Study on the Reduction Effect of Bioretention Facility on Typical Heavy Metal Pollutants in Rainfall Runoff

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Abstract: This paper studied the effect of different inflow water, heavy metal (Cu, Zn, Cd) concentration and rainfall interval on heavy metal reduction in bioretention facility. The results showed that the removal ability of heavy metals was different among the three bioretention facilities, and the removal effect of Cu was the best, while the removal effect of Cd was not stable. High inflows reduce the reducton efficiency of heavy metals in bioretention facilities. The concentration changes of heavy metals in influent did not significantly change the reduction efficiency. After comprehensive comparison, it was found that the bioretention facility with (sand + fly ash) as filler had the best reduction effect on heavy metals, and the removal rate reached 88%. The research results can provide basic data support for the design and application of bioretention facility.

1 INTRODUCTION

Bioretention facility is an efficient and low-impact development technology (LID) (Wu, 2006) that integrates landscape, water quality purification and rainfall runoff control. Some researchers have carried out relevant research on the reduction effect of bioretention facility (Zhang et al., 2021; Zhou, 2021), structural improvement (Pan et al., 2020), matrix combination (Chen, 2020), filler type (Zhang et al., 2020; Ellis et al., 1987) and some research results have been achieved on the reduction effect of nitrogen and phosphorus pollutants. However, there are still problems about the stability and efficiency of the technology, resulting in the reduction effect of the technology in the application is often not high. Especially, there are few studies on the mechanism of heavy metal reduction. In the actual rainfall runoff process, rainfall intensity, influent heavy metal concentration and rainfall interval are also the key factors determining the bioretention facility, which directly affect the reduction effect of heavy metal ions by bioretention facility. Based on the above background, this paper uses simulated rainwater pollution to study the removal effect of different bioretention facility fillers on heavy metals in runoff and its influencing factors, in order to provide reference for the design and optimization of bioretention facility.

2 RESEARCH METHOD

2.1 Bioretention Facility System

The biological retention facility is shown in Figure 1, the size of the bioretention facility in this experiment was 2.0m in length × 0.5m in width × 1.0m in depth, and poplar and ryegrass were planted in the facility. Each device from top to bottom are water storage layer (10cm), planting soil layer (30cm), artificial filler layer (60cm). Permeable geotextile is laid between each filler medium. Perforated drainage pipe is located at the bottom of the filler layer, and the drainage pipe is wrapped by geotextile. Three bioretention facilities (1#, 2# and 3#) were set up in the experiment. There were only differences in the artificial filler layer. The artificial filler layer was sand + fly ash (volume ratio of 1:1), sand + green zeolite (volume ratio of 1:1) and planting soil (Lin & He, 2019).

2.2 Condition Setting of Test Parameters

The effects of inflow rate, heavy metal (Cu, Zn, Cd) concentration and rainfall interval on the reduction of heavy metals in the system were investigated. The inflow flow is reflected by the difference of rainfall intensity, and other parameters (pollution

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concentration is low, rainfall interval is 7days) are consistent. The rainfall intensity is determined by the rainstorm intensity formula (1) and the catchment area of bioretention facilities in Xi'an. The designed bioretention facility consumes 3 times of its own surface area. The water calculation results are shown in Table 1, and the rainfall intensity is determined according to the road runoff monitoring results and existing research (Chen et al., 2012; Dong, 2013).

$$q=\frac{2785.833\times(1+1.1658\lg P)}{(t+16.813)^{0.9302}}$$

$$Q_s=q\varphi F$$

Formula:

q is the design rainstorm intensity [L / (s·hm^2)].

P is the design recurrence period. T is rainfall duration.

Qs is designed for rainwater flow (L/s).

ø is the runoff coefficient.

F is catchment area (hm^2).

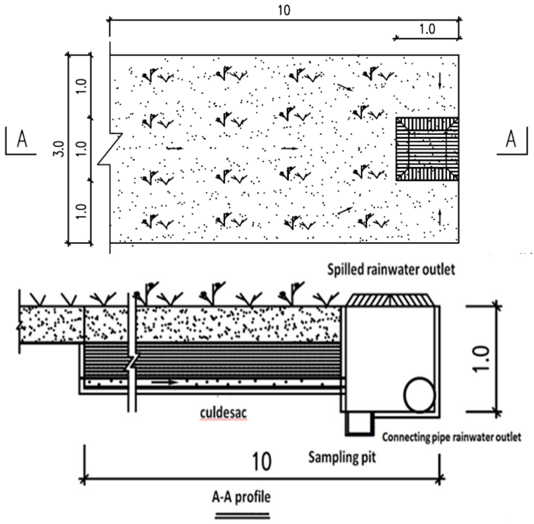


Figure 1: Schematic diagram of bioretention facilities.

Table 1: Water Quantity Calculation Table.

return period P/a	duration of rainfall t/min	rainfall intensity q/(L/s.ha)	runoff coefficientφ	catchment area F/ha	designed discharge Qs/(L/s)	design flow V/L	Rainfall mm
5	120	52.0922	0.9	0.0017	0.0798	573.7561	33.67
2	120	38.7762	0.9	0.0017	0.0594	427.2015	25.08
0.5	120	18.6300	0.9	0.0017	0.0287	205.3210	12.11

The concentration of heavy metals remained constant during simulated rainfall. Cu, Zn and Cb were selected as typical heavy metals with the highest detection frequency and concentration in Xi'an rainfall runoff process. The concentration of heavy metals was set according to the monitoring of pollutants in Xi'an rainfall (Guo, 2015; Davis et al., 2009). The concentration of heavy metals included high and low concentrations. When the rainfall interval is 7 days and the monitoring period is 5 years, the concentrations of three heavy metals were Cu ($CuCl_2·2H_2O$), 0.1mg/L and 0.05mg/L. Zn ($ZnSO_4·7H_2O$), 1.5mg/L and 0.8mg/L. Cd ($CdCl_2·2.5H_2O$), respectively.0.05 mg/L and 0.03 mg/L. The rainfall interval was set to 3d, 5d and 7d, the concentration of heavy metals was set at low concentration, and the rainfall intensity was 2a.

2.3 Analysis Methods and Evaluation Criteria of Heavy Metals

The concentration of heavy metal ions was determined by flame atomic absorption spectrometry (AAS), and the instrument was AAS Zeenit 700 atomic absorption spectrometer. The purification effect of bioretention facilities is quantitatively analyzed, and Ri represents the removal rate. The calculation formula is as follows:

$$R_i=\frac{C_0-C}{C_0}\times100\%$$

Formula:

C_0 is influent pollutant concentration, mg/L.

C is effluent pollutant concentration, mg/L.

3 RESULTS AND ANALYSIS

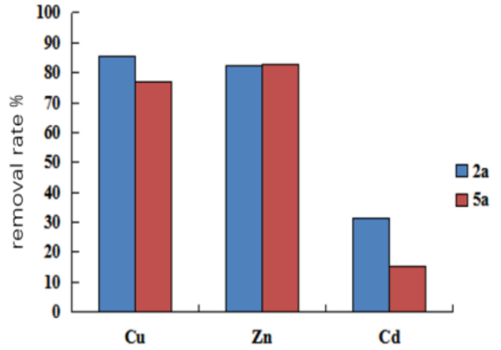
3.1 Influence of Inflow Water on Heavy Metal Reduction Rate of Biological Retention Facilities

The influence of biological retention facilities on heavy metal reduction under different influent conditions is shown in Figure 2, under the rainfall conditions corresponding to the 2a and 5a return periods, the increase of inflow flow reduced the reduction efficiency of heavy metals in the three types of bioretention facilities, and the reduction efficiency of the three heavy metals under different inflow flow conditions showed Cu>Zn>Cd. Under the two inflow conditions, the reduction efficiency of Zn changed little, while the reduction efficiency of Cu and Cd changed significantly, and the reduction efficiency of the system decreased under large flow conditions. This may be due to the increase of inflow water, the hydraulic retention time in the bioretention facilities, becomes shorter, and large water will wash out the heavy metals adsorbed by the biological retention matrix filler, resulting in the increase of the concentration of heavy metal pollutants measured in the effluent.

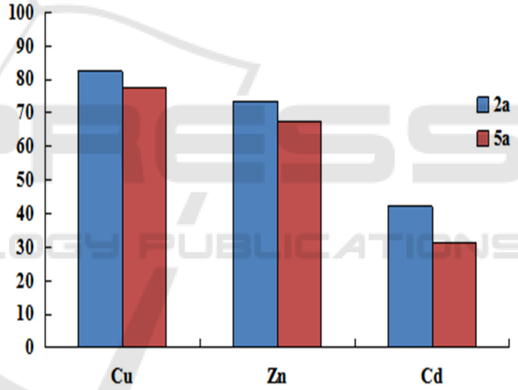
In the two-year return period, the removal rates of Cu (>80%) in the three bioretention facilities were higher than those in the other two heavy metals. The Cu and Zn reduction efficiency of 1 # bioretention device is higher. The removal rate of Cd was obviously low. Davis proved through a series of experimental studies that the type of matrix filler in bioretention facilities had a great impact on the removal effect of heavy metals, mainly because the physical and chemical properties of matrix fillers were different, and the removal effect and mechanism of heavy metals were also different.

3.2 Effect of Influent Heavy Metal Concentration on Heavy Metal Reduction in Three Bioretention Facilities

Under different concentrations of heavy metals, the removal efficiency of heavy metals by bioretention facilities with three kinds of fillers is shown in figure 3. In the 1 # bioretention facility, the reduction efficiency of Cu and Zn was more than 70%, while the reduction efficiency of Cd was significantly lower (about 15%). The reduction efficiencies of Cu, Zn and Cd in device 2# were significantly different from those in device 1#, and the reduction rates from high to low were Cu> Zn>Cd. The distribution of heavy metal reduction efficiency in 3# plant is similar to that in 1# plant. The reduction efficiency of Cu and Zn is significantly higher, while the reduction efficiency of Cd is 17-25%. Under the condition of high concentration influent, the reduction efficiency of heavy metals by bioretention facilities was slightly lower than that under low concentration influent, which may be mainly related to the adsorption rate of fillers. When the concentration of heavy metal ions in the influent is high, the filler cannot adsorb all metal ions, so there will be a large number of unabsorbed metal ions discharged from the detention facilities with the effluent. Comprehensive three types of bioretention facilities can be concluded that the reduction efficiency of 1# and 3# devices is higher, and the reduction effect of 3# on Cd is obvious.



(a) 1#



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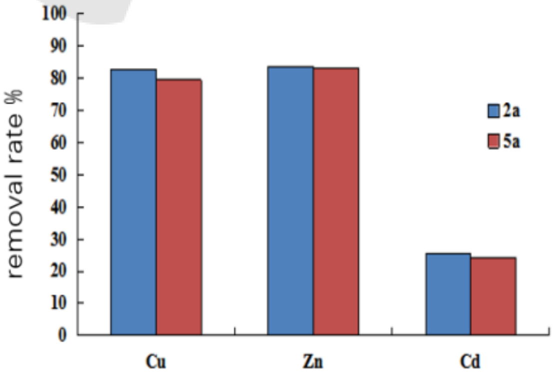
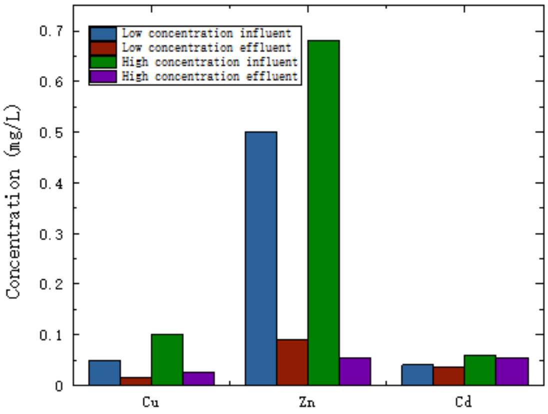


(c) 3#

Figure 2: Effects of three bioretention facilities on heavy metal reduction under different inflow conditions.

3.3 Effect of Rainfall Interval on Heavy Metal Reduction by Three Bioretention Facilities

The reduction efficiency of heavy metals in bioretention facilities with three fillers is significantly different under different rainfall intervals, as shown in Figure 4. The removal rate of Cd in the three bioretention facilities had no significant change with the increase of rainfall interval time, and the reduction effect was maintained at 15-25%, indicating that the length of rainfall interval had little effect on the purification effect of heavy metal Cd. The difference is that the removal rates of Cu and Zn in the three bioretention facilities have a relatively obvious change trend with the rainfall interval. The reduction efficiency of Cu in 1# device increases with the increase of the interval, and the reduction efficiency can reach 88% at the interval of 15 days, while the reduction efficiency of Zn in different rainfall intervals is not obvious, reaching the highest at 7 days. Cu and Zn reduction efficiency of 2# device increased with the increase of rainfall interval, and reached the maximum reduction efficiency at 15d. The reduction efficiencies of Cu and Zn in device 3# were like those in device 1#, and the maximum reduction rate of Zn (about 90%) appeared in the rainfall interval of 7d, while the reduction rate of Cu did not change basically in the rainfall interval > 7d, and the optimal reduction rate could reach 80%. Based on the results of three types of bioretention facilities in different inflow rates, influent concentrations, and rainfall intervals, it can be concluded that the bioretention facilities of 1# (sand + fly ash) artificial substrate have better reduction efficiency and stability for heavy metals.



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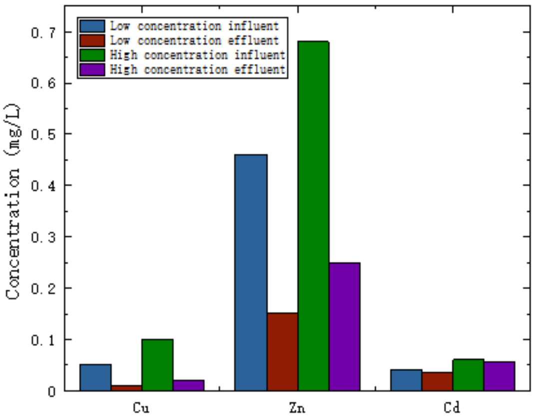

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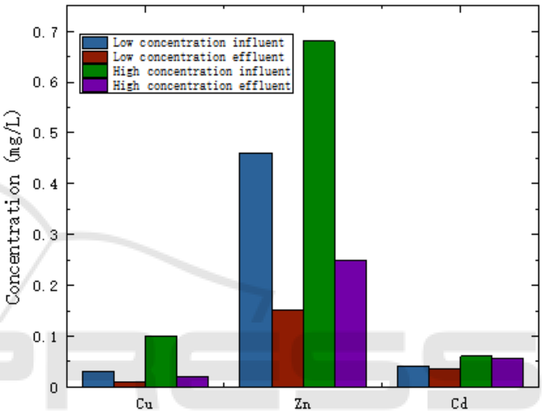

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Figure 3: Effects of three bioretention facilities on heavy metal reduction under different heavy metal concentrations.

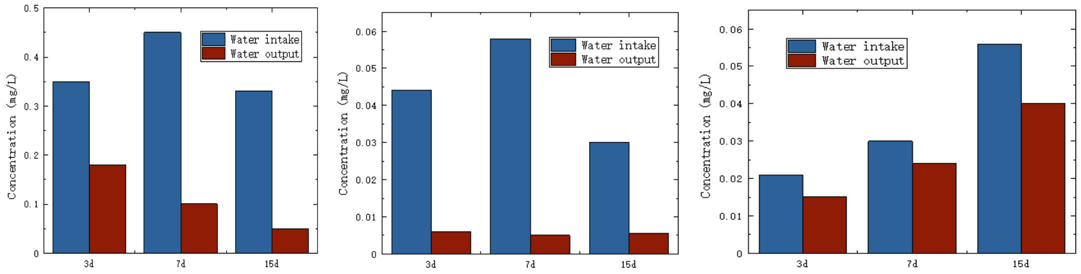
4 CONCLUSIONS AND SUGGESTIONS

(1) Bioretention facilities with different fillers have different reduction effects on three typical heavy metals. In the three types of systems, the reduction effect of heavy metals from high to low is Cu>Zn>Cd, and the reduction efficiency of Cu and Zn is more than 70%, while the reduction efficiency of Cd is significantly lower, and the efficiency is less than 30%.

(2) Inflow rate, influent heavy metal concentration and rainfall interval affected the reduction effect of bioretention facilities on heavy metals. Compared with the case when the rainfall return period was 5a, the bioretention facilities had higher purification efficiency for heavy metals when the rainfall return period was 2a. The increase in the concentration of heavy metals entering the

bioretention facilities will increase the metal content in the effluent of the system, but the overall reduction efficiency of the system is not significantly affected. Higher rainfall intervals contribute to more Cu and Zn reductions, while the reduction efficiency of Cd fluctuates less in different intervals.

(3) The reduction effect of three types of filler bioretention facilities on heavy metals from high to low was 1#>3#>2#, indicating that sand + fly ash as artificial matrix has better stability for heavy metal reduction in bioretention facilities.



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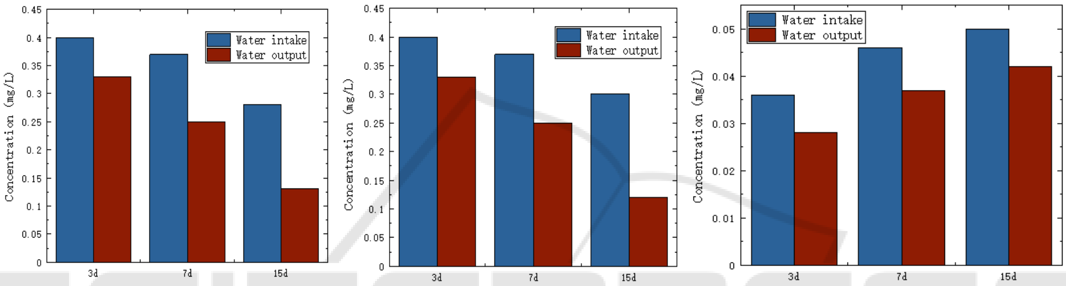

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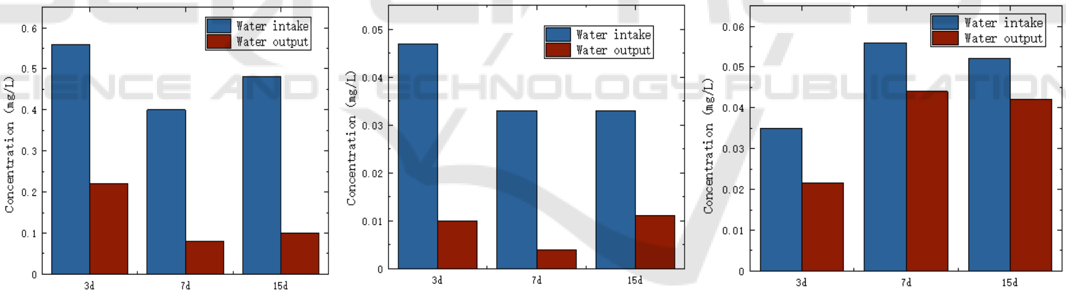

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Figure 4: Effects of three bioretention facilities on heavy metal reduction under different rainfall intervals.

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