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Removal of pollutants during storm and non-storm events by two wetlands

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ABSTRACT

This research investigated the pollutant removal efficiency by two constructed wetlands located on the north shore of the Fuxian Lake, Yunnan Province, China. We conducted continuous monitoring for a storm to examine residence time variations in pollutants (nitrogen and phosphorus) under local hydrologic conditions. During storm events, water samples with an interval of a few hours from the beginning of the rain at the inlet and outlet of the wetland were collected and analyzed for nitrogen (total nitrogen, ammonium, nitrate, and nitrite) and phosphorus (total phosphorus (TP)). The results have implications for stormwater management. While concentrations of nitrogen species are variable, they are not strongly related to flow conditions, so treatment systems must be designed to cope with stochastic inflow concentrations at all times. Principal components analysis of water quality parameters using data collected during non-storm periods at the Yaonigou wetland (Phase I) and the Yaonigou wetland (Phase II) was conducted. The greatest loadings of the first principal component, the second, and the third principal component of inflow in Yaonigou wetland (Phase I) are ammonia, TP, and nitrate, respectively.

Keywords: Nitrogen; Phosphorus; Stormwater; Wetland

1. Introduction

The use of constructed wetlands to treat sewage and other sources of water pollution is a valuable and appropriate technology to be used alone or in combination with other systems [1]. Wetlands have the capacity to improve the quality of stormwater run-off by assimilating and transforming organic, inorganic, and toxic constituents through processes associated with sedimentation and filtration (through vegetation or a filtration medium) [2–6], which are dominant in the initial interception of stormwater contaminants during a storm event [7]. The mechanisms involved in the removal of stormwater pollutants encompass physical, chemical, and biological processes. Domestic and agricultural wastewater, which are uncontaminated by toxic compounds, can

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theoretically be treated by constructed wetlands without replacing the substrate for several years.

Stormwater run-off has been identified as one of the largest sources of water pollution. Large amounts of non-point source pollution are generated during storm events when rainwater washes the impervious surfaces [8–10]. Stormwater wetlands remove pesticides, heavy metals, nutrients, organic materials, and a variety of other contaminants through a variety of processes [11,12]. Wetland treatment systems are commonly used to treat agricultural stormwater run-off, although the stochastic nature of the hydrologic and pollutant inputs makes performance prediction an inherently more difficult than that of one treating sewage [13]. In general, the pollutant removal efficiency of constructed wetlands is dependent on the hydrologic loading rate and retention time, which vary according to storm intensity and wetland size [10].

During last two decades, much data have been collected on the effectiveness of wetlands with respect to some key water quality parameters, including TSS (total suspended solids), BOD (biochemical oxygen demand), TP (total phosphorus), and TN (total nitrogen). Although wetlands constructed for treating wastewater have been well studied [13], stormwater treatment wetlands still present a particular challenge to wetland scientists [14]. The intermittent nature of rainfall and the variability in the rainfall depth, storm duration, and temporal pattern will produce unsteady intermittent hydraulic loading to stormwater wetlands. Studies suggest that wetland performance in treating stormwater is generally a function of inflow or hydraulic loading rate and detention time [15]. The unsteady intermittent pollutant loadings to stormwater wetlands further complicate the random nature of these systems, as pollutant concentrations are not necessarily correlated with discharge [16].

Constructed wetland designs generally include horizontal surface flow, subsurface flow, vertical flow, and floating systems. Surface flow wetlands are similar to natural marshes as they tend to occupy shallow channels and basins through which water flows at low velocities above and within the substrate. The basins normally contain a combination of gravel, clay-, or peat-based soils, and crushed rock, planted with macrophytes [1]. Pollutants such as phosphorus and nitrogen are typically used as indicators of wetland water quality [17–19].

In this paper, we analyze the available performance information on constructed wetlands that have been used to treat stormwater run-off or non-point source pollution; then compare the pollutant removal capacity of two wetlands during storm and non-storm events; and identify any obvious trends in the data that may aid future design efforts.

2. Material and methods

2.1. The wetlands of Yaonigou

The studied wetland is located on the north shore of Fuxian Lake, Yunnan Province, China (Fig. 1). The riparian wetland was selected to collect the non-point source pollution, domestic sewage, and stormwater run-off from Yaonigou ditch and an agricultural irrigation ditch, with an area of 26,000 m^2. The sewage treatment capacity of the wetland system is 5,720 $m^3\ d^{-1}$. And the hydraulic retention time is 72 h. Water depth and function area in the wetland vary from the inlet to the outlet. The dominant plants include Canna (*Canna indica*), Cattails (*Typha latifolia*), Reed (*Phragmites communis*), Umbrella plant (*Cyperus alternifolius* L.), etc. The riparian wetland is subdivided into two projects, Phase I and Phase II, which operated independently and have a similar design to the wetland systems shown.

2.1.1. The wetland (Phase I)

The wetland (Phase I) is located in the west of the agricultural irrigation ditch. The area of Yaonigou wetland (Phase I) is 15,000 m^2. The sewage treatment capacity of the wetland system is 3,520 $m^3\ d^{-1}$. The process flow diagram of the wetland treatment system is shown in Fig. 2. The treatment system received wastewater into a grit chamber, which reduced the organic and solids loading. Then, the sewage flowed into a precipitation tank and biological oxidation pond for further purification. The biological oxidation pond was composed of the three ponds in series, respectively. The heart of the treatment system was subsurface flow wetland unit and surface flow wetland unit. The subsurface flow wetland unit is composed of four parts, set in a row and continuous flow configuration, operating in parallel with a depth of 0.85–1.0 m filled with gravel or cinder. Surface flow wetland composed of two ponds in series, with an area of 2,300 and 1,300 m^2, respectively. Finally, the wastewater flowed through lakeside beach and discharged into Fuxian Lake. The design parameters of each function unit of the wetland treatment system (Phase I) are summarized in Table 1. Different plants are cultured in each function unit. In the four parallel parts of subsurface flow wetland unit, the plants cultured in order were

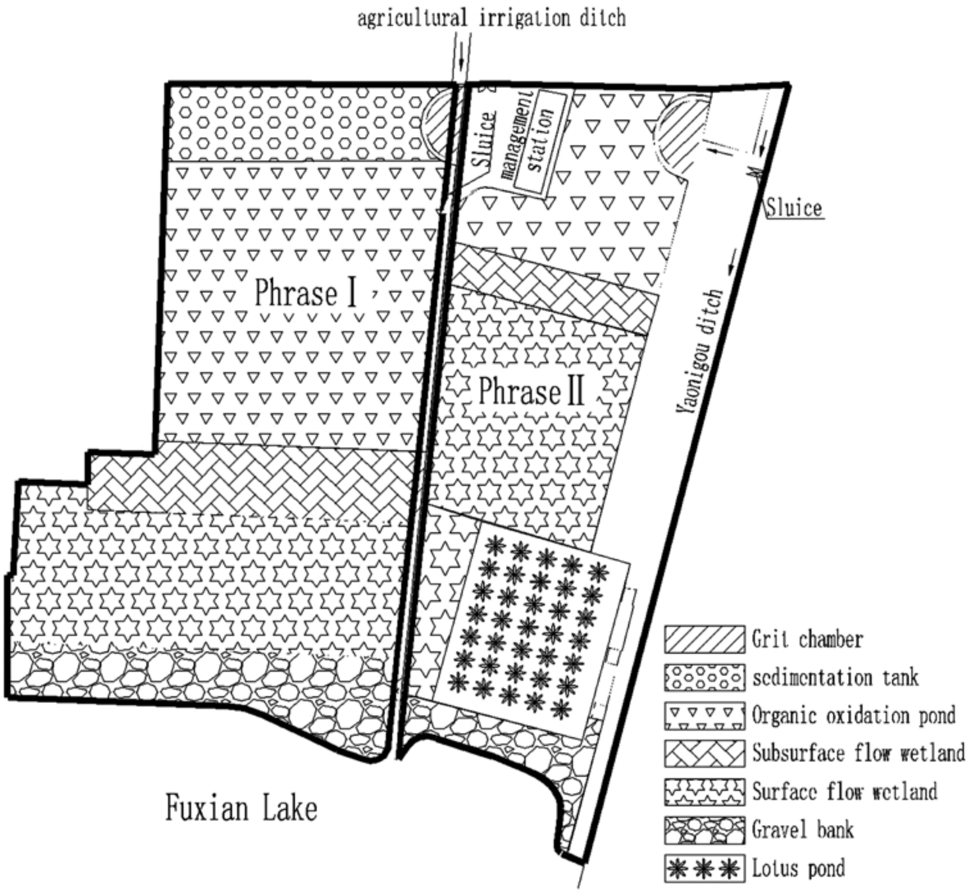

Fig. 1. The two constructed wetland systems.

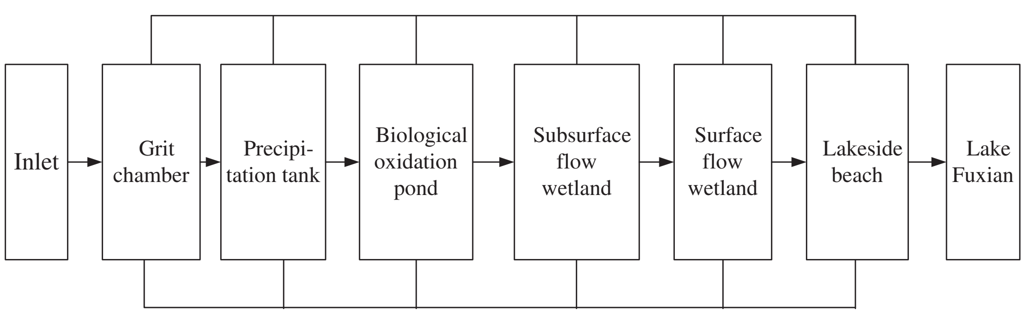

Fig. 2. The process flow diagram of the riparian wetland (Phase I).

Umbrella plant (*C. alternifolius* L.) and Cattail (*T. latifolia* L.) (50–50%), Reed (*P. communis*), Cattail (*T. latifolia* L.), Reed (*P. communis*), respectively. In the surface flow wetland, the first set is planted with Cress (*Oenanthe javanica* Bl. & DC.), while the second set is arrowhead (*Sagittaria sagittifolia* L.) and lotus (*Nelumbo nucifera*).

2.1.2. The wetland (Phase II)

The wetland (Phase II) is located in the west of the Yaonigou ditch, the east of the wetland (Phase I). The area is about 11,000 m^2. The sewage treatment capacity is 2,200 $m^3\ d^{-1}$. The process flow diagram of the wetland (Phase II) is inlet → grit chamber → biological

Table 1
Design parameters of function units of the wetlands (Phase I)

No.	Function units	Surface area (m^2)	Water depth (m)	Plants selected
1	Grit chamber	150	–	–
2	Precipitation tank	1,610	1.1–1.9	Canna (*Canna indica*) and Cattails (*Typha latifolia*)
3	Biological oxidation pond			
	(1)	2,480	1.5–1.8	Cress (*Oenanthe javanica* Bl. & DC.)
	(2)	2,480	1.5–1.8	Cress (*Oenanthe javanica* Bl. & DC.)
	(3)	1,760	1.5–1.8	Water lily (*Nymphaea tetragona*) and Water chestnut (*T. japonica*)
4	Subsurface flow wetland	1,760	0.85–1.0	Reed (*Phragmites communis*), Cattail (*Typha latifolia* L.), and Umbrella plant (*Cyperus alternifolius* L.)
5	Surface flow wetland	4,700	0.2–0.4	Cress (*Oenanthe Javanica* Bl. & DC.), Arrowhead (*Sagittaria sagittifolia* L.), and Lotus (*Nelumbo nucifera*)
6	Lakeside beach	–	–	Willow trees

Table 2
Design parameters of function units of the wetlands (Phase II)

No	Function units	Surface area (m^2)	Water depth (m)	Plants selected
1	Grit chamber	230	–	–
2	Biological oxidation pond	2,600	1.0–1.5	–
3	Subsurface flow wetland	830	0.4–0.6	Reed (*Phragmites communis*), Cattail (*Typha latifolia* L.), and Umbrella plant (*Cyperus alternifolius* L.)
4	Surface flow wetland	4,800	0.2–0.4	Cress (*Oenanthe javanica* Bl. & DC.) and Arrowhead (*Sagittaria sagittifolia* L.)
5	Lotus pond	2,600	1.5–2.0	Water lily (*Nymphaea tetragona*) and lotus (*Nelumbo nucifera*)
6	Lakeside beach	–	–	Willow trees

oxidation pond → subsurface flow wetland unit → surface flow wetland unit → lotus pond → outflow. The design parameters of each function unit of the wetland treatment system (Phase II) are shown in Table 2. The vegetation types in the wetlands comprise emergent macrophytes (large plants), rheophytes (floating plants), and freshwater swamp species.

2.2. Sampling

During non-storm periods, the wetland receives continual wastewater inputs from the Yaonigou ditch and the agricultural irrigation ditch. The source of base-flow input is primarily from agricultural run-off and domestic sewage. Water samples were collected for storm events and non-storm events and analyzed for TN and nitrate, and nitrite, ammonium, and TP. For sampling, paired water samples were collected as a means of verifying the accuracy and precision of the analysis. Only when no significant difference was found between replicated samples, then a mean was used in the subsequent data analysis. After field collection, all of the water samples were immediately taken to the laboratory and processed. All samples, which were unrefrigerated, were retrieved within 24 h of the events' completion.

2.2.1. Non-storm events

Sampling collection and analysis at the inlet and outlet of the two wetlands (Phase I and Phase II) during non-storm events were conducted from April 2009 to January 2010, usually at half-month intervals except for no flow conditions. During the dry season, there was no water at the sampling point, and therefore, no samples were collected. All samples were hand-collected (grab sample).

Table 3
The rainfall of the two wetlands from 1 July–30 August 2009

Date	Precipitation (mm)	Date	Precipitation (mm)	Date	Precipitation (mm)	Date	Precipitation (mm)
2009/7/1	–	2009/7/17	–	2009/8/2	–	2009/8/18	–
2009/7/2	–	2009/7/18	–	2009/8/3	–	2009/8/19	–
2009/7/3	–	2009/7/19	–	2009/8/4	19.5	2009/8/20	–
2009/7/4	19	2009/7/20	11	2009/8/5	1	2009/8/21	–
2009/7/5	36.5	2009/7/21	–	2009/8/6	–	2009/8/22	1
2009/7/6	1.5	2009/7/22	–	2009/8/7	–	2009/8/23	0.5
2009/7/7	–	2009/7/23	–	2009/8/8	–	2009/8/24	–
2009/7/8	–	2009/7/24	1	2009/8/9	1.5	2009/8/25	–
2009/7/9	–	2009/7/25	3	2009/8/10	–	2009/8/26	2.5
2009/7/10	–	2009/7/26	1	2009/8/11	–	2009/8/27	–
2009/7/11	–	2009/7/27	10	2009/8/12	–	2009/8/28	1.5
2009/7/12	–	2009/7/28	0.5	2009/8/13	1	2009/8/29	–
2009/7/13	–	2009/7/29	1.5	2009/8/14	5.5	2009/8/30	–
2009/7/14	–	2009/7/30	3.5	2009/8/15	–	2009/8/31	–
2009/7/15	–	2009/7/31	–	2009/8/16	27.5		
2009/7/16	–	2009/8/1	–	2009/8/17	–		

2.2.2. Storm events

Most of the rainfall occurs in the summer and there is no precipitation basically in the other three seasons in the study area. So, storm events have been monitored from 1 July 2009 through 31 August 2009 (Table 3). Precipitation data were routinely collected from the closest hydrology monitoring station, located approximately 2.5 km west of the study site, and was used as estimates for the total rainfall for each storm event. Rainfall amount from 21 rain events varied in size from 0.5 to 27.5 mm. Water sampling could not be realized completely in other storm events except for the one occurred on 4 August 2009 for some reasons. So, the stormwater samples were collected at the inlet and outlet of the wetlands (Phase I and II) on 4 August 2009.

The time and date of collection were recorded for each water sample. The inlet and the outlet were set to collect samples every 2 h from the beginning of rain until it stopped. Then, the inlet and outlet were also sampled after the rain has stopped for 4, 8, and 12 h intervals. That is, water samples have been collected every 1, 4, 8, 12, and 36 h intervals from the beginning of rain. After a rain event, the samples were brought back to the laboratory for analysis. From the discharge information at the inlet, the beginning of the storm was marked as the time right before water levels began to rise. Since the outlet always responded later slightly to the rise in water levels, the same time value was used as the beginning of the storm at the outlet as well. The end of the storm was marked as the time at which the discharge at the inlet and outlet returned to base-flow levels. SPSS 16.0 for Windows was used in performing principal components analysis (PCA).

3. Results and discussion

3.1. Yaonigou wetland (Phase I)

Concentrations for nitrogen and phosphorus in Yaonigou wetland (Phase I) during non-storm and storm event conditions are presented in Table 4 and Fig. 3, respectively.

The inflow concentrations of nitrate were 0.5–8.9 mg/L in non-storm event wetlands. The outflow concentrations were below 1.0 mg/L. And the most of the removal efficiencies were above 50%. The inflow and outflow concentrations of nitrite were not high, below 0.5 and 0.2 mg/L, respectively. The removal efficiencies reached above 80%. TN concentrations were highest for wetland (Phase I) in non-storm event wetlands. The removal efficiencies ranged between 20 and 80%, except for individual values. The inflow concentrations of phosphorus were also not high, below 1.0 mg/L. And meanwhile, the outflow concentrations were below 0.5 mg/L. According to the data, removal efficiency of phosphorus was not good. There existed phosphorus release in the wetland. Wetland soil adsorption of phosphorus has saturated after a long-time run. When phosphorus concentration of inflow was not high, phosphorus in wetland soil would release into the overlying water. Interestingly, TP concentrations during storm event conditions were

Table 4
The water quality parameters in Yaonigou (Phase I) under base-flow conditions

	Ammonia		Nitrite		Nitrate		TN		TP	
Date	Inflow (mg/L)	Outflow (mg/L)	Inflow (mg/L)	Outflow (mg/L)	Inflow (mg/L)	Outflow (mg/L)	Inflow (mg/L)	Outflow (mg/L)	Inflow (mg/L)	Outflow (mg/L)
2009/4/20	3.38	4.07	0.28	0.03	8.96	0.91	12.23	5.16	0.32	0.87
2009/5/5	0.24	1.90	0.47	0.19	8.35	6.84	9.55	9.28	0.61	0.50
2009/5/18	8.50	10.85	0.51	0.12	4.84	0.84	14.96	12.81	0.81	0.80
2009/6/2	5.44	8.75	0.45	0.07	5.88	0.91	12.00	9.57	0.73	0.82
2009/6/16	4.70	5.46	0.49	0.18	5.95	1.09	10.90	7.65	0.52	0.50
2009/7/1	1.87	7.00	0.39	0.08	8.10	0.54	10.43	8.52	0.50	0.90
2009/7/14	4.17	4.70	0.51	0.11	1.34	0.52	8.00	8.00	0.54	0.71
2009/7/27	10.80	4.08	0.20	0.03	0.14	0.00	11.94	4.87	1.00	0.92
2009/8/12	6.36	3.21	0.36	0.13	1.79	1.65	8.44	5.54	0.69	0.42
2009/8/25	4.94	2.46	0.37	0.06	3.64	0.41	13.10	4.45	0.77	0.49
2009/9/8	1.36	1.91	0.39	0.03	0.52	0.36	11.06	3.87	0.79	0.62
2009/9/22	3.78	1.99	0.45	0.14	1.31	2.13	11.11	4.08	0.68	0.48
2009/10/20	9.46	0.76	0.02	0.03	0.52	0.81	11.90	3.01	0.57	0.55
2009/11/3	10.80	0.57	0.26	0.05	3.58	1.65	16.12	3.46	1.12	0.55
2009/11/18	7.19	1.15	0.13	0.05	2.38	1.61	12.89	3.27	0.12	0.09
2009/12/1	5.59	2.34	0.28	0.04	5.36	1.54	11.25	3.43	0.44	0.19
2009/12/15	4.10	/	0.20	0.01	2.32	0.37	10.41	1.74	0.59	0.14
2010/1/12	2.46	2.53	0.54	0.44	6.45	1.79	9.81	6.63	0.78	0.82

much more when it was raining, and then less than those measured in wetland during non-storm event conditions suggesting that overlying water in the wetland was diluted under storm conditions. And the removal efficiencies of TN in storm event wetlands were also more than in non-storm event wetlands.

According to Fig. 3, the inflow and outflow concentrations of ammonia in storm event wetlands were less than in non-storm event wetlands. When it is beginning to rain (at 12:55 on 4 August 2009), the inflow and outflow concentrations of ammonia were 5.8 and 1.8 mg/L, respectively. While the rain stopped after lasting 4 h, those concentrations decreased to 3.7 and 1.5 mg/L, respectively. There is a little change between inflow and outflow concentrations of ammonia. When the rain has stopped for 12 h (at 06:35 on 5 August 2009), the inflow and outflow concentrations of ammonia were 2.8 and 0.8 mg/L, respectively. The removal efficiency was 73%. The initial inflow concentration of nitrate was 1.7 mg/L when it began raining. After 16 h, the concentration was 0.4 mg/L. The outflow concentrations were always below 0.3 mg/L. The removal efficiencies were 45–99%. The inflow concentrations of nitrite were 0.3 mg/L when it was raining. After the rain has lasted for 4 h, the concentrations increased to 0.5 mg/L. The outflow concentrations have been below 0.1 mg/L (in addition to the individual values). When it began to rain, the inflow concentrations of phosphorus was 1.15 mg/L and the outflow concentrations was 1.43 mg/L. When the rain has stopped for 4 h, the inflow and outflow concentrations of TP were 1.6 and 1.0 mg/L, respectively. After 12 h of experiments, the inflow concentration was 2.8 mg/L; after 16 h of experiment, that was 2.4 mg/L. The outflow concentrations were always about 0.5 mg/L. The reason was probably that the rainwater flowed through the farmland and part of phosphorus in the farmland was washed into the ditch and then into the wetland after the rain has stopped for several hours. So, the inflow concentrations of phosphorus increased twice after rain has stopped for 16 h.

When base-flow concentrations were compared against the storm event values, the nitrogen in wetlands indicated a decrease in concentrations and in removal efficiencies during events except for nitrite. Ammonia, nitrite, and nitrate concentrations in non-storm event wetlands were less than in storm event wetlands. And the removal efficiencies of ammonia and nitrate in storm event wetlands were higher than in non-storm event wetlands, while the opposite was true for nitrite. Similar to non-storm event wetlands, concentrations for TN were highest in storm event wetland. Dominant sources of nitrogen in the wetland were fertilizer dissolution in the farmland. In contrast to the high TN concentrations, TP concentrations in non-storm event wetland were generally very low or

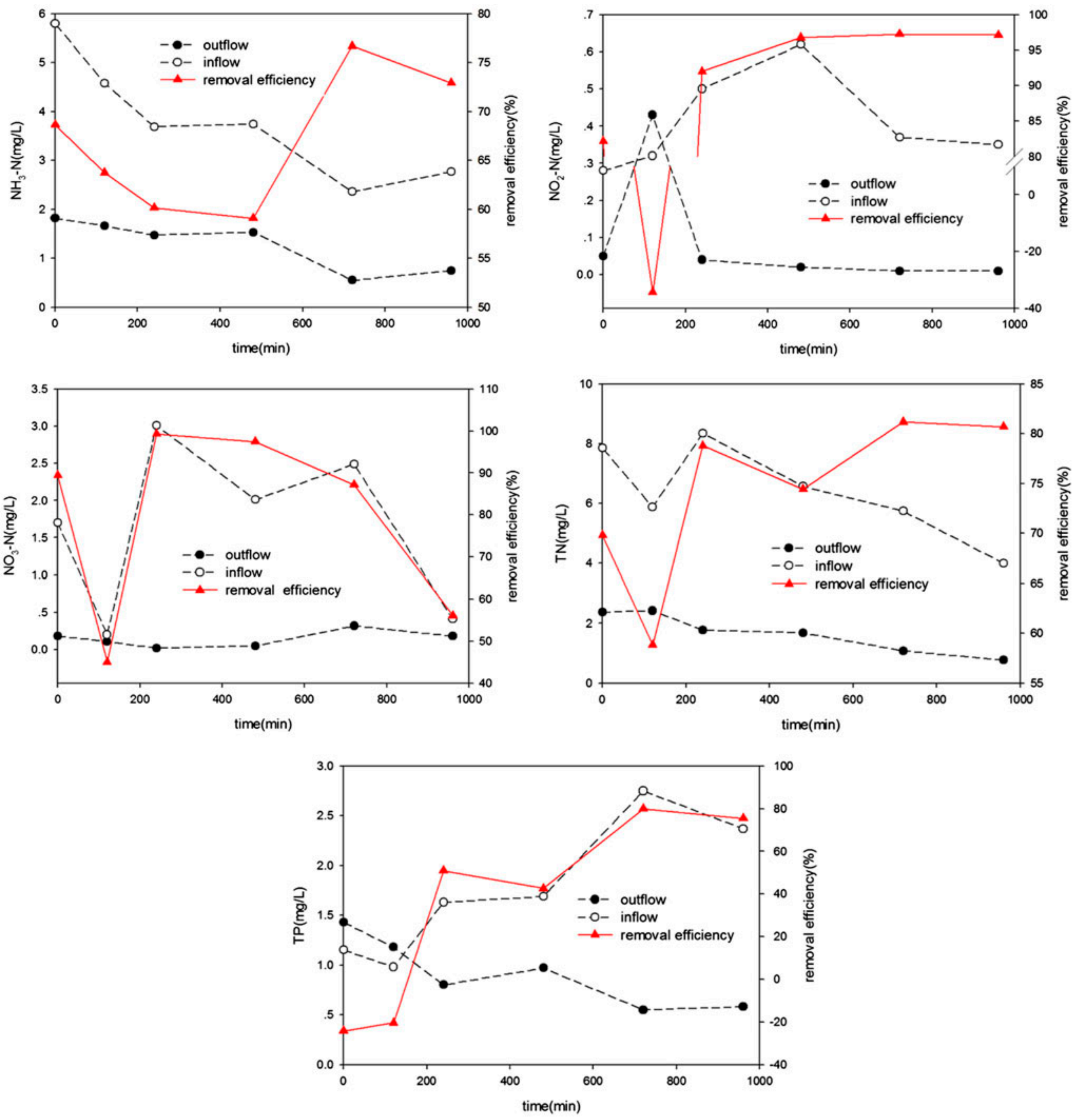

Fig. 3. Different water quality parameters in Yaonigou wetland (Phase I) for the stormwater events.

negligible. Average TP concentrations in wetland did not change much between non-storm event and storm event conditions; however, corresponding value for TP during storm events was more than twice the base-flow value. Nitrate had intermediate concentrations and decreased from non-storm to storm event conditions.

3.2. *Yaonigou wetland (Phase II)*

The inflow, outflow concentration of ammonia, nitrate, nitrite, TN, and TP in non-storm event wetlands are presented in Table 5. And the concentration changes of pollutants corresponding to the selected storm events (on 4 August 2009) are also shown in

Table 5
The water quality parameters in Yaonigou wetland (Phase II) under base-flow conditions

Date	Ammonia		Nitrite		Nitrate		TN		TP	
	Inflow (mg/L)	Outflow (mg/L)	Inflow (mg/L)	Outflow (mg/L)	Inflow (mg/L)	Outflow (mg/L)	Inflow (mg/L)	Outflow (mg/L)	Inflow (mg/L)	Outflow (mg/L)
2009/4/20	2.97	4.71	0.60	0.23	5.36	1.99	9.51	6.49	0.54	0.61
2009/5/5	1.62	0.63	0.42	0.36	6.77	5.70	9.28	8.70	0.37	0.32
2009/5/18	7.24	8.34	0.35	0.24	3.71	1.70	12.00	10.72	0.77	0.66
2009/6/2	8.02	7.12	0.54	0.15	3.26	2.83	12.58	10.84	0.81	0.57
2009/6/16	5.01	2.49	0.65	0.40	8.87	9.42	14.96	12.70	0.44	0.45
2009/7/1	1.96	2.46	0.38	0.26	7.51	3.35	9.62	8.52	0.85	0.52
2009/7/14	4.62	2.99	0.41	0.43	3.89	4.62	9.57	15.01	0.60	0.54
2009/7/27	5.05	2.67	0.32	0.19	2.44	1.18	8.95	5.15	0.60	0.77
2009/8/12	5.34	1.26	0.34	0.19	2.90	1.49	8.53	4.10	0.69	0.48
2009/8/25	3.74	1.66	0.34	0.21	4.59	1.77	10.64	5.24	0.64	0.54
2009/9/8	5.73	1.19	0.12	0.43	0.61	0.48	7.12	4.27	0.96	0.25
2009/9/22	5.14	2.10	0.29	0.30	2.47	1.88	9.65	4.87	0.73	0.47
2009/10/20	8.61	3.13	0.21	0.25	1.34	1.79	13.01	6.54	1.02	0.40
2009/11/3	9.62	0.61	0.33	0.05	0.27	1.49	11.06	3.39	1.39	0.44
2009/11/18	7.00	0.83	0.33	0.02	3.44	1.81	11.66	2.81	0.43	0.65
2009/12/1	6.59	0.68	0.58	0.04	2.15	1.65	11.34	4.01	0.63	0.23
2009/12/15	6.64	0.28	1.12	0.05	2.36	1.24	13.12	4.13	0.87	0.21
2009/12/28	–	0.41	–	0.03	–	0.20	–	3.92	–	0.20
2010/1/12	–	0.44	–	0.02	–	0.02	–	1.37	–	0.11

Fig. 4. According to figure, pollutant loads were substantially reduced. However, the reduction was typically not significant.

The inflow and outflow concentrations of ammonia in non-storm event wetlands were 1.6–9.6 and 0.2–8.3 mg/L, respectively. Monitoring values showed that the purifying effect was not satisfying. Correspondingly, the inflow concentrations of ammonia in storm event wetlands were 5.6 mg/L. With rain continued, influent concentrations showed a downward trend. The outflow concentrations of ammonia were below 3 mg/L and the removal efficiencies were 40–60%. The removal efficiency of ammonia in non-storm event wetlands was also less than in storm event wetlands. The inflow and outflow concentrations of nitrate in non-storm event wetlands were not high. The outflow concentrations were always below 2 mg/L. The removal efficiencies of nitrate in non-storm event wetlands were good. The inflow and outflow concentrations of nitrate in storm event wetland were 0.1–4.2 and 0.3–1.7 mg/L, respectively. When the storm has lasted for 2 h, the outflow concentration of nitrate was much more than the inflow. The removal efficiencies have always been about 50% when the rain has continued for 2 h. The inflow and outflow concentrations of nitrite were low in non-storm event wetlands, ranged from 0.1 to 1.1 mg/L, from 0.01 to 0.4 mg/L, respectively; the inflow and outflow concentrations were lower in storm event wetlands than in non-storm event wetlands, ranged from 0.2 to 0.6 mg/L, from 0.1 to 0.4 mg/L, respectively. The differences have not been realized obviously because of its low concentrations of nitrite. The inflow and outflow concentrations of TN in non-storm event wetlands were 7.1–15.0 and 1.3–10.8 mg/L, respectively. The removal efficiency of TN is about 50%, satisfying. When it started to rain, the inflow and outflow concentrations of TN are 7.9 and 4.7 mg/L; when rainstorm continued for 2 h, the inflow concentrations increased to 9.0 mg/L. The outflow concentrations always remained unchanged. The inflow concentrations in non-storm event wetlands were not high, below 1.0 mg/L. And the removal efficiencies were 9.0–60.9%. Removal of nitrogen by a wetland is a rather complex set of processes. Wetlands provide a unique condition which allows organic forms of nitrogen to eventually be converted to nitrogen gas. Another means of removing nitrogen and phosphorus from inflow is plant uptake.

Monitoring values showed that phosphorus release existed sometimes in non-storm event wetland. This result was consistent with that in the Yaonigou wetland (Phase I). Influent concentrations and removal efficiency of phosphors in storm event wetlands were also better than in non-storm event wetlands. TP concentrations in the storm event wetland (Phase II) decreased sharply as the removal efficiencies rose and were at their minimum when the rain has stopped for

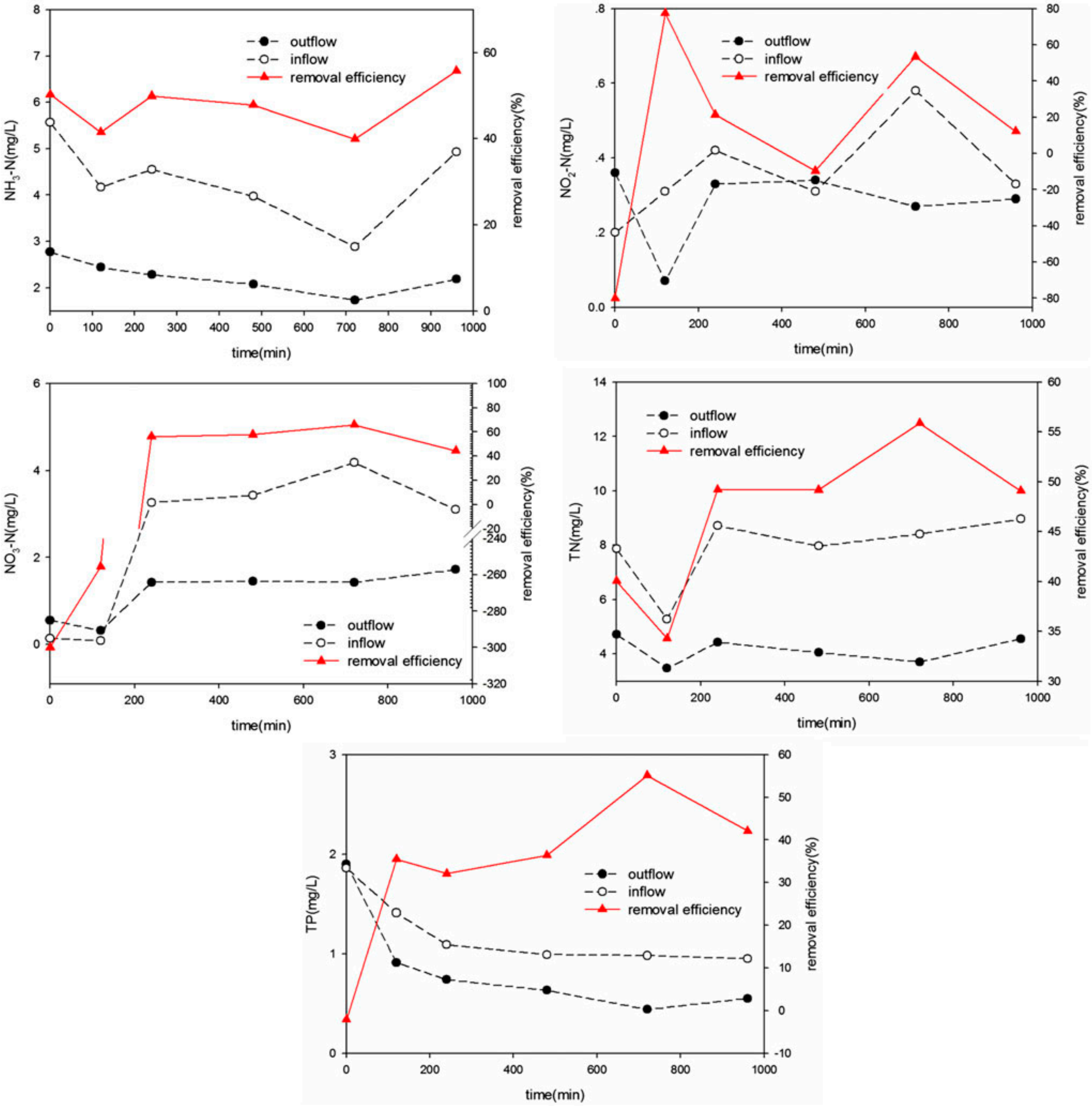

Fig. 4. Different water quality parameters in Yaonigou wetland (Phase II) under stormwater events.

4 h, which indicated a significant positive correlation between inflow and outflow concentrations, whereas the same was true for ammonia and nitrate in storm event wetland (Phase II). The initial ammonia concentrations in storm event wetlands were much lower than that in non-storm event wetlands and the decrease in outflow concentrations of ammonia was also muted. Other than ammonia and TP, nitrate, nitrite, and TN concentrations for the storm event wetland always increased as the rain has continued and then stopped for several hours, which did not follow the distinct dilution trends observed for ammonia and TP. The decreases in inflow and outflow of TN concentrations and the concomitant increases in the wetland (Phase II) were also shown in Fig. 4. The initial nitrite concentration for the storm event was low. And

Table 6
The eigenvalues, contribution rates, and accumulated contribution rates of the principal components

	Yaonigou wetland (Phase I)						Yaonigou wetland (Phase II)					
	Initial eigenvalues (Inflow)			Initial eigenvalues (Outflow)			Initial eigenvalues (Inflow)			Initial eigenvalues (Outflow)		
	Total	% of variance	Cumulative (%)	Total	% of variance	Cumulative (%)	Total	% of variance	Cumulative (%)	Total	% of variance	Cumulative (%)
1	2.295	45.902	45.902	2.361	47.223	47.223	2.359	47.178	47.178	2.806	56.125	56.125
2	1.221	24.426	70.329	1.509	30.173	77.396	1.665	33.297	80.475	1.224	24.481	80.606
3	1.005	20.095	90.424	0.698	13.953	91.349	0.546	10.912	91.387	0.462	9.240	89.846
4	0.252	5.040	95.464	0.405	8.110	99.459	0.395	7.900	99.287	0.419	8.386	98.232
5	0.227	4.536	100.000	0.027	0.541	100.000	0.036	0.713	100.000	0.088	1.768	100.000

inflow and outflow concentrations in the storm event wetland did not exceed 0.6 mg/L, while the concentrations were 0.2–1.2 mg/L in the non-storm event wetland, likely due the effect of preceding precipitation events, which diluted nitrite concentrations. Also, unlike in storm event wetland, the nitrogen and phosphorus concentrations of the non-storm event wetland displayed considerable variability during one-year monitoring. Nitrite concentrations in wetlands (Phase I and Phase II) were very low across all events.

While inflow concentrations of TP during storm events were more than twice their non-storm values, they were still lower than the TN concentrations for wetland (Phase I). In contrast to the wetland (Phase I), ammonia and TN concentrations (inflow) in the storm event wetland (Phase II) were much greater, revealing distinct trends. The correlation between outflow and inflow concentrations in the storm event wetland (Phase II) was also strong and significant. However, phosphorus and nitrogen concentrations for inflow and outflow in the storm event wetland (Phase I) did not follow the distinct trends observed. Similar to the outflow concentration, inflow concentrations of ammonia and TP in the wetland (Phase II) displayed a very slight dilution during the storm event. Wetland performance is influenced by wetland structure and hydrology, and by climate, soils, vegetation, percent watershed imperviousness, and numerous other variables not accounted for in this simplistic approach [13].

Concentrations of ammonia, nitrite, TP, and TN in the storm event wetland (Phase II) were significantly correlated with discharge values. In contrast to non-storm event wetlands, concentrations of nitrogen and phosphorus in storm event wetland showed more pronounced dilution patterns, suggesting greater contributions of rainfall to ditch during events.

PCA of water quality parameters in non-storm periods in Yaonigou wetland (Phase I) and Yaonigou wetland (Phase II) is analyzed. The eigenvalues, contribution rates, and accumulated contribution rates of the principal components are shown in Table 6. The initial loading values of the principal components of inflow and outflow in Yaonigou wetland (Phase I) and Yaonigou wetland (Phase II) are also described in Table 7. When the number of principal components is taken as 3 in Yaonigou wetland (Phase I), the accumulated contribution rates of the principal components of inflow and outflow are 90.424 and 91.349%, respectively, which are more than 85%. These three of principal components represent the 90.424 and 91.349% of the information provided by the original variables. The greatest loadings of the first principal component, the second, and the third principal component of inflow in Yaonigou wetland (Phase I) are ammonia, TP, and

Table 7
Initial loading values of the principal components[a]

	Yaonigou wetland (Phase I)						Yaonigou wetland (Phase II)			
	Component (inflow)			Component (outflow)			Component (inflow)		Component (outflow)	
	1	2	3	1	2	3	1	2	1	2
Ammonia	0.922	0.014	0.077	0.920	−0.184	−0.271	0.877	0.381	0.674	0.617
Nitrite	−0.653	0.671	−0.128	0.279	0.755	0.529	−0.267	0.783	0.760	−0.379
Nitrate	−0.615	0.199	0.716	−0.166	0.878	−0.316	−0.892	0.196	0.738	−0.529
TN	0.672	0.292	0.618	0.901	0.298	−0.289	0.067	0.932	0.937	−0.122
TP	0.436	0.804	−0.296	0.773	−0.213	0.401	0.847	−0.016	0.592	0.636
	[a]3 components extracted						[a]2 components extracted			

nitrate. This shows that the most important pollutants in Yaonigou wetland (Phase I) are ammonia and nitrate. Similarly, when the number of principal components is taken as 2 in Yaonigou wetland (Phase II), the accumulated contribution rates of the principal components of inflow and outflow are 80.475 and 80.606%, respectively. On the same time, the greatest loadings of the first principal component and the second component of inflow and outflow in Yaonigou wetland (Phase II) are ammonia and TN, and TN and TP, respectively, which also show that the most prominent pollutant is nitrogen, especially TN.

4. Conclusions

Two integrated constructed wetlands, treating non-point source pollution from arable land during non-storm periods and under a storm event condition, were studied. These two wetlands have been subject to stormwater run-off and non-point source pollution impacts for about 10 years. This study has provided a snapshot of an active water quality improvement function, with respect to nitrogen and phosphorus, associated with this established wetland.

Both the wetlands (Phase I and Phase II) revealed a slight decrease in average concentrations for ammonia, nitrate, and TN from base-flow to storm event conditions, whereas the opposite was true for nitrite and TP. The most important pollutants in both two wetlands by the PCA during the non-storm events are ammonia and TN, respectively. A decrease distinctly in inflow concentrations of ammonia in both two wetlands during the storm events indicated dilution by rainfall. The outflow concentrations of nitrite, nitrate, TN, and TP decreased slightly in these two wetlands, whereas the inflow concentrations did not reveal a change trend. This asynchrony of the inflow concentrations between ammonia and others in both two wetlands suggests that dilution was likely not the reason for the continued decrease through storm event.

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