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Restoration processes of pollution zones in Hanjiang River

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Abstract——Two pollution zones in middle and lower reaches of Hanjiang River were selected for studying restoration processes. In each zones 6 stations were set up in upper stream of sewage outfall, 50m, 100 or 150m, 250 or 525m and 1250 or 3500m apart from the outfall. Chemical monitoring and microbial community biomonitoring were carried out simultaneously. Either the chemical monitoring or the biological monitoring proved the self-purification process of water body along with the increased distance from the sewage outfall. 4 biological parameters (species number of protozoa, percentage of phytomastigophora, diversity index and heterotrophy index) and parameter *Seq* of the colonization process all have statistically significant correlations with chemical comprehensive pollution indexes *Pa* and *Pb*.

Keywords: restoration process; microbial community biomonitoring; river pollution zone.

1 Introduction

Hanjiang River is the longest branch of Yangtze River. As a drinking water source it must be satisfactory with the standard grade II for surface water (China EPA, 1988). There are more than 20 large or small pollution zones in the main course of Hanjiang River and the total length is over 10 km. Two representative pollution zones were selected. One is the sewage outfall of Hubei Pharmaceutical Plant in Xiangfan City in the middle reaches and the other is the general outlet of wastewater of Xiantao City in the lower reaches. The present study is to show how pollutants are gradually degraded and removed by self-purification of the water body, how microbial communities change accordingly, and what relationships exist between self-purification rate of wastewater and parameters of microbial communities. It is expected that this study can provide chemical and biological information for explaining the self-purification mechanism and restoration process of pollution zones and the control of pollution zones in river will be considered more effectively.

2 Materials and methods

Sampling station: 6 stations were established in each pollution zone. The upper stream of sewage outfall in two pollution zones were taken as reference stations. The 2nd station was the sewage outfall of the two pollution zones. Another 4 stations were 50, 150, 525, 3500m apart from the sewage outfall of Hubei Pharmaceutical Plant and 50, 100, 250, 1250m apart from the sewage outfall in pollution zone of Xiantao City. The last station was recovery station (Fig. 1).

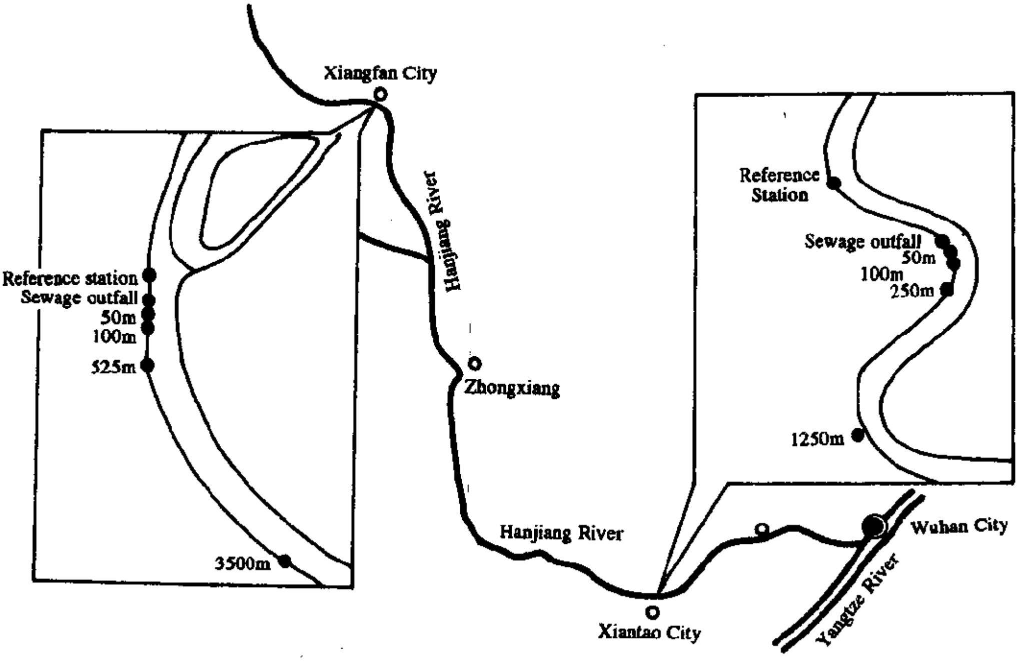

Fig. 1 Location of sampling stations in two pollution zones of Hanjiang River

According to the national standard (China BTS and EPA, 1991), the artificial substrate——polyurethane foam unit (PFU) was used to colonize the microbial communities in water. The exposure times were 1, 3, 7, 11 and 15 days. Species number of Protozoa(*S*), percentage of Phytomastigophora (Phytom %), protozoan diversity index (*D*) and heterotrophy index (*HI*) were determined. Chemical analysis of water quality was also carried out in the 3rd day, including COD_{Cr}, BOD_5, total nitrogen, ammonia nitrogen, nitrate nitrogen, total phosphorus, inorganic phosphorus, volatile phenol, dissolved oxygen and conductivity (China EPA, 1989). The analyses of cyanide and detergent (LAS) were supplemented in the pollution zone of Xiantao City. By using formula $R=(1-e^{-kd})$ (Zhang, 1983) the self-purification constant K can be obtained, where R is the removal rate of distance (m). To compare the analytical data of chemicals with reference stations of two pollution zones and national II grade of surface water standard, the comprehensive chemical pollution index Pa and Pb were obtained, respectively. In pollution zone of the Hubei Pharmaceutical Plant, 5 control items, i. e., COD_{Cr}, BOD_5, total nitrogen, total phosphorus and volatile phenol, were used for calculating Pa and Pb. In pollution zone of Xiantao City, 7 control items were measured, i. e., above mentioned 5 items, cyanide and detergent LAS. As the sewage stream of Xiantao collected waste water from woolen mill, knitting mill, chemical fertilizer factory, pesticide factory, pharmaceutical plant, oil and chemical factory and 3 hospitals, as well as some of domestic sewage, the contents of cyanide and detergent LAS were relatively high. Besides, according to the past record, no cyanide and detergent were detected in the wastewater from Hubei Pharmaceutical Plant. The comprehensive chemical pollution index (Pa, Pb) from all samples at various stations are calculated by the following formula:

$$Pa,\ Pb = \sum_{i=1}^{n} Pi,\ Pi = \frac{Cd}{Co},$$

where Pi is the single chemical pollution index, based on chemical data in reference station (for Pa) and in II grade of surface water standard (for Pb), Cd is the concentration of tested chemical parameter in sampling station. Co is the concentration of tested chemical parameter in reference station or in II grade of surface water standard and n is the number of control items.

3 Results and discussion

3.1 Chemical analysis of water quality of pollution zones

To compare with the reference stations, dissolved oxygen, conductivity, COD_{Cr}, BOD_5, in sewage outfall were 34%—48% lower, 3—17, 17—205, 23—255 times higher than reference stations, respectively. Total nitrogen, total phosphorus and volatile phenol in outfall were 12—23, 7—50 and 243—545 times higher than reference stations, respectively. The concentrations of all chemical compounds declined gradually along with the extended distance from the discharge openings. Of course, the purification rate was different between two pollution zones. In order to explain the possibility of water purification, the ratio of COD_{Cr} to BOD_5 was calculated. It is known that oxygen of organic compounds in water which can be utilized by bacteria is high, then ability of water purification is high, too (Zhang, 1983). The ratios of COD_{Cr}/BOD_5 of stations 50m and 100m in the pollution zone of Hubei Pharmaceutical Plant were the lowest and the ability of self-purification was the strongest. Although COD_{Cr} and BOD_5 contents in sewage outfall of Xiantao City were 10 times lower than that in sewage outfall of Hubei Pharmaceutical Plant, as Xiantao City gathers up the wastewater from various factories, their organic maters are complicated. The ratio of COD_{Cr}/BOD_5 in each sampling station in Xiantao City all exceeded that of Hubei Pharmaceutical Plant, Fig. 2 shows the curves of self-purification rate of two pollution zones.

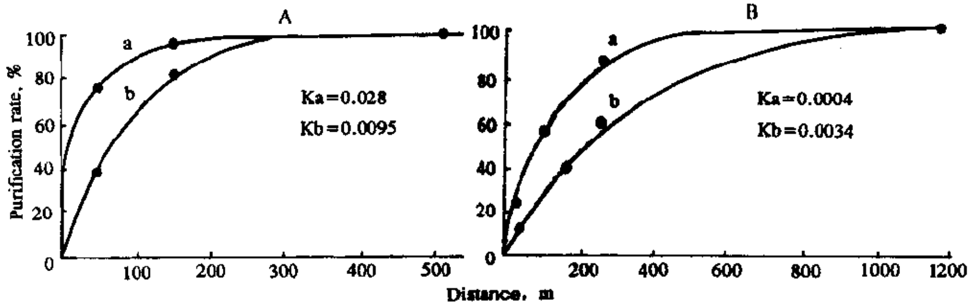

Fig. 2 Curves of the purification rate in the two pollution zones
A: Hubei Pharmaceutical Plant B: Xiantao City

Curve *a* is the self-purification rate of COD_{Cr}, BOD_5, total nitrogen and total phosphorus, Curve b is the self-purification rate of volatile phenol, Comparison of self-purification constant *K* shows that purification efficiency of pollution zone in Hubei Pharmaceutical Plant is much higher than that of pollution zone in Xiantao City. Moreover, the place of the best purification efficiency for the former is in 50m from the outfall and the latter is in 250m.

3.2 Microbial community monitoring

In the six stations of the pollution zone of Hubei Pharmaceutical Plant, 239 species of protozoans were observed, including 55 Phytomastigophora, 45 Zoomastiogophora, 41 Sarcodina and 98 Ciliate. In the six stations of the pollution zone of Xiantao City, 224 species of protozoans were observed, including 84 Phytomastigophora, 45 Zoomastigophora, 18 Sarcodina and 77 Ciliata. To compare with reference stations, protozoan species number in sewage outfall of two pollution zones of Hubei Pharmaceutical Plant and Xiantao City decreased from 85 to 16 and 78 to 41, respectively. These showed that 81.2% species of protozoa community in the zone of Hubei Pharmaceutical Plant and 47.8% species in the zone of Xiantao City were damaged. However, along with increased distance from the outfall, species number increased gradually at the latter 4 stations. In the last station species number recovered or exceeded that of reference station.

According to the species number and richness of protozoans, Maglaef diversity index was obtained in each station of two pollution zones with PFU exposed for 1, 3, 7, 11 and 15 days. The average diversity index in the pollution zone of Hubei Pharmaceutical Plant was 3.22 in reference station, 0.26 in sewage outfall, 1.84 at 50m, 2.29 at 150m, 2.77 at 525m and 3.45 at 3500m. In the pollution zone of Xiantao City, there were 2.58 in reference station, 1.09 in sewage outfall, 1.57 at 50m, 2.19 at 100m, 2.26 at 250m, and 2.70 at 1250m. These show the damage and restoration processes.

Heterotrophy indexes (*HI*) in 3rd day of PFU sampling in each station in two pollution zones was determined. Biomass in *HI* was shown no matter by ash-free dry weight or by ATP, the tendency of *HI* variation was the same. As compared with reference stations, *HI* in outfall of two pollution zones were all higher than that in reference stations, 239 times in the zone of Hubei Pharmaceutical Plant and 49 times in the zone of Xiantao City. Then *HI* dropped down gradually along with distance extending from sewage outfall. At the zone of Hubei Pharmaceutical Plant, in stations of 50m, 150m and 525m *HI* was 69, 4.7 and 2.2 times higher than that of reference stations, respectively. In last station (3500m) it is only 0.1% higher than that of reference station, nearly close to the level of reference station. At the zone of Xiantao City, in station 50m, 100m and 250m, *HI* was 6.6, 2.6 and 1.4 times higher than that of reference station, respectively. In last station (1250m), it was only 9.5% higher than that of reference station.

In each station in two pollution zones, species number of Protozoans were obtained from PFUs exposed for 1, 3, 7, 11 and 15 days. Colonization curve was made for each station (Fig. 3). Curves of the sewage outfalls were the lowest. Then, curves elevated gradually along with increased distance from the sewage outfall.

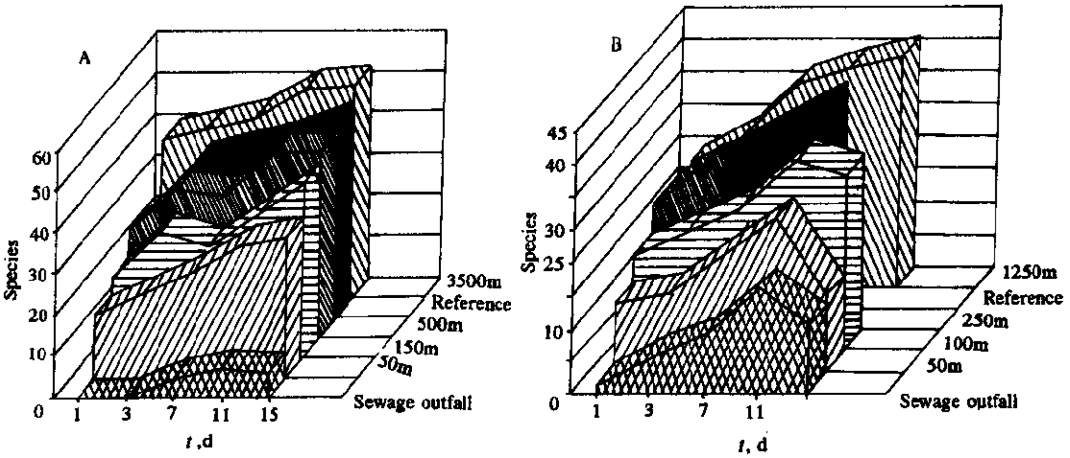

Fig. 3 Curves of protozoan colonization in PFU in sampling station of the pollution zone of Hubei Pharmaceutical Plant (A) and the pollution zone of Xiantao City (B)

The 3 curves of 50, 150 and 500m from sewage outfall in Hubei Pharmaceutical Plant rose gradually and the 3 curves of 50, 100 and 250m from sewage outfall in Xiantao City also ascended gradually, except the station at 250m, samples were collected only in 1st and 3rd day because of water level dropped down. Species number at the sewage outfalls, 50m and 100m in 15th day decreased obviously as compared with those in 11th day. The reason is that there was heavily raining during this period, small holes of PFUs were stopped up by sand and mud, which affected colonization of protozoans. In spite of this, species number of protozoans in 15th day was still in the form of stations at 100m > 50m > the sewage outfall. It shows that no matter how bad the weather is, the difference can still be monitored. In the last stations in two pollution zones, colonization curves of protozoans were very close to those in reference stations. They were all at the peak of curves, showing that they were basically recovered in 1250—3500m down. By using revised MacArthur-Wilson Model (Wang, 1989), three parameters, i.e., species number in equilibrium (*S*eq), constant of colonization rate (G) and time need to reach 90% Seq ($T90\%$) were obtained by computer. Fitness ratio to model is not high due to the complex of pollution zones but Seq parameter also restored gradually. Similar results have not been reported in restoration of pollution zones of other rivers (Cairns, 1992).

3.3 Relationships between chemical monitoring and microbial community monitoring

In two pollution zones four biological parameters (species number of protozoa, percentage of *Phytomastigophora*, diversity index and heterotrophy index) and parameter Seq of the colonization processes in microbial monitoring all have statistically significant correlations ($p < 0.05-0.0001$) with comprehensive chemical pollution indexes Pa and Pb (Table 1), except the percentage of *Phytomastigophora* in pollution zone of Xiantao City, probably due to

Table 1 Relationship between protozoan colonization parameter *Seq*, number of species (S), percentage of phytomastigophora (% Phytom), diversity index (*D*), heterotrophy index (*HI*) and comprehensive chemical pollution index (*Pa*, *Pb*) in the two pollution zones of the Hanjiang River *

The pollution zone of Hubei Pharmaceutical Plant

Parameter	Regression formula	n	Coefficient	p
Seq	$Seq = 45.2971 - 0.0304Pa$	6	-0.9781	< 0.00072
	$Seq = 44.1514 - 0.1237Pb$	6	-0.9626	< 0.00210
S	$S = 38.7145 - 0.03642Pa$	6	-0.9936	< 0.00006
	$S = 37.3755 - 0.1478Pb$	6	-0.9806	< 0.00056
Phytom, %	$\text{Phytom} = 36.0349 - 0.03437Pa$	6	-0.8762	< 0.02203
	$\text{Phytom} = 34.7169 - 0.13943Pb$	6	-0.8602	< 0.02795
D	$D = 2.97392 - 2.81488 \times 10^{-3}Pa$	6	-0.9787	< 0.00068
	$D = 2.86629 - 0.011423Pb$	6	-0.9611	< 0.00233
HI	$HI = 18.3230Pa - 1158.300$	6	0.9835	< 0.0004
	$HI = 76.7515\mathrm{Pb} - 613.5890$	6	0.9970	< 0.00001

The pollution zone of Xiantao City

Parameter	Regression formula	n	Coefficient	p
Seq	$Seq = 35.2833 - 0.02533Pa$	5	-0.8873	< 0.0446
	$Seq = 37.2042 - 0.1586Pb$	5	-0.9206	< 0.0265
S	$S = 29.1837 - 0.02599Pa$	6	-0.9150	< 0.01052
	$S = 30.9064 - 0.15573Pb$	6	-0.9005	< 0.01435
Phytom, %	$\text{Phytom} = 46.2683 - 3.22325 \times 10^{-3}Pa$	6	-0.0557	< 0.9165
	$\text{Phytom} = 53.9769 - 0.16851\,Pb$	6	-0.4782	< 0.3375
D	$D = 2.24489 - 1.89172 \times 10^{-3}Pa$	6	-0.7941	< 0.05921
	$D = 2.47034 - 0.013328Pb$	6	-0.9189	< 0.0096
HI	$HI = 5.6063\mathrm{Pa} - 489.777$	6	0.9639	< 0.0019
	$1/HI = 0.012424 - 1.15181 \times 10^{-4}Pb$	6	-0.9855	<0.00031

* The data of biological parameters (S; Phytom, %; D; HI) were sample of third day of PFU

loss of PFU samples. It could be recognized that, like chemical monitoring, microbiological monitoring can also show the restoration process of pollution zones. Results of this project show that PFU method has many advantages in evaluating water quality. We (Shen, 1992) consider that PFU method can be popularized in the world, especially in developing countries. Dr. John Cairns, Jr, (Cairns, 1993) in the scientific prospective of the 21st century indicated that PFU method in global ecotoxicological risk assessment should be applied.

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