30-year changes in the nitrogen inputs to the Yangtze River Basin

Qinxue Wang1, Hiroshi Koshikawa1, Chen Liu2 and Kuninori Otsubo2

1 Center for Regional Environmental Research, National Institute for Environmental Studies, Tsukuba, Japan
2 Graduate School of Global Environmental Studies, Sophia University, Tokyo, Japan

E-mail: wangqx@nies.go.jp

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Abstract
To understand both spatial and temporal changes in nitrogen inputs to the Yangtze River Basin (YRB), we collected decadal statistical data for 1980, 1990, 2000 and 2010 at the county level and the annual statistical data for the period 1980–2010 at the provincial level of China. Based on these datasets, we estimated the nitrogen inputs, including the atmospheric deposition, synthetic N fertilizer, biological N fixation and recycling reactive N inputs, such as N from human waste and animal excrement, crop residue recycled as manure, and N emission from burning crop residue. The results showed that, geographically, the variation of the total amount of N input during the last 30 years ($\delta N = N_{2010} - N_{1980}$) has increased about 0–50 kg ha$^{-1}$ over most of the area of the YRB. Moreover, it has increased dramatically by about 50–300 kg ha$^{-1}$ in the Sichuan Basin, the Han River Basin, the Poyang and Dongting lake basins, and the Yangtze Delta as well. Temporally, the total amount of N inputs to the whole YRB was approximately 16.4 Tg N in 2010, which was a 2.0-fold increase over 1980. It increased dramatically in the 1990s and then stabilized at a high level in the 2000s. The major N inputs were human and animal wastes as well as synthetic fertilizers, but they varied regionally. Animal waste was the major input to the water source regions, and its contribution percentage gradually decreased from upper to lower reaches. In contrast, the contribution of N fertilizer increased from upper to lower reaches, and became the major input to the middle and lower reaches. The total N inputs changed slightly in the upper reaches, but increased largely in the middle reaches in the last 30 years. However, in the lower reaches, it had increased remarkably before 2000, and then tended to decrease in the last decade. Finally, the atmospheric N deposition over the basin increased continuously in the last 30 years.

Keywords: nitrogen input, N fertilizer, atmospheric N deposition, Yangtze River Basin

1. Introduction

There is concern that increasing anthropogenic pollutant loadings from large river basins may cause wide-scale degradation of the coastal and marine environment, as exemplified by the occurrences of red tides. We are now trying to develop an integrated catchment model to simulate both water flow and pollutant loadings from a watershed in order to evaluate its impacts on the coastal and marine environment in the East China Sea (ECS). For this purpose, we need, at first, to make clear the nitrogen (N) inputs to major watersheds in East Asia. Here, we chose the Yangtze River (Changjiang) Basin (YRB) as the target area because it is the largest one in Asia, providing most of the sediments and nutrients from the terrestrial continent to ECS.

Because major sources or sinks are difficult to measure independently, the N inputs and outputs are often estimated based on a mass-balance model (Howarth et al 1996), which has been used by several groups in the US, Europe and Asia. Boyer et al (2002) estimated anthropogenic nitrogen sources and relationships to riverine nitrogen export for 16...
catchments in the northeastern USA. Han and Allan (2008) compared eight separate net anthropogenic N input budgets and one soil compartment budget for each of the 18 Lake Michigan catchments, and then the influence of climate and human activities on the relationship between watershed nitrogen input and river export has been evaluated (Han et al 2009). Hong et al (2012) evaluated the regional variation of net anthropogenic nitrogen and phosphorus inputs (NANI/NAPI) in the multinational areas of the Baltic Sea basin, and found regional nutrient inputs are strongly related to riverine nutrient fluxes. Recently, NANI to US watersheds were estimated and found that, across the US watersheds, NANI was particularly sensitive to farm N fertilizer application, cattle N consumption, N fixation by soybeans and alfalfa, as well as N yield by corn, soybeans, and pasture, although their relative importance varied among different regions (Hong et al 2013). Howarth et al (2012) found that the N flux to coastal marine ecosystems is strongly correlated with NANI to the landscape across 154 watersheds, ranging in size from 16 to 279 000 km², in the US and Europe. A brief overview of NANI to watersheds and riverine N export to coastal waters has been done by Swaney et al (2012), who pointed out that, since the development of industrial N-fixing processes early in the 20th century, anthropogenic N inputs have grown to dominate the global N cycle and have become the main sources of N in most watersheds affected by humans. The N input and output in mainland China were evaluated by using the updated data of temporally and spatially-based land use maps and statistical data at national and provincial scales (Ti et al 2012).

Several studies have addressed the nitrogen (N) balance in the YRB. Xing and Zhu (2002) estimated the N inputs and outputs for China as a whole and its three main river basins, including the YRB. Shen et al (2003) estimated the various sources of N and its transport to the mouth of the Yangtze River based on field investigations, rain sampling, and historical and literary data. Our research group investigated the changes in geographic distribution of N budgets of agricultural fields in the YRB based on county-level data from 1980 to 1990 (Xiangbao et al 2006), and then from 1980 to 2000 (Liu et al 2008). However, the situation has greatly changed in recent years due to further economic development, regional industrial transfer and population migration occurring in China. Meanwhile, air pollution has become the most serious environmental problem in China, which might influence not only the health of people, but also the atmospheric N deposition in the river basin. The World Health Organization estimated that outdoor air pollution was associated with approximately 300 000 premature deaths per year in China (Cohen et al 2005), and Chinese scientists have given similar estimates (Zhang et al 2008).

In this study, we try to assemble the credible parameters (see table 1) into the mass balance model to estimate both spatial and temporal changes in nitrogen inputs from 1980 to 2010. The spatial changes were investigated by comparing the estimated values of N inputs at the county level, but the temporal changes were investigated by analyzing the estimated values of N inputs at the provincial level in four different zones from upper to lower reaches: Qinghai Province in the water source regions, Sichuan Province and Chongqing City in the upper reaches, Hunan Province in the middle reaches, and Jiangsu Province in the lower reaches of the YRB.

2. Methodology and data collection

2.1. Study area

The Yangtze River is the largest river in Asia. It is about 6300 km long, and has a total hydrographic catchment area of 1.8 million km². The Yangtze River begins in the Kunlun Mountains, Tibetan Plateau, fed by melted snow and ice from the surrounding mountains in the southwestern part of Qinghai Province in China, and flows generally northeast and east across central China through Sichuan, Hubei, Hunan, Anhui, and Jiangsu provinces to meet ECS (figure 1).

The land use types are various, as shown in figure 1. Grasslands cover most of the water source regions in the Qinghai Province. Forests, bushes, shrubs, and grasslands cover the upper reaches of Sichuan, Gansu and Shaanxi provinces. Agricultural fields, especially paddy fields, are well developed in the Sichuan basin, Dongting Lake basin, Poyang Lake basin and the delta region in the middle and lower reaches of the Hunan, Hubei, Anhui and Jiangsu provinces. A turning cultivation system of rice-wheat, rice-rape, rice-cotton and rice-sweet potato, with a rotation of rice-peanut, rice-green manure, or double cropping of rice are practiced in these regions, with a high cropping intensity between 200% and 250% (Liu et al 2008).

With its numerous tributaries, the Yangtze River provides an important transportation network through the most densely populated and economically important areas of China. There are about 400 million people living in the basin. The central YRB is affectionately known as China’s home of rice and fish in recognition of its fertile soils and the bounty of its water resources. With a rapid development of the economy and increase in population within the last several decades, the problem of water pollution has become increasingly serious.

2.2. Methods and parameters

Because major sources or sinks are difficult to be measured independently, a mass balance model (Howarth et al 1996) can be used to estimate N input and output, in which the N input (N INPUT) was considered as two groups, anthropogenic new reactive N inputs (N ANTHRO) and recycling reactive N inputs (N RECYCLE) as shown in figure 2.

The anthropogenic new reactive N inputs (N ANTHRO) include the application of synthetic N fertilizer (N FER), atmospheric wet/dry NO3-N deposition (N DEP NO3), biologic N fixation (N BIO) by leguminous and non-leguminous crops. And the recycling N inputs (N RECYCLE) include excrements from human (N HUMAN) and animal (N ANIMAL), crop residues recycled (N RESID) as manure, crop residue recycled as animal feed, N emission from burning of crop
Table 1. Methodologies and Parameters required for the estimation of N inputs.

| Items                          | Estimation Methods                                                                 | References                          |
|-------------------------------|----------------------------------------------------------------------------------|-------------------------------------|
| Atmospheric N deposition ($N_{\text{DEP}}$) | The bulk N deposition ($N_{\text{DEP}}$) was estimated by regression linear models between $N_{\text{DEP}}$ and the year ($a$) for different regions as follows: |
|                               | (A) $N_{\text{DEP}} = 0.166a - 328.35$ (n = 31; $p < 0.001$) for the Tibet Plateau, which was used for estimation of $N_{\text{DEP}}$ over water source regions of YRB, such as Qinghai Province. |
|                               | (B) $N_{\text{DEP}} = 0.531a - 1044.03$ (n = 81; $p < 0.001$) for Southwest China, used for estimation of $N_{\text{DEP}}$ over upper and middle reaches, such as Yunnan, Sichuan, Hubei and Hunan Province. |
|                               | (C) $N_{\text{DEP}} = 0.560a - 1099.05$ (n = 212; $p < 0.001$) for Southeast China, used for estimation of $N_{\text{DEP}}$ over lower reaches, such as Jiangxi, Anhui and Jiangsu province. |
| N fertilizer ($N_{\text{FER}}$) | The data of synthetic N fertilizer ($N_{\text{FER}}$) was obtained from the National Bureau of Statistics of China. http://data.stats.gov.cn/ |
| Biological N fixation ($N_{\text{BIO}}$) | $N_{\text{BIO}}$ was estimated by multiplying the area of symbiotic and non-symbiotic crops by the rate of N fixation specific to each crop type. Here, in quantifying the symbiotic N fixation by leguminous crops, we only considered soybean and peanut, and in quantifying non-symbiotic N fixation, the N fixation in both paddy fields and the uplands was taken into account. |
|                               | (A) Rate of symbiotic N fixation - 80 kg N ha$^{-1}$ yr$^{-1}$ for soy beans - 80 kg N ha$^{-1}$ yr$^{-1}$ for peanuts |
|                               | (B) Rate of non-symbiotic crops - 30 kg N ha$^{-1}$ yr$^{-1}$ for paddy fields - 15 kg N ha$^{-1}$ yr$^{-1}$ for uplands |
| Recycling N Inputs ($N_{\text{RECYCLE}}$) | $N_{\text{RECYCLE}}$ includes N from the excrements of humans ($N_{\text{HUMAN}}$) and animals ($N_{\text{ANIMAL}}$), recycled crop residue ($N_{\text{RESI}}$), atmospheric NH4-N deposition N ($N_{\text{DEP}_{\text{NH4}}}$) and N recycled by seeds ($N_{\text{SEED}}$), in which $N_{\text{HUMAN}}$, $N_{\text{ANIMAL}}$ and $N_{\text{RESI}}$ were taken into account in this study. |
|                               | (A) $N_{\text{HUMAN}}$ and $N_{\text{ANIMAL}}$ were estimated by multiplying the amount of population of animals ($P_{\text{ANIMAL}}$) and humans ($P_{\text{HUMAN}}$) by the percentage of animal and human excrement used as manure, which was used as: |
|                               | - Human: 40% |
|                               | - Cattle, horse, sheep, goat, etc: 40% |
|                               | - Pig, and chicken: 100% |
|                               | (B) $N_{\text{RESI}}$ used as fertilizer ($N_{\text{RESI}-1}$) was estimated by multiplying the production of seed (PRO) by the straw seed ratio (SSR), and the percentage of residue returned to soil (PRS) and N content in crop residues (NCR) as: |
|                               | $N_{\text{RESI}-1} = \text{PRO} \times \text{SSR} \times \text{PRS} \times \text{NCR}$ |
|                               | (C) $N_{\text{RESI}}$ for combustion ($N_{\text{RESI}-2}$) was estimated by multiplying the production of seed (PRO) by the straw seed ratio (SSR), and the percentage of residues burned for fuel (PRF) and the emission factor for crop residues (EMF, 3.83 g N kg$^{-1}$ according to Andreae and Merlet 2001) as: |
|                               | $N_{\text{RESI}-2} = 3.83 \times \text{PRO} \times \text{SSR} \times \text{PRF}$ |
|                               | where data of PRO were obtained from the National Data Center of China, and SSR, PRS, NCR and PRF for each crop were used as follows: |
|                               | SSR PRS (%) NCR (g N kg$^{-1}$) PRF (%) |
| Rice                          | 1.0 30 7.5 70 |
| Wheat                         | 1.2 45 5.2 55 |
residues, atmospheric wet/dry NH4-N deposition N ($N_{DEP,NH4}$), and N recycled by seeds ($N_{SEED}$), which was omitted here because of a very small proportion in all the inputs. Although both $N_{DEP,NO3}$ and $N_{DEP,NH4}$ were required theoretically, in most cases only the bulk deposition ($N_{DEP}$) of inorganic N (NH4-N and NO3-N) has been systematically measured. Finally, $N_{INPUT}$ was estimated by using equation (1) as follows:

$$N_{INPUT} = N_{ANTHRO} + N_{RECYCLE} = f(N_{FER}, N_{BIO}, N_{DEP}, N_{HUMAN}, N_{RESI}).$$ (1)

The N outputs include the N in the harvested biomass (including grains and straws), denitrification, volatilization, and riverine N export to surface waters, and the N storage in the soil might be estimated from the difference between all inputs and outputs. Because the process of N outputs are so complicated, which is determined by not only natural factors such as topography, soil construction, vegetation cover and weather conditions, but also by anthropogenic factors such as land use, drainage network and reservoirs, we will estimate these items in our future work.

Methods and parameters required for equation (1) mainly come from published literatures shown in table 1, of which

| Items       | Estimation Methods | References |
|-------------|--------------------|------------|
| Maize       | 1.5 20             | 5.8 80     |
| Oil rape    | 2.5 40             | 6.7 60     |
| Potato      | 0.5 100            | 30.0 0     |
| Peanut      | 0.8 90             | 18.0 0     |
| Sugarcane   | 3.0 90             | 6.7 0      |

Table 1. (Continued.)

Figure 1. Location of the Yangtze River Basin in China and Land Use Map ca. 2005.

Figure 2. The N input including both anthropogenic new reactive N inputs ($N_{ANTHRO}$) and recycling reactive N inputs ($N_{RECYCLE}$) (real line) to the soil of watershed shown in a mass balance model.
most were reported by our previous study (Liu et al. 2008). The major improvement of this study is that the parameterization of $N_{DEP}$ was renewed based on the recent research result published in Nature by Liu et al. (2013). The atmospheric N deposition analysis is usually based on regional observational records and sub-regional scale regressions. Other researchers have used regionally-scaled results from global or regional deposition models (Dentener et al. 2006 and Lamarque et al. 2010 and Lamarque et al. 2013), although the accuracy of those models still needs to be enhanced. Liu et al. (2013) summarized available data nationwide (671 data points) on the bulk deposition of N in terrestrial ecosystems of China, and find that the average annual bulk deposition of N increased by approximately 8 kg N ha$^{-1}$ (P < 0.001) from the 1980s (13.2 kg N ha$^{-1}$) to the 2000s (21.1 kg N ha$^{-1}$). They also regionally analyzed the dynamics of the bulk N deposition by dividing deposition data into six areas: northern, southeast, southwest, northeast and northwest China and the Tibetan plateau. Here, we employed the relationships between bulk N deposition ($N_{DEP}$) and the year (a) fitted by linear mixed models for the Tibetan plateau, southwest, and southeast of China (Liu et al. 2013) to estimate $N_{DEP}$ for each province in the upper, middle and lower reaches of the YRB, respectively (table 1).

### 3. Results and discussions

#### 3.1. Spatial changes in the nitrogen inputs

To understand the geographical distribution, we developed a set of county-level maps of each part of N inputs, including the synthetic N fertilizer, human and animal wastes, biological fixation, crop residues, atmospheric N deposition, as well as the total amount of N inputs to the years 1980, 1990, 2000 and 2010, respectively. Figure 3(a) shows the distribution of N fertilizer in 1980, 1990 and 2011, respectively. It was clearly shown that both the area and intensity of N fertilizer application were enlarged in the last 30 years. The most polluted areas include the Sichuan Basin, the Poyang Lake Basin and the Yangtze Delta, where the intensity of the synthetic N fertilizer application was larger than 120 kg N ha$^{-1}$. We sum up the total amount of N fertilizer in the whole YRB, and found that the synthetic N fertilizer changed from 2.58 Tg N in 1980 to 7.38 Tg N in 2010, which means that during the last 30 years, the synthetic N fertilizer application increased nearly 2.9-fold in the YRB.

Figure 3(b) shows the distribution of the bulk N deposition in 1980, 1990 and 2011, respectively. It was clearly shown that both the area and intensity of the bulk N deposition were greatly enlarged in the last 30 years. The most polluted areas include the Sichuan Basin, the Han River Basin, the Poyang and Tongting Lake Basin and the Yangtze Delta, where the intensity of the bulk N deposition was larger than 10 kg N ha$^{-1}$. We summed up the total amount of bulk N deposition in the whole basin, and found that it increased from 0.24 Tg N in 1980 to 0.89 Tg N in 2010. This meant that during the last 30 years, the bulk N deposition in the YRB increased nearly 3.7-fold. This change can be considered highly related to the serious air pollution occurring in China during the last few decades.

The recycled N refers to organic fertilizers from human and animal wastes, crop residues and burning of crop residues. The values of organic fertilizers were estimated using the county-level agricultural statistical database of each decade. Based on the results of Xing and Yan (1999), about 40%
of human and animal wastes were applied to crop fields as manure. As a result, the total amount of human and animal wastes was estimated at 3.77 Tg N in 1980 and 5.50 Tg N in 2010, respectively. This meant that during these 30 years, N from animal and human wastes increased nearly 1.5-fold (figure 4(a)). According to the type of crop and the use of crop residues in China, an average of about 38% of crop residues were returned to the soil as fertilizers, and the rest of the crop residues, about 62%, were burnt partly on farms and partly in kitchens as cooking fuel (Xiangbao et al. 2006). Here, we estimated the crop residue N used as fertilizers and combustion by conversion data, such as the straw/seed ratio, the percentage of residues returned to the soil and the N concentration in crop residues. The result shows that the N from crop residue increased from 0.79 Tg N in 1980 to 1.81 Tg N in 2010.

To estimate both symbiotic and non-symbiotic N fixations, we just multiplied the area of leguminous crops (soybeans, peanuts, etc) and non-symbiotic crops (rice, wheat, corn etc) by the rate of N fixation specific to each crop type. The results showed that the biological N fixation changed from 0.62 Tg N in 1980 to 0.71 Tg N in 2010. This meant that during these 30 years, the biological N fixation in the basin increased nearly 1.2-fold, which indicated that the increase of biological N fixation was not remarkable (figure 4(b)).

Finally, the total N input were estimated simply by adding all parts together (equation (1)), including the synthetic N fertilizer, human and animal wastes, biological fixation, crop residues, and atmospheric N deposition. Our estimate showed that the total N inputs changed from 8.1 Tg N in 1980 to 16.4 Tg N in 2010, which was approximately a 2-fold increase in the last 30 years. The major inputs were the human and animal wastes, and the synthetic N fertilizer, in which the largest input was animal wastes in 1980 and 1990, but changed to the synthetic N fertilizer in 2010 (figure 5).

The recycled N, including human and animal wastes and N from crop residues was 4.56 Tg N in 1980, equivalent to 57% of the total N inputs, and it increased to 7.32 Tg N, while the percentage contribution decreased to 44% in 2010. The total amount of N fertilizer was about 2.58 Tg N, accounting for 32% of the total N inputs in 1980, and it increased to 7.38 Tg N in 2010, accounting for 45% of the total N inputs and became the largest source of N in 2010. Obviously, both
the amount of N fertilizer and its fraction increased during the last 30 years. The amount of biological N fixation increased slightly from 0.72 Tg N in 1980 to 0.85 Tg N in 2010, indicating that N from biological fixation was a stable source in the watershed. Finally, it is worth mentioning that the atmospheric N deposition increased continuously from 0.24 Tg N (3%) in 1980 to 0.85 Tg N (5%) in 2010. Geographically, the variation of total N input during the last 30 years ($\delta N = N_{2010} - N_{1980}$) showed an increase of about 0–50 kg ha$^{-1}$ over most of the area of the YRB. Moreover, it has increased dramatically, about 50–300 kg ha$^{-1}$ in the Sichuan Basin, the Han River Basin, Poyang and Dongting lake basins, and the Yangtze Delta. These areas are highly populated and major agricultural zones in China (figure 6).

3.2. Temporal changes in the nitrogen inputs

To understand temporal changes in each part of N inputs, we collected the annual statistical data for the period of 1980–2010 at the provincial level of China. We estimated the N inputs in all provinces over the YRB, and here, we simply presented the results of four different zones: Qinghai Province in the water source regions, Sichuan Province and Chongqing City in the upper reaches, Hunan Province in the middle
reaches, and Jiangsu Province in the lower reaches of the YRB.

In the water source regions in Qinghai Province, animal waste is the largest source, which increased from 1980 to 1992, but has decreased slightly since 1993. Its percentage contribution to the total N input was 86% in the 1990s, and decreased to 82% in the 1990s and again to 79% in the 2000s. In contrast, the synthetic N fertilizer increased from 5% in the 1980s to 10% in the 2000s. Human waste also increased slightly from 4% in the 1980s to 5% in the 2000s. The percentages of other sources were very small without obvious changes in the last 30 years (figure 7).

In the Sichuan Province and Chongqing City over the upper reaches, the total N inputs increased continuously.

Figure 6. Spatial changes of the total N input from 1980 to 2010 in the Yangtze River Basin.
during these 30 years, in which both N fertilizer and animal wastes were major sources, contributing about 35% and 32%, respectively, in the 1980s and changing to 39% and 30%, respectively, in the 2000s. The percentage of human waste decreased from 14% in the 1980s to 10% in the 2000s, and the biological N fixation also decreased slightly from 7% in the 1980s to 6% in the 2000s. However, the percentage of atmospheric N deposition increased from 4% in the 1980s to 7% in the 2000s (figure 8).

In the Hunan Province over the middle reaches, the total N inputs also increased continuously during these 30 years, in which the percentage of N fertilizer, the largest N source, increased from 38% in the 1980s to 40% in the 2000s. The second largest N source, animal wastes, also increased from 22% in the 1980s to 25% in the 2000s. The percentage of human waste decreased from 14% in the 1980s to 11% in the 2000s, and the biological N fixation also decreased from 10% in the 1980s to 7% in the 2000s. However, the percentage of atmospheric N deposition increased from 4% in the 1980s to 7% in the 2000s (figure 9).

In the Jiangsu Province over the lower reaches, the total N inputs increased rapidly from 1980 to 1998, and have slightly decreased since then, within the last decade. This decrease could be related to the industrial transfer from agriculture to other industries. The percentage of the largest source, N fertilizer, increased from 54% in the 1980s to 61% in the 2000s. The percentage of the second largest N source, animal wastes, decreased from 16% in the 1980s to 13% in the 2000s. The percentage of human waste decreased from 11% in the 1980s to 9% in the 2000s, and the biological N fixation also decreased from 7% in the 1980s to 2% in the 2000s. However, the percentage of atmospheric N deposition increased from 5% in the 1980s to 6% in the 2000s (figure 10).

In general, we come to the conclusion that the animal waste was the major source in the water source regions, but its percentage gradually decreased from upper to lower reaches. In contrast, the synthetic N fertilizer became the major source in the middle and lower reaches, and its percentage of contribution gradually increased from upper to lower reaches. The total N inputs to the whole basin increased dramatically from 1980 to 1998 and then stabilized at a high level in the last decade, in which the decrease of N fertilizer, human wastes and biological fixation in the lower reaches made a great contribution. Notably, the atmospheric N deposition has increased within the whole basin, especially in the middle and lower reaches. For instance, the percentage of atmospheric N deposition increased from 4% in the 1980s to 7% in the 2000s in the Sichuan Province over the upper reaches; from 8% to 11% in Hunan Province over the middle reaches and from 5% to 6% in Jiangsu Province over the lower reaches.

4. Conclusions

To understand both spatial and temporal changes in N inputs to the YRB, we collected the decadal statistical data for 1980, 1990, 2000 and 2010 at the county level and the annual statistical data for the period of 1980–2010 at the provincial level of China. Based on these datasets, we estimated the nitrogen inputs, including N fertilizer, human and animal wastes, biological fixation, crop residues, and atmospheric N
The results showed that the variation of total N inputs had increased about 0–50 kg ha$^{-1}$ over most of the area of the YRB during the last 30 years. Moreover, it has increased dramatically, about 50–300 kg ha$^{-1}$ in the Sichuan Basin, the Han River Basin, the Poyang and Dongting lake basins, as well as the Yangtze Delta. The total amount of N inputs to the whole basin was approximately 16.4 Tg N in 2010, which was a 2-fold increase over 1980. It increased dramatically in the 1990s and then stabilized at a high level in the 2000s.

Figure 9. Changes and percentages of N inputs to the Hunan Province over the middle reaches of the Yangtze River Basin.

Figure 10. Changes and percentages of N inputs to the Jiangsu Province over the lower reaches of the Yangtze River Basin.

deposition. The results showed that the variation of total N inputs had increased about 0–50 kg ha$^{-1}$ over most of the area of the YRB during the last 30 years. Moreover, it has increased dramatically, about 50–300 kg ha$^{-1}$ in the Sichuan Basin, the Han River Basin, the Poyang and Dongting lake basins, as well as the Yangtze Delta. The total amount of N inputs to the whole basin was approximately 16.4 Tg N in 2010, which was a 2-fold increase over 1980. It increased dramatically in the 1990s and then stabilized at a high level in the 2000s.

One major source, the recycled N, including excreta of humans and animals, and N from crop residues used as
fertilizer and for burning, increased from 4.56 Tg N in 1980 (57% of the total N) to 7.32 Tg N (44% of the total N) in 2010. The other major source, the synthetic N fertilizer, increased from 2.58 Tg N (32% of the total N) in 1980 to 7.38 Tg N (45% of the total N) in 2010, which became the largest source of N inputs. Obviously, both the amount of N fertilizer and its fraction has been increasing during the last 30 years. The amount of biological N fixation increased slightly from 0.72 Tg N in 1980 to 0.85 Tg N in 2010, indicating that N from biological fixation was a stable source. Finally, it is worth stressing that the atmospheric N deposition increased continuously from 0.24 Tg N (3%) in 1980 to 0.85 Tg N (5%) in 2010, a 3.5-fold increase during the last 30 years, which was considered to be closely related with serious air pollution occurring in China (Liu et al. 2013, Cohen et al. 2005, Zhang et al. 2008).

Although the major N inputs were human and animal wastes, and N fertilizers in the total catchment, they varied regionally. Animal waste was the largest source in the water source regions, and its percentage of contribution gradually decreased from upper to lower reaches. In contrast, the percentage of the synthetic N fertilizer increased from upper to lower reaches and became the largest source in the middle and lower reaches. The total amount of N inputs changed slightly in the water source regions within the last 30 years, but it increased greatly in the middle reaches. However, in the lower reaches, the situation was quite different; namely, the total amount of N inputs increased remarkably from 1980 to 2000 and then tended to decrease in the last decade. Finally, the atmospheric N deposition has increased notably in the whole basin, especially in the middle and lower reaches.

To evaluate the impacts of N inputs on the coastal and marine environment, we are now trying to develop an integrated catchment model to simulate both water flow and pollutant loadings from the Yangtze River. All of these parameters concerning the nitrogen inputs will be used as input data of the model to simulate how anthropogenic activities influence the pollutant loadings from the Yangtze River and how many pollutants were transported to the ECS in the last 30 years.

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