Constructing Rain Garden Systems for Stormwater Quality Control under Tropical Climates

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Abstract. Malaysia has taken an integrated approach to manage storm water that is increasingly becoming a problem in big cities. Rain gardens are recommended as green technology for a new storm water management in Malaysia. The approach is applied in urban planning and design that integrates the total water cycle management into the development process areas. Rain gardens have been effective in reducing peak discharge and consistently reduce the number of storm water pollutants. This paper will examine some of guidelines, laboratory studies and field monitoring that shows great potential and benefit of rain garden. The preliminary results for rain garden performance were reported in this paper. The findings from this research will open avenues for researchers to advance the knowledge in rain garden systems to achieve the sustainable development in Malaysia.

1. Introduction
Rain garden systems or rain garden is a best management practice (BMP) introduced by Prince George’s County, Maryland in the year 1990s [4]. The initial rain garden system system design consisted of an excavated area backfilled with planting soil underlined by a thin layer of sand and planted with native grass, shrub and tree species. The basic rain garden system design has been modified in City of Alexandria, to include an underdrain within the sand bed to collect the infiltrated water and discharge it to a downstream sewer system [7]. In the landscape area, rain garden normally located at low points so runoff cans easily draining inside the systems. Rain gardens systems efficiently can remove pollutant from stormwater runoff by using the vegetation such as trees, shrubs and grasses or other native plants. Nowadays, rain gardens system has been implemented around the world as a popular technology for stormwater management [13]. Experts have confirmed that that rain gardens have a great potential in reducing peak flow, improve water quality in a natural process and give aesthetically pleasing manner [7].

Today, Malaysia economy has rapidly changed throughout the year. Urban development is needed to cater the increasing of urban population. Due to the urbanization, the construction of paved area significantly changed the hydrologic and hydraulic characteristics of the catchments. For that

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reason, occurrence of flash flood in urban area is becoming more cruel from year to year. This urban
stormwater has negative impact to environment and ecological effects. So, a proper stormwater
management is needed to overcome these problems. Department of Irrigation and Drainage (DID)
Malaysia has introducing New Urban Drainage Manual known as Storm Water Management Manual
for Malaysia (Manual Saliran Mesra Alam or MSMA) effective from January 2001. These manual
introduced a set of guidelines for new development in Malaysia which adopting natural processes
solutions for stormwater treatment. The concept of this guideline is ‘source control techniques’ in
order to minimize the runoff flow rate from the contributing area [14]. The manual apply the concept
of Best Management Practices (BMP’s) to control stormwater at source with the target to achieve zero
development impact contribution and improve the stormwater runoff quality. Rain garden systems are
considered as a new concept in Malaysia compared with US where rain gardens was widely used [12].

2. Objective
Generally, this research seeks to have an understanding and knowledge of rain garden. The aim of the
proposed study in UNITEN is to improve the quality design criteria of rain garden systems in
Malaysia under tropical climate for supporting design guidelines in MSMA Manual. The outcome of
the study hopefully can be used to highlight the potential of rain gardens in order to maintain the
sustainable urban development in Malaysia. In order to achieve the aims above, three objectives are
outlined as follows:
- To investigate the performance of rain garden system facilities using lab scale.
- To analyze the performance of rain garden system in removing heavy metal in different media
depth.
- To produce optimum design requirements for rain garden system.

3. Research Methodology
The methodology will be carried out in four (4) stages as follows:
- Literature Review - Literature research will be conducted to gather the information research
  findings of rain garden system in order to identify the design modification, benefit and
  potential of rain garden system.
- Monitoring Program - Monitoring program will be carry out for assessing the water quality
  and also hydraulic performance test for rain garden system.
- Data Analysis and Interpretation - All the data from monitoring program will be examined in
  order to develop a preliminary design requirements, pollutant removal performance curve and
  charts.
- Finalize the design requirements, monographs, and charts for rain garden systems. At the final
  stage, the entire design requirement will be finalized and design protocol will be derived.

4. Rain Garden Performance
Rain gardens system has many potential and unique compared to most the common types of Best
Management Practices, mainly wet and dry pond. Besides the landscaping aspect, rain gardens have
many positive benefits in improving water quality for higher pollutant removal efficiencies for
nitrogen, phosphorus, and trace metals [9]. Study by Hatt (2007) showed that bi-oretention systems
can reduce runoffs volumes and concentrations of sediments, heavy metals, phosphorus,
hydrocarbons, and pathogenic bacteria [12]. [13]. All these pollutants and nutrients were being
removed through the combination of natural physical and biological processes according to the type
of soil and plants used [13]. Besides that, rain gardens system provides low maintenance as compared
to most traditional stormwater BMP’s.

Extensive research on assessing the performance of rain garden systems has been conducted in
field studies and laboratory work. Previous studies showed that rain garden systems can remove heavy
metals with load reduction generally in excess of 90% [13]. Majority of Zinc, Lead were removed
from stormwater that flowed through rain garden system system [13]. Study by Davis (2007) showed
that removal efficiencies of Zn, Cu, Pb and Cd were approximately 94%, 88%, 95% and >95%. For laboratory study, Belinda (2009) has performed a large scale of column study with 125 biofilter columns [14]. All the biofilters were constructed in greenhouse in Melbourne, Australia to test the performance of stormwater biofilters on removal sediments. Result showed that all the biofilters were highly effective in removing TSS greater than 95% consistently over the time [13], [14]. The performance of rain garden system systems in field setting by Paul Matthews (2011) in Auckland, New Zealand also showed reduction of TSS from stormwater that flowed through the rain garden system system. Observation from the study showed that concentration of TSS was reduced significantly by the rain garden system system [8].

5. Application of Rain Garden at Humid Tropic Centre
The application of WSUD on Rain Garden at local scale as pilot study was located at Humid Tropic Centre (HTC), Kuala Lumpur. It is a sub division of Department of Irrigation and Drainage (DID). The site consists of two office buildings, one toilet, one prayer building, one store cabin and two parking areas. Beside rain garden, there are also other components such as wetland, green roof, rainwater harvesting as a part of integrated stormwater management that installed at HTC.

The performance of rain garden on hydraulic conductivity and water quality has been monitored. Water quality samples were collected as grab samples from randomly selected storm event. All the samples were put in a plastic bottle and sent to certified laboratory for chemical testing by using APHA Standard Methods. Besides that, in situ water quality probe are used to measure pH and DO. The hydraulic conductivity of filter media has been monitored in situ by using method as described in Practice Note 1: In situ measurement of hydraulic conductivity. Only top layer of the filter media has been tested due to the fact that, the top layer is the one controlling the hydraulic conductivity of the system as a whole. Then the results are being compared to the baseline hydraulic conductivity before the installation of WSUD by using Horton’s Method. Results in Table 1, showed that hydraulic conductivity improved with the installation of rain garden system system at the study area. According to Urban Stormwater Management Manual for Malaysia, the suitability of soil for quality infiltration is based on the minimum infiltration rate of 13 mm/hr. Therefore, based on the results observed, the hydraulic conductivity of rain garden system system installed in the study area is above exceeded the MSMA requirement.

Table 1: Hydraulic Conductivity for Rain garden system system

| Testing point | Initial Rate of Infiltration, \( f_0 \) (mm/hr) | Constant Rate of Infiltration, \( f_c \) (mm/hr) | Shape Factor, \( k \) (hr⁻¹) | Horton Equation |
|---------------|---------------------------------|---------------------------------|----------------|----------------|
| Before installation of bioretention | 62.15 | 3 | 5.86 | \( f = f_c + (f_0 - f_c) e^{-kt} \) |
| 3 month after installation of bioretention | | | | |
| Point 1 | 211.59 | 76.36 | 0.744 | \( f = 76.36 + (211.59-76.36) e^{-0.744t} \) |
| Point 2 | 118.80 | 64.15 | 0.719 | \( f = 64.15 + (118.80-64.15) e^{-0.719t} \) |
| Point 3 | 123.39 | 30.54 | 0.961 | \( f = 30.54 + (123.39-30.54) e^{-0.961t} \) |
| Point 4 | 272.80 | 30.55 | 0.917 | \( f = 30.55 + (272.80-30.55) e^{-0.917t} \) |
| Point 5 | 413.67 | 168.00 | 0.100 | \( f = 168.00 + (413.67-168.00) e^{-0.100t} \) |
| Point 6 | 584.65 | 158.84 | 1.543 | \( f = 91.63 + (296.02-91.63) e^{1.543t} \) |

For water quality measurement, the parameters that has been analyzed are Total Suspended Solid (TSS), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), pH and heavy metals such as Zinc (Zn) and Copper (Cu). As can be seen from Figure 1, results showed that the water quality level for DO and BOD was within the range of Water Quality Index Class II. As an average, DO levels were between 5 to 7 mg/L and BOD between 1 to 3 mg/L.
6. Conclusions
This research is expected to identify the potential of rain garden systems for improvement of stormwater pollutants under Malaysia condition. Furthermore, this research will identify the obstacles to adopt rain garden due to the different rainfall intensity magnitude and make recommendation to overcome the problem in implementing rain garden system.

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