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Pollution characteristics of the rivers in suburban Shanghai

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Abstract: Forty middle and small rivers in three towns of Fengjing, Songjiang and Zhujiajiao of suburban Shanghai were chosen as sampling sites for water quality research. Measurement results of DO, COD_{Cr}, TP, TN and so on show that the rivers are under heavy eutropic conditions, which are several times greater than the critical values of the worst level (Type V) of water. Water pollution situation has different temporal and spatial characteristics. Non-point pollution, such as village domestic sewage, farmland runoff, livestock feces, has become the primary source of pollution of the middle and small rivers in suburban Shanghai.
Key words: suburban Shanghai; water quality; pollution characteristics
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1 Introduction

Since the 1970s, some developed countries have carried out studies on water quality monitoring and water environment evolvement at large. Scholars usually synthetically analyzed time and process of water environment evolvement, social and economic influence and so in the course of research. Research results of Seine river in Paris (Cun *et al*., 1997) show a trend over an 11-year (1965-1975) period with nitrate concentrations increasing by 0.11 mg/l/year; water quality in Humber area of England (Takashi Oguchi *et al*., 2000) and city rivers of Scotland (Robert C Ferrier *et al*., 2001) show that the Spey (2% arable land cover in catchment) and Dee (10% arable land) are characterized by low concentrations of nitrate-N (<1 mgl^{-1}) and show no long-term trend. The Lossie (25% arable land), Don (40% arable land) and Deveron (42% arable land) have nitrate-N concentrations of 2-3 mgl^{-1} with little discernible trend, while Ugie (79% arable land) and Ythan (88% arable land) exhibit a clear positive trend in increasing nitrate-N concentration over the 20 years of HMS monitoring; Hudson estuary in America (Feng H *et al*., 1998; Yang M *et al*., 1998), urban rivers in Osaka city of Japan (Yamamoto *et al*., 2001) and city river Harrestrup in Copenhagen, Denmark (Harremoes *et al*., 1996) and so on showed that concentration change of water pollutant had close relations with population growth, industrialization and agricultural intensification. Concentrations of nitrogen, phosphorus, heavy metals and organic pollutants in city rivers are high.

Extensive researches on relationships between city water environment and human activities were carried out in China from the 1970s to the 1980s. At present time, pollution degree of big river systems in cities of northern China is higher than that of southern China, it is particularly so in cities of industrially developed regions (Chen and Zhang, 2002). Viewing from distribution of polluted area, seriously polluted rivers are mainly distributed in the Huaihe drainage basin, some tributaries of the Yellow River, Liaohe drainage basin, Beijing-Hangzhou Grand Canal and

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some economically developed cities in southern China (Zheng and Shi, 1989; Chen *et al*., 2000; Du *et al*., 1997; Liang, 1999; Bai, 1998; Chen *et al*., 1999; Zhou and Li, 1998). Viewing from pollution feature, we found that organic pollution is still the main pollution mode of the rivers in cities and their neighbouring areas. Dissolved oxygen content in many seriously polluted city rivers is decreasing and water appears stink and offensive odor seasonally or throughout the year.

City river turning stink and offensive odor has been a common pollution problem in many large and medium-sized cities in China. There are many studies on water turning stink and offensive odor of waterways in Shanghai (Huang *et al*., 1994; Xiong, 1997; Fang *et al*., 1997). Environment in urban area of Shanghai improves year by year while pollution of small towns in suburban areas is becoming an increasingly serious problem, which affects and restricts their sustainable development. These creeks run through residential area, encircle farmland, and flow across livestock farms, so water quality is influenced greatly by people's life and farming activities, and the whole drainage network turns stink and eutrophic. These phenomena show that a new pollution pattern has been formed taking small towns in suburban areas as center center and connected rural areas encircling the city. Although some scholars have thought much of surface water pollution in suburban Shanghai (Chen *et al*., 2001; Hu *et al*., 2002; Ruan, 2000), yet research work in Shanghai water environment pollution research is still limited to city rivers, suburban river pollution has not been systematically and throughly studied. Suburban waterways have long been a blank for environmental protection department in water quality monitoring. Studies on suburban river pollution, its temporal and spatial change rule and influence mechanism are affected due to lack of first hand data and systematic understanding of the situation. Water environmental pollution has become a restricting factor affecting Shanghai's eco-city construction and environmental quality improvement as well as an important factor influencing the implementation of sustainable development stratagem of the city.

This article selects three representative suburban counties amongst the key project of developing one city and nine counties during the period 2000-2005 in Shanghai. Fengjing town is located in Jinshan district, Songjiang town located in Songjiang district and Zhujiajiao town located in Qingpu district. Then we monitored water quality of 40 creeks in 3 counties in autumn, winter and summer. After analyzing and studying sample data we tried to show temporal and spatial evolvement rule of water quality of suburban waterways, expecting others can learn river pollution situation of Shanghai suburbs. Moreover, we hope the information can provide basic data and evidence for anti-pollution and scientific decision making of small town creeks waterway networks in Shanghai even the Yangtze river delta.

2 Sampling and analyzing methods

2.1 General situation of the study area

Jinshan, Songjiang and Qingpu are catchment area of Huangpu River where rivers crisscross dotted with lakes in clusters because of sinkage of Taihu. Dense water networks are composed of middle and small rivers at district, town and village levels. These creeks belong to upstream water system of Huangpu River, located in its upstream water protection area, receiving water from Dianshan Lake, Taihu Lake, and Tianmushan and release into sea through downstream of Huangpu River. So water quality changes of these districts are of great significance.

Fengjing town is located in the northwest of Jinshan district in Shanghai city, which is a gateway of southwestern Shanghai, abuts on Zhejiang Province and borders with Jiashang, Pinghu, Songjiang, Qingpu and Jinshan. Its total area is 54.32 km^2. Songjiang district is located in the southwest of Shanghai, all of its rivers are strong sense tidal rivers. Songjiang district used to have dense network of waterways, but for with the construction of new town district and government reconstructing of its waterways, many rivers were buried or disappeared. Zhujiajiao is located by Dianshan Lake of western Shanghai with a total area of 50 km^2. It is the joint of provinces of Jiangsu and Zhejiang as well as Shanghai city. Land and water transportation are very convenient. Relief terrain of this district is very flat having rivers crisscrossed dotting with lakes. It is a representative village south of the Yangtze River.

2.2 Sample collection

Sample point distribution: According to river distribution characteristics of suburban Shanghai, rivers size levels (district is A, town is B, village is C) and factors such as water sample representativeness and so on, while considering main pollution sources such as industrial gardens, town and village residential areas, livestock farms, pound, farmland and so on, we selected 40 seasonal monitoring spots, i.e., 15 samples in Fengjing, 13 in Songjiang and 12 in Zhujiajiao. Among them there are 14 district rivers, 17 town rivers and 9 village rivers. *Water sample collection*: we acquired surface layer water samples at river monitoring spots by using collectors about 50 cm under water surface in Fengjing in November 2002, Songjiang in January 2002 and Zhujiajiao in July 2002. In order to avoid rainfall dilution influence to river pollution concentration, sampling was done in fine days after rainfall. We filtrated water samples with 0.45 μm filter strain film, added $HgCl_2$, and keep them in 80 ml glass at low temperature.

2.3 Analysis and testing method

Water sample analysis items include the following indexes: water, temperature, conductance, pH, dissolved oxygen, COD, total phosphorus (TP), total nitrogen (TN), ammonia (NH_4^+-N), nitrate (NO_3^--N), nitrite (NO_2^--N), and dissolved inorganic nitrogen (DIN). Water temperature, conductance, pH, COD_{Cr}, TP, TN etc. are measured according to literature. We filtrated water samples with 0.45 μm film in order to eliminate effect of suspended particles. All index analysis errors are controlled within less than 5% (Jin and Tu, 1990).

3 Results and discussion

3.1 Current situation for quality of waterway networks

From the analytical results of 40 water samples in Fengjing, Songjiang and Zhujiajiao in autumn, winter and summer, the main indexes (DO, COD_{Cr}, TP, NH_4^+-N) indicate that water quality has been far inferior to the national surface V level water standard (Table 1) and badly eutrophied, water becomes stink with odor smell, water pollution of waterway networks is very serious.

Table 1 shows pH average value of water is 7.665, changing range of pH is small, all within national level V water standard. These evidences reflect that water acid and alkalescence function have not been destroyed yet, other indexes, except NO_2^--N concentration range are very big; DO average value is 3.606 mg/L, though better than level V water standard, the minimum value of 0.150 mg/L indicates that DO is almost exhausted. Among the three seasonal monitoring results, 28.8% of DO content of rivers are less than level V water standard; 92.5% of

Table 1 Average monitoring result of surface water quality of the rivers in suburban Shanghai (mg/L)

Pollution index	Min	Max	Average	Standard deviation	National surface water level V standard
pH	6.590	8.950	7.665	0.460	6-9
DO	0.150	20.089	3.606	3.204	2
COD_{Cr}	8.300	116.009	41.338	15.351	40
TP	0.081	3.821	0.511	0.502	0.2
TN	1.227	43.982	17.295	15.616	
NO_3^--N	0.073	4.823	1.917	1.187	25
NO_2^--N	0.000	0.980	0.151	0.149	1
NH_4^+-N	0.410	13.780	2.913	4.059	1.5
DIN	0.873	31.562	4.981	3.782	

COD_{Cr} of water quality are 30 mg/L, higher than the level V standard. The range of COD_{Cr} content is very big with the maximum up to 116.009 mg/L, which is three times of the level V water standard. That's why many rivers turned stink.

TP average value inferior to the level V accounts for 97.5% of the monitoring spots are above V level water with the maximum value up to 3.821 mg/L, 19 times of the level V water. This indicates that water networks in suburban areas and towns of Shanghai have been eutrophied. All monitoring data of NO_3^--N are less than level II with the maximum value being 4.823 mg/L, which indicates the nitrate pollution is not serious. Some 72% of NO_2^--N content of water quality belong to levels II and III. It is noteworthy that the average content of NH_4^+-N is 2.913 mg/L, which is almost 3 times of level V. The maximum NH_4^+-N value is 13.78 mg/L, which is almost 10 times of level V, and 82.2% of the monitoring data are higher than level V water. The average value of DIN is 4.981 mg/L, contents of NO_3^--N, NO_2^--N, NH_4^+-N are 38.5%, 3% and 58.5%, respectively. It is obvious that NH_4^+-N and NO_3^--N are dominating, which indicates that farmland pollution, domestic sewage and livestock feces have greatly influenced the quality of waterway networks.

3.2 Seasonal changes of surface water quality of the rivers

Generally, water quality pollution degree of the middle and small rivers in suburban Shanghai is relatively high in summer (Table 2). The average value of DO is 3.075, lower than that of autumn and winter. The main indexes, such as COD_{Cr}, TP, NO_2^--N and NH_4^+-N, have showed an increasing trend with the rise of temperature and aggravation of biological activities. Except NO_2^--N, other pollution indexes are higher than level V, many rivers turn stink in summer. In addition, water quality pollution degree is also affected by pH, DO and so on. TP and average values have no prominent difference between winter and summer. So is NH_4^+-N. NO_3^--N and DIN contents are higher in winter, and TN content is obviously higher in autumn.

This seasonal changing pattern are closely correlated with synthetic action s of multiple factors such as intensity of anthropogenic activities, river hydrologic regimes, climate condition, propagation conditions of algae and water plants, pollutant migration and transformation. Affected by East Asian monsoon climate, temperature, rainfall, river runoff, hydrophilous plant growth and anthropogenic activities all have seasonal changes in temperature, dryness and wetness, flood and drought, rise and fall, strongness and weakness. These resulted in seasonal changes in quality of waterway networks. In winter, because domestic sewage and livestock feces effluent are less than other seasons, rivers reoxygen and self-clean ability is high, pollution degree of water networks is lower.

In mid-summer, discharge of domestic sewage and livestock feces and so on increases,

Table 2 Seasonal change of surface water quality of the rivers in suburban Shanghai (mg/L)

Pollution index	Autumn	Winter	Summer	Standard deviation	National level V water standard
pH	8.111	7.301	7.583	0.411	6-9
DO	3.407	4.346	3.075	0.661	2
COD_{Cr}	42.610	36.975	44.430	3.887	40
TP	0.409	0.556	0.568	0.089	0.2
TN	27.641	16.250	7.995	9.864	
NO_3^--N	1.776	2.766	1.208	0.788	25
NO_2^--N	0.142	0.098	0.215	0.059	1
NH_4^+-N	3.065	2.592	3.083	0.278	1.5
DIN	4.982	5.455	4.506	0.475	

rainfall and river runoff flux reach climax during monsoon and flood season, although river's pollution accommodation ability is high too, water environment characteristics of middle and small rivers determine that they cannot dilute their pollutant concentrations effectively. Such indexes as COD_{Cr} and others become higher; nitrify bacillus in surface water is very active, NH_4^+-N produces much NO_2^--N during nitration process, which causes water NO_2^--N increasing from 0.098 mg/L to 0.215 mg/L, a distinctive increase in content. In autumn, as temperature becomes low, effluent of domestic sewage and livestock feces and so on is also decreasing with the decrease of rainfall and river runoff flux synchronously. COD_{Cr}, TP, NO_2^--N, and NH_4^+-N contents in water networks decrease accordingly, but at the same time algae and hydrophytes release a lot of nitrogen and phosphorus when they blast, consuming dissolved oxygen of water, so the pollution content in water is not low in winter.

Seasonal changes of water quality pollution in suburban area are influenced by both natural and artificial factors. Its formation mechanism remains to be further studied and explored.

3.3 Spatial distribution of water pollution of networks

3.3.1 River level difference The pH and DO values have no great difference in all level rivers on average pollution value in the 3 level rivers of district, town and village. Average values of COD_{Cr}, TP, NH_4^+-N, and DIN in district creeks are less than those in town and village creeks, while NO_3^--N and NO_2^--N are reverse (Table 3 and Figure 1). This difference may be caused by such factors as pollution distributing structure, pollution releasing capacity, water hydrology condition, propagating ability of hydrophilous plant.

3.3.2 Water quality around different environments Comparing surface water quality seasonal monitoring results of 7 representative river sections around different environments, such as livestock field, town and village residential areas, factory area, scenery area, paddy field, vegetable field, and pound (Table 4). There are remarkable spatial differentiations in creek water quality. The pollution degree and type of pollution are closely related with type and intensity of anthropogenic activities.

Generally, near residential area and livestock field, water quality is worse because of great amount of effluents of domestic sewage and livestock feces without disposal. COD_{Cr}, TP, and

Table 3 Indexes of surface water quality of the rivers in suburban Shanghai (mg/L)

Pollution index	Stat. paremeter	District level	Town level	Village level	National water level V standard
pH	Average value	7.612	7.620	7.833	
	Changing range	6.590-8.280	6.860-8.580	7.090-9.780	6-9
DO	Average value	3.246	3.065	3.186	
	Changing range	0.610-6.300	0.150-9.870	0.150-20.000	2
COD_{Cr}	Average value	36.357	41.431	48.911	
	Changing range	8.300-57.900	11.200-88.200	21.700-116.000	40
TP	Average value	0.355	0.484	0.805	
	Changing range	0.081-0.698	0.085-2.899	0.209-3.821	0.2
TN	Average value	17.340	16.131	19.426	
	Changing range	5.421-33.081	1.227-35.592	6.306-43.982	
NO_3^--N	Average value	2.215	1.954	1.462	
	Changing range	0.464-4.109	0.073-4.823	0.188-3.883	25
NO_2^--N	Average value	0.182	0.142	0.127	
	Changing range	0.022-0.980	0.000-0.795	0.004-0.491	1
NH_4^+-N	Average value	2.043	2.763	4.558	
	Changing range	0.440-5.141	0.410-13.783	0.493-30.421	1.5
DIN	Average value	4.474	4.821	6.148	
	Changing range	1.555-6.657	1.717-14.937	0.873-31.562	

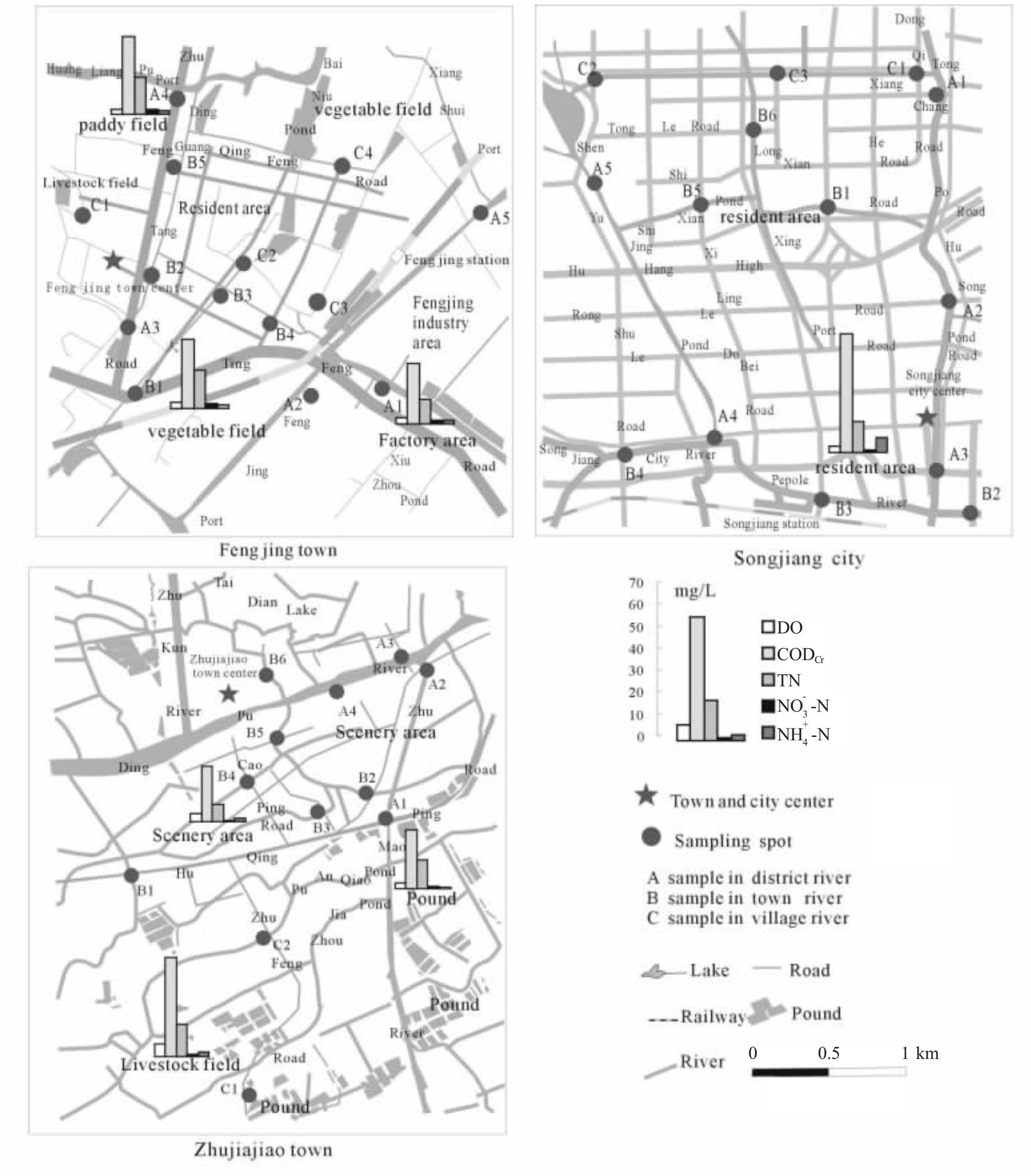

Figure 1 Distribution of the monitoring points in the rivers of suburban Shanghai

NH_4^+-N contents in water samples nearby are worse than level V water in evidence, contents of oxygen consuming organic pollution and phosphorus in rivers increase drastically. A sewage tank at sampling spot FC1 in Fengjing appears distinct alkalinity, with pH being 8.65. Monitoring result of TP is 2.460 mg/L, NH_4^+-N is content 2.621 mg/L, TN is 28.998 mg/L; at ZC1 spot in Zhoujiagan of Zhujiajiao contents of COD_{Cr} and NH_4^+-N are relatively high, being separately 55.8 and 4.311 mg/L, while TN is 35.587 mg/L, and TP is 0.791 mg/L. There exists serious NH_4^+-N pollution in creeks near residential areas, average value of NH_4^+-N is even 10 times of level V water content. FC2 in Fengjing is located at the effluent outlet of domestic sewage, where water

Table 4 Indexes of water quality of the rivers around different areas in suburban Shanghai (mg/L)

Pollution indexes	Stat. paremeter	Livestock field	Residential area	Factory area	Scenery area	Paddy field	Vegetable field	Pond
pH	Average value	8.05	7.63	7.61	7.57	7.68	7.53	7.65
	Changing range	7.46-9.78	7.07-8.21	7.10-8.16	7.10-8.30	7.09-8.08	7.09-8.18	7.06-8.07
DO	Average value	6.89	3.05	3.59	4.57	2.66	3.35	3.40
	Changing range	2.51-17.40	0.15-20.00	0.61-4.70	0.91-7.26	0.57-5.47	0.31-5.80	0.95-5.32
COD_{Cr}	Average value	56.44	55.60	32.28	31.40	40.92	36.68	33.32
	Changing range	46.20-75.00	37.10-116.00	17.50-43.80	11.20-44.30	27.90-46.70	15.40-57.90	8.30-57.90
TP	Average value	0.67	1.34	0.45	0.22	0.47	0.62	0.32
	Changing range	0.27-2.44	0.21-3.82	0.25-0.60	0.08-0.41	0.14-1.23	0.08-2.46	0.13-0.52
TN	Average value	18.24	16.05	13.29	10.14	14.48	19.27	16.26
	Changing range	6.31-35.59	7.11-26.51	7.53-23.08	1.22-18.53	8.73-30.54	5.42-43.98	5.57-29.41
NO_3^--N	Average value	1.62	1.41	1.90	0.90	2.36	2.64	1.32
	Changing range	0.30-1.80	0.20-3.32	0.46-3.67	0.77-4.26	0.18-4.07	0.55-4.10	1.01-3.90
NO_2^--N	Average value	0.21	0.16	0.05	0.07	0.20	0.10	0.18
	Changing range	0.01-0.22	0.004-0.44	0.07-0.46	0.02-0.14	0.02-0.49	0.001-0.14	0.03-0.48
NH_4^+-N	Average value	10.05	10.82	1.72	1.76	2.11	2.13	1.80
	Changing range	8.54-12.31	2.57-30.42	0.49-4.40	0.57-3.40	0.44-5.14	0.75-5.22	0.86-3.56
DIN	Average value	3.05	12.40	4.29	3.87	4.67	4.83	4.34
	Changing range	0.87-14.90	3.36-31.56	1.55-5.75	1.72-5.25	1.46-6.42	2.102-5.79	3.07-5.27

appears stink and covered with hyacinth entirely, COD_{Cr} is 116 mg/L, TP3.821 mg/L, and NH_4^+-N is 26.488 mg/L, all the indexes are higher than average value. ZB4 spot water in Zhujiajiao near residential area appears dark green, COD_{Cr} and TP reach 50.011 mg/L and 1.305 mg/L separately, NH_4^+-N is even serious, being 13.783 mg/L and TN is 21.693 mg/L; river TP and NH_4^+-N contents near paddy field and vegetable plots are higher than those near factories, scenery spots and pound area. Moreover, risk of pollution by NO_3^--N is increasing as a result of receiving water from creeks near farmland and vegetable plots. Their contents of NO_3^--N are 2.36 mg/L and 2.64 mg/L, more than 2 times than rivers near other environments.

This spatial differentiation pattern shows in the process of pollution of the middle and small rivers in the Yangtze River delta, domestic sewage of residential areas, livestock farms stale and runoff from farmland are dominating pollution factors. So creek waterway anti-pollution should attach importance to non-point pollution, it is a problem needed to be solved in small town construction.

4 Conclusions

Water pollution of the middle and small rivers in suburban Shanghai is very serious, which are under heavy eutrophied condition. TP, NH_4^+-N and COD_{Cr} of the surface water are several times greater than the worst level V of water. Some river section appear seasonal water stink, town and village rivers contain high loadings of nitrogen, phosphorus and organic pollutants.

As to seasonal change, surface water of networks are the worst. Such indexes as COD_{Cr}, TP, NH_4^+-N and DIN are higher than those in autumn and winter. DO is on the low side in evidence.

Spatial variations of N and P pollution are observed, as the creeks in different places received different types and amounts of pollutants. Affected by domestic sewage, the creeks near residential areas are often heavily polluted by NH_4^+ and TP. Content of pollution in river increases burstingly. The creeks near farmland are more easily polluted by NO_3^--N than by NH_4^+-N and phosphorus. The creeks near livestock farms often witness sudden soaring of NH_4^+-N and TP. It is obvious that non-point source pollution represented by domestic sewage, farmland runoff and livestock feces has become the main source of suburban creek water pollution.

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