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Field Performance of Rain Garden in Red Soil Area in Southern China

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Abstract: Sponge City, as a new concept in urban stormwater management, utilizes on-site or local hydrologic processes for runoff control and therefore is highly dependent on the geographical location (soil type) and site-specific climatic conditions. Field studies are valuable because of the insufficient quantity of field performance data in low-impact development (LID)-related research. Rain gardens are recommended for LID to manage stormwater. A rain garden was designed as a pilot project in Nanchang city, which is one of the typical red soil areas in southern China. Red soil is usually not conducive to runoff infiltration due to its low organic carbon, strong acidity and low permeability rainfall characteristics, but the permeability of the filter media layer is an important parameter in LID design. The construction depth of the rainwater garden was 600 mm, and 30% sand, 10% compost and 60% laterite were used as combined matrix; the permeability coefficient of medium layer was 1.48×10^{-5} m·s^{-1}. Rainfall runoff control and pollutant removal efficiencies were studied based on the on-site conditions. The analysis of almost 2 years of field data showed that volume capture ratio of annual rainfall was 78.9%, the mean load removal of TSS, NH_3-N, TP, TN, COD and NO_3-N were 92.5%, 85.3%, 82.9%, 80.5%, 79.8% and 77.5%, respectively, which could meet the technical guidelines for sponge city construction in Nanchang. The research results could provide a basis for sponge city design in low organic carbon and low permeability areas.

Keywords: rainfall runoff; low impact development; runoff control; pollutant removal; Sponge City

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1. Introduction

The rapid urbanization in China over recent decades has led to significant changes in surface hydrological characteristics, such as permeability and detention/storage, etc., and thus resulted in severe non-point source pollution and urban flooding [1–3]. In China, the Sponge City projects initiative has been promoted, and implemented since 2014, as a new approach to urban storm water management, which utilizes on-site or local hydrologic processes for runoff control and therefore is highly dependent on the geographical location (soil type) and the site-specific climatic conditions. In recent years, Sponge City technical guidelines have been issued for major cities such as Beijing, Shanghai, Wuhan and Chongqing, but are not available as yet for many other locations. For some areas, a number of demonstration projects have been completed for selected management practices such as rain gardens that led to good treatment results [4].

The rain garden is one of the most commonly used low-impact development (LID) measures due to its characteristics which reflect the natural water-cycle processes [5,6]. Rain gardens play a vital role in reducing rainwater volume and flow, preventing assets' destruction, removing pollutants from urban runoff, and recharging groundwater [7]. Rain gardens use plants, soil, and their associated microbial communities to reduce or remove pollutants with mechanisms such as filtration, evapotranspiration, adsorption and biotransformation [8–11]. Studies have shown that native soils can effectively be used in the design of rain gardens as long as volume removal goals are achieved [12–14]. Additionally, rain gardens can attenuate runoff peak flow and reduce runoff volumes through the process of detention and retention [15–18]. At present, rain gardens are widely used world-wide because of their flexibility in size and location, ecological values to the landscape and treatment cost-effectiveness compared to conventional runoff treatment methods [14,19].

In China, research efforts in relation to rain gardens have thus far mostly focused on theoretical aspects and laboratory experiments, some on policy standards and construction technology, rather than the individual, event-based or even, to a lesser extent, long-term treatment performance [20–22]. Laboratory tests could be far from reality in terms of replicating real field conditions [23]. Consequently, to date there are still insufficient available field-performance data in the literature [15]. Field tests are very much needed since rain garden performance mainly depends on site-specific infiltration and evapotranspiration, and their effectiveness would be significantly impacted by such parameters as soil type and conditions, types of plants, plant survival, rainfall patterns, pollutant levels, ground use types and other hydrological properties [24].

The precipitation pattern in Southern China is typically characterized by high-intensity, localized and uneven temporally distributed storms. The urban drainage facilities have not generally been correspondingly upgraded [25]. Urban flooding and runoff-induced pollution have thus become the most frequent hazards in many cities in Southern China. Additionally, red soil is the typical soil type in the humid areas of subtropical China, with an area of 56.9 million hm^2, including most of Jiangxi and Hunan Provinces. Red soil is not conducive to the infiltration of runoff and the construction of rain gardens due to its low permeability [26].

Therefore, it is of great interest to study the feasibility of using infiltration-type LID practices such as rain gardens in the red soil region in Southern China. The present study was thus conceived, and a full-scaled rain garden was constructed and tested at a college campus in Nanchang, Jiangxi Province. To achieve this objective, it was decided to use flow and water-quality monitoring to quantify the retention of flow and pollutant and load reductions by the rain garden system. Based on the field experimental data, an in-depth discussion on the design and construction of the facility and its treatment performance on runoff pollutant was presented, which could provide much-needed guidance for the planning and design of rain gardens in red soil regions in the world.This paper was conducted to close the gap in our theoretical research and treatment performance of these LID facilities for Sponge City.

2. Materials and Methods

2.1. Study Area

Nanchang, a typical city in Southern China (Figure 1a), has a subtropical humid monsoon climate characterized by high temperature, rainy summers and mild winters with less rain. The mean annual temperature is 17.7 °C, with an annual precipitation ranged from 941 to 1764 mm, which is unevenly distributed (42.96% of it falls during summer months). The annual runoff volume of Nanchang is 6.153 billion m^3 (831.1mm), the annual average runoff volume in the flood season is 40.5 billion m^3, with 18.9% of it in June. The analysis of rainfall statistics of Nanchang showed that the occurrence probability of acid rain was higher than 90% and the mean pH was lower than 5.6 [27]. This is an important cause of local red soil acidification.

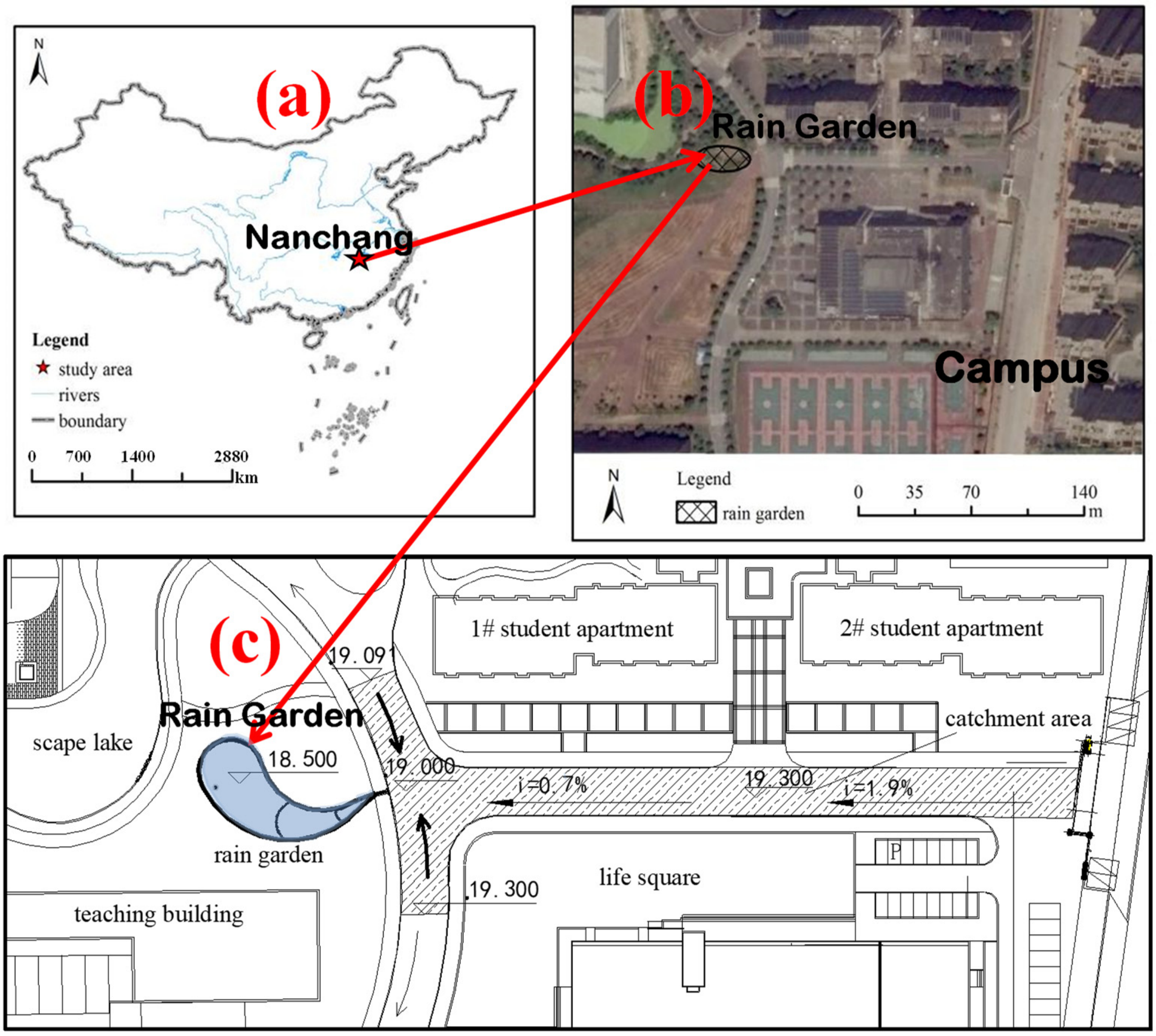

Figure 1. Location map of the rain garden (**a**) The location of Nanchang in China; (**b**) The location of the rain garden in Nanchang; (**c**) The location and surrounding schematic of the rain garden.

2.2. Design Parameters for the Rain Garden

A full-scale rain garden (Figure 1b) was constructed at the Nanchang University campus in July 2016 for the collection and treatment of road runoff. The catchment area of the test rain garden (Figure 1c) was 1533.24 m^2, obtained by measuring the size of the surrounding pavement draining into the rain garden. According to the Design Specifications of China's Outdoor Drainage Design Code [28], the surface type of the catchment area was mainly hard concrete pavement, and the runoff coefficient was set to be 0.9. The volume capture ratio of annual rainfall in the Nanchang area was 60–85% by the Sponge City Construction Technology Guide of Nanchang City. Due to the frequent occurrence of the rainy season, the control target was set at 85%, and the design rainfall depth was 38.9 mm, with the average recurrence interval (ARI) of 5 years. The total design runoff volume (V) was calculated by the volumetric method Equation (1):

$$V = 0.001FH\psi, \tag{1}$$

where F is the runoff catchment area (m^2); ψ is the runoff coefficient; and H is the design rainfall depth (mm).

The water balance method was used for the surface area of the test rain garden [27]. Firstly, it assumed that runoff from the catchment area would entirely flow into the rain garden. When the amount of runoff exceeded the capacity of storage and infiltration, the total runoff balance of the rain garden was calculated, as shown by Equation (2). Secondly, the method ignored evaporation from the rain garden during the calculation time period. In addition, in the design of the rain garden, the effluent could be assumed to be zero. Finally, the area of the rain garden could be calculated by Equation (6), which was derived from Equations (2)–(5). Parameters set in the equations were shown in Table 1.

(a) Design storage capacity:

$$V = G + V_w + W_s, \tag{2}$$

where G is the medium void storage (m^3); V_w is the aquifer storage (m^3) and W_s is the permeation during rainfall (m^3).

(b) Mediumvoid storage:

$$G = n \cdot A_f \cdot d_f, \tag{3}$$

where n is the average porosity of the filter media layer; d_f is the filter media layer thickness (m) and A_f is the rain garden area (m^2).

(c) Aquifer storage:

$$V_w = (1 - m) A_f \cdot h_m, \tag{4}$$

where m is the proportion of plants cross-sectional surface area in the surface area of the aquifer and h_m is the maximum water depth of the standing water aquifer (m).

(d) Permeation:

$$W_s = \frac{60K \cdot (d_f + h) \cdot A_f \cdot T}{d_f}, \tag{5}$$

where K is the permeability coefficient of planting soil ($m \cdot s^{-1}$); h is the average water depth of the aquifer (m) and T is the rainfall duration (min).

(e) The rain garden area:

$$A_f = \frac{V \cdot d_f}{n \cdot d_f{}^2 + (1 - m\big) h_m \cdot d_f + 60K \cdot T \cdot (d_f + h)}, \tag{6}$$

Table 1. Parameters selection and reference of Equations (2)–(5).

Parameters	Value	SU	Reference
n	0.3	-	[29]
d_f	0.25	m	Section 2.6
m	0.2	-	[30]
h_m	0.2	m	Section 2.6
K	1.5×10^{-6}	$m \cdot s^{-1}$	laboratory test
h	0.1	m	half of h_m
T	120	min	[31]

2.3. Water Sample Collection

The rain garden was constructed in August 2016. The inlet and outlet of the rain garden were monitored during the period from September 2016 to January 2018. Water quality and flow sampling points were set up at the inlet and the perforated under-drain pipe of overflow well. Automatic flow-monitoring equipment was used to collect data, which will help determine the detailed hydrological and water quality processes at the rain garden.Data collected included runoff volume and discrete samples for water quality. In a whole rainfall event, according to the duration of rainfall, the sampling intervals were 5, 10, 15 and 20 min until the flow was very small or non-detectable. The water quality samples were tested for total nitrogen (TN), nitrate (NO_3-N), ammonium (NH_3-N), total phosphorus (TP), chemical oxygen demand (COD) and total suspended solids (TSS). Sample testing was undertaken according to the test methods specified in the Standard Methods for the Examination of Water in China [32–36].

2.4. Data Analysis

During each rainfall event, the cumulative mass of pollutants in the inflow and outflow were calculated by taking the integral of the product of concentrations and flow rates, as shown in Equation (7). If the value was positive, it meant that the system retained pollutant mass. If the value was negative, it meant the system exported/leached pollutant mass. To undertake the detailed investigation of the treatment performance, the removal efficiencies of pollutant load and the even mean concentration (EMC) reduction were both calculated, as shown in Equations (8) and (9):

$$\text{Total pollutant mass } = \int_0^t C(t)Q(t)dt, \tag{7}$$

$$\text{Pollutant load removal } \% = \left[1 - \frac{\int_0^t C_{out}(t)Q_{out}(t)dt}{\int_0^t C_{in}(t)Q_{in}(t)dt}\right] \times 100\%, \tag{8}$$

$$\text{Pollutant EMC reduction } \% = \left[1 - \frac{\int_0^t C_{out}(t)Q_{out}(t)dt/V_{out}}{\int_0^t C_{in}(t)Q_{in}(t)dt/V_{in}}\right] \times 100\%, \tag{9}$$

where C_{in}(t) and C_{out}(t) are the influent or effluent concentrations of each pollutant at time t (mg·L^{-1}); Q_{in}(t) and Q_{out}(t) are the influent or effluent flow rates at time t (L·s^{-1}) and V_{in} and V_{out} are the influent or effluent volume (L). Limits of integration refer to time 0 (runoff initiation) and time t (time at which runoff ceases).

2.5. Storage Capacity and the Rain Garden Area

The rain garden was expected to not only alleviate the local flooding, but also effectively improve the water quality of a nearby landscape lake on campus. Figure 2 shows the photos of the site before, during and after the construction of the rain garden.

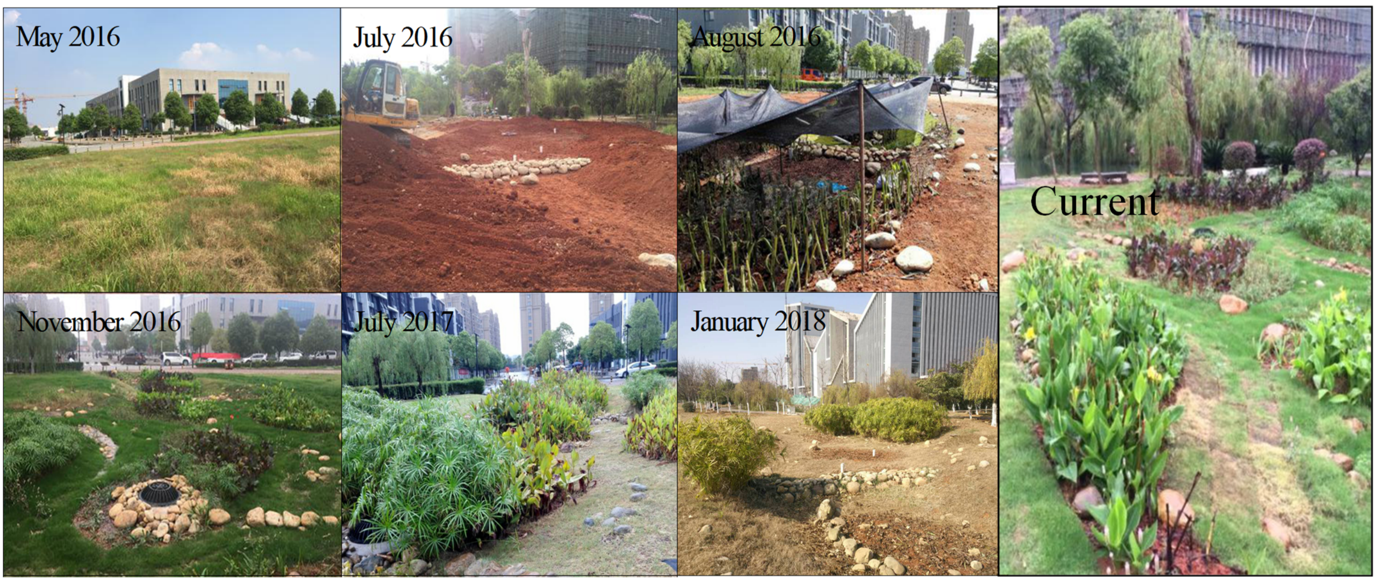

Figure 2. Pictures of the rain garden before, during and after construction.

The rain garden surface area required was at least 204.9 m^2 as calculated by Equation (5) when the design storage capacity was 54.78 m^3, calculated by Equation (1). A two-stage front pool was designed between the inlet and the rain garden (Figure 3), taking consideration of calculation results, terrain features of the site and creating some visual effects. The areas of the front pool No.1 and front pool No.2 were 15 m^2 and 64 m^2, respectively. The surfaces of the two-stage front pool were covered with turf, and the interior was filled with red soil only without a gravel drainage layer. The main function of the two-stage front pool was to provide preliminary runoff and erosion control. The filter media layer of the rain garden was filled with combination substrates. The outflow of the rain garden was collected by the PVC perforated pipe at the bottom and eventually flowed into the campus landscape lake.

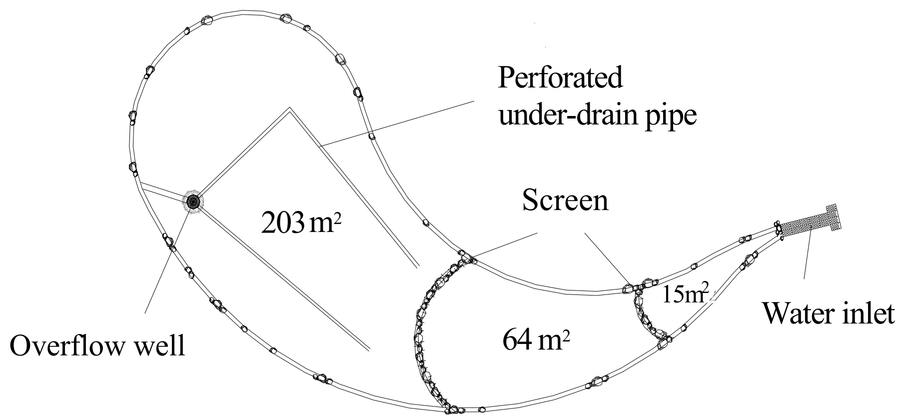

Figure 3. Plane layout of the rain garden.

Based on the design layout of the rain garden, a variety of plant communities were set up in the rain garden and the surroundings. Plants were an important part for the rain garden, which could retain water and certain pollutants. Native plants were the best choice in most cases since they were adapted for local environmental conditions and required less care. Additionally, plants should be able to tolerate periodic inundation. The principles of economic benefit, local conditions and diversity were followed and major plant species were chosen, such as *Canna generalis*, *Lythrumsalicaria*, *Cyperus alternifolius*, *Irispseudacorus* and *Miscanthus sinensiswere* [26].

2.6. Inlet and Cross-Section Design of the Rain Garden

Inlet design is a critical part of a rain garden. When the road elevation is higher than the surface of the rain garden, road runoff would flow into the rain garden and be tested. For the Nanchang site, the minimum elevation of the catchment area was 19.0 m, where catch-basins were available to collect road runoff. After the transformation (Figure 4), when the rainfall was light, road runoff could be completely collected by the rain garden.

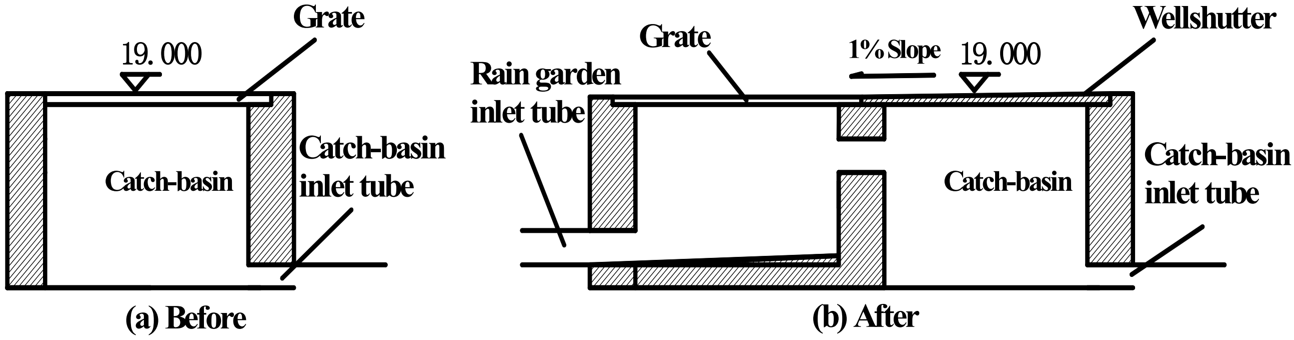

Figure 4. Before and after the inlet reconstruction.

The rain garden had some specific design features that would enhance runoff infiltration and temporary storage in underlying soil layers, which would help reduce both the total runoff volume and its peak flow [37,38]. As the elevation of the landscape lake was 17.65 m, which was 1.35 m lower than the inlet. It was necessary to strictly control the structural thickness of the rain garden. Details of the design features are shown in Figure 5. It should be noted that the design of the rain garden requires attention to the following points.

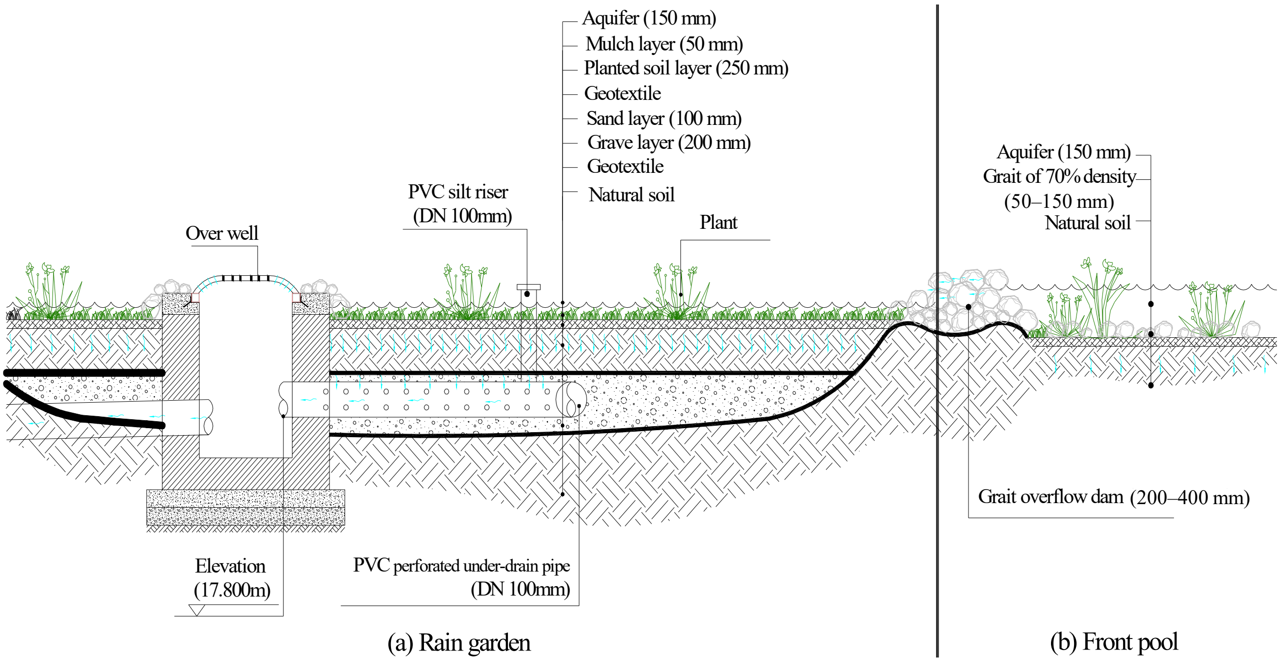

Figure 5. Section structure of the rain garden.

(a) The aquifer was mainly for storage runoff and precipitation of TSS.
(b) The mulch layer was covered with bark of 50 mm deep, which could maintain soil moisture [22,39]. Moreover, a suitable microbial environment was built between the bark and soil layer, which was propitious to the microorganisms on the degradation of organic matter and reduce runoff erosion of the topsoil.
(c) The filter layer required good permeability to provide a suitable growth environment for plants. Its depth depended on the type of soil and plants. When herbs were used, its depth was about 250 mm. As the clay content of red soil was above 40%, its permeability coefficient was only 1.5×10^{-6} m·s^{-1}. Runoff could not infiltrate as soon as possible or might even spillover if red soil was used as the planting soil without being amended. Therefore, the filter media layer was filled with a mix of 30% sand, 10% compost and 60% red soil as combination substrates, which provide better osmotic properties and organic matter. The permeability coefficient of the amended media layer was determined to be 1.48×10^{-5} m·s^{-1}.
(d) The sand filter layer, with a depth of 100 mm, prevented the soil substrate from sinking and blocking the perforated drain.
(e) The gravel drainage layer was 200 mm in depth. There were two perforated under-drain pipes, 150 mm in diameter with a drilling diameter of 15 mm to 20 mm [40,41]. The perforated pipes were used for the timely discharge of the filtered water. The particle size of the gravel was 20–30 mm, which was greater than the perforation aperture. The middle of the perforated under-drain pipe had a 100 mm-diameter silt riser, which was used to regularly remove sediment in the perforated under-drain pipe.

3. Results and Discussion

Impermeable surfaces in urbanized environments accelerate surface water runoff during rainfall events, decrease infiltration [42], reduce aquifer replenishment and degrade the water quality of aquatic ecosystems receiving pollutant-laden rain runoff, thus accelerating the issue of water pollution further [43]. Urban stormwater runoff represents a great challenge to modern water pollution management [44,45].

3.1. Runoff Reduction and Pollutant Removal

Ten rainfall events were monitored to determine the characteristics of the stormwater runoff entering the rain garden facility and evaluate its performance in terms of pollutant removal and volume reduction. Rainfall depth ranged between 6.3 and 30.9 mm with a mean value of 19.2 mm.

In particular, the planting media thickness and soil porosity in the rain garden were significant indicators of overflow in native soils with lower seepage rates [14]. Based on monitoring ten rainfall events, the rain garden had a good retention capacity and there was no overflow during the monitoring period, indicating that the rain garden worked well. The data matrix on runoff control is given in Table 2.

Table 2. Runoff reduction and pollutant removal efficiency data for every rainfall event.

Rainfall Event	Rainfall/mm	Runoff Reduction/%	EMC Reduction/%						Load Removal/%					
			NH_3-N	NO_3-N	TN	TP	COD	TSS	NH_3-N	NO_3-N	TN	TP	COD	TSS
2016.09.11	11.3	78.5	43.8	44.0	35.7	59.8	6.9	35.6	86.8	86.5	85.9	90.8	80.5	86.0
2016.10.22	26.6	71.5	13.1	−22.5	−58.9	−4.1	9.6	73.9	75.2	65.1	54.7	70.3	74.2	92.6
2016.11.23	6.3	85.6	52.6	−93.7	40.9	70.4	−58.5	59.3	93.2	38.1	91.5	95.7	77.2	94.1
2016.12.21	10.5	64.2	−0.6	3.5	−6.8	14.1	46.3	68.7	64.0	65.6	61.8	69.3	80.8	88.8
2017.03.12	22.6	87.3	33.7	−7.4	−13.1	−21.4	55.1	89.5	92.0	83.1	84.6	82.9	92.0	98.5
2017.04.09	23.5	83.6	19.9	14.1	42.0	61.7	14.7	92.6	86.8	85.9	90.5	93.7	86.0	98.8
2017.05.08	22.5	80.5	−7.9	−43.8	−62.4	−4.4	36.4	83.3	78.9	71.9	68.3	79.6	87.6	96.8
2017.06.06	30.9	81.8	47.4	44.0	27.6	27.6	−159.6	87.8	90.4	89.8	86.8	86.8	52.7	92.3
2017.11.17	27.3	87.7	7.5	32.3	−90.5	29.4	−104.4	55.6	94.9	96.3	90.8	96.0	90.5	97.2
2018.12.14	12.2	68.6	68.8	77.7	68.1	−16.6	23.8	36.3	90.2	93.0	90.0	63.4	76.1	80.0
max	30.9	87.7	68.8	77.7	68.1	70.4	55.1	92.6	94.9	96.3	91.5	96.0	92.0	98.8
min	6.3	64.2	−7.9	−93.7	−90.5	−21.4	−159.6	35.6	64.0	38.1	54.7	63.4	52.7	80.0
mean	19.2	78.9	27.8	4.8	−1.7	21.6	−13.0	68.3	85.3	77.5	80.5	82.9	79.8	92.5
SD	8.5	6.6	21.4	37.6	44.6	28.1	56.7	17.2	7.5	13.9	11.3	9.8	7.8	4.6

Overall, the total runoff control rate ranged from 64.20% to 87.70%, and the average runoff control rate was 78.9%, which achieved the Sponge City Construction Standards for Nanchang [31]. Field performance assessment demonstrated that this rain garden effectively cut inflow volumes through the filter media. This has important implications for the management of urban waterways, where increased flows are a key stressor [38].

The rain garden had the best removal efficiency for TSS, followed by NH_3-N, TP and TN. TSS, TP and nitrogen showed different removal characteristics, which could be attributed to different treatment mechanisms [7,46,47]. Rain gardens can remove nutrients and hydrocarbons from stormwater via several mechanisms [7]. Nutrients are removed by several mechanisms: filtration, adsorption, sedimentation, ion exchange, chemical precipitation, biological decomposition and plant uptake [12]. Pollutants such as TSS and TP would be primarily removed by physical processes while nitrogen would be primarily removed by biochemical processes, such as denitrification [15]. TSS was removed via the physical filtration of the particulates and colloids during percolation through the filter media. The rain garden was consistently effective in removing TSS irrespective of the rainfall sizes, runoff volumes and influent loads' amounts and treatments [23]. The rain garden was effective at treating phosphorus regardless of soil type [12].TP removal efficiency was highly dependent on the filter media. The red soil was effective in TP reduction since the content of phosphorus in red soil was relatively low. Moreover, the red soil contained a large amount of Fe_2O_3 (amorphous iron oxide), Al_2O_3 (aluminum oxide) and kaolinite, which were conducive to the adsorption and fixation of TP [48–50]. The red soil had four kinds of parent materials; details of them are shown in Table 3 [51].

Table 3. Parent materials of red soil and its compositions proportion.

Parent Material	Quaternary Red Clay	Granite	Arenite	Pelite
Proportion of red soil/%	4.1	17.1	11.6	13.2
Organic matter/%	0.7	1.4	0.9	1.5
TP/%	0.06	0.09	0.06	0.06
SiO_2/%	73.3	44.6	71.7	73.3
Fe_2O_3/%	5.7	13.7	7.0	6.6
Al_2O_3/%	15.7	37.4	17.4	16.4
Kaolinite/%	38.6	43.7	38.9	32.1

The removal efficiencies of nitrogen and COD in the rain garden fluctuated greatly. The water quality pollutant-load reduction fluctuated, which was consistent with relevant research results in bioretention tanks [52]. Soil media and plants played a vital role in the pollutant removal processes of rain gardens [7]. Plants were significant to treatment after media saturation. The extent of plants that assimilated pollutants was largely dependent on root structure, runoff detention time and the ability of plants to acquire pollutants from the media [5,30,53]. It was noteworthy that Table 2 also showed negative values for pollutant reduction percentages, particularly for EMC reduction inNO_3-N, TN and COD. This explained the occurrence of nutrient leaching which could be attributed to the flushing of runoff retained in the filter media layer from the preceding rainfall event containing elevated pollutants due to the evapotranspiration. Furthermore, nutrients presented in the rain garden could also contribute to pollutant leaching. Various plant-based mechanisms and chemical processes such as adsorption, reduction, sedimentation, cation-exchange capacity, complexation and so forth were involved in the removal of contaminants from stormwater [7].

The removal efficiency of pollutant load for NH_3-N, NO_3-N, TN, TP, COD and TSS increased by 57.4%, 72.7%, 82.2%, 61.2%, 92.7% and 24.2% compared to EMC reduction separately. The removal efficiency of the pollutant load was generally higher than the EMC reduction. This might be due to the fact that runoff volume control was taken into consideration in the calculation of pollutant load removal. In addition, the concentration of pollutants of campus runoff was generally lower than that of urban roads and parking lots, resulting in less obvious EMCs removal efficiency of the rain garden. It could be observed that there were wide differences in the efficiencies of pollutants' removal among different rainfall events due to a number of factors such as plants, rainfall patterns and soil condition [25]. The removal effectiveness had been shown to be reliant upon the rainfall patterns (e.g., length of wet and dry weather) and temperature [54,55].

3.2. Time Variation of Pollutant Concentrations

In order to discuss the migration of runoff pollutants in the rain garden, the variation in concentration of each pollutant with the change in time was analyzed by sampling data from 10 January 2017 (Figure 6). The average residence time between the start of the influent and the appearance of effluent was approximately 100 min, which included the total flow-through time in the two-stage front pool and the infiltration time in the rain garden.

As shown in Figure 6, the concentration of pollutants varies with rainfall time and showed some common characteristics, and each concentration of inflow pollutants decreased with rainfall duration and finally tended to flatten out, which was due to the initial scouring effect. The concentrations of these pollutants were higher before inflow in the early 20 min, and the pollution of rain water was more serious at the initial stage. The pollutant load was always heavy in the initial stage of the runoff [9]. There were significant fluctuations in the concentration of outflow pollutants except for TSS, which was due to different degrees of the initial scouring effect of different pollutants [56]. The fluctuations in the outflow were generally lower than those in the inflow.

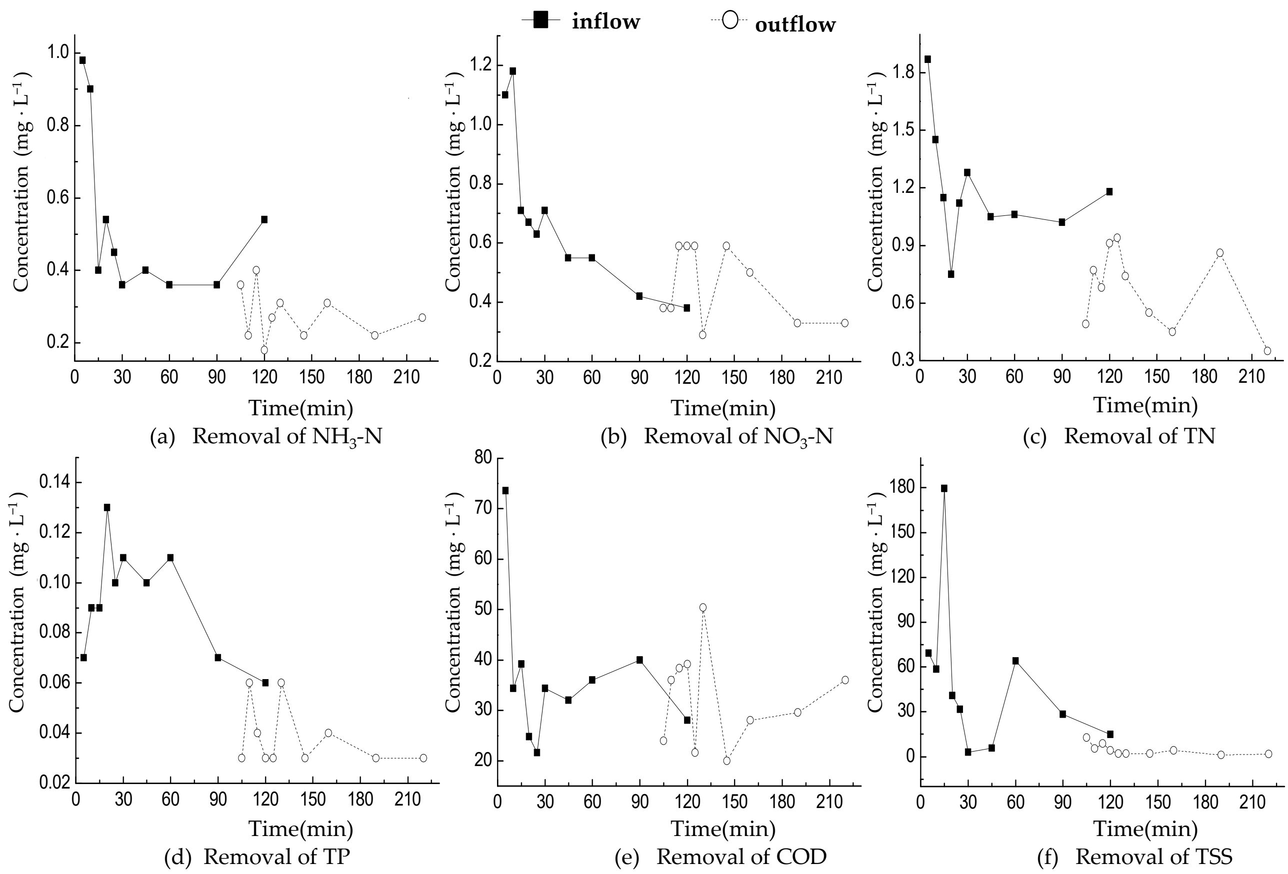

Figure 6. The time-variation of pollutant concentrations in inflow and outflow.

The average concentrations of NH_3-N, TN, TP and TSS in the outflow were relatively good, and the concentration of these pollutants decreased gradually and then tended to be stable. After adsorption and filtration by the rain garden, the concentrations of NH_3-N in the outflow were relatively steady, for the optimal sponge had an excellent treatment effect on NH_3-N in rainwater while ensuring rapid infiltration [57]. The concentrations of NO_3-N and COD in the outflow were unstable, and greater concentrations appeared in the early stage of the outflow. The concentrations of NO_3-N and TN fluctuated, which was related to the fact that the removal of NO_3-N in the rain garden was easily affected by various factors, and nitrogen retention may have occurred there [12]. Because NO_3-N is a part of TN, the fluctuation of the concentrations of NO_3-N will also cause the concentrations of TN fluctuate to some extent.

Among the water quality indicators, the COD concentration fluctuated the most. The concentrations of COD in 30 min decreased gradually before inflow, and the average concentration of COD was 25.30 mg·L^{-1} in the later stage of inflow. Even the COD concentration in the effluent was higher than that in the influent at the initial stage of operation. This was due to the poor stability of the rainwater garden at the initial stage of the operation. The microbial activities and organic secretions released by the plant roots in the rainwater garden system entered the effluent, resulting in a higher COD concentration in the effluent.

Despite variation in inflow concentrations, pollutant concentrations in the effluent were relatively constant, although an initial spike was sometimes observed forNO_3-N, and COD. It could be seen that the range of outflow pollutant concentrations were lower compared to the inflow concentrations, suggesting a level of reliability in treatment [38].

3.3. Limitations or Directions for Further Research

Rain gardens can retard surface runoff, reduce and delay flood peaks effectively and play a major role in rehabilitating the water cycle. The control effects of rain garden on pollutants could be improved by by-passing some initial runoffs.

Although stormwater cannot be treated completely without conventional sewage systems in urban areas, rain gardens can decrease the dependence on these. Stormwater infiltration and redistribution by rain gardens are also potentially significant ecosystem services and impart value to vacant land that presently has little or no value [58].

This is the first study presenting treatment performance results on rain garden in red soil area of Nanchang city at the field-scale. Ultimately, the results of this paper provide key insights into the design and operating conditions of rain garden, especially for the future reliable treatment of stormwater. However, in order to fully validate the rain garden studied, long term operational monitoring needs to be put in place to provide assurance that Sponge City construction planning and design objectives are being continuously met. More data will be obtained with auto-sampling, which is typically necessary for performance monitoring and maintenance. A large set of additional data may be provided for further simulation and model analysis, and finally for the development of a validation framework for stormwater treatment systems.

4. Conclusions

In this study, the special features in the design of a rain garden and the modification of the filter media layer play an important role in the field performance of a rain garden in a red soil region. Rainfall characteristics and catchment partition were important parameters in designing the rain garden. The construction of rain gardens in red soil regions, such as Southern China, should pay close attention to the permeability of the filter media layer and the architectonics of the rain garden.

The average runoff control rate obtained by this study was 78.9%, which achieved the Sponge City Construction Standards for Nanchang. The efficiency of runoff pollutant load removal generally was higher than the EMC reduction rates. The rain garden showed the best removal in TSS, followed by NH_3-N and TP. Under the same average recurrence interval (ARI) the mean load removal of TSS, NH_3-N, TP, TN, COD and NO_3-N were 92.5%, 85.3%, 82.9%, 80.5%, 79.8% and 77.5%, respectively. The red soil was effective in TP reduction. On the other hand, the removal efficiency of NO_3-N, TN and COD were negative at times, showing pollutant leaching.

The results of the study indicated favorable storage/infiltration functions in the field performance of this rain garden, the potential to control more than 70% of storm runoff and its effectiveness at pollutants' load removal. The results of this study could provide a good reference for the construction of rain gardens in a red soil region. Therefore, the application of this rain garden may be recommended in other red soil urban areas.

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