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The application of green roof for stormwater quantity and quality improvement

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The application of green roof for stormwater quantity and quality improvement

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Abstract. The use of green roof is becoming increasingly worldwide because of its environmental, economic, and aesthetic benefits. The ability to retain storm water and improve the quality of effluent flow are the important characteristics of green roof. It is viewed as a best technology to minimize the negative impact of urbanization. However, the application of green roof in Malaysia is less and literatures regarding these is limited. An attempt has been made to evaluate the performances of green roof in improving the water quantity and quality of stormwater runoff. A lab-scale green roof with five component layers which are vegetation layer using creeping ox-eye and beach morning glory, topsoil substrate layer, non-woven geotextile filter layer, drainage plate layer and liquid waterproofing layer was used. Results indicated that the green roof with creeping ox-eyes shows a better performance in reducing peak flow with as high as 41% percentages of reduction compared to beach morning glory (15%). On the other hand, the green roof with beach morning glory manage to improve the concentration of COD up to 99% improvement while the green roof with creeping ox-eye shows a better performance in improving BOD with 17% reduction.

1. Introduction

In recent years, the growth of urbanization is expanding, with more than 50% of the world's population currently living in cities [1]. Cities continue to grow to accommodate increases in rural migration to urban areas [2]. The replacement of forests, grasslands, and croplands by impenetrable areas, such as buildings, and streets, significantly increases stormwater runoff and the impervious area. Thus, less water can be absorbed into the soil, and the frequency and severity of flooding in urban regions increase [3]. The urbanization process has also significantly increases the pollutant build-up at the catchment surface area [4]. Rain events cause domestic sewage, and industrial wastewater to be directed to the waterways around the city.

One of the solutions to these problem is by adopting stormwater management strategies. Developed countries had adopted stormwater manuals such as Low Impact Development (LID), Green Infrastructure (GI), Sustainable Urban Drainage System (SUDS) and Water Sensitive Urban Design (WSUD) for their stormwater management strategies [1]. In Malaysia, Urban Stormwater Management Manual for Malaysia (MSMA) was firstly introduced in 2001 as a guideline to adopt and design Best Management Practices (BMPs). Infiltration basin, swale and constructed wetland are the measures adopted in controlling stormwater in terms of quantity and quality to achieve least impacts of post-development. In 2012, MSMA second edition has included bio retention/bio filter into the revised manual [5].

Green Building Index (GBI) was launched in 2009 as an initiative to support the green movement initiated by Ministry of Energy, Green Technology and Water (KeTTHA). The GBI rating system was established jointly by Malaysian Institute of Architects and the Association of Consulting Engineers Malaysia (ACEM) [6, 7]. Rooftop garden is one of the green features that can contribute to Green Building Index (GBI) in Malaysia [8]. This is due to its effectiveness in reducing the impact of urban heat island, manage storm water runoff, reduce energy consumption through thermal comfort and enhance biodiversity through the preservation of habitat for animals such as birds and insects in urban areas. With sufficient green spaces in urban areas, it will improve the quality of urban environment and the effort towards sustainable urban development can be achieved. GBI is included in the GTMP 2017 - 2030 as the voluntary green building rating tools under building sector. Green Technology Master Plan (GTMP) is fundamentally an outcome of the Eleventh Malaysia Plan (2016-2020) which creates a framework which facilitates the mainstreaming of green technology into the planned developments of Malaysia while encompassing the four pillars set in the National Green Technology Policy (NGTP) i.e. energy, environment, economy and social. The GTMP focuses on six key sectors, namely Energy, Manufacturing, Transportation, Building, Waste and Water [9].
Green roofs in Malaysia are considered as a fairly new although lots of benefits are offered. Moreover, it was not featured in MSMA, although it is one type of BMPs as well. The application of green roof is less since only a few buildings in Malaysia practice the green roof construction on buildings [10]. Thus, it is an urge to study the performance of green roof as a stormwater management alternatives for environmental sustainability. Hence, with the aim to explore the capability of green roof, a study was conducted to design and evaluate the performance of a green roof system in reducing the rate of runoff and improving the water quality.

2. Methodology

The methodology to investigate the performance of green roof in improving water quantity and quality of stormwater runoff including the design of a lab scale green roof system, the selection of plant for vegetation layer and the observation of flow rate and concentration of pollutants before and after the green roof system is presented in this section.

2.1. Experimental set-up

Lab-scale prototype model was used and the experiments were conducted at Hydraulics and Hydrology Laboratory, Faculty of Civil Engineering Technology, University Malaysia Pahang. There are three model used in this study i.e. non-vegetated (control) and two vegetated green roof model. All models have dimensions of 0.47 m x 0.36 m x 0.30 m. Two types of vegetation i.e. creeping ox-eye and beach morning glory was used as shown in Figure 1. The layer of prototype model consists of five typical components which are vegetation layer of creeping ox-eye and beach morning glory, topsoil sub rate layer 50 mm, non-woven geotextile filter layer, drainage plate layer 40 mm and liquid waterproofing layer, as illustrated in Figure 2. Filter membrane was put between the soil medium and drainage layer to prevent the losses of soil medium along with runoff. Collecting tank were connected to the discharge point of the green roof prototype model system.

(a) (b)

Figure 1. (a) Beach morning glory and (b) Creeping ox-eye in vegetated green roof model.

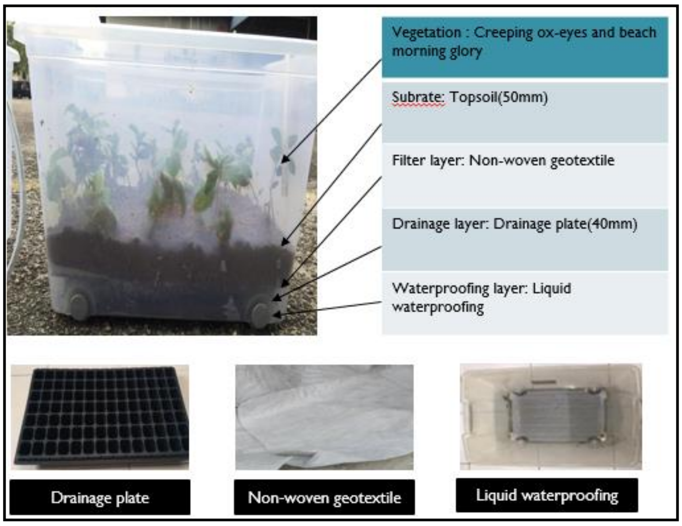

Figure 2. Components of green roof system.

2.2. Tested parameters

2.2.1. Water quantity. The performance of green roof system in reducing peak flow was observed in two events i.e. Event 1 and Event 2 with 100 mm/hr and 150 mm/hr simulated rainfall intensity respectively. 10 min duration design storm was applied for both events.

2.2.2. Water quality. The performance of green roof in improving runoff water quality was investigated based on the analysis of concentration of pollutant before and after the green roof system. A total of 15 water samples of runoff water were taken from two vegetated roof and one non-vegetated green roof prototype system (control) and then analyzed the Environmental Laboratory, Faculty of Civil Engineering Technology, University Malaysia Pahang. The tested parameters are BOD, COD and TSS.

3. Results and discussions

3.1. Water quantity improvement

Figure 3 and Figure 4 show the observed discharge of 10 minutes simulated storm for Event 1 and Event 2 respectively. The result shows that the vegetated prototype model managed to reduce the discharge where the peak flow for creeping ox-eye and beach morning glory is lower compared to the non-vegetated prototype model (control). From Figure 3, it can be seen that the peak flow of green roof with creeping ox-eye (13×10^{-6} m^3/s) is lower than the green roof with beach morning glory (20×10^{-6} m^3/s). The same trend of result is observed in Figure 4 where the peak flow of green roof with creeping ox-eye (13×10^{-6} m^3/s) is lower compared to the green roof with beach morning glory (17×10^{-6} m^3/s). This results show that the creeping ox-eye managed to retain more water during storm event compared to beach morning glory.

Figure 5 presents the comparison of flow reduction in percentages between creeping ox-eyes and beach morning glory. The highest flow reduction can be observed in Event 1 where the green roof with creeping ox-eyes manage to reduce the peak flow from 22×10^{-6} m^3/s to 13×10^{-6} m^3/s, which is 41% reduction. In Event 2, the green roof also shows a good performance where the flow reduction (35%) is higher compared to the green roof with morning glory (15%). In addition, it can be observed that the percentages of reduction for green roof with creeping ox-eyes in Event 2 (150 mm/hr rainfall intensity) is lower than Event 1 (100 mm/hr rainfall intensity). The result is in agreement with the study by Kok et al. [5] where the higher the rainfall intensity the lower the retention capacity capability for the vegetated model, thus generated lower flow reduction. In contrast, the reduction increase from 9% to 15% with the increasing intensity, for morning glory.

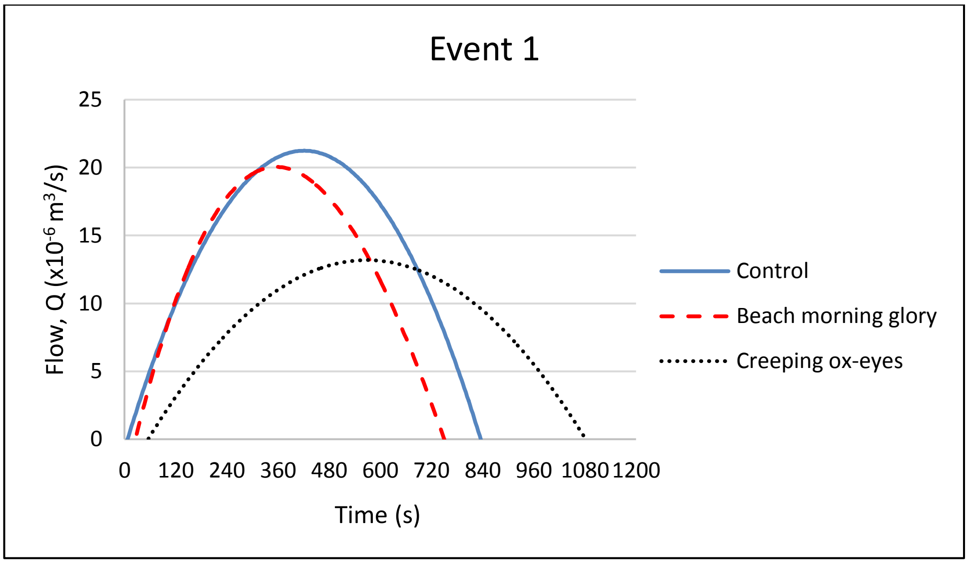

Figure 3. Peak flow comparison for Event 1.

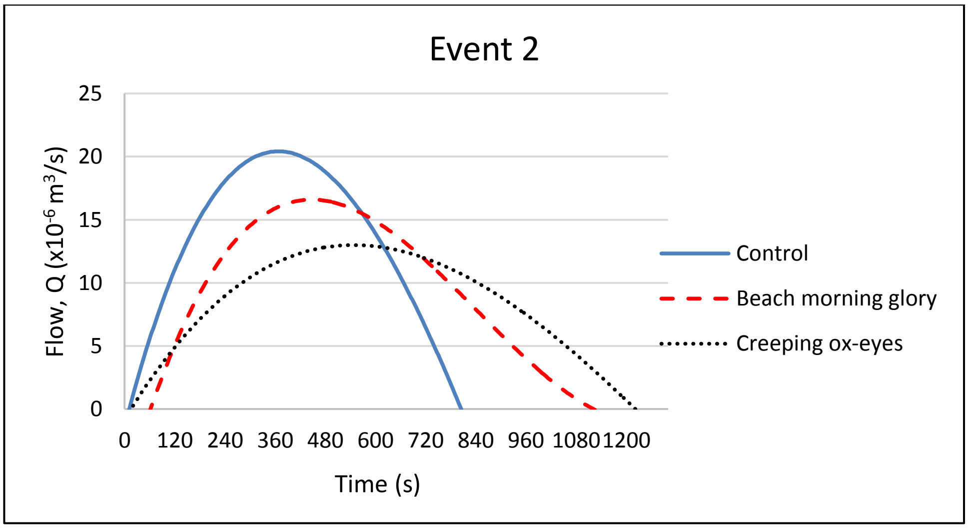

Figure 4. Peak flow comparison for Event 2

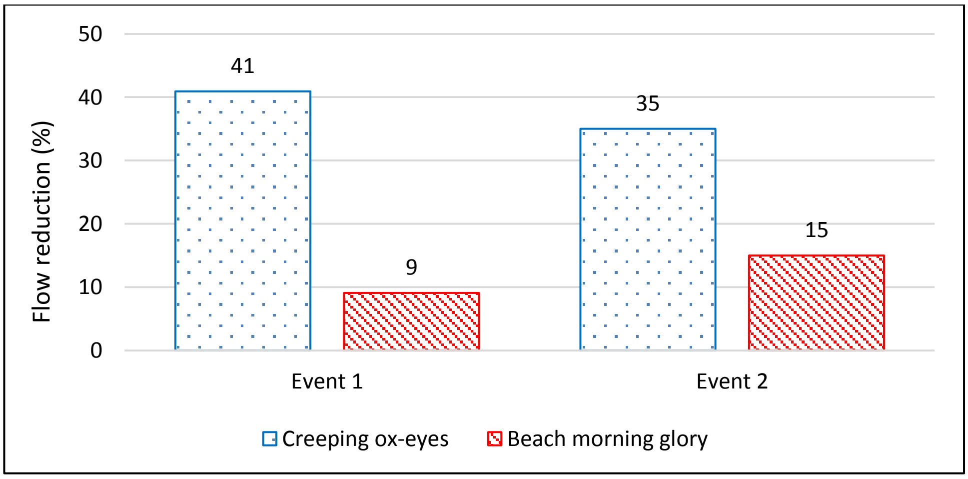

Figure 5. Comparison of flow reduction in percentages

3.2. Water quality improvement

The concentration of water quality before and after the green roof system is shown in Figure 6. Both green roof system with creeping ox-eye and beach morning glory is capable to improve the concentration of BOD and COD. Creeping ox-eye reduce concentration of COD from 23.67 mg/L to 18 mg/L while the green roof with beach morning glory manage to improve the concentration of COD to as low as 0.33 mg/L. On the other hand, the concentration of TSS increase from 13 mg/L to 87 mg/L and 40 mg/L for green roof with creeping ox-eye and beach morning glory respectively. The result indicates that the soil media may have a significant influence to the suspended solid content in the discharge water.

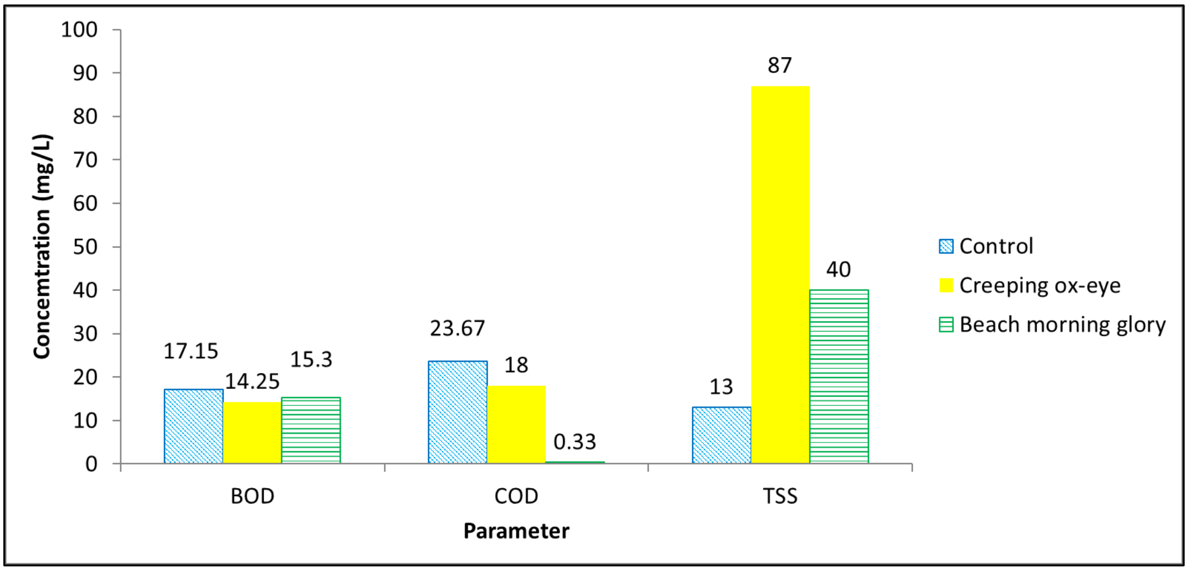

Figure 6. Comparison of concentration of water quality parameters after the green roof system

Table 1. Reduction of concentration of water quality parameters in percentages

Parameter	Reduction (%)	
	Creeping ox-eye	**Beach morning glory**
BOD	17	11
COD	24	99
TSS	0	0

The green roof with beach morning glory manage to reduce the concentration of BOD from 17.15 mg/L to 15.3 mg/L which is 11% reduction, as shown in Table 1. The percentages of reduction for parameter BOD is higher when green roof with creeping ox-eye was applied with 17% respectively. On the other hand, the green roof with beach morning glory capable to decrease the concentration of COD up to 99% reduction, compared to 24% reduction by creeping ox-eye. However, no concentration reduction for parameters TSS was detected for both green roof with creeping ox-eye and beach morning glory.

4. Conclusion

In conclusion, the green roof system shows a good performance in improving the water quantity and quality of stormwater runoff and capable to serve as an effective tool for storm water management. The green roof system managed to improve the stormwater runoff where the peak flow of vegetated model is lower than the non-vegetated model (control). The percentages of flow reduction for green

roof system with beach morning glory is 9% and 15% for event with 100 mm/hr and 150 mm/hr rainfall intensity respectively, while the reduction for green roof system with creeping ox-eye is higher which is 41% and 35% respectively. It can be concluded that green roof using creeping ox-eye is more effective in reducing flow with as high as 41% reduction compared to beach morning glory (15%).
The application of the green roof system managed to reduce the concentration of parameters COD and BOD with percentages of reduction up to 99%. The green roof with beach morning glory is excellent in reducing the concentration of COD (99%) compared to the green roof with creeping ox-eye (24%). The green roof with creeping ox-eye shows a better performance in reducing BOD where the percentages of reduction is 17% compared to the green roof with beach morning glory (11%).

5. References

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