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Forms of Nutrients in Rivers Flowing into Lake Chaohu: A Comparison between Urban and Rural Rivers

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Abstract: Nutrient inputs from rivers play an important role in lake eutrophication. To compare the forms characteristics of phosphorus (P) and nitrogen (N) in rivers flowing through rural and urban areas, water samples were collected seasonally from five urban rivers and six rural rivers flowing to Lake Chaohu, China. Higher total phosphorus (TP), particulate phosphorus (PP), soluble reactive phosphorus (SRP), and dissolved nonreactive phosphorus (DNP) concentrations and SRP/TP percentages were observed in urban rivers than in rural rivers, and PP/TP and DNP/TP ratios were lower in urban rivers than in rural rivers. The concentrations of total nitrogen (TN) and all N forms other than dissolved organic nitrogen (DON) were significantly higher in urban rivers than in rural rivers. NH_4^+/TN levels were higher in urban rivers, whereas PN/TN and DON/TN ratios were significantly lower in urban rivers compared with rural rivers. NO_3^-/TN and NO_2^-/TN levels were similar between the two groups of rivers. TP, BD-P, and NaOH-P levels in urban river surface sediments were significantly higher than those in rural rivers. NaOH-P/TP ratios were significantly elevated in urban rivers, whereas HCl-P/TP and Res-P/TP ratios were significantly lower compared with rural rivers. Urban rivers have transferred large quantities of NH_4^+ and SRP into Lake Chaohu, resulting in higher TP and TN levels and

NH$_4^+$/TN and SRP/TP ratios. Decreasing the input of NH$_4^+$ and SRP into urban rivers is a high priority for mitigating eutrophication and algal blooms in Lake Chaohu.

Keywords: phosphorus; nitrogen; river water; sediment; Lake Chaohu

1. Introduction

Eutrophication has become the primary water quality issue in most freshwater and coastal marine ecosystems worldwide [1,2]. Algal blooms resulting from eutrophication affect public health, tourism, fisheries, and ecosystems because they can be toxic and adversely affect water taste and odor [3,4]. Eutrophication is caused by excessive phosphorus (P) and nitrogen (N) inputs [2,5]. Both point and non-point nutrient inputs are key drivers of lake eutrophication [6]. Effluent from rivers is a primary point source for lakes [7]. In the absence of anthropogenic activity, the presence of nutrients in river water depends on the ecological and geological characteristics of the surrounding environment. However, anthropogenic activity is known to increase both P and N levels in rivers [8,9], and this increase results in higher nutrient inputs into lakes, thereby accelerating lake eutrophication [10]. There, intensive anthropogenic activities in the urban areas, which causes a large quantity of domestic sewage, industrial waste water, and urban stormwater runoff, flow into nearby streams [11].

Studies have shown that both the composition and the size of the nutrient pool impact eutrophication and greatly encourage harmful algal blooms [1,12]. For example, orthophosphate availability influences phytoplankton ecology [13]. Ammonium (NH$_4^+$) is a key factor in determining the distribution of common algal species and cyanobacteria blooms in freshwater systems [14]. When Microcystis utilize NH$_4^+$, they exhibit higher growth rates and photosynthesis abilities than other N forms, and an increased proportion of NH$_4^+$ in the N source facilitates Microcystis competition [12]. The higher ammonium/oxidized N ratio increases Cyanobacteria levels while decreases diatom levels [15]. Thus, it is critical to recognize the composition of the nutrients flowing into a lake to better understand the influence of river inputs on lake eutrophication and algal blooms.

Lake Chaohu is a large, shallow lake in Anhui Province, Eastern China (31°25′–31°43′ N, 117°16′–117°5′ E) and has an area of 770 km^2 [16]. The lake plays an important role in intensive commercial fishing, water supply, irrigation, navigation, tourism, and recreational activities throughout the region. However, eutrophication and algal blooms in Lake Chaohu have become serious issues in the past several decades [17]. A recent 11-year study indicates there have been no substantial improvement in water quality from 2001 to 2011, and Lake Chaohu remains highly eutrophic [18]. River inputs have accelerated the eutrophication of Lake Chaohu [10]. There are 11 main rivers that flow into Lake Chaohu, five of which pass through urban areas and six of which flow through rural lands. The present study aimed to compare the characteristics of P and N forms in the urban and rural rivers that flow into Lake Chaohu (Figure 1). To achieve this goal, (1) a year-long study was conducted on all 11 rivers; (2) the concentrations and compositions of P and N in rural and urban river water were compared; and (3) total nitrogen (TN), total phosphorus (TP), and the ratios of P forms as a proportion of TP in sediments from the urban and rural rivers were also compared.
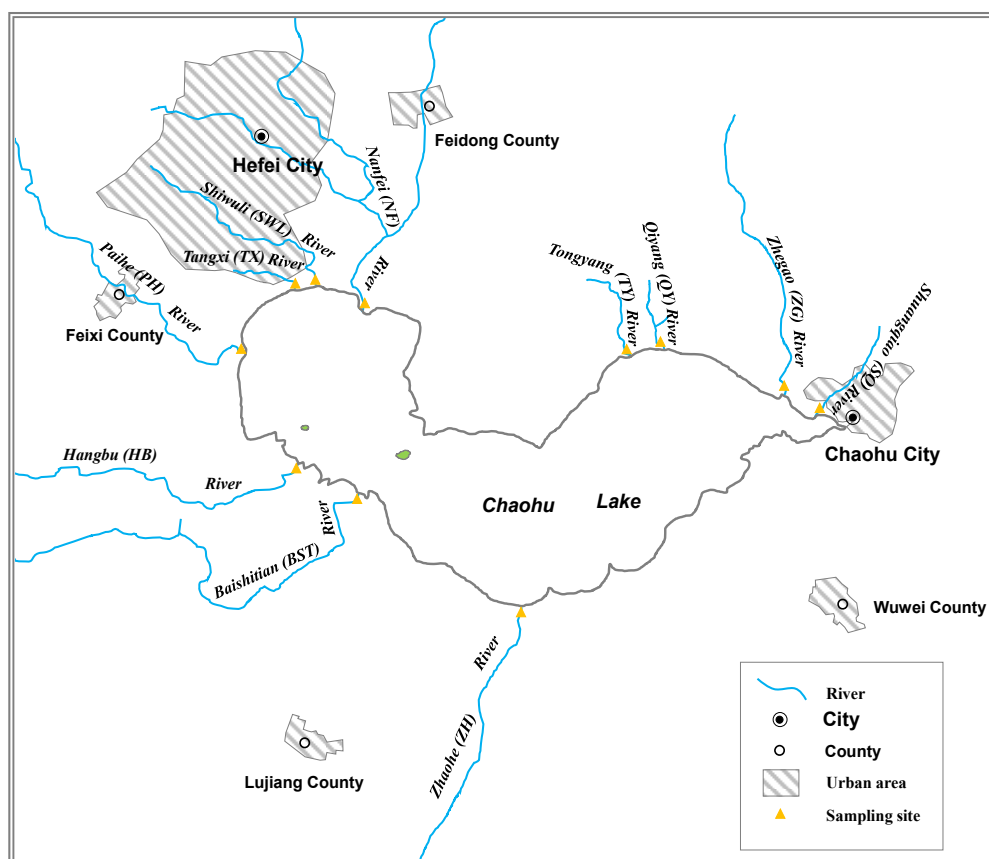
Figure 1. Sketch of the sampling sites and 11 rivers flowing into Lake Chaohu.

2. Materials and Methods

2.1. Field Sampling

The following rivers flowing into Lake Chaohu were studied: Nanfei River (NF), Shiwuli River (SWL), Tangxi River (TX), Paihe River (PH), Hangbu River (HB), Baishitian River (BST), Zhaohe River (ZH), Shuangqiao River (SQ), Zhegao River (ZG), Qiyang River (QY), and Tongyang River (TY) (Figure 1). In this study we classified rivers flowing through city and county town as the urban river group, and grouped other rivers as rural river group. NF, SWL, and TX flow through Hefei City, the provincial capital of Anhui Province. PH and SQ flow through the county town of Feixi and Chaohu City, respectively. The urban population of Hefei City, Feixi county town, and Chaohu City were separately 2,408,000, 148,000 and 272,000 [19,20]. These 5 rivers were classified as the urban group. The other 6 rivers did not flow through any city and county town, and they were classified as the rural group. In the Chaohu basin, the rural land is covered by cropland, forest, and grassland, with a ratio of about 15:3.6:1 [21]. The main agricultural crops are rice, wheat, and corn.

Each sampling site was located approximately 0.5 km upstream from the river mouth. Because nutrient levels fluctuate throughout the year, water samples were collected in December 2013 and April, July, and October 2014 to obtain data for winter, spring, summer, and autumn, respectively. When sampling, the water depth was first determined, and water samples were then collected using a handheld water sampler at 0.5 m above the river's bed. Water temperature, dissolved oxygen (DO), and pH were measured onsite using a handheld DO meter (JPB-607A, Inesa, Shanghai, China) and a

handheld pH meter (PHB-4, Inesa, Shanghai, China). Then, 250 mL of water was filtered through 0.45 μm cellulose acetate membranes. Both 250 mL of filtered water and 250 mL of unfiltered water were stored in a cooler box with ice. Sediment cores were collected in December 2013 only. One sediment core was collected at each site using a core sampler with a plexiglas tube (length 50 cm, inner diameter 8.6 cm), and each tube was sealed with rubber stoppers at both ends. All water samples and sediment cores were transported to the laboratory immediately after sampling. Water samples were preserved in a refrigerator at 4 °C for analysis.

2.2. Analyses of Water Samples

Nitrate N (in short nitrate or NO_3^-), nitrite N (in short nitrite or NO_2^-), ammonium N (in short ammonium or NH_4^+), total dissolved nitrogen (TDN), soluble reactive phosphorus (SRP), and total dissolved phosphorus (TDP) in the filtered water were analyzed separately. TN and TP in unfiltered samples were also examined. NH_4^+ and NO_2^- were determined using Nesster's reagent and *N*-(1-Naphthyl) ethylenediamine dihydrochloride spectrophotometry, respectively. To examine TDN, TDP, TN, and TP, water samples were digested in an alkaline potassium persulfate solution. TDN, TN, and NO_3^- were measured using ultraviolet spectrophotometry. SRP, TDP, TP were determined using the molybdenum blue method. These methods were performed according to the Methods for the Examination of Water and Wastewater protocols [22]. All measurements of absorbance were examined using a UV-Vis spectrophotometer (UV-2550, Shimadzu, Kyoto, Japan). All samples were analyzed within 3 days of sampling.

The relationships between different forms of P and N were summarized as follows [23]. Particulate phosphorus (PP) was determined as the difference between TP and TDP, and dissolved nonreactive phosphorus (DNP, sometimes defined as dissolved organic P) was determined as the difference between TDP and SRP. Dissolved inorganic nitrogen (DIN) was determined as the sum of NH_4^+, NO_3^-, and NO_2^-. Dissolved organic nitrogen (DON) was calculated as TDN minus DIN, and particulate nitrogen (PN) was calculated as TN minus TDN. Thus, there were 3 basic forms (PP, SRP, and DNP) of TP and 5 basic forms of TN (NH_4^+, NO_3^-, NO_2^-, DON, and PN):

$$TP = TDP + PP = SRP + DNP + PP \tag{1}$$

$$TN = TDN + PN = DIN + DON + PN = NH_4^+ + NO_3^- + NO_2^- + DON + PN \tag{2}$$

The results and discussion presented herein focus on the analysis of these 8 forms.

2.3. Analyses of Sediment Cores

The top 10 cm of each sediment core was sectioned into 5 layers at 2-cm intervals. A portion of the fresh surface sediment (0–2 cm) samples was used to examine P fractions following a sequential extraction [24,25]. Sediment samples were successively extracted using 0.46 $mol \cdot L^{-1}$ NaCl, 0.11 $mol \cdot L^{-1}$ NaBD (0.11 $mol \cdot L^{-1}$ $Na_2S_2O_4$ in 0.11 $mol \cdot L^{-1}$ $NaHCO_3$), 0.1 $mol \cdot L^{-1}$ NaOH, and 0.5 $mol \cdot L^{-1}$ HCl; the residue was then ashed at 550 °C for 2 h and extracted with 1 $mol \cdot L^{-1}$ HCl. The P fractions were labeled as NaCl-P, BD-P, NaOH-P, HCl-P, and Res-P, respectively. The NaOH extract was digested with potassium persulfate ($K_2S_2O_8$) for the measurement of the total P extracted using NaOH. The difference between total P and SRP in the NaOH extract was considered the organic P (Org-P) content

of the sediment. The remaining sediment samples were dried under 45 °C and ground to pass through 150 μm mesh. Sediment TN was examined after digestion by alkaline potassium persulfate, and TP in sediment samples was extracted using 3.5 mol·L^{-1} HCl according to the SMT method [26]. All P extracts and TN samples were also analyzed using a UV-Vis spectrophotometer according to the molybdenum blue and ultraviolet methods, respectively.

2.4. Statistical Analysis

Differences in concentrations of P and N forms and the ratios of those forms as a proportion of TP and TN between the two groups of rivers were examined using a *t* test with SPSS 13.0 software (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. General Results

Of the 11 rivers flowing into Lake Chaohu, NF, PH, HB, BST, ZH, and ZG were the larger and had the greater water depths ($\geq$3.5 m, Table 1). Lower DO levels were found in all of the urban rivers, except TX, compared with levels found in the rural rivers. Temperature and pH levels were similar in all rivers. The highest mean annual levels of TP and TN in water were detected in SWL, whereas the lowest levels were found in QY (Figure 2). For the five rivers flowing through urban areas, TP and TN ranged from 1.42 ± 0.476 to 0.265 ± 0.113 mg·L^{-1} and from 19.2 ± 3.96 to 4.65 ± 0.795 mg·L^{-1}, respectively. For the six rural rivers, TP varied between 0.142 ± 0.079 and 0.098 ± 0.027 mg·L^{-1}, and TN varied between 2.73 ± 0.934 and 1.41 ± 0.495 mg·L^{-1}. The results of the statistical analysis indicated that TP and TN levels were significantly higher in the urban rivers (0.684 ± 0.208 mg·L^{-1} and 11.0 ± 2.52 mg·L^{-1}) than in the rural rivers (0.120 ± 0.008 mg·L^{-1} and 2.09 ± 0.196 mg·L^{-1}) (Figures 3a and 4a).

Table 1. Physico-chemical parameters of 11 rivers flowing into Lake Chaohu at the time of sampling.

| Group	River (Abbreviation)	Water Depth (m)			Water Temperature (°C)			DO (mg·L^{-1})			pH		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Urban	Nanfei River (NF)	3.1	2.8	3.5	18.3	9.2	24.9	4.1	3.2	4.9	7.53	7.46	7.56
	Shiwuli River (SWL)	2.2	1.9	2.5	18.1	9.3	25.0	1.6	0.8	2.5	7.61	7.36	7.75
	Tangxi River (TX)	2.2	2.0	2.3	17.7	9.3	24.2	7.4	6.6	8.7	7.54	7.28	7.69
	Paihe River (PH)	4.1	3.1	4.6	17.7	10.2	22.8	3.5	1.8	7.5	7.45	7.17	7.60
	Shuangqiao River (SQ)	2.5	1.7	3.4	18.3	10.8	24.2	2.1	1.5	2.8	7.55	7.19	7.97
Rural	Hangbu River (HB)	3.7	3.4	3.9	18.0	9.7	23.3	9.1	7.8	9.9	7.50	7.22	7.76
	Baishitian River (BST)	4.0	3.5	4.5	17.9	9.4	23.9	7.8	7.1	8.6	7.46	7.09	7.80
	Zhaohe River (ZH)	3.1	2.4	3.5	18.0	10.1	23.8	7.4	6.7	8.0	7.47	7.04	7.76
	Zhegao River (ZG)	4.3	4.1	4.5	18.3	10.8	24.7	7.5	6.8	8.5	7.55	7.30	7.72
	Qiyang River (QY)	1.8	1.6	2.0	18.3	10.6	25.1	7.1	6.4	8.1	7.60	7.32	7.88
	Tongyang River (TY)	1.8	1.2	2.2	18.5	10.4	25.0	7.3	5.9	8.1	7.48	7.31	7.72
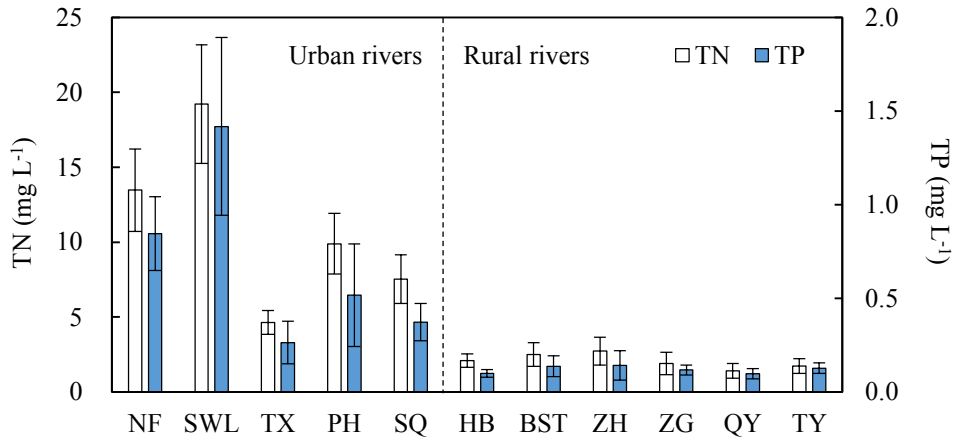
Figure 2. Total phosphorus (TP) and total nitrogen (TN) in 11 rivers flowing into Lake Chaohu. NF = Nanfei River; SWL = Shiwuli River; TX = Tangxi River; PH = Paihe River; HB = Hangbu River; BST = Baishitian River; ZH = Zhaohe River; SQ = Shuangqiao River; ZG = Zhegao River; QY = Qiyang River; TY = Tongyang River.
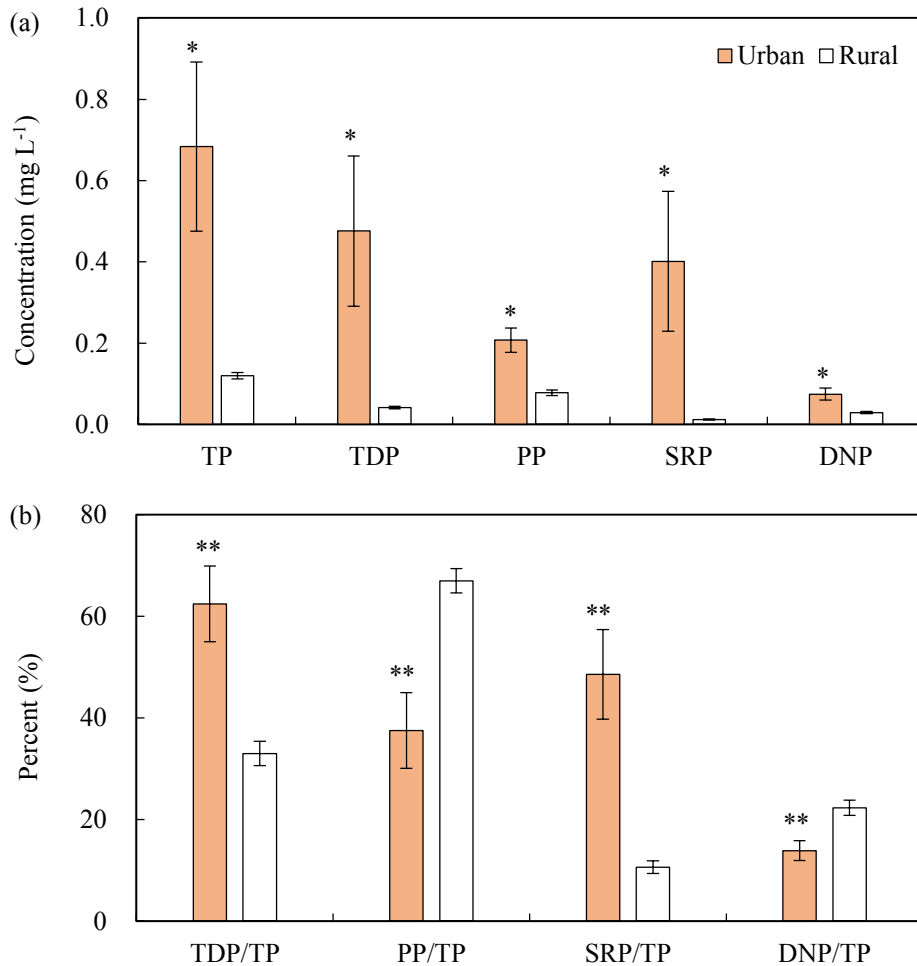

Figure 3. Concentrations of TP, TDP, PP, SRP, and DNP (**a**); and percentages of TDP/TP, PP/TP, SRP/TP, and DNP/TP (**b**) in rural and urban rivers. TP = total phosphorus; TDP = total dissolved phosphorus; PP = particulate phosphorus; SRP = soluble reactive phosphorus; DNP = dissolved nonreactive phosphorus. * ($p < 0.05$) and ** ($p < 0.01$) indicate significant differences between the rural and urban rivers (*t* test).
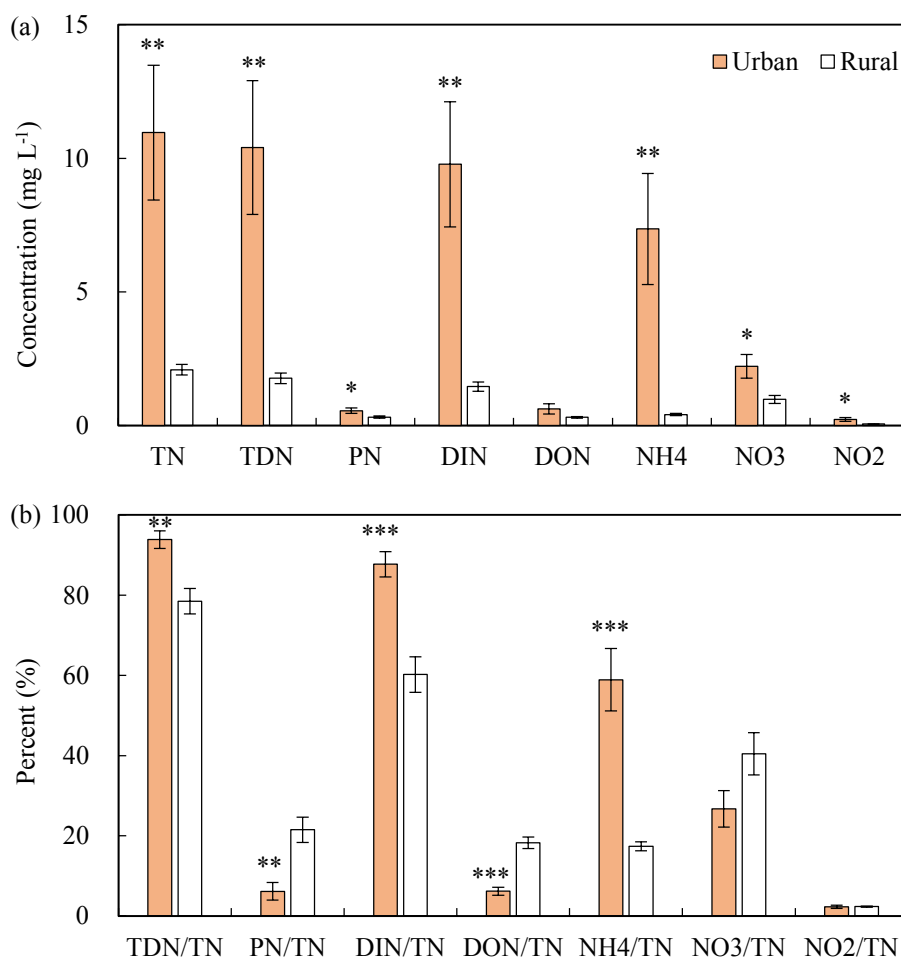
Figure 4. Concentrations of TN, TDN, PN, DIN, DON, NH_4, NO_3, and NO_2 (**a**); and percentages of TDN/TN, PN/TN, DIN/TN, DON/TN, NH_4/TN, NO_3/TN, and NO_2/TN (**b**) in the rural and urban rivers. TN = total nitrogen; TDN = total dissolved nitrogen; PN = particulate nitrogen; DIN = dissolved inorganic nitrogen; DON = dissolved organic nitrogen; NH4 = ammonium; NO_3 = nitrate; NO_2 = nitrite. * ($p < 0.05$); ** ($p < 0.01$); and *** ($p < 0.001$) indicate significant differences between the urban and rural rivers (*t* test).

3.2. Composition of P and N in Water

The concentrations of TP and P forms detected in each river were summarized in Table S1, and the ratios of P forms to TP were listed in the Table S2 in the supplementary material. Statistical analyses were conducted in the urban and rural group rivers. TDP, PP, SRP, and DNP concentrations were significantly higher in the urban rivers than in the rural rivers. Of the three basic TP forms (PP, SRP, and DNP), SRP was the dominant form in the urban rivers; however, in the rural rivers, SRP was the least abundant form, whereas PP was the most abundant form (Figure 3a). The TDP/TP ratio was significantly higher in urban rivers than in rural rivers, and the PP/TP ratio was significantly lower in urban rivers. Of the two TDP forms, SRP/TP was significantly higher in urban rivers than in the rural rivers, whereas DNP/TP was significantly lower in the urban rivers (Figure 3b).

The annual mean of TN, TDN, PN, DIN, DON, NH_4^+, NO_3^-, and NO_2^- in different rivers were separately grouped in Table S3 in the supplementary material. The ratio of TDN/TN, PN/TN, DIN/TN,

DON/TN, NH_4^+/TN, NO_3^-/TN, and NO_2^-/TN in different rivers were listed in Table S4. The statistical analyses were carried out between the urban and rural groups. With the exception of DON, the concentrations of TN forms were significantly higher in the urban rivers compared with the rural rivers. Of the five basic TN forms (NH_4^+, NO_3^-, NO_2^-, DON, and PN), NH_4^+ was the most abundant form in the urban rivers, whereas NO_3^- was the most abundant form in the rural rivers. NO_2^- was the least abundant form in both urban and rural rivers (Figure 4a). TDN/TN was found to be significantly higher in urban rivers than in rural rivers, whereas the situation was reversed for PN/TN. For the TDN forms, DIN/TN was significantly elevated in the urban rivers, whereas DON/TN was significantly lower in the urban rivers compared with the rural rivers. NH_4^+/TN was also higher in the urban rivers than in the rural rivers, although there were no significant differences between NO_3^-/TN or NO_2^-/TN levels in the urban and rural groups (Figure 4b).

3.3. P and N in Sediments

Sediment TN was greater than 2 mg·g^{-1} in BST and SQ and less than 0.5 mg·g^{-1} in HB. In the other eight rivers, sediment TN varied between 1 and 2 mg·g^{-1} (Figure 5). For all rivers, sediment TP levels were highest in NF and SQ. Sediment TP levels in SWL and PH were lower than in NF and SQ, however, these levels were higher than the TP levels in the other seven rivers. The detailed TP and P forms in the surface sediments for the eleven studied rivers were listed in the Table S5, and the ratio of different P forms to TP were summarized in Table S6 in the supplementary material. Statistical analyses indicated that surface sediment TP levels were significantly higher in the urban rivers than in the rural rivers (Figure 6a). BD-P and NaOH-P levels were both significantly greater in urban rivers than in rural rivers. NaCl-P, Org-P, HCl-P, and Res-P levels were similar across the two groups of rivers. The NaOH/TP ratios were significantly greater in the urban rivers, whereas the HCl-P/TP and Res-P/TP ratios were significantly lower in the urban compared with rural rivers. The percentages of NaCl-P, BD-P, and Org-P in TP were similar in both river types (Figure 6b).
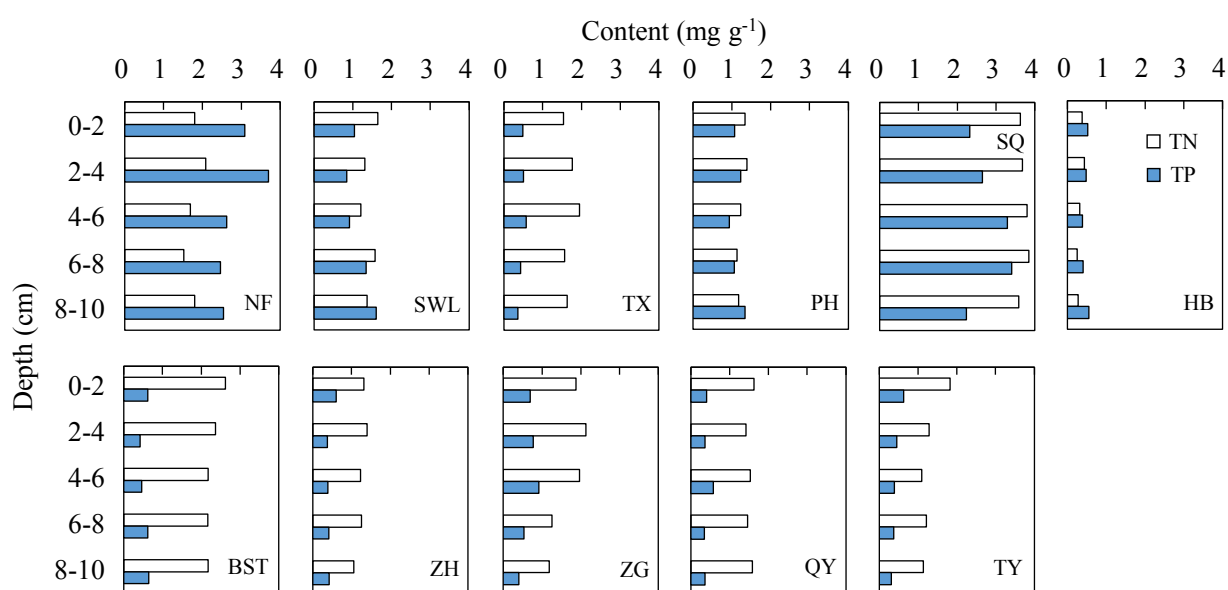

Figure 5. Distributions of TN (total nitrogen) and TP (total phosphorus) in sediment cores from 11 rivers flowing into Lake Chaohu.
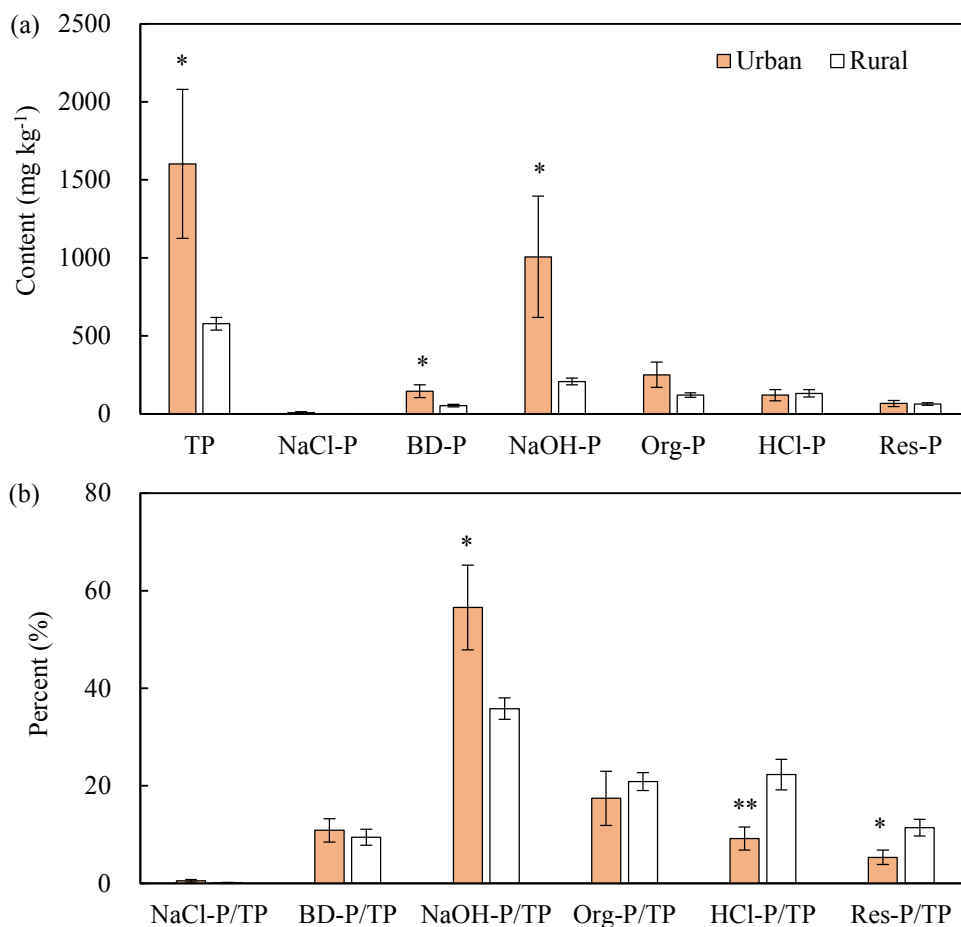
Figure 6. TP and P fractions (**a**); and percentages of P fractions of TP (**b**) in surface sediments (0–2 cm depth) from the urban and rural rivers flowing into Lake Chaohu. NaCl-P = P extracted by NaCl; BD-P = P extracted by $Na_2S_2O_4$ and $NaHCO_3$; NaOH-P = P extracted by NaOH; Org-P = organic P; HCl-P = P extracted by HCl; Res-P = residual P. * ($p < 0.05$) and ** ($p < 0.01$) indicate significant differences between the urban and rural rivers (*t* test).

4. Discussion

In rivers discharging into Lake Chaohu, the most polluted rivers are those that flow through urban areas (NF, SWL, PH, and SQ) [27]. Our results further indicated that there were higher P and N levels in rivers flowing through urban areas before entering Lake Chaohu than those flowing through rural areas (Figure 2). In addition, the N and P forms were also significantly different between rivers flowing through urban areas and the rural areas (Figures 3 and 4).

In the urban rivers, the elevated level of three basic components (PP, SRP, DNP) of P resulted in a significant higher TP compared with rural rivers. It should be noted that SRP increased at a greater rate than TP, PP, and DNP. Five rivers flowing through cities received large quantities of wastewater [28]. It has been verified that P from wastewater treatment effluent is primarily composed of TDP, and TDP primarily consists of SRP [29]. There is a positive correlation between SRP in wastewater treatment plant effluent and SRP in the receiving river [30,31]. This may be why there were higher TP and SRP levels and larger SRP/TP proportion in urban rivers. Surface runoff is a main way for P entering into

rural rivers, and the major P form in surface runoff from soil is PP [32]. This explains why there was a significantly higher percentage of PP/TP in the rural rivers compared with the urban rivers in this study.

The elevated levels of TP in surface sediment of the urban rivers were attributed to rise in BD-P and NaOH-P (Figure 6). Both of these fractions correspond to metal-bound P. Specifically, BD-P, also called Fe-P, is a redox-sensitive form of P bound to reducible Fe and Mn oxides, and NaOH-P correspond to P bound to Al oxides and non-reducible Fe oxides [25,33]. Fe-P is positively correlated with TP and SRP in water [34], and higher levels of Fe-P have been detected in more heavily polluted sediments [35]. NaCl-P is P loosely adsorbed onto sediment particles and P in pore water [36], and thus, this P fraction has a high likelihood of being released [37]. These traits made NaCl-P more likely to be found at greater levels in the urban rivers than in the rural rivers, in terms of both the content and percentage of P (Figure 6), although no significant differences were identified between the two groups. HCl-P mainly corresponds to P bound to carbonates and apatite-P [33]. HCl-P is typically determined by the geology and geochemistry of the studied basin and generally mirrors the characteristics of the basin. For this reason, HCl-P was similar in both urban and rural rivers. However, the HCl-P/TP ratio in urban rivers was lower than the rural rivers due to the raise of TP and the stability of HCl-P in urban rivers. Res-P represents the refractory organic P and inert inorganic P fractions [25]. Res-P levels were similar between the urban and rural rivers, and TP in urban rivers were higher than the rural rivers. Thus, we observed the lower Res-P to TP ratio in urban rivers.

In Chaohu and other basins, urban rivers receive large amounts of N pollutants from wastewater effluent [9,11,27], which explains the higher levels of TN in the urban rivers in our study (Figure 4). The higher TN levels in urban rivers resulted from raise of PN, NH_4^+, NO_3^-, and NO_2^- (Figure 4). In previous study there were also higher NH_4^+ in NF, SWL, PH, and SQ rivers that flowing through urban areas [27]. Ammonium is the greatest N form in rivers receiving effluent from urban sources [9,38,39]. This is why we observed the higher NH_4^+ concentration and larger NH_4^+/TN ratio in urban rivers. The high levels of NH_4^+ in urban rivers also correlated with lower DO levels (Table 1). For the rural rivers, relatively higher DO levels were found in the water (Table 1), which supported high NO_3^- levels also found in rural rivers. However, there was no difference in NO_3^-/TN and NO_2^-/TN ratios between the two river types because NO_3^-, NO_2^- and TN increased at similar rates. PN originates from phytoplankton, plankton, bacteria, and organic detritus found in water [23], whereas effluent from wastewater treatment plants contain large quantities of organic particulate matter [11]. Thus, PN levels in the urban rivers were greater than those in the rural rivers. However, PN levels increased less than TN levels, resulting in a reduced PN/TN ratio in the urban rivers compared with the rural rivers.

The urban rivers NF, SWL, TX, and PH are located in the northwestern region of the Lake Chaohu basin. Flow rates for NF, SWL, and PH were 14.3, 3.49, and 12.7 $m^3 \cdot s^{-1}$, respectively. SQ, located in the northeast, had a flow rate of 1.3 $m^3 \cdot s^{-1}$ [27]. Therefore, most of the pollutants from urban flows have been deposited in the western part of Lake Chaohu. These pollutants are mainly comprised of SRP and NH_4^+, suggesting that urbanization is responsible for the large quantity of SRP and NH_4^+ that has entered West Lake Chaohu over the past three decades. SRP has a greater capacity to facilitate river eutrophication [30]. Ammonium is also a key factor in determining the distribution of algal species and cyanobacteria blooms in freshwater ecosystems [14]. Cyanobacteria levels increase with higher NH_4^+/oxidized N ratios [15], and raise in NH_4^+ in N sources enhance competition by Microcystis [12]. These factors explain the extensive algal blooms that occur in West Lake Chaohu

during the spring and summer [17,40]. Furthermore, decreases in SRP found in wastewater treatment plant effluent result in decreases in SRP concentrations in receiving rivers [31]. A reduction of SRP and NH_4^+ in river bodies will decrease their concentrations in the receiving lake and mitigate both eutrophication and algal blooms [5]. Thus, to reduce eutrophication and algal blooms in Lake Chaohu, we must first reduce the levels of SRP and NH_4^+ flowing into NF, SWL, TX, PH, and SQ.

5. Conclusions

This study indicates that there were higher levels of TP and TN in rivers flowing through urban areas than those flowing through rural regions. Higher TP levels in urban rivers were attributed to the higher PP, DNP, and SRP. Compared with rural rivers, there were higher SRP/TP ratios and lower DNP/TP and PP/TP ratios in urban rivers. The higher TN levels in urban rivers resulted from increases in PN, NH_4^+, NO_3^-, and NO_2^-. NH_4^+/TN ratios were higher and PN/TN and DON/TN were lower in urban rivers compared with rural rivers. NO_3^-/TN and NO_2^-/TN occurred at similar levels in both river types. Surface sediment TP, BD-P, and NaOH-P were significantly higher in urban rivers than in rural rivers. NaOH-P/TP ratios were significantly greater in urban rivers, whereas HCl-P/TP and Res-P/TP were significantly lower than in rural rivers. Due to the higher TN and TP levels and NH_4^+/TN and SRP/TP ratios in the urban rivers, urban rivers transferred a large quantity of NH_4^+ and SRP into Lake Chaohu. Of the five urban rivers, four were located to the northwest of Lake Chaohu and resulted in more serious eutrophication and algal blooms in the western region of the lake. To mitigate eutrophication and algal blooms in Chaohu, we must first reduce SRP and NH_4^+ levels flowing into NF, SWL, TX, PH, and SQ from urban areas.

Author Contributions

This study was designed by Lei Zhang. Field sampling was conducted by Shiguang Shao, Lei Zhang and Cheng Liu. Chemical analysis in the laboratory was performed by Tingting Xu, Cheng Liu and Shiguang Shao. The manuscript was prepared by Lei Zhang and revised by Chengxin Fan.

Conflicts of Interest

The authors declare no conflict of interest.

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