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A field study of lined bioretention systems in removing nutrients from stormwater runoff

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ABSTRACT

In this study, two lined bioretention systems were designed and installed in Chongqing University of Arts and Sciences. Totally 15 natural rainfall events were sampled for analysis from July 2015 to April 2017. Compared with the inflow samples, the outflow samples contained a lower concentration of pollutants and especially NH_3–N. In the spring of 2017, the average removal rate of total nitrogen (TN), NH_3–N, NO_3–N, total phosphorus (TP), and PO_4^{3-}–P for two systems were 70.33%–85.71%, 88.89%–96.15%, 21.13%–66.67%, 28.57%–66.67%, and 33.33%–66.67%, respectively, besides, the effluent met the class-III criteria specified in the Environmental Quality Standards for Surface Water (GB 3838-2002). In the summer of 2017, the content of NO_3–N in the effluent nitrogen from two systems was the highest (61%–85%), while that of NH_3–N was the lowest (5%–13%). However, the composition of effluent nitrogen was different in autumn, the effluent nitrogen had the lowest content of NH_3–N (5%–26%) but the highest content of total organic nitrogen (TON) (58%–69%). The annual pollution load of nitrogen and phosphorus was decreased by 61.33%–94.62%. As shown by the correlation analysis, TN, and PO_4^{3-}–P both demonstrated a significantly negative correlation with temperature, while NH_3–N was positively correlated with NH_3–N concentration in the roof runoff (NH_3–NR). The concentration of TP from the system I or PO_4^{3-}–P from system II was positively correlated with the interval dry days (IDD) and TP or PO_4^{3-}–P concentration in the roof runoff, respectively.

Keywords: Bioretention system; Field study; Nitrogen; Phosphorus; Stormwater runoff

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1. Introduction

With the rapid development of urbanization, the stormwater runoff from urban areas becomes a serious problem due to its increasing volume and deteriorating water quality [1,2]; and the high concentration of pollutants carried by the urban stormwater runoff is the major factor for the degradation of water bodies [3,4]. There are many concepts developed for the better management of urban runoff. In 2014, "Sponge City" was put forward in China which focused on mitigating the negative effects of runoff in modern cities.

A variety of stormwater control measures (SCMs) have been taken to reduce the pollutant load from the urban stormwater runoff. The bioretention system seems outstanding in capturing stormwater as an effective urban SCM, and it is widely used in the globe due to its low costs and convenient installation; its capability to improve the water quality in the developed areas has been proven in many fields and laboratory studies [5–8]. The pollutants can be removed by the bioretention system effectively, such as oil, suspended solids, grease, heavy metals, and fecal coliform. However, several studies have suggested that the removal rate of nutrient pollutants (e.g., nitrogen and phosphorus) was low systematically, with a nitrogen export of 0%–60% [7,9].

With a purpose of exploring the running efficiency of field bioretention systems, many completed studies were designed to capture more stormwater runoff on-site. Manka et al. [9] reviewed nearly 10 field studies and found that at most sites, the concentrations of TN and NO_3–N in the effluent demonstrated a difference between summer and winter. In some studies, the excellent performance was achieved in controlling nitrogen and phosphorus, but the serious discharge of nutrient pollutants was found at some sites. Payne et al. [10] found that a 20% decrease of TN was realized by bioretention systems without the saturated layer, as compared with columns with the submerged layer (45%); Zinger et al. [11] verified that the application of submerge zone in bioretention systems was beneficial for the improvement of TN removal. Unfortunately, anaerobic zone in combination with some factors might be unhelpful for TP removal [6,11].

However, few studies focused on the lined bioretention systems because of their poor hydrologic performance [12]. In fact, these systems provide some benefits, and they can be installed close to the buildings or in the areas with a high groundwater level. Richards et al. [13] observed that the lined rain-garden was more effective for rainfall events during the dry periods and advantageous for water conservation. Some studies have summarized the development, management and challenges of sponge city in China [14–16]. Nguyen et al. [15] pointed out that Sponge City should be implemented at the watershed scales and be flexible, depending on different decision levels or catchment characteristics to obtain multi-ecosystem services. Jiang et al. [16] proposed that China should expand the consideration of technological options and practices in relation to local conditions in developing technical guidance. Vast territory of China determined the huge environmental differences between different regions, and the technical requirements for implementing sponge city should also be adapted to local conditions. So far, much government effort had been expended on specific technological and engineering solutions with insufficient attention paid to scientific research, experiment-based learning, and knowledge management [17].

In Chongqing of a mountainous terrain located at Three Gorges Reservoir (a key component responsible for the water quality of Yangtze River), there is a limited area for urban construction, and the buildings are often densely constructed with big underground parking lots. The infiltration of urban stormwater runoff may be harmful to the stability of building foundation and local geology, thus it is more necessary to install the lined bioretention systems. Furthermore, the field bioretention systems are designed with little attention to the water quality, which indicates a great environmental risk. Therefore, it is very urgent to develop the lined bioretention systems considering both water quality control and geological safety. In this study, two field lined bioretention systems were installed with different plants depending on the requirements of civil construction in Chongqing of China to investigate the management effects and compare the seasonal differences in the inflow/outflow and estimate the retention of nutrient pollutants.

2. Methods and materials

2.1. Study sites

In 2014, two bioretention systems (6.4 m^2, 4.0 m (length) × 1.6 m (width) × 1.5 m (depth)) were installed in Chongqing University of Arts and Sciences (Chongqing, China; 29°20′46.4″N, 105°56′39.3″E). They received the roof stormwater runoff from an adjacent building with a roof of 60 m^2 (i.e., their area was approximately 10.7% of the catchment area). Considering a short distance to the buildings, these two systems were built with reinforced concrete to prevent water from draining into the building foundation, and connected with their own forebays (1.6 m (length) × 1.6 m (width) × 1.5 m (depth)) via three bottom holes (Φ75 mm) on the forebay floor to reduce soil erosion (Fig. 1). Meanwhile, the water depth in the forebays was determined according to the height of outlets (i.e., 600 mm).

The bioretention systems were composed of three layers: a gravel layer, a filter layer, and a growing medium. The bottom layer of 300 mm gravel was overlain by a 200 mm filter layer of fine sand and an 800 mm top layer of plant growing medium (a blend of local soil and sand in a volume ratio of 4:6). When a rainfall event occurred, the roof runoff was delivered directly into the forebays via two standpipes, then transferred obliquely upwards through three layers of bioretention systems, and finally discharged from the outlets. Given that the whole roof was divided into two parts by the axial beam, each bioretention system received an equal amount of water from the runoff, with the identical water quality (Fig. 1). The above mentioned two systems were installed with the same design. Considering the development of root systems and the capability of nutrient retention, *Vetiveria zizanioides* (L.) and *Medicago sativa* (L.) were selected as experimental plants. Bioretention system I was initially constructed with *Vetiveria zizanioides* (L.). However, with a low overwintering capability, *Vetiveria*

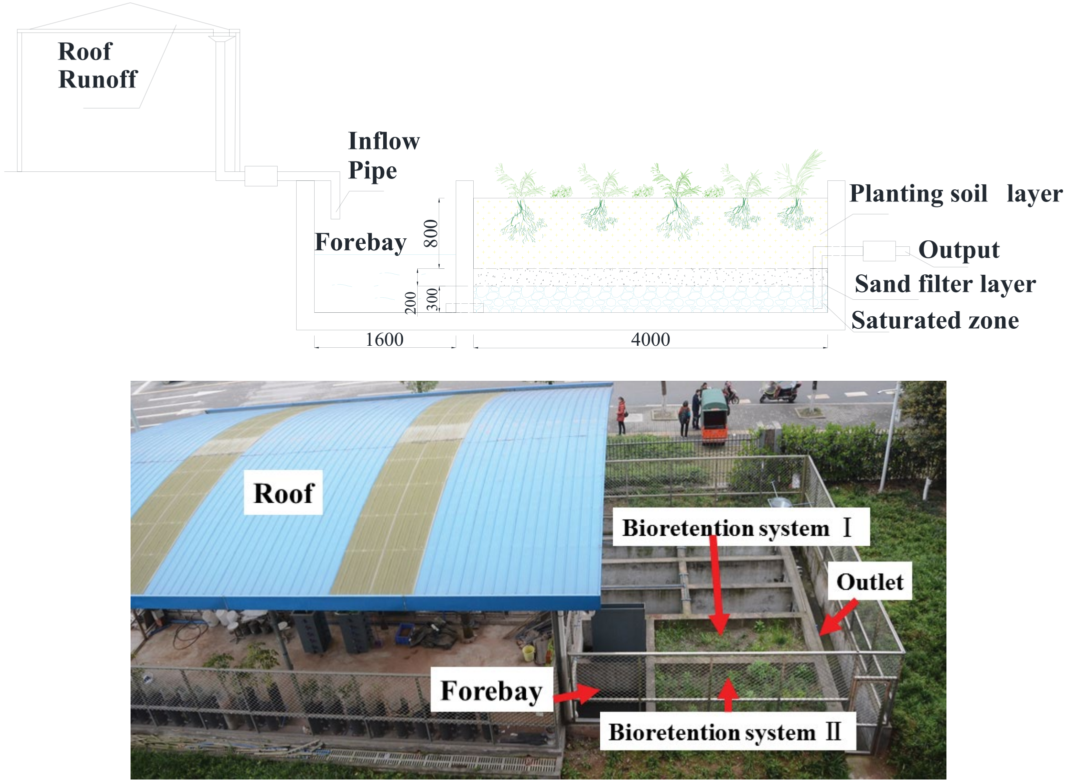

Fig. 1. Design and field photo of bioretention systems taken in April, 2017.

zizanioides (L.) naturally withered in 2015, so *Ophiopogon japonicas* was used instead in 2016. For bioretention system II, *Medicago sativa* (L.) was selected as test plant for observing the developed root systems.

2.2. Climate data

Chongqing, an inland city located at Three Gorges Reservoir in the upper reaches of Yangtze River (Southwest China), has a subtropical humid monsoon climate, with an average annual temperature of 18°C (6°C–8°C (minimum –2°C) in winter and ≥35°C (maximum 43°C) in summer), and an average annual precipitation of 1,100 mm (only 4%–5% in winter and 40%–50% in summer) [2].

2.3. Analytical methods

The rainfall intensity and depth were measured by an on-site CR2-D automatic tipping-bucket rain gauge. The 500 mL polyvinyl chloride bottles were used for sampling. Before sampling, all bottles were washed clean. During rainfall events, the samples were collected 1 time/5 min within the first 30 min and 1 time/10 min within 30–60 min when the stormwater runoff occurred, and thereafter 1 time/30 min till the runoff disappeared [2]. The total nitrogen (TN), total phosphorus (TP), NH_3–N, and NO_3–N in these samples were determined according to the following procedures: Firstly, the samples were directly digested with $K_2S_2O_4$ solution and alkaline $K_2S_2O_4$ solution, and then TP and TN in the digestion solution were tested using an automated discrete analyzer (CleverChem 380, Germany). Secondly, these samples were filtered with an acetate fiber filter membrane (0.45 μm), and then NO_3–N and NH_3–N in the filtrate were measured with the same device. Each measurement was done in triplicate [8]. Nitrite was ignored for its low concentration in the stormwater runoff, and total organic nitrogen (TON) was calculated by subtracting NO_3–N and NH_3–N from TN. From June 2015 to April 2017, totally 15 natural rainfall events were monitored (Table 1). Unfortunately, the data of bioretention system II in the summer and autumn of 2016 was missing because of equipment faults.

The annual pollutant load (g/y) was used to illustrate the running efficiency of two bioretention systems, and it was calculated using the following equation:

$$M = F \times A \times 0.9 \times C \quad (1)$$

where M is the annual pollutant load (g/y) input to or output from the bioretention systems; F is the average annual rainfall rate in Chongqing (mm); A is the on-site drainage area (m^2); C is the average annual pollutant concentration (mg/L); and 0.9 is the runoff coefficient for impervious roofs.

3. Results and discussion

3.1. Changes of pollutant concentration in the runoff during rainfall events

During rainfall events, the pollutant concentration in the runoff from roofs was generally declined and trended

Table 1
Statistics and hydrologic performance metrics of sampled events

Date	Temperature (°C)	IDD (d)	RV (mm)	RD (h)	RI (mm/min)	No. of inlet samples	No. of system I samples	No. of system II samples
June 20, 2015	24	2	21.20	8.85	0.04	10	9	9
July 14, 2015	25	5	442.00	8.83	0.83	12	12	12
July 21, 2015	28	7	78.70	13.00	0.10	9	9	9
August 4, 2015	30	4	19.60	0.90	0.36	9	9	9
August 7, 2015	25	3	23.70	1.67	0.24	9	9	9
August 16, 2015	26	2	16.00	1.00	0.28	9	9	9
July 9, 2016	32	3	13.40	1.25	0.18	11	11	–
July 18, 2016	31	4	57.00	8.00	0.12	10	10	–
August 3, 2016	27	12	17.40	1.33	0.22	11	10	–
August 30, 2016	22	2	4.80	4.47	0.02	13	5	–
September 4, 2016	22	4	17.00	3.47	0.08	8	8	–
November 6, 2016	15	7	9.80	21.33	0.01	12	12	–
March 24, 2017	12	2	2.24	4.17	0.01	9	8	9
March 30, 2017	14	3	2.45	7.23	0.01	6	6	6
April 12, 2017	17	1	0.51	1.97	0.00	8	8	8

*RV = Rainfall volume; RD = rainfall duration; RI = rainfall intensity; IDD = interval drying day.

to decrease gradually over time (Fig. 2). However, there was a difference among rainfall events and even within the same rainfall events, which was attributed to the interaction of pollutant flushing and dilution. Furthermore, the flush effect also existed in rainfall events, because the atmospheric deposition during dry and wet days is the main source of nitrogen and phosphorus in the stormwater runoff. For example, the pollutant concentration was increased when the rainfall events reached the second peak on July 9 and August 30, 2016, and August 7, 2015. Besides, it varied in the initial runoff among rainfall events. TN concentration in this study was a minimum 1.53 mg/L and a maximum 5.71 mg/L, which may be correlated with the intensity of runoff flushing and the pollutant accumulation on the roof surface during the antecedent dry days.

However, there was a significant difference between pollutants in the runoff between bioretention systems and roofs. In order to explore the leaching dynamics of nutrient pollutants in the outflow, several rainfall events were analyzed to show the leaching process in two bioretention systems (Fig. 2). Compared to the influent samples, the concentration of pollutants and especially NH_3–N in the effluent samples was decreased markedly, but there was no significant difference, though the mentioned concentration often exhibited an initial spike in the influent samples [7]. During a rainfall event, the concentration of pollutants in the effluent samples was monotonically increased due to the dilution of water stored in the systems, and these pollutants might be purified during the interval dry days (IDD). At 5 and 30 min after the occurrence of runoff, the concentrations of TN, NH_3–N, NO_3–N, and TP in the runoff samples collected from bioretention system I or II on August 16, 2015 were 0.58, 0.00, 0.44, and 0.01 mg/L or 0.29, 0.00, 0.27, and 0.01 mg/L, and 0.73, 0.02, 0.57, and 0.01 mg/L or 0.44, 0.00, 0.34, and 0.01 mg/L, respectively. In two bioretention systems, the influent samples had a higher concentration of pollutants than the effluent samples, showing a slight flush effect; however, two systems worked well in narrowing the concentration range of nutrient pollutants in the stormwater runoff and reducing the peak contamination discharge of the influent.

3.2. Removal efficiency of pollutants

The concentration (arithmetic mean) of nutrient pollutants in all samples collected from the inlets and outlets was calculated in different seasons, and the results are shown in Table 2. In most rainfall events, more than eight samples were collected at the inlet (i.e., runoff from roofs) and outlet (i.e., runoff from bioretention systems). There were variable differences in pollutants between the effluent samples and the influent samples. The removal rate of NH_3–N (>80%, except bioretention system II in the spring of 2017) was excellent in all seasons, which showed good nitrification or adsorption of NH_3–N in two systems. The concentration of pollutants was lower at the outlet than at the inlet except in the spring of 2017; TN and NH_3–N were better removed; the removal rate of TP and NO_3–N was slightly lower, but still up to >20% (Table 2). In the spring of 2017, however, an increase were found in the concentrations of TN and NO_3–N. There was the greatest export of TN (>40%) and the release of NO_3–N in bioretention system I, which indicated incomplete or inadequate denitrification in the systems [18]; 50% TP was removed, perhaps attributed to a difference in the purification mechanism between nitrogen and phosphorus.

Generally, particulate phosphorus is well-removed via filtration mechanisms in bioretention systems, similar to particulate matter. Some scholars believed that dissolved phosphorus removal mechanism for bioretention wss adsorption onto the media during transport through the media [19], but some study showed 57.1%–76.1% of total phosphorus input was stored in the above-ground biomass

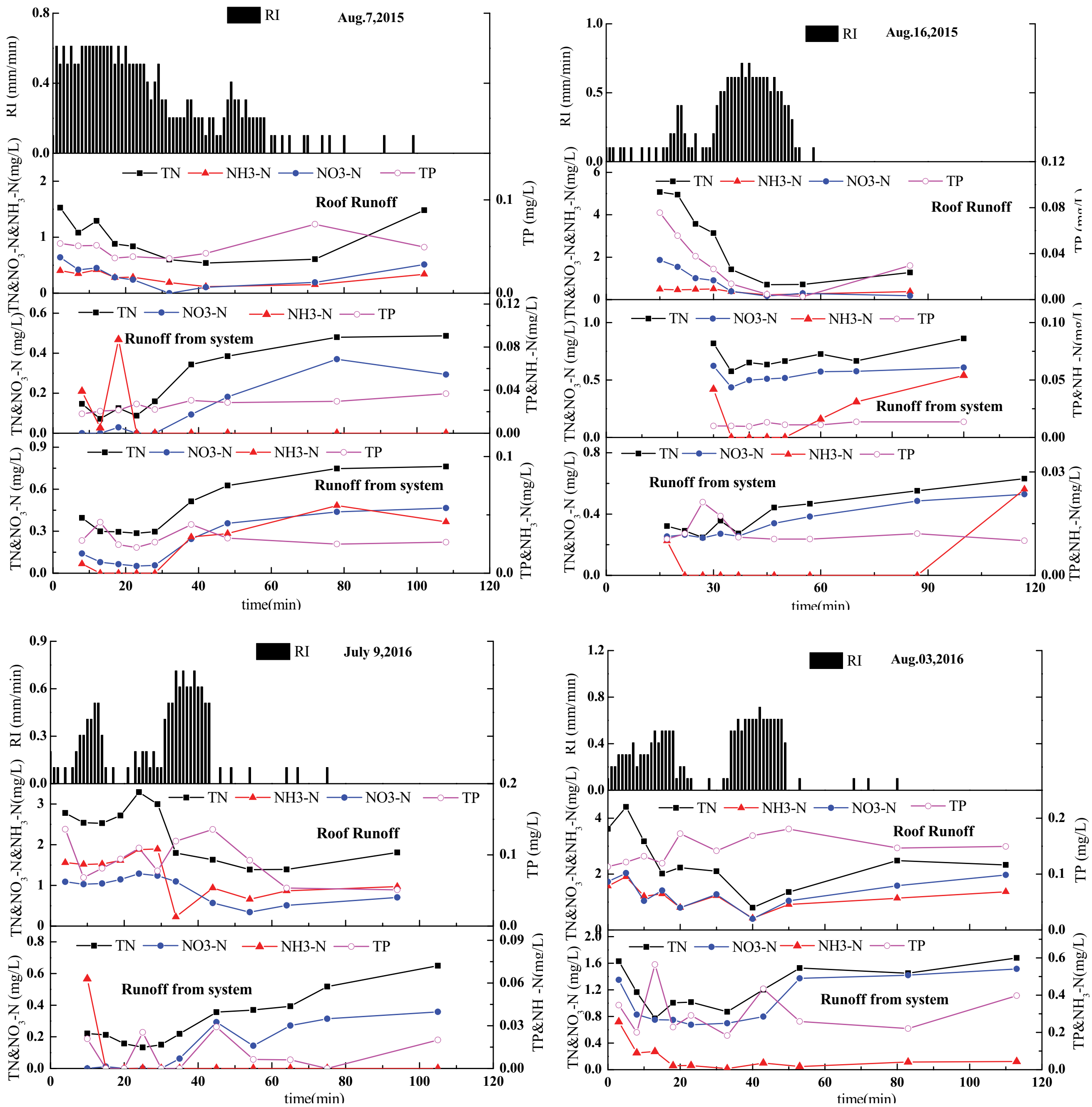

Fig. 2. Temporal variation of pollutants in runoff from color-coated steel roof and bioretetion systems (4 of 15 rainfall events).

when PO_4^{3-}–P was used to simulate stormwater runoff [20]. In this study, sedimentation, adsorption by media, filtration, uptake by plants and biochemistry effects, etc. may all contribute to the removal of phosphorus. For nitrogen removal, our early study found that 60.24% total nitrogen was removed by plants assimilation and denitrification, and 35.79% total nitrogen remained within bioretention system. For ammonia removal, with the help of isotope tracing technology, we also found that 40.70% of ammonia input with runoff was transformed into organic nitrogen, and 16.58% of ammonia existed in the form of inorganic nitrogen (i.e., nitrate and ammonia), and denitrification and assimilation contributed to 41.46% of ammonia removal [21]. The biochemical process played a key role in nitrogen removal, which was influenced by many factors, such as temperature, hydraulic retention time, oxygen level, etc.

The specifications of pollutants specified in the class-III criteria of Environmental Quality Standards for Surface Water (GB 3838–2002) are summarized in Table 3. The input and output TP concentrations shall be 0.02–0.04 and 0.01–0.02 mg/L. In our study, TP concentration in both influent and effluent samples was <0.2 mg/L. However, there was a

Table 2
Pollutant concentrations of stormwater at inlet and outlet

Months	Date	Roof runoff		Runoff from system I		Runoff from system II	
		Pollutants	Concentration (mg/L)	Concentration (mg/L)	Removal rate (%)	Concentration (mg/L)	Removal rate (%)
June July August	Summer, 2015	TN	2.09 ± 2.00	0.46 ± 0.50	77.99	0.62 ± 0.30	70.33
		NH_3–N	0.78 ± 0.74	0.06 ± 0.11	92.31	0.03 ± 0.04	96.15
		NO_3–N	0.74 ± 0.79	0.28 ± 0.33	62.16	0.39 ± 0.33	47.30
		TP	0.06 ± 0.06	0.02 ± 0.01	66.67	0.02 ± 0.01	66.67
		PO_4^{3-}–P	0.03 ± 0.02	0.02 ± 0.01	33.33	0.02 ± 0.01	33.33
June July Aug.	Summer, 2016	TN	3.81 ± 2.88	0.66 ± 0.32	82.68	–	–
		NH_3–N	1.44 ± 0.70	0.06 ± 0.07	95.83	–	–
		NO_3–N	0.71 ± 0.81	0.56 ± 0.47	21.13	–	–
		TP	0.14 ± 0.08	0.10 ± 0.15	28.57	–	–
		PO_4^{3-}–P	0.03 ± 0.02	0.01 ± 0.02	66.67	–	–
September October November	Autumn, 2016	TN	3.50 ± 1.83	0.50 ± 0.37	85.71	–	–
		NH_3–N	0.45 ± 0.35	0.05 ± 0.04	88.89	–	–
		NO_3–N	0.84 ± 0.47	0.37 ± 0.37	55.95	–	–
		TP	0.04 ± 0.03	0.02 ± 0.01	50.00	–	–
March April May	Spring, 2017	TN	1.78 ± 0.44	2.65 ± 1.00	–48.88	2.57 ± 0.92	–44.38
		NH_3–N	1.32 ± 1.45	0.20 ± 0.22	84.85	0.67 ± 0.95	49.24
		NO_3–N	0.44 ± 0.36	0.61 ± 0.34	–38.64	0.35 ± 0.30	20.45
		TP	0.02 ± 0.03	0.01 ± 0.01	50.00	0.01 ± 0.01	50.00

"–" means not tested.

Table 3
Class-III pollutants standard values specified in Environmental Quality Standards for Surface Water (GB 3838–2002)

Indicator	Value (mg/L)
TN	1.0
TP	0.2
NH_3–N	1.0

difference in the concentrations of TN and NH_3–N between influent samples and effluent samples. At the inlet, TN concentration was >1.0 mg/L (a reference in the class-III criteria of Environmental Quality Standards for Surface Water (GB 3838–2002)), while NH_3–N concentration exceeded the reference occasionally; at the outlet, the above two concentrations both met the class-III criteria except TN in the spring of 2017. Therefore, the effluent from the lined bioretention systems is mostly recyclable in Chongqing.

3.3. Comparison between the previous studies and our study

In a review, Manka et al. [9] found many differences among 14 field case studies. In removing TN, TP, NH_3–N, and NO_3–N, the cases with good performance (i.e., the concentration of pollutants in the effluent was lower than that in the influent) accounted for 71.43%, 64.29%, 83.33%, and 53.85% (12, 12, 12, and 13 cases), respectively. Most systems in these studies are effective in controlling NH_3–N but slightly inefficient in removing NO_3–N and TP. There is a difference in the running performance of systems between these studies and our study, which indicated the complexity of factors influencing the operation of field systems. The above difference may be explained by a lower concentration of pollutants in the influent samples from roofs and a slightly larger ratio of surface area/drainage area in our study and by a higher average annual temperature in Chongqing.

3.4. Composition of nitrogen

In summer, the nitrogen composition in the influent samples was nearly reflected by NH_3–N concentration (i.e., 37%–38%), and its high variability was also found between spring and autumn (TON had the largest proportion in the autumn of 2016 and NH_3–N accounted for 74% in the spring of 2017). In the effluent samples from two bioretention systems, the percentage of TN in the nitrogen composition was consistent with a few exceptions (i.e., NO_3–N and NH_3–N had the highest and lowest percentages in summer, respectively). Therefore, two bioretention systems used in this study are effective for nitrification in summer. However, the composition of nitrogen in the effluent samples demonstrated a difference between autumn and spring, in which NH_3–N and TON accounted for 5%–26% (minimum) and 58%–69% (maximum), respectively (Fig. 3). In two systems, NH_3–N retention remained high, and NH_3–N was mainly removed by the uptake of plants or the adsorption of media. These two systems were less capable for nitrification due to a low water temperature in autumn and spring in Chongqing.

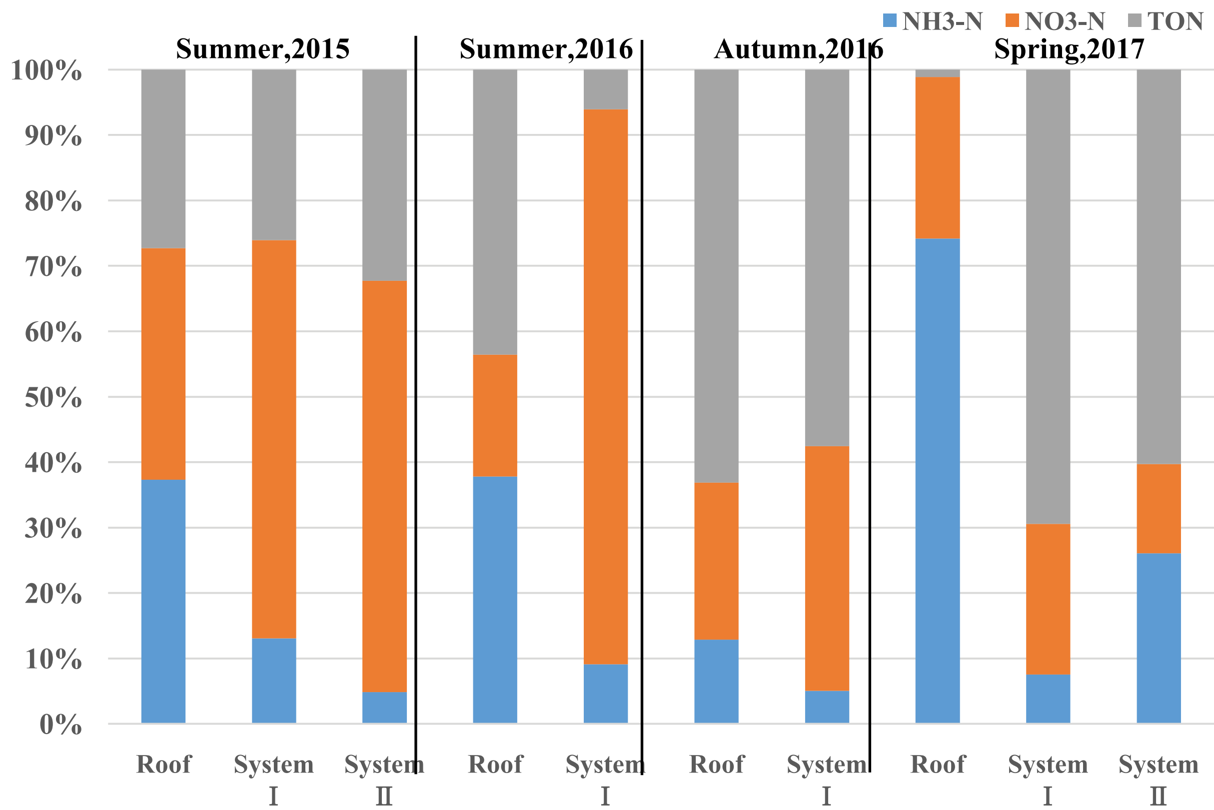

Fig. 3. Nitrogen forms in influent and effluent.

Li and Davis [7] found that NO_3–N was the main nitrogen form in the initial period, and dissolved organic nitrogen (DON) accounted for the largest percentage of TN at the end one of a rainfall event. In the study of Manka et al. [9], the concentrations of nitrogen species were integrated into the nitrogen composition (Fig. 4) [9]. The main nitrogen forms in the outlet runoff were TON and NO_3–N, while NH_3–N was significantly decreased, which is consistent with our study and the study of Li and Davis [7]. There was a significant difference in the percentage of nitrogen forms in the inlet and outlet runoffs among study sites (Fig. 4). TON was the primary nitrogen form in the effluent at Graham-S, Graham-N, Mango-L Knightdale, Mango-S Knightdale, and RM Rocky Mount with internal water storage zones, and TN concentration was well-controlled, showing good nitrification and denitrification [9]. In our study, NO_3–N was a dominant component, though TN was greatly removed (except the spring of 2017), which indicated inadequate denitrification due to the insufficient carbon source. NO_3–N accounted for 43%–68% (maximum) of TN at nash-pre-D, nash-pre-S, nash-post-D, and nash-post-S without internal water storage zones, but TN contained 54%–70% (maximum) TON at Hal Marshall Charlotte, Louisburg L1, and Louisburg L2 without saturated zones. However, TN was seriously released at nash-pre-D, nash-pre-S, nash-post-D, and nash-post-S, while the systems demonstrated good performance in nitrogen removal (i.e., the removal rate was about 30%–40%) at Hal Marshall Charlotte, Louisburg L1, and Louisburg L2. These findings have suggested that the installation of bioretention systems with a saturated zone is helpful for nitrification and denitrification.

3.5. Reduction of pollutant load

The hydrological process of bioretention systems in this study was discussed in our previous studies, and the volume ratio of input and output stormwater runoffs from the same system was 0.58 during our 1 y monitoring. The annual input and output pollutant loads are summarized in Table 4. In this study, the annual input and output loads of TN, NH_3–N, NO_3–N, and TP were 166.02, 59.25, 40.54, and 3.86 g/y, while those of and 36.78–54.95, 3.19–12.06, 12.75–15.68, and 0.52–1.29 g/y, respectively. From the perspective of input and output runoffs, the bioretention systems exhibited a moderate decrease in the nitrogen and phosphorus loads which resulted from the reduction of runoff volume. Bioretention system I demonstrated better performance in NH_3–N control, indicating good adsorption, assimilation, or nitrification of NH_3–N [22]; however, bioretention system II had a higher reduction rate of TP, perhaps attributed to the difference of vegetated plants. Due to a failure of retention by soil media, nitrate is highly mobile in the soil/water systems, and its removal mainly depends on the balance of nitrification and denitrification [7]. Despite poor nitrate control in spring, two systems greatly lowered the annual nitrate load because of the reduction in the overall runoff volume.

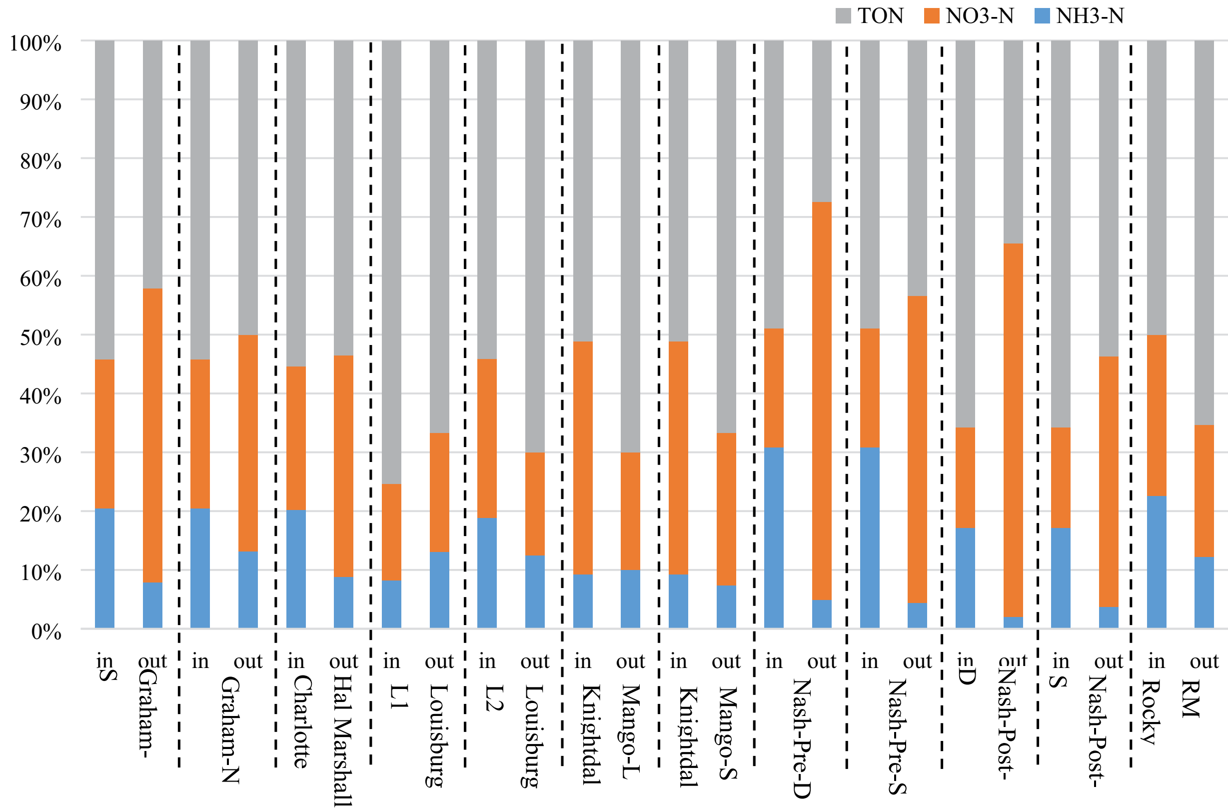

Fig. 4. Nitrogen composition in influent and effluent summarized (Manka et al. [9]).

Table 4
Reduction of pollution loads

Roof runoff		Runoff from bioretention system I		Runoff from bioretention system II	
Pollutants	Pollution load (g/y)	Pollution load (g/y)	Removal rate (%)	Pollution load (g/y)	Removal rate (%)
TN	166.02	36.78	77.85	54.95	66.90
NH_3–N	59.25	3.19	94.62	12.06	79.65
NO_3–N	40.54	15.68	61.33	12.75	68.56
TP	3.86	1.29	66.54	0.52	86.62

3.6. Analysis of correlations

The correlations among nutrient pollutants in the effluent and influent samples were analyzed with a significance level of $p < 0.050$ or 0.100 (Table 5). TN in the effluent samples was under a significantly negative correlation with the temperature, while NH_3–N was positively correlated with NH_3–NR. There was a positive correlation between TP from bioretention system I and IDD or TPR, and between PO_4^{3-}–P from bioretention system II and PO_4^{3-}–PR.

The same relationship between TN in the effluent samples and the temperature was observed at two sites, that is, a greater temperature corresponded to a lower TN concentration in the effluent, which may be explained by the high denitrification and TN uptake of plants or microorganisms at the increasing temperature. Many studies have suggested that TN concentration can be decreased by a greater number of IDD, which was similarly observed in our study (Table 5); it may be attributed to the combination of microbial activity with the flush effect of frequent rainfall events [9]. There was a bigger NH_3–N concentration in the effluent samples when NH_3–NR concentration was higher. NH_3–N concentration was higher in the effluent when it was increasing in the influent. However, no positive correlation between nitrate and temperature was found, which suggested that the removal of NH_3–N might be attributed to the absorption by media, uptake by plants or microorganisms, and insufficient nitrification.

Hatt et al. [23] observed that the increased IDD could resulted in a higher NH_3–N concentration, while Blecken et al. [24] found that NH_3–N concentration was decreased with the increase of TP. Wang et al. [8] and Manka et al. [9]

Table 5
Correlation analysis of nutrients and environmental parameters

Systems		Temperature (°C)	IDD (d)	RV (mm)	RD (h)	TNR (mg/L)	NH_3–NR (mg/L)	NO_3–NR (mg/L)	TPR (mg/L)	PO_4^{3-}–PR (mg/L)
System I (n = 15)	TN (mg/L)	–0.57*	–0.36	–0.28	–0.23	0.05	0.32	0.30	–0.09	0.31
	NH_3–N (mg/L)	–0.43	–0.20	–0.21	–0.12	–0.27	0.64**	–0.41	–0.30	0.07
	NO_3–N (mg/L)	–0.24	0.15	–0.16	–0.16	–0.28	0.11	0.09	0.20	0.50
	TP (mg/L)	0.16	0.74**	–0.09	–0.29	0.05	0.02	0.27	0.60*	–0.36
	PO_4^{3-}–P (mg/L)	–0.60*	0.30	–0.21	0.07	0.29	0.03	–0.04	–0.17	0.07
System II (n = 9)	TN (mg/L)	–0.75*	–0.60	–0.34	–0.25	0.10	0.26	–0.34	–0.18	0.27
	NH_3–N (mg/L)	–0.66	–0.14	–0.24	–0.15	–0.27	0.69*	–0.26	–0.53	0.35
	NO_3–N (mg/L)	–0.14	–0.28	–0.12	0.25	–0.30	0.34	–0.33	–0.44	–0.20
	TP (mg/L)	0.43	0.35	0.48	–0.53	–0.17	–0.37	–0.03	0.43	–0.28
	PO_4^{3-}–P (mg/L)	–0.72*	–0.28	–0.31	–0.22	–0.05	–0.11	0.21	0.40	0.92**

TNR = Total nitrogen concentration in roof runoff, NO_3–NR = NO_3–N concentration in roof runoff, NH_3–NR = NH_3–N concentration in roof runoff, TPR = TP concentration in roof runoff.
**significant at $P < 0.1$, *significant at $P < 0.05$.

discussed the multiple relationships between the removal performance of NH_3–N and the influential factors. However, no significant correlation was found between NO_3–N and the selected environmental variables in our study. Some studies showed a negative relation between NO_3–N concentration and the antecedent rainfall events [24]; many influential factors were also discussed, such as TP, the installation of saturated zone, IDD, medium composition, and so on [8,9].

In respect of phosphorus, TPR and PO_4^{3-}–PR were significantly correlated with TP and PO_4^{3-}–P, respectively. Furthermore, the concentration of TP from bioretention system I was increased with the prolongation of IDD, while that of PO_4^{3-}–P was decreased with the increase of temperature in both systems. However, our findings are inconsistent with the study results of Blecken et al. [24] that there were no correlations between phosphorus removal and environmental variables.

4. Conclusion

To manage the urban stormwater runoff in Chongqing (a mountainous city), two lined bioretention systems were built and operated from 2015 to 2017, with the stormwater runoff from the roof as influent. Different from the influent, the concentration of pollutants in the effluent was monotonically increased during rainfall events. Except in the spring of 2017, the average concentration of all pollutants was lower at the outlet than at the inlet, and the better performance was observed in the removal of TN and NH_3–N; the water quality of the effluent from the lined bioretention systems met the class-III criteria, thus the effluent was mostly recyclable. Therefore, it is concluded that the lined bioretention systems demonstrate good performance in controlling the nutrient pollutants.

In the influent, TON and NH_3–N both account for the highest percentage of nitrogen pollutants in spring, summer, and autumn. In the effluent from two bioretention systems, NO_3–N or TON is the largest component of nitrogen in summer or in spring and autumn. These two systems are both capable to reduce the polutant load in respect of good runoff management. And the influence of plant species is proven by the better performance of bioretention system I planted with *Vetiveria zizanioides* (L.)/*Ophiopogon japonicas* and bioretention system II the influence of plant separately in removing NH_3–N and reducing TP.

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