Comparative sedimentation characteristics of suspended solids and phosphorus particles in discrete and flocculent sedimentation to treat influent of lake

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ABSTRACT

In order to understand the phosphorus (P) removal characteristics, which is the main controlling factor of eutrophication and algal blooms in a lake, the particle size distribution (PSD) and behavior were investigated in the inflow water and trapped sediments of Lake Saemangeum. A series of settling column tests (SCT) was carried out on the raw water taken from two influents of the lake to evaluate the sedimentation efficiency and P removal using two types of settling tests, discrete particle sedimentation (DPS) and flocculent particle sedimentation (FPS). In particular, the variation in the PSD and the P removal efficiency was traced to determine the impact of rain on the P treatment characteristics for three periods: the summer rainy period and before and after the rainy season. The PSD of the trapped sediments had increased in the rainy season, with a decrease after the rainy season. Based on the SCT results of the suspended solids, a longer sedimentation time for the DPS in the dry season was required than in the rainy season, whereas the sedimentation times for the FPS were not much different for the three periods. However, the clarifying velocity of the total phosphorus concentration was slower than the suspended solid concentration for both DPS and FPS, which suggest the particles containing phosphorus settled much more slowly than typical particles in both tests. The findings of this study will be important information in determining whether to add a coagulation process in the design of a sedimentation basin for the removal of phosphorus to be constructed for eutrophication and removal of lakes.

Keywords: Eutrophication; Particle; Sediments; Settling column test; Suspended solid; Phosphorus

1. Introduction

Phosphorus (P) is a critical element controlling the primary production in a stagnant water body, which can be classified into internal loadings, such as phytoplankton, and external loading from sediments accumulated on the bottom of the lake from upstream [1,2]. Because soluble inorganic phosphate ion removal is challenging without proper treatment such as chemical coagulation, phosphate does not precipitate to the bottom of the lake unless it is adsorbed onto phytoplankton or aquatic plants. However,

particulate P precipitates and forms sediments on the bottom of the lake and acts as a sink releasing P from sediments under anoxic conditions [3]. Therefore, in order to control the eutrophication of the lake, the removal of particulate P by sedimentation should be considered. Otherwise, when the removal of P is necessary to obtain much lower concentrations, not only particulate P but also dissolved P can be removed using chemical coagulation. Because P is eventually removed by particles containing P, the behavior of particles and the sedimentation characteristics are required to treat the inflow water of the lake.

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Most of the previous papers [4,5] dealing with the precipitation of phosphorus in lakes have studied the elution and precipitation of phosphorus from a geochemical point of view, and studies on aggressive particulate phosphorus precipitation or coagulation precipitation of water-soluble phosphorus are very rare. A few previous studies have shown that the chemical coagulation process was effective in controlling internal loading and algal growth [6]. Research over past decades has shown that Al permanently binds P in sediment when using the capping method using alum [7–9]. However, although whole-lake alum treatment can be temporally effective for controlling P in the water, it is not an effective alternative to prevent the return to the pre-capping treatment state of P when external loading influences the water quality. The P in inflow water can be treated continuously using the chemical coagulation process to solve this problem. Pilgrim and Brezonik [10] have applied alum coagulation to remove the P from inflow water and achieved 61%–84% of total phosphorus (TP) removal efficiency in Tanners Lake. In the case of the P immobilization conducted in the heavily eutrophic lake, coagulation with polyaluminum chloride (PAC) resulted in the complete removal of phosphates and a considerable (up to 50%–60%) reduction of total phosphorus in the lake water [11]. Under an 11:1 Al:P weight ratio [12] or a molar Al:P ratio of minimally 10:1 [13], PAC coagulation could effectively immobilize P in the lake water.

Lake Saemangeum, which is an artificial lake containing a vast water surface area of 118 km², had been constructed as a national project. Nation-wide attention has been focused on the water quality by preventing eutrophication of Lake Saemangeum that dominates the developmental fate of the reclamation area. After constructing the long sea dike of 33.9 km, inflow pollutant control has emerged as a challenging task to manage the extensive stagnant newly formed water regime. First, understanding the sedimentation characteristics of P has become essential because, if not adequately removed from Lake Saemangeum, the sediment containing P can be a source of nutrients leading to algal blooming.

Although considerable research has been devoted to understanding the behavior of P and particulate matters in the water body of lakes, rather less attention has been paid to the sedimentation characteristics and the correlation between particle distribution and phosphorus concerning the coagulated particle as well as the discrete particles in order to apply sedimentation. For the sedimentation process to remove inflow particles from pond-shaped structures, the clarification efficiency for a settling tank or pond is a function of the ratio of the particle sedimentation velocity in the water to the areal hydraulic loading rate. Considering the epilimnion of the lake as a completely mixed box, the change in particle concentration can be gained from the settling column test (SCT) of inflow particles in water [14]. For the design of the sedimentation tank to remove coagulated particles, the design parameters can be deduced through the interpretation of the graphical technical drawing based on the data of SCT. The removal efficiency of particles, hydraulic loading rate, and settling velocity can be calculated and predicted based on the graph [15]. Particularly, Żarczyński et al. [16] reported that grain-size analysis is useful for more than the characterization of the mineral components of biogenic lake sediments.

In order to conserve the water quality and to prevent the eutrophication of Lake Saemangeum, this study aimed to investigate the particle size distribution (PSD) change influenced by rainfall and the behavior and characteristics of particles with and without alum coagulation in the sedimentation process. Field samples taken from two sites were analyzed, and SCT experiments were conducted by discrete particle sedimentation (DPS) and flocculent particle sedimentation (FPS) to determine the size distribution of particles containing P in the two primary upper streams. We considered the consequential P removal efficiency and essential characteristics in the analysis of the series of SCT experiments and tried to provide useful information for the design of sedimentation processes to control the inflow P of the lake. First of all, we tried to find out how the removal rate of P varies by the precipitation efficiency that appears according to the particle size distribution. In particular, the relationship between the change in the characteristics of particles flowing into the water body due to rainfall on the removal efficiency of phosphorus was investigated and analyzed in comparison with the dry season. The results of this study will be important information on the determination of the form of coagulation or independent sedimentation in the design of a sedimentation basin for the P removal, which is performed to inhibit eutrophication in a lake.

2. Materials and methods

2.1. Sites and water quality of Lake Saemangeum

Two points from the Mankyung River and Dongjin River inflows for Lake Saemangeum were selected to take the samples for sedimentation experiments and to measure water quality and PSD. The two sites representing the monthly water quality for each inflow water region are shown in Fig. 1. Table 1 lists a summary of the results of water quality measurements made by a national monitoring network [17] during 2011–2019 after the completion of the sea dike.

The upstream catchment of the lake has an area of 3,319 km², and of that area, the two rivers compose 78.5%. The upstream catchment mostly consists of agricultural (49.8%) and forest (34.6%) areas [18], with most of the agricultural area located in the lower part of the catchment, which is adjacent to Lake Saemangeum. Precipitation in the watershed is concentrated in the summer, that is, July to September [19]. The TP loading from the catchment is 3,751 kg/d, with nonpoint source pollution accounting for 83% [20].

The field measurements and samplings were conducted three times in 2019, the dry period (May) in the spring, rainy period (July), and dry period (August) in the summer, to examine the impact of rainfall on the P concentration and sedimentation characteristics. To analyze the variation in the PSD, sediments, as well as water samples, were taken from the sediment traps installed at the center of inflow points of the two upper streams, as shown in Fig. 2. The trapped sediments were sampled in the typical manner [21] 7 d after the sediment trap installation.
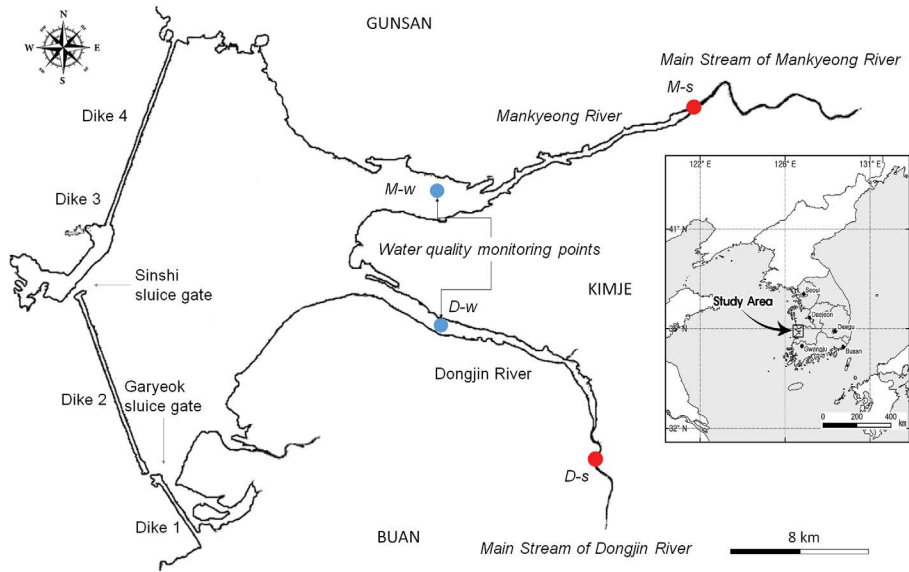
Fig. 1. Map and location of sampling site in Lake Saemangeum.

Table 1
Water quality at the two main monitoring sites of Lake Saemangeum

Site	Month	pH	Temp.[a] (°C)	Salinity (PSU)	DO (mg/L)	COD (mg/L)	SS (mg/L)	TN (mg/L)	TP (mg/L)	Chl-a (mg/m³)
M-w	January	8.09	3.54	11.54	12.81	10.08	18.69	5.01	0.17	28.34
	February	8.03	4.70	10.34	12.51	10.16	21.09	6.11	0.15	31.94
	March	8.31	7.40	10.06	11.65	12.30	29.33	5.48	0.17	50.76
	April	8.16	14.20	6.10	11.09	9.75	27.90	4.74	0.20	37.43
	May	8.28	19.96	6.75	9.42	12.00	38.84	3.09	0.15	62.55
	June	8.04	23.19	3.86	8.34	11.90	47.29	3.67	0.20	45.01
	July	8.34	27.61	2.96	8.84	9.32	35.84	3.49	0.21	37.15
	August	8.61	30.34	2.39	9.05	9.33	34.28	2.88	0.20	40.31
	September	8.29	25.36	1.99	9.44	8.26	33.76	2.40	0.13	38.04
	October	8.06	20.73	7.74	8.85	9.44	31.89	3.35	0.19	50.98
	November	7.88	14.73	10.78	9.65	7.52	21.93	3.52	0.13	32.40
	December	7.99	6.30	6.54	11.36	9.00	19.24	3.95	0.18	41.63
	Mean	8.17	16.50	6.75	10.25	9.92	30.01	3.97	0.17	41.38
D-w	January	8.04	3.19	14.13	13.32	7.82	22.50	2.34	0.10	23.23
	February	8.33	4.37	14.61	12.97	6.61	18.01	2.79	0.06	14.22
	March	8.13	6.94	12.01	12.19	8.33	32.91	2.53	0.07	29.23
	April	8.30	13.63	14.56	9.54	10.37	35.35	3.23	0.11	28.51
	May	8.47	19.32	6.99	10.23	9.06	31.53	2.13	0.07	39.14
	June	8.41	24.20	6.00	8.70	10.98	43.93	2.57	0.20	54.08
	July	8.19	27.66	2.57	8.84	8.91	41.91	2.90	0.16	36.71
	August	8.51	30.16	2.93	8.11	9.79	37.90	2.46	0.18	37.93
	September	8.35	25.65	2.84	10.10	7.83	33.41	2.03	0.14	28.33
	October	8.14	20.85	9.29	8.98	7.58	24.65	2.01	0.10	34.75
	November	8.15	15.34	11.19	11.61	8.01	27.50	2.75	0.10	42.75
	December	7.88	6.64	12.20	11.85	9.76	31.70	2.55	0.15	111.35
	Mean	8.24	16.50	9.11	10.54	8.75	31.78	2.52	0.12	40.02

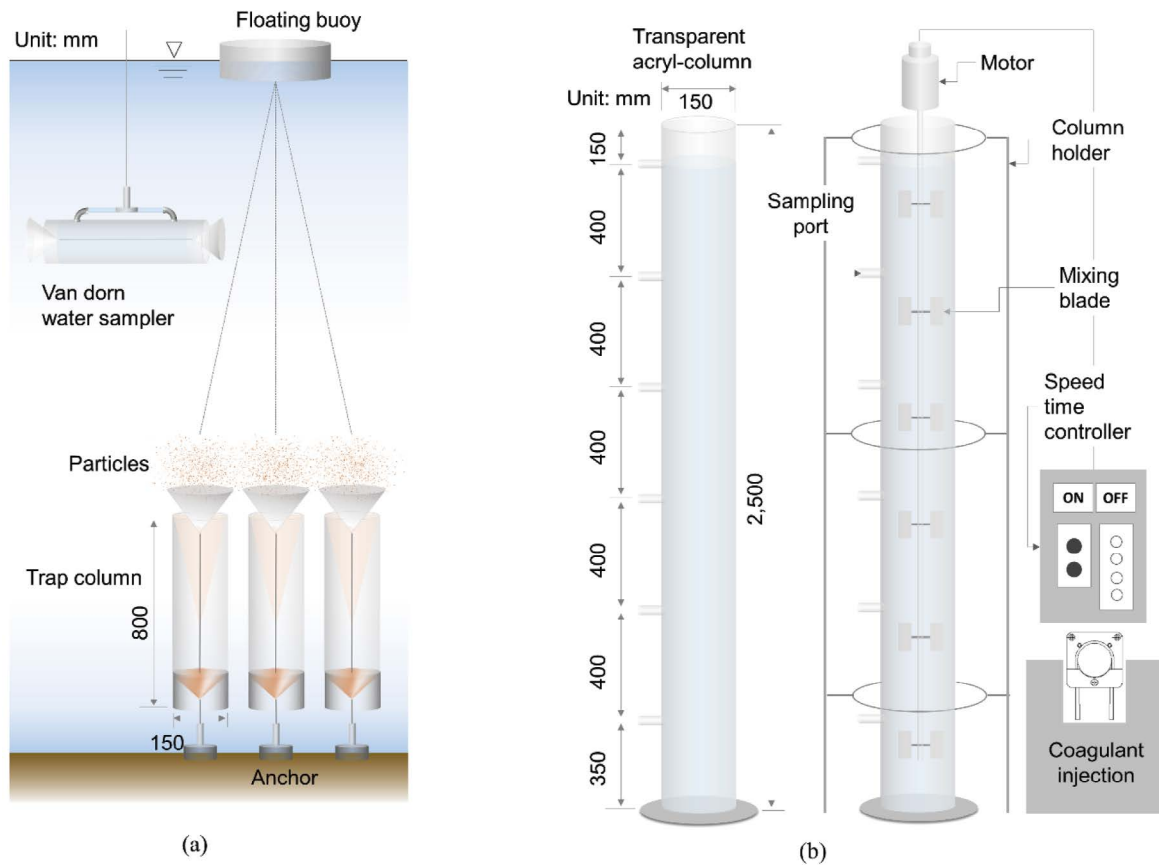[a]Water temperature.
TN – total nitrogen.

Fig. 2. Schematic diagram of sedimentation experiment apparatus : (a) sediment trap and water sampler and (b) sedimentation column and coagulation devices.

The water quality was measured at three layers of the water depth using the Van Don Water Sampler, and the dissolved oxygen (DO) and pH of the water was gauged using a multi-parameter water quality analyzer (HL4, Hydrolab Company, USA) in the field. The water quality analyses were applied differently in freshwater and brackish water, depending on the salinity content. The water quality and sediment analysis following the Standard Methods (American Public Health Association [22] included the following techniques: total organic carbon (TOC), the high-temperature combustion method; chemical oxygen demand (COD_{Mn}), the acidic (alkaline) potassium permanganate method; total solids (TS), suspended solids (SS), and fixed solid (FS), the gravimetric method; TP, the ammonium molybdate spectrophotometric method; phosphate (PO_4^{3-}), the molybdenum-antimony (Mo–Sb) anti-spectrophotometric method followed by 0.45 μm GF/C filtration; Chlorophyll-a (Chl-a), the trichromatic spectrophotometric method; moisture content, the dry oven method; ignition loss, the furnace method; particle size, sieves and electrical image analysis method (UPA-150 Micromeritics, USA). The breach in the plastic basket was sealed under dark, cold conditions after the sediment samples were visually examined, and the samples were carried to the laboratory to measure the water content. After drying and sieving at 2mm, the powdered sediment samples were analyzed.

2.2. Sedimentation experiments

The evaluation of sedimentation characteristics using SCT is useful to understand the behavior characteristics not only for typical particles but also specific particles such as the submicron-sized aluminum oxide (α-Al_2O_3) particles [23,24].

The water samples taken from the inflow sites were filled into the settling column, and samples were collected from the six ports of the column at the various scheduled sedimentation times for the two types of SCT, DPS (6 h–4 d) and FPS (10 min–3 h) as shown in Fig. 2. The optimal coagulant dose determined by a jar test was directly injected and agitated rapidly with the installed flocculation paddle in the column, followed by slow mixing to form flocs for FPS. The coagulant was PAC, $Al_nCl_{(3n-m)}(OH)_m \cdot 14H_2O$ as Al_2O_3 10%. Turbidity and SS were measured simultaneously to compensate for an analytical error, and a correlation equation was derived. The total suspended solids were measured in the range of 10–300 mg/L as dry weight of the suspended solids trapped on a 0.45 mm micro-pore membrane filter [22]. Turbidity was tested immediately using a turbidity meter (2100P, Hach Company, USA) to avoid spoilage of the samples or an interferential reaction, as per a previous study [25].

The fractional mass removal (X_{ij}) and SS removal efficiency (R) were calculated to determine the percentage of

solids removed from individual samples, which is given by the below expression.

$$X_{ij} = \left(1 - \frac{C_i}{C_0}\right) \times 100 \tag{1}$$

where i = depth (m); j = time interval (min); C_0 = initial solid concentrations (mg/L); C_i = solid concentration at depth, i (mg/L).

$$R = r_0 + \frac{1}{D}\sum(\Delta R \cdot Z_i) \tag{2}$$

where r_0 = removal percentage at retention time or intercept from horizontal axis (min); D = column depth or height of column (m); ΔR = interval between iso-removal percentage curve ($d/100$); d = individual interval between iso-removal curves from horizontal axis; Z_i = average value reading for the points of bisection of with any iso-removal curve line denoted as intervals $\Delta h_1, \Delta h_2, ..., \Delta h_n$.

3. Results and discussion

3.1. Particle distribution and composition of water quality and sediment

The first measurement in the spring dry period was conducted on May 8–9, 2019 (mean temperature 14.7°C), when there had been no rainfall event for 10 d over 29 mm/d. The second measurement in the summer rainy period was on June 29–30, 2019 (mean temperature 23.7°C), in the middle of a rainfall event of 48 mm/d, and the third measurement in the summer dry period was on August 2–3, 2019 (mean temperature 28.4°C), when there had been no rainfall event for 5 d over 27 mm/d. The amount of rainfall and temperature was cited from the Weather Information System [26] of the Buan Meteorological Observation Station.

The change in water quality for the three periods was similar to a typical pattern, as all water parameters had increased by the rainfall of the second measurement, as shown in Table 2. Only the Chl-a concentration was an exception, with the highest concentration displayed in the first measurement. The mean volatile solids (VS)/TS ratios representing organic content in the solids were 0.85, 0.58, and 0.75 in order of measurement precedence (0.71 at M-s site and 0.73 at D-s site), whereas the PO_4–P/TP ratios indicating the fraction of soluble inorganic P in TP were 0.18, 0.34, and 0.22 in order of measurement precedence.

The measurement results of the trapped sediment samples are presented in Table 3. The change in sediment composition was shown as similar to the changing pattern of water quality except for the TOC and Chl-a concentrations. The second measurement period was highest among the three periods for organic content in the sediment, which was similarly ranked as the Chl-a concentration. The TP concentration in the sediment was in the range of 210–1,700 mg/kg in previous studies [27,28].

The effects of the PSD of the trapped sediments on the sedimentation properties were evaluated under the classification [29], as shown in Fig. 3. Coarse-grained sediments are basically non-cohesive, while fine-grained sediments less than 62.5 μm are cohesive with each other or other materials. The cohesiveness of the particle acts as an essential physicochemical factor on the sedimentation characteristics of the particles.

The PSD of the rainy period measurements had increased by the influence of the period's rainfall, as shown in Fig. 3. The average value of PSD was within the boundaries of medium silt and coarse silt (34.7 μm at M-s site and 34.0 μm at D-s site) and demonstrated cohesive particles.

3.2. Settling column test

The particles in a stagnant water body, such as a lake or reservoir, have a tendency to have the adhesive characteristics of cohesive particles that are similar to the artificial coagulation in the water treatment process. Furthermore, as a natural particle grows, the settling velocity is gradually increased due to natural aggregation [30]. Because of the cohesiveness of the particles in the lake, the SCT experiments were classified into two types of sedimentations, DPS

Table 2
Water quality of sampling sites in Lake Saemangeum

Site	TOC	TS	SS	VS	TN	TP	PO_4–P	Chl-a
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/m³)
Dry season (May)								
M-s	5.95	333.2	23.7	290.4	2.920	0.120	0.000	167.6
D-s	5.95	159.2	16.5	127.2	2.490	0.110	0.000	89.0
Rainy season (July)								
M-s	6.10	204.5	34.0	93.3	3.888	0.137	0.050	5.3
D-s	8.80	187.5	22.4	91.5	3.389	0.149	0.043	4.5
Dry season (August)								
M-s	4.15	421.5	31.4	342.0	3.723	0.139	0.032	45.1
D-s	3.80	117.6	27.0	104.5	2.247	0.118	0.025	39.8

Table 3
Particle composition of sediment at the sampling sites of Lake Saemangeum

Site	Solid content	COD	Organic conc.	TOC	TN	TP	Chl-a
	(%)	(mg/kg)	(%)	(%)	(mg/kg)	(mg/kg)	(mg/kg)
Dry season (May)							
M-s	25.0	44,216	7.4	2.42	1,921	855	89.8
D-s	26.0	74,600	7.2	2.09	1,435	700	48.1
Rainy season (July)							
M-s	19.0	42,223	28.5	2.74	1,802	1,087	63.1
D-s	23.8	30,362	10.2	3.50	2,758	1,368	118.9
Dry season (August)							
M-s	47.8	18,315	8.0	1.88	1,445	825	92.4
D-s	58.9	10,866	5.0	1.04	2,635	576	42.8
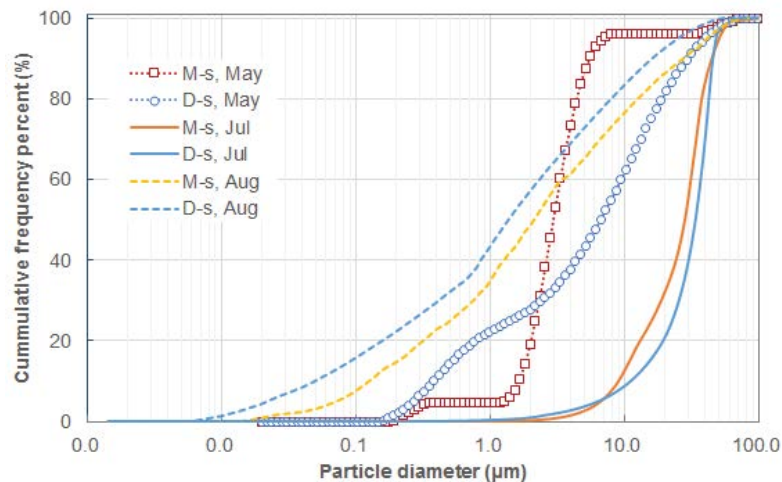
Fig. 3. Cumulative particle size distribution in terms of particle diameter taken from sediment traps for each sampling site.

and FPS. The procedures and operations were examined in accordance with the typical SCTs [31]. The sedimentation time of DPS was extended by 96 h for the samples to be clarified sufficiently, while 2 h was the maximum in FPS.

The SS concentration profiles by the depth of the settling column in the first experiment in May (dry period) show noticeable differences with July and August. These variances imply that the required sedimentation time for the dry season samples is longer for the periods affected by heavy summer rain. However, the SS concentration profiles by the depth are clarified rapidly and have similar sedimentation patterns in the FPS experiments, as shown in Fig. 4. Furthermore, the variance range of the TP concentrations by depth is greater than that of the SS concentrations, which also implies that the particle containing P is precipitated much more slowly than SS. Furthermore, the TP concentration by depth in the second experiment for July (rainy period) presents a much wider fluctuation than the dry period (May and August). The TP profile of the July experiment in the rainy period verified that rainfall leads to TP sedimentation highly variable. Additionally, the TP

particles formed with alum coagulation precipitated slower than the SS particles.

From the TP removal of the SCT experiment slower than the SS removal, the sedimentation tank should be larger than typical sedimentation for particle separation in order to obtain enough time to settle P particles when sedimentation is applied to remove P. The difference of sedimentation profiles between P particles and SS gave us useful information to design and operate a sedimentation tank to control P concentration in the lake.

Fig. 5 shows the SS and TP removal efficiencies in terms of sedimentation time, which was calculated by Eq. (2) based on the results of the SCT experiments. The TP removal efficiency of DPS of 32.5% was substantially lower than of FPS (57.4%). In the three periods, the TP removal efficiency ratio from August was the highest as 39.9% in the DPS experiments, while July was highest as 63.3% in the FPS experiments similar to the TP removal efficiency. Furthermore, there was no noticeable difference in the removal efficiency ratios of TP to SS; FPS (0.66) was slightly higher than DPS (0.61). However, the
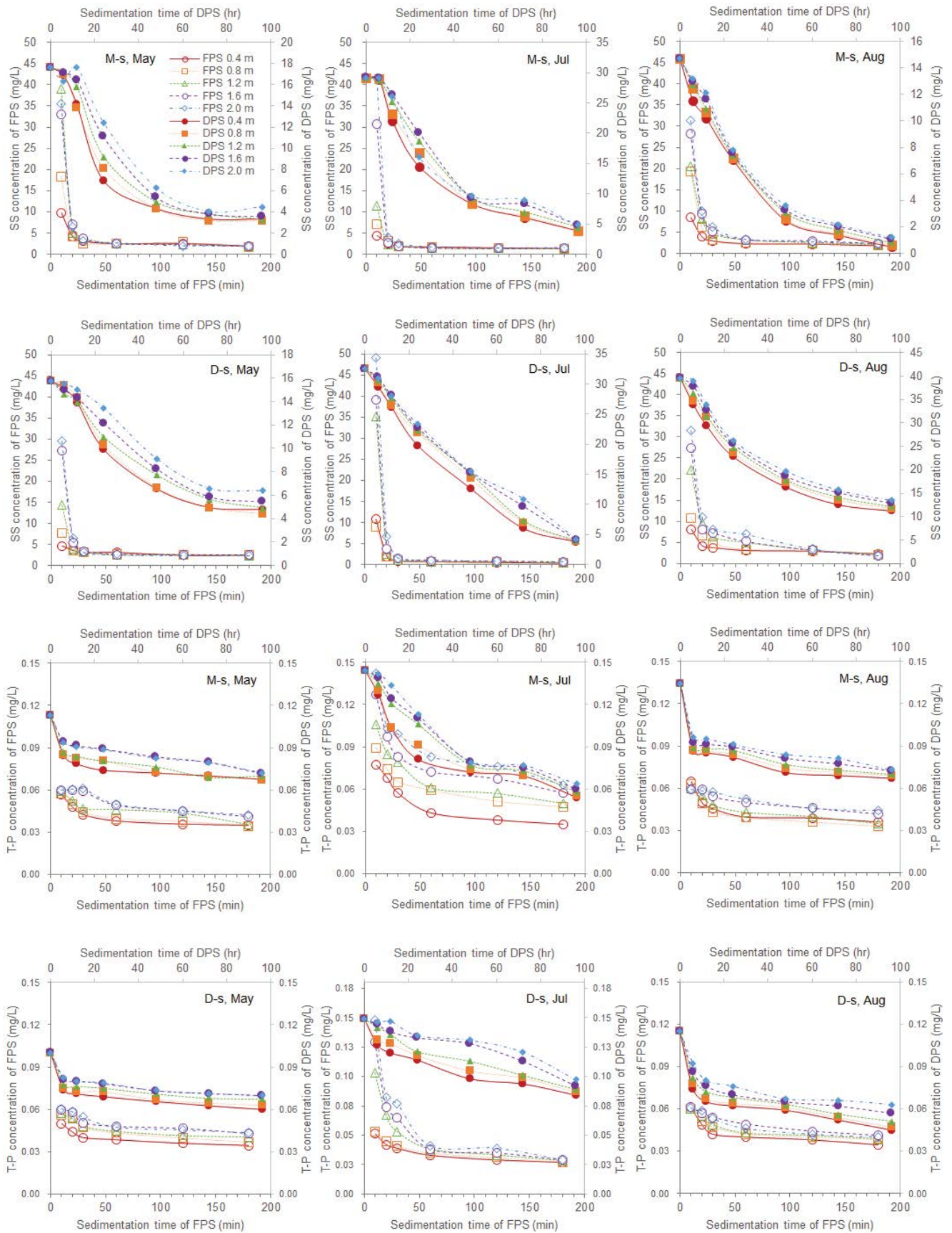
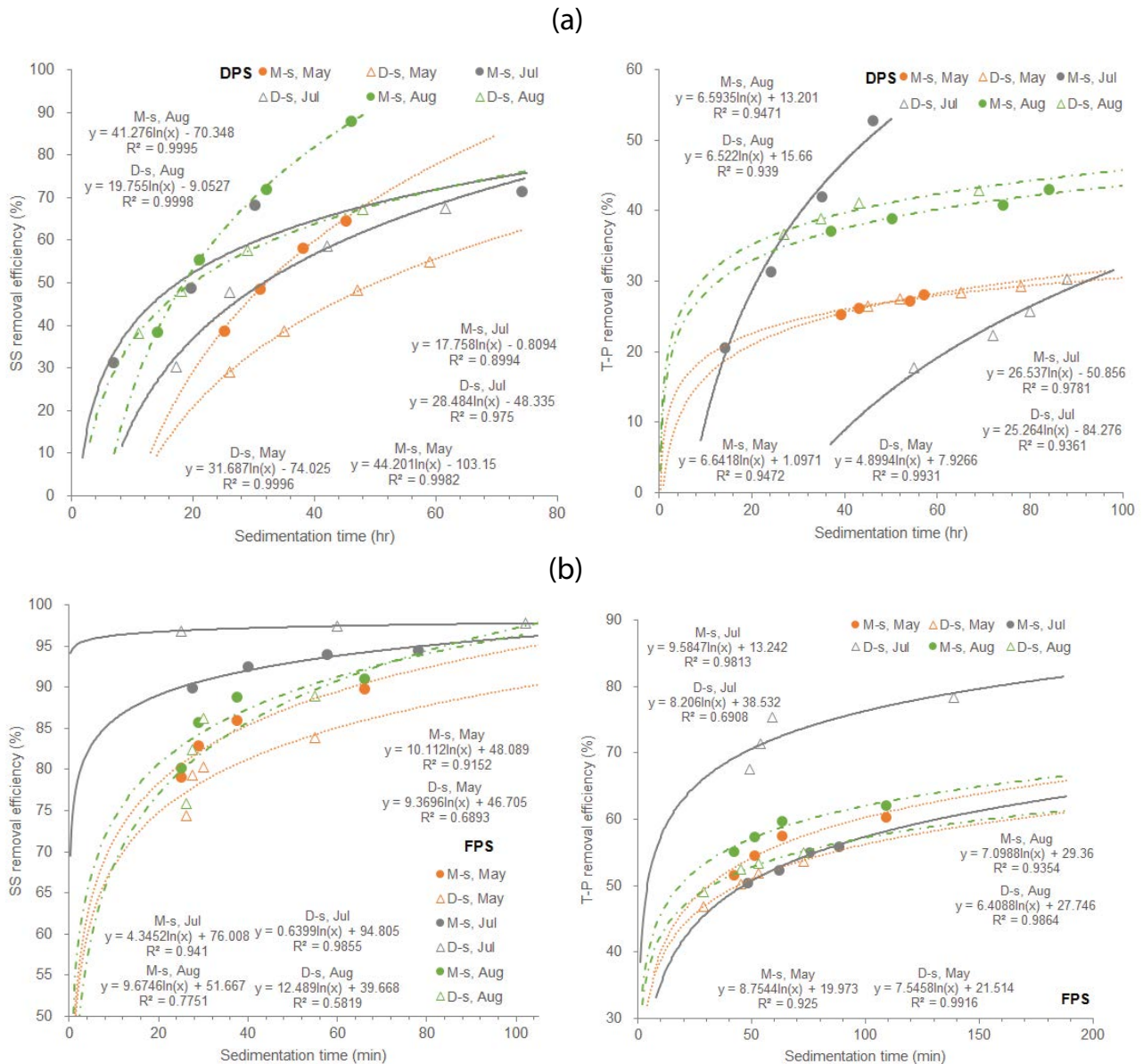Fig. 4. Variation of SS and TP removal efficiency in terms of sedimentation time for SCT.

Fig. 5. Variation of SS and TP removal efficiency in terms of sedimentation time: (a) sedimentation curves for discrete particles sedimentation and (b) sedimentation curves for flocculent particles sedimentation.

temporal aspect was also different than the removal efficiency ratio of TP to SS. In August, the highest was 0.69 in the DPS experiments, while July's highest was 0.67 in the FPS experiments, similar to the results of the TP removal efficiency. The reason for the low TP removal in May and high removal in July could be that the TOC concentration was the highest in May, which can deteriorate TP removal efficiency. Additionally, the high SS due to rainfall promoted the TP removal efficiency in July. According to the previous study [32], the P removal efficiency increased with increasing SS concentrations because of non-point-source pollution by rainfall, whereas the organic matter decreased P removal.

The analysis of PSD was also investigated in the SCT experiments, as shown in Fig. 6. For both DPS and FPS,

the PSD had increased in July, and that of August had decreased much less than in May. The temporal change of the PSD in the SCT, which was influenced by the rainfall, was similar to the PSD of the trapped sediments.

3.3. Removal efficiency and relationship between SS and phosphorus

The correlation between the TP removal efficiency and SS removal efficiency is presented using the results of the SCT experiments in Fig. 7, which is an indicator of the TP removal fraction of particle sedimentation. The correlation value of DPS is higher than of FPS, and the determination coefficients (R^2) of the rainy period is the highest among the three periods. The correlation trend is in accordance
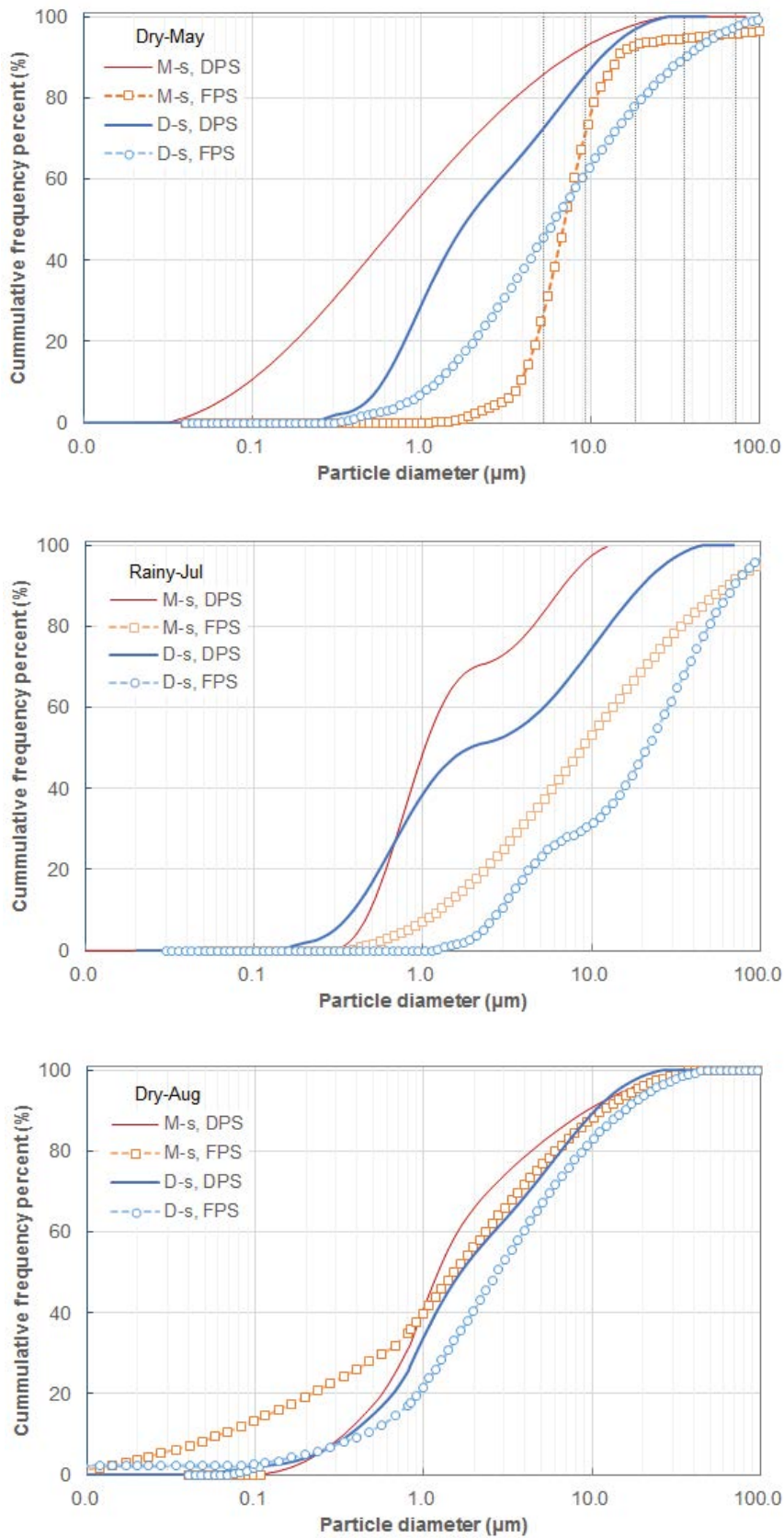
Fig. 6. Cumulative particle size distribution in terms of particle diameter taken from sediment column.
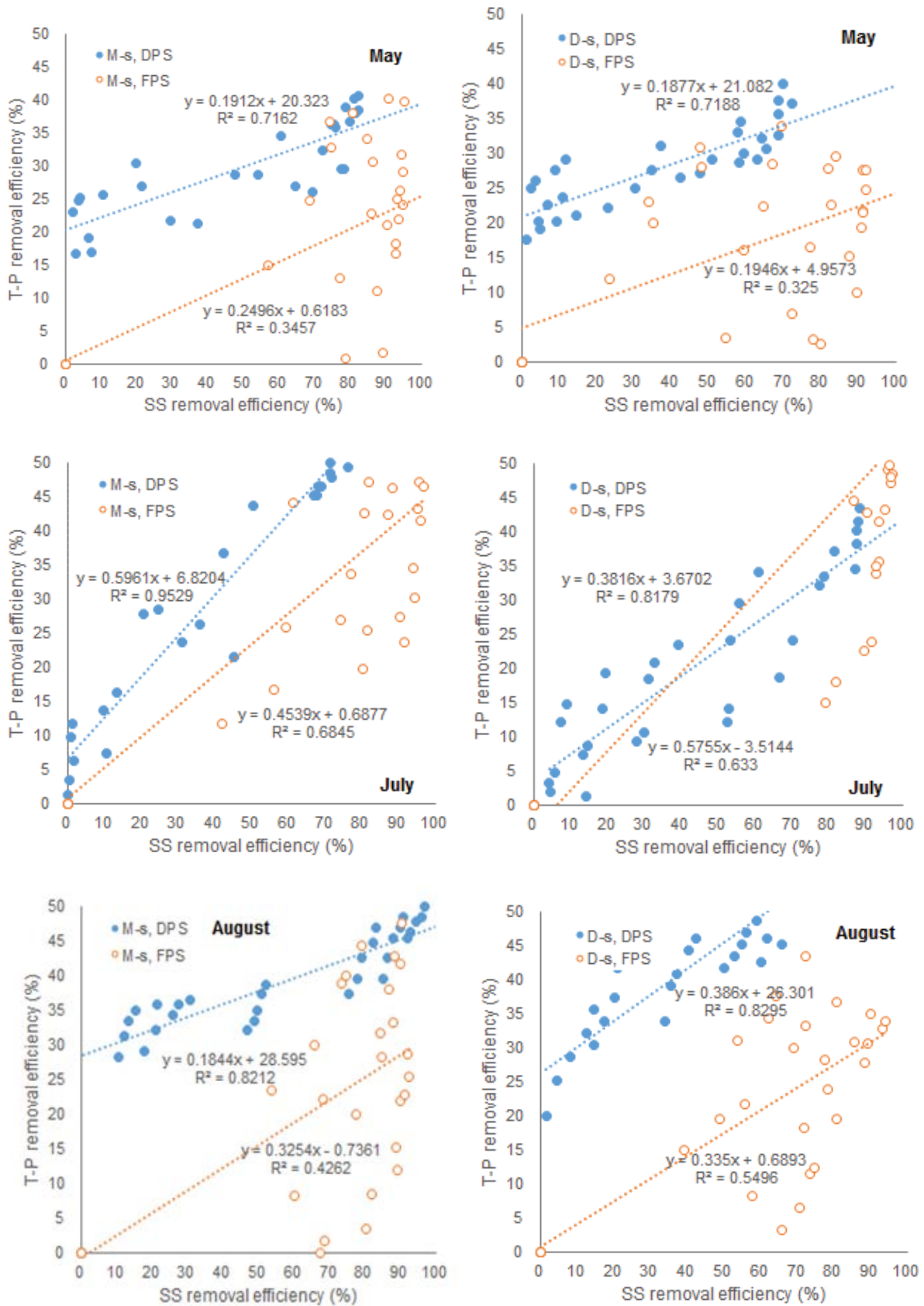
Fig. 7. Relationship between SS and TP removal efficiency for three periods.
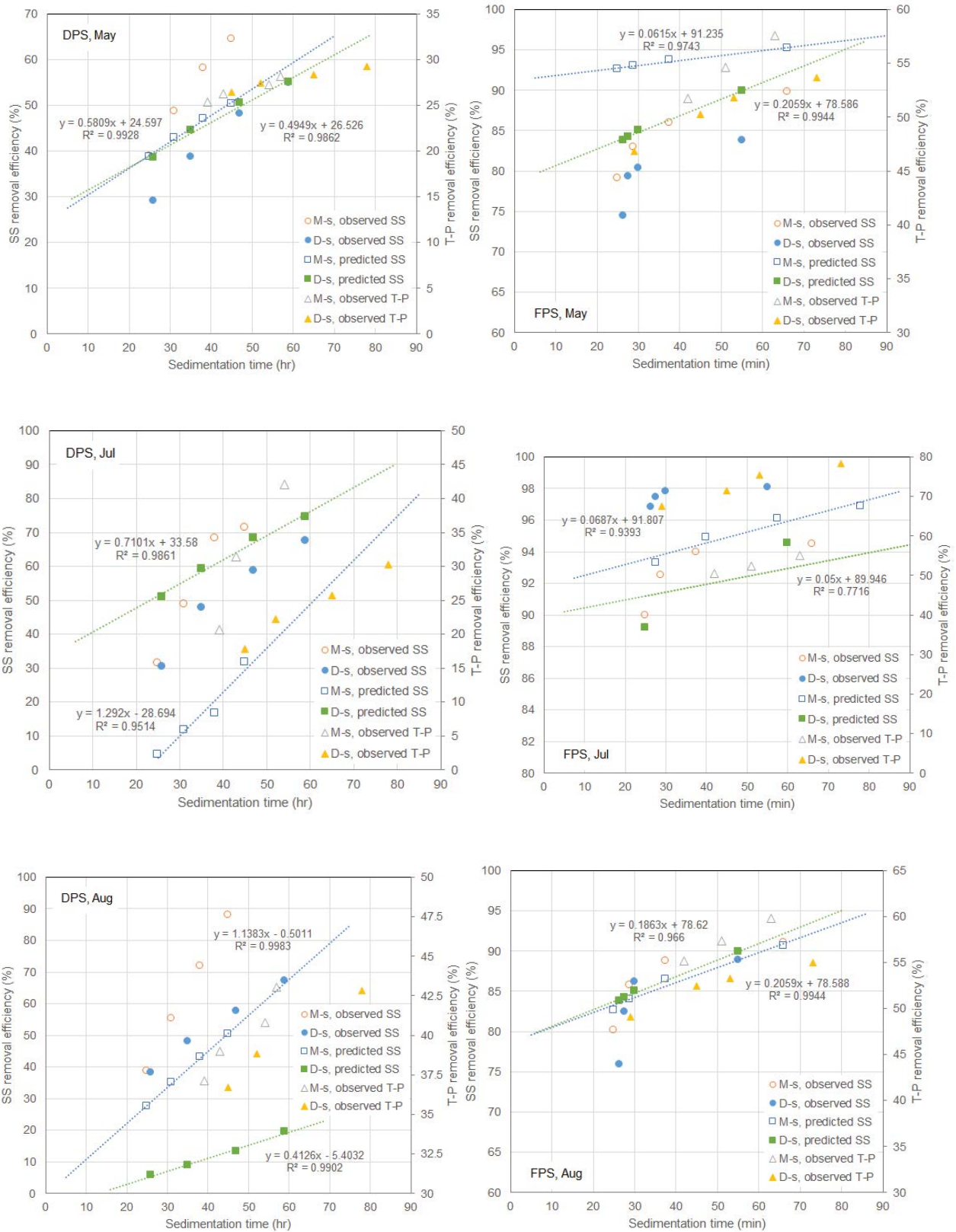
Fig. 8. Comparison of removal efficiency between observed values and predicted values in terms of sedimentation time.

Table 4
Results of correlation analysis between observed values and observed values

Site	Period	Description	Discrete sedimentation		Flocculent sedimentation	
		Variables	Observed SS	Observed TP	Observed SS	Observed TP
M-s	May	Observed SS	–	0.999[b]	–	0.957[a]
		Predicted SS	0.999[b]	1.000[b]	0.968[a]	0.999[b]
	July	Observed SS	–	0.948	–	0.970[a]
		Predicted SS	0.880	0.971[a]	0.989[a]	0.995[b]
	August	Observed SS	–	1.000[b]	–	0.880
		Predicted SS	1.000[b]	1.000[b]	0.908	0.998[b]
D-s	May	Observed SS	–	1.000[b]	–	0.831
		Predicted SS	1.000[b]	1.000[b]	0.843	1.000[b]
	July	Observed SS	–	0.987[a]	–	0.992[b]
		Predicted SS	0.992[b]	0.999[b]	0.994[b]	0.979[a]
	August	Observed SS	–	1.000[b]	–	0.762
		Predicted SS	0.988[a]	0.990[a]	0.780	1.000[b]

[a]$p > 0.05$; [b]$p > 0.01$

with the SS concentration of the sampling sites, as shown in Table 2. This correlation indicates that high SS concentrations can provide a much more substantial surface for particles to adsorb so that it is favorable to achieve high P removal. The previous studies [33,34] reported that phosphate was readily adsorbed onto aluminum oxide hydroxide because of the hydroxyl groups, and P sorption had increased the surface area of the flocs.

This result implies that even if the phosphorus concentration increases (particulate phosphorus and dissolved phosphorus) during rainfall, the incoming SS particles provide a surface capable of adsorbing phosphorus removal, thereby increasing the removal efficiency. In particular, the results of this study revealed that the shortened sedimentation efficiency could be compensated due to the providing of surface area to adhere P from the many particles during the rainfall though the residence time in the sedimentation basin may be shortened by the inflow amount that increases with concentrated rainfall.

Based on the PSD data, the calculated values of TP removal efficiency were compared with the observed values obtained by Eq. (2) in the SCT experiments. The relationship between the observed values and predicted values is presented in Table 4. The results of the correlation analysis between the observed SS and observed TP show high positive values in both DPS and FPS for all three periods, as shown in Table 4 and Fig. 8. In particular, the reliability of the relationship in DPS was higher than in FPS except for the rainy period. However, the correlation analysis between the data predicted for PSD and observed TP was slightly lower than that of the inter-observed values. Therefore, to predict the TP removal efficiency, the direct measurement of SS or turbidity is more useful than the PSD analysis, which needs a relatively long time to measure.

4. Conclusions

Based on the PSD analysis on the inflow particles and the SCT experiments, SS and TP removal efficiency were investigated to find the feasibility and characteristics of the sedimentation process in the lake. A series of SCT experiments and the analytical results of the PSD and examinations in Lake Saemangeum for three periods revealed that high SS concentrations from rainfall could improve TP removal efficiency, and a simple measurement is more useful than the PSD analysis of inflow water. A summary is as follows.

- Most of the particles taken from the sediment trap were cohesive, and the PSD of the trapped sediments had increased in the rainy period; however, it decreased in the dry period after rainfall more than the decrease in the dry period before rainfall.
- A longer sedimentation time for the dry period before rainfall was required than for the rainy period and the dry period after rainfall in the DPS, whereas there was no difference in the FPS.
- The TP removal in the SCT experiment was slower than the SS removal, which means a longer sedimentation time is needed compared with SS sedimentation to gain high TP removal efficiencies.
- The results of the SCT experiments for the three periods led us to conclude that the high SS concentration of the rainy period provides an ample surface area of particles to adsorb phosphate ions onto discrete particles or coagulated flocs so that a higher TP removal efficiency can be achieved in the rainy season than in the dry season.
- The correlation value between the SS removal efficiency and TP removal efficiency in the DPS was higher than in the FPS, and the determination coefficients were higher in the rainy period than in the dry period.

In order to predict TP removal efficiency, a direct measurement of SS or turbidity is more useful than the PSD analysis, which requires a considerably long time to measure. Therefore, a continuous water measuring device like a turbidity meter could be an alternative to monitor or to

treat P in the sedimentation process of the lake regardless of coagulation.

Acknowledgments

This study was supported by the National Research Foundation of Korea with grants (NRF: NRF-2019R1A 2C1006441) from the Ministry of Education.

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