Supplementary Information

Insight into Municipal Reactive Nitrogen Emissions and Their Influencing Factors: A Case Study of Xiamen City, China

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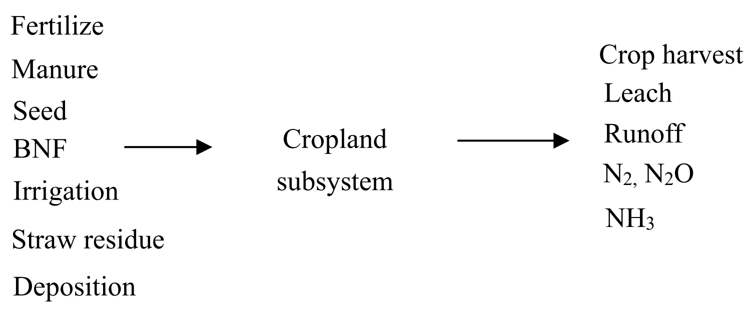
The purpose of this supplementary is to describe and explain each of the values and the calculating course (such as equation, parameter and activity data) use to calculate reactive nitrogen in Xiamen city. The reactive nitrogen refers to the nitrogen pollutants that have negative impacts on the atmosphere and water bodies produced during the nitrogen flow process, mainly including nitrogen pollutants that enter water bodies through runoff and infiltration, as well as NOx, NH_3 and N_2O emission.

Appendix A. Various subsystems of nitrogen flows

Cropland system

- Model of N flows in cropland system



- Equation

According to the cropland system nitrogen flow model the input-output are shown above. This section describes in detail the calculation of each input item, coefficients and activity data. The equation of cropland system can be calculated using the following method:

$$C_{input} = C_{fertilizer} + C_{BNF} + C_{seed} + C_{deposition} + C_{manure} + C_{straw-residue} + C_{irrigation} \quad (1.1)$$

$$C_{output} = C_{harvest} + C_{N_2} + C_{N_2O} + C_{leach} + C_{runoff} + C_{ammonia-volatilization} \quad (1.2)$$

Where C_{input} and C_{output} are the total nitrogen input and output to cropland; $C_{fertilizer}$ is synthetic fertilizer application; C_{BNF} is biological fixation of nitrogen, including leguminous plant nitrogen fixation and non-leguminous plant nitrogen fixation; C_{seed} is the seeds of different crops; $C_{deposition}$ is nitrogen deposition; C_{manure} is manure recycled to cropland from both livestock and human; $C_{straw-residue}$ is straw recycled to cropland; $C_{irrigation}$ is nitrogen input to the cropland from irrigation; $C_{harvest}$ is crop production; C_{N_2} is nitrogen loss by denitrification N_2 ; C_{N_2O} is N_2O emission ; C_{leach} is nitrogen leaking to groundwater C_{runoff} is nitrogen loss through runoff $C_{ammonia-volatilization}$ is ammonia volatilization during fertilization.

Table S1. Input and output items in processes of cropland system.

Items	Equations	Activity Data and Parameters Description
Chemical fertilizer	$C_{fertilizer} = F1 \times R1 + F2$	F1: Consumption of compound fertilizer F2: Consumption of nitrogenous fertilizer R1: N content of compound fertilizer
BNF	$C_{BNF} = F4 \times R2 + (F3 - F4) \times R3$	F3: Total sown area; F4: Sown area of legume crops R2: Symbiotic N-fixation rate of cropland R3: Non-symbiotic N-fixation rate of cropland
Deposition	$C_{deposition} = F5 \times R4$	F5: Area of cropland R4: N deposition rate
Seed	$C_{seed} = F6 \times R5 \times R6$	F6: Sown area of different crops R5: Seed rate R6: N content of seed

Irrigation water	$C_{irrigation} = F5 \times R7$	R7: Irrigation rate
Manure to field	$C_{animal\ \mathrm{manure}} = F7 \times R8 \times R9 / 365 \times R10$ $C_{human\ \mathrm{manure}} = F8 \times R11 \times R12$	F7: Number of livestock and poultry R8: N excreta rate for animals R9: Feeding period of livestock and poultry R10: Ratio of animal excreta back to field F8: Population (count) R11: N excreta rate for humans R12: Ratio of human excreta back to field
Crop residue	$C_{crop\ \mathrm{residue}} = F9 \times (1 / R13 - 1) \times R14 \times R15$	F9: Yield of grain crops R13: Harvest Index of crops R14: N content of straws R15: Ratio of straw back to field
Denitrification (N_2+N_2O)	$C_{denitrification} = C_{surplus} \times R16$	R16: Denitrification percentage (N_2) R17: Direct N_2O emission factor from chemical fertilizer R18: Direct N_2O emission factor from organic fertilizer R19: N_2O-yield ratio of denitrification R20: Leaching ratio of applied N R21: Runoff ratio of applied N
N_2O	$C_{N_2O} = (C_{manure} + C_{crop\ residue}) \times R17 + C_{fertilizer} \times R18 + C_{denitrification-N_2O}$	
Denitrification (N_2O)	$C_{denitrification--N_2O} = C_{denitrification} \times R19 / 1.039$	
Ammonia-volatilization	$C_{ammonial-volatilization} = (C_{manure} + C_{crop\ residue}) \times R22 + C_{fertilizer} \times R23$	R22: Volatilization coefficient of organic fertilizer R23: Volatilization coefficient of chemical fertilizer
Crop harvest	$C_{crop\ \mathrm{harvest}} = F9 / R13 \times R24$	R24: N content of crop
Runoff	$C_{runoff} = C_{surplus} \times R20 \times R25$	R25: the retention coefficient of N runoff
Leach	$C_{leach} = C_{input} \times R21$	
Surplus	$C_{surplus} = C_{input} - C_{ammonial-volatilization} - C_{crop-harvest}$	

Table S2. The parameter of cropland system.

NO	Item description	Unit	Reference	Value
R1	N content of compound fertilizer	%	[63]	33.3
R2	Symbiotic N-fixation rate of cropland	kg/ha	[64]	Legumes:105; peanut:112
R3	Non-symbiotic N-fixation rate of cropland	kg/ha	[64]	18.75
R4	N deposition rate	kg/ha	[65]	30.15
R5	Seed rate	kg/ha	[66]	Rice:37.5; soybean:76.05; potatoes:225; peanut:285;rapeseed:1; sesame:5; vegetables:15.38
R6	N content of seed	%	[66]	Cereal:1.3;potatoes:0.3;soybean:4.2;peanut:4.4;rapeseed:4;sesame:3.49;sugarcane:0.13;vegetables:0.2;furits:0.21
R7	Irrigation rate	kg/ha	[67]	26.3
R8	N excreta rate for animals	kg/cap	[68]	Pig:8; cattle:40; sheep:5; rabbit:0.4; poultry:0.3
R9	Feeding period of livestock	day	[68]	Pig:199;cattle:365;sheep:365; rabbit:120; poultry:55
R10	Ratio of animal excreta back to field	%	[68]	Pig:60;cattle:77.7;sheep:70; rabbit:35; poultry:39
R11	N excreta rate for humans	%	[68]	5
R12	Ratio of human excreta back to field	%	[68]	urban :10; rural :30
R13	Harvest Index of crops		[68]	Cereal:0.53; potatoes:0.66; soybean:0.5; peanut:0.55; rapeseed:0.28; sesame:0.37; sugarcane:0.67;
R14	N content of straws	%	[68]	Cereal:0.91; potatoes:2.51; soybean:2.1; peanut:1.82; rapeseed:0.87; sesame:1.31; sugarcane:1.1;
R15	Ratio of straw back to field	%	[68]	Cereal:41.7; potatoes:50; soybean:16.8; peanut:26; rapeseed:47.6; sesame:0; sugarcane:10;
R16	Denitrification percentage (N_2)	%	[69]	72.5
R17	Direct N_2O emission factor from chemical fertilizer	%	[70]	0.86
R18	Direct N_2O emission factor from organic fertilizer		[36]	0.01
R19	N_2O-yield ratio of denitrification	Kg/N_2	[3]	0.039

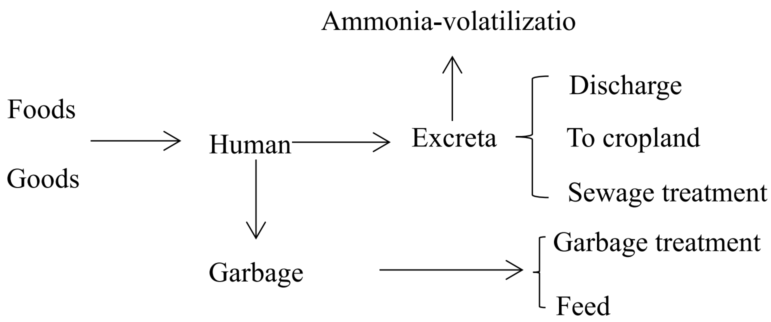
R20	Leaching ratio of applied N	%	[40]	12.5
R21	Runoff ratio of applied N	%	[69]	16.7
R22	Volatilization coefficient of excreta	%	[71]	Pig:19; cattle:17; sheep:25; rabbit:54; poultry:22; human:25
R23	Volatilization coefficient of chemical fertilizer	%	[72]	20
R24	N content of crop	%	[73]	Cereal:1.12; potatoes:1.04; soybean:3.15; peanut:3.25; rapeseed:1.75; sesame:2.12; sugarcane:0.37;vegetables:0.3;furits:0.19
R25	the retention coefficient of N runoff	%	[74]	42.5%

Table S3. the activity data of cropland system.

No.	**Item description**	**Unit**	**Ref.**
F1	Consumption of nitrogenous fertilizer	T	
F2	Consumption of compound fertilizer	T	
F3	Total sown area	ha	
F4	Sown area of legume crops	ha	[75]
F5	Area of cropland	ha	
F6	Sown area of different crops	ha	
F7	Number of livestock and poultry		
F8	Population (count)		
F9	Yield of grain crops	T	

Human consumption system

- Model of N flow in human consumption system



- Equation

According to the human consumption system nitrogen flow model the input-output are shown above. This section describes in detail the calculation of each input item, coefficients and activity data. The equation of household consumption system can be calculated using the following method:

$$H_{input} = H_{food-consumption} + \mathrm{H}_{goods} \quad (2.1)$$

$$H_{output} = H_{\mathrm{excreta}} + H_{ammonia-volatilization} + H_{garbage} \quad (2.2)$$

Where H_{input} and H_{output} are the total nitrogen input and output to household consumption system; $H_{food-consumption}$ is human food consumption; H_{excreta} is human excretion which can be recycle to cropland, sent to WTPs and discharge to surface water; $H_{\mathrm{amm}onia-volatilization}$ is the ammonia emission from the human excreta; $H_{garbage}$ is the garbage mainly including foods and goods waste.

Table S4. Input and output items in processes of human consumption system.

Items	Equations	Activity data and parameters description
Food consumption	$H_{food-consumption} = F10 \times (1+R26) \times R28 \times F12$ $+F11 \times (1+R27) \times R28 \times F13$	F10: Per capita consumption of foods in urban region F11: Per capita consumption of foods in rural region F12: the population of urban F13: the population of rural R26: the proportion of urban population dining outside R27: the proportion of rural population dining outside R28: N content of foods
Kitchen garbage	$H_{kitchen-garbage} = H_{food-consumption} \times (R29 + R30)$	R29: Ratio of kitchen garbage in outside R30: ratio of kitchen garbage in house
Excreta	$H_{exceta} = (H_{food-consumption} - H_{kitchen-garbage}) \times R31$	R31: the proportion of excreta
Ammonia-volatilization	$H_{NH_4} = H_{excreta} \times R22$	

To sewage	$H_{sewage} = H_{excreta} \times R32$	R32: human excreta into the sewage treatment system
Discharge	$H_{discharge} = H_{excreta} - H_{NH_4} - H_{sewage}$	
Kitchen garbage to feeds	$H_{kitchen-garbage-feeds} = H_{kitchen-garbage} \times R15$	
G_{goods}	$G_{goods} = G_{input} - G_{foods}$	G_{input}: municipal garbage (detail in table13) G_{goods}: goods garbage
Goods	$H_{goods} = G_{goods} \times R33$	R33: The percentage of goods that go to waste

Table S5. The parameter of human consumption system.

NO.	**Item description**	**Unit**	**Reference**	**Value**
R26	the proportion of urban population dining outside	%	[68,73]	Cereal:41;potao:20;beans:41;vegeTable S:42; fruits:10;pork:42;beef:33;mutton:33;chicken:31; eggs:31; aquatic:31
R27	the proportion of rural population dining outside	%	[68,73]	Cereal:10;potao:10;beans:10;vegeTable S:13; fruits:12;pork:20;beef:25;mutton:25;chicken:13; eggs:5; aquatic:19
R28	N content of foods	%	[74]	Cereal:1.36;pork:2.1;beef:2.97;mutton:3.04; Chicken:3.1;duck:2.5;eggs:2.1;fish:2.32;shrimp: 2.32 VegTable S:0.32;fruits:0.18;milk:0.5
R29	Ratio of kitchen garbage in outside	%	[76]	Cereal:5;fruits:5;vegeTable S:5;pork:10;beef:10; Mutton:10;chicken:10;duck:10;eggs:10;shrimp: 10 Milk:10
R30	ratio of kitchen garbage in house	%	[76]	Cereal:18;fruits:20;vegeTable S:20;pork:21;beef:21; Mutton:21;chicken:21;duck:21;eggs:24;shrimp: 24 Milk:22
R31	the proportion of excreta	%	[15]	88
R32	human excreta into the sewage treatment system	%	[68]	Urban:75; rural:7.2

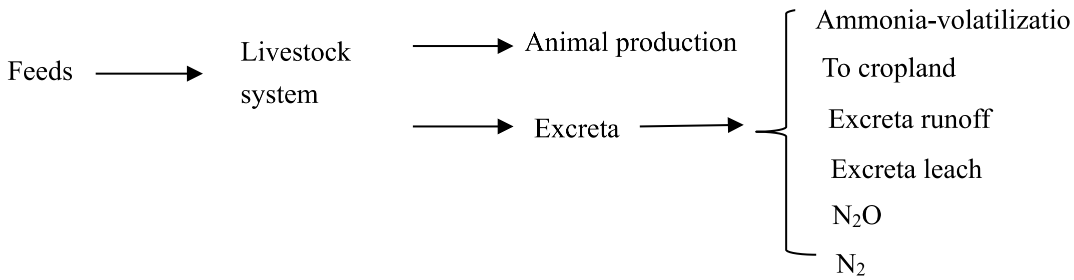
R33	The percentage of goods that go to waste		[77]	1/15

Table S6. The activity data of human consumption system.

No.	Item description	Unit	Ref
F10	Per capita consumption of foods in urban region	T	
F11	Per capita consumption of foods in rural region	T	[75]
F12	the population of urban		
F13	the population of rural		

Livestock system

- Model of N flow in livestock system



- Equation

According to the livestock system nitrogen flow model the input-output are shown above. This section describes in detail the calculation of each input item, coefficients and activity data. The equation of livestock system can be calculated using the following method:

$$L_{input} = L_{straw-feeds} + L_{seed-feeds} + L_{import-feeds} + L_{kitchen-garbage-feeds} \quad (3.1)$$

$$L_{output} = L_{animal-production} + L_{excreta} \quad (3.2)$$

Where H_{input} and H_{output} are the total nitrogen input and output to livestock system; $L_{straw-feeds}$ is straw used as livestock feed; $L_{seed-feeds}$ is seed used as livestock feed; $L_{kitchen-garbage-feeds}$ is cooking wastes used as livestock feed; $L_{import-feeds}$ is feeds from the out system; $L_{animal-production}$ is the production of animal foods ; $L_{excreta}$ is livestock excretion.

Table S7. Input and output items in processes of livestock system.

Items	Equations	Activity data and parameters description
Straw feeds	$L_{straw-feed} = C_{crop\ \text{residue}}$	Table 1
Seed feeds	$L_{seed-feed} = F9 \times (1/R13-1)/R34 \times R35$	R34: the ratio of straw to grain R35: The N content of grain
Garbage feeds	$L_{garbage-feed} = H_{kitchen-garbage-feeds}$	Human system (table3)
Animal excreta	$L_{animal-excreta} = C_{animal-manur}$	Human system (table3)
Animal production	$L_{animal-production} = F14 \times R36$	F14: the production of animal foods R36: The N content of animal foods
Denitrification (N_2)	$L_{denitrification} = L_{animal-excreta} \times R37$	R37: N_2 emission from nitrification process
N_2O	$L_{denitrification} = L_{animal-excreta} \times R38$	R38: the ratio of N_2O emission
Ammonia volatilization	$L_{ammonia-volatilization} = L_{ammonia-volatilization}$	Cropland system (table2)
Excreta runoff	$L_{excreta-runoff} = (L_{excreta} - L_{ammonia-volatilization} - L_{to-cropland} - L_{N_2O} - L_{N_2}) \times R39$	R39: the ratio of runoff
leach	$L_{excreta-runoff} = (L_{excreta} - L_{ammonia-volatilization} - L_{to-cropland} - L_{N_2O} - L_{N_2}) \times R40$	R40: the ratio of leach

Table S8. The parameters of livestock system.

NO.	Item description	Unit	Reference	Value
R34	the ratio of straw to grain		[68]	Cereal:0.9;potao:0.66;beans:0.5;peanut:0.55; Rapeseed:0.28;sesame:0.37;sugarcane:0.67
R35	The N content of grain	%	[68]	Cereal:1.3;potao:0.3;beans:4.2;peanut:4.4; Rapeseed:4;sesame:3.49;sugarcane:0.13
R36	The N content of animal foods	%	[74]	Pork:1.77; beef:2.19;mutton:2.22;poultry:1.90 Rabbit meat:3.4;dairy:0.55;eggs:1.83
R37	N_2 emission from nitrification process	%	[77]	5

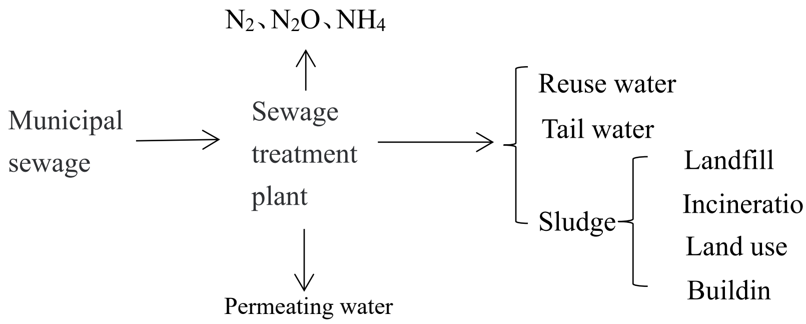
R38	N_2O emission from nitrification process	%		0.5
R39	the ratio of runoff	%	[59,62]	60%
R40	the ratio of leach	%	[59,62]	5%

Table S9. The activity data of livestock system.

No.	Item description	Unit	Ref
F14	the production of animal foods	T	[75]

Sewage treatment

- Model of N flow in sewage treatment system



- Equation

According to the sewage treatment system nitrogen flow model the input-output are shown above. This section describes in detail the calculation of each input item, coefficients and activity data. The equation of sewage treatment system can be calculated using the following method:

$$S_{input} = S_{municipal-sewage} \quad (4.1)$$

$$S_{output} = S_{sludge} + S_{tail-water} + S_{reuse-water} + S_{gaseous(N_2,\ N_2O,\ NH_3)} + S_{permeat} \quad (4.2)$$

Where S_{input} and S_{output} are the total nitrogen input and output to sewage treatment system; $S_{municipal-sewage}$ is municipal waste water including domestic wastewater, industry wastewater and others; S_{sludge} is sludge from WTPs; $S_{reuse-water}$ is recycled water after treated; $S_{gaseous}$ is gaseous emission in treatment process including N_2、NH_3 and N_2O; $S_{permeat}$ is nitrogen leaching during the wastewater transferred to the WTPs; $S_{tail-water}$ is discharged after sewage treated;

Table S10. Input and output items in processes of sewage treatment system.

Items	Equations	Activity data and parameters description
Sewage input	$S_{input} = F15 \times R41$	F15: the input of sewage treatment R41: N input per ton of water
Sludge	$S_{sludge} = F15 \times R42 \times (1 - R43) \times R44$	R42: The ration of sludge generation R43: percent of sludge contained water R44: N content of sludge
Permeate	$S_{permeate} = S_{input} \times R45$	R45: The permeability of pipe
Reuse water	$S_{reuse-water} = S_{input} \times R46$	R46: Recycling rate of water
Ammonia-emission	$S_{ammonia-emission} = F16 \times R47$	F16: The volume of input sewage R47: ammonia emission per cubic meter of sewage
N_2O emission	$S_{N_2O} = S_{input} \times R48$	R48: the ration of N_2O emission
Denitrification(N_2)	$S_{N_2} = S_{input} \times R49 - S_{N_2O}$	R49: the removal ration of nitrogen
Tail water	$S_{tail-water} = S_{input} - S_{sludge} - S_{reuse-water} - S_{N_2O} - S_{N_2}$	

Table S11. The parameters of sewage treatment system.

NO.	Item description	Unit	Reference	Value
R41	N input per ton of water	Kg/t	[62]	0.0468
R42	The ration of sludge generation	%	Field survey	0.05
R43	percent of sludge contained water	%	Field survey	80
R44	N content of sludge	%	Field survey	2.9

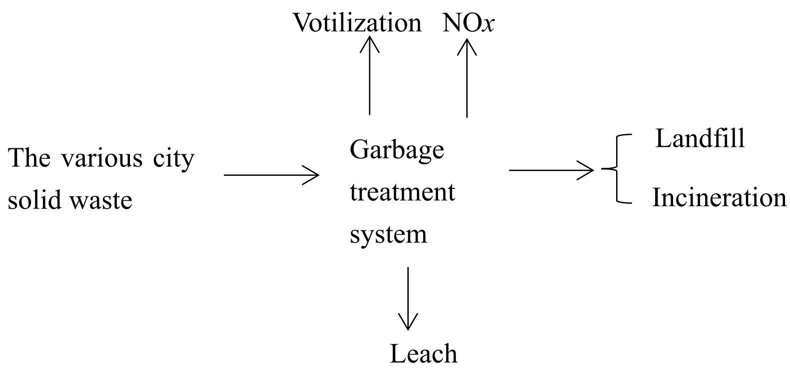
R45	The permeability of pipe	%	[15]	9
R46	Recycling rate of water	%	Field survey	10
R47	ammonia emission per cubic meter of sewage	g/m³	[78]	3.2
R48	the ration of N_2O emission	%	[36]	1.25
R49	the removal ration of nitrogen	%	Field survey	60.42

Table S12. The activity data of sewage treatment system.

No.	Item description	Unit	Ref
F15	the input of sewage treatment	T	[62]
F16	The volume of input sewage	M^3	[62]

Garbage treatment system

- Model of N flow in garbage treatment system



- Equation

According to the garbage treatment system nitrogen flow model the input-output are shown above. This section describes in detail the calculation of each input item, coefficients and activity data. The equation of garbage treatment system can be calculated using the following method:

$$G_{input} = G_{city-solid-waste} \quad (5.1)$$

$$G_{output} = G_{leach} + G_{volatilization} + G_{NO_X} \quad (5.2)$$

Where G_{input} and G_{output} are the total nitrogen input and output to garbage treatment system; $G_{city-solid-waste}$ are municipal solid wastes including household waste, medical waste, industrial waste, garden waste and so on. and others; G_{leach} is the nitrogen contained in garbage released to the groundwater during the landfill process; $G_{volatilization}$ is generated during process of incineration; G_{NO_X} is emission from the process of incineration;

Table S13. Input and output items in processes of garbage treatment system.

Items	Equations	Activity data and parameters description
Garbage input	$G_{input} = (1 - R50) \times F17 \times R51 \times R52$	R50: the rate of garbage disposal F17: the amount of garbage R51: the percentage of various types of garbage R52: the N content of garbage
Landfill	$G_{landfill} = G_{input} \times R53$	R53: the ratio of landfill
Incineration	$G_{landfill} = G_{input} \times R54$	R54: the ratio of incineration
leach	$G_{leach} = G_{landfill} \times R55$	R55: the ratio of leach
NOx	$G_{NO_X} = G_{incineration} \times R56$	R56: the factor of NOx emission
Volatilization	$G_{volatilization} = G_{landfill} \times R57$	R57: the factor of volatilization

Table S14. The parameters of garbage treatment system.

NO.	Item description	Unit	Reference	Value
R50	the rate of garbage disposal	%	Field survey	96.92
R51	the percentage of various types of garbage	%	[79]	Food-waste:51.5;papers:9.3; plastics:15;textile:5.1 Woods:2;glasses:2.9; metals:0.7;dust:13.5
R52	the N content of garbage	%	[79]	Food-waste:2.6;papers:0.3; plastics:0.5;textile:10 Woods:0.3;glasses:0.1; metals:0.1;dust:0.98

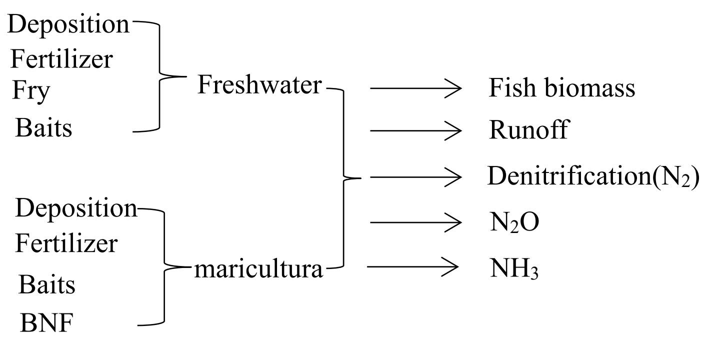
R53	the ratio of landfill	%	Field survey	56.8
R54	the ratio of incineration	%	Field survey	43.2
R55	the ratio of leach	%	[19]	1/6
R56	the factor of NOx emission	g/kg	[77]	67
R57	the factor of volatilization	g/kg	[77]	0.6

Table S15. The activity data of garbage treatment system.

No.	Item description	Unit	Ref
F17	the amount of garbage	T	[75]

Aquaculture system

- Model of N flow in aquaculture system



- Equation

According to the aquaculture system nitrogen flow model the input-output are shown above. We divided it into freshwater aquaculture and mariculturist. This section describes in detail the calculation of each input item, coefficients and activity data. The equation of aquaculture system can be calculated using the following method:

$$A_{input} = A_{freshwater} + A_{mariculture} \quad (6.1)$$

$$A_{output} = A_{fish-biomass} + A_{runoff} + A_{N_2O} + A_{denitrification} + A_{NH_3} \quad (6.2)$$

Where A_{input} and A_{output} are the total nitrogen input and output to aquaculture system;

$A_{freshwater}$ is freshwater aquaculture; $A_{mariculture}$ is the mariculture; $A_{fish-biomass}$ is aquaculture production; A_{runoff} is water runoff; $A_{denitrification}$ is N_2 denitrification during aquaculture production; A_{N_2O} is N_2O emission from aquaculture production; A_{NH_3} is NH_3 volatilization.

Table S16. Input and output items in processes of aquaculture system.

Items	Equations	Activity data and parameters description
Fertilizer (freshwater)	$A_{fertilizer\text{-}1} = F18 \times R58 \times R59$	F18: the area of freshwater aquaculture R58: the amount of compound fertilizer per unit area of freshwater aquaculture R59: N content of compound fertilizer
Fertilizer (mariculture)	$A_{fertilizer\text{-}2} = A_{baits} \times R60$	R60: the percentage of compound fertilizer and baits in mariculture
Bait	$A_{bait} = F19 \times R61 \times R62$	F19: the production of aquaculture R61: the ratio of feed in aquaculture R62: The N content of bait in aquaculture
Fry	$A_{fry} = F20 \times R63$	F20: the amount of fry per unit area R63: the N content of various fry
Deposition	$A_{deposition\text{-}1} = F18 \times R4$ $A_{deposition\text{-}2} = F21 \times R4$	F21: the area of freshwater maricultuer
BNF	$A_{BNF} = F22 \times R64$	F22: The amounts of algae R64: The N content of algae
Fish biomass	$A_{fish-biomass} = F19 \times R65$	R65: The N content of aquaculture
Runoff	$A_{runoff} = A_{loss} \times R66$	R66: the factor of runoff
Denitrification	$A_{denitrification} = A_{loss} \times R67$	R67: the factor of denitrification
Ammonia-volatilization	$A_{NH_3} = A_{loss} \times R68$	R68: the factor of ammonia volatilization

N2O	$A_{N_2O} = A_{loss} \times R69$	R69: the factor of N_2O

Table S17. The parameter of aquaculture system.

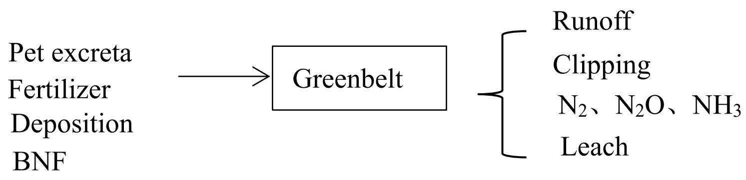
NO.	**Item description**	**Unit**	**Reference**	**Value**
R58	the amount of compound fertilizer per unit area of freshwater aquaculture	$kg.hm^{-2}$	[62]	225.52
R59	N content of compound fertilizer	%	[63]	33.3
R60	the percentage of compound fertilizer and baits in mariculture	%	[80];[81]	20
R61	the ratio of bait in aquaculture	%	[7]	Fish:2; shrimp:1.5;crab:2
R62	The N content of bait in aquaculture	%	[81]	Fish:6.4; shrimp:4.96;crab:5.76
R63	the N content of various fry	%	[62]	Fish:2.45; shrimp:2.43;crab:2.22
R64	The N content of algae	%	[7]	2.7
R65	The N content of aquaculture	%	[7]	Fish:3;shrimp:2.9;crab:2.9;shellfish:2.1
R66	the factor of runoff	%	[81]	10
R67	the factor of denitrification	%	[77]	50
R68	the factor of ammonia volatilization	%	[77]	15
R69	the factor of N_2O	%	[81]	1.25

Table S18. The activity data of aquaculture system.

No.	Item description	Unit	Ref
F18	the area of freshwater aquaculture	Hm^2	[75]
F19	the production of aquaculture	T	[75]
F20	the amount of fry per unit area	Kg/hm^2	[75]
F21	the area of freshwater maricultural	Hm^2	[75]

Greenbelt system

- Model of N flow in greenbelt system



- Equation

According to the green space system nitrogen flow model the input-output is shown above. We divided it into the city lawn and city forest. This section describes in detail the calculation of each input item, coefficients and activity data. The equation of green space system can be calculated using the following method:

$$GR_{input-greenbelt} = GR_{deposition} + GR_{fertilizer} + GR_{BNF} + GR_{pet} \quad (7.1)$$

$$GR_{output\text{-}greenbelt} = GR_{clip} + GR_{runoff} + GR_{N_2O} + GR_{N_2} + GR_{NH_3} + GR_{leach} \quad (7.2)$$

Where $GR_{input-greenbelt}$ are the total nitrogen inputs of greenbelt; $GR_{output-greenbelt}$ are the total nitrogen outputs of greenbelt; $GR_{deposition}$ is nitrogen deposition of greenbelt; $GR_{fertilizer}$ is fertilizer applied to greenbelt; GR_{BNF} is biological nitrogen fixation in greenbelt ; GR_{pet} is pet excretion recycled to greenbelt; GR_{clip} is nitrogen output through grassland clipping; GR_{runoff} is water runoff from greenbelt; GR_{N_2O} is N_2O emission from greenbelt; GR_{N_2} is N_2 denitrification during nitrogen loss process in greenbelt; GR_{leach} is the nitrogen leaching through greenbelt; GR_{NH_3} is NH_3 volatilization from greenbelt;

Table S19. Input and output items in processes of green space system.

Items	**Equations**	**Activity data and parameters description**
BNF	$GR_{BNF} = F22 \times R70$	F22: Area of greenbelt R70: Nitrogen fixation rate of greenbelt

Fertilizer	$GR_{fertilizer} = F22 \times R71$	R71: fertilizer rate of greenbelt
Pet-excreta		Table25 in Pet system
Deposition	$GR_{depositon\text{-}lawn} = F22 \times R4$	
Runoff	$GR_{runoff} = GR_{fertilizer} \times R72 + GR_{pet} \times R73$	R72: Rate of fertilizer nitrogen runoff R73: Rate of manure nitrogen runoff
N_2O	$GR_{N_2O} = GR_{fertilizer} \times R74$	R74: Factor of N_2O emission in greenbelt
NH_3	$GR_{NH_3} = GR_{fertilizer} \times R75 + GR_{pet} \times R76$	R75: Factor of NH_3 emission from fertilizer R76：Factor of NH_3 emission from manure
Leach	$GR_{leach} = GR_{input} \times R77$	R77: Factor of leaching from greenbelt

Table S20. The parameter of green space system.

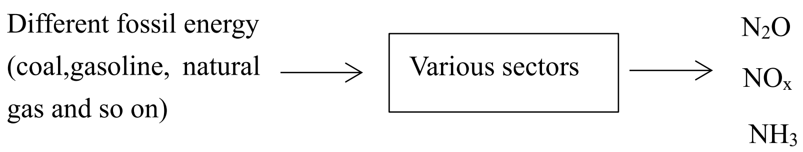
NO.	**Item description**	**Unit**	**Reference**	**Value**
R70	Nitrogen fixation rate of lawn	kg. ha^{-2}	[16]	18
R71	fertilizer rate of urban lawn	kg. ha^{-2}	[82]	300
R72	Rate of fertilizer nitrogen runoff	%	[19]	11
R73	Rate of manure nitrogen runoff	%	[19]	5
R74	Factor of N_2O emission in greenbelt	%	[19]	1.1
R75	Factor of NH_3 emission from fertilizer	%	[19]	11
R76	Factor of NH_3 emission from manure	%	[19]	23
R77	Factor of leaching from lawn	%	[77]	3.2

Table S21. The activity data of green space system.

No.	**Item description**	**Unit**	**Ref**
F22	Area of urban lawn	Ha^2	[75]
F23	Forest volume	M^3	[75]
F24	Area of forest	Ha^2	[75]

Energy system

- Model of N flow in energy system



- Equation

According to the energy system nitrogen flow model the input-output are shown above. We based on mass balance the input is estimated according to the output. This section describes in detail the calculation of each input item, coefficients and activity data. The equation of energy system can be calculated using the following method:

$$E_{input} = E_{output} \quad (8.1)$$

$$E_{output} = E_{N_2O} + E_{NO_X} + E_{NH_3} \quad (8.2)$$

where E_{input} and E_{output} are the total nitrogen input and output to energy system; E_{N_2O} is the N_2O emission from fossil fuel combustion; E_{NO_x} is the NO_x emission from fossil fuel combustion; E_{NH_3} :is the NH_3 emission.

Table S22. Input and output items in processes of green space system.

Items	Equations	Activity data and parameters description
NO_X	E_{NO_X}=(1-R78)$\times F26 \times R79$	F26: Energy consumption of various sector R78: Removal rate of NO_x- R79: Factor of energy sector NO_x-N emission
N_2O	E_{N_2O}=F26$\times$R80$\times$R81	R80: Factor of energy sector N_2O emission R81: Conversion of fuel calorific value

NH_3	$E_{NH_3} = F27 \times R82$	F27: vehicle-miles of travel R82: Factor of vehicle-miles of travel NH_3 emission

Table S23. The parameter of energy system.

NO.	**Item description**	**Unit**	**Reference**	**Value**
R78	Removal rate of NO_X	%	[82]	30
R79	Factor of energy sector NO_X-N emission	Kg/t	[50]	Table S23-a
R80	Factor of energy sector N_2O emission	kg/TJ	[50]	Table S23-b
R81	Conversion of fuel calorific value	kJ/kg; kJ/m^3	[50]	Table S23-c
R82	Factor of vehicle-miles of travel NH_3 emission	g/km	[50]	Table S23-d

Table S24. The activity data of energy system.

No.	Item description	Unit	Ref
F25	Energy consumption of various sector		[75]

Table S23-a. Factor of energy sector NO_X emission(kg/t).

Sector	**Emission source**	**Coal**	**Coke**	**Crude oil**	**Gasoline**	**Kerosene**	**Diesel**	**Fuel oil**	**Natural gas**
Energy	Electric	9.95		7.24	16.7	21.2	7.4	10.06	41
	Manufacture	0.75	0.9	2.19			9.62	5.84	
	Oil refining	0.37		0.24					
Construction		7.5	9		16.7	7.46	9.62	5.84	20.9
Transportation	Highway				21.2	27.4	27.4	27.4	
	Railway	7.5	9				54.1	54.1	
	others	7.5	9	5.09	16.7	27.4	36.3	36.3	20.9
Consumption		1.88	2.25	1.7	16.7	2.49	3.21	1.95	14.6
Commerce		3.75	4.5	3.05	16.7	4.48	5.77	3.5	14.6
Agriculture		3			6.7		9.4		
others		3.75	4.5	3.05	16.7	4.48	5.77	3.5	14.6

Table S23-b. Factor of energy sector N_2O emission (kg/TJ).

Sector	Coal	Coke	Crude oil	Gasoline	Kerosene	Diesels	Natural gas
Consumption	1.5	1.5	0.6	0.6	0.6	0.6	0.1
Transportation				3.2	2	3.9	0.1
Agriculture	1.5	1.5	0.6	0.6	0.6	0.6	0.1
Construction	1.5	1.5	0.6	0.6	0.6	0.6	0.1
Commerce	1.5	1.5	0.6	0.6	0.6	0.6	0.1

Table S23-c. Conversion of fuel calorific value (kJ/kg; kJ/m^3).

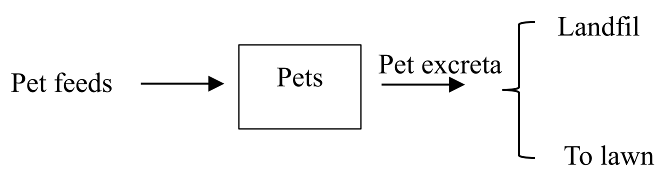
Item	Lower calorific value
Coal	20908
Coke	28435
Coal gas	16726
Crude oil	41816
Gasoline	43070
Kerosene	43070
Diesel	42652
Fuel oil	41816
Natural gas	38931

Table S23-d. Factor of vehicle-miles of travel NH_3 emission.

	Factor of NH_3 emission g/km
Heavy-duty car	0.028
light car	0.026
Heavy-duty diesel car	0.017
Light diesel car	0.017

Pet system

- Model of N flow in pet system



- Equation

According to the pet system nitrogen flow model the input-output are shown above. This section describes in detail the calculation of each input item, coefficients and activity data. The equation of pet system can be calculated using the following method:

$$P_{input} = P_{feeds} \quad (9.1)$$

$$P_{output} = P_{landfill} + P_{lawn} \quad (9.2)$$

Where P_{input} and P_{output} are the total nitrogen input and output to pet system; P_{feeds} is pet feed input including dog and cat feed; $P_{landfill}$ is pet excretion which is sent to landfill; P_{lawn} is pet excretion which is recycled to urban lawn.

Table S25. Input and output items in processes of pet.

Items	Equations	Activity data and parameters description
Feeds	P_{feeds}=F12/13×(R83×R84×R85+R86×R87×R88)	R83: The proportion of the dog R84: The weight of dog R85: The per kilogram of dog needs nitrogen for per day R86: The proportion of the cat R87: The weight of cat R88: The per kilogram of dog needs nitrogen for per day
Landfill	$P_{landfill} = P_{excretion-cat} / 2$	$P_{excretion-cat}$: the excretion of cat
Greenbelt	$P_{greenbelt} = P_{excretion-cat} / 2 + P_{excretion-dog}$	$P_{excretion-dog}$: the excretion of dog

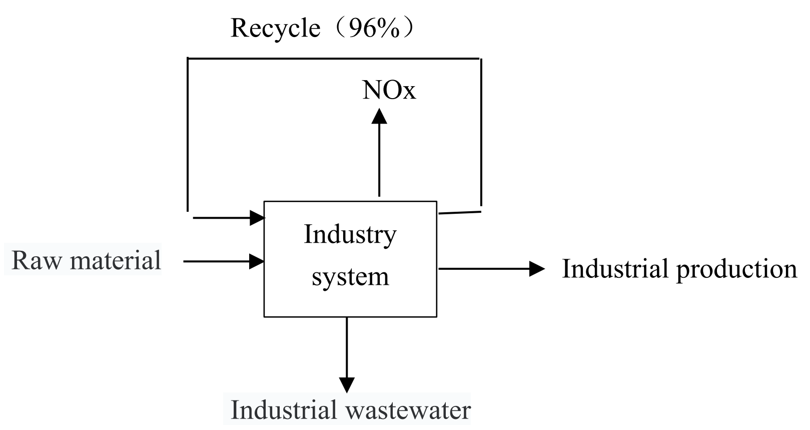
Table S26. The parameter of pet system.

NO.	Item description	Unit	Reference	Value
R83	The proportion of the dog	%	[62]	69.2
R84	The weight of dog	kg	[16]	20

R85	The per kilogram of dog needs nitrogen for per day	g/kg	[16]	0.56
R86	The proportion of the cat	%	[62]	30.8
R87	The weight of cat	kg	[16]	3.6
R88	The per kilogram of dog needs nitrogen for per day	g/kg	[16]	0.88

Industry system

- Model of N flow in industry system



- Equation

According to the industry system nitrogen flow model the input-output are shown above. Ammonia synthesis industry and nitrogen fertilizer production is less in Xiamen, so we ignore the ammonia emission. Due to the lack of data, we only calculate NOx emission and waste water. These data come from local government statistical documents. The equation of industry system can be calculated using the following method:

$$I_{input} = I_{material} \quad (10.1)$$

$$I_{output} = I_{production} + I_{waste-water} + I_{NO_X} \quad (10.2)$$

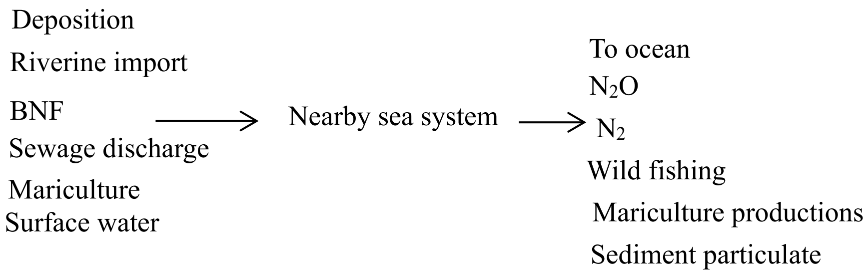
Where I_{input} and I_{output} are the total nitrogen input and output to industry system; $I_{material}$ is raw materials for industrial production; $I_{production}$ is industrial production; $I_{water-water}$ is the waste water discharge from industry; I_{NO_x} is NOx emission during industrial production.

Table S27. Input and output items in processes of industry system.

Item	Value (Gg)	Reference
$I_{waste-water}$	0.11	[62]
I_{NO_X}	11.7	[62]

Nearby sea system

- Model of N flow in coastal system



- Equation

According to the coastal system nitrogen flow model the input-output are shown above. This section describes in detail the calculation of each input item, coefficients and activity data. The equation of nearby sea system can be calculated using the following method:

$$O_{input} = O_{deposition} + O_{riverine} + O_{BNF} + O_{sewage-discharge} + O_{mariculture} + O_{surfacewater} \quad (11.1)$$

$$O_{output} = O_{wild-fish} + O_{N_2} + O_{N_2O} + O_{mariculture-productions} + O_{to-ocean} + O_{sediment-particulate} \quad (11.2)$$

Where O_{input} and O_{output} are the total nitrogen input and output to nearby sea system; $O_{deposition}$ is atmospheric deposition to coastal region; $O_{riverine}$ is riverine import from out of system; O_{BNF} is the microbial nitrogen fixation in coastal; $O_{sewage-discharge}$ is the tail water from sewage treatment plants; $O_{surfacewater}$: the surface water from inland to near sea; $O_{mariculture}$ is nitrogen from marine aquaculture in coastal; $O_{wild-fish}$: The total amount of wild fish $O_{mariculture-productions}$ is the nitrogen of marine catch productions; O_{N_2} is denitrification in nearby sea mainly including N_2; O_{N_2O} is N_2O emission from nearby sea; $O_{sediment-particulate}$ is particulate nitrogen sediment; $O_{to-ocean}$ is nitrogen transferred to further ocean.

Table S28. Input and output items in processes of coastal system.

Items	Equations	Activity data and parameters description
Deposition	$O_{deposition}$=F26×R4	F26: Area of coastal
Riverine import	$O_{riverine}$=F27×R89	F27: The inflow of river into the sea R89: The N content of river
BNF	$O_{riverine}$=F26×R90	R90: The rate of microbial nitrogen fixation
Tail water	$O_{sewage-discharge}$=$S_{tail-water}$	Table10 Sewage system
Mariculture	$O_{mariculture}$=$A_{fertilizer-2}+A_{bait}$	Table16 Aquaculture system
Wild fish	$O_{wild-fish}$=F28×R65	F28: Wild catches
Mariculture productions	$O_{mariculture-productions}$=F29×$R$65	F29: Mariculture productions
Denitrification	$O_{denitrification}$=F26×R91	R91: Rate of denitrification
N_2O	O_{N_2O}=F26×R92	R92: Rate of N_2O
Sediment of particulate N	O_{N_2O}=O_{input}×R93×R94	R93: Particle inorganic nitrogen ratio R94: Particle sediment ratio

Table S29. The parameter of coastal system.

NO.	Item description	Unit	Reference	Value
R88	The N content of river	Mg/L	[40]	3.22
R89	The rate of microbial nitrogen fixation	Mg N/m^2.d	[83]	25
R90	Rate of denitrification	Umol.m^{-2}.h^{-1}	[84]	239.9-707.7

R91	Rate of N_2O	Umol.m^{-2}.h^{-1}	[85]	0-4.68
R92	Particle inorganic nitrogen ratio	%	[86]	4.24
R93	Particle inorganic nitrogen ratio	%	[86]	57

Table S30. The activity data of coastal system.

No.	Item description	Unit	Reference
F26	Area of coastal	ha	[75]
F27	The inflow of river into the sea	M^3	Field survey
F28	marine catches	T	[75]

Reference

63. Ti, C.; Pan, J.; Xia, Y.; Yan, X. A nitrogen budget of mainland China with spatial and temporal variation. *Biogeochemistry* **2012**, *108*, 381–394.
64. Yan, W.; Yin, C.; Zhang, S. Nutrient budgets and biogeochemistry in an experimental agricultural watershed in Southeastern China. *Biogeochemistry.* **1999**, *45*, 1–19.
65. Chen, N.W.; Hong, H.S.; Huang, Q.J.; Wu, J.Z. Atmospheric nitrogen deposition and its long-term dynamics in a southeast China coastal area. *J. Environ. Manag.* **2011**, *92*, 1663–1667.
66. Zhou, T.; Wang, Y.; Wang, F.; Feng, Y. Analysis of the nitrogen footprint of agriculture in Guangdong. *China Environ. Sci.* **2014**, 34, 2430–2438.
67. Wang, M.; Ma, L.; Strokal, M.; Ma, W.Q.; Liu, X.J.; Kroeze C. Hotspots for nitrogen and phosphorus losses from food production in China: A county-scale analysis. *Environ. Sci. Technol.* **2018**, *52*, 5782–5791.
68. Cui, S.; Shi, Y.; Groffman, P.M.; Schlesinger, W. H.; Zhu, Y.G. Centennial-scale analysis of the creation and fate of reactive nitrogen in China (1910–2010). *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 2052–2057.
69. Ma, L.; Velthof, G.L.; Wang, F.H.; Qin, W.; Zhang, W.F.; Zhang, F.S.; Oenema, C. Nitrogen and phosphorus use efficiencies and losses in the food chain in China at reginal scales in 1980 and 2005. *Sci. Total Environ*. **2012**, *434*, 51–61.
70. Zheng, X.; Han, S.; Huang, Y.; Wang, Y.; Wang, M. Re-quantifying the emission factors based on field measurements and estimating the direct N_2O emission from Chinese croplands. *Glob. Biogeochem*. Cycles **2004**, *18*, GB2018.
71. Möller, D.; Schieferdecker, H. Ammonia emission and deposition of NHx in the GDR. *Atmos. Environ.* **1989**, *23*, 1187–1193.
72. Cai, B.F. *City's Greenhouse Gas (GHG) Emission Inventory Research*; Chemical Industry Press: Beijing, China, 2009. (In Chinese).
73. Ma, L.; Ma, W.Q.; Velthof, G.L.; Wang, F.H.; Qin, W.; Zhang, F.S.; Oenema, O. Modeling nutrient flows in the food chain of China. *J. Environ. Qual.* **2010**, *39*, 1279–1289.
74. Min, J.; Shi, W. Nitrogen discharge pathways in vegetable production as non-point sources of pollution and measures to control it. *Sci. Total Environ*. **2018**, *613*, 123–130.
75. NBS. *Xiamen Statistic Yearbook*; Xiamen Bureau of Statistics of China: Xiamen, China, 2015. (In Chinese).
76. Liao, C.; Xia, Y.; Wu, D. Nitrogen flows associated with food production and consumption system of Shanghai. *Environ. Pollut*. **2021**, 279, 116906.
77. Gu, B.; Ju, X.; Chang, J.; Ge, Y.; Vitousek, P.M. Integrated reactive nitrogen budgets and future trends in China. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 8792–8797.
78. Huang, X.; Song, Y.; Li, M.; Li, J.; Huo, Q.; Cai, X.; Zhang, H. A high-resolution ammonia emission inventory in China. *Glob. Biogeochem. Cycles*. **2012**, *26*, 1030.
79. Xian, C.; Ouyang, Z.; Lu, F.; Xiao, Y.; Li, Y. Quantitative evaluation of reactive nitrogen emissions with urbanization: A case study in Beijing megacity, China. *Environ. Sci. Pollut. Res.* **2016**, *23*, 17689–17701.
80. Crab, R.; Avnimelech, Y.; Defoirdt, T.; Bossier, P.; Verstraete, W. Nitrogen removal techniques in aquaculture for a sustainable production. *Aquaculture* **2007**, *270*, 1–14.

81. Shu, T.F.; Wen, Y.M.; Tang Y.T. Cycle and budget balance of nitrogen in the cultivated water. *Fish. Sci.* **2002**, *21*, 30–34. (In Chinese).
82. Zhang, R.L. Research advances on fertilizer application to lawn. *Chin. J. Trop. Agric.* **2002**, *22*, 77–81. (In Chinese).
83. Xu, J.R.; Wang, Y.S.; Sun, S. The characteristics of nitrogen fixation, ammonification, nitrification and denitrification in coastal zones. *Acta Ecol. Sin.* **2004**, *24*, 2907–2914(In Chinese).
84. Hu, W.; Huaiyang, Z.; Xiaotong, P.; Qunhui, Y.; Chaomei, Q.; Xijie, Y.; Guangqian, C. Denitrification in Qi'ao Island coastal zone, the Zhujiang Estuary in China. *Acta Oceanol. Sin.* **2009**, *28*, 37–46. (In Chinese).
85. Yan, W.; Yang, L.; Wang, F.; Wang, J.; Ma, P. Riverine N_2O concentrations, exports to estuary and emissions to atmosphere from the Changjiang River in response to increasing nitrogen loads. *Glob. Biogeochem. Cycles* **2012**, *26*, 4006.
86. Yu, Y.; Song, J.; Li, X.; Yuan, H.; Li, N. Distribution, sources and budgets of particulate phosphorus and nitrogen in the East China Sea. *Cont. Shelf Res.* **2012**, *43*, 142–155.