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Studies on kinetics of water quality factors to establish water transparency model in Neijiang River, China

Ronghui Li[1],Wei Pan[1], Jinchuan Guo[1], Yong Pang[3],Jianqiang Wu[4],Yiping Li[3], Baozhu Pan[5], Yong Ji[6] and Ling Ding[2]*

[1]Guangxi Institute of Water Resources Research, Nanning-530 023, China
[2]Shanghai Investigation, Design & Research Institute, Shanghai-200 434, China
[3]College of Environment, Hohai University, Nanjing-210 098, China
[4]Shanghai Academy of Environmental Sciences, Shanghai-200 233, China
[5]Changjiang River Scientific Research Institute, Wuhan-430 010, China
[6]College of Hydraulic and Ecological Engineering, Nanchang Institute of Technology, Nanchang-330 099, China
*Corresponding Author E-mail: dl@sidri.com

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Abstract

The basis for submerged plant restoration in surface water is to research the complicated dynamic mechanism of water transparency. In this paper, through the impact factor analysis of water transparency, the suspended sediment, dissolved organic matter, algae were determined as three main impact factors for water transparency of Neijiang River in Eastern China. And the multiple regression equation of water transparency and sediment concentration, permanganate index, chlorophyll-a concentration was developed. Considering the complicated transport and transformation of suspended sediment, dissolved organic matter and algae, numerical model of them were developed respectively for simulating the dynamic process. Water transparency numerical model was finally developed by coupling the sediment, water quality, and algae model. These results showed that suspended sediment was a key factor influencing water transparency of Neijiang River, the influence of water quality indicated by chemical oxygen demand and algal concentration indicated by chlorophyll a were indeterminate when their concentrations were lower, the influence was more obvious when high concentrations are available, such three factors showed direct influence on water transparency.

Key words

Impact factors, Neijiang river, Numerical model, Suspended sediment, Water transparency

Introduction

One of the primary requirements of submerged plant community restoration is to improve the water transparency. Light field below the water surface is a significant factor of the aquatic ecosystem, which has direct effect on the growth of submerged plants (Lian *et al.,* 1996). The low water transparency hinders the photosynthetic activity and results in the death of submerged plants(Gaevsky *et al.,* 2002).

Water transparency means the distance from water surface to Secchi Disc, when Secchi Disc can be observed faintly from the water surface. Water transparency is an important parameter describing the optical properties of the water body and a key index for assessing the eutrophication status of the water body, and it can visually reflect the degree of clarity and turbidity of the water body (Zhang *et al.,* 2003) . The water transparency reflects the projection deepness of the sunbeams, it is closely related to solar radiation, physical and chemical properties of water body, composition and content of suspended sediment, weather condition and so on, and it is influenced by various environmental factors(Barko *et al.,* 1986; Figueroa *et al.,* 1997).

As water transparency of Neijiang River suffers from comprehensive influences by suspended sediment, dissolved organic pollutant, algae, etc. These factors must be considered when the transparency model is established (Wang *et al.,* 2012). However, the movements and changes of suspended sediment, dissolved organic pollutant, algae under hydrodynamic effect are very complex, a numerical model could be established to describe the movement and change mechanism of suspended sediment, dissolved organic pollutant and algae in water(Liu and Li, 2010). This paper aimed at studing the complex transport process of water transparency of Neijiang River, and to establish water transparency model for Neijiang River, and further to develop a plan for water quality management for this river.

Materials and Methods

Neijiang River is a typical shore-type urban water body in Zhenjiang City in eastern China. It is connected with Yangtze River through approach channel and Jiaonan Sluice, and can form a better water body exchange with the Yangtze River (Fig.1). Under the influence of tidal characteristic of Yangtze River, the hydrodynamic movement of Neijiang River is more complex. Due to large number of sediments brought by water from the Yangtze River, the water of Neijiang River is riley and slight yellow.

Two field survey were conducted in Neijiang River to determine the main water quality indexes, such as chemical oxygen demand (COD), total phosphorus (TP), total nitrogen (TN), chlorophyll a (Chl-*a*), water transparency, water temperature, suspended Solid (SS), pH value. On-the-spot survey data were adopted to analyze the factors influencing water transparency. The sampling time was between 8:00-11:00 hr in April 21^{st}-22^{nd} and 18^{th}-19^{th} August. In the meantime, a synchronous monitoring of full-tide 26 hr on the field water quality was conducted. Four monitoring sections and 7 monitoring points were arranged for Neijiang River. A horizontal-type suspended load sampler was adopted for sampling. The sampling interval was 3hr, superficial water samples were collected at the sampling locations, after sampling of TP, TN, NH_4^+-N, COD and Chl-*a*. Those samples were delivered to the laboratory by batch according to specifications in order determine in accordance with Water and Wastewater Monitoring Analysis Methods (Wei *et al.*, 2012) and Specifications for Lake Eutrophication Survey (2^{nd} Edition) (Jin and Tu, *2010)*, of which TN and NH_4^+-N were determined by wet chemical flow analyzer. pH, dissolved oxygen, water temperature, transparency, etc. were surveyed on the spot test.

The modeling approach for transparency model includes: SS model (Bian *et al.,* 2013),, water quality model (Mann *et al.,* 2012) and algae ecological kinetics model (Gupta *et al.,* 2010) coupled with hydrodynamic model (Duan, 2011) was established respectively to simulate the dynamic changes of SS, COD and Chl-a under hydrodynamic effect. The simulated results were substituted into the established relation formula of transparency with SS, COD and Chl-a, for simulative calculation of the transparency (Table 1).

From the process of model calibration and validation, the hydrodynamic numerical model can reflect the flow movement characteristics of Neijiang River perfectly. It can be used for flow simulation of Neijiang River and set up a sound foundation for the sediment and pollutant transportation simulation of Neijiang River.

A model was built up to stimulate SS, water quality and algae dynamic state. Based on the verification of flow model and full-tidal on-the-spot survey sediment content, with the water quality process and pollution source data which were derived from Neijiang River of approach channel and Yunliang River, it showed that the model suited well. In addition, on-the-spot survey process on water level of approach channel and Jiaonan Sluice and the sediment content of Neijiang River within one year from May 2004 to May 2005, the riverbed distortion was simulated (Table 2). For (SD) water body transparency, an optimization disposal (Ding, 2005) was done and the results which observation and simulation values had been compared at four locations as shown in Fig.2. as for the finally-confirmed model parameter values (Ding, 2005).

Results and Discussion

Suspended matter is an important factor influencing water transparency. The composition and content of suspended matter in water influence the transparency change of water body (Janse *et al.,* 2010; Ruan *et al.,* 2012). The main ingredient of suspended matter includes suspended sediment. The relations between water transparency and suspended sediment content were dependent on the simultaneous monitoring data. The water transparency decreased with the increase of suspended sediment content (Fig. 3). Two of them showed an obvious relation of inverse ratio, it was found through curve fitting that the fitting effect of reciprocal relation was the best, which was accordant with the result obtained by Yang *et al.,* (2003) from the Meiliang Bay in Taihu Lake, with fitting result as follows:

$$SD = 8.1376 / SS + 0.1043 \quad (R = 0.81, P < 0.001) \quad (1)$$

Where, SD was water body transparency (m), *SS* was suspended sediment content (gm^{-3}), *R* was the relevant coefficient, *P* was the significance level for inspection. It was obvious that the suspended sediment content in Neijiang River was closely related the water transparency, and water transparency could be derived from suspended sediment content.

The dissolved organic matter, especially colored in the water body (CDOM) can incur certain influence on water transparency (Serizawa *et al.,* 2010; Li *et al.*, 2009) . The colored dissolved organic matter named as xanthine as well, exists in various water bodies and consists of a series of matters such as humic acid, aromatic polymer and so forth. CDOM is mainly discharged towards the river and land sources along the inland water body and bay shore, and the concentration of CDOM was excessively low in off-lying seas, which mainly comes from the

Table 1 : The comparison of flow velocity values of Neijiang River,China obtained from physical model and mathematic model

Location	Velocity of urgent rising (ms^{-1})		Velocity of urgent falling (ms^{-1})	
	Physical model	Mathematical model	Physical model	Mathematical model
Approach Channel	0.80-1.20	0.85-1.05	0.40-0.65	0.40-0.55
Zhonghong Area	0.50-0.90	0.41-0.79	0.45-0.80	0.38-0.69
Beigushan Wetlands	0.16-0.17	0.10-0.14	0.15-0.16	0.09-0.13
Jiaonan Sluice Cross-section	0.17-0.23	0.09-0.13	0.55-0.65	0.43-0.55

Table 2 : Values of water quality parameters of Neijiang River model, China

Parameter	Implication	Unit	Value
D_x	Longitudinal diffusion coefficient	$(m^2s)^{-1}$	1.0
D_y	Transversal diffusion coefficient	$(m^2s)^{-1}$	0.1
ã	Unit weight of water	kgm^{-3}	1000
ã$_S$	Unit weight of suspended sediment	kgm^{-3}	1685
ã'	Unit weight of dry suspended sediment	kgm^{-3}	1045
d_{50}	Suspended sediment median grain size	mm	0.01
õ	Kinetic viscosity coefficient	m^2s^{-1}	10^{-6}
á	Recovered saturation coefficient		0.5
k	COD_{Mn} degradation coefficient	d^{-1}	0.1
D	Algae mortality	$(24h)^{-1}$	0.17
K_{1R}	Respiratory rate of algae	$(24h)^{-1}$	0.4
è$_{1R}$	Temperature coefficient		1.08
a_{NC}	Nitrogen content in algae	$mg\ mg^{-1}$	0.08
a_{PC}	Phosphorus content in algae	$mg\ mg^{-1}$	0.004
UN_{max}	Maximum absorption rate of algae on nitrogen	$(24\ hr)^{-1}$	0.025
UP_{max}	Maximum absorption rate of algae on phosphorus	$(24\ hr)^{-1}$	0.01
F_{maxN}	Maximum absorption rate of algae on nitrogen	$mg\ mg^{-1}$	0.1
F_{maxP}	Maximum phosphorus content in algae	$mg\ mg^{-1}$	0.015
F_{minN}	Minimum nitrogen content in algae	$mg\ mg^{-1}$	0.015
F_{minP}	Minimum phosphorus content in algae	$mg\ mg^{-1}$	0.001
K_N	Nitric half saturation constant	$mg\ l^{-1}$	0.2
K_P	Phosphoric half saturation constant	$mg\ l^{-1}$	0.02
K_I	Luminary half saturation constant	$\mu mol\ (m^2s)^{-1}$	300
μ_{max}	Maximum growth rate of algae	$(24hr)^{-1}$	1.25

putrescence and degradation of middle and low plant residues in the seas (Zhang, 2005). CDOM is called as inert matter in the water body and has excessively stable properties (Su *et al.*, 2001). CDOM content in sea water body relates to the light transmission intensity of the water body directly. In inland rivers and lakes, because there are more suspended matters available in the water bodies, attenuation of CDOM of the light is much less than the component borne in the sea. General speaking, CDOM contained in water body absorbs the optical spectrums below 500nm; as for visible light, the absorption of CDOM on the optical spectrums weakens with increase of wavelength (Zhang *et al.*, 2002). CDOM is an important component incurring light attenuation in the water body, so it is an important factor influencing was transparency. Due to complex nature of chemical components of CDOM, their extraction and determination is difficult. COD_{Mn} was adopted in this study to find out the relation between dissolved organic matter and transparency. As for the relation between transparency and COD_{Mn} concentration of Neijiang River, it was obvious that water transparency was higher and some were lower when COD_{Mn} concentration was lower, which revealed the influence of COD_{Mn} concentration on water transparency was lower. Water transparency was mainly influenced by suspended sediment content in water. However, transparency would decrease with increase in COD_{Mn} concentration when the COD_{Mn} concentration in water was higher, which showed that COD_{Mn} with higher concentration greatly influenced the transparency. As a whole, the transparency and COD_{Mn} concentration of Neijiang River showed a obvious relation of inverse ratio (Fig.4). The curve fitting was adopted and it showed a good fitting result.

The attenuation of chlorophyll a on light mainly resulted due to the absorption and scattering of algae on light (Mooij *et al.*, 2009). Based on the simultaneous monitoring data and the

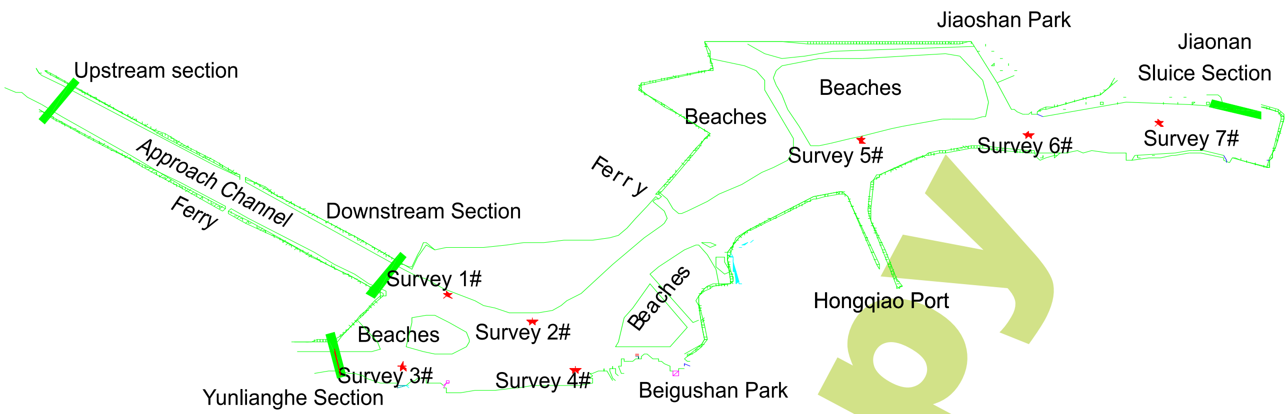

Fig. 1 : Location of monitoring points in Neijiang River,China

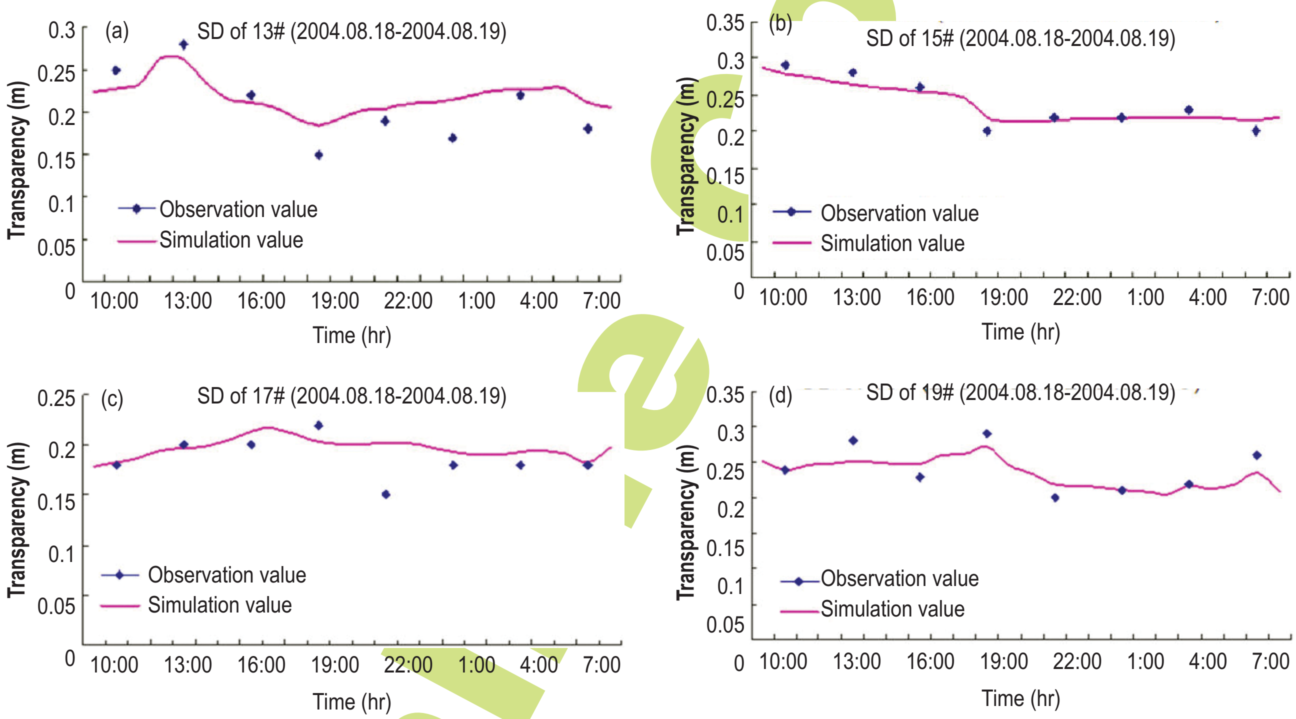

Fig. 2 : The comparison of observation and simulation values at four locations for transparency model calibration; (a) Location 13#; (b) Location 15#; (c) Location 17#; (d) Location 19#

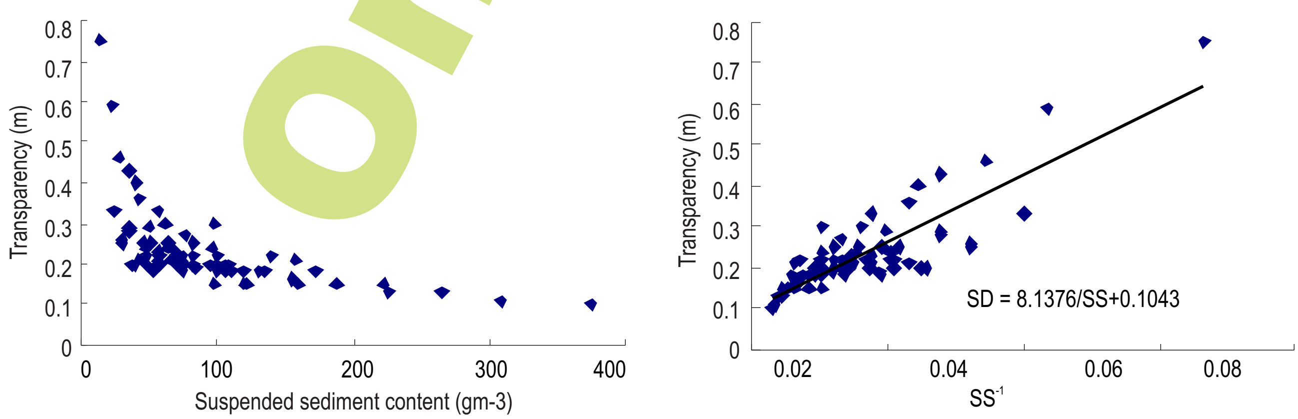

Fig. 3 : Relation between water transparency and suspended sediment of Neijiang River

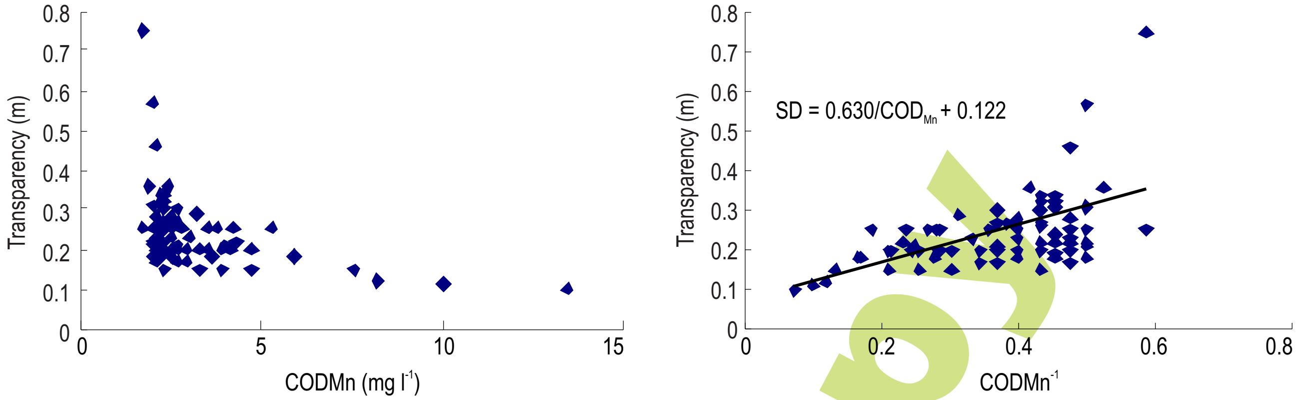

Fig. 4 : Relation between transparency and CODMn concentration of Neijiang River

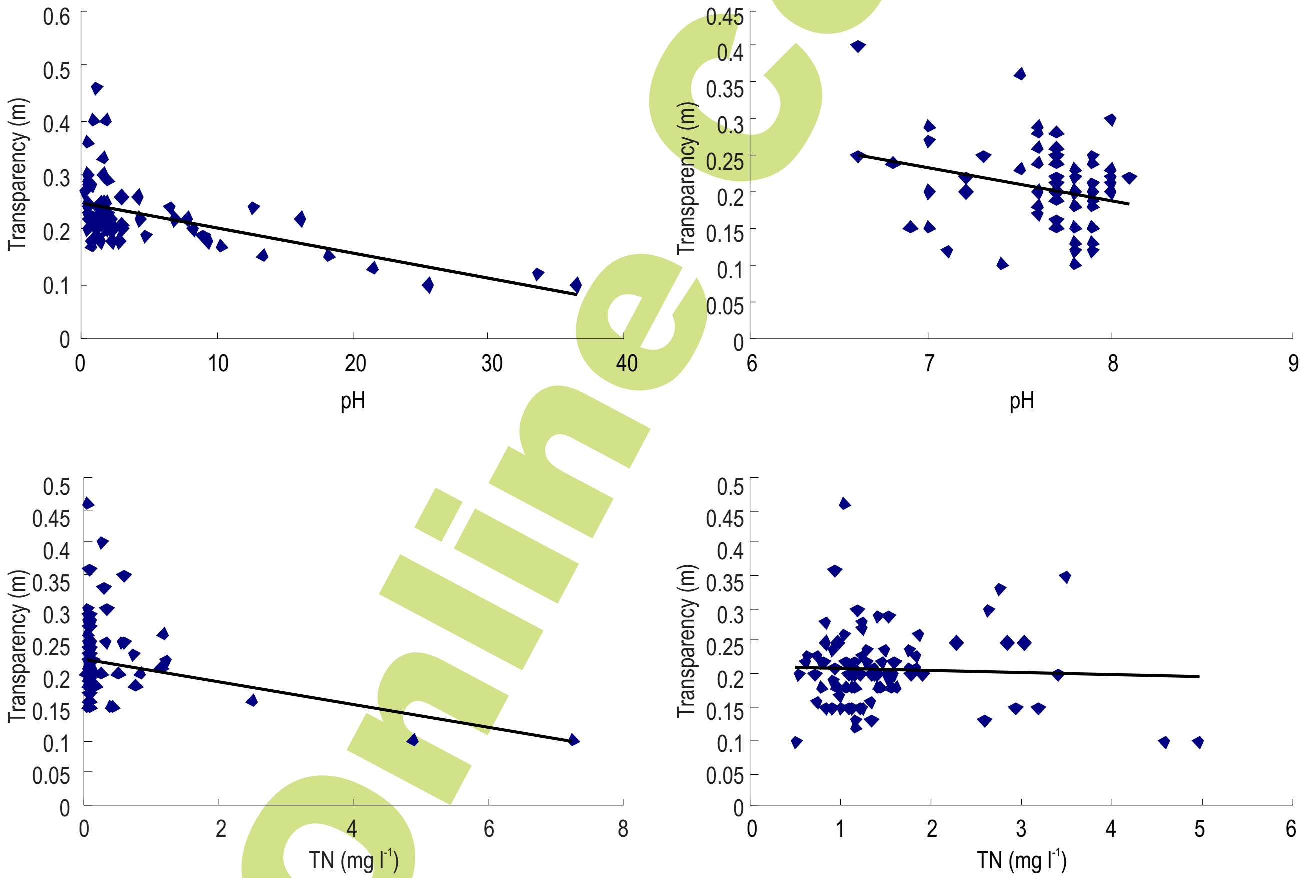

Fig. 5 : Relations of transparency of Neijiang River with other environmental factors

relation between transparency and Chl-*a*,it showed that Chl-*a* value was more lower than before. The concentration was mostly within 1-6mg m^{-3}, but chlorophyll a concentration near pollutant source was higher only in periods of low water and was found between 10-40 mg m^{-3}.

When Chl-*a* concentration was low, its relation with transparency was complex, some transparency was higher and some was lower. However, when the concentration of Chl-*a* was high, transparency decreased with increase in Chl-*a* concentration. On a whole, transparency showed a relation of inverse ratio with Chl-*a*. Therefore, It was also an important factor influencing transparency when its concentration was high.

Table 3 : Water quality factor correlation coefficient of Neijiang River,China

	SD	SS	COD_{Mn}	Chl-a	pH	TP	TN
SD	1						
SS	-0.609**	1					
COD_{Mn}	-0.378**	-0.036	1				
Chl-a	-0.314*	0.167	0.407**	1			
PH	-0.099	0.222	-0.204	-0.042	1		
TP	-0.155	-0.194	0.481**	0.831**	-0.129	1	
TN	-0.01	-0.356**	0.533**	0.487**	-0.303*	0.712**	1

Note: **represents the obvious level totaling 1%, * represents the obvious level totaling 5%

pH value is a comprehensive reflection of chemical characteristics of water body. When the water body remains alkaline, the acid, alkali and salt can form dissolved tricalcium phosphate, and Fe^{3+} forms $Fe(OH)_3$, suspended in the water body. Some other alkaline metal ions can also form relative slight or difficult dissolved matters suspended in the water body, which can influence water transparency. Relationship between transparency and pH value of Neijiang River, determined by two field simultaneous monitoring, showed pH value of Neijiang River within 6.0-8.0, presenting alkalescence. Transparency showed a falling tendency with the rise of pH value (Fig.5).

Nitrogen and phosphorus are essential nutrient required for growth of algae, and they play an important role in the growth and reproducion of aglae.The relationship of transparency and TP and TN was dependent on the simultaneous monitoring data., Water transparency showed a falling tendency with increase in TP concentration, especially when TP concentration was high and transparency was low. But the relation between TN and transparency was not yet obvious (Table 4).

On the whole, the suspended sediment, which was found to be one of the key factors influencing water transparency of Neijiang River. The influence of COD_{Mn} and Chl-*a* on transparency was indeterminate greatly when the concentration was low. And when high concentration was high the influence was more obvious.

However, pH, nitrogenous, phosphoric nutrient matters, etc., influenced water transparency by increasing suspended matter and COD_{Mn} content. In order to verify these result, water quality indexes, from two field simultaneous monitoring in April and August 2004 was studied. The results showed a negative relation between suspended sediment and transparency, the relevant coefficient was high. And the relevant coefficient between COD_{Mn} , chlorophyll a and transparency was high, while the suspended sediment was low. pH, TN and TP showed no obvious relation with transparency.

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