

# Spatiotemporal distributions of nutrients in the downstream from Gezhouba Dam in Yangtze River, China

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## Abstract

**Introduction** From December 2008 to November 2009, an investigation of water quality was performed in the 70-km long downstream from Gezhouba Dam in Yangtze River.

**Methods** Twelve sites in all were chosen. Nine parameters of water quality including the total phosphorus, the total nitrogen, chlorophyll a (Chl.a), nitrite, nitrate, ammonia, water temperature, DO, and pH were monitored almost monthly. The multivariate statistical technique (cluster analysis) and the nonparametric method (Kruskal–Wallis Test and Spearman’s rank correlation) were applied to evaluate the spatiotemporal variations of water quality data sets.

**Results and discussion** According to the Chinese environmental quality standards for surface water (GB3838-2002), the water quality in the river section investigated can attain to the III water standards except total nitrogen. Further analysis indicated that there were no significant spatial differences in these parameters of water quality, but the sampling date had a significant effect. The temporal variation of water quality can be related to the discharge of Gezhouba Dam and moreover be affected by the reservoir regulation. During the discharge, the discharge increased the concentration of total phosphorus and then decreased the N:P ratio, which helps to the occurrence of algae blooms. The high consternation of phosphorus and the low N:P ratio show that the water body can be in the process of eutrophication during the discharge of Gezhouba Dam. In fact, Chl.a had begun to rise in the same period.

**Keywords** Nitrogen · Phosphorus · Chl.a · Water level · Gezhouba Dam

## 1 Introduction

All this time, an increasing attention has been paid attention to water quality problems. Among these problems, excessive loading of nutrients causing water quality is particularly prominent. N and P exports from point and nonpoint sources can have profound effects upon the quality of receiving waters (Carpenter et al. 1998). Commonly the majority of freshwater eutrophication research during the past several decades has been focusing on lakes and reservoirs, but the nutrient enrichment of flowing waters is also of great concern (Smith et al. 1999). In China, lake eutrophication has become one of the most severe environment problems and then the concern about the rivers is relatively less.

Nutrients in a river mainly come from various sources including domestic sewage, industrial wastewater, livestock and poultry breeding excretion, aquaculture byproduct, groundwater, surface runoff, and atmospheric inputs. Compared to the lake, the issue of water quality in flowing waters is more intricate, although the flowing waters can transport pollutants to the downstream and a large number of interacting processes involving several biotic and physical factors restrict the development of nutrient enrichment on algal growth (Hilton et al. 2006).

Yangtze River as the longest river in Asia is the most important river in China. In the past several years, many studies concerned about the effect of the Three Gorges Dam on the water quality downstream and assessing the water quality of the Three Gorges reservoir have been carried out (Liu et al. 2010; Duan et al. 2008; Müller et al. 2008; Cao et al. 2011). Besides directly taking the Three Gorges reservoir

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as the object, the studies about the Yangtze estuary under the conditions of the impounding of the Three Gorges Dam are also another hot topic (Zhang et al. 2007; Chai et al. 2009; Zhou et al. 2009; Zhu et al. 2009). There is some work about the total valley or the confluent (Yuan et al. 2006; Tang and Liu 2006; Li et al. 2009). In summary, those studies of nutrient about some section in the main stem of the Yangtze River are less.

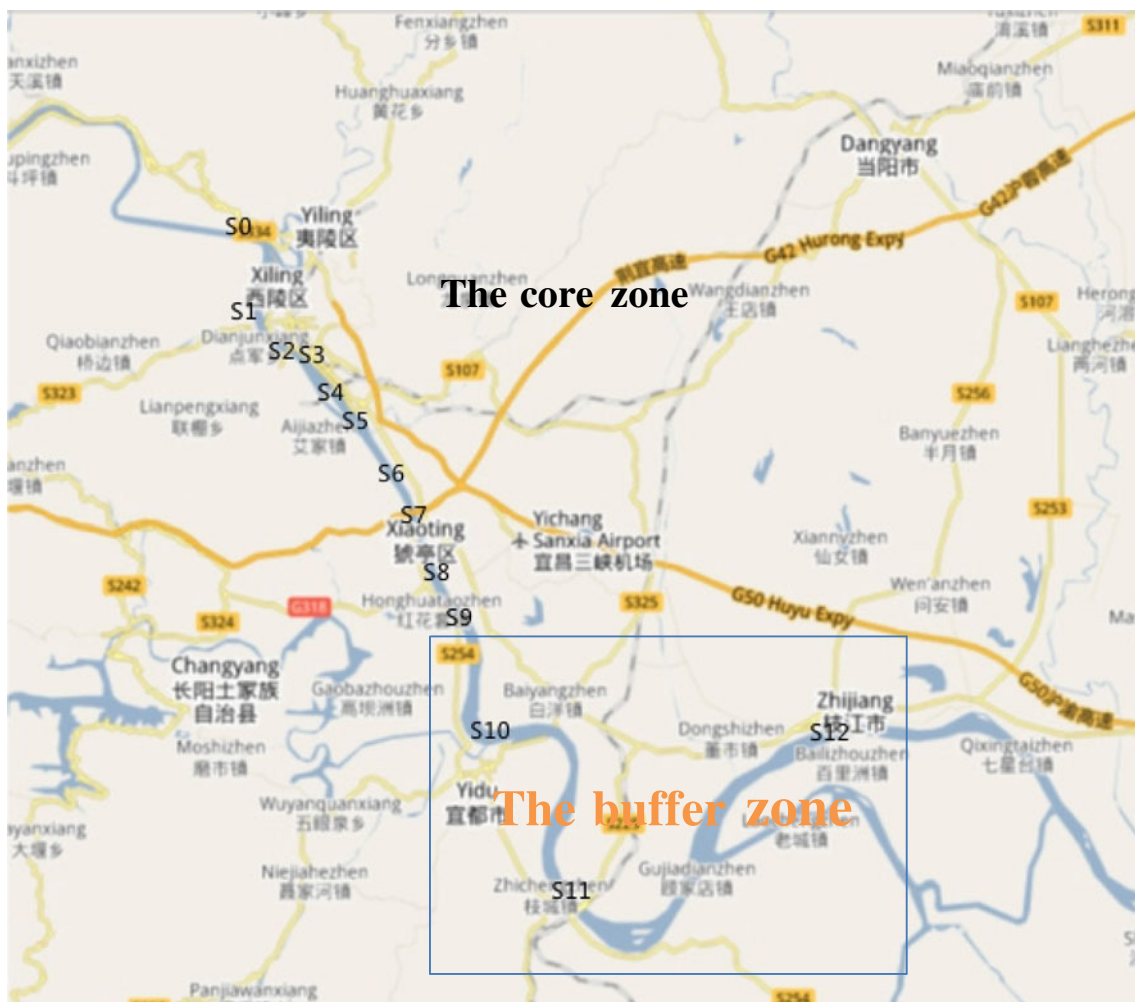
Gezhouba Dam is the first dam in Yangtze River, and then the study about the impact of Gezhouba Dam on water quality is very lacking. Gezhouba Dam is concerned more on account of the spawning sites for Chinese sturgeon in the downstream (Yang et al. 2008; Wang and Xia 2009). In 2008, a water quality investigation, as a part of a project of the breeding population and scale of Chinese sturgeon in Yichang section, was carried out. The investigation was performed with high-frequency and density monitoring in the downstream relatively near the dam, and made up for the lack of study taking the main stem of Yangtze River as the object and monitoring in high frequency. The data from the

investigation will help better to understand the relation of the regulation of the dam and the water quality downstream. The aim in this paper is to: (1) access the water quality; (2) analyze the spatiotemporal distributions of water quality especially for N and P using some statistical technique; and (3) identify the relations between the distributions and water level/water quantity, and then discuss the effect of the reservoir on the water quality in the downstream relatively near the dam.

## 2 Materials and methods

### 2.1 The study area

Because Chinese sturgeon migration paths were obstructed by Gezhouba Dam, rendering these fish unable to return to their original spawning sites, Chinese sturgeon species' spawning grounds shrank to a length of 30 km downstream of the Gezhouba Dam, which is set up to the core zone of



**Fig. 1** The map of the area investigated

**Table 1** The sampling site and the analysis parameters

		Sample site	Left	Middle	Right	Parameters	
The protected zone of China sturgeon	The core zone	Before the dam	S0	111°16'51.7"; 30°45'15.9"			
		Ziyang River	S1	111°16'01.3"; 30°43'29.4"	111°15'46.1"; 30°43'27.1"	111°15'38.0"; 30°43'56.4"	Total nitrogen
		YaoChang	S2	111°15'58.3"; 30°42'38.2"	111°15'43.8"; 30°42'37.1"	111°15'35.0"; 30°42'36.3"	Total phosphorus
		Miaozhui	S3	111°16'07.3"; 30°42'15.7"	111°15'55.9"; 30°42'17.1"	111°15'47.6"; 30°42'06.3"	Water temperature
		Yuzhen Dock	S4	111°17'08.2"; 30°41'19.3"	111°17'07.7"; 30°41'11.0"	111°17'04.3"; 30°41'02.6"	NH <sub>4</sub> <sup>+</sup> -N
		Yangtze River Bridge	S5	111°17'36.6"; 30°41'07.6"	111°17'29.7"; 30°40'55.9"	111°17'21.7"; 30°40'49.0"	NO <sub>3</sub> <sup>-</sup> -N
		Yiwang road	S6	111°19'41.3"; 30°39'09.4"	111°19'40.7"; 30°39'09.8"	111°19'43.3"; 30°39'25.9"	NO <sub>2</sub> <sup>-</sup> -N
		Yanzhiba	S7	111°21'01.7"; 30°37'56.6"	111°20'35.9"; 30°38'03.0"	111°20'19.7"; 30°38'09.7"	pH
		Huyatan	S8	111°23'44.6"; 30°34'42.2"	111°23'20.0"; 30°34'52.3"	111°23'03.2"; 30°34'55.7"	DO
	Gulaobei	S9	111°24'35.7"; 30°31'49.2"	111°24'25.7"; 30°31'41.2"	111°24'14.6"; 30°31'34.1"	Chl.a	
	The buffer zone	Yidu	S10	111°30'41.6"; 30°25'06.3"			
		Zhichen	S11	111°30'45.6"; 30°17'29.7"			
Zhijiang		S12	111°43'41.8"; 30°25'01.7"				

the Chinese sturgeon conservation district. The whole conservation district is more than 75 km long which is from the Gezhouba Dam to Zhijiang city. The river section from 30 to 75 km is set up to the buffer zone. In this investigation, there were nine sampling sites (S1–S9) in the core zone and three sites (S10–S12) in the buffer zone (Fig. 1).

From Nov 2008 to Dec 2009, all sites were monitoring almost monthly, ten times in all. At the same time, the site S0 400 m before the Gezhouba Dam was added to contrast the difference of water quality between the reservoir and the downstream (Fig. 1). The 11 sampling sections were established by GPS navigation from Gezhouba Dam to Zhijiang city (Table 1). Each site in the core zone was separately sampled in the left bank, the right bank, and the middle of the Yangtze River.

### 2.2 Sampling and analytical

The monitoring parameters refer to Table 1. As a part of a project of the breeding population, the four parameters were mandatory including the total phosphorus (TP), the total nitrogen (TN), ammonia (NH<sub>4</sub><sup>+</sup>), and chlorophyll a (Chl.a). But the other parameters were optional, so the data of these optional parameters were lacking in a few months.

The water samples on the water surface and at the 1-m depth were gotten manually with the common cleaned organic glass samplers, but Eh, dissolved oxygen (DO), and pH of the samples were measured by putting the probe into the river. Water samples collected on the water surface and

**Table 2** The summary of nutrients and the parameters in situ

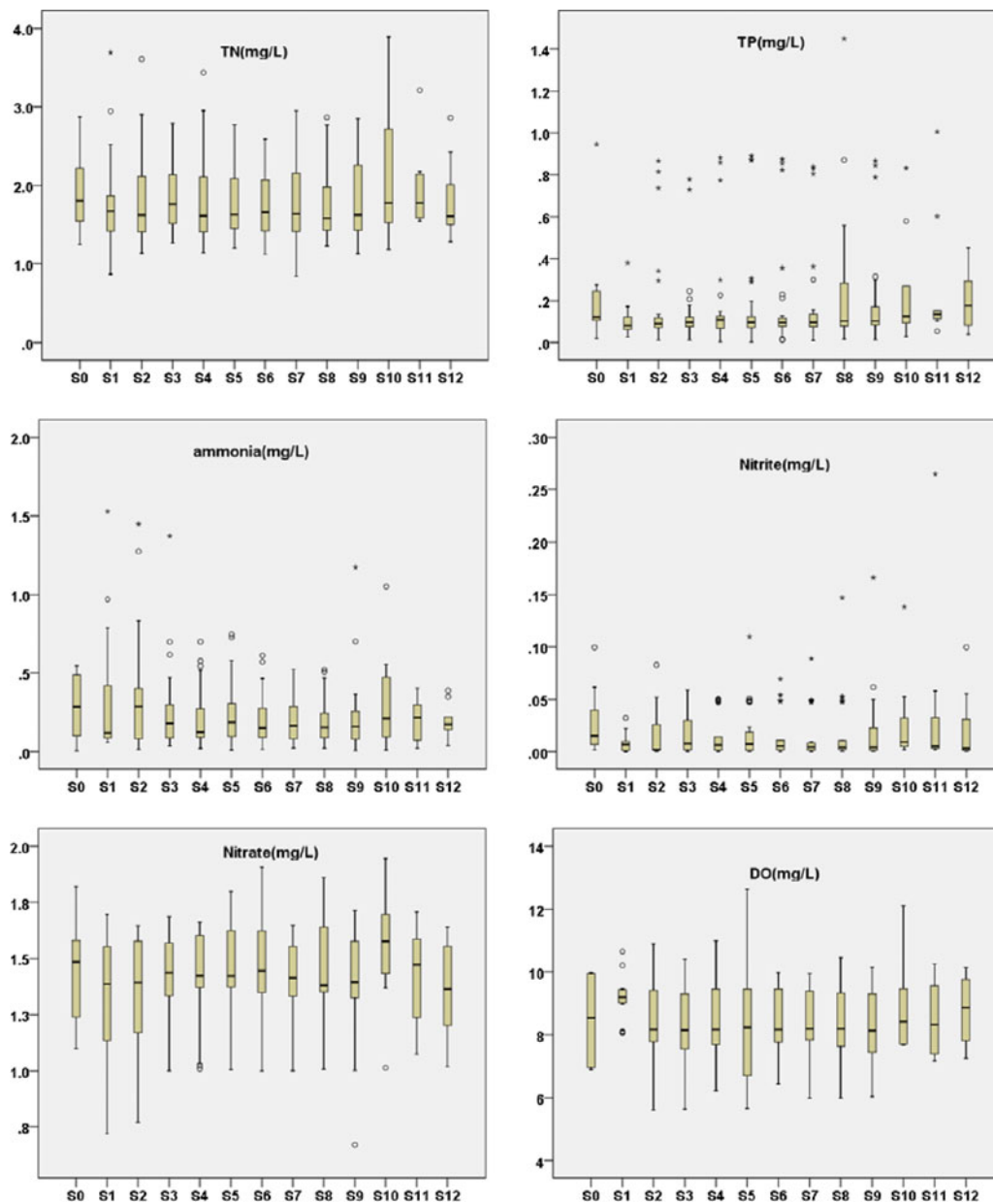
	Mean	Standard error of mean	Median	Maximum	Minimum	Standard deviation	Threshold value of water standard		
							I	II	III
TN (mg/L)	1.8171	0.0304	1.6405	3.8929	0.8429	0.5199	≤0.2	0.5	1.0
TP (mg/L)	0.1813	0.0133	0.1027	1.4497	0.0031	0.2294	≤0.02	0.1	0.2
Ammonia (mg/L)	0.2415	0.0138	0.1694	1.5288	0.0060	0.2376	≤0.15	0.5	1.0
Nitrite (mg/L)	0.0210	0.0041	0.0052	0.9954	0.0001	0.0671			
Nitrate (mg/L)	1.4149	0.0139	1.4127	1.9460	0.6709	0.2265			
DO (mg/L)	8.49	0.09	8.19	12.63	5.60	1.31	≥7.5	6	5
WT (°C)	18.97	0.46	18.79	26.70	11.80	5.27			
pH	7.83	0.03	7.84	8.48	7.10	0.32	6–9		
Chl.a (µg/L)	3.5270	0.5539	1.5687	74.8255	0.1777	9.1346			

at the 1-m depth were mixed for analyzing. All the samples were kept in the portable refrigerator and delivered to the laboratory. They were stored at 4°C until analyzed. In the laboratory, the water samples were immediately analyzed to determine TP, TN, nitrite, nitrate ( $\text{NO}_3^-$ -N), and  $\text{NH}_4^+$ . TP was analyzed from a persulfate digested of raw water sample. TN was analyzed from an alkaline persulfate digested of raw water sample. Nitrate was determined by spectrophotometric method with phenol–disulfonic acid. Ammonia nitrogen was determined by Nessler's reagent colorimetric method. Nitrite was determined by ultraviolet spectrophotometric method.

### 2.3 Statistical analyses

In this study, the environmental variables do not meet the requirement of homogeneity and follow a normal distribution. Consequently, Kruskal–Wallis test (K-W test) and Spearman's rank correlation coefficient (Spearman's rho) were used.

K-W test as one-way analysis of variance by ranks is a nonparametric method for testing whether samples originate from the same distribution in statistics. In this study, K-W test was performed to study the spatiotemporal variations by examining whether factors such as sampling site or sampling



**Fig. 2** The distributions of TN, TP, ammonia, nitrite, nitrate, and the parameters in situ (mean±SD) in 12 sites

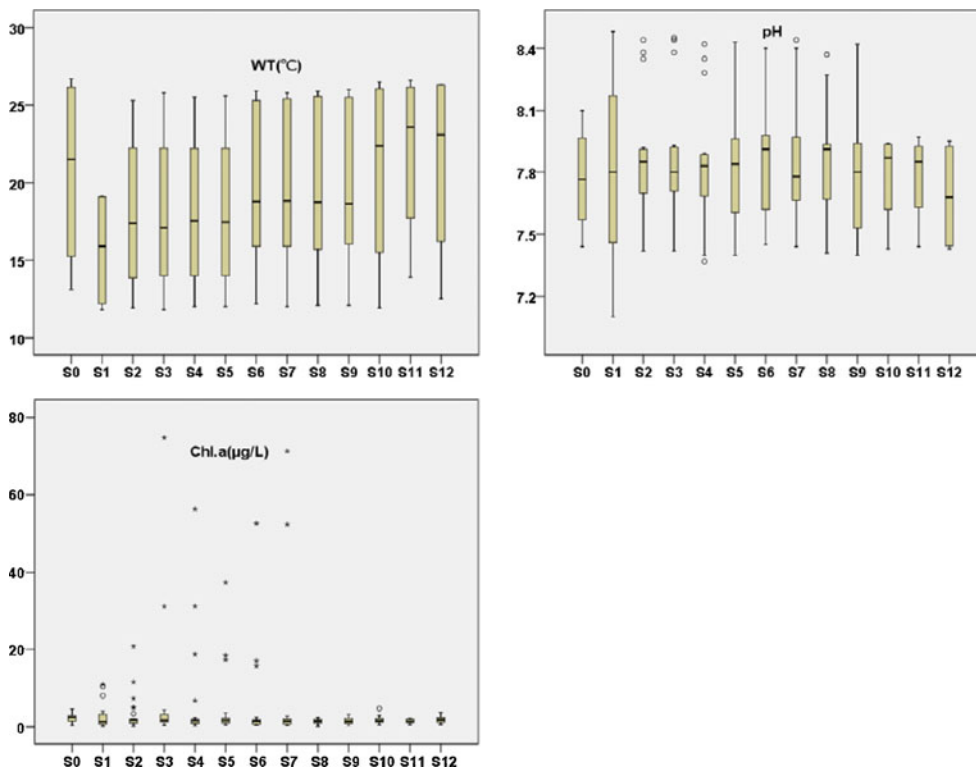


Fig. 2 (continued)

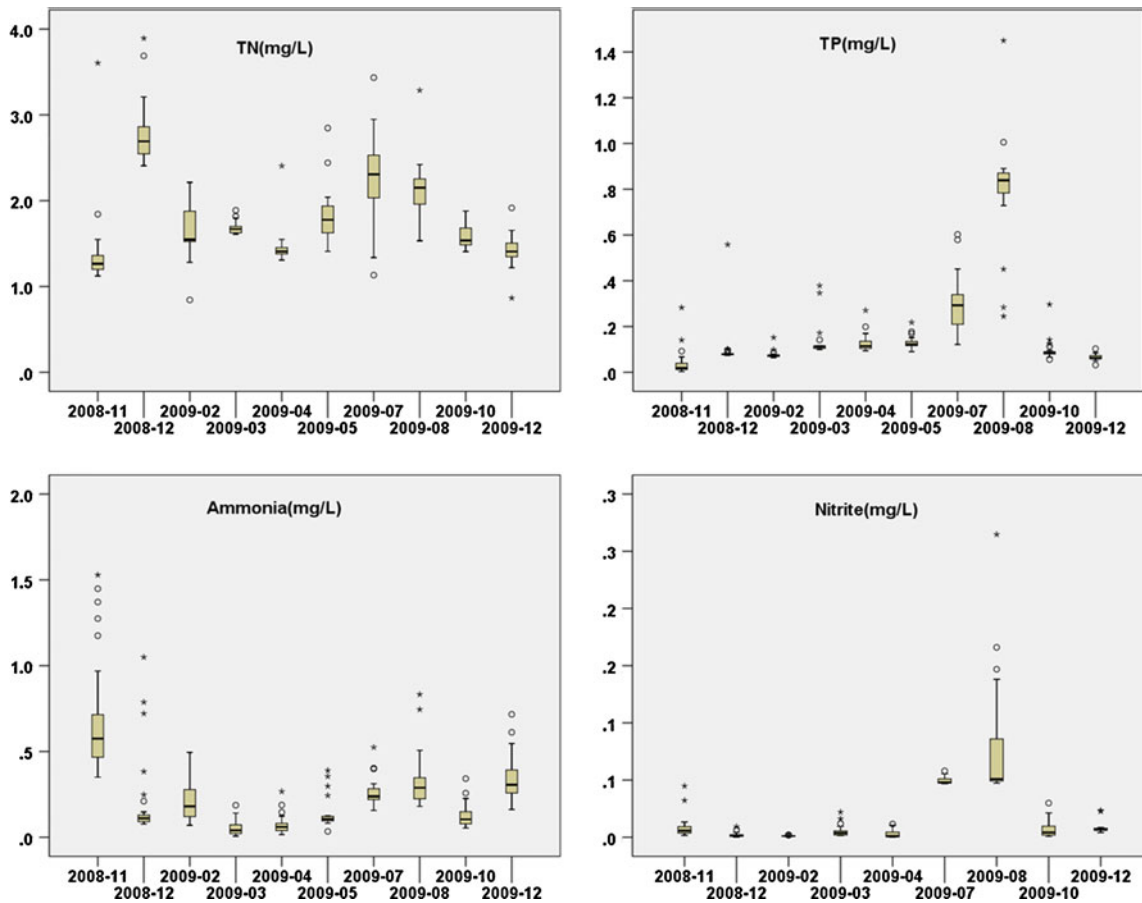


Fig. 3 The distributions of TN, TP, ammonia, nitrite, nitrate, and the parameters in situ (mean±SD) during the whole sampling

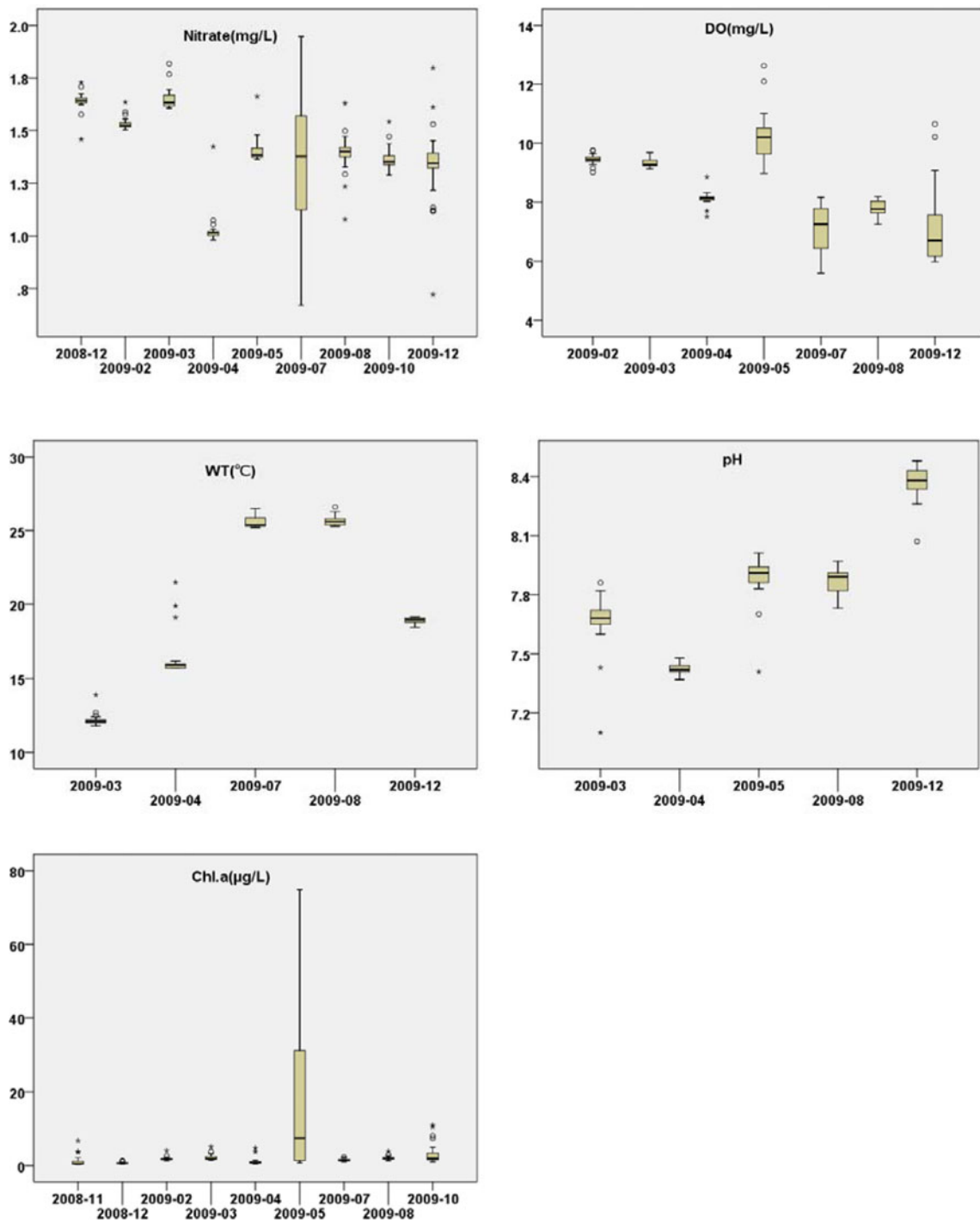


Fig. 3 (continued)

date had a significant effect on the observed parameters of water quality. Spearman's rho is a nonparametric measure of

statistical dependence between two variables. It assesses how well the relationship between two variables can be described

**Table 3** The K-W test results of the parameters of water quality using sampling site as factor

K-W test	TN	TP	Ammonia	Nitrite	Nitrate	DO	WT	pH	Chl.a
<i>P</i> value	0.977	0.331	0.992	0.707	0.931	0.928	0.552	0.999	0.935



**Table 4** The K-W test results of the parameters of water quality using sampling date as the factor

K-W test	TN	TP	Ammonia	Nitrite	Nitrate	DO	WT	pH	Chl.a
<i>P</i> value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

using a monotonic function. In this study Spearman's rho was used to study the relationship between the parameters of water quality.

Beside the nonparametric method, the multivariate statistical technique such as the cluster analysis (CA) was applied to the data. CA is an unsupervised pattern recognition technique. It can uncovers intrinsic structure or underlying behavior of a data set without making a priori assumptions about the data, in order to classify the objects of the system into categories or clusters based on their nearness or similarity (Vega et al. 1998). In this study, CA was performed to identify any analogous behavior among the different sampling sites. The experimental data were firstly standardized through z-scale transformation so as to avoid misclassification due to wide differences in data dimensionality, and then the hierarchical cluster analysis was carried out on the standardized data by means of group average method, using squared Euclidean distances as a measure of nearness. All statistical analysis including the statistical plots was performed using SPSS 19 software package.

### 3 Results and discussion

The nutrient parameters including TP, TN, nitrate, nitrite, and ammonia, and the parameters of DO, water temperature (WT), and pH in situ over a period of 1 year (2008-2009) at 13 sites in Yichang of Yangtze River were summarized in Table 2. It can be seen that the variation ranges of TN and Chl.a were bigger than TP, ammonia, and nitrite from Table 2. The rank orders of the different N parameters is nitrate > ammonia > nitrite. Table 2 shows that TN is mostly nitrate.

According to the environmental quality standards for surface water (GB3838-2002) in China, the mean concentration of TP meets the requirement of the III water standards. TN was beyond the III standard. The concentration of ammonia was between I and II. But ammonia has been regarded as the most important contamination indicator in rivers in China all along. pH from 6.88 to 8.48 indicated the reach in Yichang was weakly alkaline, which is the same with those rivers/lakes in the midstream and downstream of Yangtze River in China.

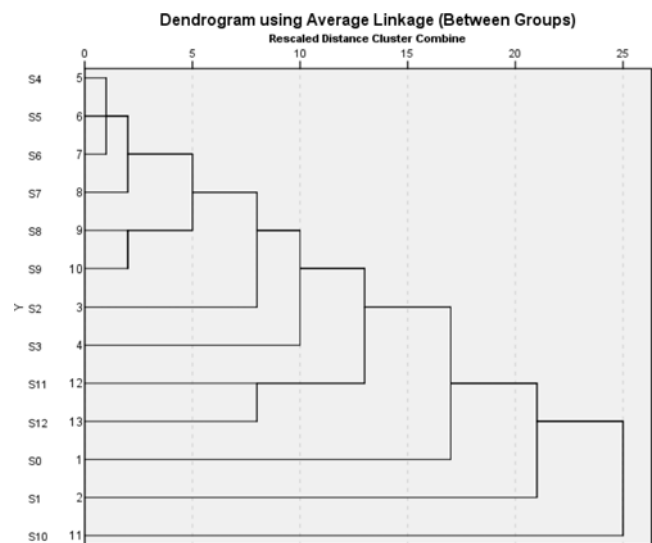
#### 3.1 The spatiotemporal distribution

The visualized spatiotemporal distributions of the parameters of water quality can be readily observed from Figs. 2 and 3. K-W test indicates that there are no significant

differences in the parameters among the 12 sites (Table 3), but the sampling date has a significant effect on all parameters including the nutrients and the parameters in situ (Table 4). Besides, K-W test also shows there is no significance among on the left riverside, the right riverside, and the center of the river in the core zone ( $P \gg 0.05$ ), although the urban district mainly concentrated on the left riverside and there are more intense human activates. All that revealed that the water in the 70-km main stem was uniformly mixed from the reservoir to the downstream from Gezhouba Dam.

After the K-W test showed no significant differences among the sites, CA was applied to further detect similarity groups in the sampling sites. The dendrogram in CA is a tree diagram used to illustrate the arrangement of the clusters. It can be a good description of the relationship among the data sets and a very intuitive way of expression. So the similarity in the sampling sites was expressed using the dendrogram (Fig. 4). The result shows that the spatial characterization in 11 sites was relatively continuous. S0 in the reservoir (400 m before the dam) had the similar characterization with S1 in the downstream from the dam, which indicates that the discharging process had no effect on the water quality. S2 and S3 were similar. S4–S9 in the core zone belongs to a cluster. As a whole, S10, S11, and S12 in the buffer zone had the similar characterization with the sites S1 nearest the dam and S0 before the dam.

According to Fig. 3, the temporal variation can be seen obviously. In summary, TN, TP, and nitrite reached the peak



**Fig. 4** The dendrogram plot of cluster analysis

**Table 5** Spearman's rho between the parameters of water quality

Spearman's rho	TN	TP	Ammonia	Nitrite	Nitrate	DO	WT	pH	Chl.a
TN	1.000	0.423 <sup>a</sup>	-0.102	0.191 <sup>a</sup>	0.549 <sup>a</sup>	-0.059	0.408 <sup>a</sup>	0.054	0.071
TP	0.423 <sup>a</sup>	1.000	-0.185 <sup>a</sup>	0.452 <sup>a</sup>	-0.142 <sup>b</sup>	-0.195 <sup>a</sup>	0.513 <sup>a</sup>	-0.197 <sup>b</sup>	0.293 <sup>a</sup>
Ammonia	-0.102	-0.185 <sup>a</sup>	1.000	0.395 <sup>a</sup>	-0.070	-0.409 <sup>a</sup>	0.713 <sup>a</sup>	0.654 <sup>a</sup>	-0.128 <sup>b</sup>
Nitrite	0.191 <sup>a</sup>	0.452 <sup>a</sup>	0.395 <sup>a</sup>	1.000	-0.120	-0.578 <sup>a</sup>	0.784 <sup>a</sup>	0.504 <sup>a</sup>	0.301 <sup>a</sup>
Nitrate	0.549 <sup>a</sup>	-0.142 <sup>b</sup>	-0.070	-0.120	1.000	0.291 <sup>a</sup>	-0.198 <sup>b</sup>	0.102	-0.030
DO	-0.059	-0.195 <sup>a</sup>	-0.409 <sup>a</sup>	-0.578 <sup>a</sup>	0.291 <sup>a</sup>	1.000	-0.667 <sup>a</sup>	-0.209 <sup>b</sup>	0.257 <sup>a</sup>
WT	0.408 <sup>a</sup>	0.513 <sup>a</sup>	0.713 <sup>a</sup>	0.784 <sup>a</sup>	-0.198 <sup>b</sup>	-0.667 <sup>a</sup>	1.000	0.500 <sup>a</sup>	0.063
pH	0.054	-0.197 <sup>b</sup>	0.654 <sup>a</sup>	0.504 <sup>a</sup>	0.102	-0.209 <sup>b</sup>	0.500 <sup>a</sup>	1.000	0.552 <sup>a</sup>
Chl.a	0.071	0.293 <sup>a</sup>	-0.128 <sup>b</sup>	0.301 <sup>a</sup>	-0.030	0.257 <sup>a</sup>	0.063	0.552 <sup>a</sup>	1.000

<sup>a</sup> Correlation is significant at the 0.01 level (two tailed)

<sup>b</sup> Correlation is significant at the 0.05 level (two tailed)

value in July–August 2009. Chl.a reached the peak value in May 2009 and a high variability of measure occurred at the same time, which can be as a result of an obvious seasonal variation in the biomass of algal. In fact, contrasting Fig. 2 with Fig. 3, it can be seen that the variation of measurement of all parameters in time was higher than in space. The apparent difference can suggest more temporal variation, which corresponds with the result of the K-W test. Due to lack of the data of WT, DO, and pH in September and October, this investigation showed that WT was the highest in July and August, while DO was the lowest. It is reasonable that DO and WT are affected by the season. Nutrients in a river mainly come from agricultural and urban areas including domestic sewage (Nyenje et al. 2010), but the concentrations of nutrients not only were controlled by the discharge of pollutions but also affected by the flow in the river (Hilton et al. 2006; Smith et al. 1999).

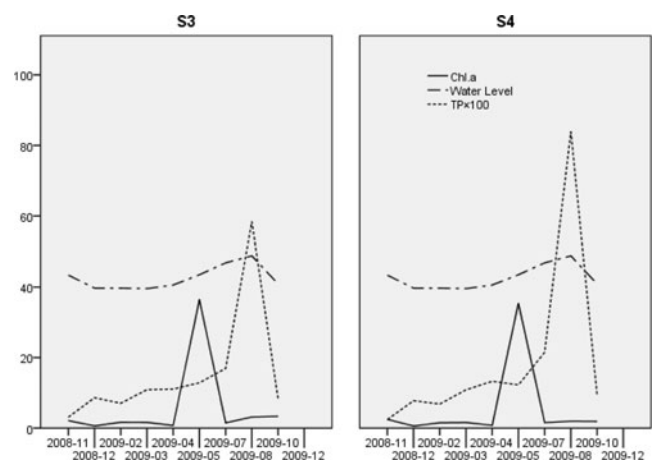
### 3.2 The analysis of correlation

Spearman's rho was used to study the relationship between the parameters of water quality (Table 5). According to Table 5, TN is strongly correlated to nitrate and moderate to TP. The strong correlation between TN and nitrate is accorded with the fact that TN consisted of nitrate. TP is weakly correlated to Chl.a. WT has the strongest ranking correlation with ammonia, nitrite, and DO, but it has a moderate ranking correlation with TP and pH. pH is strongly positively correlated to ammonia and Chl.a, and moderate to nitrite and DO. In general, the decomposition of riverine dissolved organic matter is the main process that controls the oxygen concentrations (Rixen et al. 2010). So DO is negatively correlated to ammonia and nitrite with the stronger reducibility. Many factors have an effect on DO, but DO which is weak positively correlated to Chl.a can indicate that DO was affected by plankton represented by Chl.a to a certain extent. At the same time, Chl.a is positively correlated to pH.

In fact, the rise of DO and pH is as a result of photosynthesis. WT is the most objective parameter, which is almost not affected by human activity and organism in the river. TN and TP were significantly correlated to WT, which maybe in the warm weather, and human activity increase. This apparent relationship of nutrients and Chl.a with WT might suggest a somewhat predictable temporal variation, i.e., more nutrients and Chl.a are present in warmer temperatures and possibly more sources.

### 3.3 The effect of the discharge from Gezhouba Dam on the water quality

In this study, the data of water level (unit, meters) and flow derived from the Yichang hydrological station. The station is located between S3 and S4. The variations of water level and flow are presented in Fig. 5. In order to study the relationship between the water level and the parameters, the data in S3 and S4 site were analyzed combined with the data of water level and flow, respectively. The flow and



**Fig. 5** The temporal variation of TP, Chl.a and water level (TP was amplified to 100 times to be clearly presented in the plot)



**Table 6** Spearman’s rho between the water level and the parameters of water quality

Spearman's rho		TN	TP	Ammonia	Nitrite	Nitrate	DO	WT	pH	Chl.a
Water level	S3	0.362	0.572 <sup>a</sup>	0.158	0.562 <sup>a</sup>	−0.212	−0.224	0.392	−0.186	0.418 <sup>b</sup>
	S4	0.308	0.634 <sup>a</sup>	0.111	0.654 <sup>a</sup>	−0.155	−0.004	0.389	−0.131	0.401 <sup>b</sup>

<sup>a</sup> Correlation is significant at the 0.01 level (two tailed)

<sup>b</sup> Correlation is significant at the 0.05 level (two tailed)

the water level have a high degree of linear correlation (Pearson's correlation=0.996,  $P<0.01$ ), so the water level was chosen to study the relationship between the hydrological parameters and the water quality parameters.

Spearman’s rho showed that the water level was strongly positively correlated to TP and nitrite, and moderately to Chl.a (Table 6). The variations of TP, Chl.a, and water level were presented in Fig. 5.

From Table 6 and Fig. 5, it can be seen that the water level was strong positively correlated to TP and nitrite and moderate to Chl.a. The correlation can show that water level had an effect on the trophic in the river. According to Fig. 5, while the water level reached the maximum in August 2008, the maximum TP appeared simultaneously. With the discharge flow increasing from the Gezhouba Dam, the water level went up gradually. Although the rising of TP can be a result of the discharge with the high concentration of phosphorus from the dam, the data showed that TP as well as other nutrients in the S0 site had no significant difference compared with it in the sites from the downstream of the Gezhouba Dam. In the period of the discharge, it can be seen that the water in the whole core zone turned turbid by the agitation of the discharge. Nearer the dam, the water turned more turbid. It is speculated that more phosphorus was derived from the resuspended process (Hu et al. 2009). In fact, there was a phenomenon that the maximum of Chl.a appeared ahead of TP and the water level. It is speculated that plankton is difficult to be observed in the turbid water or it can be rushed to the downstream under the condition of high velocity of flow.

### 3.4 N:P ratio

Table 2 has showed that TN was beyond the III standard of water quality in the main stem, while TP was acceptable.

However in China, eutrophication resulting from excessive nutrients loading in which phosphorus is the most important nutrient has become one of the important environmental problems. In this study, the trophic status in the section investigated will be further discussed.

In the study of eutrophication, phosphorus is regarded as the mainly limiting factor in the lake eutrophication, and decreasing inputs of phosphorus is critical to reduce eutrophication (Schindler et al. 2008). N:P ratio in the water body is often used to define eutrophic conditions. For example, algal community structure responded strongly to both N:P ratio and total nutrient concentration (Stelzer and Lamberti 2001), and the critical N:P ratios have been successfully used to establish the nature of nutrient limitation in aquatic and agricultural ecosystems (Koerselman and Meuleman 1996).

K-W test was again used to determine the effect of the sampling sites and the sampling date on N:P ratio. At the same time, Spearman’s rho between N:P ratio and TN, TP, and Chl.a in the whole river (all sites) and S3 and S4 were calculated separately (Table 7). The results showed that there were no significant differences of N:P ratio among the different sites ( $P=0.661$ ), while the sampling date had a significant effect on N:P ratio ( $P<0.01$ ). From Table 7, there is a very strong negative correlation between N:P ratio and TP, but it is weakly negatively correlated to Chl.a and TN.

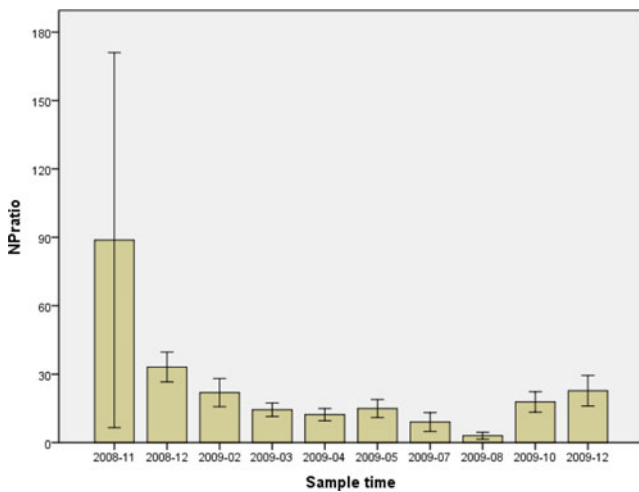
Moreover, the temporal variation of N:P is present in Fig. 6. It can be seen that the N:P ratio gradually decreased from April to August and in August went to the minimum value (Fig. 6), which can mean the occurrence of eutrophication processes and blooms (Quirós 2002; Schindler 1977). The contribution of cyanobacteria is relatively high in low N:P ratio waters (Smith 1983; Bianchi et al. 2000; Kim et al. 2010). Although no bloom was observed even if the water

**Table 7** Spearman’s rho between the N:P ratio and TP, TN, Chl.a, and water level

Spearman's rho		TP	TN	Chl.a	TP	TN	Chl.a	Water level	
N:P ratio	In the whole river section	−0.919 <sup>a</sup>	−0.123 <sup>b</sup>	−0.254 <sup>a</sup>	S3	−0.774 <sup>a</sup>	−0.022	−0.211	−0.381 <sup>b</sup>
					S4	−0.912 <sup>a</sup>	−0.180	−0.335	−0.496 <sup>a</sup>

<sup>a</sup> Correlation is significant at the 0.01 level (two tailed)

<sup>b</sup> Correlation is significant at the 0.05 level (two tailed)



**Fig. 6** The characterization of N:P ratio during the sampling

had turned green with naked eyes during the sampling and the occurrence of algae blooms has been not reported before, the increasing of TP and the decrease of N:P ratio show that the tendency of bloom must be relatively obvious.

According to the discussion, TP and the water level were closely related. There is a moderate negative correlation between N:P ratio and the water level (Table 7). So it is speculated that the increasing of TP and the decrease of N:P ratio both were as a result of the lift of the water level. The discharge can help to the occurrence of algae bloom or cyanobacteria bloom. In fact, Chl.a had begun to rise in the period. The occurrence of algae bloom is restricted by more conditions in river (Hilton et al. 2006). While the water level provided more phosphorus and suitable N:P ratio, the more intensive agitation by the higher velocity of discharge can make the green of algae invisible in water or be rushed to the downstream and thus suppress the occurrence of algae bloom. As mentioned previously, the maximum of Chl.a appeared ahead of TP and the water level in the period.

#### 4 Conclusion

The detailed discussion was carried on about the water quality in the 70-km main stem river downstream from Gezhouba Dam. Some conclusive recognition could be summarized.

The water quality had no difference in the main stem investigated, and in fact, no difference was found between the reservoir (S0) and the sites downstream from Gezhouba Dam. However, the sampling date had a significant effect on the water quality parameters. The change of water quality should be closely related to the discharge of Gezhouba Dam. The construction of Gezhouba Dam ended in 1988. Now Gezhouba Dam does not carry out the independent reservoir

regulation due to the construction of the Three Georges Dam, the site of which is 60 km upstream from the Gezhouba Dam. So the temporal variation of water quality was ultimately affected by the regulation of the Three Gorges reservoir.

In the investigation, the water quality parameters except TN in the river stem investigated is lower than the III standards using the single-factor evaluation on the basis of the water quality (GB3838-2002) in China. But TP concentration began to increase in the downstream from the Gezhouba Dam with the rising of the water level and flow derived from the discharge of the Gezhouba Dam. The increase of TP was as result of the resuspended process by the scour and agitation of the discharge, instead of the input directly from the discharge water. With the rise of water level, the N:P ratio decreased gradually. The decrease of the N:P ratio and the increase of TP will help to the occurrence of eutrophication, and the river section can be in the process of eutrophication in the period, according to the fact that the concentration of Chl.a began to rise in the same period.

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#### References

- Bianchi TS, Engelhaupt E, Westman P, Andren T, Rolff C, Elmgren R (2000) Cyanobacterial blooms in the Baltic Sea: natural or human-induced? *Limnol Oceanogr* 45(3):716–726
- Cao Z, Zhang X, Ai N (2011) Effect of sediment on concentration of dissolved phosphorus in the Three Gorges Reservoir. *Int J Sediment Res* 26(1):87–95. doi:10.1016/s1001-6279(11)60078-4
- Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH (1998) Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecol Appl* 8(3):559–568. doi:10.1890/1051-0761(1998)008[0559:NPOSWW]2.0.CO;2
- Chai C, Yu Z, Shen Z, Song X, Cao X, Yao Y (2009) Nutrient characteristics in the Yangtze River Estuary and the adjacent East China Sea before and after impoundment of the Three Gorges Dam. *Sci Total Environ* 407(16):4687–4695. doi:10.1016/j.scitotenv.2009.05.011
- Duan S, Liang T, Zhang S, Wang L, Zhang X, Chen X (2008) Seasonal changes in nitrogen and phosphorus transport in the lower Changjiang River before the construction of the Three Gorges Dam. *Estuar Coast Shelf Sci* 79(2):239–250. doi:10.1016/j.ecss.2008.04.002
- Hilton J, O'Hare M, Bowes MJ, Jones JI (2006) How green is my river? A new paradigm of eutrophication in rivers. *Sci Total Environ* 365(1–3):66–83. doi:10.1016/j.scitotenv.2006.02.055
- Hu J, Liu J, Liu Y (2009) Phosphorus in suspended matter and sediments of a hypertrophic lake. A case study: Lake Dianchi, China. *Environ Geol* 58(4):833–841. doi:10.1007/s00254-008-1559-7
- Kim T-H, Lee Y-W, Kim G (2010) Hydrographically mediated patterns of photosynthetic pigments in the East/Japan Sea: low N:P ratios and cyanobacterial dominance. *J Mar Syst* 82(1–2):72–79. doi:10.1016/j.jmarsys.2010.03.005

- Koerselman W, Meuleman AFM (1996) The vegetation N:P ratio: a new tool to detect the nature of nutrient limitation. *J Appl Ecol* 33(6):1441–1450. doi:10.2307/2404783
- Li S, Liu W, Gu S, Cheng X, Xu Z, Zhang Q (2009) Spatio-temporal dynamics of nutrients in the upper Han River basin, China. *J Hazard Mater* 162(2–3):1340–1346. doi:10.1016/j.jhazmat.2008.06.059
- Liu L, Zhou J, An X, Zhang Y, Yang L (2010) Using fuzzy theory and information entropy for water quality assessment in Three Gorges region, China. *Expert Syst Appl* 37(3):2517–2521. doi:10.1016/j.eswa.2009.08.004
- Müller B, Berg M, Yao ZP, Zhang XF, Wang D, Pfluger A (2008) How polluted is the Yangtze river? Water quality downstream from the Three Gorges Dam. *Sci Total Environ* 402(2–3):232–247. doi:10.1016/j.scitotenv.2008.04.049
- Nyenje PM, Foppen JW, Uhlenbrook S, Kulabako R, Muwanga A (2010) Eutrophication and nutrient release in urban areas of sub-Saharan Africa—a review. *Sci Total Environ* 408(3):447–455. doi:10.1016/j.scitotenv.2009.10.020
- Quiros R (2002) The nitrogen to phosphorus ratio for lakes: A cause or a consequence of aquatic biology? *El Agua en Iberoamerica: De la Limnología a la Gestion en Sudamerica*. CYTED XVII, Centro de Estudios Transdisciplinarios del Agua, Facultad de Veterinaria, Universidad de Buenos Aires, Buenos Aires
- Rixen T, Baum A, Sepryani H, Pohlmann T, Jose C, Samiaji J (2010) Dissolved oxygen and its response to eutrophication in a tropical black water river. *J Environ Manage* 91(8):1730–1737. doi:10.1016/j.jenvman.2010.03.009
- Schindler DW (1977) Evolution of phosphorus limitation in lakes. *Science* 195(4275):260–262. doi:10.1126/science.195.4275.260
- Schindler DW, Hecky RE, Findlay DL, Stainton MP, Parker BR, Paterson MJ, Beaty KG, Lyng M, Kasian SEM (2008) Eutrophication of lakes cannot be controlled by reducing nitrogen input: results of a 37-year whole-ecosystem experiment. *Proc Natl Acad Sci* 105(32):11254–11258. doi:10.1073/pnas.0805108105
- Smith V (1983) Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. *Science* 221(4611):669–671. doi:10.1126/science.221.4611.669
- Smith VH, Tilman GD, Nekola JC (1999) Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environ Pollut* 100(1–3):179–196. doi:10.1016/S0269-7491(99)00091-3
- Stelzer RS, Lamberti GA (2001) Effects of N:P ratio and total nutrient concentration on stream periphyton community structure, biomass, and elemental composition. *Limnol Oceanogr* 46(2):356–367. doi:10.4319/lo.2001.46.2.0356
- Tang C, Liu C (2006) Non-point source pollution of Wujiang River watershed in Guizhou Province, SW China. *Chin J Geochem* 25:141–142. doi:10.1007/bf02840012
- Vega M, Pardo R, Barrado E, Debán L (1998) Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. *Water Res* 32(12):3581–3592. doi:10.1016/S0043-1354(98)00138-9
- Wang Y, Xia Z (2009) Assessing spawning ground hydraulic suitability for Chinese sturgeon (*Acipenser sinensis*) from horizontal mean vorticity in Yangtze River. *Ecol Model* 220(11):1443–1448. doi:10.1016/j.ecolmodel.2009.03.003
- Yang Y, Z-m Y, J-b C (2008) Hydrodynamic characteristics of Chinese sturgeon spawning ground in Yangtze River. *J Hydrodyn Ser B* 20(2):225–230. doi:10.1016/S1001-6058(08)60050-5
- Yuan X, Shen Z, Deng X, Gao Y (2006) Characteristics of trace elements in contaminated rivers and their environmental significance. *Chin J Geochem* 25:140–141. doi:10.1007/bf02840010
- Zhang J, Liu SM, Ren JL, Wu Y, Zhang GL (2007) Nutrient gradients from the eutrophic Changjiang (Yangtze River) Estuary to the oligotrophic Kuroshio waters and re-evaluation of budgets for the East China Sea Shelf. *Progr Oceanogr* 74(4):449–478. doi:10.1016/j.pocean.2007.04.019
- Zhou S, Jin B, Guo L, Qin H, Chu T, Wu J (2009) Spatial distribution of zooplankton in the intertidal marsh creeks of the Yangtze River Estuary, China. *Estuar Coast Shelf Sci* 85(3):399–406. doi:10.1016/j.ecss.2009.09.002
- Zhu Z-Y, Ng W-M, Liu S-M, Zhang J, Chen J-C, Wu Y (2009) Estuarine phytoplankton dynamics and shift of limiting factors: a study in the Changjiang (Yangtze River) Estuary and adjacent area. *Estuar Coast Shelf Sci* 84(3):393–401. doi:10.1016/j.ecss.2009.07.005