Supporting Text S1

The description of the stable isotopic analysis:

In this study, nitrate stable isotopic analysis can be divided into two parts, i.e., surface water analysis and determination of end-member values.

For surface water analysis, A cadmium column was used to reduce NO_3^- to nitrite (NO_2^-) at a pH of 8.0; (2) the azide method (Eq. 1) was applied to convert NO_2^- to nitrous oxide (N_2O).

$$\delta^{15}N_{Air}(N_2O) = \frac{\delta^{15}N_{Air}(N_3^-) + \delta^{15}N_{Air}(NO_2^-)}{2} = \frac{\delta^{15}N_{Air}(N_3^-) + \delta^{15}N_{Air}(NO_3^-)}{2} \quad (1)$$

To determine the end-member values, five types of potential NO_3^- sources were collected in the field. Liquid samples can be determined directly, i.e., rainwater and tailwater. Pre-treatment for isotopic analysis: 25 mL of KCl (2 mol L^{-1}) was added to 5 g of the solid sample (i.e., manure, fertilizer, or soil). After oscillating the mixture at 200 rpm for 2 hours, the supernatant was filtered through a 0.45-μm filter. Liquid samples were filtered through 0.45-μm glass fiber filters and diluted to 40 μmol N L^{-1} for further isotopic analysis.

The $\delta^{15}N$ and $\delta^{18}O$ of NO_3^- were measured using an isotope ratio mass spectrometer (DELTA Q, Thermo Fisher Scientific) equipped with Gasbench system (Gasbench Plus, Thermo Fisher Scientific) and automatic sampler (TriPlus RSH, Thermo Fisher Scientific).

Supporting Text S2

The description of the stable isotopic analysis:

The MixSIAR is an R package that can run Bayesian mixing models to analyze biotracer data (stable isotopes, fatty acids). The MixSIAR incorporates several years of advances in Bayesian mixing model theory since MixSIR and SIAR. The model can generate multiple models based on the research data and objectives, allowing situation-specific conditions within the mixing system. The mass conservation equation (2) is expressed as follows

$$X_{ij} = \sum_{k=1}^{n_S} p_{ik} S_{kj} + \varepsilon_{ij} \qquad (2)$$

Where X_{ij} is the value of the *j*th tracer (isotopic composition) for the *i*th sample; n_S represents the number of sources; p_{ik} denotes the proportional contribution of the *k*th source to the *i*th sample; S_{kj} denotes the value of the *j*th tracer in the *k*th source; ε_{ij} represents the error of the *j*th tracer (isotopic composition) for the *i*th sample.

Table S1

The parameters in the crop-production system.

Parameter		Unit	Species					
			Rice	Wheat	Cole	Vegetables	Fruits	Soybean
N application level		kg ha^{-1}	179.0	312.0	216.0	490.7	689.9	216.0
Seeding rate		kg ha^{-1}	69.2	225.0	62.13	2.8	0	67.5
Grain N content		%	1.4	2.1	3.8	0.2	0.1	5.3
Grain fate	Ration	%	86.0	88.0	100	5.0	57.0	88.0
	Fodder	%	6.0	2.0	0	30.0	30.0	8.0
	Other uses	%	8.0	10.0	0	65.0	13.0	4.0
Ration fate	Fodder	%	13.0	28.0	73.0	38.0	38.0	0.0
	Fertilizer	%	0	0	20.0	0	0	0
	Plant-oriented food	%	85.0	70.0	5.0	60.0	60.0	60.0
	Other uses	%	2.0	2.0	2.0	2.0	2.0	14.1
Straw	Straw returned to the field	%	41.7	40.2	34.1	2.2	0	16.8
	Fuel	%	25.5	20.3	26.6	0	0	41.6
	Field burning	%	7.82	9.0	12.5	0	0	4.1
	Fodder	%	16.2	14.3	20.4	0	0	34.4
	Material	%	5.6	8.3	1.0	0	0	1.2
	Yarding	%	3.1	7.9	5.4	0	0	4.1
Biological N fixation rate		kg ha^{-1}	40.1	18.8	85.0	15.0	17.0	77.0
Atmospheric N deposition rate		kg ha^{-1}	36.3	36.3	36.3	36.3	36.3	36.3
Irrigation water N content		kg ha^{-1}	26.3	26.3	26.3	26.3	26.3	26.3
Fertilizer NH_3 volatilization rate		%	11.6	2.1	9.7	9.7	9.7	5.5
Manure NH_3 volatilization rate		%	20.0	20.0	20.0	20.0	20.0	20.0
Fertilizer N_2 emission rate		%	37.0	37.0	37.0	37.0	37.0	37.0
Fertilizer N_2O emission rate		%	1.3	1.3	1.3	1.3	1.3	1.3
Manure N_2 emission rate		%	20.0	20.0	20.0	20.0	20.0	20.0
Fertilizer N losses from runoff		%	0	4.2	3.2	1.1	6.4	9.0
Manure N losses from runoff		%	20.0	20.0	20.0	20.0	20.0	20.0
Fertilizer N losses from leaching		%	0.3	3.4	4.4	30.0	30.0	30.0
Manure N losses from leaching		%	5.0	5.0	5.0	5.0	5.0	5.0

Table S2

The parameters in the LBS.

Parameter	Unit	Species			
		pig	cattle	sheep	poultry
Meat percent	%	50.0	45.0	55.0	65.0
Bone percent	%	13.0	20.0	24.0	20.0
By-products percent	%	37.0	35.0	21.0	15.0
Meat N content	%	2.0	3.0	3.0	3.0
Bone N content	%	1.9	1.9	1.9	2.6
By-products N content	%	2.2	2.2	2.2	1.5
Egg N content	%				2.2
Excreta N content	kg cap^{-1}	11.5	48.8	5.8	0.4
Rate of livestock excreta returning to the field	%	18.0	27.0	11.5	11.0
Volatilization rate of livestock excreta	%	22.9	17.9	26.2	25.4
Proportion of livestock excreta entering the water bodies	%	59.1	55.1	62.3	63.6

Table S3

The parameters of kitchen waste in the HCS.

Parameter		Unit	City	Rural
Vegetalitas N consumption		kg yr^{-1}	1.38	3.02
Animal N consumption		kg yr^{-1}	1.98	1.21
Food N absorbed by the body		%	2.00	2.00
N production of kitchen waste		kg yr^{-1}	0.48	0.55
kitchen garbage	Fodder	%	5.00	100.00
	Entering the water bodies	%	45.00	0.00
	Other uses	%	50.00	0.00
Human urine and feces	Returned to the field	%	25.48	25.48
	NH_3 volatilization rate	%	24.00	24.00
	N_2O emission rate	%	0.50	0.50
	Entering the water bodies	%	67.43	67.43

Table S4

Spatial differences in physicochemical parameter variation in the surface water and ground water in TGRN.

	Dec. TGRN		Aug. TGRN		Jun. TGRN		GW TGRN	
	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD
T (°C)	10.2–12.2	11.5±0.5	31.4–34.4	32.1±0.7	30.8–34.2	31.9±1.0	18.6–34.5	25.2±5.0
DO (mg L^{-1})	7.00–11.47	9.65±1.29	1.33–9.56	4.11±2.07	3.31–15.39	5.48±2.83	2.16–6.40	4.81±1.21
EC (µS cm^{-1})	326.7–609.0	484.2±70.4	410.0–753.0	521.2±97.1	438.0–738.0	558.4±58.8	254.4–849.0	564.3±200.3
pH	7.70–8.08	7.88±0.10	7.42–8.66	7.71±0.30	7.41–8.93	7.67±0.39	6.92–7.72	7.37±0.20
TN (mg L^{-1})	1.73–5.56	3.39±0.75	3.75–6.02	4.72±0.74	2.08–3.87	3.31±0.51	0.65–36.58	6.55±8.59
NH_4^+ (mg L^{-1})	0.13–1.27	0.46±0.25	0.04–0.44	0.10±0.10	0.08–0.34	0.18±0.08	0.00–1.11	0.20±0.33
NO_3^- (mg L^{-1})	1.59–4.24	2.53±0.52	1.04–2.29	1.78±0.41	1.99–3.74	3.09±0.50	0.46–21.41	5.05±5.06
TP (mg L^{-1})	0.078–0.488	0.279±0.118	0.297–0.647	0.439±0.099	0.198–0.540	0.284±0.084	0.050–3.930	0.718±0.977
Cl^- (mg L^{-1})	19.26–63.73	31.57±11.45	13.93–39.50	21.54±7.05	23.80–125.28	65.32±20.77	2.97–144.23	61.37±38.21

Note: Dec. TGRN, Aug. TGRN, Jun. TGRN and GW TGRN refer to the samples collected from the Tai-ge Canal river network area of Wujin District in December 2021, August 2023, and June 2025, groundwater, respectively.

Table S5

Spatial differences in physicochemical parameter variation in the surface water and ground water in LRN.

	Dec. LRN		Aug. LRN		Jun. LRN		GW LRN	
	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD
T (℃)	10.8–12.1	11.6±0.4	30.3–34.5	31.9±1.3	24.4–28.6	26.0±1.5	18.9–24.5	21.7±1.8
DO (mg L^{-1})	3.13–23.93	13.91±4.58	1.38–8.54	3.98±2.32	2.04–5.83	3.71±1.28	2.64–8.68	5.42±1.93
EC (µS cm^{-1})	234.8–443.9	370.0±51.4	298.2–528.0	410.2±56.4	362.6–595.0	468.6±54.5	175.8–1392.0	525.7±332.9
pH	7.89–8.43	8.17±0.14	7.23–7.85	7.49±0.20	6.98–7.49	7.22±0.17	6.77–7.77	7.25±0.31
TN (mg L^{-1})	1.49–3.96	2.37±0.77	1.17–6.29	2.76±1.24	2.97–21.23	8.03±4.85	1.09–17.73	8.34±4.88
NH_4^+ (mg L^{-1})	0.03–2.41	0.35±0.58	0.12–5.25	0.69±1.28	0.17–0.87	0.34±0.20	0.00–0.30	0.09±0.10
NO_3^- (mg L^{-1})	0.62–2.88	1.38±0.59	0.33–1.76	0.84±0.41	2.78–17.22	7.32±4.05	0.25–15.05	7.57±4.45
TP (mg L^{-1})	0.056–0.278	0.132±0.056	0.102–1.211	0.506±0.290	0.164–5.706	1.706±1.665	0.072–2.674	01.021±0.820
Cl^- (mg L^{-1})	24.38–79.86	53.60±15.41	5.80–22.98	14.06±4.71	29.51–114.34	53.73±20.41	9.68–222.63	59.17±74.34

Note: Dec. LRN, Aug. LRN, Jun. LRN and GW LRN refer to the samples collected from the lakeside river network area of Yixing City in December 2021, August 2023, and June 2025, groundwater, respectively.

Table S6

Uncertainty analysis of TGRN during wet and dry flow seasons.

Source	P5–P95 Range	UI_{90}	Uncertainty level
AD	0–0.3%	0	Low
AW	0–2.1%	2×10^{-4}	Low
NF	43.9%–62.3%	2×10^{-3}	Low
M	36.4%–54.7%	2×10^{-3}	Low
SL	0–1.8%	2×10^{-4}	Low

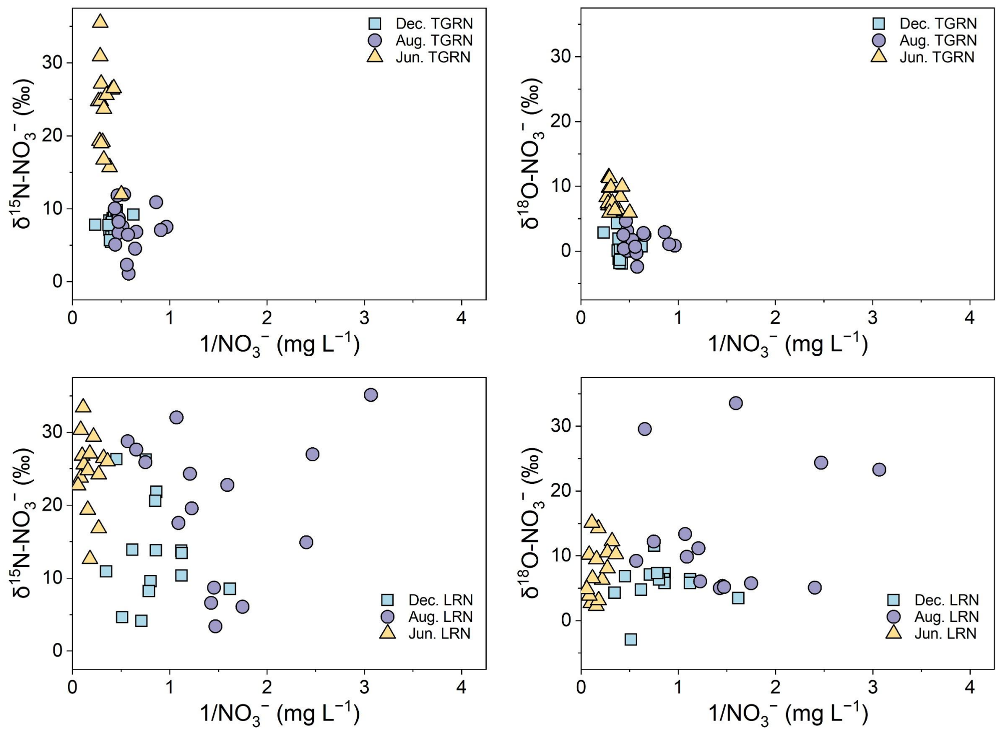

Fig. S1. Identification of potential NO_3^- yield processes at the time and catchment scales. Keeling plots of the ratio of $1/NO_3^-$ with $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$.

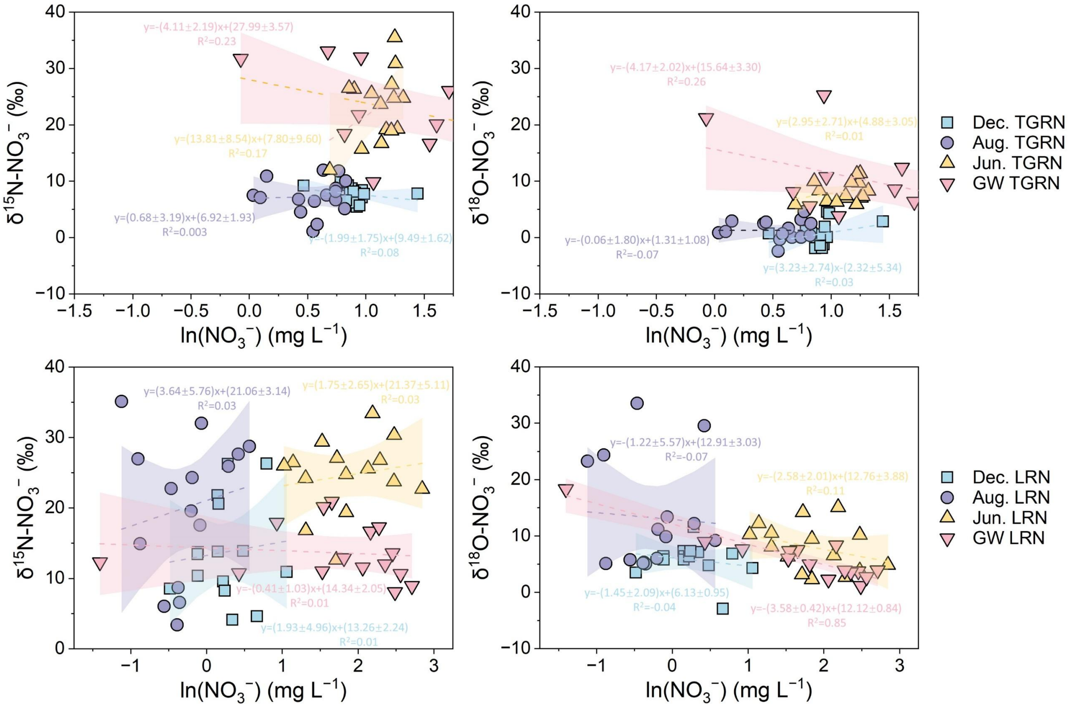

Fig. S2. The natural Ln of NO_3^- concentration versus $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$ in surface and groundwater.

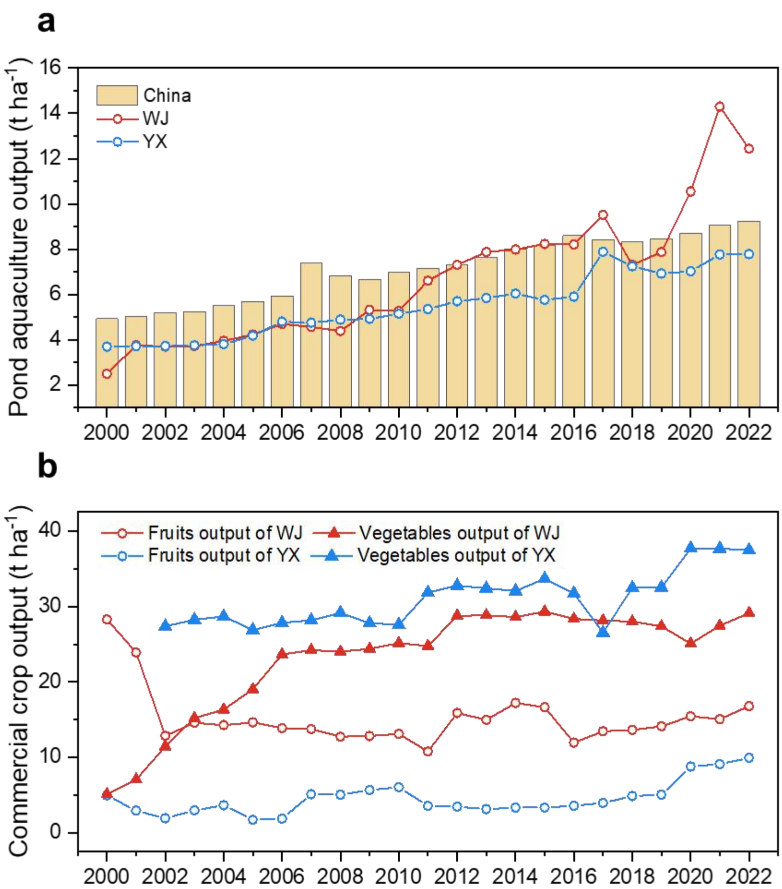

Fig. S3. Regional high-density and yield agricultural activities. (a) Unit pond aquaculture output of China, WJ (Wujin District), and YX (Yixing City). (b) Unit commercial crop output of WJ and YX.