between economic growth and surface water quality in Shanghai showed an inversed-*U*-shaped curve, which reflected a similar pattern in most developed countries. This research suggests that decision makers and city officials should be more aware of the recent pollution increases in Shanghai.

Keywords: Temporal variations; Surface water quality; Urbanization; Shanghai

1. Introduction

Since 1979 China has been the world's fastest growing economy. But rapid growth has strained China's water resources. The Huai, Hai and Huang (Yellow) River basins supply just under half the country's population, yet the area accounts for less than 8% of national water resources, and more than 70% of the water is polluted (United Nations Development Programme, 2006).

Shanghai is the largest city with the highest level of urbanization in China. Taking the ratio of non-agricultural population to the total population as the evaluative standard for the level of urbanization, it was 84.5% at the end of 2005, while the national level was only 42.9%. As the economic center, since the late 1980s, Shanghai's economy has maintained a high-speed growth, with its annual Gross Domestic Product (GDP) increasing at about 10%. However, it is also listed by the United Nations (Zheng, 2001) as one of six cities with serious deficiency of water resources of the 21st century, with potable water amounting to only 20% of total surface water resources. In average water resources per capita, Shanghai stands at 40% of the national average in China and 10% of the global average (Zheng, 2001). In addition, the water quality grade of the Huangpu River, which provides over 80% of Shanghai's water supply, varies between grade III and over grade V, whereas over grade V is the worst score in the national standard for water quality in China, and only water

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with a grade lower than III is potable (Shanghai Environmental Protection Bureau, 1983–2006). Thus, the use of water resources is strongly limited by the water quality. Sustainable development in terms of water quality becomes the chief focus in the ecology of urbanization.

Many research studies have shown a close relationship between water quality and urban development. For example, LeBlanc et al. (1997) found that land-use intensification increased water temperature. Fisher et al. (2000) also discovered that land use had impacts on the quality of surface water. Feng et al. (2004) characterized rapid urbanization and recent coastal wetland reclamation as main contributors to the Yangtze River's heavy metal contamination. Tang et al. (2005) indicated that urban expansion was a major driving force in increasing non-point source pollution. Several studies on water quality issues in Shanghai have been weakened by limitations. For example, the classifications of water quality used by Ren et al. (2003) could not reflect actual water quality, and Yin et al. (2005) only used one year's water quality data to investigate the relationship between spatial patterns of urban land-use and water quality.

Since many environmental data are sensitive and not available to the general public, only a few long-term studies on various spatial scales have been published. In this paper, an integrated pollution index was used to characterize spatial and temporal variations of surface water quality during Shanghai's rapid urbanization between 1982 and 2005. The results of this study may help decision makers and city officials to alleviate water quality issues in the course of Shanghai's development as a "global city".

2. Methods

2.1. Study area

Shanghai is located on the coast of the East China Sea and at the estuary of the Yangtze River. The total area of the Municipality of Shanghai is 6340.5 km^2, of which 121 km^2 is water (Fig. 1).

To explore the consequences of urbanization, we classified Shanghai into urban, suburban and rural areas. The general descriptions of the three spatial areas are shown in Table 1.

Like most cities in China, Shanghai is overbounded in its administrative territory. Especially after 1992, Shanghai began a rapid developing phase with an annual GDP increment of 12.4% (Shanghai Statistical Bureau, 1983–2006), and its administrative territories were redivided continually. Though the urban territory remained unchanged, the administrative territory of suburban areas expanded from four districts (Pudong New Area, Minhang, Baoshan and Jiading) in 1992 to nine districts (Pudong New Area, Minhang, Baoshan, Jiading, Nanhui, Fengxian, Songjiang, Jinshan and Qingpu) in 2005, with a total increase in area 1624.2 km^2–4865.6 km^2. Further, the administrative territory of the rural areas, whose total area was 4426.8 km^2 in 1992, shrunk from six counties (Nanhui, Fengxian, Songjiang, Jinshan, Qingpu, and Chongming) to one county (Chongming) in 2005, with a total area of just 1185.5 km^2. To date, only Chongming is counted as a rural area, but the other five administrative areas still contain substantial rural land and a number of rural residents who continue to farm for their livelihood. Moreover, the urban areas are located in the centre of city. The suburban areas are next to them, and the rural areas are farthest away. In this study, to characterize spatial and temporal variations of surface water quality, the division of spatial areas is based on the administrative territories of 1992.

According to the three censuses of China of 1982, 1990 and 2000, the average level of urbanization for urban areas was 100% all along. The average urbanization level for suburban areas increased from 31.7% in 1982 to 44.0% in 1990, while for rural areas, it rose from 10.0% to 14.0%. At the end of 2000, suburban areas were in the process of middle-development, with an average urbanization level of 58.4%. But rural areas were at the stage of early-development, with an average urbanization level of 29.8% (Table 2).

2.2. Analytical methods

Systematic monitoring on water pollution in Shanghai was started in 1982. For this paper, the study has been carried out over a period of 24 years (1982–2005). Surface rivers and lakes have been polluted mainly by integrated organic pollution, so we use nine water parameters that include permanganate value, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), Kjeldahl nitrogen (KN), total phosphorus (TP), total nitrogen (TN), total mercury (THg), volatile phenol (VP) and oils to calculate the integrated pollution index for the three areas. The larger the integrated pollution index is, the worse the surface water quality. Data from 73 monitored cross-sections were provided by the Shanghai Environmental Monitoring Center (Shanghai Environmental Protection Bureau, 1983–2006). Locations of monitored cross-sections in three spatial areas are shown in Fig. 1.

Based on the "Environmental Quality Standards for Surface Water" of China (State Environmental Protection Administration, 2002), the surface water environment is divided into five grades, and each grade has its corresponding standard value. In Shanghai, surface water quality has been improved in recent years, but according to the comprehensive evaluation of 2005 on 16 main rivers with 612.9 km length, 68.3% of total length was still grade V and over grade V (Shanghai Water Authority, 2005). In order to compare spatial and temporal variations of the three regions, we use the value of grade V as surface water standard concentration for all monitored cross-sections.

We use the following formula to calculate the surface water quality.

$$\mathrm{PI} = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{C_o} \quad (i = 1, 2 \ldots, n) \tag{1}$$

where PI is the integrated pollution index; C_i is the actual surface water concentration, mg/l; C_o is the value of surface water standard concentration, mg/l (Table 3); and n is the number of monitoring parameters.

3. Results

3.1. Spatial patterns according to the integrated pollution index

The values on the integrated pollution index spatially showed that surface water pollution in urban areas was the most severe, followed by suburban areas, and with rural areas relatively better (Fig. 2). Except for 1982, the integrated pollution index for urban areas was far above the standard value. And it was 3 times higher than the standard value during 1986–2000, which was also the period with the highest economic growth. From 1988 to 1999 (except for 1989, 1991, 1992 and 1998), it was a little above the standard value in suburban areas. But for rural areas, it was actually below the standard value. In sum, the contribution rates of the pollution loads from the three spatial regions were mainly determined by urban water pollution.

Specifically, the spatial variations in the level of urbanization were consistent with the variations on the integrated pollution index. The higher the urbanization level was, the worse the surface water quality (Fig. 3).