The Transport Process of Total Suspended Substance and Its Influence on TN and TP Fluxes in Urban River: A Case Study of Baoxiang River, Yunnan China

Bin Su1,2,a, Zhengtao Shi1,2,* , Liaoyuan Ye1,2, Zebo Feng1,2 and Dongdong Xiao1,2

1School of Tourism and Geographical Science, Yunnan Normal University, Kunming 650500, China
2Key Laboratory of plateau surface processes and environmental changes in Yunnan Province, Kunming 650500, China

*Corresponding author e-mail: shizhengtao@163.com, asuynnu@163.com

Abstract. To reveal the characteristics of solid phase TSS (Total suspended substance) distribution and transported flux in urban river, and explore its effect on TN (Total nitrogen) and TP (Total phosphorus) transported fluxes. The TSS concentrations and flux, TN flux and TP flux, river runoff flux were be monitored and calculated systematically in Baoxiang River, the results shows that: (1) the annual TSS quantity transported by Baoxiang River into Dianchi Lake was 578.86t. Urban areas were the major transported areas of TSS, and summer and autumn were the main transported periods. (2) TSS has a certain correlation with TN ($R^2=0.28$, $P<0.01$, n=72) and TP ($R^2=0.34$, $P<0.01$, n=72), but there correlations were not significant. However, the correlations of river runoff flux with TN and TP were significant, it indicated that liquid phase was the main factor affecting TN TP fluxes, priority should be given to liquid phase when dealing with TN and TP pollution. The results can provide a basis for eutrophication control of urban rivers and nonpoint pollution management of Dianchi Lake river basin.

1. Introduction

It is the major problem for water environment improvement of Dianchi river and lake system that pollution loads from drainage area exceeds Lake self-purification capacity [1-2]. Among the pollution loads from drainage area, the contaminations generated by urban development accounts for a large proportion [3-4], and the proportion will increased rapidly because of the accelerating urbanization process of Dianchi River Basin, so it is very urgent to study urban non-point source pollution and improve urban water environment. Urban rivers of Dianchi Lake Basin are the major collecting area and transported channel of nonpoint pollutions, therefore, studying the formation process of urban river pollution is the key to solve the water environment problem.

TSS (Total suspended substance) is an important part of the water environment, TSS is sensitive to pollution source, climate change and Land use/ cover change [5-7], it is better indicator material for regional environmental changes. Studies have shown that TSS plays an important role in ammonia nitrogen conversion [8], phosphorus adsorption [9], heavy metal transport [10] and fish habitat protection [11]. However, current researches on the urban river environment in Dianchi River Basin are
mainly concentrated on nitrogen and phosphorus concentration and occurrence forms [12-13]. The studies of TSS are mainly focused on the TSS response under different land use types [14]. Researches on TSS transport process of urban river and whether it has an impact on nutrients flux still need to be carried out.

Therefore, this research carried out as the mainly purpose of quantitatively studied the transport flux of TSS and revealed whether the transport of solid TSS has an effect on water environment TN TP. The results can provide a basis for the control of urban non-point source pollution and the ecological restoration of urban rivers in the Dianchi Lake Basin.

2. Sampling and experimental section

2.1. Study area description

The Dianchi River Basin is located in the central part of Yunnan Guizhou Plateau. And the Baoxiang River, the second largest in-flow river of Dianci Lake, lies northeast of the lake (N24°58’–25°03’, E102°41’–102°56’) (Figure 1). The main stream of Baoxiang River is 47.1 km, and it’s catchment area is 302 km², which accounting for about 10.3% of the whole Dianchi River Basin. The Baoxiang River basin is in a subtropical humid monsoon climatic region, among the whole the year the temperature difference is small, and the dry and wet seasons are distinct. More than 80% of the rainfall occurring from May to October. The average annual rainfall and average annual temperature of Baoxiang River basin are 953 mm and 14.7 degrees centigrade, respectively. Baoxiang River flows through the main city zone of Kunming, which strongly disturbed by human activities, it is a typical urban river.

![Figure 1. Sketch map of the Baoxiang River basin and sampling point distribution](image)

2.2. Sample collection

From upstream to downstream of Baoxiang River main stream, there were 7 critical points has been chose as monitoring sites: Yiduoyun village, Shagoucun village, Chaohe River, Jinmacun village, Gaoqiaocun village, Jihong Road, Baofeng wetland. Water samples have been collected from May-2016
to April-2017. Sampling period was once time per month, and 2 L water was collected each time, 2L washed polyethylene bottles were been used for water samples transportation. In the research we were systematically collected samples 12 times, and 84 samples were collected in total. The collected samples were sent back to Key Laboratory of plateau surface processes and environmental changes in Yunnan Province, and all of the water quality experiments were complete in 24 hours.

2.3. River discharge monitoring
For monitored the river discharge of the different sections in Baoxiang River, 6 key positions were chose as monitoring sections: Shagoucun village, Chaohe River, Jinnacun village, Gaoqiaocun village, Jihong Road, Baofeng wetland. River discharge monitoring was carried out as the same of water samples collected, during May-2016 to April-2017, and monitored monthly. Section selection, measurement and water level observation were refer to Code for measurement of fluid flow in open channels (GB50179-93) and Standard for observation of water level (GB/T20138-2010). The velocity of river runoff was measured by LS20B type propeller current meter, and the measuring range is 0.04 m/s–15 m/s, and the measuring error is less than 5%.

2.4. Water quality experiment
The indexes of water quality as follows TSS (Total Suspended Substance), TN (Total nitrogen) and TP (Total phosphorus) were tested in laboratory. TP was tested by ammonium molybdate spectrophotometry (GB11893-89), TN was determined by alkaline potassium persulfate digestion and ultraviolet spectrophotometry (HJ636-2012), TSS was tested by gravimetric method (GB11901-89). To ensure the accuracy of the experiment and the reliability of the data, the final value of each index was obtained from the average value of three parallel experiments.

2.5. Data Processing
Data statistics analysis and image rendering were carried out by ArcGIS10.2, Origin9.0 and SPSS23.0. The flux of TN, TP and TSS were calculated according to formula (1).

\[ W = 10^{-6} \times \sum_{i} f_{i} t_{i} C_{i} \]  

In the formula (1), \( W \) is the flux of target substance (t/Month, the following abbreviated as t/M). \( f_{i} \) is the water volume of i monthly(m³/s). \( t_{i} \) is the total seconds of i monthly (s). \( C_{i} \) is the average concentration of target material of i monthly (s).

3. Results

3.1. Characteristics of TSS concentration and flux

3.2. Temporal and spatial characteristics of TSS concentration

(1) Spatial variation of TSS concentration.
The distribution of TSS concentration showed significant differences at each sampling point. The river source Yiduoyun village area was dominated by forest, and it was the water source protection area, where human activities were relatively low. On the river source Yiduoyun village and upstream Shagoucun village region the annual average concentration of TSS were 8.05 mg/L and 7.03 mg/L, respectively. The values in the source and upstream of Baoxiang River were lower compared with other regions (Fig2), it means on the lower human effect region, there were less TSS water in the water body, and it was not the main contribution area of TSS. In the middle stream of Baoxiang River city is the mainly region along the river sides. At the middle stream sampling sites Jima Village and Gaoqiao village, the annual average concentration of TSS were 10.25 mg/L and 16.25 mg/L, the TSS annual average concentration of Gaoqiao village reached the highest value of the river. The data showed that in the higher human effect city region the TSS concentrations were increased, which means city source...
pollutions may lead to increasing of TSS concentrations in the water environment. Middle reaches area were the mainly places of TSS transportation. Jihong Road and Baofeng Wetland sampling sites were located in the downstream and Baoxiang River lake inlet, the annual average concentration of TSS at these two sites were 8.26 mg/L and 5.56 mg/L, the concentration were lower than that of the upstream, significant reduction of water flow velocity in the end of the river might inconveniece to TSS transmission, so TSS concentration reduced in the downstream.

(2) Temporal variation of TSS concentration.

From the time scale, at the upstream and downstream of Baoxiang River TSS concentration show a little difference between each months, but greater in the middle reaches (Fig.3). On the whole, the fig.3 showed that in the most sampling points TSS concentration in rainy season (from May to October) were higher than dry season (from September to April). The surface of river basin be washed off by rainfall runoff in rain season might lead to TSS concentration increasing. And higher TSS concentration in rainy season means that rainy season was the main transport period of TSS.

Figure 2. Characteristics of TSS concentration along the river
3.2.1. **Temporal and spatial characteristics of TSS flux.** From the spatial scale, on the upstream Shagoucun village and Caoh River sampling sites both monthly flux and annual flux of TSS were relatively low (Table 1), and on the downstream Baofeng wetland both monthly and annual flux of TSS were lower too. Shagoucun Village showed the lowest average monthly flux and annual flux, and the values of which were 0.69 t/M and 8.32 t/a. On the middle stream both monthly flux and annual flux of TSS were increased, and Gaoqiaocun Village had the highest TSS average monthly flux and annual flux, the values of them were 108.86 t/M and 1306.32 t/a. From the time scale, from the upstream to downstream, except the estuary site Baofeng wetland, summer and autumn were the peak transport period of TSS flux (Table 1). As mentioned before, Baoxiang River basin is in subtropical humid monsoon climatic region, summer and autumn were coincide with rainy season, river basin surface nonpoint pollution brought by rainfall runoff into river course might be the main reason for the increase of TSS flux. At the estuary area Baofeng wetland sampling site, spring and summer were the mainly period of TSS flux transportation. In the estuary area river water velocity decreases obviously, and sediment deposition in river channel, the influenced of river inner source might lead to the increased of TSS flux in spring. The annual TSS quantity that transported by Baoxiang River to Dianchi Lake was 578.86t.
### Table 1. Temporal and spatial characteristics of TSS flux in Baoxiang River

| Monthly flux (n=12) | Min value(t/M) | Max value(t/M) | Average value(t/M) | Spring(t) | Summer(t) | Autumn(t) | Winter(t) | annual flux(t/a) |
|---------------------|----------------|----------------|--------------------|-----------|-----------|-----------|-----------|------------------|
| Shagoucun Village   | 0.00           | 2.40           | 0.69               | 2.40      | 3.32      | 2.04      | 0.57      | 8.32             |
| Caohe River         | 2.06           | 147.47         | 35.71              | 75.43     | 162.91    | 169.52    | 20.64     | 428.50           |
| Jinmacun Village    | 3.76           | 178.18         | 39.79              | 50.09     | 133.44    | 262.75    | 31.22     | 477.51           |
| Gaoqiaocun Village  | 14.27          | 266.81         | 108.86             | 212.45    | 355.95    | 577.70    | 160.21    | 1306.32          |
| Jihong Road         | 10.91          | 155.56         | 54.56              | 87.81     | 234.15    | 266.80    | 66.00     | 654.77           |
| Baofeng wetland     | 7.70           | 82.32          | 48.24              | 195.12    | 193.11    | 118.86    | 71.76     | 578.86           |

### 3.3. Temporal and spatial characteristics of TN and TP flux

#### 3.3.1. Temporal and spatial characteristics of TN flux

The minimum value of TN flux located in Shagoucun Village, where TN average monthly flux was 0.13(t/M) and TN annual flux was 2.02(t/a). And downstream Baofeng wetland area had the maximum value of TN flux, where the average monthly flux and annual flux of TN were 81.11(t/a) and 973.27(t/a). The data indicated that along the river nitrogen pollutants were inflow into river course continuously. The quantity of annual TN transported by Baoxiang River to Dianchi Lake was 973.27t.

From the time scale, on the upstream and middle stream summer and autumn were the main transport period of TN flux (Table2). But on the downstream Jihong Road area the most TN flux were transported in spring, summer and autumn. On the river inlet Baofeng wetland region four seasons were all TN flux transportation period, among which the TN flux quantity transported in summer was relatively low.

### Table 2. Temporal and spatial characteristics of TN flux in Baoxiang River

| Monthly flux (n=12) | Min value(t/M) | Max value(t/M) | Average value(t/M) | Spring(t) | Summer(t) | Autumn(t) | Winter(t) | annual flux(t/a) |
|---------------------|----------------|----------------|--------------------|-----------|-----------|-----------|-----------|------------------|
| Shagoucun Village   | 0.00           | 0.48           | 0.13               | 0.09      | 0.62      | 0.74      | 0.57      | 2.02             |
| Caohe River         | 7.38           | 21.88          | 12.62              | 24.04     | 41.89     | 56.41     | 29.15     | 151.48           |
| Jinmacun Village    | 10.45          | 37.16          | 19.69              | 46.05     | 86.80     | 62.85     | 40.48     | 236.18           |
| Gaoqiaocun Village  | 8.51           | 53.53          | 30.15              | 74.87     | 123.33    | 102.59    | 61.07     | 361.85           |
| Jihong Road         | 23.50          | 72.68          | 47.52              | 161.17    | 140.97    | 174.03    | 94.05     | 570.21           |
| Baofeng wetland     | 55.76          | 127.69         | 81.11              | 296.64    | 176.15    | 252.17    | 248.30    | 973.27           |
3.3.2. Temporal and spatial characteristics of TP flux. From the spatial scale, as the same with TN flux, both average monthly flux and annual flux of TP showed increasing trend from upstream to downstream in Baoxiang River (Table 3). The minimum value of TP flux located in Shagoucun Village, where TP average monthly flux was 0.01(t/M) and TP annual flux was 0.12(t/a). And downstream Baofeng wetland area had the maximum value of TP flux, where the average monthly flux and annual flux of TP were 4.99(t/a) and 59.86(t/a). The data indicated that along the river phosphorus pollutants were inflow into river course continuously. The quantity of annual TP transported by Baoxiang River to Dianchi Lake was 59.86t.

From the time scale, on the upstream and middle stream summer and autumn were the main transport period of TP flux (Table2). But on the downstream Jihong Road area the most TP flux were transported in spring, summer and autumn. On the river inlet Baofeng wetland region four seasons were all TP flux transportation period, and TP flux transported in summer was lower among them.

| Monthly flux\( (n=12)\) | Min value(t/M) | Max value(t/M) | Average value(t/M) | Spring(t) | Summer(t) | Autumn(t) | Winter(t) | annual flux(t/a) |
|---------------------------|----------------|----------------|-------------------|-----------|-----------|-----------|------------|-----------------|
| Shagoucun Village         | 0.00           | 0.06           | 0.01              | 0.01      | 0.04      | 0.07      | 0.00       | 0.12            |
| Caohe River               | 0.10           | 0.63           | 0.27              | 0.41      | 1.00      | 1.27      | 0.59       | 3.26            |
| Jinmacun Village          | 0.33           | 0.97           | 0.68              | 1.54      | 2.22      | 3.37      | 1.05       | 8.18            |
| Gaoqiaocun Village        | 0.54           | 2.63           | 1.36              | 3.77      | 4.19      | 6.47      | 1.90       | 16.34           |
| Jihong Road               | 0.70           | 7.35           | 2.36              | 11.67     | 5.73      | 6.88      | 4.07       | 28.35           |
| Baofeng wetland           | 1.57           | 18.93          | 4.99              | 28.40     | 6.30      | 13.82     | 11.35      | 59.86           |

3.4. Response relation between TSS and TN and TP

3.4.1. Correlation between TSS flux and TN, TP fluxes. The fig.4 and fig.5 were showed the Correlation between TSS flux and TN, TP fluxes, results revealed that the correlation coefficient between TN and TSS was 0.28 (P<0.01, n=72), and between TP and TSS was 0.34 (P<0.01, n=72). The data indicated that on the whole TN, TP fluxes were related with TSS flux, however, the correlation were not obviously, among which the correlation between TP flux and TSS flux was better than the other. Correlation analysis showed that in Baoxiang River the transported of TSS has no significant effect on the transport of TP and TN.
3.4.2. Correlation between river runoff flux and TN, TP fluxes. The fig.6 and fig.7 were showed the correlation between Baoxiang River runoff flux and TN, TP fluxes, results revealed that the correlation coefficient between TN flux and Baoxiang River runoff flux was 0.89 ($P<0.01$, $n=72$), and between TP flux and Baoxiang River runoff flux was 0.86 ($P<0.01$, $n=72$). The data indicated that on the whole TN, TP fluxes were significantly related with river runoff flux. And the correlation between TN flux and river runoff flux was better than the other. Correlation analysis showed that in Baoxiang River the transported of river runoff flux has significant effect on the transport of TP and TN.
4. Discussion

Previous studies have shown that according to the monitoring of nitrogen and phosphorus contents in natural waters, the concentration of absorbed phosphorus in sediment is much larger than that in dissolved phosphorus, the ratio of adsorbed to total phosphorus was about 90\% [15-16]. And total suspended substance have been proved to adsorb ammonia nitrogen, therefore, it was also affected total nitrogen [8]. However, according to the analysis of this study, although the correlation between TSS flux and TP flux was better than that of TN flux, there were not obviously correlation between TSS flux and TN, TP fluxes. But there were significant correlation between river runoff flux and TN, TP fluxes. The mainly reason may because of that as shown above, on the spatial scale, the trend of TSS flux was first increasing and then decreased, and the trends of TN and TP fluxes were sustained growth, the spatial distributions of TSS, TN and TP fluxes were significant difference. Besides, after field measurement by our research team, we found that dissolved state nitrogen and phosphorus of urban pollution runoff, rural pollution runoff and farmland ditch runoff were the main forms of TN and TP in Baoxiang River basin. So the correlation between TN and TP fluxes and liquid phase such as river runoff flux were better. To sum up, in urban river, where human activities were more concentrated and urban areas at different stages of development were the main source of pollutions, liquid phase was the main factor affected TN TP fluxes.

![Figure 6. Correlation between river runoff flux and TN flux](image)

![Figure 7. Correlation between river runoff flux and TP flux](image)
5. Conclusion

(1) The annual TSS quantity that transported by Baoxiang River to Dianchi Lake was 578.86 t. The spatial distribution of TSS flux showed increases first and then decreases, summer and autumn were the main transported periods of TSS.

(2) The quantity of annual TN and TP transported by Baoxiang River to Dianchi Lake were 973.27 t and 59.86 t. Both TN and TP fluxes were increased from upstream to downstream, and summer and autumn were the main transported periods of TN and TP.

(3) TSS has a certain correlation with TN ($R^2=0.28$, $P<0.01$, $n=72$) and TP ($R^2=0.34$, $P<0.01$, $n=72$), but there correlations were not significant. However, the correlations of river runoff flux with TN TP were significant, it indicated that liquid phase was the main factor affecting TN TP fluxes, priority should be given to liquid phase when dealing with TN and TP pollution.

Acknowledgments

This work was financially supported by the Water Conservancy Science and Technology Project of Yunnan Provincial Water Resources Department (2014003).

Reference

[1] W Ma, X J Li, X R Tian, et al. Investigation on countermeasures for water environment management and water pollution prevention in Dianchi Lake [J]. Journal of China Institute of Water Resources and Hydropower Research, 2007, 5 (1): 8-14.

[2] W M Deng, K Lei, H D Su. Assessment of water environmental carrying capacity in the Dianchi Lake watershed in 2008 [J]. Research of Environmental Sciences, 2012, 25 (4): 372-376.

[3] W Gao, F Zhou, H C Guo, et al. High-resolution nitrogen and phosphorus emission inventories of Lake Dianchi Watershed [J]. Acta Scientiae Circumstantiae, 2013, 33 (1): 240-250.

[4] J N Chen. Nonpoint source pollution control: Case studies in Dianchi Lake catchments [M]. Beijing: China Environmental Science Press, 2009.

[5] I Donohue, J G Molinos. Impacts of increased sediment loads on the ecology of lakes [J]. Biological reviews, 2009, 84: 517–531.

[6] V Elbrecht, A J Beermann, G Goessler, et al. Multiple-stressor effects on stream invertebrates: a mesocosm experiment manipulating nutrients, fine sediment and flow velocity [J]. Freshwater Biology, 2016, 61: 362–375.

[7] P J Wood, P D Armitage. Biological effects of fine sediment in the lotic environment [J]. environmental management. 1997, 21: 203–217.

[8] YU Hui, X Q Zhang, X Zhang, et al. Effect of Particulates on Nitrification in Natural Waters of the Yellow River Under laboratory Conditions [J]. Acta Scientiae Circumstantiae, 2004, 24 (4): 601-606.

[9] L Cheng, S G Shao, Q S Shen, et al. Effects of riverine suspended particulate matter on the post-dredging increase in internal phosphorus loading across the sediment-water interface [J]. Environmental Pollution, 2016, 211: 165-172.

[10] T Nasrabadi, H Ruegner, Z Z Sirdarid, et al. Using total suspended solids (TSS) and turbidity as proxies for evaluation of metal transport in river water [J]. Science of the Total Environment, 2017: 598: 1160–1168.

[11] T R Shaylah, J M Todd, D Josef. Ackerman. Suspended solid concentration reduces feeding in freshwater mussels [J]. Science of the Total Environment, 2017, 598: 1160–1168.

[12] L Y Yuu, H Yang, C C Huang, et al. Characteristic of nitrogen and phosphorous pollution in Lake Dianchi and its inflow rivers in summer [J]. Journal of Lake Sciences, 2016, 28 (5): 961-971.

[13] L Li, H F Wang, S R Wang, et al. Spatial and temporal changes in nitrogen loading of rivers into Dianchi Lake and contributions of different components [J]. Research of Environmental Sciences, 2016, 29 (6): 829-836.

[14] W R Ding. Change Regularity and Response to the Environment of river suspended sediment of
the Panlonghe Basin in Yunnan province [D]. Kunming: Kunming University of Science and Technology, 2008.

[15] P Y Lu, W D Huang, J Li. Study on adsorption experiment for phosphorous pollutant with suspended sediment [J]. Water Resources and Hydropower Engineering, 2005, 36 (10): 93-96.

[16] X Y Wang, Y X Wang, X F Wang, et al. The Character of Nutrient Loss and Land Use in A Small Watershed of Miyun Reservoir [J]. Research of Environmental Sciences, 2003, 16 (1): 30-33.