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Regional nitrogen budgets for China and its major watersheds

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Abstract. Since the Changjiang River, Huanghe River and Zhujiang River are the three major rivers in China that are flowing into the Pacific Ocean, this paper addresses nitrogen budgeting, source (input) and sink (output and storage), in these three river valleys, and the China watershed as well. In the China watershed, the anthropogenic reactive N has far exceeded the terrestrial bio-fixed N in nature, and human activities have significantly altered the N cycling in this region. In 1995, the total amount of anthropogenic reactive N in China reached 31.2 Tg with 22.2 Tg coming from synthetic fertilizers and 4.18 Tg from NO_X emission from fossil fuel combustion, and the input of recycling N amounted to 30.5 Tg, consisting mainly of human and animal excrement N, reflecting the intensity of the human activity. The sink of N includes N in the harvested crop, denitrification and storage in agricultural soils, transportation into waterbodies and volatilization of NH_3. N output and storage in soil reached up to 48–53 Tg. Of this amount, 14 Tg was in the harvested crops, 12 Tg stored in agricultural soils, 11 Tg transported into waterbodies, 5 – 10 Tg denitrified in the soils and a limited amount exported through food/feed.

In this paper – besides the N budget in the China watershed – the N budgets and especially N transports into waterbodies in the Changjiang, Huanghe and Zhujiang river valleys are estimated.

Introduction

Human activity has markedly altered N cycling in nature, with the anthropogenic reactive N far exceeding the bio-fixed N in amount in the natural terrestrial ecosystem (Galloway et al. 1995). As a result of the increase in anthropogenic N, emission of N_2O, NO_y and NH_x intensifies during the biogeochemical N cycling. For instance, N_2O, a long-lived greenhouse gas and a participant in the atmospheric photochemical reaction that leads to depletion of stratospheric ozone, has been increasing drastically since the pre-industrial era. N_2O emission, due to increasing application of synthetic N fertilizers and other agricultural activities, contributes 6.30 Tg N yr^{-1} (IPCC 1996; Mosier et al. 1998). The amount of NO_3^- transported from terrene to water has also increased rendering a negative impact on water quality and the aquatic ecosystem process. As a result, eutrophication of waterbodies and red tides in lakes and estuaries occur frequently in China and in other parts of the world as well.

NO_x emitted from fossil fuel combustion is not only a second source of N_2O, but also a major cause of acid rain, which affects adversely forest and aquatic ecosystem process, corrodes architecture and degrades soil quality. The increase in anthropogenic N has significantly disturbed the natural biogeochemical N cycling on a global scale, thus attracting more and more attention from scientists and governments the world over.

China is the second biggest country on the Eurasian Continent, with a terrestrial area of 9.6×10^6 km^2, accounting for 19% of the continent's and the biggest watershed on the west Pacific Ocean. Besides, China has the largest population in the world. To meet the food and fiber demands of the 1.2 billion people, application of synthetic N fertilizers has been increasing drastically, reaching 22.20 Tg N in 1995 (China Agricultural Yearbook 1980 – 1996), about one fourth of the world's total. Moreover, as China is still a developing country, coal remains the chief energy source in use. In 1995, China consumed approximately 1.4×10^9 tons of coal, accounting for 74.6% of the total energy materials used (China Statistical Yearbook 1996). Combustion of coal generates and emits large amounts of NO_x into the atmosphere, some of which will later return to the earth through dry and wet deposition and enter into N cycling in the terrestrial and hydrologic ecosystems.

Although N_2O emission, NH_3 volatilization and NO_3^- transport from cropland (Xing & Zhu 1997; Xing 1998; Xing & Yan 1999; Xing & Zhu 2000), NO_x emission from fossil fuel combustion (Wang et al. 1996), anthropogenic NH_3 volatilization (Wang et al. 1997), production and emission of anthropogenic reactive N (Galloway et al. 1996) and N input to estuaries from the Changjiang, Huanghe and Zhujiang Rivers (Duan et al. 2000) have been estimated, the integrated effects of human activities on N cycling in the China watershed are less investigated (Xing & Zhu 2000). We regard the terrestrial part of China as a watershed on the west Pacific Ocean. By using the statistics and conversion factors available, we present here an estimated nitrogen budget of the China watershed.

The Changjiang, Huanghe and Zhujiang Rivers are the three major outflowing rivers located in different climatic zones in China. The regions in the middle and lower reaches of the three rivers and on the west coast of the Pacific Ocean are the most developed areas in China, and bear the strongest impact of human activities. However, little work has been done to estimate nitrogen budgets on a valley scale in China. Besides nitrogen budgeting on the scale of the China watershed, we also analyzed and estimated nitrogen

Table 1. Hydrological data in the China watershed and the Changjiang, Huanghe and Zhujiang River valleys (Ren et al. 1980; Wu 1998; Cui 1999)

Country and river	Drainage area	River length	Annual precipitation	Average flow	Total runoff
	10^6 km^2	10^3km	10^3mm yr^{-1}	10^3 m^3/s	10^{11} m^{3}yr^{-1}
China	9.6		0.63		27.15
Changjing	1.81	6.38	1.05	31.06	9.79
Huanghe	0.75	5.46	0.49	1.82	0.57
Zhujiang	0.45	2.20	1.44	11.07	3.49

Table 2. Cultivated land area, consumption of chemical N fertilizers in the China watershed and the Changjiang, Huanghe and Zhujiang River valleys*

Country and river	Cultivated area (10^7 ha)			Chemical fertilizer-N consumption (Tg N)		
	Upland	Paddy field	Total area	Upland	Paddy field	Total amount
China	7.01	2.49	9.50	17.2	5	22.2
Changjing	1.14	1.27	2.41	3.18	4.12	7.30
Huanghe	0.84	0.029	0.86	1.71	0.07	1.78
Zhujiang	0.18	0.31	0.49	0.51	0.96	1.47

*Calculated on the basis of the data cited from China Agricultural Yearbook (1996).

input, output and storage in the Changjiang, Huanghe and Zhujiang River valleys in this paper.

Basic data and valley characters

Some basic data of the China watershed and the Changjiang, Huanghe and Zhujiang River valleys are listed in Tables 1, 2, 3 and 4 including area of the river valleys, length and mean flow of the rivers, total amount of runoffs, population and density, land area, area of cultivated land, consumption of chemical N fertilizers; cultivation area of crops; and size of livestock.

The average total runoff in China is 27.15×10^{11} m^3 yr^{-1} (Wu 1998). China has a number of out-flowing rivers that cover an area of 6.12×10^6 km^2, accounting for 63.8% of the total terrestrial part of China, whereas the drainage areas of the rivers flowing out into the Pacific amount to 5.64×10^6 km^2, making up 56.7% of the total. Among them, the Changjiang, Huanghe

Table 3. Population and Population density in the China watershed and the Changjiang, Huanghe and Zhujiang River valleys*

Country and river	Population (10^8)			Population density
	Rural area	City	Total	Individual per km^2
China	9.02	2.82	11.84	123
Changjing	3.23	0.86	4.09	226
Huanghe	0.57	0.19	0.76	101
Zhujiang	0.76	0.21	0.97	215

*Calculated on the basis of the data cited from the China Agricultural Yearbook (1996).

Table 4. Size of livestock in the China watershed and the Changjiang, Huanghe and Zhujiang River valleys*

Country and river	The number of the domesticated animals (10^4 head)					
	Cattle	Milk cows	Horses & others animals	Sheep	Pigs	Poultry
China	12789	417	7656	27695	44169	410858
Changjing	3868	37	302	3924	19464	99447
Huanghe	1110	34	291	3640	2364	37156
Zhujiang	1237	4.5	66	221	4479	32025

*Calculated on the basis of the data cited from the China Agricultural Yearbook (1996).

and Zhujiang Rivers are the three major ones (Figure 1), covering in total an area of 3.01×10^6 km^2, about 31.1% of the total (Ren et al. 1980), with a total runoff amount of 13.8×10^{11} m^3yr^{-1}, about 51.1% of the total.

The Changjiang River, zigzagging eastwards between 24°–30° Lat. N, is the largest out-flowing river in China, covering an area of 1.81×10^6 km^2. With its main stream being 6.38×10^3 km long, the river runs through 18 provinces, metropolises and autonomous regions, that is, Tibet, Qinghai, Yunnan, Sichuan, Guizhou, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, Shanghai, Shaanxi, Henan, Gansu, Zhejiang, Fujian, Guangxi and Guangdong. Its middle and lower reaches stretch from east to west through the subtropics in the central and northern parts, where the annual precipitation is averaged 1.05×10^3mm. The average annual runoff in the Changjiang River valley reaches 9.79×10^{11} m^3, more than one-third of the total in China (Table 1). About one-fourth of the country's cultivated land is within the valley. Of the 2.41×10^7 ha, 1.27×10^7 ha is paddy and 1.14×10^7 ha upland (Table 2).

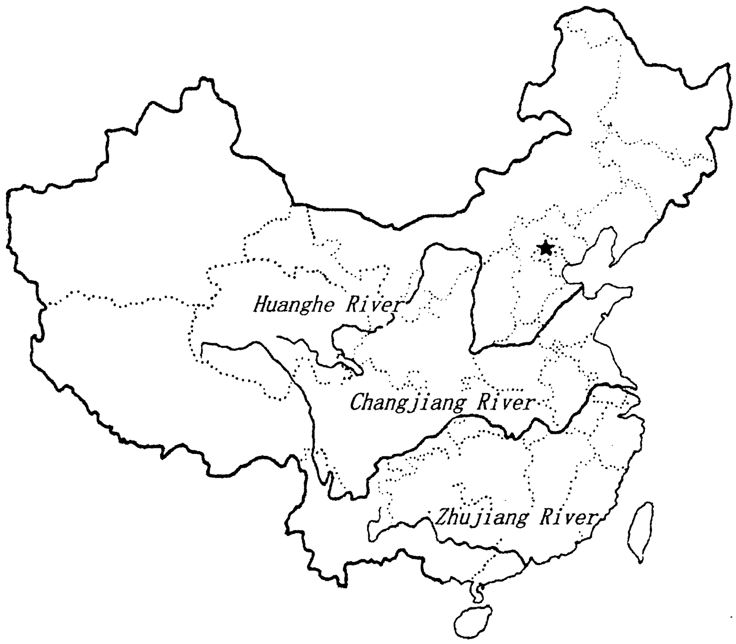

Figure 1. Changjiang, Huanghe and Zhujiang river in China.

The Huanghe River, the second largest out-flowing river, winds between 32.5°–41.7° Lat. N, running 5.46×10^3 km into the Pacific. It passes through 8 provinces and autonomous regions, i.e. Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan and Shandong, covering an area of 0.75×10^6 km^2, mostly arid and semi-arid regions, where the annual precipitation is 0.49×10^3mm. So the average annul runoff in the valley is only 0.57×10^{11}m^3, the lowest among the three river valleys (Table 1). The Huanghe River valley has a total of 0.86×10^7 ha of cultivated land, of this amount, 0.029×10^7 ha are paddy fields and 0.84×10^7 ha uplands (Table 2), constituting 9.1% of the total in China.

The Zhujiang River, the fourth largest out-flowing river with 2.2×10^3 km length, flows through 6 provinces and autonomous regions, namely, Guangxi, Guangdong, Yunnan, Guizhou, Hunan and Jiangxi, stretching over an area of 0.45×10^6 km^2 in the southern subtropics between 20°–26° Lat. N. The river valley enjoys a humid climate with an annual rainfall of 1.44×10^3 mm. Its annual runoff reaches 3.49×10^{11} m^3, almost half of that in the Changjiang River valley and over 6 times as much as that in the Huanghe River valley (Table 1). The cultivated land in the valley consists of 0.31×10^7 ha of paddy fields and 0.18×10^7 ha of uplands, adding up to 0.49×10^7 ha (Table 2), about 5.1% of the total of the country. The high proportion of paddy fields in the Zhujiang River valley is incomparable in the Changjiang River and the Huanghe River valleys.

Methods

Computation of the basic data of the valleys

All the basic data used in computing N inputs and outputs in the Changjiang, Huanghe and Zhujiang Rivers valleys were gathered from the 1996 Statistical Yearbook and 1996 Agricultural Yearbook of the related provinces, metropolises and autonomous regions, which, however, were usually compiled on the basis of an administrative region, a province, a metropolis or an autonomous region, rather than a river valley. In order to calculate N budgets of the valleys, the area of the part that the river flows through and its percentage of the total land area of each region should first be calculated. Based on the percentage, basic data, like cultivated land area, sown area, population, size of livestock, consumption of chemical N fertilizers, consumption of fossil fuel, and area of major crops in the region were calculated. Here in the paper, the percentage of the area of River valley within each province to the area of that province where the corresponding river passes was cited from Zhang (1986), Yi (1957), Xi et al. (1994), the Geological Department of Zhengzhou Normal College (1959), the Research Committee of China Natural Resources (1992) and Sun (1959).

Sources of N input

The N inputs of the China watershed and the Changjiang, Huanghe and Zhujiang River valleys can be sorted into two groups, anthropogenic reactive N and recycling N. Sources of the former include application of synthetic fertilizer N, NO_x emission from combusting fossil fuel, symbiotic N fixation by leguminous crops, N fixation by azotobacteria in farmlands and N imported with food/feed. Nevertheless, in calculating N input to the Changjiang, Huanghe and Zhujiang River valleys, the last portion was not taken into account. And sources of the recycling N include excrements from human and animals, atmospheric wet deposition, crop residues left in the farmland as manure and NO_x emission from burning of crop residues in the fields or in kitchens. Atmospheric dry deposition, however, was not considered in the group.

Output and storage of N

In calculating N output, the following factors were counted, i.e. N in the harvested crops and N storage in the farmlands, denitrification of soil N in the fields, NH_3 volatilization, NO_3^- transport into waterbodies and N exported with food/feed. In calculating N fluxes to the waterbodies, according to Howath et al. (1996), the anthropogenic reactive N and that of human wastes were reckoned separately. The computation of the N flux from the Changjiang, Huanghe and Zhujiang River valleys did not cover the N exported with food/feed.

NO_x emission from combusting fossil fuel

Because of the huge variety of fossil fuels and the sharp difference in conversion factor for calculating NO_x emission of the same kind of fuels used in different industries (Wang et al. 1996), the consumption of the fuels by different industries in China and the Changjiang, Huanghe and Zhujiang River valleys were worked out separately on a kind-by-kind basis. And then the NO_x fluxes from combustion of coal, coke, crude petroleum, petrol, diesel oil, kerosene, residual oil, liquefied gas and natural gas consumed in different industries were figured out and summed up separately according to their attribute under three categories, coal, petroleum and natural gas. Eventually, the NO_x flux in China in 1995 from the consumption of coal, petroleum and natural gas was obtained, individually.

Storage and denitrification

As chemical N differs from organic N in storage rate and denitrification rate in soil and their rates also vary from paddy fields to uplands, N storage from chemical fertilizers and organic manure in paddy fields and uplands was calculated, separately. However, N loss through denitrification of organic manure N was calculated regardless of whether paddy fields or uplands.

Atmospheric deposition

N input through atmospheric wet deposition to the Changjiang River and Zhujiang River valleys in South China was reckoned separately from that to the Huanghe River valley in North China, because NO_x and NH_3 concentrations in the atmospheric wet deposition show significant zonal difference between north and south.

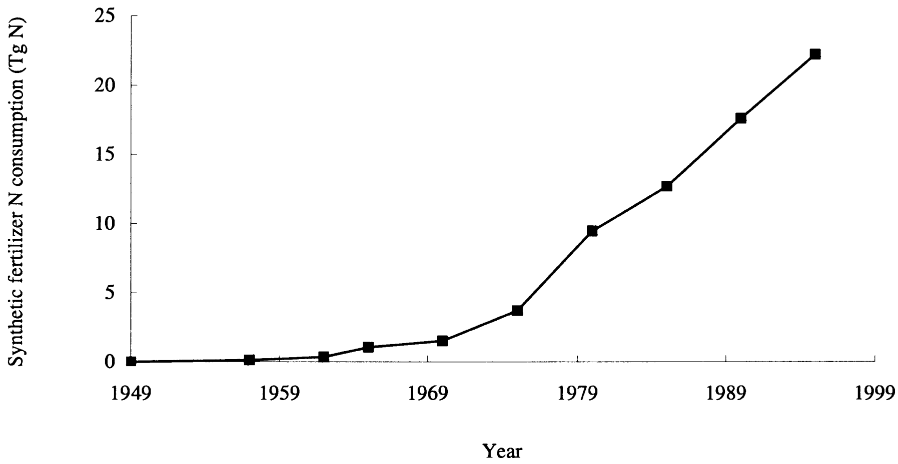

Figure 2. Consumption of synthetic N fertilizers in China from 1949 to 1995.

Conversion coefficients

The calculations of the N budgets in the China watershed and the Changjiang, Huanghe and Zhujiang River valleys were based on the same conversion coefficients except that for N in atmospheric wet deposition in the three valleys.

Results and discussion

Input N

N input in the China watershed
Synthetic N fertilizers: Application of synthetic N fertilizers is the largest N source in the China watershed, contributing 22.2 Tg in 1995. However, before 1950, the consumption of synthetic N fertilizers was rather limited and only 6×10^{-3} Tg in 1949, about 0.03% of that in 1995. It multiplied by 3.7×10^3 times during the 46 years from 1949 to 1995 (Figure 2).

NO_x emission from combusting fossil fuel: With the development of industry and agriculture in China, the consumption of fossil fuel has been increasing drastically. Based on the conversion factors Wang et al. (1996) suggested for calculating NO_x emitted from combustion of different fossil fuels, the NO_x flux in China was worked out on a year-by-year basis (Figure 3). In 1995, 4.18 Tg N was emitted into the atmosphere in the form of NO_x from combusting fossil fuel in China (Table 5).

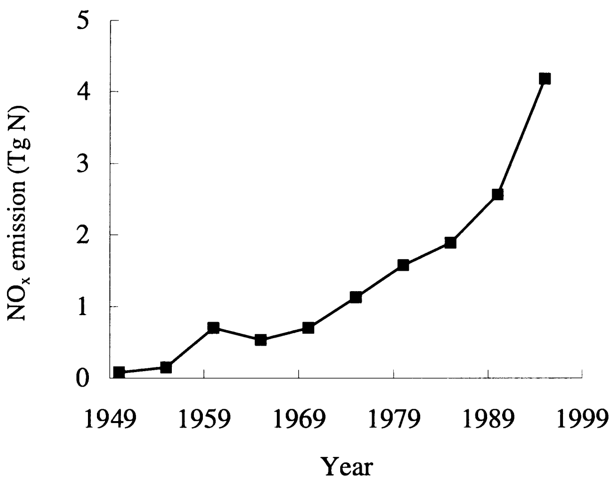

Figure 3. Increasing trend of NO_X emission from combustion of fossil fuels in China.

Table 5. NO_X emission from fossil fuel combustion in 1995 in China.

Type of fossil fuel	NO_X emission (Tg N)	Percentage to total
Coal (including coking)	3.47	83.0
Petrol (including refining)	0.70	16.8
Natural gas	0.01	0.2
Total	4.18	100

Table 5 list NO_x fluxes from consumption of coal, petroleum and natural gas in China in 1995, showing clearly that coal is the biggest contributor, responsible for 83% of the total.

Symbiotic N fixation by leguminous crops: In reckoning symbiotic N fixation by leguminous crops in China, only soybean, peanut, pulses and also leguminous green manure crops were taken into account. Based on the data cited from the China Agricultural Yearbooks of 1980, 1981, 1986, 1991 and 1996, and the conversion factors suggested by Zhu (1997), the symbiotic N fixation by leguminous crops during the period from 1949 to 1995 was calculated and is shown in Figure 4. There is an increasing trend from 1949 to 1976 and then a decline from 1976 to 1980 due to population pressure leading to displacement of green manure with grain crops. The gap in N supply was filled by chemical N fertilizers, which rapidly increased in application rate. Figure 4 also shows that the symbiotic N fixation by leguminous crops began

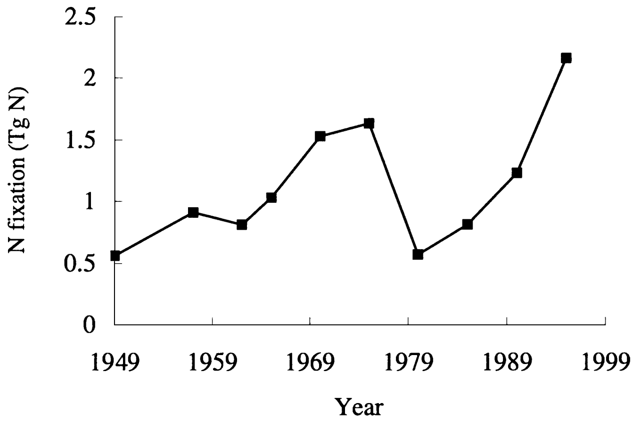

Figure 4. Change in the N fixation by legumes.

to turn upward after 1980 due to expansion of the production of soybean, peanut and pulses. In 1995, the symbiotic N fixation by leguminous crops reached 2.16 Tg N in China (Table 6).

Non-symbiotic N fixation: In China, paddy fields account for 26% of its total cultivated land and one-fifth of the world's total paddy field area. Moreover, N fixation in the paddy field is higher than in the upland. So in calculating N input, non-symbiotic N fixation was also reckoned as a source. As is suggested by Zhu (1997), the conversion coefficient used for non-symbiotic N fixation in the paddy field and upland was 45 kg $N{\cdot}ha^{-1}{\cdot}yr^{-1}$ and 15 kg $N{\cdot}ha^{-1}{\cdot}yr^{-1}$, respectively. Based on the conversion coefficient, the basic data of the acreage of paddy fields and uplands in 1995 were converted into non-symbiotic N fixation in the farmland, 2.17 Tg N, among which 1.12 Tg in the paddy field and 1.05 Tg in the upland (Table 6).

N import in food/feed: Based on the quantities of agricultural and animal products imported from other countries (China Statistical Yearbook 1996) and N contents in different products (China Agricultural Technical and Economic Manual 1983), the 1995 N inputted from food/feed import was estimated to be only 0.52 Tg N (Table 6).

Recycling N: Human and animal wastes in the rural areas in China are commonly used as manure. Based on the conversion coefficient suggested by Xing and Yan (1999), the total amount of the wastes in 1995 was estimated at 18 Tg N, among which 13.7 Tg was from livestock, 3.07 Tg from the rural population and 1.14 Tg the urban residents (Table 6). About 40% of the

Table 6. Estimated N input in China (1995)

Items	Amount (Tg N)
Anthropogenic reactive N	
– Synthetic fertilizer N	22.2
– NO_x-N formed during fossil fuel combustion	4.18
– N fixation by legumes in agricultural field	2.16
– Non-symbiotic N fixation in agricultural field	2.17
– Food/feed import	0.52
Subtotal	31
Recycling N	
– N from the excrements of domesticated animal and rural human	
N from the excrements of the domesticated animals	13.7
N from the excrements of rural people	3.07
N from excrements of urban people	1.14
– N from crop residue used as fertilizer	1.43
– NO_x-N formed during the combustion of crop residue	0.12
– N from atmospheric wet deposition	
N from NO_x	2.68
N from NH_x	8.28
Subtotal	31
Total	62

wastes were used as manure applied into crop fields. And also about 38% of the crop residues were utilized for the same purpose. Based on the work of Xing and Yan (1999), the amount of the residues used in this field was estimated to be 1.43 Tg (Table 6). The rest of the crop residues, about 62%, were burnt partly in farm fields and partly in kitchens as cooking fuel. On the basis of the conversion coefficient, 0.35g $N{\cdot}kg^{-1}$ dm (Delmas et al. 1995) for estimating NO_x flux from burning crop residues, the total amount of NO_x generated from burning of crop residues was reckoned roughly at 0.12 Tg N in 1995 (Table 6). Reports from 27 year-round monitoring posts scattered all over the country (Wang 1994), from the 2 similar posts in Shandong Province (Zhang & Liu 1994) and from the one in Qinghai Province, West China (Yang et al. 1991) indicated that the mean value of the concentrations of NO_3 and NH_4 in the precipitation monitored was 4.36×10^2 mg N m^{-3} and 1.35×10^3 mg N m^{-3} in China, respectively. And based on the data of the mean annual precipitations from 1951 to 1990 (Table 1), we estimated the atmospheric wet deposition N in the early 1990s to be 11 Tg, of which

2.68 Tg was NO_3 and 8.28 Tg NH_4 (Table 5), showing a NO_3:NH_4 ratio of 1:3. Obviously the proportion of NH_4 in the ratio is much higher in China than in other parts of the world (Galloway 1985; Loye-pilot & Morelli 1988; Weijer & Vugts 1990), which might be attributed to the high proportion of ammonium dicarbonate, about 50%, in the makeup of the chemical fertilizers in China. This type of fertilizer suffers higher NH_3 loss through volatilization than urea and any other types of N fertilizers. Moreover, inadequate handling facilities for human and animal wastes also result in higher volatilization of NH_3 from the wastes in China.

The above-described fluxes of anthropogenic reactive N and recycling N to the China watershed are summarized in Table 6, which shows that the total amount of N fluxes to the China watershed is estimated at 62 Tg, of which 31 Tg, about 50%, is anthropogenic reactive N and 31 Tg, about 50%, recycling N.

N input to the Changjiang, Huanghe and Zhujiang River valleys

The input of anthropogenic reactive N to the Changjiang, Huanghe and Zhujiang River valleys was 9.5 Tg, 2.3 Tg and 1.9 Tg, respectively, accounting for 31%, 8% and 6%, respectively, of the total to the China watershed in 1995. Synthetic chemical N fertilizers were also the main source of N input to the valleys and estimated at 7.30 Tg, 1.77 Tg and 1.47 Tg (Table 7), respectively, accounting for 77%, 76% and 79% of their corresponding total of anthropogenic reactive N input. The N fluxes from the other sources of anthropogenic reactive N to the valleys are all shown in Table 7.

The flux of recycling N to the Changjiang, Huanghe and Zhujiang Rivers was 9.5 Tg, 2.2 Tg and 2.8 Tg, respectively (Table 7). Being the predominant source of recycling N, human and animal wastes in the three valleys contained 5.32 Tg N, 1.45 Tg N and 1.36 Tg N, respectively, accounting for 56%, 66% and 49% of their corresponding total of recycling N input.

The atmospheric wet deposition N to the Changjiang, Huanghe and Zhujiang River valleys was estimated on the basis of two different groups of values, because the concentrations of NO_3 and NH_4 in the precipitation differ from North China to South China (Wang 1994). By integrating the monitoring results of different researchers (Wang 1994; Zhang & Liu 1994; and Yang et al. 1991), yielded were the mean concentrations of NO_3 and NH_4 in the precipitation, 3.35×10^2 mg $N{\cdot}m^{-3}$ and 1.42×10^3 mg $N{\cdot}m^{-3}$, respectively, in North China and 5.11×10^2 mg $N{\cdot}m^{-3}$ and 1.47×10^3 mg $N{\cdot}m^{-3}$, respectively, in South China. As the Huanghe River valley is located in North China, the atmospheric wet deposition of NO_3 and NH_4 there was estimated to be 0.12 Tg N and 0.52 Tg N, respectively (Table 7). Whereas the Changjiang River valley and the Zhujiang River valley are

Table 7. Estimated N input in the Changjiang, Huanghe and Zhujiang River valleys (1995)

Items	Amount (Tg N)		
	Changjiang	Huanghe	Zhujiang
Anthropogenic and naturally reactive N			
– Synthetic fertilizer N	7.30	1.77	1.47
– NO_X formed during fossil fuel combustion	0.91	0.28	0.16
– N fixation by legumes in agricultural field	0.56	0.15	0.10
– Non-symbiotic N fixation in agricultural field	0.74	0.14	0.16
Subtotal	9.5	2.3	1.9
Recycling N			
– Excretia N of humans and raised animals			
N from the excrements of raised animals	3.93	1.24	1.03
N from the excrements of the rural population	1.10	0.14	0.26
N from the excrements of the urban population	0.29	0.07	0.07
Subtotal	5.32	1.45	1.36
– N from crop residue used as fertilizer	0.43	0.14	0.14
– NO_X-N formed from crop residue combustion	0.04	0.011	0.01
– Atmospheric wet deposition N			
NO_X-N	0.96	0.12	0.33
NH_X-N	2.79	0.52	0.96
Subtotal	9.5	2.2	2.8
Total	19.0	4.6	4.7

in South China, and their atmospheric wet deposition of NO_3 and NH_4 was determined to be 0.96 Tg N and 2.79 Tg N, and 0.33 Tg N and 0.96 Tg N, respectively (Table 7). The NO_3:NH_4 ratio in the atmospheric wet deposition in the Changjiang, Zhujiang and Huanghe River valleys was 1:3, 1:3 and 1:4, respectively.

N fluxes from other sources to the Changjiang, Huanghe and Zhujiang River valleys are also listed in Table 7.

N output and storage

N output and storage in the China watershed

N in the harvested crops: Based on the data from the China Agricultural Yearbook (1996) about yields of 30 major agricultural crops (including 7 species of vegetables) and the data about N contents in the crops and N distribution ratio between straw (leaves and stems) and grains (edible parts) listed in a number of agricultural handbooks and fertilizers handbooks (Lu &

Table 8. Conversion factors for N loss through denitrification in agricultural fields of China

Fertilizer type	Conversion factor	Reference
Synthetic fertilizer N		
– Rice paddy fields	33–41%	Zhu (1997)
– Uplands	13–29%	Cai et al. (1998)
Organic fertilizer N	10–30%	Wen et al. 1988; Shi et al. 1991; Chen et al. 1994; He et al. 1994

Shi 1982; China Agricultural Technology and Economy Manual 1983; Pang 1994; Huang et al. 1996), the N in the harvested crops was worked out to be 14 Tg, of which 10.5 Tg in grains and edible parts and 3.5 Tg in straws (Table 11).

Denitrification in farmland: N loss through denitrification differs in rate between paddy fields and uplands, being higher in the former than in the latter. And it also differs between from chemical fertilizers and from organic manure (Table 8). The data in Table 8 are all based on micro-plot field experiments carried out with chemical fertilizers, green manure, rice straw, ping dung and sheep droppings, all labeled with ^{15}N. In 1995, China applied 5 Tg N to the paddy fields and 17 Tg N to the uplands in chemical fertilizer, and 10 Tg N in organic manure to the farmlands. By using the data in Table 8 as conversion coefficients, the N losses through denitrification in 1995 from chemical fertilizers in paddy fields and in uplands organic manure in cropland were figured out. The N loss was estimated at 1.65–2.05 Tg N from chemical fertilizers in paddy fields, 2.23–4.99 Tg N from chemical fertilizers in uplands, and 1.03–3.10 Tg N from organic manure in cropland. So the total N loss through denitrification from the farmland reached 5–10 Tg in China in 1995 (Table 11).

N storage in farmland: The N detention rate of chemical N fertilizers varies from paddy fields to uplands. On average, it is higher in the former than in the latter. It also differs from that of organic manure, which has a higher residue rate. Zhu* summarized the results of 142 field and greenhouse experiments with ^{15}N-labeled chemical N fertilizers and ^{15}N-labeled organic manure in different soils (Table 9). Based on the data in Table 9 as conversion factors, the N retention was worked out as 12 Tg N in China in 1995, indicating this was the most important access to sink.

Table 9. Estimated N storage in agricultural soils in China (1995)

N type	Application amount (Tg N)	Storage ratio* (%)	N storage (Tg N)
Synthetic N			
– Paddy fields	5.00	20 (12–30)	1.00
– Uplands	17.20	27 (11–68)	4.64
Organic N	12.04	49 (27–78)	5.9
Total	34.97		12

*The data in unpublished paper of Zhu ZL.

N transport to waterbodies: In calculating N transport to waterbodies in the China watershed, it can be divided into two portions, anthropogenic reactive N and human wastes discharged direct into waterbodies, to be calculated separately. The former includes synthetic chemical N fertilizers, symbiotic N fixation by leguminous crops and green manure crops, N imported with food and feed, N in atmospheric wet deposition and also non-symbiotic N fixation in the cropland, because paddy fields account for 26% of the country's total farmland and, what is more, non-symbiotic N fixation in the paddy field is much higher than in the upland. And the latter encompasses wastes from urban residents and rural population. In calculation, only 60% of the wastes from rural population were counted because about 40% of the wastes in the rural area are used as manure.

The anthropogenic reactive N transported into waterbodies through leaching and runoff was estimated at 8.20 Tg by using IPCC (1996) default value, 30% (ranging between 10 and 80%), as the conversion factor, whereas the N in human wastes discharged direct into waterbodies was figured out as 2.7 Tg in China in 1995 on the basis that the contribution rate of human wastes to N load in waterbodies was 3.3 kg $N \cdot yr^{-1}$ per person (Meybeck 1989). So the total N transport into waterbodies was 11 Tg. In the calculation, only N in atmospheric wet deposition was covered, but not that in atmospheric dry deposition. Besides, the rural area still had 60% of the animal wastes left unused. It is very hard to reckon how much N was transported into waterbodies from it. Consequently, the N transport into waterbodies in China might be underestimated. Nevertheless, China differs from other countries in climate and farming system. Under the significant influence of monsoon, in most agricultural regions, rainfalls concentrate in summer and occur grudgingly in winter and spring. Moreover the major agricultural regions with humid and warm climate can grow crops all year round. In addition, China has 26% of its farmland growing rice. Thus, using 30% of the N applied as conversion factor for calculation of N transport into waterbodies

Table 10. NH_3 volatilization conversion coefficient

Sources	Emission factors (kg N kg^{-1} N)		References
Animal and human excrement N		0.20	IPCC, 1996
Synthetic fertilizer N	Upland:	0.08 for urea and 0.10 for NH_4HCO_3	Xing & Zhu, 2000
	Paddy field:	0.22 for urea and 0.28 for NH_4HCO_3	

in the China watershed might lead to overestimation. It seems that there is much uncertainty in calculating N transport into waterbodies in the China watershed.

NH_3 volatilization: China does not have many varieties of chemical N fertilizers. Urea and ammonium bicarbonate are the two dominant ones, sharing half and half in the makeup of chemical N fertilizers in 1995. Things have been changing since 1995, with the latter declining in proportion and being replaced by the former. Studies reveal that N loss rate through NH_3 volatilization varies, with ammonium bicarbonate higher than urea and with upland higher than paddy field. Human and animal wastes are another source of NH_3 volatilization. In calculating its N loss through NH_3 volatilization, IPCC-recommended default value, 0.2kg N (NH_3 + NO_x) per kg of N in human and animal wastes, was used as conversion factor. However, the NO_x content in the wastes is rather limited. Schimel et al. (1986) reported that NH_3 volatilization from the animal wastes applied into the farmland accounted for about 20% of the N in the wastes, whereas it was 25% in the report by Van der Hoek (1994). In Table 10 listed are the IPCC-recommended default value and conversion factors used in calculating NH_3 volatilization from animal and human excrements N. Based on the conversion factors listed in Table 10, the NH_3 volatilization in the agriculture of China was estimated at 6.1 Tg N, of which 3.35 Tg originated from human and animal wastes (Table 11).

Food/feed exports: Although China is the country that turns out the most agricultural products, the demand of such a big population greatly limits its export of agricultural products. According to the statistical data about the export of agricultural products in the China Agricultural Yearbook and the data about N contents in these products, the total estimated N exported with food/feed was limited to 0.11 Tg (Table 11).

From Table 11, it can be inferred that N in the harvested crops and N storage in soils are the largest sink of input N in the China watershed,

Table 11. Estimation of N output and storage in China (1995)

Items	Amount (Tg N)
N in the harvested crops	
– N in the grains (edible parts)	10.5
– N in the straws	3.5
Subtotal	14
Denitrification	
– Synthetic fertilizer N	
Rice fields	1.65–2.05
Uplands	2.23–4.99
– Organic fertilizer N	1.03–3.1
Subtotal	5–10
Storage in agricultural land	
– Synthetic fertilizer N	
Rice fields	1.0
Uplands	4.6
– Organic fertilizer N	5.9
Subtotal	12
N transported into waterbodies	
– Anthropogenic reactive N	8.2
– Excretia N directly from human in urban and rural area	2.7
Subtotal	11
NH_3 volatilization	
– From chemical fertilizer N	2.71
– From excretia of raised animal and human being	3.35
Subtotal	6.1
Food/feed exports	0.11
Total	48–53

followed by N transport into waterbodies, denitrification in agricultural soils and NH_3 volatilization.

N output and storage in the Changjiang, Huanghe and Zhujiang River valleys

The N output and storage in the Changjiang, Huanghe and Zhujiang River valleys was estimated at 16–18 Tg, 3.6–4.1 Tg, and 4.1–4.4 Tg, respectively (Table 12).

Based on the statistical data about the yields of the 30 major agricultural crops on a province-by-province basis in the China Agricultural Yearbook (1996) and the method described in the previous paragraphs, the N in the harvested crops in the Changjiang, Huanghe and Zhujiang River valleys were worked out. By using the data in the agricultural handbooks and fertilizers handbooks about N contents and distribution ratio of grains and straws, N in the harvested crops from the Changjiang, Huanghe and Zhujiang River valleys were figured out to be 4.34 Tg N, 1.04 Tg N and 1.07 Tg N, respectively.

Of the output and storage N from the Changjiang, Huanghe and Zhujiang River valleys, 3.51 Tg, 0.95 Tg and 1.16 Tg was stored in soil, respectively (Table 12). The calculation was performed based on the conversion factors listed in Table 9.

The N transport to waterbodies in the Changjiang, Huanghe and Zhujiang River valleys was calculated in the same way as that in the China watershed. It was divided into two portions for calculation, anthropogenic reactive N and human wastes discharged direct into waterbodies. The same conversion factors were used, the IPCC (1996)-recommended 30% default value for the former and Meybeck-suggested (1989) 3.3 kg N yr^{-1} per person for the latter. The total N transport into waterbodies in the Changjiang, Huanghe and Zhujiang River valleys was estimated at 3.79 Tg, 0.83 Tg and 0.84 Tg, respectively (Table 12). Though the acreage of the Zhujiang River valley is only 60% that of the Huanghe River valley, the N transport into waterbodies differs little between them. This is because the Zhujiang River valley is in the tropical and subtropical South China with much higher precipitation and runoff than in the Huanghe River valley located in the semi-arid temperate North China. Due to the humid and warm climate, the former can have 2–3 croppings a year whereas the latter can only have one cropping and a vast area of grassland. As a result, the per-unit application rate of chemical N fertilizers in the former is much higher than that in the latter. Moreover, the population density of the former is almost twice that of the latter (Table 3).

Based on the information about DIN concentrations in the three rivers and related hydrological data gathered in 1980–1989 from three observation posts located at each of the lower reaches of the rivers, Duan et al (2000) figured out the DIN transported into the estuaries as 0.78 Tg, 0.06 Tg and 0.15 Tg, respectively. Though the results did not cover organic N, they are much lower than our results (Table 12), indicating that there is much uncertainty in calculating N transport from the valleys into estuaries, which calls for further studies.

Denitrification of soil N in farmland is another access to sink for input N in the Changjiang, Huanghe and Zhujiang River valleys. By using the

Table 12. Estimated N output and N storage in the Changjiang, Huanghe and Zhujiang River valleys (1995)

Items	Amount (Tg N)		
	Changjiang	Huanghe	Zhujiang
N in the harvested crops	4.34	1.04	1.07
Denitrification in agricultural soils			
– Synthetic fertilizer N			
Rice fields	1.36–1.69	0.02–0.03	0.32–0.39
Uplands	0.41–0.92	0.22–0.50	0.07–0.10
– Organic fertilizer N	0.37–1.12	0.10–0.29	0.09–0.28
Subtotal	2.14–3.73	0.34–0.82	0.48–0.77
Storage in agricultural land			
– Synthetic fertilizer N			
Rice fields	0.82	0.012	0.19
Uplands	0.86	0.46	0.14
– Organic fertilizer N	1.83	0.48	0.83
Subtotal	3.51	0.95	1.16
N transported into the waterbodies			
– Anthropogenic and natural reactive N from input sources	2.87	0.65	0.62
– N from the excretia of people in cities and rural areas	0.92	0.18	0.22
Subtotal	3.79	0.83	0.84
NH_3 volatilization			
– From chemical fertilizer N	1.32	0.17	0.29
– From excretia N of raised animals	1.0	0.28	0.27
Subtotal	2.32	0.45	0.56
Total	16–18	3.6–4.1	4.1–4.4

conversion coefficients listed in Table 6, the N loss through denitrification of soil N in farmland in the Changjiang, Huanghe and Zhujiang River valleys was estimated at 2.14–3.73 Tg, 0.34–0.82 Tg and 0.48–0.77 Tg (Table 12), accounting for 18–30%, 13–27% and 16%–25%, respectively, of the N output and N storage in the valleys. The percentages of the N loss through denitrification against N output in the Changjiang River valley and the Zhujiang River valley were quite close to each other, but higher than in the Huanghe River valley. This is because the former two valleys are the major rice growing regions of China, while the latter has only a limited acreage of paddy fields

(Table 2), and what is more, denitrification of soil N is much higher in paddy fields than in uplands.

The calculation of the NH_3 volatilization of synthetic chemical N fertilizers and human and animal wastes in the three valleys was carried out based on the conversion factors listed in Table 10. The N loss through NH_3 volatilization in the Changjiang, Huanghe and Zhujiang Rivers was estimated at 2.32 Tg, 0.45 Tg and 0.56 Tg, respectively.

The N output and N storage in the Changjiang, Huanghe and Zhujiang River valleys are summarized and listed in Table 12.

Conclusion

In China – with the biggest population in the world – anthropogenic activities have been significantly altering the N biogeochemical cycling in the region with the rapid development of industry and agriculture. The total anthropogenic reactive N was estimated at 31 Tg in 1995, of which 22.2 Tg came from application of synthetic chemical fertilizers, 4.18 Tg from NO_x emission from combusting fossil fuel, 2.16 Tg from N fixation by leguminous crops and 0.52 Tg from food/feed import. Non-symbiotic N fixation in farmlands was estimated to be 2.17 Tg. Although N fixation in forests, grasslands, natural wetland and lightning N are not counted in, it is indubitable that human-created N far exceeds terrestrial biological N fixation. Synthetic chemical N fertilizer is the dominant source of anthropogenic reactive N. NO_x emission from combusting fossil fuel is another major source since China is one of the biggest coal consumers in the world.

The amount of recycling N reflects acceleration of the N cycling as influenced by human activities. The analysis and evaluation of the recycling N in the China watershed shows that this part of N could not be negligible, and totaled 31 Tg in 1995, with 17.9 Tg coming from human and animal wastes.

The total N sink in the China watershed amounted to 48–53 Tg in 1995, with N in the harvested crops and N storage in agricultural soils being the major sinks and amounting to 14 Tg and 12 Tg, respectively. The total N loss through denitrification of soil N was estimated at 5–10 Tg in 1995, and the total N transport into waterbodies at 11 Tg, which was an estimate with much uncertainty.

The N budgeting on the basis of valley show that the N input and N output in the Changjiang, and Zhujiang River valleys, which are the well-developed regions of China, were much higher than that in the Huanghe River valley located in the arid and semi-arid warm temperate zone.

This estimation was performed mainly based on agricultural N recycling and NO_x emission from combusting fossil fuel. The N sources and sinks in forests, grasslands and natural wetlands are not yet integrated into our N budgeting in China. However, from the viewpoint of evaluating the influence of human activities on N cycling, it is reasonable to estimate N input and sinks on the basis of agricultural N cycling.

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