Water Quality Improvement through Reductions of Pollutant Loads on Small Scale of Bioretention System

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Abstract. Bioretention system is introduced as an important topic namely Urban Storm Water Management Manual for Malaysia (MSMA) by the Department of Irrigation and Drainage Malaysia (DID) in May 2012. The main objective of this paper is to evaluate the performance of water quality for small scale bioretention system under tropical climate via MUSIC model. Two bioretention systems 1 and 2 are observed based on the difference media depth. The result of bioretention system is compared with a reference model which has infrastructure with Urban Stormwater Improvement Conceptualisation (MUSIC) for pollutants load reduction and water quality results. Assessment of results via MUSIC software indicates a significant percentage of reduction for Total Suspended Solid (TSS), Total Phosphorus (TP) and Total Nitrogen (TN). The prediction of pollutant reduction via using MUSIC has the harmony for requirement in MSMA. TSS pollutant reduction is more than 80%, while for TP and TN more than 50%. The outcome of this study can be helpful for improvement of the existing MSMA guidelines for application of bioretention systems in Malaysia.

1. Introduction

Best Management Practices (BMPs) is introduced to help in planning storm water properly such as Low Impact Development (LID), Sustainable Urban Drainage (SUD), Water Sensitive Urban Design (WSUD) and Urban Storm Water Management Manual for Malaysia (MSMA) [1]. The main objective of stormwater management practices is to match the state of the development area that was altered in terms of its hydrologic condition due to urbanization to the level of condition before the area was developed. The common BMPs are to use the concept of detention and retention systems to attenuate the peak runoff and prevent or reduce sediments, nutrients and other pollutants from transport between land and surface water. Storm water management integrates to the aspect of quality, quantity and amenities. Best management practice should be seen as the best way in making the neighborhoods and natural habitats become greener with the improvement of environmental conditions in urbanized and surrounding areas [2].
In Malaysia, Urban Stormwater Manual (MSMA) has been introduced by Department of Irrigation and Drainage (DID) to provide guidance pertaining to the latest stormwater best management practices (BMPs). This technical guideline can assist decision makers such as engineers, developers and stakeholders to implement sustainable development in Malaysia. The first urban drainage manual, “Planning and Design Procedures No.1: Urban Drainage Design Standards and Procedures for Peninsular Malaysia” was published in 1975 and followed by “Urban Stormwater Management Manual (MSMA) published in year 2000 and was revised with the MSMA second edition in 2012. Every development project must follow and comply with the stormwater quantity and quality objectives to meet the pre-development condition.

A new chapter on bioretention system is introduced in Chapter 9 in Urban Stormwater Manual for Malaysia (MSMA) 2nd Edition. Bioretention system or also known as ‘rain garden’ is one of BMP’s techniques that is used to control the water quantity at attributed sources and it can be the adaptable method applied throughout many regions. Bioretention system can retain and treat urban runoff by using vegetation or plants before it flows into the main storm drain system. Bioretention system is made of an excavated basin or landscape depression consisting of plants, ponding area, mulch layer, several layers of planting soil and underdrain (optional). Two types of bioretention system which are bioretention 1 and 2 with different media depth were monitored. This study focuses on the application of bioretention system as a micro scale of BMP’s that works in reducing stormwater quality from entering the drainage system.

2. Site Description

A bioretention research and education site was constructed at Universiti Tenaga Nasional (UNITEN), Putrajaya Campus in August 2013. The bioretention systems (1 and 2) were designed as impermeable system and constructed according to the standard criteria based on Urban Stormwater Management Manual for Malaysia (MSMA) 2nd Edition. The site contains two parallel bioretention cells that capture and treat stormwater runoff from catchment of an asphalt surface parking area (approximately 0.08 hectare). Each bioretention cell (system) is rectangular in shape with the length of 12.0 m and width of 4.0 m resulting surface area is about 48m$^2$ for each cell. The standard materials in each cell consist of an engineered soil mix of 20 to 25 % top soil, 50 to 60 % medium sand and 20 to 25 % organic leaf compost. The total engineered soil depth in each cell is 1.0m and 0.45m thickness promoted stormwater treatment through infiltration process. A network of perforated pipes with 100mm in diameter in the drainage layer is conveyed the infiltrated stormwater to the outlet point.

3. Methodology

The stormwater from the catchment area flows through the drainage system to the bioretention system inlet where the stormwater is monitored. The monitoring stations are recorded on-site rainfall data, measured the inflow and outflow into the bioretention system and automatically captured the stormwater samples for selected rainfall events. All field data are recorded in a data logger that is kept inside the housing together with other apparatus such as automatic sampler and batteries. Water samples are transferred into sampling bottles and clearly labelled for future identification. During transportation, stormwater samples are stored in a cool box with ice cubes to maintain the required low temperature. The selections of parameters for analysis are Total Suspended Solid (TSS), Total Phosphorus (TP) and Total Nitrogen (TN) according to the targeting parameters for removal efficiency in Urban Stormwater Manual (MSMA) 2nd edition. The performance of bioretention systems at the study area has been modelled with MUSIC as conceptual design tool software. This software can estimate stormwater pollutant loads that are generated in a catchment and predict the performance of stormwater treatment measures. By stimulating the performance of stormwater quality improvement measures, MUSIC is able to determine whether if the proposed stormwater management systems can meet the specified water quality objectives.
4. Result and Discussion

The existing and future pollutant loads generated from catchment in the study area is computed by MUSIC using adopted pollutant concentrations. The rainfall data template for year 2014 is taken from UNITEN rainfall gauge station to provide more accurate simulation of study area condition. The entire cumulative pollutants load that coming from the upstream of the catchment has been considered to provide a clear sample of pollutions has come out from the catchment. Table 1 shows the results obtained from MUSIC simulation modelling with the application of bioretention systems. Bioretention systems are incorporated into the MUSIC modelling to study the performance water quality at the study area.

Table 1 MUSIC modelling result for bioretention 1 and 2

| Parameter (kg/year) | Before Bioretention Implementation | After Bioretention Implementation | % of Reduction |
|---------------------|------------------------------------|-----------------------------------|----------------|
|                     | Final Discharge                     |                                   |                |
|                     | Bioretention 1                      | Bioretention 2                    |                 |
|                     | 1                                 | 2                                 |                 |
| TSS                 | 123                                | 123                               | 97.8%          |
|                     | 2.76                               | 3.49                              |                 |
|                     | 97.8                               | 97.2                              |                 |
| TP                  | 0.328                              | 0.328                             | 85.5%          |
|                     | 0.047                              | 0.052                             |                 |
|                     | 85.5                               | 84.2                              |                 |
| TN                  | 4.06                               | 4.06                              | 76.8%          |
|                     | 0.943                              | 1.04                              |                 |
|                     | 76.8                               | 74.3                              |                 |

Based on the MUSIC modelling results with bioretention system, it can be seen that the water quality parameters of TSS, TP, TN and gross pollutants accomplished significant reduction with the implementation of bioretention system components (Table 1). The targeted reduction of TSS is 97.8% to 97.2% for bioretention 1 and bioretention 2 respectively. Moreover, reduction goal of TP is obtained 85.5% to 84.2% for bioretention 1 and 2 respectively. Finally, TN outputs are between 76.8% and 74.3% for bioretention 1 and 2. MUSIC has been used to predict the effectiveness of bioretention system in terms of water quality for selected storm event based on rainfall depth between 25.6 mm to 94.8 mm for year 2014 (Table 2). The attributed dates of selected rainfall events are 6th January 2014, 31st March 2014, 9th April 2014, 21st May 2014, 28th October 2014 and 15th November 2014. The ranges of recorded rainfalls intensity for the selected events are between 27.93 mm/hr and 66.92 mm/hr. Prediction at final outlet for all storms events, gross pollutants are predicted to reduce totally 100%. Based on the MUSIC result in Table 2, the prediction of removal efficiency for overall parameters shows that percentage of reduction is slightly higher for bioretention 1 compared to bioretention 2. In regard with the depth of filter media, which is different as 1.0m and 0.45m, the removal efficiency between two bioretention system are less than 1% for TSS and less than 15% for TP and TN based on selected events (Table 2).

Table 2 Percentage of differences on predicted removal efficiency by MUSIC Model between bioretention 1 and 2

| Parameters | Rainfall intensity (mm/hr) | 06/01/14 | 31/03/14 | 09/04/14 | 21/05/14 | 28/10/14 | 15/11/14 |
|------------|---------------------------|----------|----------|----------|----------|----------|----------|
| TSS        | 0.50                      | 0.30     | 0.30     | 0.20     | 0.30     | 0.10     |
| TP         | 6.10                      | 4.91     | 4.91     | 3.02     | 3.23     | 1.90     |
| TN         | 13.13                     | 11.04    | 11.04    | 7.02     | 7.48     | 4.76     |

The result from bioretention system 1 and 2 is compared at the final discharge 1 and final discharge 2 (Table 3). It can be seen as an average, the percentage removal efficiency for monitoring
samples and MUSIC modelling result are not much different. However, the predicted removal efficiency using MUSIC showed slightly higher percentage removal than monitoring results. For example, the TSS removal efficiency for monitoring bioretention 1 and 2 are 92.2 % and 92.4 % compared to MUSIC result 97.8 % and 97.2 %. For TP removal efficiency, ranges of monitoring result are 82.1% to 83.3% while MUSIC results are 85.5 % to 84.2%. Monitoring results are 61.4 % to 64.7 % for TN range in comparison with MUSIC result which are 74.3 % to 76.8 %.TN shows that it has highest overestimation by MUSIC model for two bioretention systems. Moreover, TP includes shortest overestimation by MUSIC model.

Table 3 Comparison of Percentage Removal Efficiency between MUSIC Modelling Results and Monitoring Results

| Parameters | Average % Removal Efficiency from Observation | % Removal Efficiency from MUSIC Modelling | % Difference |
|------------|-----------------------------------------------|----------------------------------------|--------------|
|            | Bioretention 1 | Bioretention 2 | Bioretention 1 | Bioretention 2 | Bioretention 1 | Bioretention 2 |
| TSS        | 92.2 | 92.4 | 97.8 | 97.2 | 5.7 | 4.9 |
| TP         | 82.1 | 83.3 | 85.5 | 84.2 | 4.0 | 1.1 |
| TN         | 61.4 | 64.7 | 76.8 | 74.3 | 20 | 13.0 |

This study can show the modelling of water quality using MUSIC is necessary during the planning and design process in order to predict the removal efficiency of applied bioretention system. MUSIC is a design tool which currently one of the popular models to predict the performance of various WSUD techniques applied in Australia [3].

5. Conclusion

Bioretention system on a local scale in Universiti Tenaga Nasional Malaysia is a pilot study that can serve as effective and great integrated solution to improve urban stormwater pollution. Results indicated that bioretention system have the ability to remove TSS, TP and TN significantly. The MUSIC model is able to simulate the performance of bioretention system with the optimum treatment train. In conclusion, the outcome of this study can contribute to support the design procedure and criteria of bioretention facilities as outlined in the MSMA.

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References

[1] Lariyah M S Mohamed Roseli Z A Zulkefli M Amirah Hanim M P .2014. Application of porous pavement system for MSMA stormwater management ecoHydrology: comparison of asphalt, interlocking and turf pavement. 13th International Conference on Urban Drainage, 7-12 September , Sarawak, Malaysia.

[2] A. E. Barbosa, J. N. Fernandes, and L. M. David, “Key issues for sustainable urban stormwater management.,” Water Res., vol. 46, no. 20, pp. 6787–98, Dec. 2012.

[3] M. A. Imteaz, A. Ahsan, A. Rahman, and F. Mekanik, “Modelling stormwater treatment systems using MUSIC: Accuracy,” Resour. Conserv. Recycl., vol. 71, pp. 15–21, 2013.