Journal of *Marine Science and Engineering*

MDPI

Supplementary Information

Assessment of Water Quality in a Coastal Region of Sea Dike Construction in Korea and the Impact of Low Dissolved Oxygen Concentrations on pH Changes

Yong-Woo Lee [1], Yong Hwa Oh [2], Sang Heon Lee [3], Dohyun Kim [1] and DongJoo Joung [3,*]

[1] Marine Environment Monitoring Department, Korea Marine Environment Management Corporation, Busan 49111, Republic of Korea; wbluesea@koem.or.kr (Y.-W.L.); dhkim@koem.or.kr (D.K.)
[2] Department of Convergence Study on the Ocean Science and Technology, Korea Maritime and Ocean University, Busan 49112, Republic of Korea; yhoh@kmou.ac.kr
[3] Department of Oceanography, Pusan National University, Busan 46241, Republic of Korea; sanglee@pusan.ac.kr
* Correspondence: dongjoo.joung@pusan.ac.kr

Content:

Table: 5

Figure: 12

Supplementary Table S1. Descriptive statistics of data.

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Std. Error	Kurtosis	Std. Error
Salinity	43772	13.68	32.29	29.4997	1.67290	−2.166	0.012	9.910	0.023
Temperature (℃)	43912	0.01	36.61	15.1459	7.10531	0.058	0.012	−1.223	0.023
pH	43273	7.32	8.68	8.0566	0.23824	0.043	0.012	−0.690	0.024
Dissolved Oxygen (mg/L)	42302	0.50	17.39	8.7498	2.45201	−0.112	0.012	−0.122	0.024
Turbidity (NTU)	42964	0.01	383.81	11.2022	17.00290	6.909	0.012	78.288	0.024
Chlorophyll *a* (μg/L)	43347	0.01	99.16	5.0618	4.47361	2.774	0.012	21.379	0.024
Chemical oxygen demand (mg/L)	38788	0.003	21.220	2.37704	1.926626	1.653	0.012	5.174	0.025
Total Nitrogen (mg/L)	35445	0.001	2.178	0.15076	0.129788	4.516	0.013	42.551	0.026
Total Phosphorus (mg/L)	39076	0.001	2.129	0.03029	0.043270	19.105	0.012	565.314	0.025

Supplementary Table S2. Multivariant coefficients of parameters monitored in this study. Temp.: temperature, DO: dissolved oxygen, NTU: Nephelometric Turbidity Unit, Chl *a*; chlorophyll *a*, COD: chemical oxygen demand, TN: total nitrogen, and TP: total phosphorus.

Correlation	Salinity	Temp. (°C)	pH	DO(μM)	NTU	Chl *a* (ug/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)
Salinity									
Temp. (°C)	−0.299								
pH	0.272	−0.328							
DO (μM)	0.318	−0.804	0.512						
NTU	0.164	−0.174	0.257	0.165					
Chl *a* (ug/l)	0.182	−0.361	0.350	0.489	0.401				
COD (mg/l)	0.016	0.063	−0.481	−0.170	−0.004	0.067			
TN (mg/l)	0.090	−0.080	−0.357	−0.103	0.098	0.052	0.377		
TP (mg/l)	-0.227	0.168	0.158	−0.095	0.111	−0.006	−0.140	−0.087	

Supplementary Table S3. Scores of principal components for each variable.

	Component		
	1	2	3
Temp	−0.824	0.069	−0.171
DO (μM)	0.817	−0.275	0.248
Salinity	0.617	0.062	0.022
COD	−0.015	0.808	0.019
TN (mg/l)	0.072	0.763	0.146
pH	0.379	−0.685	0.383
NTU	0.107	0.086	0.791
Chl *a*	0.446	0.047	0.651
TP mg/l)	−0.515	−0.291	0.529

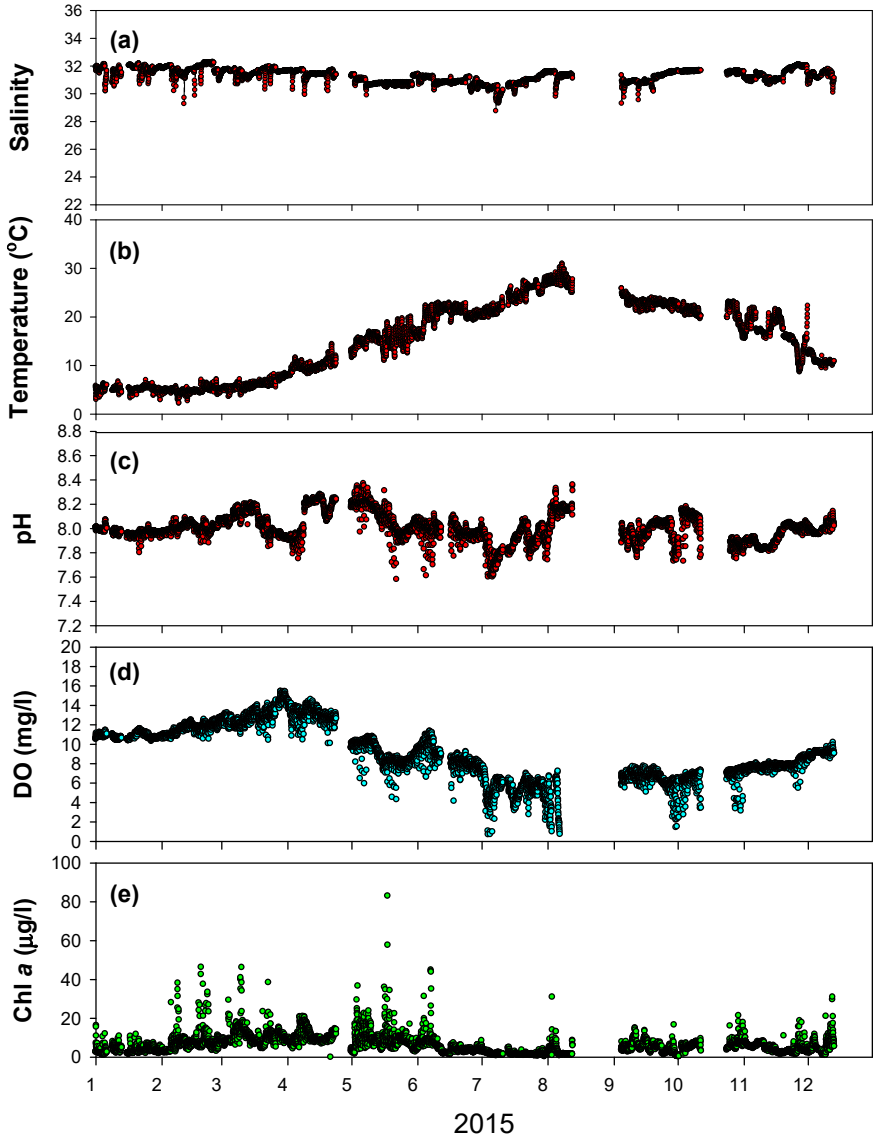
Supplementary Table S4. Component Score Coefficient Matrix.

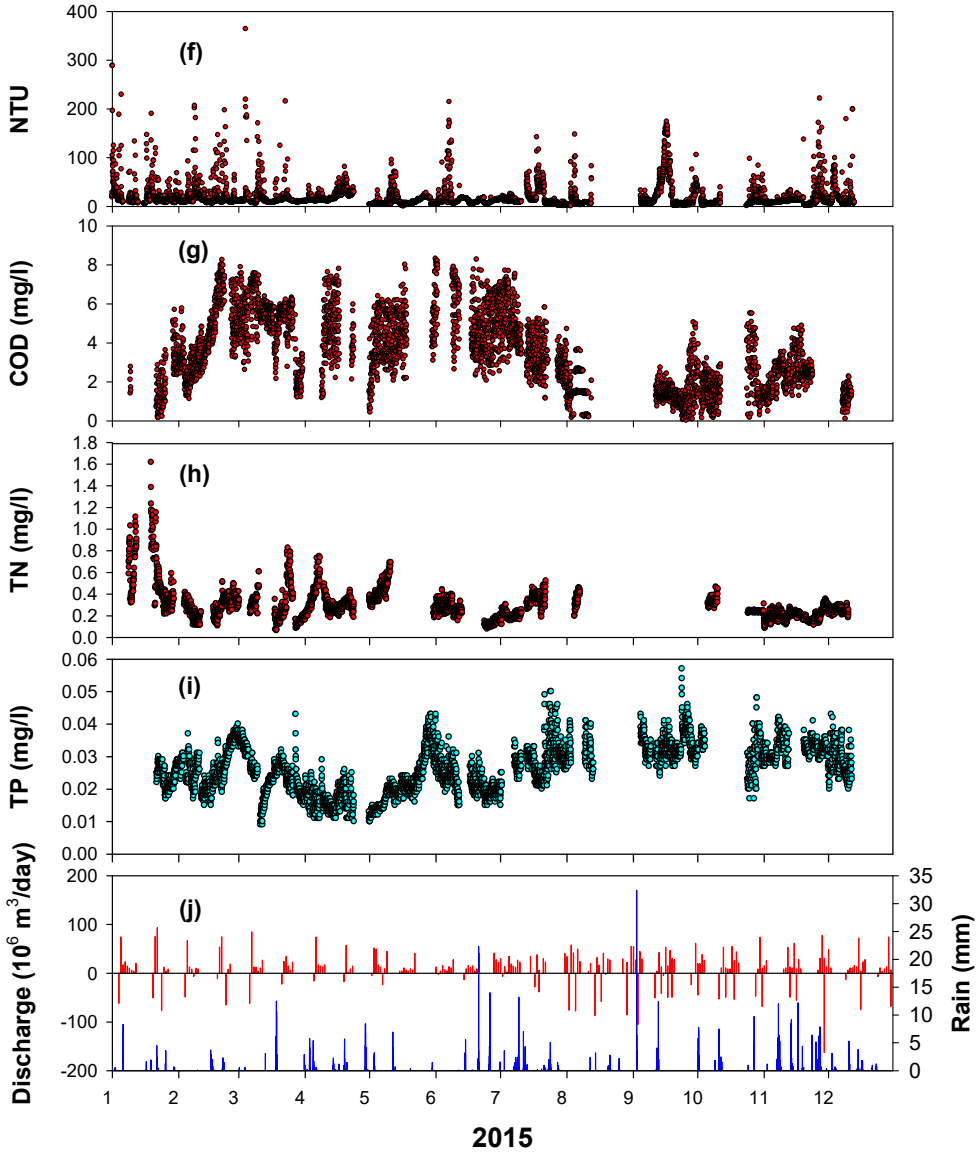
	Component Score Coefficient Matrix		
	1	2	3
Salinity	0.293	0.064	−0.089
Temp	−0.359	−0.013	0.029
pH	0.082	−0.330	0.154
DO (uM)	0.333	−0.095	0.011
NTU	−0.085	0.112	0.550
Chl *a*	0.100	0.095	0.387
COD	0.026	0.444	0.077
TN (mg/l)	0.043	0.433	0.148
TP (mg/l)	−0.352	−0.143	0.445

Supplementary Table S5. Comparison of water quality parameters outside and inside the sea dike.

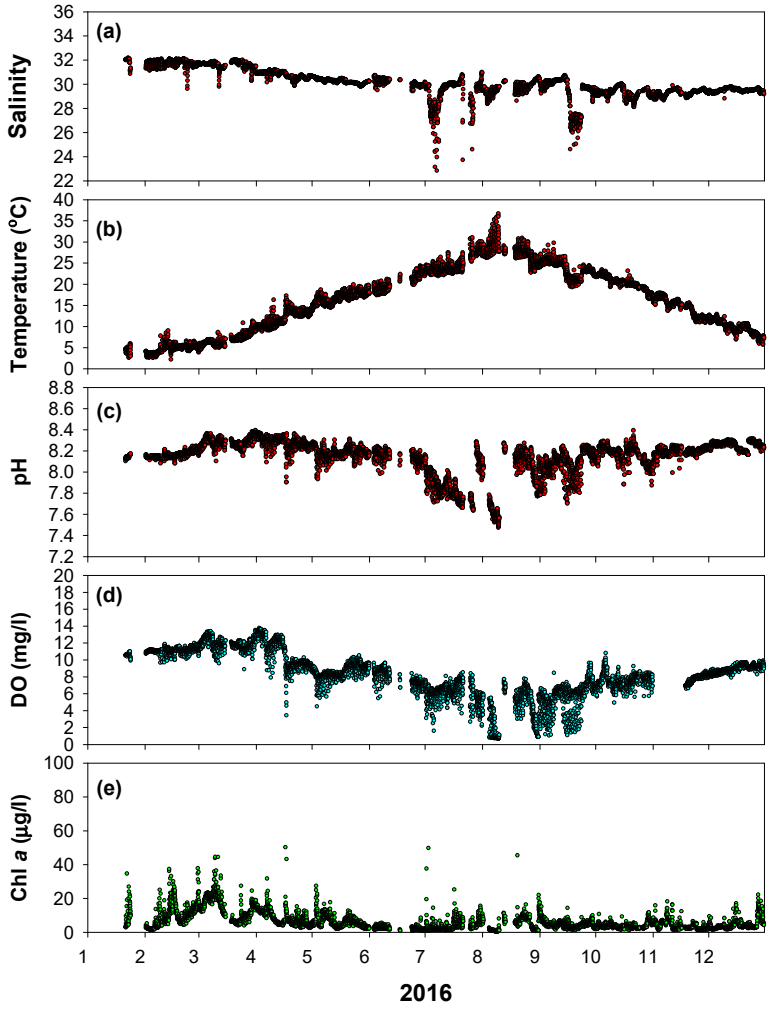
	[a]**Outside (This study)**	Inside (artificial lake water)									
	2016–2020	[b]1999			[c]2000			[d]2006–2009			[d]2011–2015
		July	Sep	Nov	Feb	Apr	June	Inner zone	Middle zone	Outer zone	
Temperature (ºC)	0.01–36.61 (15.15)	23.5–29.4 (26.5)	23.5–28.0 (26.6)	14.9–15.9 (15.5)	1.9–3.2 (2.7)	8.0–11.0 (9.4)	15.5–20.5 (18.5)	20.24±7.96	19.84±8.05	19.58±6.79	15.9±0.89
Salinity	13.68–32.29 (29.5)	18.1–30.31 (28.02)	23.54–30.15 (27.66)	12.20–32.30 (22.14)	24.86–30.67 (29.59)	24.90–30.45 (27.98)	27.27–30.81 (29.57)	17.6±8.54	22.67±7.08	27.09±4.66	16.17±9.06
pH	7.32–8.68 (8.06)	7.97–8.09 (8.05)	7.8–8.00 (7.93)	7.93–8.06 (8.01)	7.86–7.93 (7.90)	8.10–8.24 (8.15)	7.82–8.06 (7.99)	8.3±0.43	8.28±0.36	8.33±0.21	8.22±0.12
DO (mg/L)	0.5–17.39 (8.75)	6.21–8.09 (7.12)	4.95–13.12 (6.44)	7.77–11.92 (9.35)	11.10–12.08 (11.69)	10.00–13.01 (10.68)	8.18–11.82 (9.16)	9.71±2.99	9.33±2.4	9.48±1.78	9.64±0.36
COD (mg/L)	0.003–21.22 (2.384)	0.64–2.95 (1.29)	1.20–2.85 (2.12)	0.78–1.44 (0.97)	1.40–6.40 (2.75)	1.64–6.08 (2.62)	1.08-3.24 (2.01)	6.87±3.21	5.19±2.52	3.75±1.56	6.48±2.99
Chl *a* (μg/L)	0.01–99.16 (5.06)	3.28–43.88 (14.68)	2.82–26.30 (11.5)	2.31–9.33 (4.89)	3.39–25.75 (8.52)	5.40–51.55 (16.03)	1.95–28.35 (6.9)	10.48±22.53	7.17±10.46	3.98±5.23	25.27±8.8
TP (μg/L)	0.001–2.129 (0.03)	0.66–5.40 (1.58)	0.70–2.04 (1.32)	1.33–4.16 (2.51)	1.74–5.44 (2.81)	1.05–7.48 (2.97)	0.70–3.22 (1.65)				0.11±0.04
	[d]2016 (September to November, artificial lake)										
	*M-1a	M-2	M-3	M-4	M-5	M-6	M-A	**D-1a	D-2	D-3	D-4	D-5	D-6
Depth (m)	0.8–1.0	0.6–1.0	1.5–3.0	2.5–3.1	2.1–2.1	11.8–12.2	1.5–1.6	2.5–2.6	0.9–1.0	1.5–2.0	2.5–3.0	2.6–3.1	11.8–12.2
Temperature (ºC)	13.6–27.0	14.5–26.3	14.9–25.	15.1–25.2	14.2–25.2	13.8–23.6	14.1–25.1	12.9–17.3	14.2–27.1	14.5–25.5	14.8–25.3	14.6–25.3	15.3–25.2
Salinity	0.3–0.6	4.9–13.4	211.3–20.0	21.9–23.5	18.8–24.1	31.6–31.8	21.4–25.4	0.1–0.2	0.2–16.8	10.6–22.9	11.8–23.9	12.3–23.1	18.2–28.8
pH	7.9–8.6	7.4–8.5	7.8–8.7	8.2–8.5	8.3–8.7	7.8–8.0	8.3–8.7	7.6-7.91	7.5–8.7	8.2–8.5	8.2–8.5	8.1–8.5	7.9–8.1
DO (mg/L)	4.3–9.10	4.2–11.2	5 3.2–7.2	5.9–7.1	7.2–9.1	1.8–4.4	7.1–7.8	7.0–9.6 0	5.7–7.10	6.5–7.0	5.9–6.9	6.9–7.4	1.8–5.0
COD (mg/L)	6.4–9.6	5.6–8.4	4.4–10.4	4.8–9.6	2.5–7.00	5.2–7.20	3.4–8.3	3.8–18.8	7.6–12.0	5.6–12.8	4.8–11.2	5.4–9.2	4.8–7.20
Chl *a* (μg/L)	6.5–76.8	6.5–60.4	19.5–101.3	6.5–26.0	4.9–11.9	4.2–28.7	10.9–17.6	6.5–88.4	9.5–115.5	10.7–90.2	8.4–81.0	6.9–44.8	4.2–44.0
TP (μg/L)	100–135	85–197	46–149	60–96	55–86	62–85	44–74	66–151	102–273	80–142	73–103	65–105	69–111

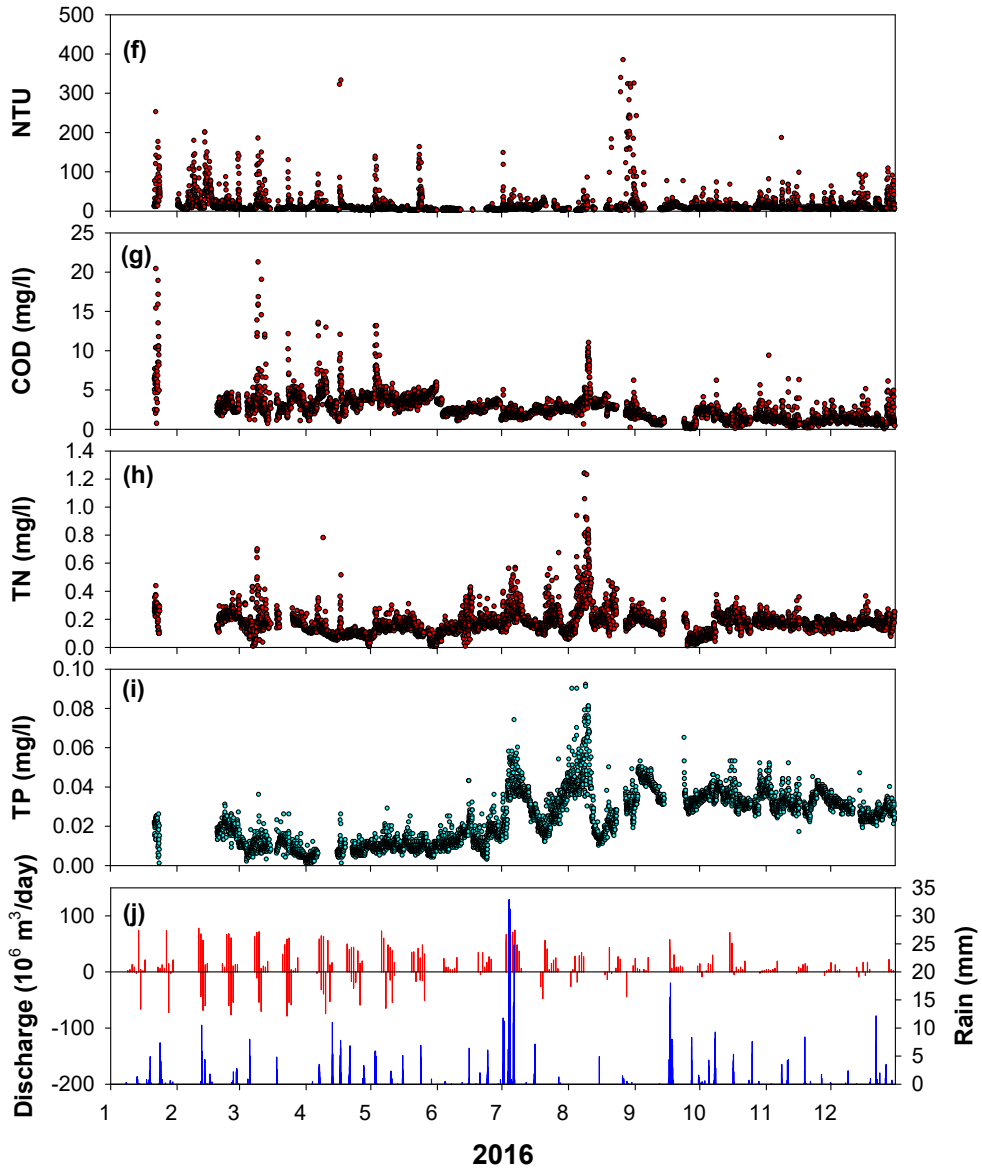
* and ** indicate transect on Mangyung and DongJin River outflows, respectively. Values in parenthesis are averages. Data sets of 2006–2009, and 2011–2015 are presented as average and standard deviation. [a], [b], [c], and [d] represent data from this study, [1], [2], and [3], respectively.


(a)
Salinity
(b)
Temperature (°C)
(c)
pH
(d)
DO (mg/l)
(e)
Chl a (µg/l)
2015

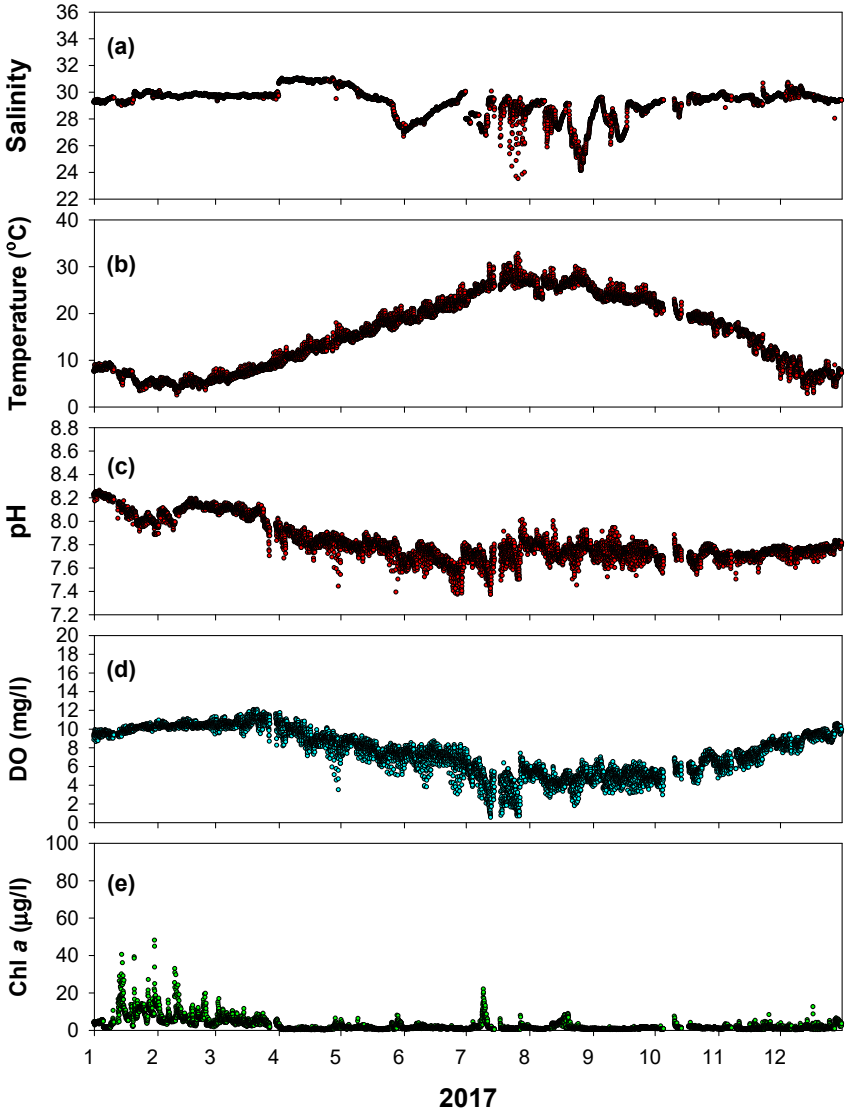


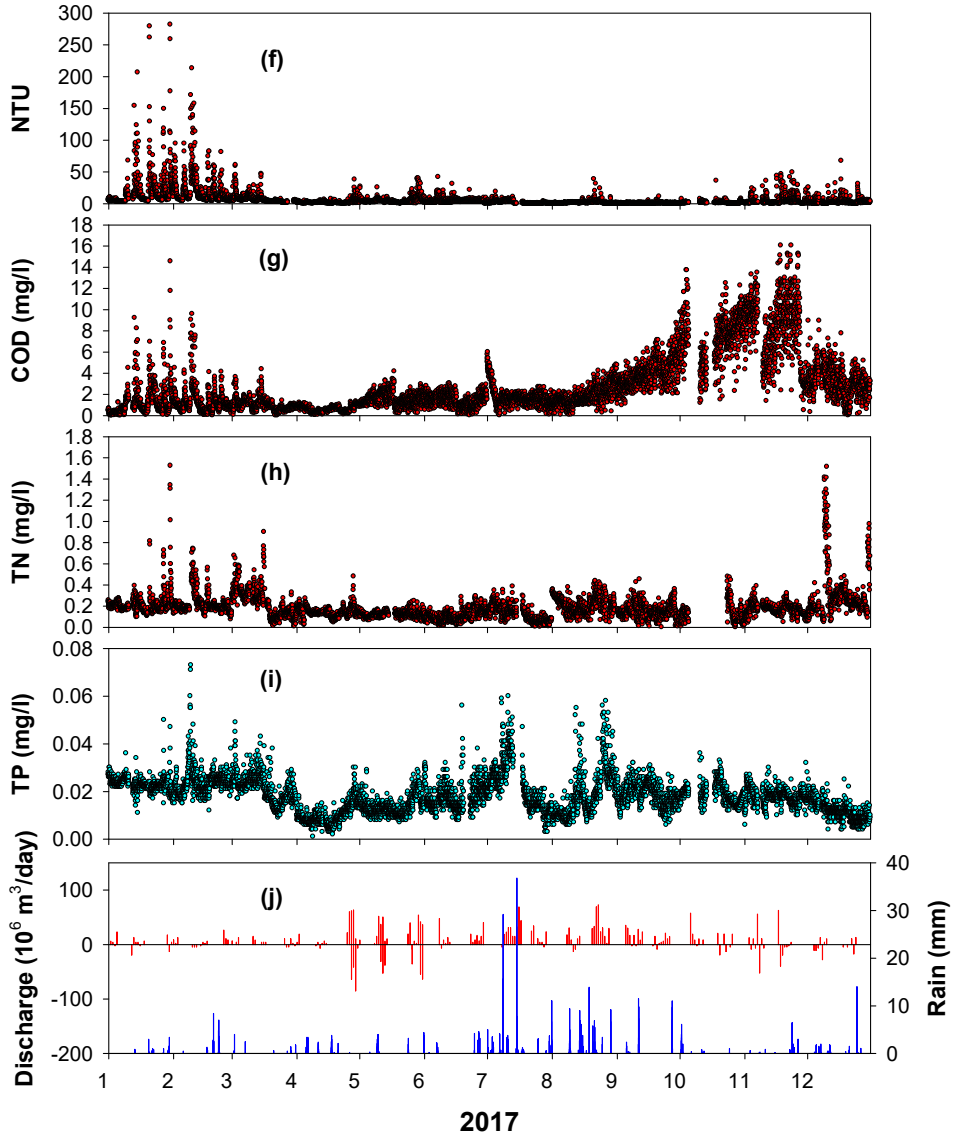
Supplementary Figure S1. Temporal variations in water quality parameters **(a)** salinity, (**b**) temperature, (**c**) pH, (d) DO (dissolved oxygen), (**e**) chlorophyll *a*, **(f)** NTU (total dissolved solid), (**g**) COD (chemical oxygen demand), (**h**) TN (total nitrogen), (**i**) TP (total phosphorus), and (**j**) discharge (amount of water flow through the sluice gate, Positive and negative signals indicate a flow of water outward and inward to the artificial lake, respectively.) in 2015 (original data set).


(a)
Salinity
(b)
Temperature (°C)
(c)
pH
(d)
DO (mg/l)
(e)
Chl a (µg/l)
2016

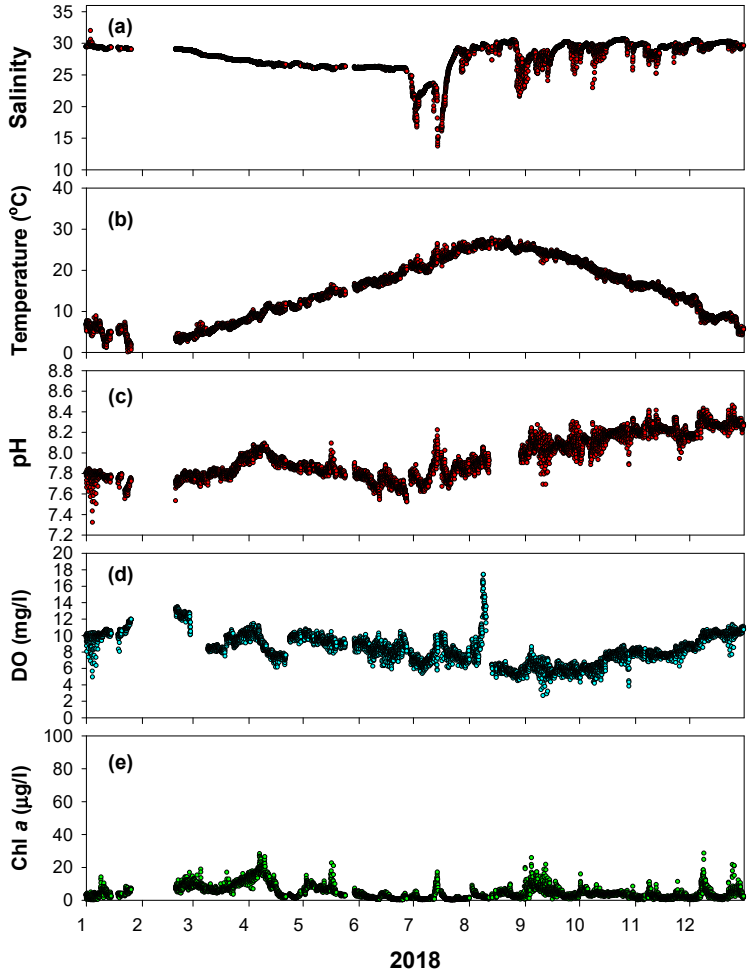


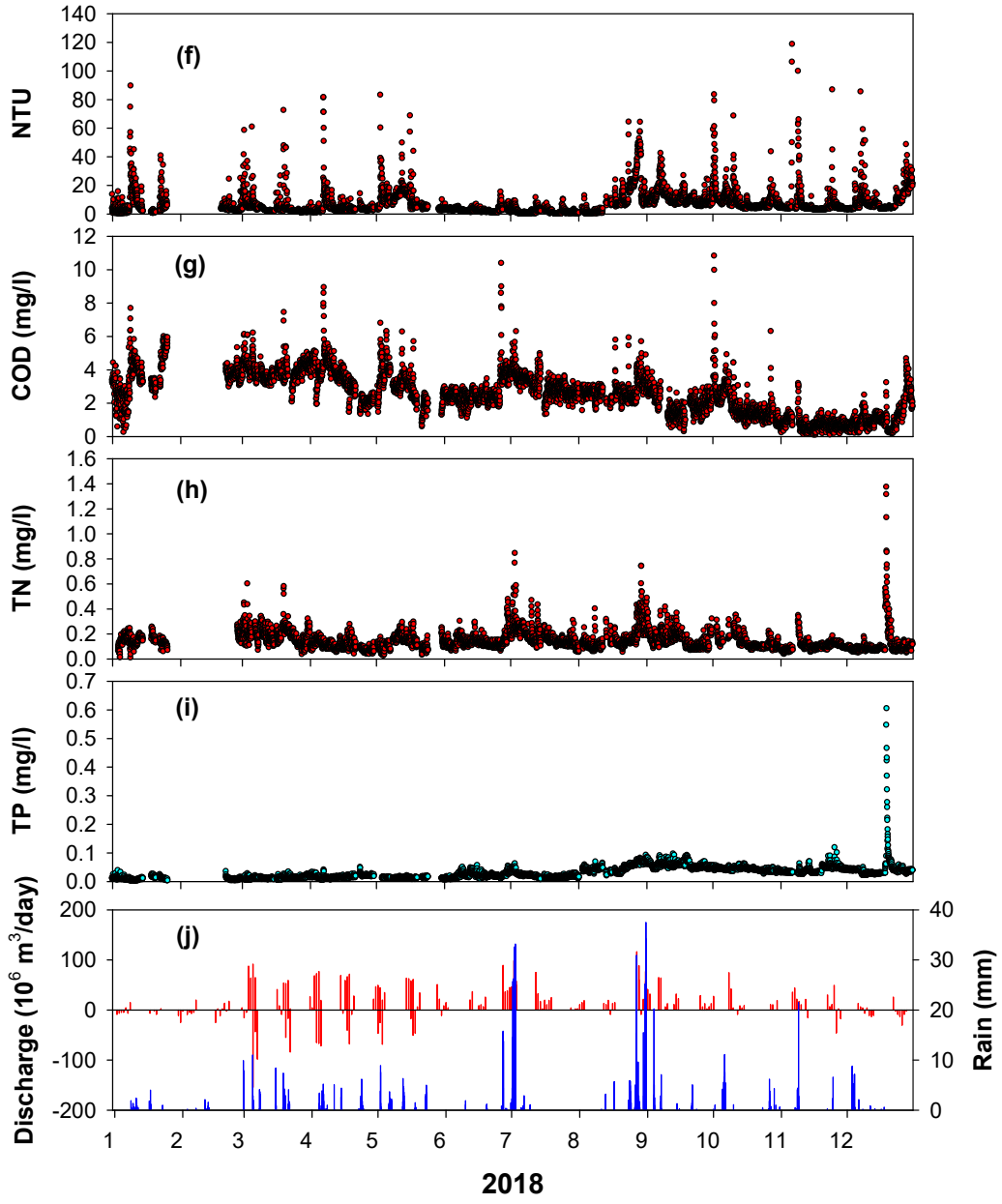
Supplementary Figure S2. Temporal variations in water quality parameters in 2016 (original data set). The labels are the same as those in Supplementary Figure 1.


(a)
Salinity
(b)
Temperature (°C)
(c)
pH
(d)
DO (mg/l)
(e)
Chl a (µg/l)
2017

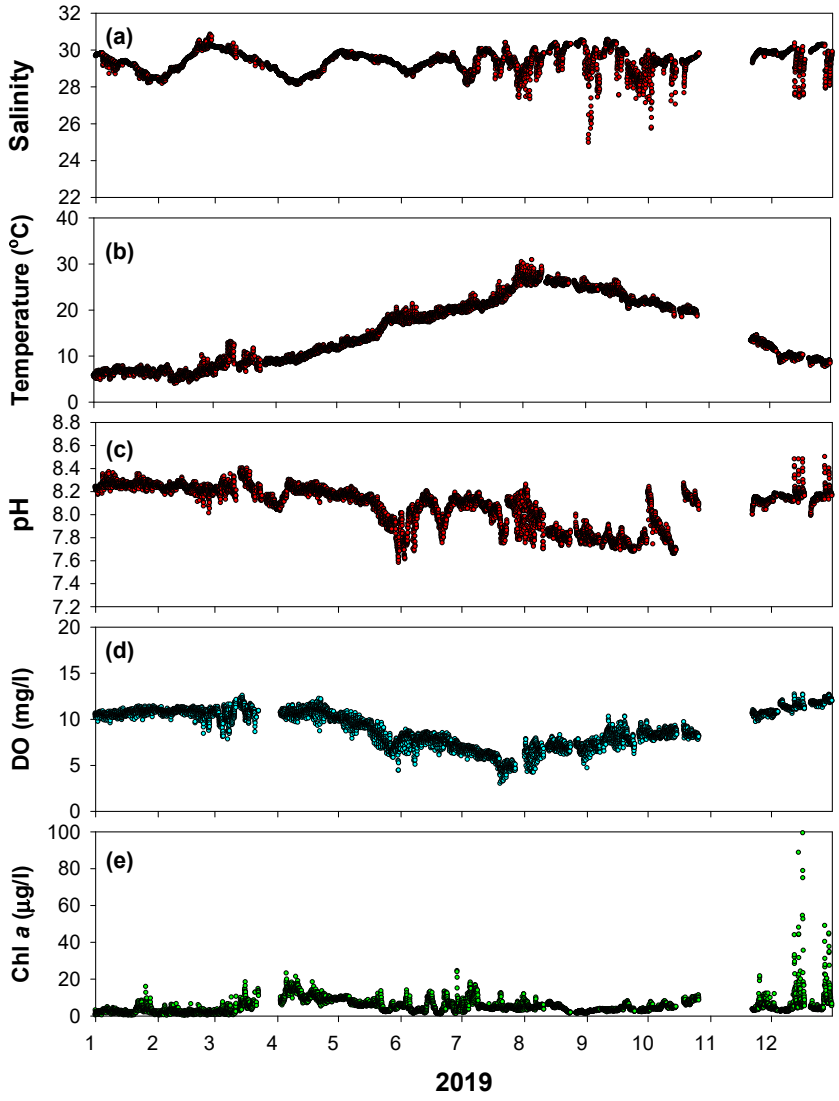


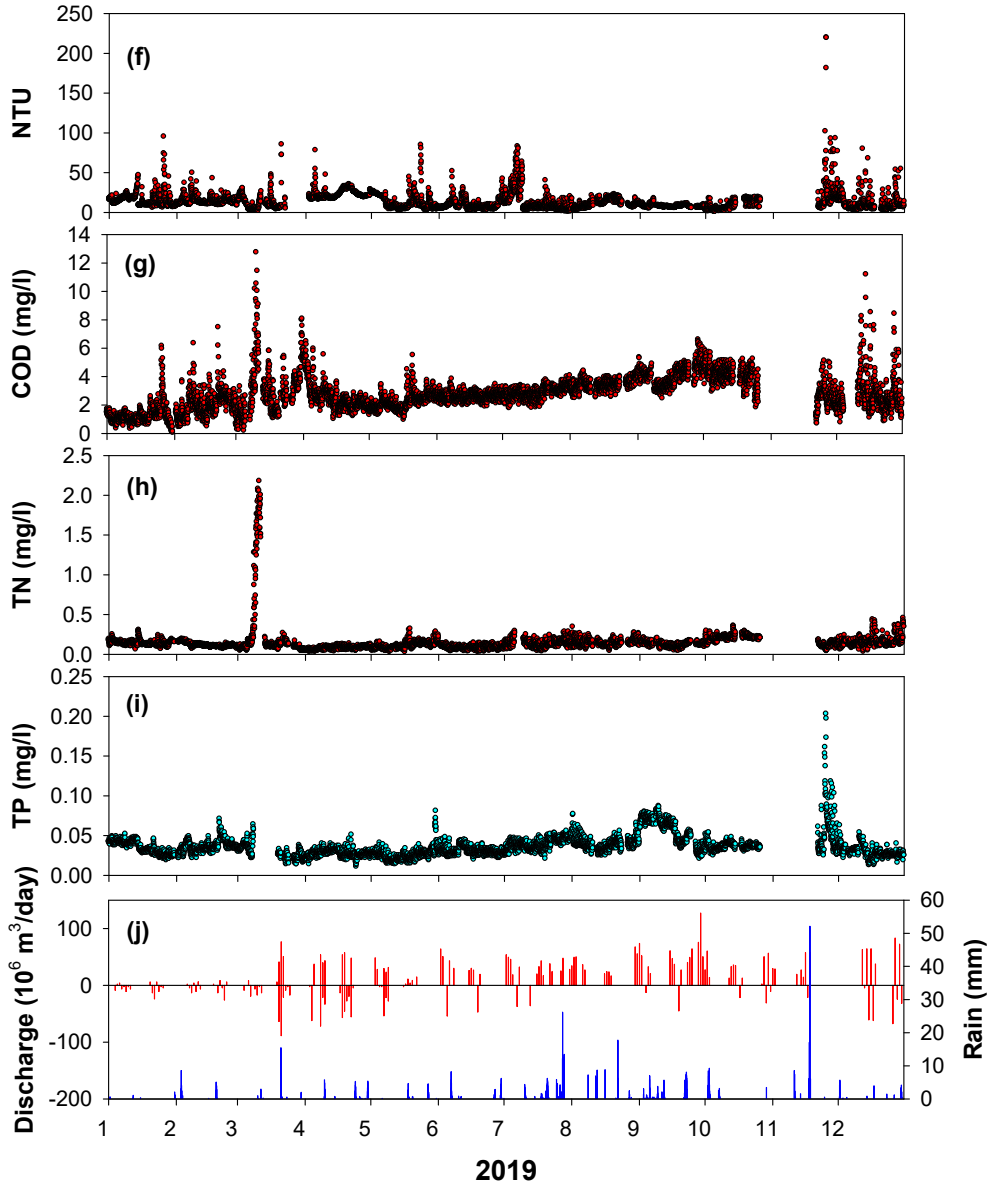
Supplementary Figure S3. Temporal variations in water quality parameters in 2017 (original data set). The labels are the same as those in Supplementary Figure 1.


(a)
Salinity
(b)
Temperature (°C)
(c)
pH
(d)
DO (mg/l)
(e)
Chl a (µg/l)
2018

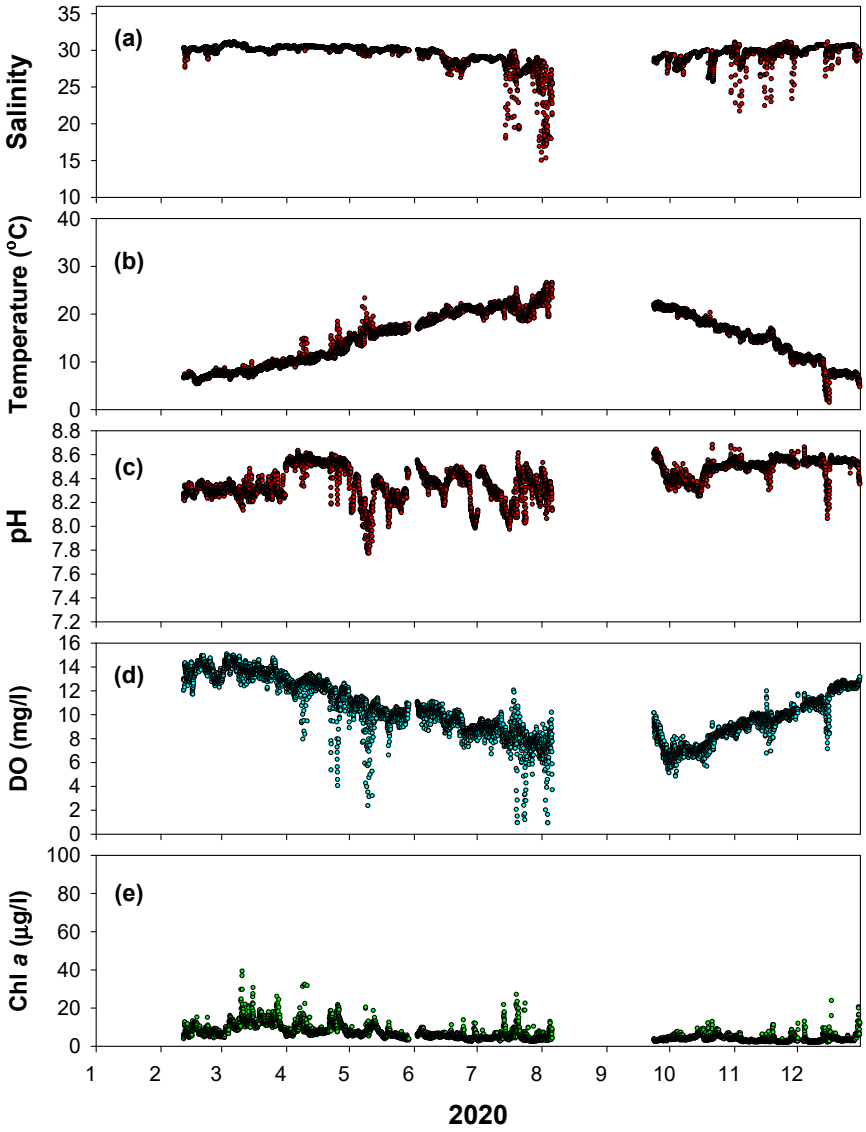


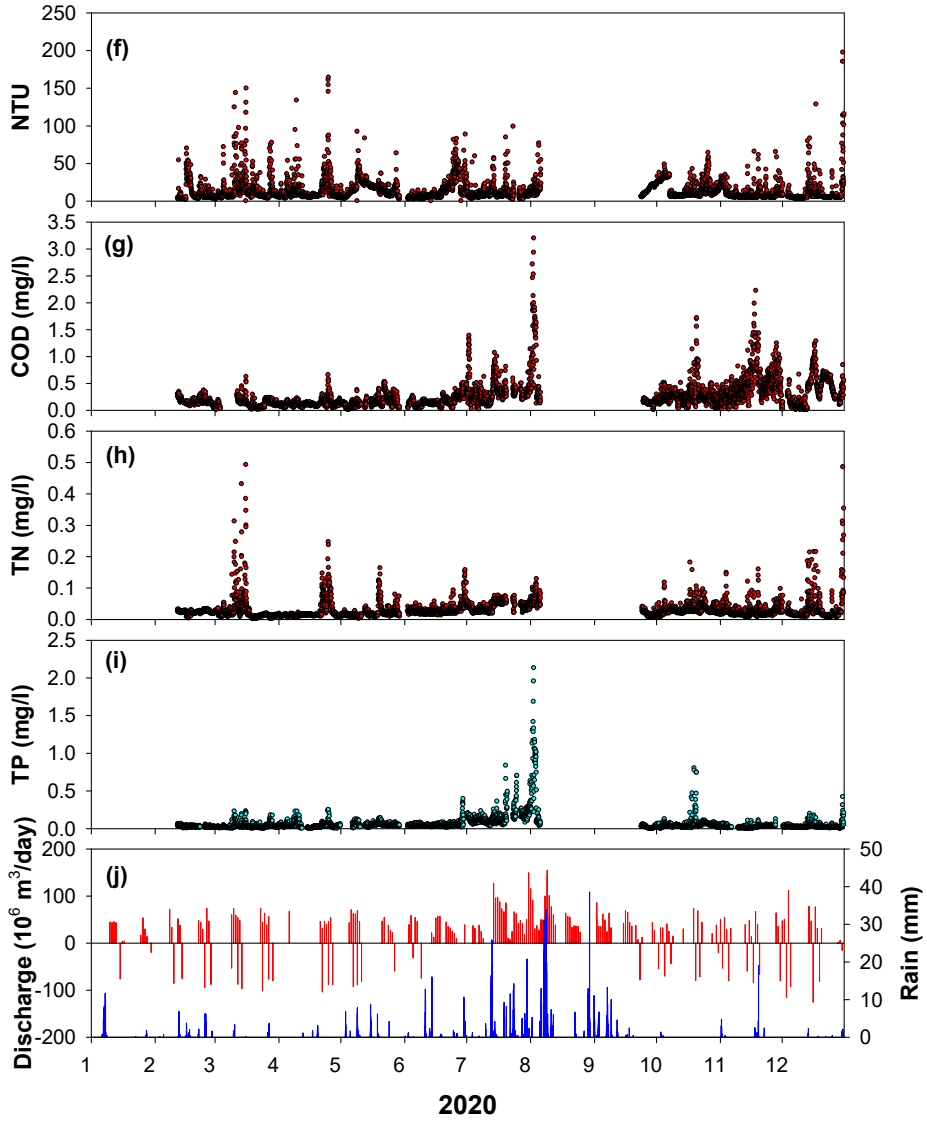
Supplementary Figure S4. Temporal variations in water quality in 2018 (original data set). The labels are the same as those in Supplementary Figure 1.


(a)
Salinity
32
30
28
26
24
22
(b)
Temperature (°C)
40
30
20
10
0
(c)
pH
8.8
8.6
8.4
8.2
8.0
7.8
7.6
7.4
7.2
(d)
DO (mg/l)
20
15
10
5
0
(e)
Chl a (µg/l)
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
2019

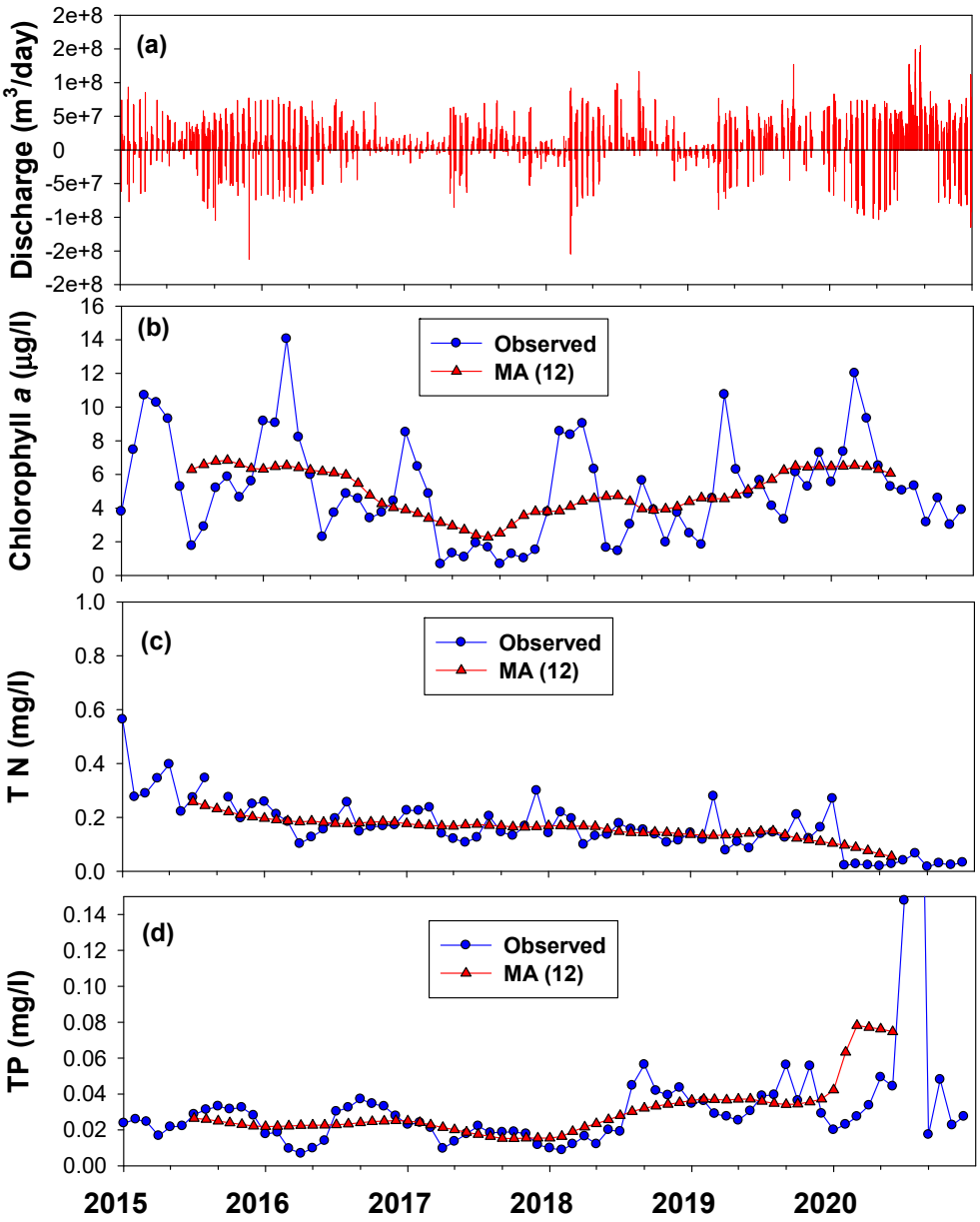


Supplementary Figure S5. Temporal variations in water quality parameters in 2019 (original data set). The labels are the same as those in Supplementary Figure 1.

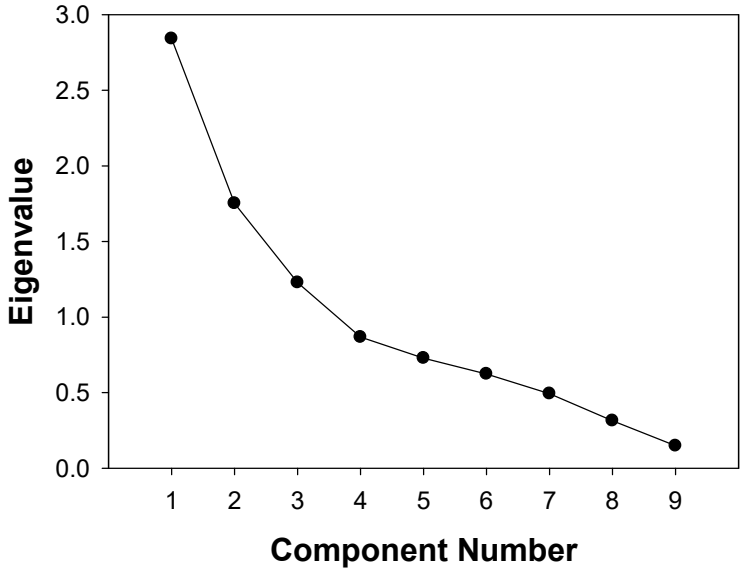

(a)
Salinity
35
30
25
20
15
10
(b)
Temperature (°C)
40
30
20
10
0
(c)
pH
8.8
8.6
8.4
8.2
8.0
7.8
7.6
7.4
7.2
(d)
DO (mg/l)
16
14
12
10
8
6
4
2
0
(e)
Chl a (µg/l)
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
2020



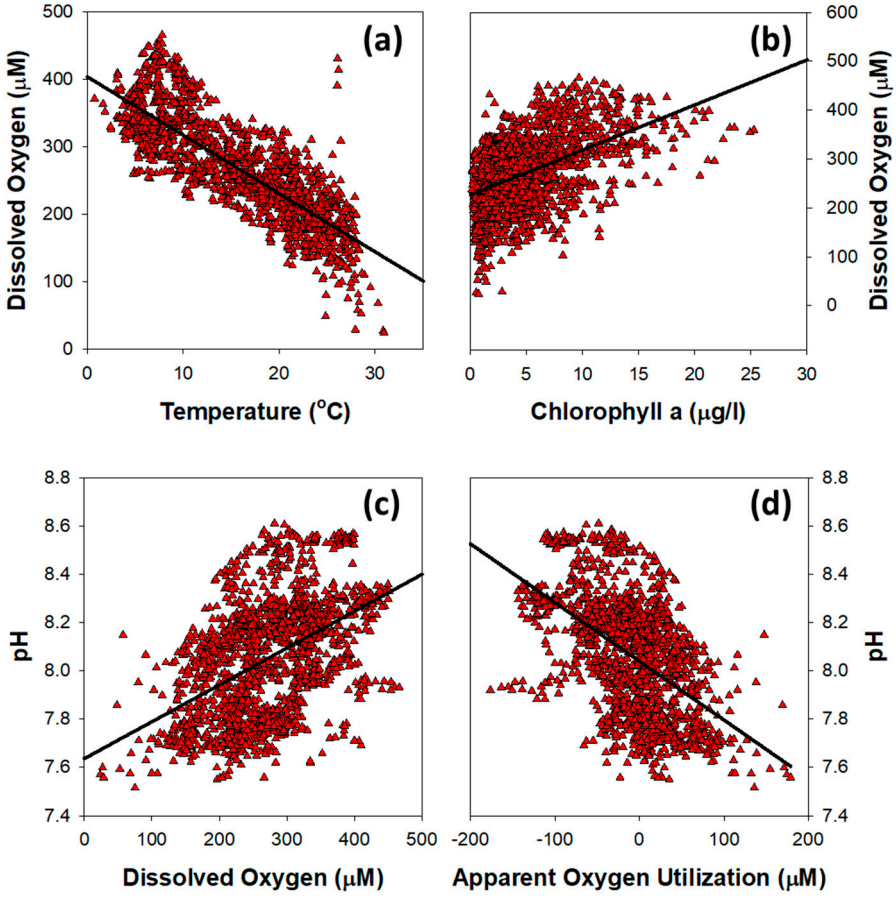
Supplementary Figure S6. Temporal variations in water quality parameters in 2020 (original data set). The labels are the same as those in Supplementary Figure 1.



Supplementary Figure S7. Variations in monthly averaged parameters of (**a**) discharge, (**b**) chlorophyll *a*, (**c**) total nitrogen, and (**d**) total phosphorus and interannual trend using moving average of 12 months (MA(12)).

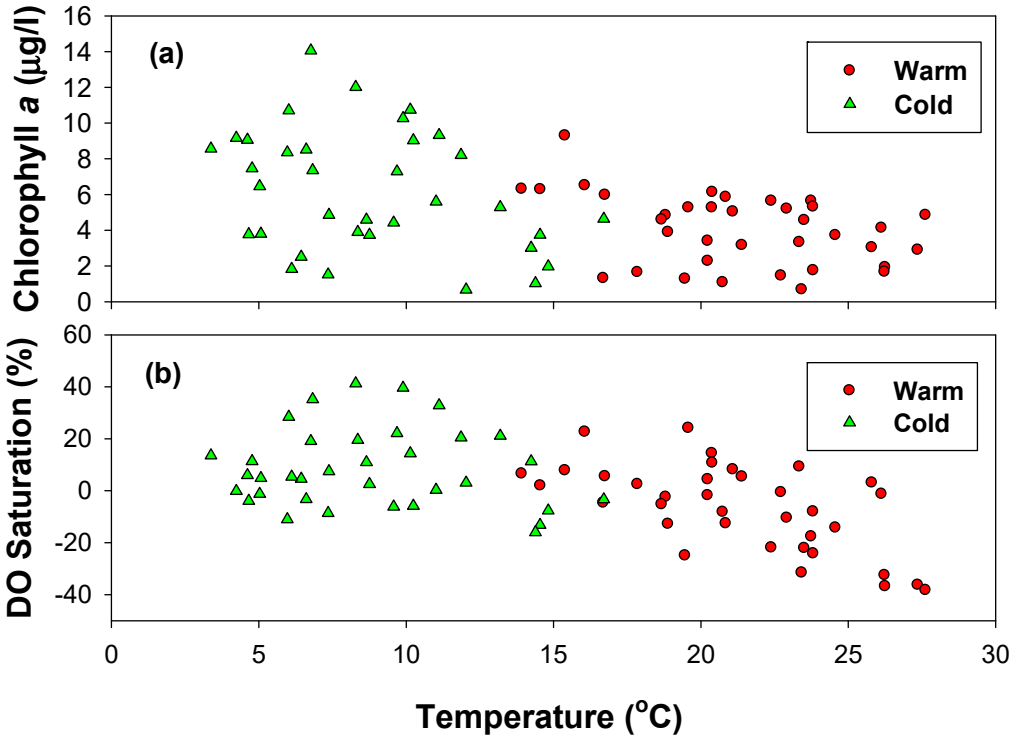


Supplementary Figure S8. Screen plot of the principal component analysis. Three components were identified by the eigenvalue of > 1.

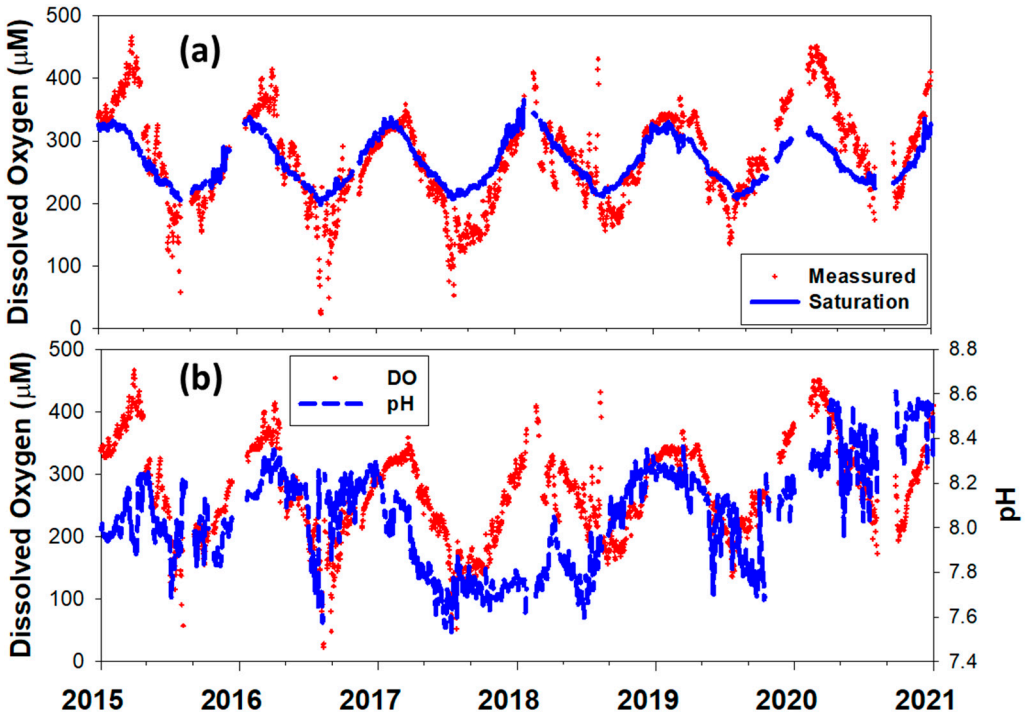


Supplementary Figure S9. Property–property plots of the variables. (**a**) Temperature with dissolved oxygen (Y = − 8.6607x + 403.97, n = 1854, r = 0.82, p < 0.0001), (**b**) chlorophyll *a* and dissolved oxygen (Y = 9.21x + 226.29, n = 1854, r = 0.48, p < 0.0001), (**c**) dissolved oxygen with pH (Y = 0.0015x + 7.636, r = 0.48, n = 1837, p < 0.0001), and (**d**) apparent oxygen utilization (AOU) with pH (Y = − 0.0024x +

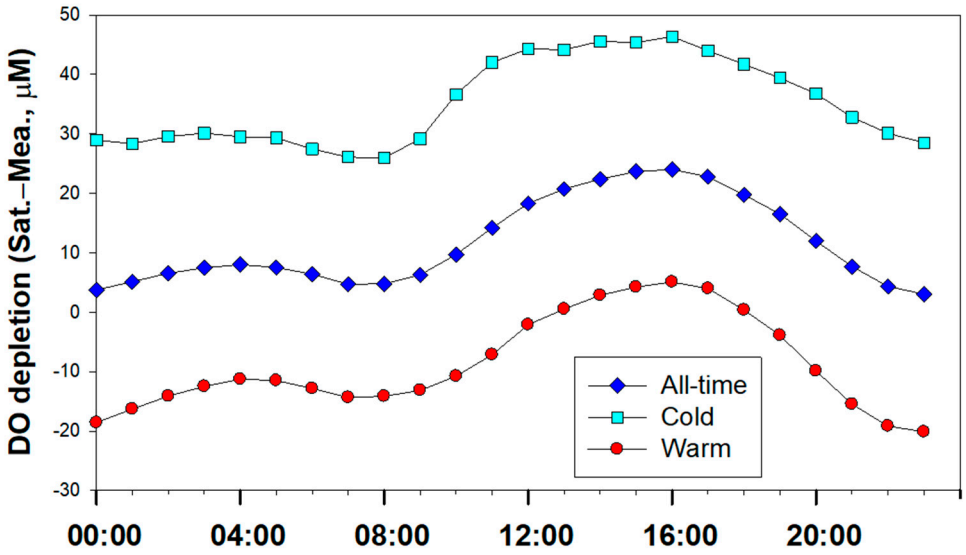
8.039, $r = 0.52$, $n = 1837$, $p < 0.0001$). AOU was determined by subtracting the measured concentration from the saturated concentration.



Supplementary Figure S10. Distributions of (**a**) chlorophyll *a* and (**b**) dissolved oxygen (DO) in warm (May–October) and cold (November–April) periods. Monthly averaged.



Supplementary Figure S11. Seasonal variations in the daily averaged parameters: (**a**) dissolved oxygen and saturation concentrations, and (**b**) dissolved oxygen and pH during 2015–2020.



Supplementary Figure S12. Hourly evolution of DO depletion. The DO depletion was determined as the difference between saturated and measured DO concentrations. Thus, negative values represent a supersaturation of DO. The warm period is from May to October, while the cold period is from November to April.

References

1. Choi, C. H., Jung, S. W., Yun, S. M., Kim, S. H., & Park, J. G. Changes in Phytoplankton Communities and Environmental Factors in Saemangeum Artificial Lake, South Korea between 2006 and 2009. *Environ. Biol. Research*. **2013,** *31*, 213–224. https://doi.org/10.11626/kjeb.2013.31.3.213
2. Kim, J. G., & Kim, Y. S. Application of Ecosystem Model for Eutrophication Control in Coastal Sea of Saemankeum Area -1. Characteristics of Water Quality and Nutrients Released from Sediments-. *Korean J. Fish. Aquat. Sciences.* **2002,** *35*, 348–355. https://doi.org/10.5657/kfas.2002.35.4.348
3. Kwak, D. H., Jeon, Y. T., & Duck Hur, Y. Phosphorus fractionation and release characteristics of sediment in the Sae-mangeum Reservoir for seasonal change. *Int. J. Sediment Research*. **2018,** *33*, 250–261. https://doi.org/10.1016/j.ijsrc.2018.04.008