

A decade of variation of COD in the Changjiang River (Yangtze River) and its variation trend analysis

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Abstract The average annual value of COD (chemical oxygen demand) fluxes of the Changjiang River (Yangtze River) and its main tributaries in the past decade (i.e., 1991–2000), has been evaluated. Based on the data from the Datong Hydrological Station (DHS), it was found that the Dongting Lake drainage basin contributed the greatest water discharge (35.8%) and COD flux (48.3%) among the main tributary drainage basins, followed by the Poyang Lake drainage basin with the contributions of 15.4% and 19.3%, respectively. By the end of the year of 2000, COD flux in the Changjiang River rose by almost 45% relative to that in the year of 1991, reaching about 1941000 ton/a at DHS. Statistical analysis revealed that industrial wastewater discharge, as well as COD in it, was found decreasing in the same period, due to the gradual reinforcement of environmental management. Moreover, correlation analysis indicated that non-point pollution from agriculture and increasing discharge of domestic sewages caused by rapid growth of population along the Changjiang River drainage valley should be responsible for the high COD. Furthermore, with the current trend of population growth and agricultural development in this basin, water quality of the Changjiang River, in terms of COD level, is going to deteriorate in the near future. Thus, the rational applications of fertilizers and pesticides in agriculture and the proper treatment of domestic sewages before they are discharged would be the most concerned controlling parameters.

Key words COD flux; Changjiang River drainage basin; water quality; population

1 Introduction

River, as a bridge to link terrestrial and marine ecosystems, plays a unique role in transporting nutrients from land to ocean. Changes in river water quality will make a significant impact on coastal ecosystems (Liu Sumei et al., 2003). For instance, coastal eutrophication is a critical factor, which can affect water quality and then cause the shift of phytoplankton species (Rabalais et al., 1996). Therefore, much attention has been paid to the variation trend of river water quality.

The Changjiang River is the largest river on the Eurasian Continent, with a draining area of 1.80×10^6 km², and ranks the third in length (6300 km), the fifth in freshwater flow (924.8×10^9 m³/a) and the fourth in sediment discharge (0.5×10^9 tons/a) in the world (Liu Sumei et al., 2003; Yan Weijing and Zhang Shen, 2003). The population density of the Changjiang River drainage basin was 197 per km² (1982), much higher than that of the whole country (107 per km²)

and that of the world (39 per km²). Although this drainage basin covers one-fifth of the total land area of China, its gross product from industry and agriculture accounts for more than 40% of the total. In the past decade (i.e., 1991–2000), rapid economical development has been made in China, particularly in the Changjiang River drainage basin. According to the available data from the natural resources database of China (<http://www.naturalresources.csdb.cn>, 2004), it was estimated that, compared with the data in 1991, nitrogen and phosphorous fertilizers applied in the whole China at the end of 1999 increased almost by 26% and 40%, respectively. However, due to the lag pollution controls and treatments, the aquatic environments in the Changjiang River drainage basin have been greatly impacted by human activities. It has been reported that water quality of the global rivers has been seriously impacted by recent anthropogenic activities (Chen Jingsheng et al., 1998; Zhang Jing et al., 1999; Duan Shuiwang and Zhang Shen, 1999; Chen Jingsheng et al., 1999; Vörösmarty and Sahagian, 2000; Xia Jin et al., 2001; Turner et al.,

2003; Zhu Jun et al., 2005). The deterioration of water quality is evidenced mainly by the increase of nutrients (e.g. nitrates and phosphates) and organic loads. Generally, COD in a river is composed mainly of natural organic matter from watershed and that produced in the channels, anthropogenic organic matter from industrial, agricultural and domestic sewages, and other deoxidized substances. Thus, there is a linear relationship between total organic carbon (TOC) and COD (Cui Jiansheng et al., 2003). In many river monitoring projects, COD is used to evaluate the pollution status in the aquatic environment (Xu Kaiqin et al., 2004; Brodnjak-Vončina et al., 2002; Ahsan et al., 2001; Chandra and Anand, 1995).

Reported in this study are the variation trends of water quality of the Changjiang River drainage basin, in terms of COD level along the mainstream of the Changjiang River and its main tributaries. In combination with the statistics data on economic development, this study has evaluated the major sources of COD in the Changjiang River and its evolution trend.

2 Materials and methods

2.1 Study area

The Changjiang River drainage basin is located at 24°30'–35°45'N and 90°33'–122°25'E with an area of 1.8×10^6 km². The major tributaries include the Yalongjiang, Minjiang, Tuojiang, Jialingjiang, Wujiang, Hanshui, Xiangjiang, Yuanjiang, and Ganjiang rivers (Fig. 1). The Xiangjiang and

Yuanjiang rivers join the Changjiang River via the Dongting Lake, and the Ganjiang River via the Poyang Lake. Both the Poyang and Dongting lakes are the two largest freshwater lakes in China (Chen Jingsheng et al., 2002).

2.2 Data sources and statistical results

The data from 34 hydrological stations along the mainstream and main tributaries (Fig. 1) of the Changjiang River were collected in the unpublished "Hydrological Yearbooks of the Changjiang Drainage Basin of the People's Republic of China", from which the data on COD and water discharge were taken from 1991 to 2000, while NO₃⁻ contents at DHS were recorded from 1964 to 2000. Among the 34 stations, 19 are located along the mainstream, including (from upstream downwards) Luzhou, Zhutuo, Cuntan, Qingxichang, Sandouping, Yichang, Zhicheng, Shashi, Hankou, Echeng, Huangshi, Jiujiang, Datong, Wuhu, Maanshan, Nanjing, Zhenjiang, Nantong and Xuliujing (Fig. 1), and the other 15 stations are located along the main tributaries of the Changjiang River. Historical monitoring data presented in the "Hydrological Yearbooks" generally lack detailed quality assurance/quality control information, but these data have been considered reliable, as has been examined by Chen Jingsheng et al. (2002).

COD and water discharge were reported monthly during the years of 1991–2000. The average annual COD and NO₃⁻ contents at DHS were calculated in terms of discharge weight, and the average COD within this period was equal to the arithmetic average

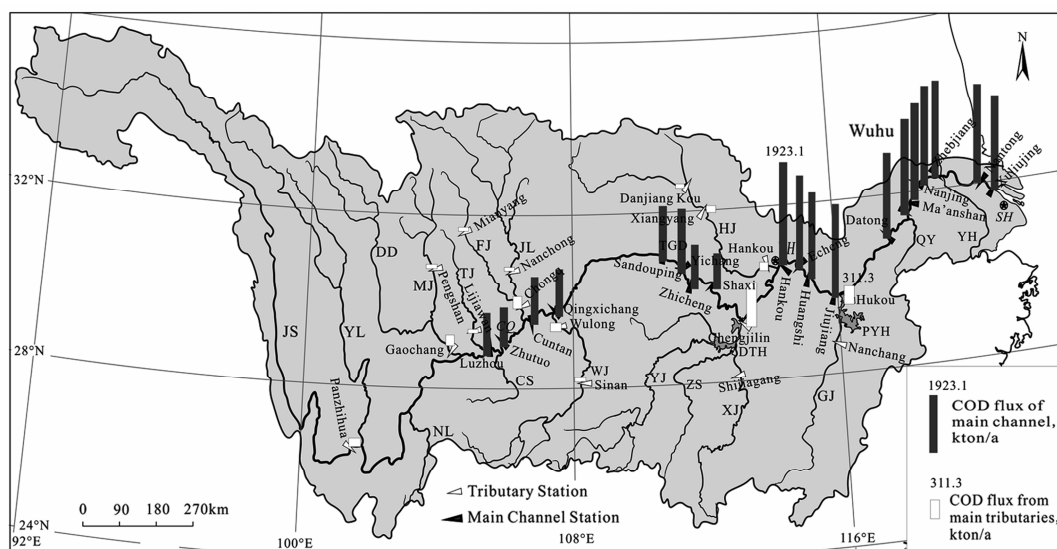


Fig. 1. Annual COD fluxes along the mainstream and tributaries of the Changjiang River, with the detailed data listed in Table 2. JS. Jinsha River; YL. Yalong River; DD. Dadu River; MJ. Minjiang River; NL. Niulan River; CS. Chishui River; TJ. Tuojiang River; FJ. Fujiang River; JL. Jialing River; WJ. Wujiang River; HJ. Hanjiang River; YJ. Yuanjiang River; ZS. Zhishui River; XJ. Xiangjiang River; GJ. Ganjiang River; DTH. Dongting Lake; PYH. Poyang Lake.

Table 1. Provincial composition and area percentage in the Changjiang River drainage basin*

| Province | Province area (10 ³ km ²) | Area within the Changjiang River drainage basin (10 ³ km ²) | Percentage (%) |
|-----------|--|--|----------------|
| Jiangxi | 163.2 | 163.3 | 100.0 |
| Shanghai | 6.34 | 6.3 | 100.0 |
| Hubei | 185.9 | 185.9 | 100.0 |
| Hunan | 211.8 | 211.8 | 100.0 |
| Sichuan | 567.4 | 567.4 | 100.0 |
| Guizhou | 176 | 115.7 | 65.8 |
| Anhui | 139.4 | 65.6 | 47.1 |
| Jiangsu | 102.6 | 39.9 | 38.8 |
| Shanxi | 205.6 | 72.8 | 35.4 |
| Yunnan | 394.1 | 109.1 | 27.7 |
| Qinghai | 721.2 | 169.3 | 23.5 |
| Henan | 167 | 27.4 | 16.4 |
| Zhejiang | 101.8 | 12.2 | 12.0 |
| Gansu | 454 | 38.4 | 8.5 |
| Guangxi | 236.7 | 8.4 | 3.6 |
| Tibet | 1200 | 29.2 | 2.4 |
| Fujian | 121.4 | 1.0 | 0.9 |
| Guangdong | 177.9 | 0.3 | 0.2 |

* Percentage of a province in the Changjiang River Basin; including Chongqing City. * Data partly from Yan Weijing and Zhang Shen (2003).

of monthly reported data. Other statistics data on industrial wastewater, COD in industrial wastewater, population growth, grain output, annual application of pesticides and nitrogen and phosphorus fertilizers were taken from the datasource (<http://www.naturalresources.csdb.cn>). All the statistics data were obtained at the provincial level within the Changjiang River Basin (Yan Weijing and Zhang Shen, 2003), and conversion of the provincial data to basin-scale data based on the area. The provincial composition and absolute area and area percentage in the whole basin are listed in Table 1.

3 Results and discussion

3.1 Total COD flux in the whole basin

According to the monthly reported data (i.e., 1991–2000) from the 34 hydrological stations along the Changjiang River drainage basin, the annual average COD fluxes along the mainstream and tributaries were calculated, as shown in Fig. 1 and listed in Table 2. From Fig. 1 it was estimated that about 1788.0 kton of COD were transported into the East China Sea annually, from Xiuliujing, a station near the Changjiang River Estuary, and COD fluxes were significantly increased around the middle reaches of the Changjiang River. Among the main tributaries, the Dongting Lake drainage basin contributed most of the COD load to the mainstream, followed by the Poyang Lake basin (Table 3). By plotting the distance from the Changjiang River Estuary vs. annual COD flux and water discharge, respectively (Fig. 2), it is clear that remarkable

increases in both annual COD flux and water discharge along the mainstream occur mainly within the area of 1200–1500 km inland from the estuary. Lake and the Hanjiang River joined into the Changjiang River mainstream.

DHS (117°37'E, 30°46'N) is located 625 km

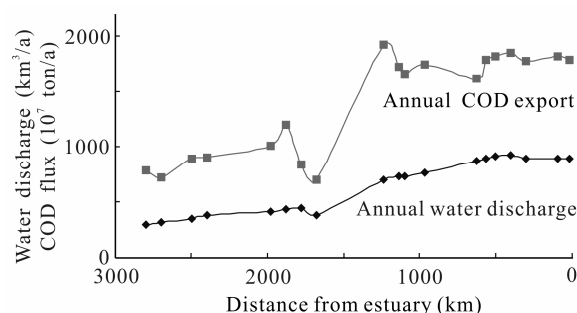


Fig. 2. Plot of distance from the Changjiang River Estuary vs. annual water discharge and COD export flux, respectively.

inlandwards from the river mouth on the mainstream (Fig. 1), which is free from tidal influence. No serious sewage discharge from industrial and domestic sources have been found nearby DHS (Yan Weijing and Zhang Shen, 2003). Its drainage area is as large as about 1.71×10^6 km², i.e., >95% of the total Changjiang River watersheds (Duan Shuiwang, 2000). Therefore, the data from DHS are generally used to evaluate the variation trend of water quality of the Changjiang River and to estimate the seaward flux by global rivers in literature. Presented in Table 3 are the calculated annual COD yields within the main tributary drainage basins and those of the whole

Table 2. COD contents, fluxes and water discharge of the mainstream and tributaries

| Hydrological stations along the mainstream | | | | Hydrological stations at the main tributaries | | | | |
|--|--|----------------------------------|--|---|---------------|--|----------------------------------|--|
| Station | Annual discharge (km ³) | Average COD [mg/L(1991–2000)] | Flux of COD (10 ³ ton/a) | Station | River | Annual discharge (km ³) | Average COD [mg/L(1991–2000)] | Flux of COD (10 ³ ton/a) |
| Luzhou | 295.9 | 2.7 | 791.2 | Panzhihua | Jinshajiang | 53.9 | 1.8 | 98.6 |
| Zhutuo | 319.9 | 2.3 | 721.8 | Gaochang | Minjiang | 86.1 | 1.9 | 162.7 |
| Cuntan | 352.3 | 2.5 | 893.1 | Pengshan | Minjiang | 8.8 | 4.8 | 42.2 |
| Qingxichang | 382.1 | 2.4 | 899.8 | Lijiawan | Tuojiang | 12.6 | 4.6 | 57.1 |
| Sandoupin | 410.4 | 2.5 | 1005.4 | Chongqing (jia) | Jialinjiang | 68.7 | 3.0 | 208.8 |
| Yichang | 437.9 | 2.8 | 1204.3 | Mianyang | Fujiang | 6.9 | 1.8 | 12.5 |
| Zhicheng | 441.8 | 1.9 | 835.0 | Nanchong | Jialinjiang | 10.9 | 2.5 | 27.0 |
| Shashi | 385.3 | 1.8 | 697.3 | Daxian | Qujiang | 6.3 | 2.7 | 16.6 |
| Hankou | 699.3 | 2.8 | 1923.1 | Chenglinji | Dongting Lake | 312.6 | 2.5 | 781.5 |
| Echeng | 737.9 | 2.3 | 1726.7 | Xiangyang | Hanjiang | 43.5 | 2.6 | 112.7 |
| Huangshi | 737.9 | 2.3 | 1660.3 | Hankou (han) | Hanjiang | 51.7 | 2.7 | 139.1 |
| Jiujiang | 766.3 | 2.3 | 1747.2 | Hukou | Poyang Lake | 134.2 | 2.3 | 311.3 |
| Datong | 874.1 | 1.9 | 1617.1 | Danjiangkou | Hanjiang | 40.9 | 1.9 | 77.6 |
| Wuhu | 892.5 | 2.0 | 1784.9 | Sinan | Wujiang | 28.0 | 1.6 | 44.8 |
| Ma'anshan | 914.5 | 2.0 | 1819.9 | Wulong | Wujiang | 52.0 | 2.1 | 109.2 |
| Nanjing | 926.6 | 2.0 | 1853.2 | | | | | |
| Zhengjiang | 893.3 | 2.0 | 1777.7 | | | | | |
| Nantong | 894.0 | 2.0 | 1814.8 | | | | | |
| Xuliujing | 894.0 | 2.0 | 1788.0 | | | | | |

Changjiang River Basin based on the data from DHS. On average, the annual COD yield of the Changjiang River Basin is only 0.9 ton·km⁻²/a. Among the main tributaries, the Dongting Lake drainage basin has the highest annual COD yield, followed by the Tuojiang

River and Poyang Lake, known as the most important grain production area in China. In order to disclose the relative contributions of water discharge and COD fluxes of the main tributaries to the Changjiang River, data of the main tributaries were compared on the

Table 3. Drainage areas, COD yields and COD contributions and water discharge of the main tributaries, based on the data from DHS

| Main tributaries | Drainage area (10 ³ km ²) | COD yield (ton/km ² ·a) | COD contribution (%) | Water discharge contribution (%) |
|-----------------------|--|------------------------------------|----------------------|----------------------------------|
| Jinshajiang | 490.5 | 0.2 | 6.1 | 6.2 |
| Hanjiang | 159.0 | 0.9 | 8.6 | 5.9 |
| Minjiang | 133.0 | 1.2 | 10.1 | 9.9 |
| Wujiang | 87.9 | 1.2 | 6.8 | 5.9 |
| Jialinjiang | 159.6 | 1.3 | 12.9 | 7.9 |
| Poyang Lake | 162.2 | 1.9 | 19.3 | 15.4 |
| Tuojiang | 27.9 | 2.0 | 3.5 | 1.4 |
| Dongting Lake | 262.8 | 3.0 | 48.3 | 35.8 |
| Main channel (Datong) | 1710.0 | 0.9 | 100 | 100 |

Contributions of the tributaries (in comparison with the data from the Datong Hydrological Station); DHS as the controlling station of the mainstream.

basis of the data from DHS. It was found that COD contributions are positively correlated to water discharge of the tributaries, of which the Dongting Lake Basin made the greatest contribution (Table 3).

3.2 Sources of COD in the Changjiang River

3.2.1 COD from industrial discharge

The contents of COD in the river have long been regarded as an index of anthropogenic pollution (Cui Jiansheng et al., 2003; Mancini et al., 2005). River pollution caused by industrial activities is mainly due to industrial wastewater discharge. Shown in Fig. 3 are the historical variation trends of COD flux at DHS and COD in industrial wastewater in this drainage basin. A rapid increase in COD flux has been observed in the last decade (i.e., 1991–2000), though COD from industrial wastewater in this drainage basin

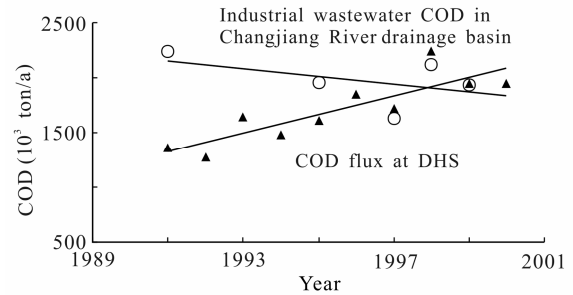


Fig. 3. Historical variation trends of annual COD flux at DHS and COD discharge from industrial wastewater in the Changjiang River drainage basin for the years of 1991–2000.

showed a decreasing trend in the same period of time due to the reinforcement of environmental management (Peng et al., 1995). This indicates that the contribution of COD from industrial wastewater is decreased. As an indicator of organic load in water,

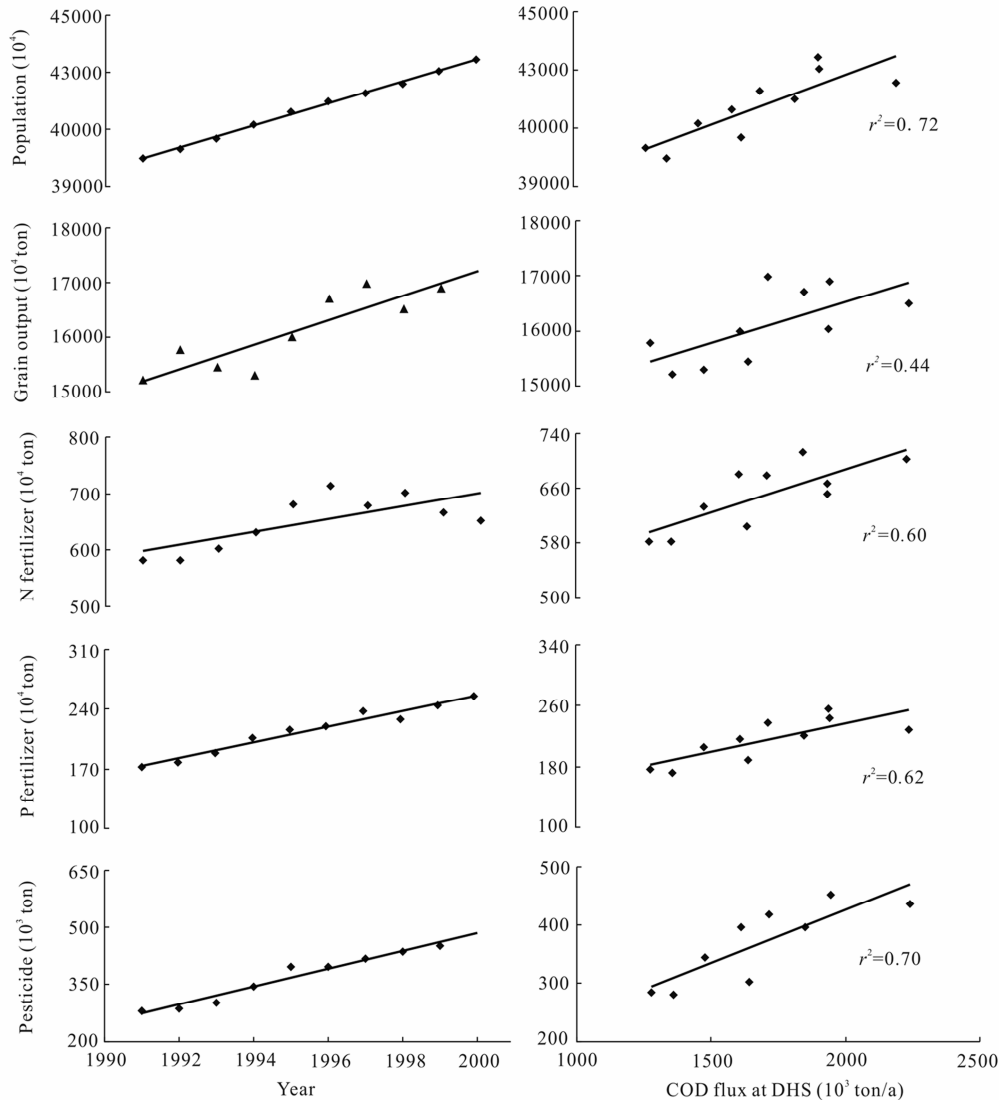


Fig. 4. Historical trends of population growth, grain output, fertilizer (N, P) and pesticide consumption in the Changjiang River drainage basin for the years of 1991–2000, and their correlation plots to COD fluxes at DHS.

COD contents tend to decrease when organic matter is decomposed (Jing et al., 2001). Hence, the gross COD flux in industrial wastewater is greater than the COD flux at DHS, and it also is difficult to distinguish technically how much total COD in the Changjiang River would come from industrial activities. The last decade (i.e., 1991–2000) has witnessed rapid development in industry in the Changjiang River Basin, but the amount of COD from industrial wastewater has decreased rapidly. Obviously, industrial development in this basin has not caused more COD to be discharged into the Changjiang River. Thus, additional COD sources should be taken in consideration.

3.2.2 COD from agricultural activities versus population growth

Agricultural activities have long been known as an important factor leading to the discharge of more COD and nutrients into the river (Bolan et al., 2004). Organic matter (e.g. remnant pesticide and soil organic matter) flushed from farmland by runoff can cause COD to increase directly in the river. On the other hand, the wide application of chemical fertilizers has become an important non-point source of nutrients, which will lead to eutrophication in the river and then a direct increase in COD. Then, grain output and the application of fertilizers (all fertilizers are converted to pure N and P) and pesticides are involved in this study so as to evaluate agricultural production in the Changjiang River drainage basin in the last decade (1991–2000). It is clearly seen that agricultural activities have been intensified obviously during the last decade (1991–2000), as shown in Fig. 4. The figure shows that grain output and the application of pesticides and nitrogen and phosphorous fertilizers show positive correlations with COD flux at DHS, indicating that agricultural development has a significant impact on COD level in the Changjiang River.

In the year of 2000, the total population in this drainage basin approximately reached 430 million, almost 34 million over that in the year of 1991. Correspondingly, the grain output also was found to show an increase of 80 million tons during the same period. The number of population is closely related to the amount of domestic sewage discharged from both urban and rural areas, which is known as an important source of COD load in a river, specifically in those rivers running across urban areas (Mancini et al., 2005; Chebbo and Gromaire, 2004), and it is estimated that an adult can excrete 39.0 kg of organic matter, 4.4 kg of nitrogen and 0.6 kg of phosphorus per year (Duan Shuiwang, 2000). If extrapolating to the whole drainage basin (the number of population is multiplied

by 0.85 to give the number of adults), about 120×10^6 tons of organic matter, 12×10^6 tons of nitrogen and 2×10^6 tons of phosphorus would be produced annually. Generally, organic matter and nutrients are discharged via domestic sewage, part of which (urban sewage in particular) may be discharged into rivers, causing significant deterioration of river water quality. In Fig. 4, COD fluxes at DHS show a strong positive correlation with the number of population in this drainage basin, revealing a significant impact on water quality of the Changjiang River as a result of the rapid growth of population. Due to a greater demand for food by more people, farmers have to apply much more fertilizers (including chemical and organic fertilizers) and pesticides to maintain high grain yield on the limited farmland to cope with this problem. However, the bleeding rate of chemical fertilizers can reach up to more than 50%, which has become an important source of nutrients (e.g. nitrate and phosphate) in the aquatic environment. Yan Weijing and Zhang Shen (2003) pointed out that fertilizers have determined the input of nitrogen since 1983, supplying an additional input of about 4.4×10^9 kg/a. In Fig. 5A, the nitrate flux at DHS shows a remarkable correlation with the total fertilizer consumption (1964–2000), in which the total fertilizer consumption refers to the sum of pure N, P and K fertilizers. Input of nutrients (e.g. nitrate and phosphate) in large amounts will boost the primary

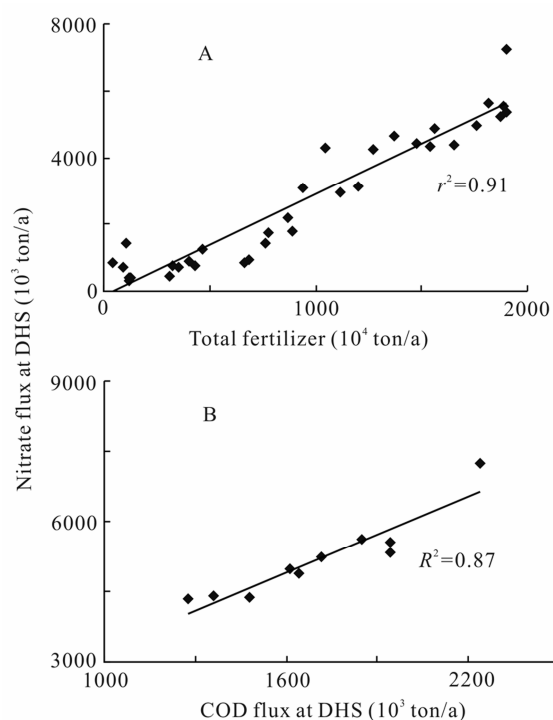


Fig. 5. Correlation plots of nitrate flux at DHS versus total fertilizer application in the Changjiang River Basin (A. 1964–2000) and COD flux at DHS (B. 1991–2000), respectively.

productivity in the river, and then raise the COD level in river water, as shown in Figs. 4 and 5B. This demonstrates that COD in the Changjiang River has close relationship with agricultural activities (Fig. 4), which is mainly ascribed to the enhancement of primary production of the river in response to the input of nutrient salts from both agriculture and domestic sewage (Fig. 5A).

3.3 Analysis of the variation trend of water quality of the Changjiang River

From the above discussion we can see that water quality of the Changjiang River, in terms of COD level, has been significantly impacted by agricultural activities and population growth, while the contribution from industrial wastewater tends to decrease thanks to strict environmental monitoring and control. During the past four decades (i.e., 1960–2000), population and agricultural production have significantly increased, together with a 10-folds increase in riverine nitrate flux (Fig. 6). Nitrate concentrations in the Changjiang River are positively correlated with fertilizer consumption ($r^2=0.91$), and nitrate flux shows a significant positive correlation with COD flux at DHS ($r^2=0.87$) (Fig. 5). This demonstrates that human activities, in particular farming activities in the history and population status in this drainage basin are the important indicators for the COD evolution trend of the Changjiang River. Currently, because of the steady growth of population, it is urgently needed to reinforce the management of domestic sewage discharge and monitor agricultural activities in the near future. As also shown in Fig. 6, water quality (in terms of the COD level) of the Changjiang River has got worse obviously. To solve this problem, the rational use of fertilizers and pesticides and the proper disposal of domestic sewage before discharge are the important measures which need to be taken into first consideration.

4 Conclusions

Results of the analysis showed that most of the COD was generated around the middle reaches of the Changjiang River. Among the main tributaries, based on the data from DHS, the Dongting Lake basin has made the greatest contributions, with 35.8% of water discharge and 48.3% of COD flux, followed by the Poyang Lake basin with the contributions of 15.4% and 19.3%, respectively.

In the year of 2000, about 1941000 tons of COD were transported into the East China Sea from DHS, an increase almost by 45% as compared with that in 1991, indicating the recent deteriorating trend of water quality of the Changjiang River. Correlation analysis

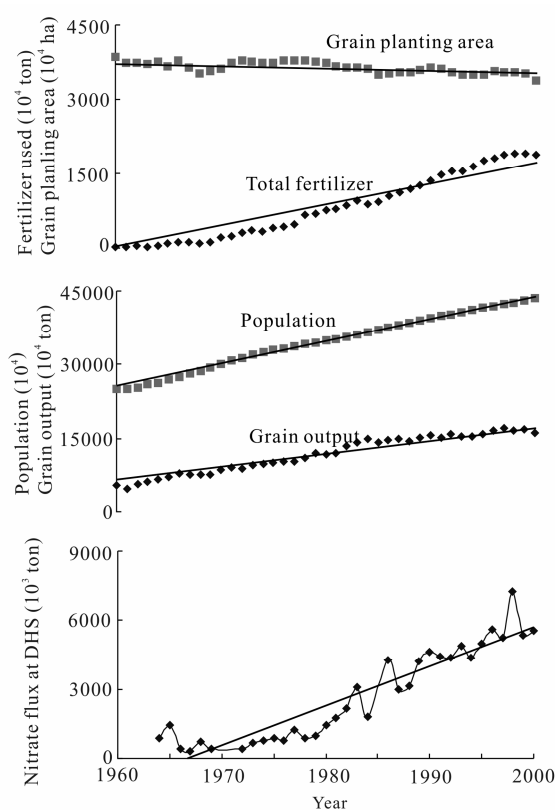


Fig. 6. Long-term variation trend of factors affecting COD flux in the Changjiang River Basin.

revealed that non-point pollution of agriculture and population growth are the prime sources of COD in the Changjiang River in recent years. As viewed from the trend of social and economic development in the Changjiang River drainage basin, water quality of the Changjiang River will be getting worse and worse. Therefore, research on how to rationally apply fertilizers and pesticides and how to conduct the pre-treatment of domestic sewages before they are discharged has to be intensified so as to control the deterioration tendency of water quality of the Changjiang River.

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