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Trapping efficiency with rainfall and seasonal changes in vegetative filter strips over a course of three years

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ABSTRACT

Nonpoint source pollution does not have a clear route for elimination, and due to the amounts of these types of pollution, it is not easy to eliminate the polluting substances. In addition, the characteristics of nonpoint source pollution can easily be affected by factors other than the concentration, making it difficult to predict the pollution sources. Therefore, we installed a vegetative filter strip, which is a natural type of nonpoint source, around Kyung-An stream and calculated the trapping efficiency occurring during rainfalls, after which we analyzed these results. Over a period of 3 y, we monitored these strips 17 times, dividing the events by growth periods and non-growth periods to look more carefully into their effectiveness according to the rainfall levels. Owing to the special characteristics of nonpoint source pollution, the range of data was wider, but as we went through the elimination process, the number of outflows appeared to be more stable than the number of inflows. During the growth period, the efficiency appeared to be higher than it was in the non-growth period, but the range of data appeared wider. Regarding the rainfall levels, the trapping efficiency showed maximum efficiency at less than 10 mm of rainfall.

Keywords: Nonpoint source; Trapping efficiency; Rainfall; Vegetative filter strips; Seasonal change; Vegetation coverage

1. Introduction

Pollution sources can be divided into point source pollution, which has a stable route for discharge, and nonpoint source pollution, which does not have a clear route of discharge. Thus far in Korea, the quality of water has been maintained based on point pollution such as residential sewage or industrial sewage, but in keeping with the need for basic measures, a special counter plan is being developed to decrease nonpoint source pollution [1–3]. In advanced countries, the importance of nonpoint source pollution is well recognized. Starting in the 1980s, institutional methods have been in place [4]. Since this time, the Ministry of the Environment in Korea has monitored the Kyung-An stream by installing vegetative filter strips, a means of reducing nonpoint pollutant through the use of vegetation. Examples that decrease nonpoint pollution include grassed swale and constructed wetlands [5]. Vegetated filter strips can be defined as bands of cropland adjacent to streams or drainage ditches that are set aside from production crops and that are planted with permanent vegetation [6].

This study investigates the factors that lead to the elimination of pollution by analyzing the effectiveness

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of nonpoint source pollution using a filtration method that is known to promote a decrease in nonpoint source pollution. The result of this research can be used when determining where to install equipment that decreases nonpoint source pollution.

2. Experimental methods

2.1. The present condition of land use in areas for research

To be able to calculate the trapping efficiency of nonpoint pollution, we placed the vegetative filter strips along Kyung-An stream in Yongin City, which is in Gyeonggi Province in Korea. The background to this research commenced in 2005, and the filter strips were installed in May of 2006, continuing to the present. During the 3 y of data collection, we monitored 17 times in total, and using the results, we analyzed the effectiveness of this method. Fig. 1 depicts the target area, and Fig. 2 shows a schematic of the watershed areas. Out of a total watershed area of 25,300 m^2, 70.4% is mountainous, 3.6% is composed of paddy fields, and the rest, 26.0%, is composed of cropland. As shown in Fig. 2, outflows in these areas usually occur from vegetation, and during the farmers' busy season, outflows typically of agricultural water or underground water occur frequently, even when it is not raining.

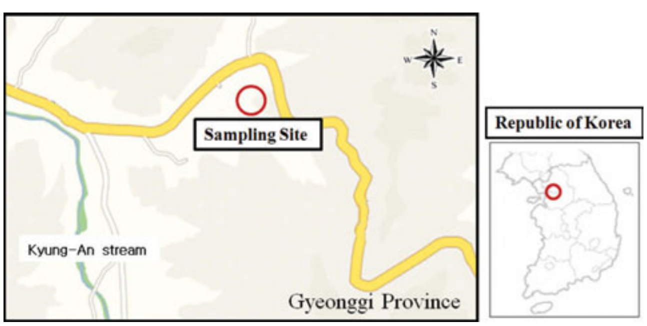

Fig. 1. Location of the study area.

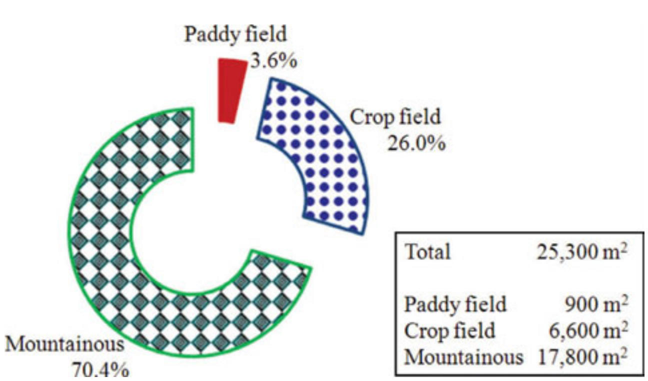

Fig. 2. Characteristics of the watershed used in this study.

3. Sample collection procedure

Litter collection for the analysis of the water quality was determined by constant measurement of the turbidity of the site, as the consistency curve can differ according to the amount of rainfall. Usually, this data is collected at 10 to 15 min intervals from the point of the peak of the flow. Samples are collected into aseptic bottle and moved without delay to perform the analysis. After a rainfall event, measurements are taken at 1 h intervals.

4. Analysis methods

The water quality analysis was performed to assess the following categories: TSS, turbidity, BOD_5, DOC, TN, NH_4^+-N, NO^-_3, TP, and PO_4^-. These categories are analyzed using Standard Methods, 20th Edition [7]. Table 1 shows a schematic of the analysis method for each of the categories.

In this research, because major differences can arise according to the method of the calculation of outflow loading, we used Event Mean Concentration (EMC) to study the characteristics of nonpoint source pollution during a rainfall event. Eq. (1) shows the EMC calculation, specifically showing the manner of the division of the overall amount of polluted materials from a certain rainfall. This method is used to find the average concentration of nonpoint source pollution.

$$\mathrm{EMC}(\mathrm{mg\ l^{-1}}) = \frac{\sum_{t=0}^{t=T} C(t)\cdot q_{\mathrm{run}}(t)}{\sum_{t=0}^{t=T} q_{\mathrm{run}}(t)} \tag{1}$$

In this equation, $q_{\mathrm{run}}(t)$ and $C(t)$ denote the density and the rate, respectively, of outflow in polluted substances [8–12].

Table 1
Analytical methods

Constituents	Analysis method
TSS	Vacuum filtration (Glass Fiber Filters, GF/C)
Turbidity	Turbidity meter
BOD_5	Winkler method azide modification
DOC	O.I. analytical TOC 1010
TN	UV/Vis spectrophotometry
NH_4^+-N	Nessler method
NO^-_3	ICS-1000
TP	Ascorbic acid method
PO_4^-	ICS-1000

Table 2
Event table for monitored events

Event no.	Event date (y/mo/date)	ADD (d)	Total rainfall (mm)	Runoff duration (h)	Avg. rainfall intensity (mm h^{-1})	Total rainfall volume (m^3)	Total runoff volume (m^3)
E-1	2006/06/29	2	13.5	9	1.59	341.6	21.7
E-2	2006/08/17	19	6.5	4	1.12	164.5	34.9
E-3	2006/10/22	45	22.0	15	1.38	556.6	16.6
E-4	2006/11/06	13	7.0	3	2.13	177.1	3.0
E-5	2007/03/04	1	34.0	11	3.02	860.2	37.6
E-6	2007/05/17	3	60.5	11	5.63	1530.6	54.4
E-7	2007/05/24	4	48.0	10	4.65	1214.4	19.4
E-8	2007/06/27	3	10.2	15	0.70	258.1	9.7
E-9	2007/07/19	2	72.3	8	8.98	1829.2	323.3
E-10	2007/09/17	7	120.0	18	6.67	3036.0	1058.1
E-11	2008/03/22	8	22.5	12	1.82	569.3	17.2
E-12	2008/04/22	9	12.0	5	2.36	303.6	3.3
E-13	2008/05/18	5	33.0	8	3.92	834.9	4.2
E-14	2008/06/02	5	63.0	7	9.45	1593.9	39.1
E-15	2008/06/17	9	71.5	6	11.76	1809.0	29.4
E-16	2008/07/02	3	4.0	0.17	23.53	101.2	0.03
E-17	2008/07/16	3	55.0	6	9.29	1391.5	31.3

5. Hydrologic data plot

The results from 17 monitoring events over 3 y of the Kyung-An stream are well organized in Table 2, showing the date of occurrence, the antecedent dry days, the total rainfall, the runoff duration, and the average rainfall intensity. The antecedent dry days for each event range from 1 to 45 d, the total rainfall ranges from 4.0 to 120.0 mm, the runoff duration ranges from 0.17 to 18 h and the average rainfall intensity ranges from 0.70 to 23.53 mm h^{-1}.

6. Results and discussion

6.1. Monitoring results in the VFS

The trapping efficiency for the 17 monitoring events of the vegetative filter strips is expressed in Fig. 3. The trapping efficiency of TSS was 89.61%, that of turbidity was 88.31%, and BOD_5 showed 27.14%. For DOC it was 38.86%, TN showed 60.40%, NH_4^+-N read 55.78%, NO^-_3 showed 69.37%, TKN showed 51.88%, and for TP it was 46.97%. Finally, the trapping efficiency of PO_4^- was 0%. All figures are averages.

Except for TSS and turbidity, the trapping efficiency showed a wide range. This result stems from the characteristics of nonpoint pollution, which is easily affected by a range of variables, such as the amount of rainfall, the runoff duration, the antecedent dry days, the vegetation coverage, the concentration of nonpoint source pollution, and other factors. However, compared to all types of nonpoint pollution decreasing equipment, we acquired relatively stable data in this case. Tables 3 and 4 express the minimum, maximum, standard deviation, and the average of inflow and outflow of EMC for each system. The average inflow EMCs of TSS, BOD_5, DOC,

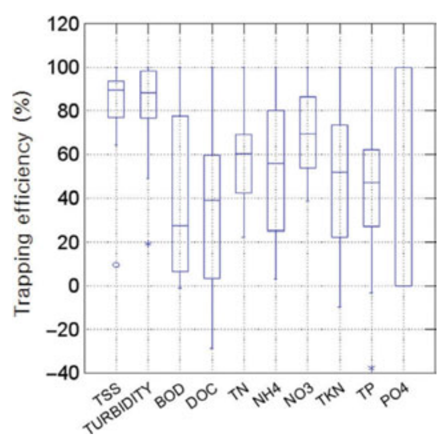

Fig. 3. Overall trapping efficiency in this study. (a) Growth periods, (b) non-growth periods.

Table 3
Fundamental statistics pertaining to the inflow EMCs

Constituents	Minimum (mg l^{-1})	Maximum (mg l^{-1})	Mean (mg l^{-1})	Standard deviation
TSS	22.52	350.70	126.99	108.11
BOD_5	2.30	38.69	6.42	8.55
DOC	2.50	12.10	6.52	3.22
TN	2.20	6.80	3.71	1.28
NO^-_3	1.10	5.47	2.20	1.14
NH_4^+-N	0.10	0.70	0.33	0.21
TKN	0.42	2.70	1.55	0.68
TP	0.10	0.82	0.35	0.19
PO_4^-	0.00	0.09	0.05	0.04

Table 4
Fundamental statistics pertaining to the outflow EMCs

Constituents	Minimum (mg l^{-1})	Maximum (mg l^{-1})	Mean (mg l^{-1})	Standard deviation
TSS	4.60	247.63	39.47	65.29
BOD_5	1.00	17.21	3.99	3.88
DOC	2.60	10.49	5.05	2.07
TN	1.30	5.33	1.93	1.05
NO^-_3	0.20	2.46	0.84	0.55
NH_4^+-N	0.00	0.40	0.20	0.11
TKN	0.13	2.87	1.05	0.65
TP	0.10	0.85	0.24	0.19
PO_4^-	0.00	0.21	0.06	0.10

TN, NO^-_3, NH_4^+-N, TKN, TP, and PO_4^- were 126.99, 6.42, 6.52, 3.71, 2.20, 0.33, 1.55, 0.35, and 0.05 mg l^{-1}, respectively. The average outflow EMCs for TSS, BOD_5, DOC, TN, NO^-_3, NH_4^+-N, TKN, TP, and PO_4^- were 39.47, 3.99, 5.05, 1.93, 0.84, 0.20, 1.05, 0.24, and 0.06 mg l^{-1}, respectively. This shows that as it goes through the vegetative filter strips, the pollution concentration decreases dramatically. The standard deviation is decreased as well. Therefore, the polluted concentration of the outflow can be seen as a stable discharge amount compared to the inflow of the polluted concentration.

7. Trapping efficiency according to seasonal changes

The data compiled over 3 y from the 17 monitoring events were divided it into growth periods and non-growth periods to determine trapping efficiency in each of the seasons. The growth periods included a total of 12 events, from May to September, while the non-growth periods included the total of 5 events from October to April. Fig. 4 shows the statistical data of the trapping efficiency in the growth periods and non-growth periods. In the growth periods, TSS was 90.84% on average, BOD_5 was 30.27%, NO^-_3 was 71.61%, NH_4^+-N was 58.84%, TKN was 53.97 %, and TP read 50.69%. As above, all figures are averages. During the non-growth period, TSS reached an average of 66.26%, for BOD_5 the average was 26.58%, NO^-_3 read 69.37%, NH_4^+-N was 42.52%, TKN was 45.19%, and TP was 20.46%, with all figures averages. In the organic substances BOD_5 and the nutriments NO^-_3, NH_4^+-N, and PO_4^-, the trapping efficiency was found to be relatively high in the growth periods compared to the non-growth periods.

8. Trapping efficiency according to the rainfall level

Fig. 5 indicates the rainfall amounts as monitored from 2006 to 2008. Out of 432 rainfall, the rainfall events, those of less than 10, 10–20, 20–50 mm, and more than 50 mm accounted for 78%, 8%, 10%, and 4%, respectively. Fig. 6 shows a schematic of the rainfall rates. To determine the trapping efficiency according to different rainfall events, we divided the level

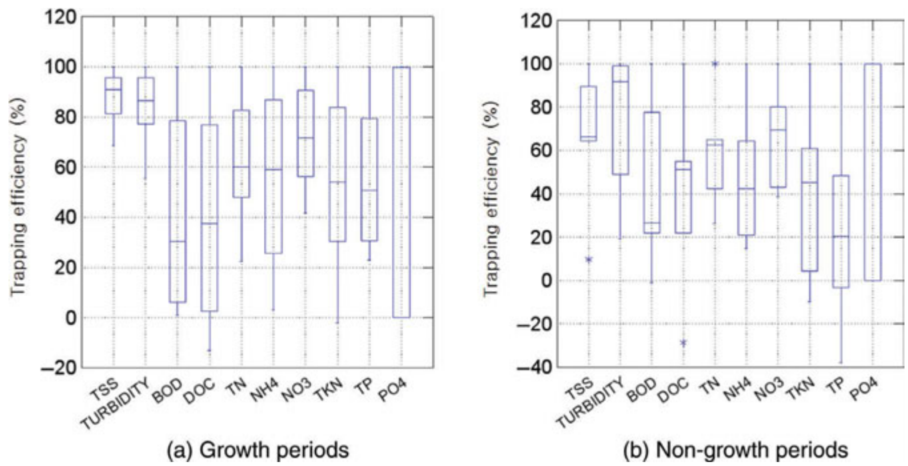

Fig. 4. Trapping efficiency according to the season.

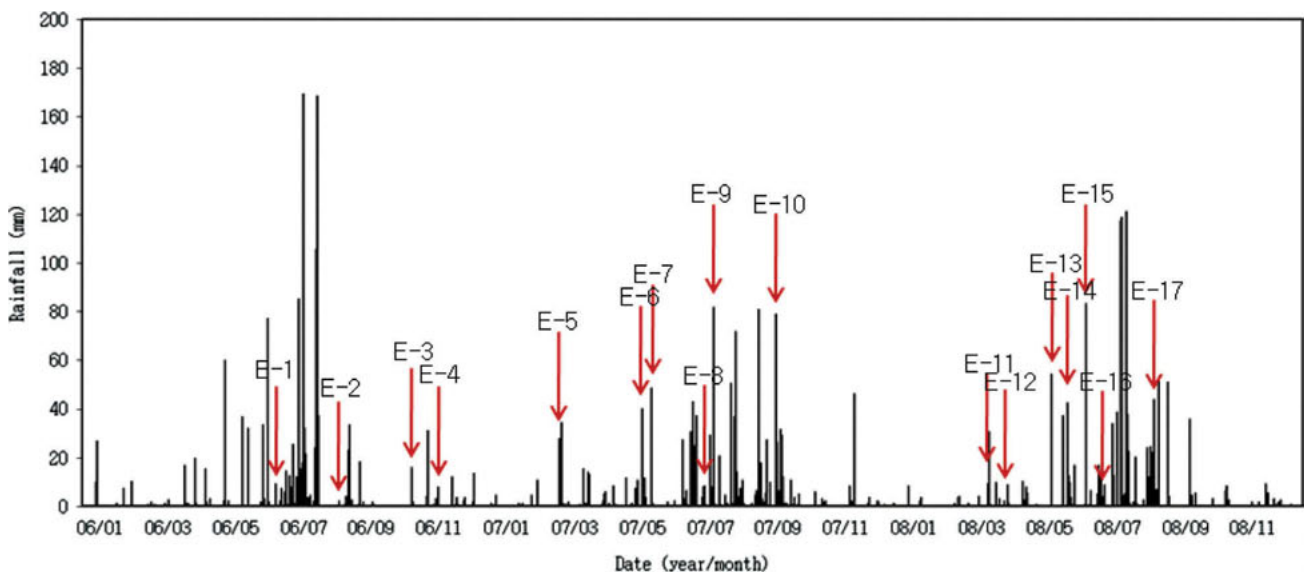

Fig. 5. Monitored rainfall during rainfall events.

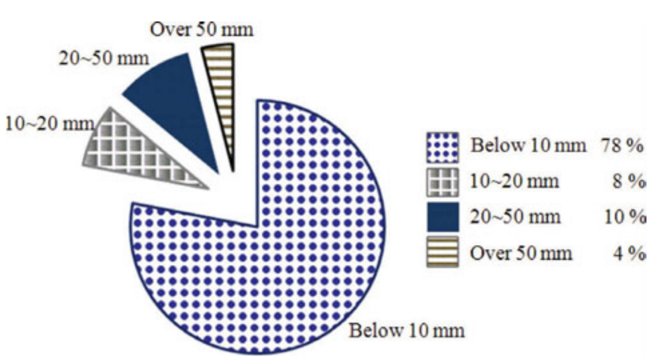

Fig. 6. Rates for different rainfall events. (a) Below 10 mm, (b) 10–20 mm, (c) 20–50 mm, (d) over 50 mm.

of rainfall into 4 categories: less than 10, 10–20, 20–50 mm, and more than 50 mm. Fig. 7 shows the statistics of the trapping efficiency for different rainfall levels. The efficiency for the particle-like substance TSS for rainfall events of 10, 10–20, 20–50 mm, and more than 50 mm averaged 97.71%, 80.23%, 89.62%, and 90.62%, respectively. The organic substance BOD_5 appeared, during rainfall events of 10, 10–20, 20–50 mm, and more than 50 mm at an average of 98.26%, 26.58%, 22.04%, and 25.12%, respectively. The nutriment TN at 10, 10–20, 20–50 mm, and more than 50 mm was noted at the average of 97.45%, 64.91%, 62.59%, and 59.81%, respectively.

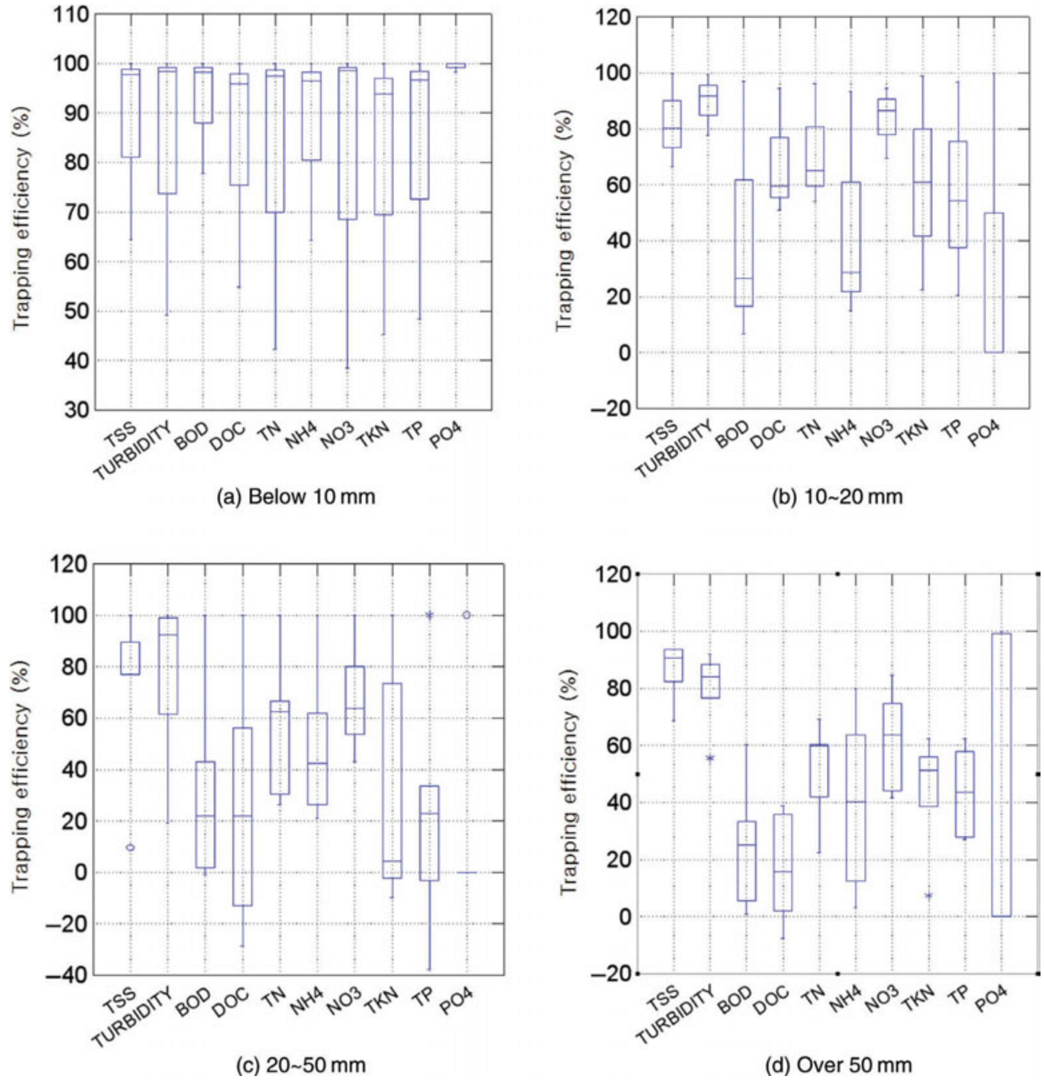

Fig. 7. Trapping efficiency for different rainfall events.

9. Conclusions

- The trapping efficiency result using the vegetative filter strips showed a wide range of effectiveness despite the relatively few data collection events 17 times. The results show that the concentration of nonpoint source pollution affects the trapping efficiency, as does the number of antecedent dry days, the amount of rainfall, the runoff duration, the vegetation coverage, and the growth period.
- We found that the change in the outflow concentration is less than the inflow for each event. This result shows that nonpoint source pollution has a wider concentration range during inflow events; however, as it goes through a nonpoint source pollution reducing system, it will have a comparatively small concentration range given a stable discharge.
- In the growth period from May to September, we noted that the trapping efficiency is higher than it is in the non-growth period from October to April. We also found that the growth period affects the trapping efficiency as well.
- Compared to heavy rainfall, meaning a rainfall event of more than 50 mm, light rainfall of less than 10 mm showed higher trapping efficiency in the vegetative filter strips. Due to the large amount of rainfall at these times, the time remaining for the action of the vegetative filter strips became shorter, thus disturbing the absorption into the root of the plant. This also caused a disturbance related to precipitation, implying that the pollution was not eliminated but was swept away instead.

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