



Supplement of

Characterization of variability of water and nutrient cycles in small floodplain water bodies using a geochemical multi-tracer

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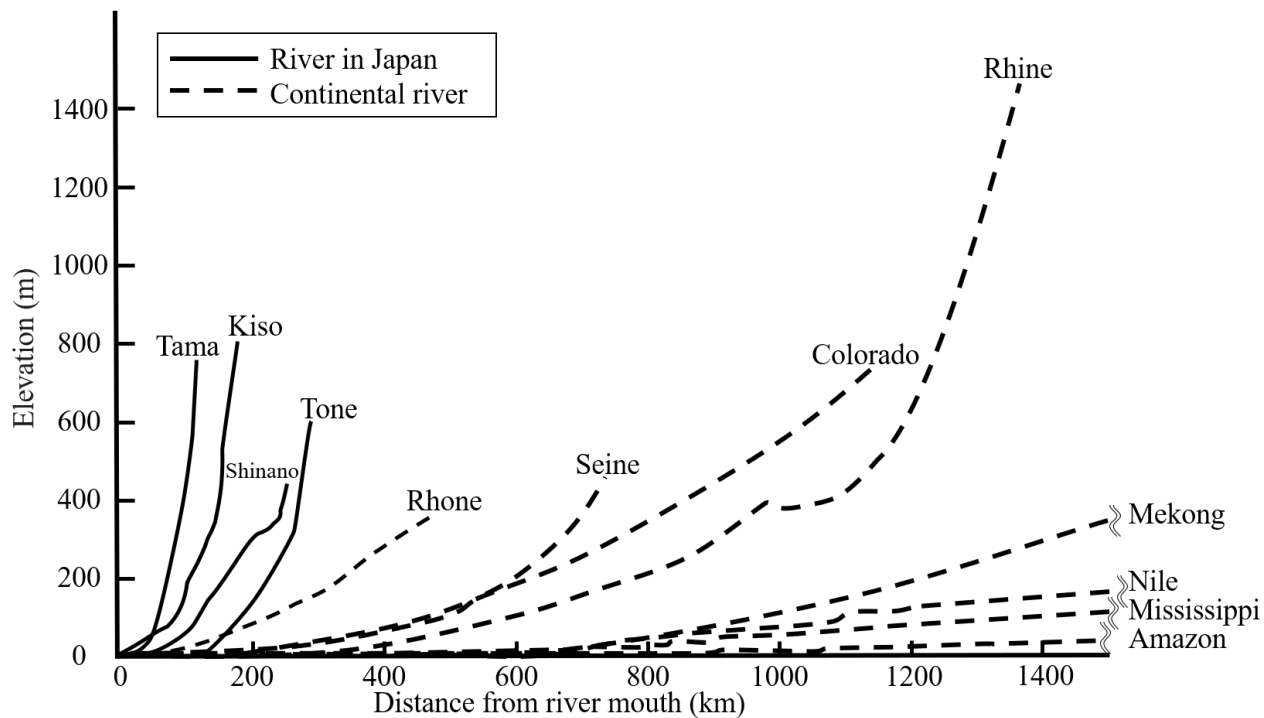


Figure S1 Schematic Diagram of River Length and Elevation in Japan and on the Mainland. Created based on Oguchi et al., 2001; solid lines indicate rivers in Japan, and dashed lines indicate rivers on the mainland.

Table S1 The maximum, minimum, average, and standard deviation of ²²²Rn concentrations at each location during the survey period. The values of each of the ²²²Rn categories in rivers and backwaters were calculated using measurement results from April to November 2022. For shallow groundwater, the values were calculated using data collected from six locations during the November 2022 survey.

	²²² Rn concentration (dpm L ⁻¹)				
	n	Max	Min	Mean	SD
Backwater A	7	617	204	474	136
River A	7	173	41	78	41
Backwater B ₁	7	589	317	498	84
Backwater B ₂	7	571	488	528	29
River B	7	278	40	100	79
Backwater C	7	692	293	487	145
River C	6	134	21	75	44
Shallow groundwater	6	1119	406	700	275

Table S2 The maximum, minimum, average, and standard deviation of hydrogen and oxygen isotope ratios at each location during the survey period.

Month	Backwater A			River A			Backwater B ₁		
	$\delta^{18}\text{O}\text{--H}_2\text{O}$ (‰)	$\delta^2\text{H}\text{--H}_2\text{O}$ (‰)	d-excess (‰)	$\delta^{18}\text{O}\text{--H}_2\text{O}$ (‰)	$\delta^2\text{H}\text{--H}_2\text{O}$ (‰)	d-excess (‰)	$\delta^{18}\text{O}\text{--H}_2\text{O}$ (‰)	$\delta^2\text{H}\text{--H}_2\text{O}$ (‰)	d-excess (‰)
2	−9.2	−61.3	12.3	−9.3	−61.4	12.8	−8.6	−58.6	10.1
4	−8.9	−57.8	13.6	−8.0	−51.9	11.9	−8.8	−56.9	13.6
5	−8.9	−57.2	13.6	−8.5	−59.2	8.6	−8.7	−58.9	10.3
6	−9.0	−58.5	13.3	−9.1	−60.6	12.5	−8.8	−58.6	11.4
7	−8.8	−57.9	12.9	−8.8	−58.7	11.5	−8.7	−56.8	12.5
9	−8.3	−57.5	8.8	−8.7	−58.7	11.0	−8.2	−54.5	10.9
10	−8.4	−55.7	11.3	−8.4	−56.4	10.9	−8.2	−54.5	11.3
11	−8.3	−55.5	10.6	−8.6	−57.0	11.7	−8.3	−54.6	11.5
Max	−8.3	−55.5	13.6	−8.0	−51.9	12.8	−8.2	−54.5	13.6
Min	−9.2	−61.3	8.8	−9.3	−61.4	8.6	−8.8	−58.9	10.1
Mean	−8.7	−57.7	12.0	−8.7	−58.0	11.4	−8.5	−56.7	11.4
SD	0.4	1.8	1.7	0.4	3.0	1.3	0.3	1.9	1.1

Month	Backwater B ₂			River B			Backwater C			River C		
	$\delta^{18}\text{O}\text{--H}_2\text{O}$ (‰)	$\delta^2\text{H}\text{--H}_2\text{O}$ (‰)	d-excess (‰)	$\delta^{18}\text{O}\text{--H}_2\text{O}$ (‰)	$\delta^2\text{H}\text{--H}_2\text{O}$ (‰)	d-excess (‰)	$\delta^{18}\text{O}\text{--H}_2\text{O}$ (‰)	$\delta^2\text{H}\text{--H}_2\text{O}$ (‰)	d-excess (‰)	$\delta^{18}\text{O}\text{--H}_2\text{O}$ (‰)	$\delta^2\text{H}\text{--H}_2\text{O}$ (‰)	d-excess (‰)
2	n.d.	n.d.	n.d.	−9.3	−61.9	12.3	−8.3	−55.6	10.7	−9.2	−59.5	14.1
4	−8.6	−58.6	10.2	−8.3	−55.4	10.7	−9.0	−58.0	14.1	−8.3	−53.6	13.1
5	−8.6	−57.9	11.2	−8.5	−59.0	8.6	−9.2	−59.4	14.1	−8.7	−59.4	10.3
6	−8.3	−57.6	9.1	−9.2	−60.8	12.6	−8.7	−57.3	11.9	−9.2	−62.2	11.2
7	−8.2	−58.5	7.5	−8.8	−58.4	11.9	−8.5	−57.5	10.1	−8.7	−58.6	11.1
9	−8.0	−55.1	8.6	−8.8	−59.4	10.8	−8.4	−56.5	10.5	−8.7	−59.0	10.6
10	−8.1	−53.9	10.9	−8.7	−55.2	14.5	−8.2	−55.9	9.9	−8.6	−56.4	12.4
11	−8.2	−55.1	10.5	−8.5	−57.9	9.8	−8.2	−56.7	9.3	−8.5	−55.5	12.6
Max	−8.0	−53.9	11.2	−8.3	−55.2	14.5	−8.2	−55.6	14.1	−8.3	−53.6	14.1
Min	−8.6	−58.6	7.5	−9.3	−61.9	8.6	−9.2	−59.4	9.3	−9.2	−62.2	10.3
Mean	−8.3	−56.7	9.7	−8.7	−58.5	11.4	−8.6	−57.1	11.3	−8.7	−58.0	11.9
SD	0.2	1.9	1.4	0.4	2.3	1.8	0.4	1.2	1.9	0.3	2.7	1.3

Table S3 Nutrient concentrations (NH₄⁺, NO₃⁻, PO₄³⁻, DSi), nutrient ratios (DIN/DIP, DIN/DSi), and stable isotope ratios of nitrogen and oxygen in nitrate (δ¹⁵N–NO₃ and δ¹⁸O–NO₃) at Backwater A and River A, February–November 2022. Note: N/A = not applicable; n.d. = not detected.

Month	Backwater A				DIN/DIP	DIN/DSi	δ ¹⁵ N–NO ₃ (‰)	δ ¹⁸ O–NO ₃ (‰)
	NH ₄ ⁺ (μmol L ⁻¹)	NO ₃ ⁻ (μmol L ⁻¹)	PO ₄ ³⁻ (μmol L ⁻¹)	DSi (μmol L ⁻¹)				
2	1.7	297	7.6	175	39	1.7	N/A	N/A
3	1.0	249	9.0	189	28	1.3	N/A	N/A
4	0.8	102	4.8	270	21	0.4	15.4	0.5
5	0.3	113	5.6	276	20	0.4	15.7	-1.0
6	0.9	122	4.1	244	30	0.5	N/A	N/A
7	n.d.	153	5.9	242	26	0.6	N/A	N/A
9	0.9	76	5.2	238	15	0.3	N/A	N/A
10	3.3	122	5.2	248	24	0.5	17.5	3.6
11	0.3	122	5.9	225	21	0.5	15.8	1.1

Month	River A				DIN/DIP	DIN/DSi	δ ¹⁵ N–NO ₃ (‰)	δ ¹⁸ O–NO ₃ (‰)
	NH ₄ ⁺ (μmol L ⁻¹)	NO ₃ ⁻ (μmol L ⁻¹)	PO ₄ ³⁻ (μmol L ⁻¹)	DSi (μmol L ⁻¹)				
2	2.9	272	7.2	191	38	1.4	N/A	N/A
3	0.9	264	10.6	199	25	1.3	N/A	N/A
4	2.1	142	4.2	164	34	0.9	15.0	0.8
5	0.9	179	6.1	167	29	1.1	17.6	-0.5
6	1.8	206	4.1	194	50	1.1	N/A	N/A
7	n.d.	243	5.0	174	48	1.4	N/A	N/A
9	1.3	106	3.7	201	29	0.5	N/A	N/A
10	1.3	173	5.7	199	31	0.9	12.8	-0.6
11	2.0	199	8.1	172	25	1.2	13.0	-1.0

Table S4 Nutrient concentrations (NH₄⁺, NO₃⁻, PO₄³⁻, DSi), nutrient ratios (DIN/DIP, DIN/DSi), and stable isotope ratios of nitrogen and oxygen in nitrate (δ¹⁵N–NO₃ and δ¹⁸O–NO₃) at Backwater B₁, B₂ and River B, February–November 2022. Note: N/A = not applicable; n.d. = not detected.

Backwater B ₁								
Month	NH ₄ ⁺ (μmol L ⁻¹)	NO ₃ ⁻ (μmol L ⁻¹)	PO ₄ ³⁻ (μmol L ⁻¹)	DSi (μmol L ⁻¹)	DIN/DIP	DIN/DSi	δ ¹⁵ N–NO ₃ (‰)	δ ¹⁸ O–NO ₃ (‰)
2	n.d.	174	1.4	277	125	0.6	N/A	N/A
3	n.d.	229	1.5	276	151	0.8	N/A	N/A
4	0.4	146	1.8	234	83	0.6	14.0	-0.6
5	0.2	141	1.5	264	94	0.5	15.2	0.2
6	0.5	192	2.0	276	97	0.7	N/A	N/A
7	n.d.	175	1.8	243	98	0.7	N/A	N/A
9	0.7	136	1.9	237	71	0.6	N/A	N/A
10	1.0	143	2.1	240	68	0.6	10.7	0.0
11	n.d.	143	2.3	210	61	0.7	11.9	0.9
Backwater B ₂								
Month	NH ₄ ⁺ (μmol L ⁻¹)	NO ₃ ⁻ (μmol L ⁻¹)	PO ₄ ³⁻ (μmol L ⁻¹)	DSi (μmol L ⁻¹)	DIN/DIP	DIN/DSi	δ ¹⁵ N–NO ₃ (‰)	δ ¹⁸ O–NO ₃ (‰)
4	1.0	130	1.4	257	91	0.5	N/A	N/A
5	n.d.	140	1.5	241	94	0.6	14.8	1.6
6	n.d.	165	1.5	260	111	0.6	N/A	N/A
7	n.d.	160	1.6	238	101	0.7	N/A	N/A
9	0.9	117	1.9	263	63	0.4	N/A	N/A
10	0.5	151	2.1	240	73	0.6	10.1	-1.0
11	n.d.	121	2.1	267	57	0.5	12.1	1.0
River B								
Month	NH ₄ ⁺ (μmol L ⁻¹)	NO ₃ ⁻ (μmol L ⁻¹)	PO ₄ ³⁻ (μmol L ⁻¹)	DSi (μmol L ⁻¹)	DIN/DIP	DIN/DSi	δ ¹⁵ N–NO ₃ (‰)	δ ¹⁸ O–NO ₃ (‰)
2	2.5	296	7.2	203	41	1.5	N/A	N/A
3	1.1	257	10.9	201	24	1.3	N/A	N/A
4	1.0	147	4.3	170	35	0.9	15.5	-1.0
5	2.8	180	6.6	200	27	0.9	17.8	-0.5
6	1.0	206	4.2	208	49	1.0	N/A	N/A
7	0.1	248	5.2	157	48	1.6	N/A	N/A
9	1.0	104	3.4	203	31	0.5	N/A	N/A
10	1.9	198	6.2	189	32	1.1	12.9	-1.9
11	1.5	202	8.5	172	24	1.2	13.7	-0.4

Table S5 Nutrient concentrations (NH₄⁺, NO₃⁻, PO₄³⁻, DSi), nutrient ratios (DIN/DIP, DIN/DSi), and stable isotope ratios of nitrogen and oxygen in nitrate (δ¹⁵N–NO₃ and δ¹⁸O–NO₃) at Backwater C and River C, February–November 2022. Note: N/A = not applicable; n.d. = not detected.

Backwater C								
Month	NH ₄ ⁺ (μmol L ⁻¹)	NO ₃ ⁻ (μmol L ⁻¹)	PO ₄ ³⁻ (μmol L ⁻¹)	DSi (μmol L ⁻¹)	DIN/DIP	DIN/DSi	δ ¹⁵ N–NO ₃ (‰)	δ ¹⁸ O–NO ₃ (‰)
2	3.4	59	2.4	236	26	0.3	N/A	N/A
3	n.d.	122	2.2	251	56	0.5	N/A	N/A
4	0.6	108	2.4	216	45	0.5	N/A	N/A
5	n.d.	97	2.8	213	35	0.5	24.1	7.0
6	n.d.	53	3.0	252	17	0.2	N/A	N/A
7	n.d.	26	3.2	199	8	0.1	N/A	N/A
9	0.3	30	3.6	225	8	0.1	N/A	N/A
10	0.8	20	3.1	189	7	0.1	20.1	6.2
11	0.3	18	3.3	199	6	0.1	35.7	15.9

River C								
Month	NH ₄ ⁺ (μmol L ⁻¹)	NO ₃ ⁻ (μmol L ⁻¹)	PO ₄ ³⁻ (μmol L ⁻¹)	DSi (μmol L ⁻¹)	DIN/DIP	DIN/DSi	δ ¹⁵ N–NO ₃ (‰)	δ ¹⁸ O–NO ₃ (‰)
2	n.d.	309	8.4	218	37	1.4	N/A	N/A
3	6.4	294	12.4	215	24	1.4	N/A	N/A
4	4.3	157	5.5	170	29	1.0	n.d.	n.d.
5	0.6	268	8.7	173	31	1.6	18.1	1.4
6	3.7	222	4.2	214	53	1.0	N/A	N/A
7	1.2	235	7.5	172	31	1.4	N/A	N/A
9	0.8	121	4.2	206	29	0.6	N/A	N/A
10	n.d.	228	10.7	206	21	1.1	13.8	-2.1
11	0.5	187	10.5	186	18	1.0	14.3	0.9

Table S6 Nutrient concentrations (NH_4^+ , NO_3^- , PO_4^{3-} , DSi), nutrient ratios (DIN/DIP , DIN/DSi), and stable isotope ratios of nitrogen and oxygen in nitrate ($\delta^{15}\text{N}\text{--NO}_3$ and $\delta^{18}\text{O}\text{--NO}_3$) at each shallow groundwater site, February–November 2022. Note: n.d. = not detected.

	Shallow groundwater							
	NH_4^+	NO_3^-	PO_4^{3-}	DSi	DIN/DIP	DIN/DSi	$\delta^{15}\text{N}\text{--NO}_3$ (‰)	$\delta^{18}\text{O}\text{--NO}_3$ (‰)
	($\mu\text{mol L}^{-1}$)	($\mu\text{mol L}^{-1}$)	($\mu\text{mol L}^{-1}$)	($\mu\text{mol L}^{-1}$)				
Spring 1	0.3	231	1.2	236	201	1.0	6.8	−1.5
Spring 2	n.d.	172	0.7	252	241	0.7	6.5	−1.5
Spring 3	n.d.	296	0.8	260	351	1.1	6.1	0.0
Spring 4	n.d.	223	0.8	333	289	0.7	6.4	−0.2
Spring 5	n.d.	356	0.8	332	441	1.1	6.9	−0.5
Spring 6	n.d.	132	1.3	730	100	0.2	1.7	1.7

Table S7 Average and standard deviation nutrient concentrations, measured as NO₃⁻ and PO₄³⁻, calculated from public water data at Tama Suidobashi, 2012–2021.

Source: Water Information System, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan.

Month	NO ₃ ⁻ (μmol L ⁻¹)		PO ₄ ³⁻ (μmol L ⁻¹)	
	Mean	SD	Mean	SD
1	356	81	10.8	1.6
2	359	34	11.0	2.0
3	344	45	11.1	2.4
4	289	14	11.1	1.3
5	275	51	10.8	3.0
6	294	36	11.6	1.8
7	242	51	6.9	2.7
8	230	59	7.0	2.3
9	226	47	9.5	2.4
10	242	48	8.2	1.6
11	302	20	9.7	2.2
12	339	34	8.9	2.2

Table S8 Water quality of the effluent in the upper reaches of Backwater A. The survey was conducted in February 2024.

parameters	
Electrical conductivity (mS m ⁻¹)	205
CDOM (ppb)	167
Alkalinity (ppb)	364
Na ⁺ (μmol L ⁻¹)	10768
K ⁺ (μmol L ⁻¹)	373
Mg ²⁺ (μmol L ⁻¹)	509
Ca ²⁺ (μmol L ⁻¹)	2401
Cl ⁻ (μmol L ⁻¹)	1989
SO ₄ ²⁻ (μmol L ⁻¹)	7124
NO ₃ ⁻ (μmol L ⁻¹)	54
NH ₄ ⁺ (μmol L ⁻¹)	2.0
PO ₄ ³⁻ (μmol L ⁻¹)	0.77
DSi (μmol L ⁻¹)	570