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Water quality characteristics along the course of the Huangpu River (China)

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Abstract

Huangpu River is about 114.5 km from upriver Dianfeng to downriver Wusong, near the estuary of the Yangtze River. It plays a key role in supplying water for production, life, shipment and irrigation. With the industrial development, the pollution of the Huangpu River has become serious recently. The biological oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP), oil, phenol and suspended solids (SS) were lower in the upstream sites than in the downstream sites, indicating pollutants being input along its course. Water quality was the worst in the Yangpu site, near the center of Shanghai City. Dissolved oxygen (DO) content was less than 2 mg/L in the site of Yangpu in July. Among relations between thirteen characteristics, relations between BOD, DO, TN, TP, NH_4^+-N, NO_3^--N and the count of total bacteria or *Escherichia coli* were significant and interdependent. Inner relationships between these main characteristics in the Huangpu River were studied. High nutrient concentration led to growth of microorganisms, including *E. coli*. Degradation of organic matters and respiration of bacteria made oxygen concentration decreased in the water body, and DO was a key factor for nitrification-denitrification process of nitrogen. In the Yangpu site, DO was decreased to less than 3.0 mg/L with BOD higher than 7.5 mg/L in May and July. Low DO concentration will decrease nitrification rate. Nitrification need at higher DO value than other organic substrate oxidation. Consequently, river water contains low NO_3^--N values with high amounts of TN and NH_4^+-N there. This will block the self-purification of surface water, by decreasing the rate of nitrification-denitrification transformation process in the water body.

Key words: water quality; ecological assessment; Huangpu River; nitrification

Introduction

Freshwater ecosystems play unique roles for society through provision (e.g., products and food), supporting (e.g., waster processing and supply of clean water) and enriching or cultural (e.g., aesthetic and recreational) services (Postel and Carpenter, 1997; Covich *et al*., 2004). However, with the development of industry and agriculture, the number and magnitude of anthropogenic stressors arose from the myriad of human activities including pollution, engineering and overexploitation of water resource that threaten these services was growing rapidly (Giller, 2005; Postel and Carpenter, 1997).

In the past, water resource managers relied primarily on water chemistry data and chemical toxicity test to determine the condition of the water chemistry and to assess the quality of surface waters. The collection of biological data has been tested significantly for water quality prediction and water resource management (Brian *et al*., 2003). Fecal coliforms (FC) were most commonly used as indicators of microorganisms. *Escherichia coli* is the most common FC, although most *E. coli* strains are non-pathogenic, some strains, such as *E. coli* O157:H7, pose a serious health risk to humans. The United States Environmental Protection Agency (USEPA) recommended that *E. coli* be used as the principle indicator organism in freshwaters, instead of FC. Research has shown that *E. coli* density was more strongly correlated with swimming-associated gastroenteritis than FC (USEPA, 2001). Examining *E. coli* and total bacteria, together with physico-chemical characteristics, helps discern changes brought about by industrial and domestic wastewater discharge along the river course. A combination of physical, chemical and biological indicators should be used to assess water quality (Lavado *et al*., 2006). However, inner relations between main physico-chemical and biological characteristics in surface water need to be fully discussed to critically evaluate surface water ecosystems.

As an important potable water source river for nearly 20 million citizens in Shanghai, China, Huangpu River also plays a key role in supplying water for production, shipment and irrigation (Shanghai EPB, 2002). With the development of industry and agriculture, its pollution has become serious (Shanghai EPB, 2005). Pollution from domestic, industrial and agricultural activities has led to

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deterioration of water quality. The water quality undergoes large changes in chemistry and biology along its course as a result of growing human interference.

With the Shanghai municipality was implementing the 2nd potable water resource protection project (WRPP) in the sub-upstream of the Huangpu River, monitoring the current water quality status scientifically and analyzing the characteristics of pollutants systemically was one of the most important basic work, which can provide constructive directions for controlling the water pollution and improving the water quality. In 2004, characteristics of the eleven physico-chemical and two microbial factors along the whole river were analyzed at bimonthly intervals (Jan. 2004–Nov. 2004), the objective of this study was to evaluate natural water quality changes brought by non-point pollutant discharges along the Huangpu River, to discern the microbial water quality of surface water affected by physico-chemical characteristics, and to elucidate effect mechanisms between main characteristics in surface water.

1 Methodology

1.1 Study area

The study area covered the whole Huangpu River, which is about 114.5 km from upriver Dianfeng to downriver Wusong, the estuary near the Yangtze River. The width of the river is about 500–800 m and depth is about 10–20 m, the annually average flux is about 316 m^3/s. Dianfeng, Songpu, Linjiang, Yangpu and Wusong sites were chosen as the investigation sites, fully according to the routine monitoring sites of Shanghai environmental monitoring center, as shown in Fig.1.

Fig. 1 The bridged general view of the sampling locations in Huangpu River.

Dianfeng site: the headstream of the Huangpu River. The reach between this site and Linjiang site was used as raw water supply for drinking purposes to the city.

Songpu site: an upriver outskirt site of drinking water resources for Shanghai City at a distance of about 40 km from Dianfeng site.

Linjiang site: at a distance of about 70 km from Dianfeng site, and which located near the famous Jinshan petrochemical industry area.

Yangpu site: near the center of Shanghai City, at a distance of about 90 km from Dianfeng site, and which located in the old industrial base of last century.

Wusong site: the estuary joint with the Yangtze River, and the distance along the Yangtze River to the East Sea is about 80 km.

1.2 Sample collection and processing

Water sample were collected at bimonthly intervals during 2004 and analyzed for several chemical parameters including TP and TN. Measurements of temperature and DO were conducted at 0.5 m underwater in the water column using a portable dissolved oxygen meter "DO-11P" (TOA Electronics Ltd., Japan). Measurement of pH was conducted using CyberScan PH310 pH/mV Meter (Eutech Instruments Pte Ltd., Singapore). TN, NO_3^--N, NO_2^--N, NH_4^+-N and TP were analyzed by San^{++} Automated Wet Chemistry Analyzer (Skalar, The Netherlands), after water samples filtered through pre-rinsed Whatman Grade 934-AH glass fiber filters. Total count of bacteria colonies (TCBC) was analyzed by plate count method (Rolf and Lars, 1987). The count of *E. coli* was numbered in light with the method proposed by Chang and Lum (1995). A spectrophotometric method has been developed for the determination of phenol in water, according to Kang *et al*. (2000). Oil in water was determined using infrared by spectrophotometric methods (Simard *et al*., 1951). All the experiment data were presented with mean of five tests.

2 Results and discussion

The bimonthly variations of water properties are given in Figs.2–6 and correlation coefficients between various parameters are indicated in Table 1.

2.1 Physical-chemical features

2.1.1 pH

pH value is a significant factor for water ecosystems, including toxicity to vegetations and animals. pH values in all the sites in Huangpu River showed slightly alkaline as shown in Fig.2. pH of natural waters is governed by the carbonate-bicarbonate-carbon dioxide equilibrium. Slightly alkaline pH is preferable in waters, as heavy metals are removed by carbonate or bicarbonate precipitates (Ahipathy and Puttaiah, 2006). On average, river water in Dianfeng site was a little more alkaline than in other sites in the whole year. It might be due to that water was cleaner in upriver sites, with lower SS and BOD; while in the polluted water, decomposition of organic matters can lead to acidification and lowered pH values (Chetana and Somashekar, 1997).

There was significant negative correlation with BOD, TN, and SS with pH (Table 1). It aligned with the results of Chetana and Somashekar (1997).

2.1.2 Suspended solids

High values of SS indicate an enhanced pollution status of a water body. It is indicated in Fig.2 that SS in the water increased along the river stream. Downstream sites

Table 1 Correlation coefficients between the water characteristics in the Huangpu River (n=30)

	pH	SS	DO	BOD_5	TN	TP	NH_4^+-N	NO_3^--N	Phenol	Oil	Cl^-	Total bacteria	*E. coli*
pH	1.000	–0.570**	0.392*	–0.357	–0.482**	–0.289	–0.291	0.042	–0.419*	–0.135	0.081	–0.106	–0.108
SS		1.000	–0.080	0.645**	0.347	0.329	0.463**	–0.238	0.355	0.298	0.164	0.267	0.164
DO			1.000	–0.407*	–0.151	–0.176	–0.337	0.542**	–0.464**	–0.357	0.210	–0.319	–0.519**
BOD_5				1.000	0.398*	0.479**	0.722**	–0.403*	0.495**	0.537**	0.250	0.657**	0.616**
TN					1.000	0.516**	0.683**	0.173	0.296	0.355	0.270	0.401*	0.443*
TP						1.000	0.554**	–0.104	0.325	0.284	0.027	0.400*	0.424*
NH_4^+-N							1.000	–0.261	0.488**	0.725**	0.392*	0.765**	0.656**
NO_3^--N								1.000	–0.314	–0.440*	0.148	–0.299	–0.502**
Phenol									1.000	0.380*	0.252	0.257	0.390*
Oil										1.000	0.183	0.822**	0.538**
Cl^-											1.000	0.180	0.121
Total bacteria												1.000	0.652**
E. coli													1.000

* $r \geqslant 0.463$ means significant at p=0.01; ** $r \geqslant 0.361$ means significant at p=0.05; n=30.

were heavily polluted with very high content of SS, while the content of SS was lower in the upstream sites, which indicated that the polluting process of the river was acting. Yangpu site had the highest SS concentration. However, SS concentration decreased in the Wusong site, which was due to the dilution of tides at the estuary of the Huangpu River. The river water contained the higher SS concentration during the dry season, spring, and on the contrary during the rainy season, summer and autumn. A large amount of water input diluted the SS in the river in the rainy season.

Significant positive correlation was found with BOD, NH_4^+-N and SS, and negative correlation with DO and SS. It was owing to that SS can adsorb many organic matters and microorganisms (Ling *et al.*, 2002).

2.1.3 Dissolved oxygen

Dissolved oxygen content was one of the most important parameters in water ecological health, and it showed the visible spatial and seasonal variations in the whole year in the Huangpu River (Fig.2). DO values were higher in winter than in summer in the river. The highest values of DO were observed in upstream sites and lowest in the Yangpu site. DO content was less than 2 mg/L in the Yangpu site in July. The low DO values in summer were possibly due to high water temperature and considerable activities of microorganisms, which consumed appreciable amount of oxygen as a result of metabolizing activities and

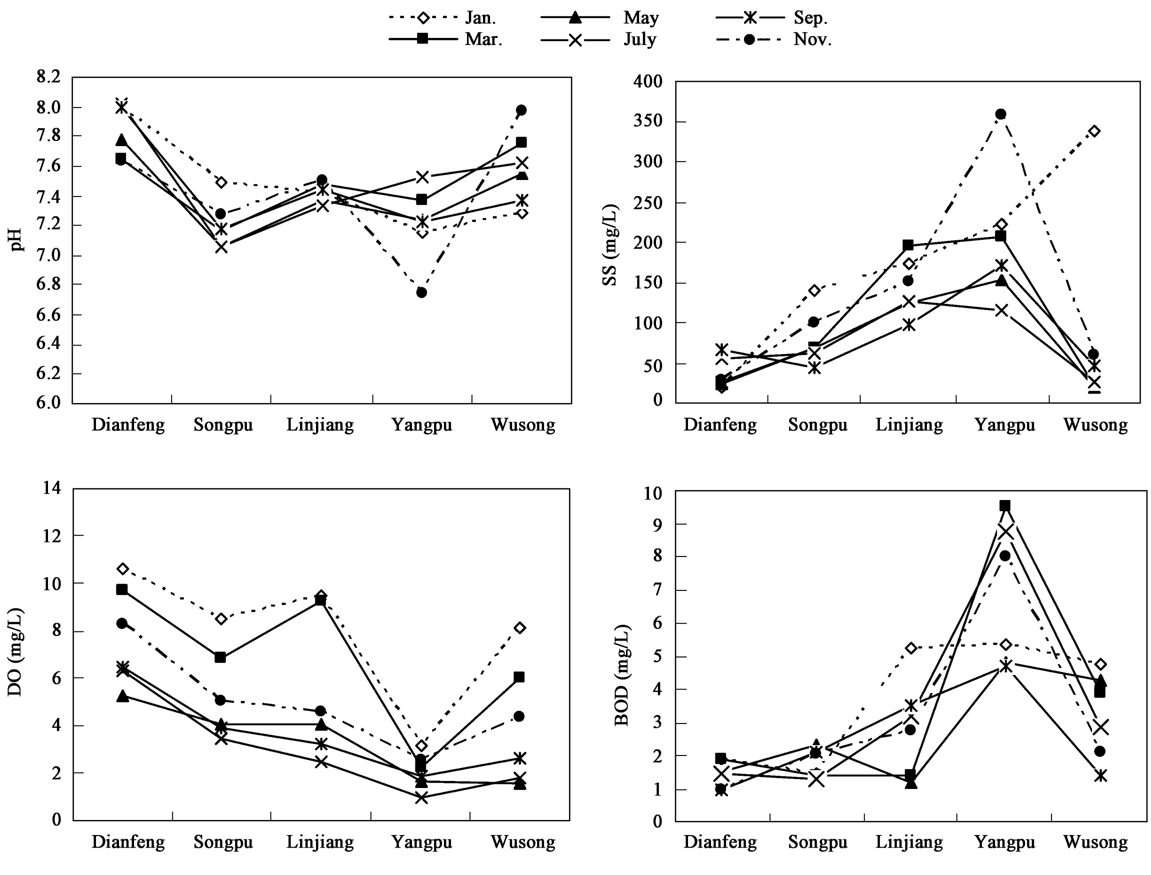

Fig. 2 Variation of comprehensive water quality characteristics (pH, SS, DO and BOD) in the Huangpu River (2004).

decay of organic matters.

The oxygen content in water samples depends on a number of physical, chemical, biological and microbiological activities. Significant negative correlation was observed with BOD, *E. coli*, and DO and positive correlation with NO_3^--N.

2.1.4 Biological oxygen demand

BOD is another important factors used to assess the water quality regarding organic matter both suspended and dissolved. In all the tested sites, highest BOD_5 values were observed in the Yangpu site with lowest values in Dianfeng site in the study of the whole year (Fig.2). The high BOD_5 values in the downstream sites indicated organic matter being input during its course.

BOD was significantly in positive correlation with NH_4^+-N, total bacteria and *E. Coli*. BOD and NH_4^+-N may be input in company with each other during the polluting process along the stream. It was aligned with the previous work of Ahipathy and Puttaiah (2006).

2.1.5 Nutrients

At present, one of the most common ecological problems of inland water bodies is eutrophication. TN, ammonia nitrogen, nitrate nitrogen and TP are main nutrients enriched in water body. Surplus nutrients will promote the excessive growth of algae and producing much microcystin in water body. It poses great health risks to consumers, and produces serious environmental issues. In the Huangpu River the lowest of TN and TP values were observed in Dianfeng site, as shown in Fig.3. They quickly increased from the upstream sites to the downstream sites. Variations of NH_4^+-N concentrations were similar to those of TN. There were many densely cultivated farms and oyster bed in the upriver areas near Songpu and Linjiang sites, annual fertilizer used in this area was about five thousand tons (Shanghai EPB, 2001). Land runoff and pollutants from the oyster bed should be the main input resources of nutrient. As spring is the cultivation time along the river, surplus nitrogen and phosphorous are fertilized in March. So river water contained the highest nutrient concentration in March. However, the highest NO_3^--N values were found in Songpu site and the lowest NO_3^--N values in the Yangpu site. It was due to DO values in the Yangpu site was very low. Nitrification process needs not only certain amount of nitrogen but also oxygen existing in water body. DO value is a key factor relating to nitrogen removal capacity by nitrification-denitrification in surface water.

There were significant positive correlations between BOD, TN, TP, NH_4^+-N, total bacteria and *E. coli*. Nevertheless, NO_3^--N values were in significant positive correlations with DO.

2.1.6 Phenol and oil

Phenol and oil are main specific chemical pollutants in the river. Their results are given in Fig.4. Although phenol concentration gradually increased from the upstream sites to the downstream sites, there was no significant input site. The lowest oil concentrations were observed in the Linjiang site and the highest concentrations were observed in the Yangpu site. As Yangpu District was the old industry base of Shanghai City in the last century, and there were more conveying ships in the Yangpu site than in the other sites. Oil must mainly come from ships transporting in the

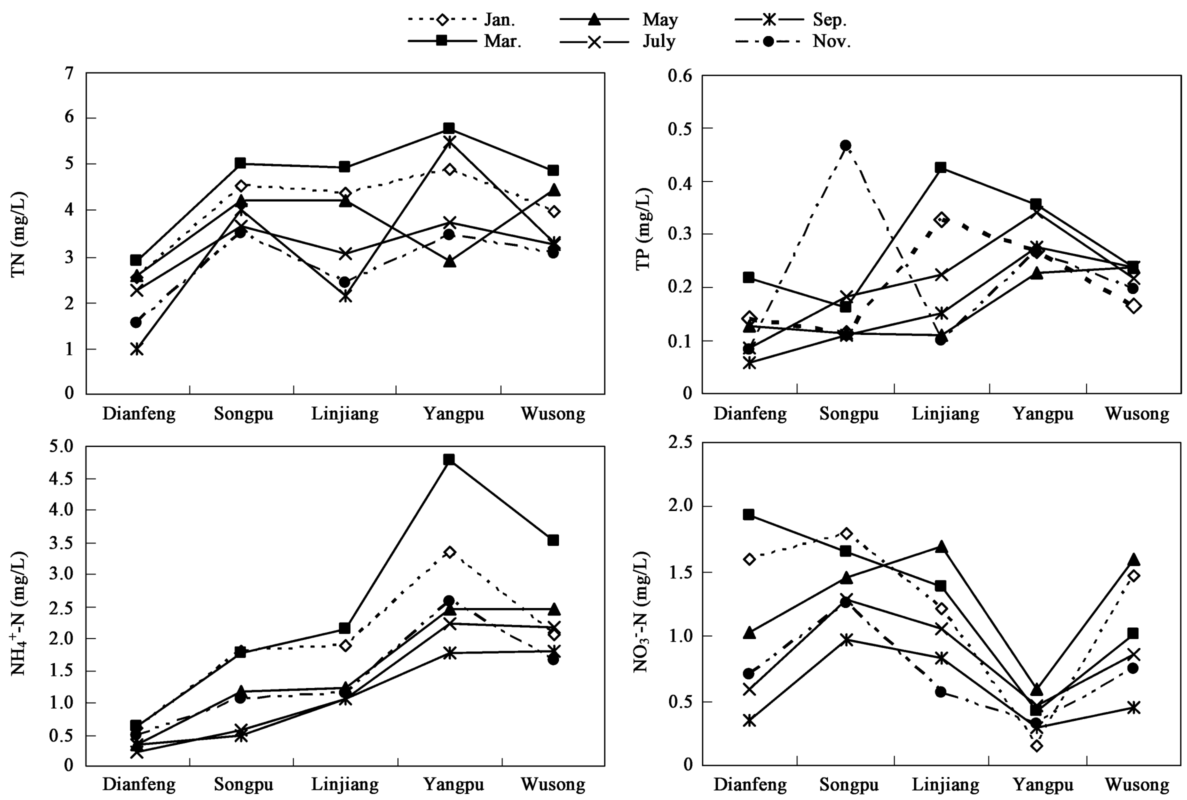

Fig. 3 Variation of nutrients (TN, TP, NH_4^+-N and NO_3^--N) in the Huangpu River (2004).

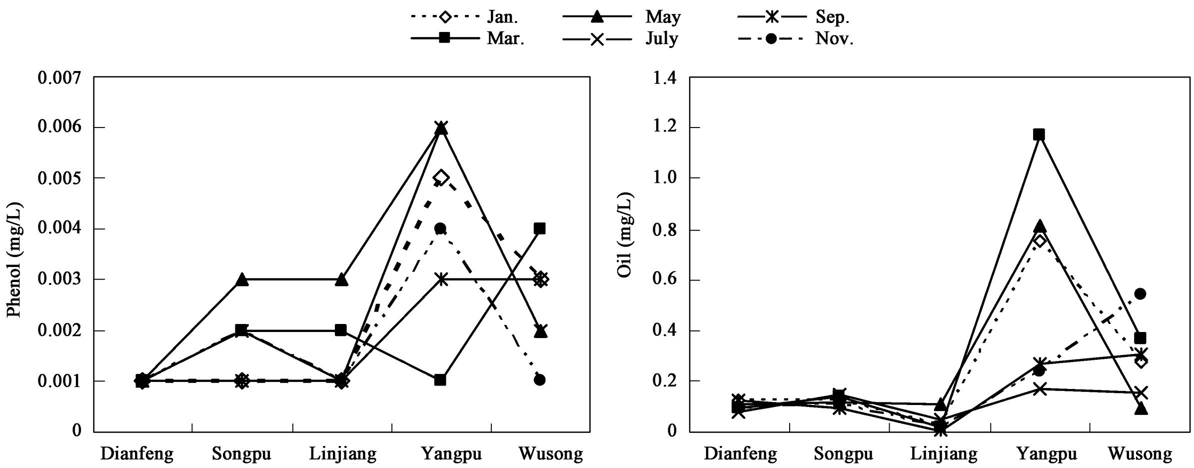

Fig. 4 Variation of typical chemicals, phenol and oil in the Huangpu River (2004).

river.

Oil was in significant positive correlations with NH_4^+-N and total bacteria.

2.1.7 Salinity

Cl^- concentrations were detected to show the variations of alkalinity in the river. It was concluded from Fig.5 that there was no significant change along the stream except in the Wusong site. Wusong site had the highest salinity, as it was the estuary of the river. Much salt from the ocean was mixed with water there with the tides. In all the present investigation, maximum salinity was observed in January, the dry season. Salinity showed no specific relation with other characteristics.

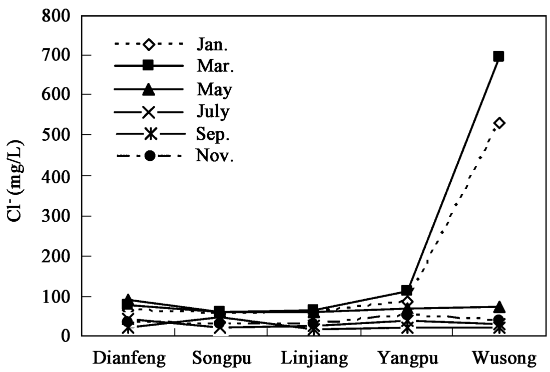

Fig. 5 Variation of salinity, Cl^- in the Huangpu River (2004).

2.1.8 Total bacteria and *E. coli*

Microorganism and their activities indicate decomposition capacity of organic matters in the water body. Total bacteria and *E. coli* were detected and given in Fig.6. The highest total counts of bacteria and *E. coli* were all observed in the Yangpu site. Microorganism amounts increased with the concentration of biodegradable organic matters and nitrogen. It has been approved that removal rates of organic matters were significant positive in correlations with numbers of bacteria (Liang *et al.*, 2003). The microbial loading may come from point sources, such as storage facilities and feedlots, and from non-point sources, such as grazed pastures and rangelands. Microorganisms can be transported by both advection and dispersion processes in stream environments. Advection refers to transport with the mean water flow, and dispersion represents the movement of contaminants through the action of random motions. However, availability of nutrients should be one of the major factors which have been shown to influence microbial survival in the aquatic environments, besides temperature, light, pH, and salinity (Jamieson *et al.*, 2004).

Significant positive correlation was found with BOD, NH_4^+-N, oil and total bacteria or *E. coli*, and negative

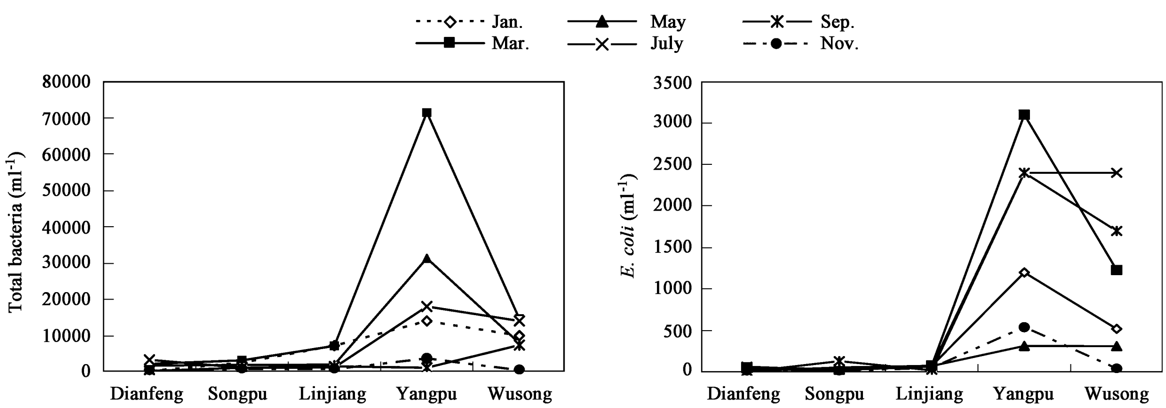

Fig. 6 Variation of microorganisms, total bacteria and *E. coli* in the Huangpu River (2004).

correlation with DO, NO_3^--N and total bacteria or *E. coli*.

2.2 Mechanisms between the main characteristics

Among relations between thirteen characteristics, relations between BOD, DO, TN, TP, NH_4^+-N, NO_3^--N and total bacteria or *E. coli* were significant and interdependent. Effect mechanisms between these main characteristics in the Huangpu River are shown in Fig.7.

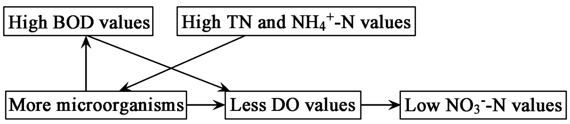

Fig. 7 Effect mechanisms between the main characteristics in the Huangpu River.

High nutrient concentration led to growth of microorganisms, namely, if there was a large quantity of organic waste in the water supply, there would also be a lot of bacteria present working to decompose this waste. Degradation of organic matters and respiration of bacteria decreased oxygen concentration in water body; BOD was a measure of the oxygen used by the microorganisms. DO was a key factor for nitrification-denitrification process of nitrogen. Due to the high oxygen demand for ammonia oxidation, decrease of DO must lead to low nitrification rate in water body (Ruiz *et al*., 2006). It had been testified that DO higher than 1.0 mg/L was necessary for degradation of cell-biodegradable organic matters. Nitrification need at higher ORP values (380–420 mV) than it did in the case for organic substrate oxidation (250–300 mV). DO must be higher than 4.0 mg/L to get a good oxidative status for nitrification (Li and Bishop, 2004). In the Yangpu site, DO decreased to less than 3.0 mg/L in May and July with BOD higher than 7.5 mg/L. Low DO concentration will decrease nitrification rate. Consequently, river water contains low NO_3^--N values with high amounts of TN and NH_4^+-N there. This will block the self-purification of surface water, by decreasing the rate of nitrification-denitrification transformation process in water body.

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