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ORIGINAL ARTICLE

Correlation analysis of factors affecting removal efficiency in vegetative filter strips

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Abstract Nonpoint pollution sources (NPSs) are difficult to manage because their pathways, pollutant load, and runoff characteristics are unclear, unlike point pollution sources. Hence, the Korean government plans to research and develop best management practices (BMPs) for the management of NPSs. The removal efficiency of BMPs varies due to several factors, including rainfall events. These BMPs can be evaluated by numerous methods, and continuous research is being conducted on improving them. In this study, a correlation analysis was conducted to investigate vegetation coverage and retention time as factors affecting the removal efficiency of a vegetative filter strip (VFS), which is a natural nonpoint pollution reduction facility. The results showed that a longer retention time was associated with a higher removal efficiency of a VFS when the vegetation coverage was maintained. Therefore, adequate vegetation coverage and retention time are required to increase the removal efficiency for the VFSs.

Keywords Vegetative filter strips · VFS · Nonpoint source pollution · Retention time · Vegetation coverage

Introduction

NPSs can deteriorate the water quality of rivers and lakes. Point pollution sources have clear discharge points and are discharged at one point through sewer pipes; meanwhile,

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NPSs discharge points, pollutant load, and pathways are unclear, and they are both diffused and diluted by rainfall (Chiew and McMahon 1999; Gil and Kim 2012). Furthermore, it is difficult to predict the pollutant load and characteristics of NPSs, because they are changed by natural factors such as land use, climate, date and time, and hydrologic conditions (Elci and Selcuk 2013; Wu et al. 2013). Thus, it is difficult to manage NPSs. It has been predicted that NPSs will contribute up to 65 % of all river water pollution by 2020 in South Korea (Kim and Gil 2012; Kwon 2011). For this reason, the Korean government has introduced the total pollution load management system (TPLMS) to show the importance of managing NPSs for regulating total quantity of pollutants during flow events. Furthermore, the government has mandated the installation of BMPs and has conducted various research and development activities regarding BMPs (Majed et al. 2003; Gil and Wee 2012).

BMPs are largely classified into equipment types and natural types. The equipment types include screen type, vortex type, and filter type (Huang et al. 2007; Pasquini et al. 2012). The natural types include artificial wetland, vegetated facilities, and infiltration facilities (Choi et al. 2008; Sin 2011). For vegetated facilities, there are grassed swale and VFS forms of BMPs. The pollution removal efficiency of vegetated facilities varies by way of the plant's filter, adsorption, and infiltration features. BMPs are difficult to design and maintain because they are affected by rainfall; therefore, the factors affecting nonpoint pollution reduction facilities need to be researched.

In this study, factors influencing removal efficiency such as vegetation coverage and retention time were investigated. A Pearson correlation analysis was conducted to investigate the effects of these factors which influence removal efficiency. The vegetation coverage was organized

into four categories, 0–25, 25–50, 50–75 and 75–100 %. In addition, each vegetation coverage class was analyzed for retention time to determine removal efficiency.

Study method

Monitoring location and methods

The subject of this study was a VFS, which is a vegetative BMP installed in Hae-gok dong, Cheo-in gu, Yong-in, South Korea, with a 25,300 m^2 basin area. The drainage area consists of farmland and forestland, and the facility site area is 3321 m^2. Figure 1 shows the location of this facility. Because rainfall characteristics vary, water sampling for monitoring was determined by total rainfall (mm), rainfall time (h), and rainfall intensity (mm/h). Turbidity at the site was monitored continuously. The rainfall duration and water sampling interval were determined from the starting point of inflow into the facility. The following pollutants, TSS, BOD, COD, TN, and TP, were analyzed by standard methods (APHA 1998).

EMC

The event mean concentration (EMC) was calculated to examine the discharge characteristics of each pollutant. EMC is calculated by dividing the total quantity of discharged pollutants by the total runoff for a particular period of rainfall. Equation (1) shows the EMC calculation formula:

$$\text{EMC (mg/L)} = \sum_{t=1}^{T} C(t)Q(t) / \sum_{t=1}^{T} Q(t) \tag{1}$$

where $Q(t)$ denotes the flowrate over time (m^3/s), $C(t)$ denotes the concentration over time (mg/L), and T denotes the total rainfall duration time.

Removal efficiency

Equation (2) shows the efficiency ratio (ER) calculation formula for calculating the removal efficiency of BMP. The ER method calculates the removal efficiency for each event through rainfall monitoring, and then its arithmetic mean is calculated (EPA 1996; Martin and Smmot 1986).

$$\text{ER (\%)} = \frac{\sum_{t=1}^{N} \text{Removal Efficiency}}{N} \tag{2}$$

Table 1 Measure of correlation

Correlation range	Criteria
−1.0 to −0.7	Strong negative correlation
−0.7 to −0.3	Clear negative correlation
−0.3 to −0.1	Weak negative correlation
−0.1–0.1	Negligible correlation
0.1–0.3	Weak positive correlation
0.3–0.7	Clear positive correlation
0.7–1.0	Strong positive correlation
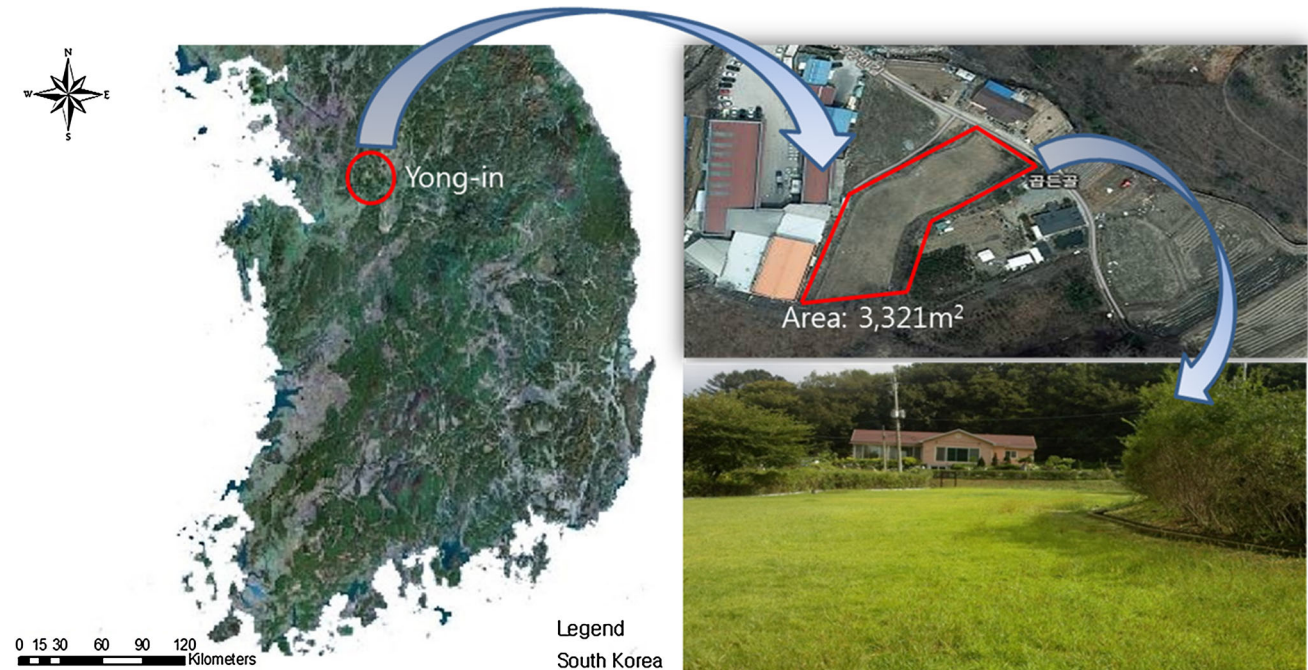
Fig. 1 Location of the vegetative filter strips

Table 2 Event table for monitored event

| N = 25	ADD (day)	Total rainfall (mm)	Rainfall duration (h)	Avg. rainfall intensity (mm/h)
Min	1.2	2.0	0.2	0.7
Max	45.0	120.0	25.0	23.5
Mean	5.0	30.5	8.0	3.7
SD	9.0	30.4	5.6	5.0

Pearson correlation

Table 1 shows the intensity and direction of variables in the Pearson correlation analysis. The Pearson correlation coefficient R has a value greater than -1 and smaller than 1. A value closer to -1 or 1 indicates a higher positive and negative correlation, respectively.
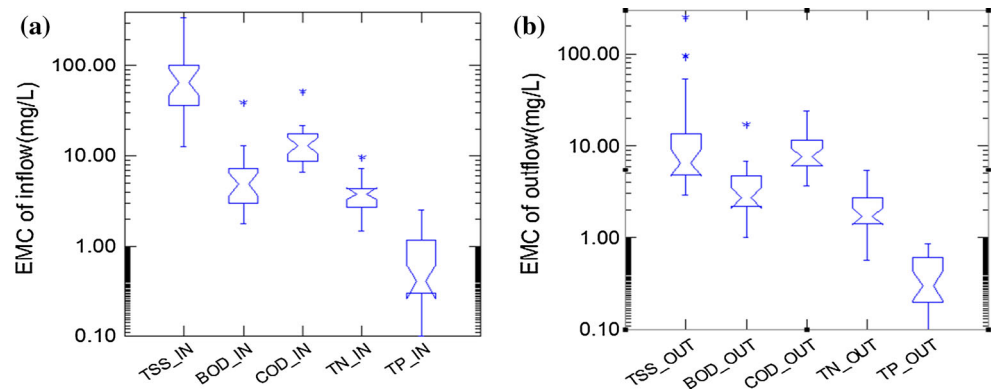
Results and discussion

Hydrologic data plot

This study was monitored 25 times between 2006 and 2013. Table 2 summarizes all events that were monitored; number (N), antecedent dry days (ADD), total rainfall, runoff duration time, and average rainfall intensity are shown. ADD was 1.2–45.0 days, total rainfall was 2.0–120.0 mm, runoff duration time was 0.2–25.0 h, and the average rainfall intensity was 0.7–23.5 mm/h. Figure 2 shows the representative hydro and pollutograph of the drainage area to the VFS. The pollutograph shows the runoff pattern of a farming village where the concentration of pollutants changes as rainfall varies.
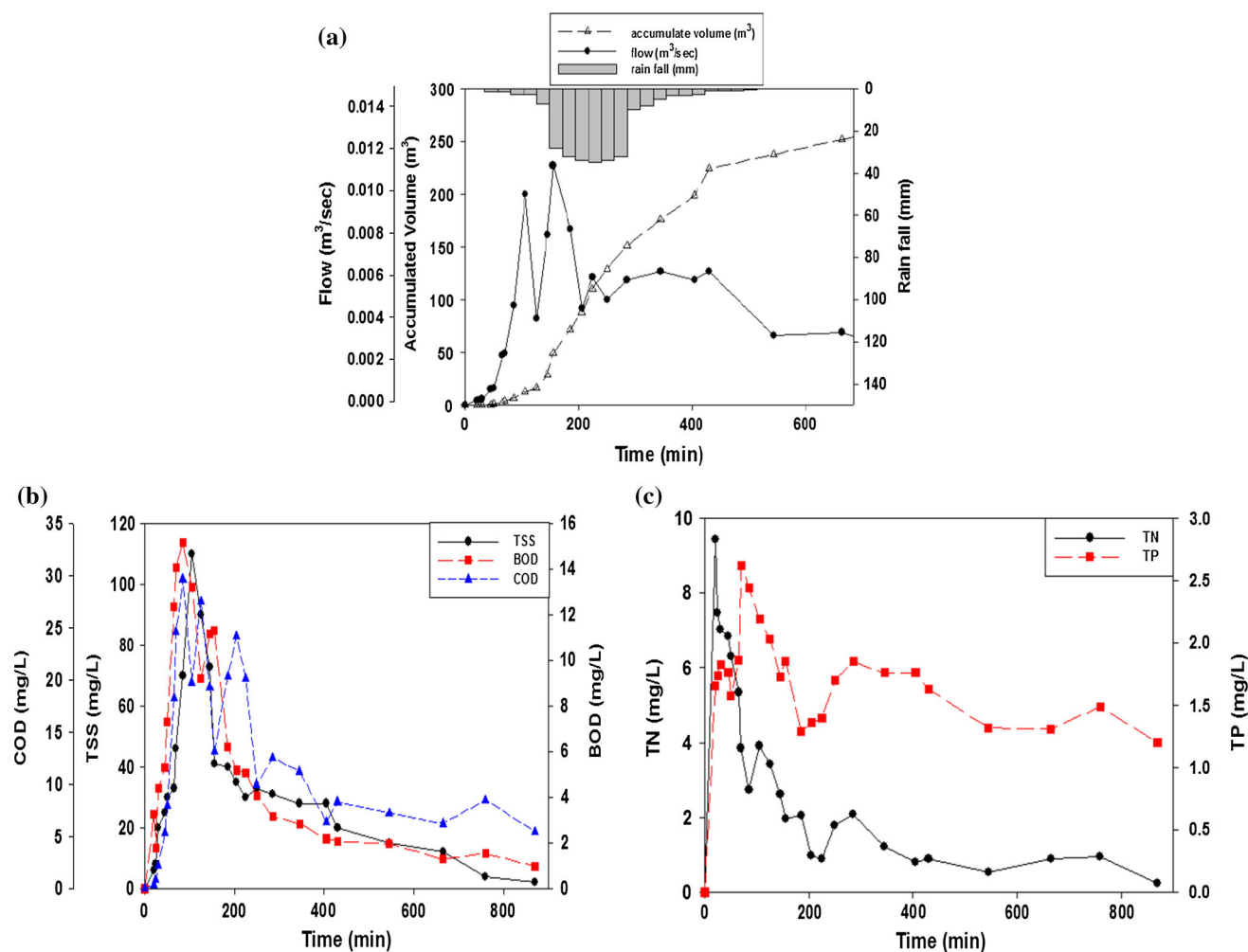
Fig. 2 Representative hydro- and pollutograph of studied area. **a** Hydrograph, **b** TSS, BOD, COD, **c** TN, TP

Fig. 3 Inflow EMCs and outflow EMCs

Inflow and outflow EMCs

Figure 3 shows the influent and effluent EMCs which were calculated based on the monitoring results from the 25 rainfall events. In the case of influent EMCs, TSS was 12.8–350.7 mg/L, BOD was 1.8–38.7 mg/L, COD was 6.6–51.8 mg/L, TN was 1.5–9.6 mg/L, and TP was 0.1–2.6 mg/L. In the case of effluent EMCs, TSS was 29.8–247.6 mg/L, BOD was 1.0–17.2 mg/L, COD was 3.6–23.8 mg/L, TN was 0.6–5.3 mg/L, and TP was 0.1–0.9 mg/L. Tables 3 and 4 show the values of inflow and outflow EMCs.

Vegetation coverage

Figure 4 shows the removal efficiency values of the VFS by vegetation coverage which were calculated in this study. For BOD, the removal efficiency increased as the vegetation coverage increased. However, the removal efficiency was low when vegetation coverage was 25–50 %. The

Table 3 Fundamental statistics pertaining to the inflow EMCs

Constituents	Minimum	Maximum	Mean
TSS (mg/L)	12.8	350.7	65.6
BOD (mg/L)	1.8	38.7	4.8
COD (mg/L)	6.6	51.8	13.0
TN (mg/L)	1.5	9.6	3.8
TP (mg/L)	0.1	2.6	0.4

Table 4 Fundamental statistics pertaining to the outflow EMCs

Constituents	Minimum	Maximum	Mean
TSS (mg/L)	2.9	247.6	6.5
BOD (mg/L)	1.0	17.2	2.7
COD (mg/L)	3.6	23.8	7.6
TN (mg/L)	0.6	5.3	1.7
TP (mg/L)	0.1	0.9	0.3

removal efficiency of COD was similar to that of BOD, but the removal efficiency was high when the vegetation coverage was 25–50 %. For TSS, the removal efficiency increased as the vegetation coverage increased. These results suggest that organic that had not biologically degraded was discharged when the vegetation coverage was 25–50 %. Furthermore, for TN and TP, the removal efficiency increased as the vegetation coverage increased.
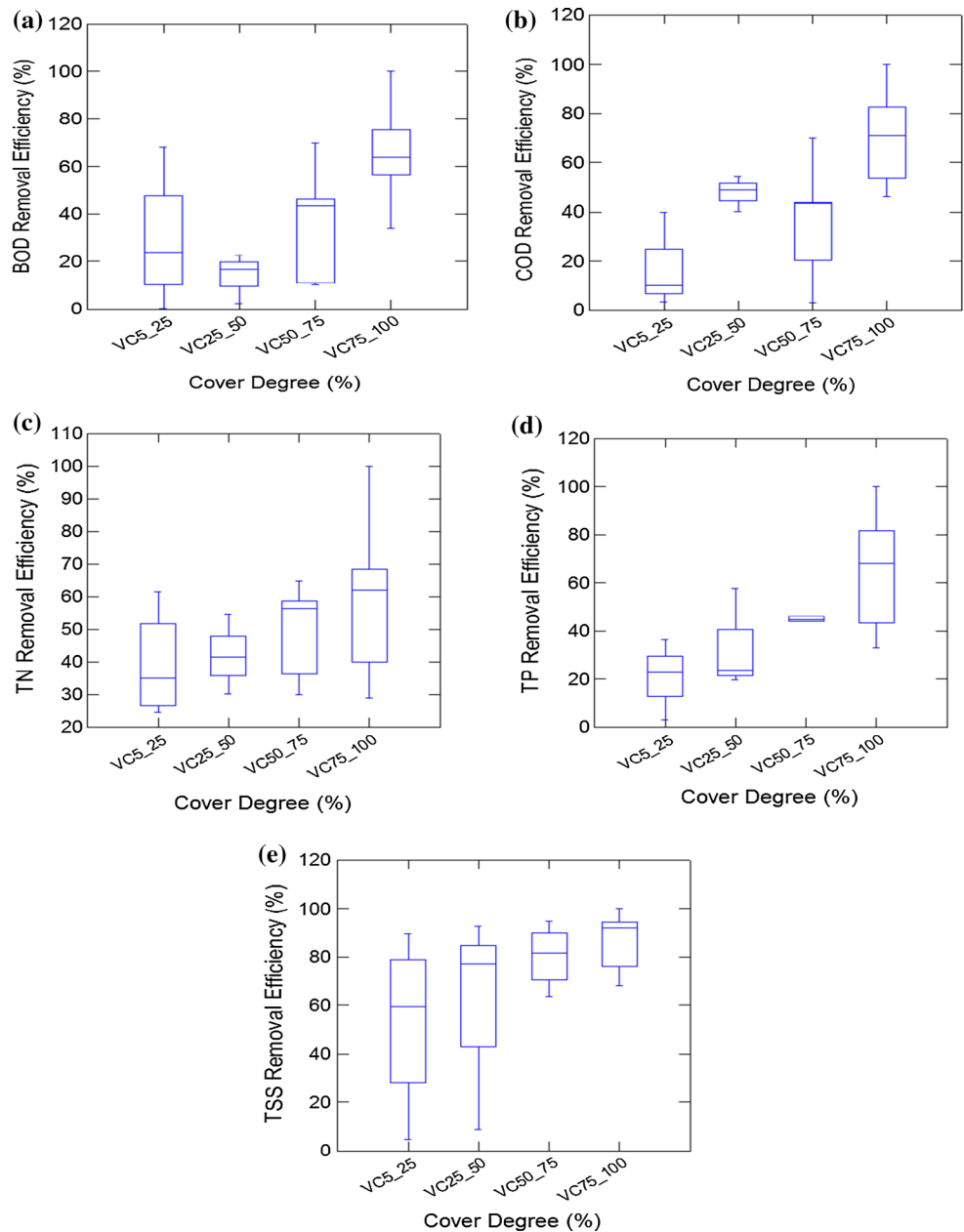
Retention time

Figure 5 shows removal efficiency of the VFS versus retention time. In the case of BOD, the removal efficiency was highest when the retention time was 50 min or longer, but the removal efficiency did not increase as the retention time increased. In the case of COD, as with BOD, the removal efficiency was highest when the retention time was 50 min or longer, but there was no correlation between retention time and removal efficiency. In the case of TSS, the removal efficiency was generally high. In the case of TN, the highest median value appeared when the retention time was 50 min or longer, and the efficiency values were generally similar. TP generally did not show a correlation between removal efficiency and retention time.

Relationship of removal efficiency, vegetation coverage, and retention time

The analysis of the removal efficiency and vegetation coverage of NPSs reduction matters in a VFS showed that the removal efficiency increased together with the vegetation coverage, but there was no significant correlation between the removal efficiency and retention time. Therefore, in this study, the retention time of the vegetation coverage class 75–100 %, which had the highest removal efficiency, was analyzed as shown in Fig. 6. As a result, for BOD, the removal efficiency increased as the retention time increased. In addition, the removal efficiency for COD increased as the retention time increased, and the highest

Fig. 4 Removal efficiency by vegetation coverage class. **a** BOD, **b** COD, **c** TN, **d** TP, and **e** TSS


removal efficiency appeared when the retention time was less than 10 min. These results seem to have been influenced by specific rainfall, due to the classification of the vegetation coverage. For TSS, the removal efficiency increased as retention time increased. TN and TP showed similar removal efficiency values until 30 min of retention time, but the removal efficiency was highest when the retention time was 50 min or longer. These results suggest the need for sufficient retention time for the removal of nitrogen and phosphorous in a VFS.

In addition, a Pearson correlation analysis was conducted to analyze the correlation between retention time and removal efficiency when the vegetation coverage of the VFS was maintained at 75–100 %. Table 5 shows the

results of the Pearson correlation analysis for every event monitored for eight years. Furthermore, Table 6 shows the monitoring results, from the Pearson correlation analysis, when the vegetation coverage was 75–100 %. When the correlation between retention time and removal efficiency in Table 1 was examined, BOD showed a weak positive correlation between BOD and TN or TP. Furthermore, in the case of COD, the correlation between retention time and removal efficiency was ignored. It shows a strong negative correlation for TSS. However, the correlation between retention time and removal efficiency increased when the vegetation coverage was maintained at 75–100 %. This suggests that while the vegetation coverage was maintained, the removal efficiency of the VFS was

**Fig. 5** Removal efficiency by retention time. **a** BOD, **b** COD, **c** TN, **d** TP, and **e** TSS
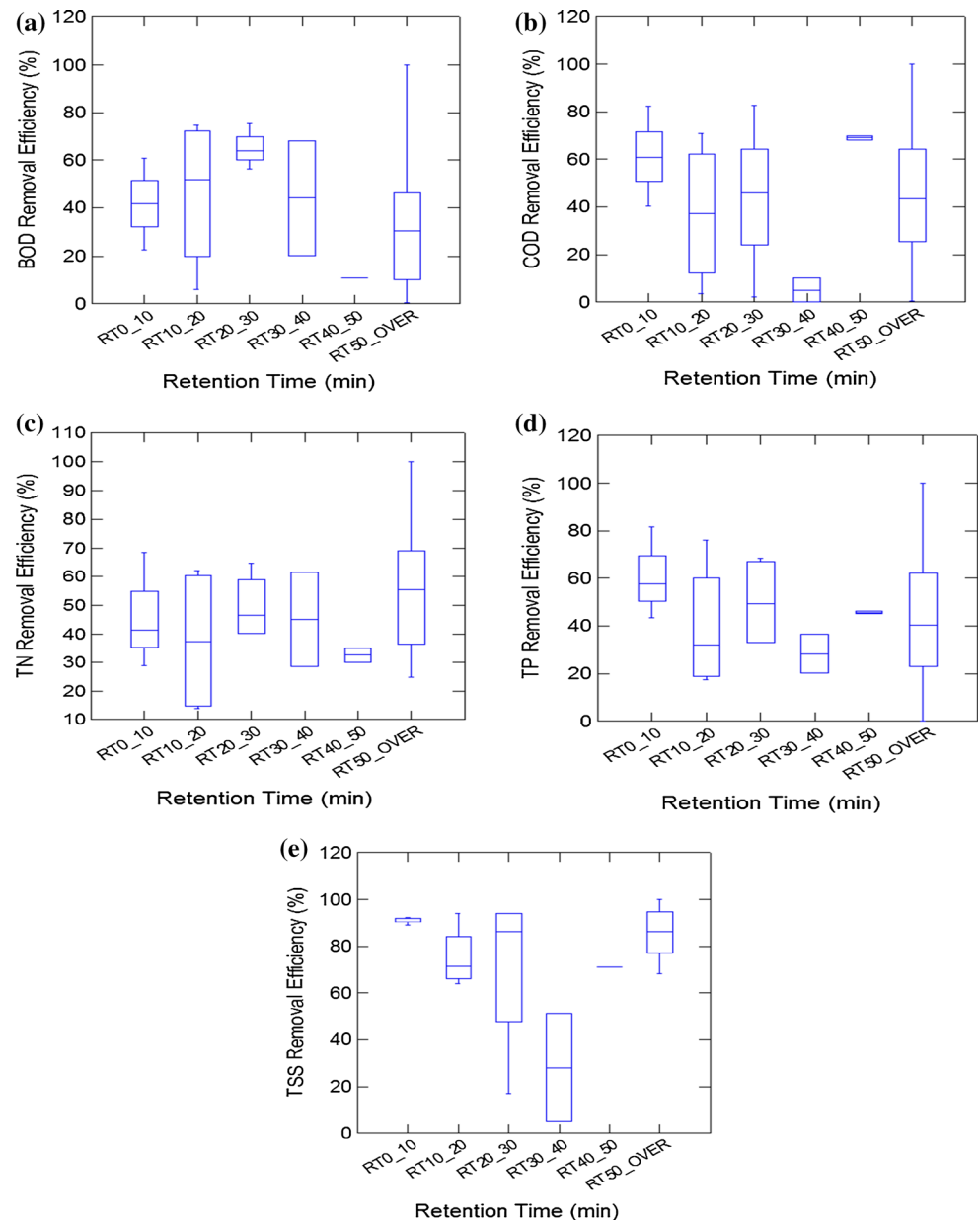
influenced by the retention time. The correlations between vegetation coverage and removal efficiency in Table 6 were generally lower than those in Table 5. The results seem to have been influenced by specific events, due to the smaller number of events caused by the vegetation coverage classification.

Conclusions

This paper analyzes vegetation coverage, retention time, and removal efficiency based on the monitoring results of VFS. The conclusions of this study are as follows:

- An analysis of the EMC inflow and outflow in the subject basin of this study showed that EMC concentrations decreased further with SS, BOD, and COD than with TN and TP. This result suggests that the removal efficiency of organic matter was greater than that of nutrient salts in the VFS.

- When the correlation between vegetation coverage and removal efficiency of the VFS was examined, in the case of organic matter, the removal efficiency was low when the vegetation coverage was 25–50 %, but it was high when the vegetation coverage was 75–100 %. Furthermore, the higher the removal efficiency of nutrient salts, the higher the removal efficiency of

Fig. 6 Retention time removal efficiency in vegetation coverage of 75–100 %. **a** BOD, **b** COD, **c** TN, **d** TP, and **e** TSS
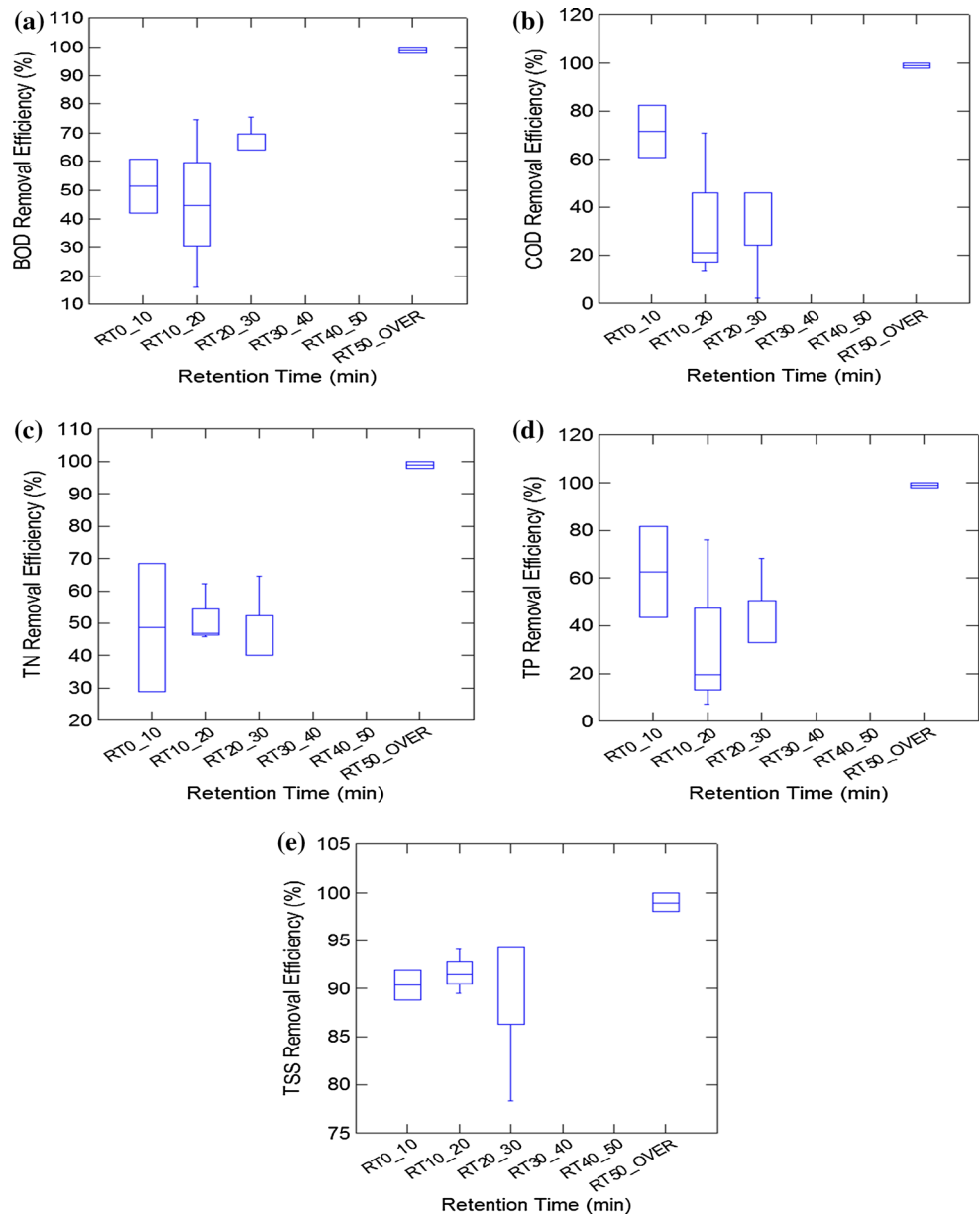
Table 5 Pearson's correlation analysis of all events

Constituents	Retention time	Cover degree	TSS	BOD	COD	TN	TP
Retention time	1	–	–	–	–	–	–
Cover degree	−0.043	1	–	–	–	–	–
TSS	−0.087	0.379	1	–	–	–	–
BOD	0.156	0.309	0.026	1	–	–	–
COD	0.067	0.586	0.252	0.162	1	–	–
TN	0.018	0.245	0.108	−0.190	0.366	1	–
TP	0.262	0.571	0.420	−0.025	0.625	0.728	1

organic matter. This shows that the removal efficiency increased together with the vegetation coverage of the VFS for every pollutant.

- An analysis of retention time and reduction efficiency showed that for every pollutant, the removal efficiency was highest when the retention time was 50 min or

Table 6 Pearson's correlation analysis of vegetation coverage 75–100 %

Constituents	Retention time	Cover degree	TSS	BOD	COD	TN	TP
Retention time	1	–	–	–	–	–	–
Cover degree	0.385	1	–	–	–	–	–
TSS	0.160	0.216	1	–	–	–	–
BOD	0.477	0.449	−0.137	1	–	–	–
COD	0.264	0.478	0.058	0.057	1	–	–
TN	0.394	0.410	0.331	−0.335	0.540	1	–
TP	0.351	0.327	0.220	−309	0.609	0.963	1

longer, and TN and TP generally showed similar removal efficiency values. However, the removal efficiency did not increase as the retention time increased. This result suggests that the retention time influences the removal efficiency in a VFS.

- The results of the analysis of the removal efficiency versus retention time were maintained at a vegetation coverage between 75 and 100 % in a VFS. The reduction efficiency was highest when the retention time was 10 min or lower. The TN and TP showed similar removal efficiency values until 30 min of retention time. However, with every pollutant, the removal efficiency was increased as the retention time increased. Furthermore, a Pearson correlation analysis of all monitoring showed a low correlation between retention time and pollutants. However, a Pearson correlation analysis for the vegetation class of 75–100 % showed an increased correlation between the retention time and pollutants. This suggests that the retention time influences the removal efficiency when vegetation coverage is maintained.

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