Estimating Water Quality Pollution Impacts Based on Economic Loss Models in Urbanization Process in Xi'an, China

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Abstract: The study investigates water quality pollution impacts on urbanization by analyzing temporal and spatial characteristics of different water quality parameters, and simulating economic loss of water quality pollution in Xi'an, China from 1996 to 2003. Results show that organic pollutants were the greatest contributors of surface water quality pollution from 1996 to 2003. High values existed in petroleum concentration, chemical oxygen demand index (KMnO4), biochemical oxygen demand index, and phenol concentration, followed by nitrogen concentration (TN and NH3-N). From spatial analysis in different buffers from central urban area (inner buffers: 1–5 km; central buffers: 5–10 km; outer buffers: >10 km), socioeconomic activities such as business activities, car transportation, industry factories, agriculture practices, and households were likely to lead to different behaviors of water quality parameters in nature. Results also reveal that both surface and ground water quality improved gradually after enforcement of control measures within the 7 years from 1996 to 2003. It shows the total economic loss, including cost of water use and supply, agriculture economic loss, ecosystem conservation costs, and economic loss of human health, reached $\$1.12\times10^9$ from 1996 to 2003, which increased $\$1.79\times10^7$ from $\$1.26\times10^8$ in 1996 to $\$1.46\times10^8$ in 2003. However, economic loss of water quality pollution increased while water quality pollution alleviated in the past years. This can be explained by more intensive social activities in broader regions, more populations were moved from rural area into urban area, and more costs were input in water quality pollution treatment.

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Introduction

The greater impacts of environment quality pollution have drawn increasing attention of scientists to assess water environmental damage (Batty 1971; Asako 1980; Galuzzi 1996; Grigg 1997; Marans 2003; Trauth and Shin 2005; Uzzell and Moser 2006). Research has targeted the assessment toward economic loss evaluation (Grossman and Alan 1995; Ofiara 2001; Uzzell 2004). Economic loss of environment pollution is defined as the total monetary cost of environment pollution, including continuing or future expenses to be incurred, and it includes costs such as property damage, medical and legal fees, funeral expenses, and actual and reasonably expected lost wages or profits (Bockstael and McConnell 1980; Gregory 1986). Conducting environment assessment work may provide a way to enhance the efficiency of government decision making, and further improve public awareness of the quantitative impact of environment pollution. In recognition of these facts, environmental economists have begun developing viable methods to estimate economic losses resulting from environment pollution. These studies derive from two basic theories, economic welfare theory (Negisihi 1960; Hearne and Easter 1995; Dinar et al. 1997) and environment Kuznets curve theory (James and Lee 1971; Selden and Song 1994; Grossman and Alan 1995; Cole et al. 1997; Andreoni and Levinson 2001). On the basis of these two theories, viable economic loss techniques and models were developed (such as direct and nondirect market evaluation methods—direct market evaluation methods includes dose-response, changes in productivity or effect on production, cost of illness and human capital, opportunity cost; and nondirect market evaluation methods include revealed preference, hedonic property pricing, preventive expenditure, travel cost, contingent valuation, bidding game, trade-off game, costless choice) to assess net economic value or changes in economic welfare or well being. Ofiara (2001) elaborate on these economic principles

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and methods from a view of assessment of economic losses from marine pollution.

For evaluation of economic loss of water quality pollution, these methods are developed into three categories: water body evaluation, computational economics evaluation, and restoration value evaluation. The water body evaluation approach consists of two-step calculations. The first step is to individually estimate economic loss of water quality pollution according to different water bodies, such as water use in drinking, manufacturing, fisheries, and irrigating, then to sum up all individual items of economic loss. When calculating individual items, a shadow value method, marginal cost method, substitute method, and benefit method are often used (Chang et al. 2001; Chang 2005; St-Pierre et al. 2003; Wilson and Greg 2005; Cabrera et al. 2006; Reddy and Behera 2006). A computational economics evaluation approach takes on water body as an integrated part. Functions are established by fully investigating the relationship between economic activities and water resource value. Economic loss of water quality pollution can be calculated after choosing function parameters. And these prototype mathematic functions include the Solow model, blurred maths methods, and pollution loss rate model (Rizzoli et al. 1998; Cheng and Yang 2001; Cheng et al. 2003). A restoration value approach is used to estimate economic restoration costs for damaged water resource, and substitute value, engineering value, and poll investigation methods are used for calculating evaluation (Dobson et al. 1997; Gao et al. 1998; Miao and Marrs 2000; Li 2006).

These efforts have resulted in steadily improving evaluation methods. However, most of this research was limited to water pollution concentration-loss curve. Seldom did the studies establish all pollutants concentration-loss curves in water quality evaluation, the integrated effects of multiple pollutants were ignored, and the simple method of summing up all individual water body economics cannot comprehensively reflect the total effects of economic loss of water pollution. Meanwhile, these studies failed to disclose the dynamic economic loss on the basis of industrial sectors and spatial distribution. Noticing these problems, we developed an economic loss evaluation model of water quality pollution in an integrated manner to simulate the water quality pollution impacts on economic losses in urbanization. We first develop a comprehensive pollution index for evaluating water quality pollution, and analyze dynamic water quality pollution status in spatial and temporal dimensions. Then the economic loss evaluation model is proposed for estimating the total economic loss of water quality pollution in terms of industrial sectors and spatial distribution. Our proposed economic loss evaluation model stands out compared to other models due to its integrated analysis of dynamic water quality pollution and social economic development in view of urbanization. The model can easily be developed into an economic evaluation model of environmental pollution when broader views of environmental data are acquired sufficiently.

In recent years, rapid economic growth in Xi'an, China has been accompanied by rapid urbanization. However, the urban and rural ecological environments have both been deteriorating. During this rapid urbanization process, water pollution has become a serious issue. Studies of Xi'an water quality pollution have focused on time series analysis between water quality parameters concentration (Yan and Li 1999; Wang et al. 2002; Gang et al. 2003). No studies have been carried out to relate water quality pollution with environment economic loss. To address these issues, we analyzed dynamic water quality pollution from 1996 to 2003. This study contributes to these efforts by calculating the economic loss of water quality pollution, and it concentrates on an estimate of economic losses resulting from the impact of water pollution on human health, industry, crop yields, livestock, and fisheries in Xi'an based on data from 1996 to 2003.

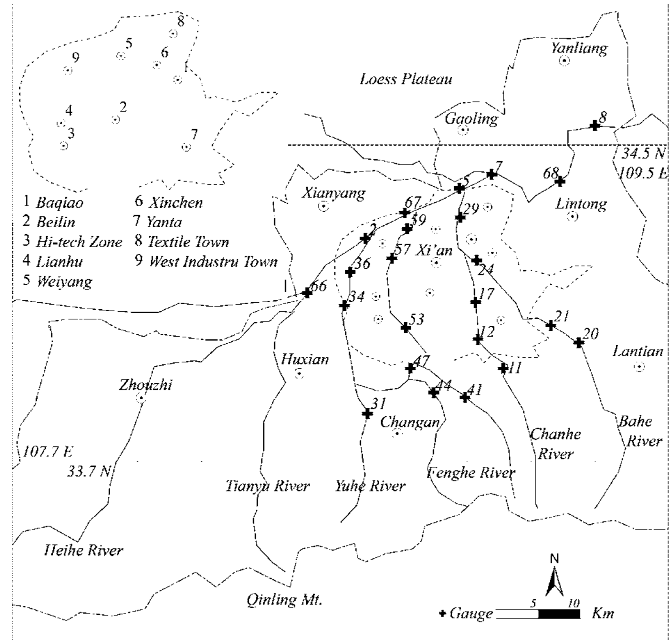

Fig. 1. Sketch map of study area: river network and water quality sampling sites in and around Xi'an

Study Area

Xi'an is the capital of Shaanxi Province and is one of northwestern China's key cities from the perspective of politics, the economy, and culture. It lies in the center of the Guanzhong Plain (107°40′E–109°49′E, and 33°39′N–34°44′N, within the larger Weihe Plain), bounded by the Qinling Mountains in the south and the Loess Plateau in the north. Xi'an has 14 administrative districts and counties. The most urbanized regions had a total area of 363.66 km^2 in 2003, including Baqiao, Beilin, the Hi-Tech Zone, Lianhu, Weiyang, Xinchen, and Yanta, and represent the main part of the urban area. Around these urban areas lie Changan and Lintong, two regions that are vigorously developing their potential and showing strong urban-rural interactions. The Gaoling, HuXi'an, Lantian, Yanliang, Changan, and Zhouzhi areas surround Xi'an and have predominantly rural characteristics (Fig. 1).

The river network of Xi'an belongs to the lower Weihe River drainage system. The Weihe River originates thousands of kilometers west of the Guanzhong Plain, runs across deserts and Loess Plateau, and finally reaches Xi'an. The 150-km lower Weihe River in Xi'an connects nine tributary rivers from west to east such as the Heihe River, the Laohe River, the Xinhe River, the Fenghe River, the Zaohe River, the Bahe River, and the Linhe River. The Yuhe River and the Chanhe River are the second-order tributaries of the Weihe River, and flow into the Fenghe River and the Bahe River, respectively (Fig. 1). These tributaries run through the urbanized area, and reach the lower Weihe River main channel. Most of these tributaries provide the industrial and residential water supply for Xi'an. To study the response of water quality to urbanization, we selected 35 monitoring sites that covered these rivers from upstream to downstream within the area of Xi'an City. Sampling sites were selected along the middle of the Weihe River (Sites 2, 5, 7, and 8), the Chanhe River (Sites 11, 12, 17, and B7), the Bahe River (Sites 20, 21, 24, 29, B8, and B9), the Fenghe River (Sites 31, 32, 34, 36, and B4), the Yuhe River (Sites 41, 43, 44, 47, B5, and B6), the Zaohe River (Sites 53, 57, and 59), the Heihe River (Sites 65 and B1), the Laohe River (Sites 66 and B2), Xinhe River (Sites 67 and B3), and Linhe River (Site 68). Upper stream sites (B1–B9) were used to examine water quality parameters background values. Data from 35 river monitoring sites covered the above-mentioned nine rivers.

Materials and Methods

Data Collection

Our study workflow chart is illustrated in Fig. 2. For the first step, we collected socioeconomic data, such as industrial factors of manufacture, agriculture, services (Xi'an Statistical Bureau 2003) to identify the process of urban expansion. Water quality data and other environmental data were from Xi'an Municipality Bureau of Environment Protection (2003). Data of discharged water pollutants from industrial sectors (manufacture, agriculture, services); household, and pollution events are used to analyze dynamic change of water quality pollution status. Ecological data such as species decline and extinction are used to estimate ecosystem degradation. We obtained human health data from Xi'an Human Health Centre (2005). Health care costs and environmental diseases are data sources of human health.

Water Quality Evaluation

For surface water quality analysis, we examined water quality parameters, including dissolved oxygen (DO), chemical oxygen demand (COD index as the permanganate index, KMnO4), 5-day biological oxygen demand (BOD5), nitrogen as ammonia or NH3 (NH3-N), total nitrogen (TN), petroleum, phenol, arsenic (As), lead (Pb), and total mercury (THG) between 1996 and 2003 (Xi'an Municipality Bureau of Environment Protection 2003). At each monitoring site, at least two samples were taken under different hydrological conditions each month (normally four to six times), e.g., high water, middle water, and low water conditions. The annual average values were used in this study. Water quality samples were measured by the standard analytical methods for surface water quality provided by GB 3838-88 (NSPRC 1988). All analytical procedures were carried out in duplicate using instrumentation which was fully calibrated against relevant ranges of standard concentrations.

For ground water quality evaluation, we combined our monitoring data for many parameters to produce a comprehensive pollution index (K_j). K_j is defined by Eqs. (1)–(3):

$$K_j = \left(\frac{1}{n} \sum_{i=1}^{n} \mathrm{PI}_{ij} \Big/ \sum_{j=1}^{m} \mathrm{PI}_j \right) \times 100\% \quad (1)$$

where

$$\mathrm{PI}_j = \frac{1}{n} \sum_{i=1}^{n} \mathrm{PI}_{ij} \quad (2)$$

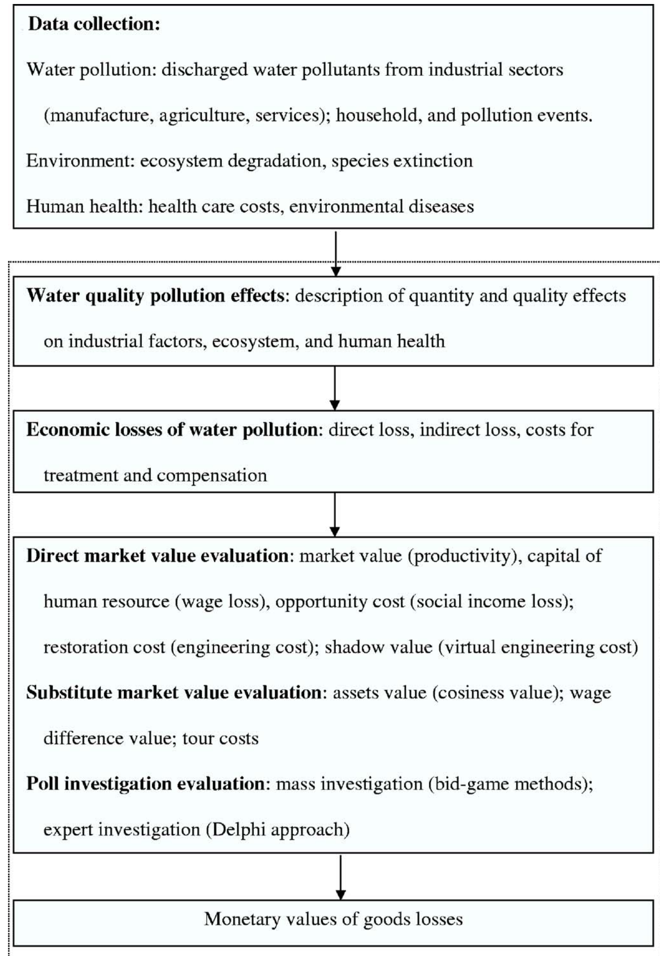

Fig. 2. Flow chart of economic loss evaluation of water quality pollution model

$$\mathrm{PI}_{ij} = \begin{cases} \dfrac{C_i}{C_{im}} & \text{if } C_{im} = C_{\text{lower limit}} \\ \dfrac{|C_i - C_{\text{median}}|}{|C_{\text{upper limit}} - C_{\text{lower limit}}|} & \text{if } C_{\text{lower limit}} \leqslant C_{im} \leqslant C_{\text{upper limit}} \\ \dfrac{C_{i\,\max} - C_i}{C_{i\,\max} - C_{im}} & \text{if } C_{im} = C_{\text{upper limit}} \end{cases} \quad (3)$$

where i=evaluated parameter; j=gauge code; n=total number of parameters evaluated; C_i=mean value of item i; C_{im}=value of evaluated item i specified in the water quality standard; $C_{i\max}$ =maximum value of item i; PI_{ij}=pollution index of item i in gauge j; PI_j=pollution index of all evaluated items in gauge j; and K_j=pollution load of gauge j.

Assessment of Economic Loss of Water Quality Pollution

Water quality pollution effects are quantitatively and qualitatively estimated as goods values, and then transformed into monetary values. For this purpose, all economic losses including direct loss, indirect loss, and costs for treatment and compensation are estimated by using approaches such as direct market evaluation method, substitute market evaluation method, and poll investigation evaluation method. Direct market evaluation aims to estimate the direct loss evaluation which includes market value (productivity), capital of human resource (wage loss), opportunity cost (social income loss), restoration cost (engineering cost), and shadow value (virtual engineering cost). Substitute market evaluation (assets value, wage difference value, tour costs) and poll investigation method (mass investigation and expert investigation) focus on indirect losses evaluation [Ofiara (2001), detailed descriptions in the appendices].

To evaluate water quality pollution situation in urbanization process, we propose a water quality pollution economic loss coefficient (η), defined as the ratio of total water quality pollution economic loss (E) over gross domestic product (GDP, marked as D)

$$\eta = f(E,D) \tag{4}$$

For calculation purposes, we define total water quality pollution economic loss (E) as

$$E = \sum_{i=1} E_i \tag{5}$$

where E_i=water quality pollution economic loss of individual parameter; i=individual parameter, including the lost value of resource by water pollution, treatment costs of waste water, agriculture production loss, human health loss, landscape degradation loss, tourism industry loss, built-engineering costs for water supply. E_i is calculated by

$$E_i = f(W_i, C_i) \tag{6}$$

$$E_i = k_i C_i W_i + r_i \tag{7}$$

where W_i=total events of individual water quality pollution related to the specific parameter; C_i=economic loss per event related to W_i, and is defined by the market value evaluation method, shadow value evaluation method, or poll investigation evaluation method; k_i=transfer coefficient, and chosen by considering its reality, logistics, and computability; r_i=perturbation value, and selected by its intrinsic character.

By inducing the input-output economic theory (Ofiara 2001), we can construct a model of water quality pollution economic loss or industrial product values in different industrial sectors or regions. Therefore, we define

$$C = AB^T \tag{8}$$

where A=amount of water pollutant discharge or amount of industrial outputs; B=unit treatment cost related to water pollutant discharge or unit value of industrial outputs which is related to matrix A. Matrixes A and B can be expressed by

$$A = (a_{gh}) = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \tag{9}$$

$$g = 1,2,3, \dots ,m, \quad h = 1,2,3, \dots ,n \tag{10}$$

$$B = (l_j) = (l_1 \; l_2 \; \dots \; l_n) \tag{11}$$

$$C = (c_g) = \begin{bmatrix} c_1 \\ c_2 \\ \dots \\ c_m \end{bmatrix} = AB^T \tag{12}$$

In calculating water quality pollution economic loss, a_{gh}=total water pollutant discharged from different industrial sector or region (m) in individual event (n); and l_j=average unit treatment cost of water pollution in one industrial sector or region. For industrial outputs calculation, a_{gh}=total products from different industrial sector (m) in different region (n) or from different region (m) for different sectors (n); and l_j=unit product value of individual industrial sector or region. Based on functions (8)–(12), we can qualitatively describe dynamic water quality pollution situations in urbanization process.

Results

Dynamic of Water Quality Pollution in Urbanization

A close investigation on LUCC and water quality demonstrates that water quality was most vulnerable around urban-rural fringes; urbanized area improved slowly. The most seriously polluted surface water parameters were included in urban downstream (Figs. 1–3). During the study periods, organic water quality parameters were the most seriously polluted such as petroleum, COD index (KMnO4), BOD5, and phenol, followed by nitrogen parameters, including TN and NH3-N (Fig. 4). Water quality parameters of heavy metals had the slightest pollution. We ranked surface water quality into five categories from high quality to poor quality: Very good (Type I), good (Type II), slightly polluted (Type III), seriously polluted types (Type V), moderately polluted (Type IV). From Figs. 1 and 3, it was assumed that urban district area similarly correlated with water quality parameters. This was further illustrated by the distribution of point pollution sources of surface water in Xi'an. Point pollution sources were higher in smaller buffers of the central urban area, decreasing outwards. With increasing urban expansion, two-thirds of the moderately polluted (Type VI) organic parameters (petroleum, COD index as KMnO4, BOD5, and phenol) degraded into serious types (Type V), TN and NH3-N of 18 monitoring sites degraded from slightly polluted (Type III) into moderately polluted (Type IV), and heavy metals with good conditions (Type II) in 11 monitoring sites became slightly polluted (Type III). This relationship suggested that the impact of urbanization on surface water quality tended to amplify with an accelerated pattern as urbanization intensifies.

For different buffers from central urban area (inner buffers: 1–5 km; central buffers: 5–10 km; outer buffers: >10 km), business activities, car transportation, industry factories, agriculture practices, and households were likely to lead to different water quality parameter behaviors in nature (Fig. 3). As to individual water quality parameters, DO and BOD5 were among the best-explained. All industry factories, business centers, and households contributed to DO and BOD5 degradation in inner buffers (1–5 km) around the central urban district. In central buffers (5–10 km), industry factories were the contributors. Outer strips (>10 km) in rural area, agriculture practice became dominate factors, but it had slight pollution effects on DO and BOD5. High concentration of NH3-N, TN, and TP were presented in downstream rivers of central buffers. Industry factories dominated

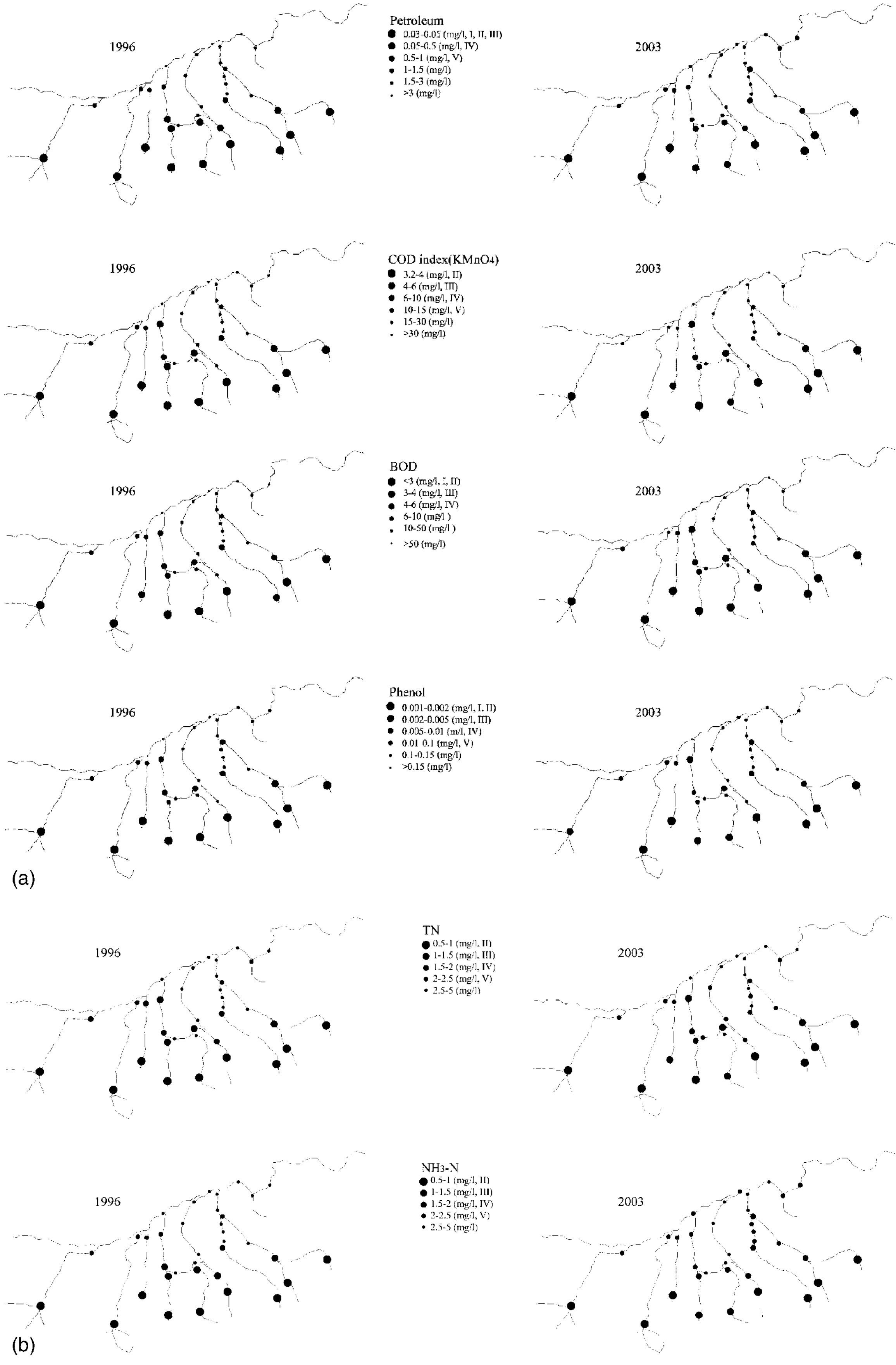

Fig. 3. Surface water parameter behaviors in urbanization process in Xi’an

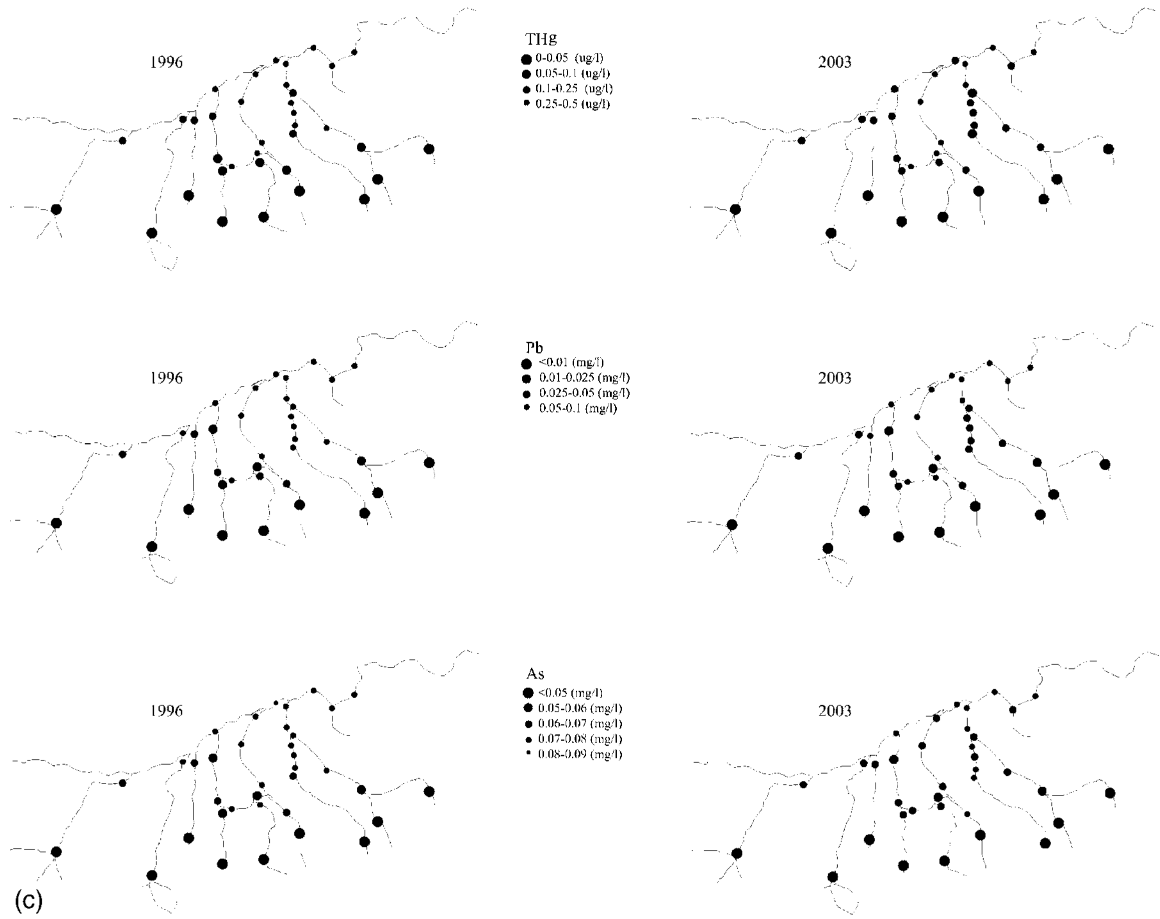

Fig. 3. (*Continued*).

water quality parameter behaviors of COD, phenol, As, Cd6+, lead, and THG downstream of the outer buffers (5–10 km). High petroleum values were in the downtown area of inner buffers and river banks of industry factories in central buffers. With urban expansion, buffers of central urban area were changing, and surface water quality parameters value varied accordingly.

Fig. 4 is a result of complex pollution index (K_j) calculated by Eqs. (1)–(3). We ranked ground water quality pollution into four categories: good (Type I, $K_j \leqslant 0.8$), slightly polluted (Type II, $0.8 \leqslant K_j \leqslant 2.5$), moderately polluted (Type III, $2.5 \leqslant K_j \leqslant 7.2$), and strongly polluted (Type IV, $K_j \geqslant 7.2$). After operating the spatial analysis in ArcView software, we got the result that about 13.4% of the strongly polluted (Type IV) area improved to moderately polluted (Type III), 4.5% of moderately polluted (Type III) improved to slightly polluted (Type II), 1.7% of slightly polluted (Type II) improved to good ground water quality (Type I). Obviously, ground water quality improved gradually after enforcement of control measures within the 7 years from 1996 to 2003.

Economic Loss Assessment of Water Quality

To estimate economic loss from water quality pollution, we choose different methods in calculating. In the manufacturing industry, opportunity cost and shadow value evaluation methods are

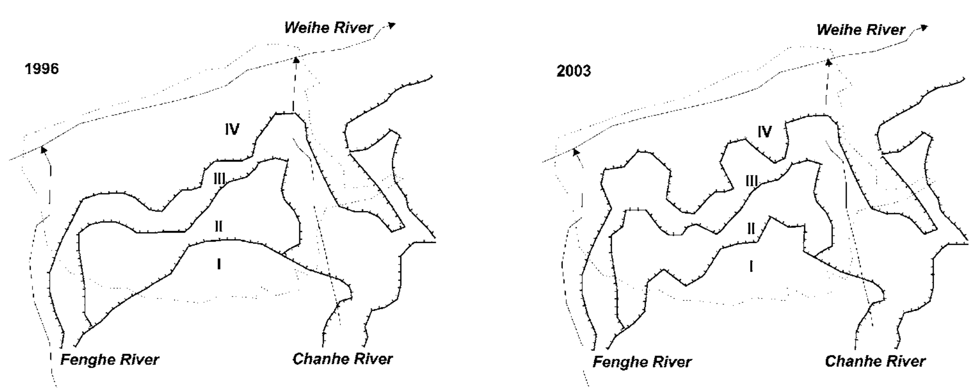

Fig. 4. Dynamic change of ground water quality in urbanization process in Xi’an

Table 1. Costs of Water Use and Supply for Water Quality Pollution from 1996 to 2003 in Xi'an

Types of water use	Units of calculated waste water	1996	2003	Changes from 1996 to 2003	Total from 1996 to 2003
Water supply	Surface ($m^3, \times 10^5$)	3,200	16,200	13,000	121,060
	Ground ($m^3, \times 10^5$)	10,600	5,300	–4,700	99,220
	Total ($m_{w1}, m^3, \times 10^5$)	13,800	21,500	7,700	220,270
	Unit price for waste water treatment ($p_{w1}, \$/m^3$)	0.012			
	Water supply cost ($C_{w1}, \$, \times 10^5$)	170	270	90	2,640
Waste water	Household ($m^3, \times 10^5$)	1,530	1,310	–180	17,720
	Industries ($m^3, \times 10^5$)	1,210	890	–320	13,100
	Total ($m_{w2}, m^3, \times 10^5$)	2,740	2,200	–460	30,830
	Unit-price for treatment ($p_{w2}, \$$)	0.12			
	Treatment cost of discharged ($C_{w2}, \$, \times 10^5$)	330	260	–060	3,700
Engineer projects	Total input cost ($p_{w3}, \$, \times 10^5$)	1,600			1,600
	Life expectancy (n)	50 (year)			
	Cost discount rate ($r_w\%$)	10			
	Cost for waste water in study period ($C_{w3}, \$, \times 10^5$)	160			1,280
Total ($\$C_{Tw}, \times 10^5\$$)		660	690	30	7,620

used for the calculation of economic loss of water resource shortage, and restoration cost method is used for calculation of pollution treatment costs. In agriculture, market value evaluation method is used for economic loss of food production, fishery, and horticulture. Poll investigation method is used for the calculation of economic loss of ecosystem soil degradation. For the calculation of economic loss of human health, substitute market value evaluation method is adopted (see details in the appendices).

In urbanization process from 1996 to 2003 in Xi'an, total water supply reached 13.8 and 21.5×10^8 m^3 and increased an amount of 7.7×10^8 m^3. The total discharged waste water decreased 0.46×10^8 m^3. The treated waste water from industries improved from 58.3 to 81.4%. In order to control the degraded situation of water pollution and depletion, the Xi'an municipal government issued laws to encourage industries and households using advanced techniques for water treatment and savings, and to prohibit industrial sectors from extracting water from ground and irrigating waste water into the ground. Meanwhile, the government proposed the construction of water storage and transportation engineering projects such as the Heihe River Dam and Heihe River Water Transportation Channel. The two projects were started in 1996 and completed in 2003. Table 1 presents the computed results of economic loss of water quality pollution in water use and supply from 1996 to 2003 in Xi'an. The total economic loss reached $\$7.62 \times 10^8$, and was $\$6.6 \times 10^7$ in 1996 and $\$6.9 \times 10^7$ in 2003, the increased economic loss of water quality pollution in water use and supply was $\$3 \times 10^6$ from 1996 to 2003 in Xi'an.

We estimated agriculture economic losses of food, fishery, and horticulture by using the market value evaluation method. Results are shown in Table 2. Water pollution led to an increased economic loss of agriculture of $\$4.23 \times 10^5$ from $\$4.41 \times 10^5$ in 1996 and $\$8.64 \times 10^5$ in 2003. In all agriculture sectors, food agriculture was most seriously affected, and reached 75% of the total agriculture economic losses.

Ecosystem conservation efforts emphasize the preservation of individual species, of landscapes, and of an indicator species whose presence correlates with that of other. Ecosystem value of aquatic species is estimated through expert investigation evaluation method, and landscape restoration costs are estimated from engineering cost evaluation method. Results show total ecosystem conservation costs in water quality pollution reached $128.8 $\times 10^5$ from 1993 to 2003 in Xi'an, but decreased from $\$27.71 \times 10^5$ in 1996 to $\$12.67 \times 10^5$ in 2003 (Table 3).

Water-borne diseases include skin infection, teeth corrosion, joint pain, loss of appetite, defective vision, fever, abdominal pain, and respiratory diseases. Human health economic loss includes disease treatment costs and economic loss from earlier death, and the calculated results show that total health cost is $\$4,153 \times 10^5$ from 1996–2003, and increased $\$179 \times 10^5$ from $\$567 \times 10^5$ in 1996 to $\$746 \times 10^5$ in 2003 (Table 4).

The total economic loss, including cost of water use and supply, agriculture economic loss, ecosystem conservation costs, and economic loss of human health, reached $\$11,968.65 \times 10^5$ from 1996 to 2003, which increased $\$179.19 \times 10^5$ from $\$1259.13 \times 10^5$ in 1996 to $\$1457.32 \times 10^5$ in 2003.

Relationship between Economic Loss and Manufacture Industrial Structures and Spatial Patterns

By comparing economic losses with GDP values, water quality pollution economic loss coefficients (η) were calculated (Table 5). From 1996 to 2003, water quality pollution economic loss coefficient reached 0.052, and decreased from 0.024 in 1996 to 0.013 in 2003. We further analyzed water quality pollution economic loss coefficients (η) in view of industrial sectors and spatial distribution.

For different industrial sectors, model results revealed that water quality pollution in Xi'an has been dominated by manufacturing, such as chemistries and machineries. Chemical industrial plants were the largest contributor ($\eta = 0.012$) to water quality pollution economic loss from 1996 to 2003, followed by paper plants ($\eta = 0.009$), textile plants ($\eta = 0.007$), metal plants ($\eta = 0.006$), food service, oil refinery plants ($\eta = 0.005$), farmland ($\eta = 0.004$), and others ($\eta = 0.003$).

Water quality pollution economic loss coefficients presented dynamic behaviors in urbanization process by industrial structure adjustment from 1996 to 2003. The values of most of the industrial sectors dropped, especially that of paper plants ($\eta = 0.005$ in 1996, and $\eta = 0.001$ in 2003). However, the values of food service increased (η was 0.02 in 1996, and was 0.03 in 2003) as well as farmland (η was 0.01 in 1996, and was 0.02 in 2003).

For different spatial regions, water quality pollution economic loss coefficients varied according to the above-mentioned buffers

Table 2. Agriculture Economic Loss in Water Quality Pollution from 1996 to 2003 in Xi'an

Agriculture economic loss	Units of agriculture economic loss		1996	2003	Changes form 1996 to 2003	Total from 1996 to 2003
Food	Irrigated waste water amount ($\times 10^5$ m^3)		413	349	−64	3,901
	Irrigated farmland area (p_{pa1}, $\times 10^5$ m^2)		788	665	−123	
	Unit product (p_{ap1}, kg/m^2)		0.4	0.69	0.29	
	Market price (p_{mp1}, \$/kg)		0.91	1.2	0.29	
	Quantity	Decreased unit product (p_{ua1}, %)	26	40	15	
		Economic loss ($\times 10^5$, \$)	0.09	0.27	0.18	1.83
	Quality	Decreased unit price (p_{up1}, %)	8.6	11.2	2.6	
		Economic loss ($\times 10^5$\$)	3.28	6.22	2.94	48.64
	Total economic loss (C_{a1}, $\times 10^5$\$)		3.37	6.49	3.12	50.47
Fishery	Water area (p_{pa2}, $\times 10^5$ m^2)		2.18	2.40	0.22	
	Unit product (p_{ap2}, kg/m^2)		0.43	0.56	0.13	
	Market price (p_{mp2}, \$/kg)		1.9	2.3	0.4	
	Quantity	Decreased unit product (p_{ua2}, %)	3.20	2.70	−0.50	
		Economic loss ($\times 10^5$\$)	0.06	0.10	0.04	0.83
	Quality	Decreased unit price (p_{up2}, %)	5.70	6.30	0.06	
		Economic loss ($\times 10^5$\$)	0.11	0.24	0.13	1.77
	Total economic loss (C_{a22}, $\times 10^5$\$)		0.61	1.26	0.65	9.54
Horticulture	Irrigated waste water amount ($\times 10^5$ m^3)		1.2	1	−0.2	11.3
	Irrigated farmland area (p_{pa3}, $\times 10^5$ m^2)		5	6.2	1.2	
	Unit product (p_{ap3}, trunk/m^2)		3	3.5	0.5	
	Market price (p_{mp3}\$/trunk)		2	2.4	0.4	
	Quantity	Decreased unit product (p_{ua3}, %)	4.70	5.60	0.9	
		Economic loss ($\times 10^5$\$)	0.17	0.36	0.18	2.69
	Quality	Decreased unit price (p_{up3}%)	7.30	8.60	1.3	
	Economic loss ($\times 10^5$\$)	0.27	0.55	0.28	4.15	
	Total economic loss (C_{a3}, $\times 10^5$\$)		0.44	0.90	0.46	6.84
Total economic loss (C_{Ta}, $\times 10^5$\$)			4.42	8.65	4.23	66.85

Table 3. Ecosystem Conservation Costs in Water Quality Pollution from 1993 to 2003 in Xi'an

Ecosystem conservation costs	Unit of ecosystem conservation costs	1996	2003	Changes from 1996 to 2003	Total from 1996 to 2003
Aquatic species	Lost species (number)	71	55	−16	−16
	H'	0.47	0.76	0.29	0.29
	C_{ex} ($\times 10^5$\$)	26.5	12	14.5	114.5
Landscape restoration	Treatment costs of Moat rivers ($\times 10^5$\$)	1.21	0.67	−0.54	14.3
Total economic loss (C_{Te}, $\times 10^5$\$)		27.71	12.67	−15.04	128.8

Table 4. Economic Loss of Human Health in Water Quality Pollution from 1996 to 2003 in Xi'an

Economic loss of human health	1996	2003	Changes from 1996 to 2003	Total from 1996 to 2003
Earlier death cases	45	67	22	359
Economic loss from earlier death ($\times 10^5$\$)	247	336	89	1,960
Infected of disease cases	343	308	−35	2,190
Economic loss from disease treatment ($\times 10^5$\$)	320	410	90	2,193
Total economic loss ($C_H \times 10^5$\$)	567	746	179	4,153

Table 5. Water Quality Pollution Economic Loss Coefficients (η)

Economic loss coefficients (η)			1996	2003	Changes from 1996 to 2003	Total from 1996 to 2003
Environmental economic loss/GDP (ŋ)			0.024	0.013	0.003	0.052
Industrial sector/GDP (ŋ)		Chemical plants	0.006	0.003	−0.0002	0.012
		Paper plants	0.005	0.001	−0.0004	0.009
		Textile plants	0.003	0.002	−0.0002	0.007
		Machinery plants	0.003	0.001	−0.0001	0.006
		Food service	0.002	0.003	0.004	0.006
		Oil refinery	0.002	0.001	−0.0001	0.005
		Farmland	0.001	0.002	0.0002	0.004
		Others	0.002	0.001	−0.0002	0.003
		Total	0.024	0.013	0.003	0.052
Region/GDP (ŋ)	Inner buffer (1–5 km)	Food service	0.002	0.003	0.001	0.007
		Car washing	0.002	0.001	−0.001	0.004
		Household	0.002	0.001	−0.001	0.006
		Others	0.001	0.001	−0.0008	0.004
		Total	0.007	0.006	−0.0018	0.021
	Central buffer (5–10 km)	Chemical plants	0.003	0.001	−0.001	0.005
		Paper plants	0.005	0.001	−0.001	0.004
		Textile plants	0.003	0.001	−0.0001	0.003
		Metal plants	0.002	0.001	−0.0002	0.006
		Oil refinery	0.001	0.001	−0.0001	0.002
		Others	0.001	0.001	0.0001	0.005
		Total	0.015	0.006	−0.0023	0.025
	Outer buffer (>10 km)	Farmland	0.002	0.001	0.001	0.005
		Others	0.0003	0.0001	−0.0001	0.0006
		Total	0.0023	0.0011	0.0009	0.0056
		Total	0.024	0.013	−0.003	0.052

(inner buffer, 1–5 km; central buffer, 5–10 km; outer buffer, >10 km). The value of central buffer was the highest (η =0.025) from 1996 to 2003, followed by inner buffer (η =0.021) and outer buffer (η=0.0056). Within different buffers, contribution factors differently affected water quality pollution economic loss coefficients. Values of the inner buffer were imposed by food service, car washing, households, and other business activities, and manufacturing industries dominated that of the central buffer, and agricultural activities controlled that of the outer buffer. While the values of the inner buffer decreased from 1996 to 2003, value of the outer buffer increased. One reason was that the increasing population of the city pushed the farmland to provide more food supply, and fertilizers increased.

Conclusion and Discussion

We evaluate the impacts of urbanization on water quality pollution from an economic view in Xi'an from 1996 to 2003. Water pollution in the rivers of Xi'an showed a strong organic component. As discharges of both domestic and industrial effluents have increased, clean water has become increasingly scarce. The distribution of factories also had large impacts on river water quality. The increasing industrial and service sector products were both accompanied by increased organic pollution, but the total water quality improved due to industrial structure adjustment and enforcement of the government's tough measures.

Although dose-loss curves show that water quality improved, economic loss of water quality pollution slowed down. The slight increase in economic loss reaches $\$198.19 \times 10^5$ from 1996 to 2003; these are mainly caused by human health loss and agriculture economic loss, as polluted area clustered more population in urbanization process, and more fertilizers were used to support more urban food supply. By calculating water quality pollution economic loss coefficients (η), economic loss decreased (from 0.024 in 1996 to 0.013 in 2003). This shows that economic losses are controlled during the past year from 1996 to 2003. Further analysis of water quality pollution economic loss coefficients (η) in view of industrial sectors and spatial distribution also shows that the total economic loss decreased.

As an abstraction of reality, modeling will always have shortcomings. Nevertheless, we are reliant on simulations to plan for the future implications of current decisions. Relying on economic tools to measure environmental factors, such as the economic costs of environmental pollution, is a difficult task for four reasons. First, the environment is a public resource that is not easily assigned a market value. Second, the result of calculations may vary widely depending on the particular approach selected by researchers. Third, environmental economic measurement relies heavily on extensive research in the natural sciences. For instance, the dose-response relationship between pollution and human health will remain unclear until extensive observation and experimentation have been completed. Further, numerous variables influence this relationship. As a result, data on certain variables cannot be obtained. Fourth, it is not clear whether and how to calculate costs to future generations. Further research is expected to include estimates of the indirect effects of environmental pollution facing similar issues.

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