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Bioretention System as Stormwater Quality Improvement Mechanism

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Abstract- **Stormwater Management is very challenging in Malaysia due to the intense rainfall within short durations. Stormwater may contain a broad range of pollutants such as sediments, nutrients, heavy metals and oil from impervious areas which can be released directly to waterways. Bioretention is a practical option within the measures of stormwater mitigation to increase water quality and reduce peak discharge. Universiti Tenaga Nasional (UNITEN) in collaboration with Universiti Sains, Malaysia (USM) has constructed bioretention systems near the parking lot of the College of Engineering, UNITEN. The system was designed as a small scale and impermeable mechanism with an aim to assess the performance of the bioretention system for stormwater quality improvement. Water quality result showed that the removal efficiency of Total Phosphorus (TP), Total Nitrogen (TN), Turbidity and Total Suspended Solids (TSS) reached more than 40%. In the preliminary monitoring, it was observed that the bioretention system was able to remove pollutants. This outcome is significant as there is no prior field study that was done of this scale in Malaysia. The findings can be used to enhance understanding on the application of bioretention system in tropical climate in improving water quality of stormwater runoff.**

Keywords: Bioretention System, Stormwater Management, Best Management Practice, Urban Runoff

I. INTRODUCTION

In recent years, rapid growth of the city has resulted to the increase in urban runoff into existing infrastructures that can directly alter local environment [1]. The process of urbanisation may involve the removal of vegetation that leads to the change in land use, as well as the replacement of permeable areas into impermeable areas such as paved surfaces, parking lots and roads. The impacts of urbanisation have proven to cause adverse effects to the natural watershed storage by increasing the impervious surface areas. In long term, the rapid rate of urbanisation will deteriorated the water quality and quantity of stormwater runoff [2]. This makes stormwater management become more challenging to control, particularly the increase of peak discharges which is generated from urban catchments that forces the changes of geomorphic properties of rivers or canals which subsequently leads to flooding [3],[4].

Today, stormwater pollution has been identified as one of the leading causes of declining water quality. Since stormwater pollution can originate from anywhere, it is considered as a major crisis that has been affecting the quality of water in the country, especially the river's drainage basin [5]. As an example, during the dry periods, a broad range of pollutants that are readily accumulated on impervious surface may later be swept off during the storm events and discharged to our receiving water [6]. Urban stormwater may contain a mixture of natural organic and inorganic materials including suspended solids, oil and grease, debris, floatable materials, heavy metals, bacteria, toxic pesticides and sediments [7].

Urban planners, engineers and local authority are looking into the best solution to create a more sustainable environment, namely through stormwater management to protect the environmental values of urban areas and their surroundings. Best Management Practices (BMP's) technique have been introduced such as Low Impact Development (LID) in USA, Sustainable Urban Drainage (SUD) in the UK and Water Sensitive Urban Design (WSUD) in Australia. These practices were designed by combining the importance of quality, quantity, and amenities by which they are seen as opportunities that can provide sustainable water management for improved environmental conditions in urbanised and their surrounding areas [3]. Bioretention system which can also be named as 'rain garden' is one of BMP's techniques that is used to control water at its sources and it is the most adaptable method applied throughout many regions. Bioretention system can retain and treat urban runoff using vegetation 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).

In Malaysia, there exists a design guideline in managing urban stormwater called the Urban Stormwater Management Manual for Malaysia (MSMA). This guideline was published by the Department of Irrigation and Drainage of Malaysia (DID) in 2001 as the first edition to chronicle the long term policies to be applied nationwide, particularly on the directions and needs in ensuring sustainable urban drainage systems are set up and fully utilized in Malaysia. The purpose of stormwater management is to minimise the impact of urbanisation and rainfall runoff to achieve a balance in social, economic, and environment progress around the creation of sustainable development. This guideline standard provides effective practices in maintaining the environment for the next generation. The improved version of MSMA which is called MSMA 2nd Edition was published in 2012. In this edition, a new chapter on Bioretention System is introduced in Chapter 9. Currently there is a lack of knowledge and exposure on data collections of the performance of the bioretention systems in Malaysia. Therefore, there is an urgent need to develop a database on the performance of bioretention systems to support the local design guideline since is a relatively new facility in Malaysia.

This paper describes the implementation of bioretention as a pilot project which has been constructed in UNITEN, Putrajaya Campus as a new application of Bioretention System as a component of Stormwater Management. The aim of this study is to assess water quality performance of the bioretention systems at the preliminary stage.

II. STUDY AREA

The research and education site of bioretention system was built in Universiti Tenaga Nasional, Putrajaya Campus in August 2013. The site consists of two parallel bioretention cells that capture and treat runoff from around 0.08 ha of an asphalt parking surface at the College of Engineering UNITEN. Parking areas are mostly used during the entire semester except during the semester break. Each bioretention cell is a rectangle shaped with a width of 4.0 m, resulting in a bioretention surface area of about 48m^2 for each cell and in the length of 12.0 m.

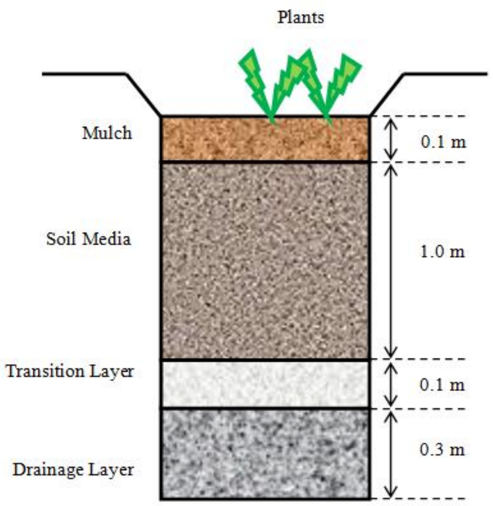

Fig. 1 Cross Section of Bioretention 1

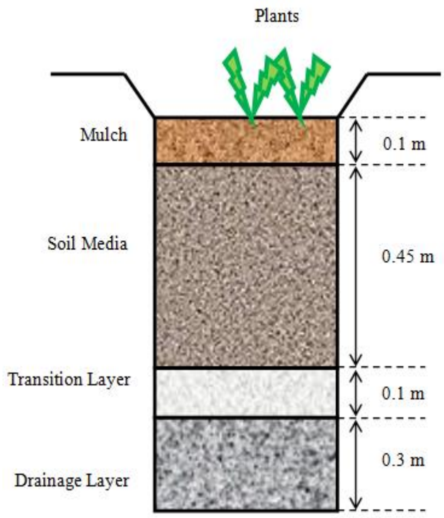

Fig. 2 Cross Section of Bioretention 2

Bioretention cells were constructed according to the standard design of bioretention as outlined in the Urban Stormwater Manual, (MSMA) Second Edition. It was designed as an impermeable system where in this system, water from filtration media flows through the transition layer and underdrain located in the drainage layer. Standard media in each cell consists of a mixture of soil engineered with 20% to 25% topsoil, sand medium of 50% to 60% and 20 to 25% of organic leaf compost. The total depth of soil media in each cell is 1.0 m and 0.45 m respectively. Plants were selected based on terrestrial vegetated community which consists of shrubs and groundcover materials. Dense plant covers are used to treat stormwater runoff and to withstand insect and disease infections. Besides that, the plants selected can survive in dry and wet weather.

Fig. 3 Inlet of Bioretention

Fig. 4 Outlet of Bioretention

III. METHODOLOGY

Grab samples were taken every month between January and May 2014. Influent samples were grabbed manually at inlet sump which collects direct stormwater runoff from impervious area of the parking space and effluent samples were grabbed manually at outlet sump which collects the under drained water. Composite samples were collected in a single 2 litre container and analysed as a single sample representative of the entire sampling period and clearly labelled for future identification. Once collected, the samples were cooled in a cool box with ice cubes and transported to the College of Engineering Laboratory for water quality analysis. Analytical procedures were carried in accordance with the Standard Methods for the Examination of Water and Wastewater, 20th Edition. Selected water quality parameters including total suspended solids (TSS), turbidity, total phosphorus (TP) and total nitrogen (TN) were analysed. The change in contaminant concentration which is based on Removal Efficiency, (R) was calculated by using the following Removal Efficiency equation to compare both the inlet and outlet concentrations.

$$R(\%) = \frac{(C_{in} - C_{out})}{C_{in}} \times 100\% \quad (1)$$

where R=the removal efficiency, C_{out}=the outflow pollutant concentration (mg/L); and C_{in}=the inflow pollutant concentration (mg/L).

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The value of 100% removal efficiency means that the bioretention system has totally removed the pollutant. If removal efficiency equals to 0%, it means that the concentration in effluent is the same as the one in influent. In the case where removal efficiency <0%, the bioretention system is considered to have released a more concentrated water than runoff

IV. RESULT AND ANALYSIS

A. Water Quality Improvements

The performance of pollutant removal in the bioretention system based on previous laboratory and field studies proposed that bioretention system are potentially one of the best BMP's practice in pollutant removal [8]. In this study, fourteen samples were taken as preliminary analysis for water quality measurements using a 2 litre sampling bottles manually. The initial results showed a significant improvement in the performance of water quality.

The concentrations of water quality at inlet and outlet were compared to understand the changes in water quality parameters due to the treatment within the bioretention system. In Table 1, the analysis results of the pollutant concentration including TSS, turbidity, TP and TN throughout fourteen selected rainfall events are shown.

Table 1. Water Quality Concentration at Inlet and Outlet Points

Event	TSS (mg/L)			Turbidity (NTU)			TP (mg/L)			TN (mg/L)		
	Inlet	**Out.1**	**Out.2**	**Inlet**	**Out.1**	**Out.2**	**Inlet**	**Out.1**	**Out.2**	**Inlet**	**Out.1**	**Out.2**
4/1/2014	12	2	2	32	4	2	0.09	0.01	0.01	0.06	0.01	0.03
6/1/2014	35	1	2	96	7	6	0.25	0.03	0.02	0.18	0.06	0.08
7/1/2014	14	2	1	39	5	1	0.10	0.02	0.01	0.07	0.01	0.04
2/3/2014	38	4	2	105	10	8	0.27	0.04	0.03	0.20	0.01	0.03
28/03/14	40	2	3	110	9	7	0.29	0.03	0.03	0.21	0.02	0.06
31/03/14	38	4	4	105	8	10	0.27	0.03	0.03	0.20	0.10	0.08
9/4/2014	44	2	2	121	9	12	0.32	0.05	0.06	0.23	0.08	0.07
21/04/14	42	2	2	116	11	8	0.30	0.06	0.02	0.22	0.08	0.06
23/04/14	48	5	1	132	10	10	0.34	0.02	0.01	0.25	0.10	0.08
24/04/14	25	2	2	20	5	2	0.09	0.01	0.01	0.06	0.02	0.03
5/5/2014	48	2	1	132	10	10	0.34	0.06	0.05	0.25	0.02	0.07
8/5/2014	36	3	2	99	3	8	0.26	0.06	0.03	0.19	0.06	0.07
21/05/14	40	1	3	110	6	9	0.29	0.02	0.02	0.21	0.08	0.08
24/05/14	20	2	2	55	2	4	0.14	0.03	0.03	0.10	0.01	0.03
Mean	**34.29**	**2.43**	**2.07**	**90.86**	**7.07**	**6.93**	**0.24**	**0.03**	**0.03**	**0.14**	**0.05**	**0.06**
Min.	**12**	**1**	**1**	**20**	**2**	**1**	**0.09**	**0.01**	**0.01**	**0.06**	**0.01**	**0.03**
Max.	**48**	**5**	**4**	**132**	**11**	**12**	**0.34**	**0.06**	**0.06**	**0.25**	**0.1**	**0.08**

It can be seen that the pollutant concentration at inlet and outlet were totally different due to the changes in values between inlet and outlet concentrations. In Outlet 1 and Outlet 2, TSS concentrations was very low. The TSS concentration was between 12 mg/L to 48 mg/L for the inlet compared 1 mg/L to 5 mg/L at Outlet 1 and 1 mg/L to 4 mg/L at Outlet 2.

Similarly, for turbidity, the intense changes in concentration can be determined at the inlet and outlets. The average pollutant concentration at the inlet for turbidity was 90.86 NTU while the average value for Outlet 1 and Outlet 2 were 7.07 NTU and 6.93 NTU. In addition, the range of inlet's concentration for TP and TN were 0.09 mg/L to 0.34 mg/L and 0.06 mg/L to 0.25 mg/L. Both TP and TN also showed reduction in concentration value at the two outlet points.

The data shown in Table 1 suggest that significant water quality changes occur when the stormwater runoff flows from the inlet point to the two outlet points through two different depths on filter media of bioretention system. In this regard, the study by Hunt and Smith (2008) highlighted that bioretention systems can reduce the concentration in target runoffs of most pollutants [9].

B. Sediments

The presence of suspended solids in the stormwater runoff was a good indicator of the existence of nutrients, organic matter, metals and also other pollutants. It is well known that these pollutants especially nutrients, heavy metals and hydrocarbon can closely be attached with suspended solids due to adsorption process. Based on the result in Figure 5, the average removal efficiency of TSS was about 83.33% to 97.50% in Outlet 1 and 83.33% to 97.92% in Outlet 2.

Therefore, TSS concentration was reduced effectively through the bioretention system, normally through sedimentation in the basin and filtration process in the media layers. Figure 6 and 7 shows the correlation between TSS concentration at inlet with TSS concentration at Outlet 1 and Outlet 2. Results indicated that there are weak correlations between the inlet and the two outlet points with R^2 value equal to 0.082 and 0.007 for Outlet 1 and Outlet 2.

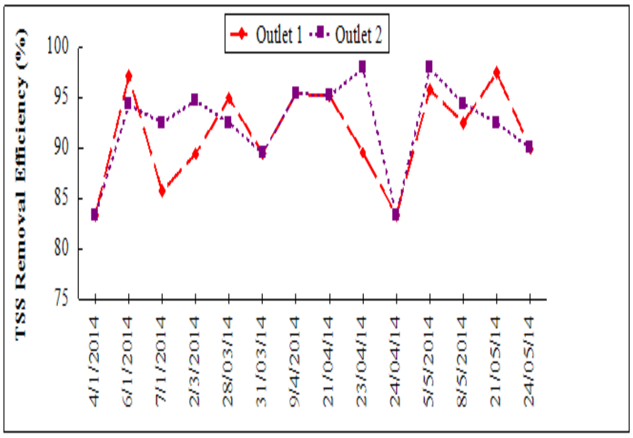

Fig. 5 TSS Removal Efficiency for Outlet 1 and Outlet 2

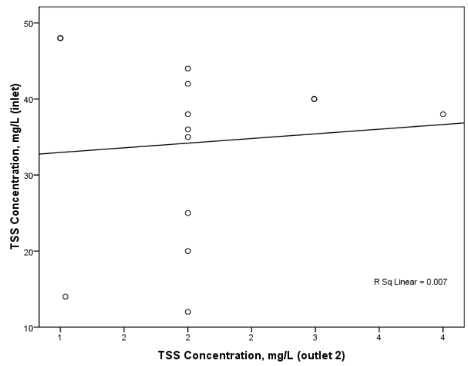

Fig. 6 Correlation of TSS Concentration at Inlet with TSS Concentration at Outlet 1

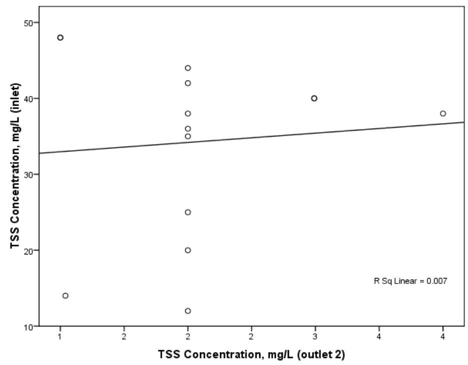

Fig. 6 Correlation of TSS Concentration at Inlet with TSS Concentration at Outlet 2

Table 2 shows the comparison performance of TSS between UNITEN, Malaysia with various studies done at other bioretention sites. As an average, UNITEN bioretention site achieved a high percentage removal of within the range of 83.33% to 97.92%.

Table 2.Comparison of Bioretention Field Studies on TSS Performance

Authors	Location	Percentage of TSS Performance
Brown and Hunt, 2011 [10]	Rocky Mount, North California	58%
Debusk and Wynn, 2011 [11]	Blacksburg, Virginia, United States	99%
Hathaway and Hunt, 2011 [12]	Wilmington, North Carolina, United States	100%
Li and Davis, 2009 [13]	College Park, Maryland Silver Spring, Maryland	96% 99%
Hunt et al., 2008 [9]	Charlotte, North Carolina	60%
Li and Davis, 2008 [14]	Washington, DC	55%-99%
Brown and Hunt, 2008 [15]	Rocky Mount, North California	92%
UNITEN	Malaysia	83.33%-97.92%

Figure 8 shows the removal efficiency of turbidity with an average removal value of within 84.85% to 96.97% for Outlet 1 and 90.08% to 97.40% for Outlet 2. This result demonstrated that turbidity can be successfully removed based on the high percentage recorded, reaching more than 80% at average for Outlet 1 and Outlet 2. It can be seen in Figure 9 and 10 that there were strong correlations between R^2=0.536 for Outlet 1 and R^2=0.874 for Outlet 2 compared with turbidity concentration at the inlet. The explanation for this is that the turbidity concentration at the two outlet points were affected by the turbidity concentration at the inlet point of the bioretention system.

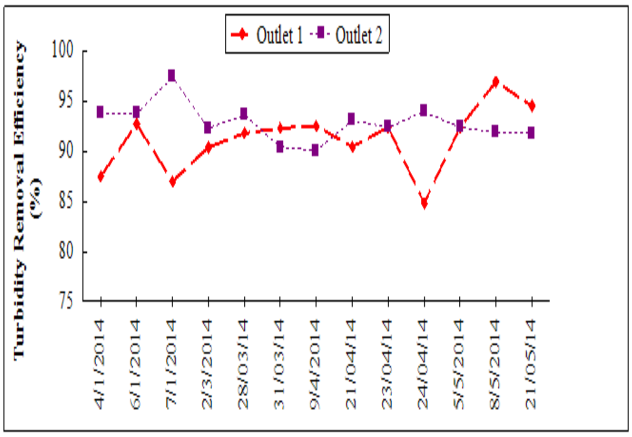

Fig. 8 Turbidity Removal Efficiency for Outlet 1 and Outlet 2

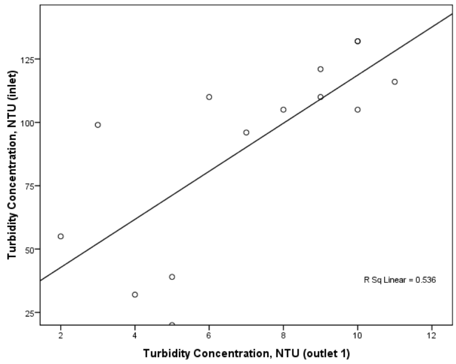

Fig.9 Correlation of Turbidity Concentration at Inlet with Turbidity Concentration at Outlet 1

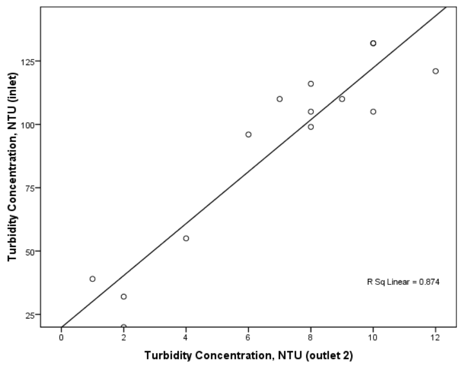

Fig.10 Correlation of Turbidity Concentration at Inlet with Turbidity Concentration at Outlet 2

Normally, turbidity concentration is highly affected by TSS concentration. During rainfall events, small particles from road side are carried by the stormwater flow to the bioretention system. When the TSS is high, value of turbidity is increased. The statistical analysis demonstrated that the source of turbidity in inlet correlated in the TSS in inlet with the R^2 value equals to 0.888 (Figure 11). This indicated that, TSS concentration from sources of stormwater and turbidity has a strong correlation with the justification that turbidity increases as the TSS increased.

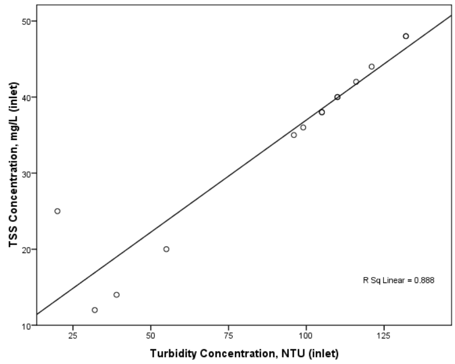

Fig.11 Correlation of Turbidity Concentration at Inlet with TSS Concentration at Inlet

C. Nutrients

An excess amount of nutrients such as phosphorus and nitrogen can lead to the increasing of plant growth in waterways which is called eutrophication. As stormwater containing a large concentration of nutrients enters the waterways, it may cause a negative impact to aquatic life. It cause nutrient enrichments, decreasing water clarity and low levels of dissolved oxygen due to decomposition and oxidation of the plant matter. Due to the complexity of the chemistry of TP and TN, the results for these nutrients had been varied based on previous research. Nutrients pollutants' removal is complicated due to the chemical processes involved, such as denitrification and dissolved phosphate which are leached by the soil and vegetation within the bioretention system.

Phosphorus in stormwater can be present in organic or inorganic form. It has the ability to adsorb to particles and organic matter which are mainly transported in the stormwater runoff. The removal efficiency of TP varied within 76.74% to 97.09% for Outlet 1 and Outlet 2. There was no great difference in the two points of outlets in terms of the removal efficiency even though the depths of filter media were not the same. As an average, TP had reduced by 85.71% and 88.83% for Outlet 1 and Outlet 2 (Figure 12). Results in Figure 13 and 14 indicated that there were weak relationship between inlet and two outlet points with R^2 value equal to 0.38 and 0.301 for Outlet 1 and Outlet 2. This is because TP concentration at the inlet had little effect on TP concentration at the two outlets.

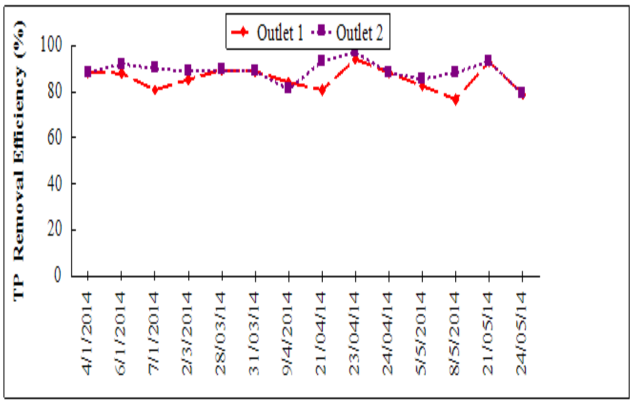

Fig.12 TP Removal Efficiency for Outlet 1 and Outlet 2

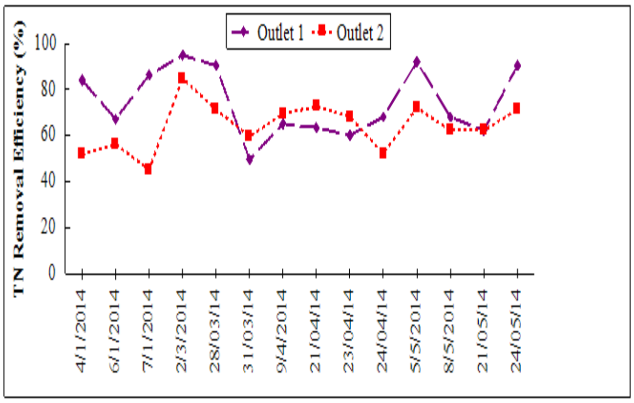

Fig.15 TP Removal Efficiency for Outlet 1 and Outlet 2

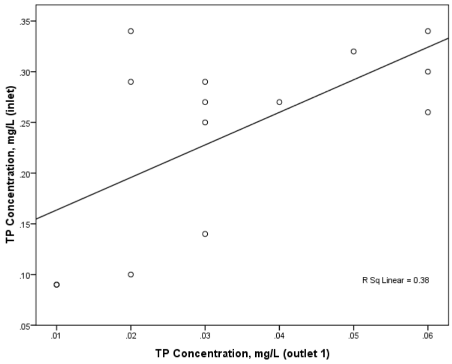

Fig.13 Correlation of TP Concentration at Inlet with TP Concentration at Outlet 1

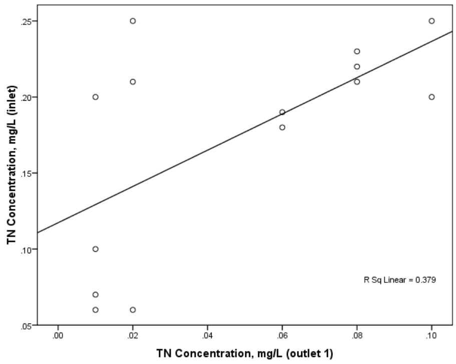

Fig.16 Correlation of TN Concentration at Inlet with TN Concentration at Outlet 1

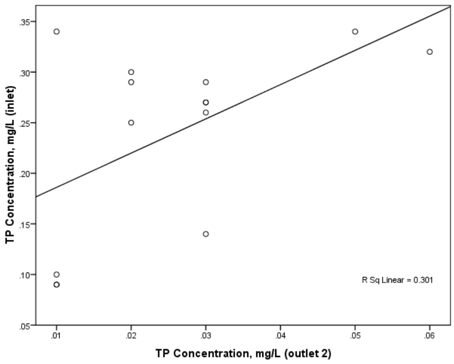

Fig.14 Correlation of TP Concentration at inlet with TP Concentration at Outlet 2

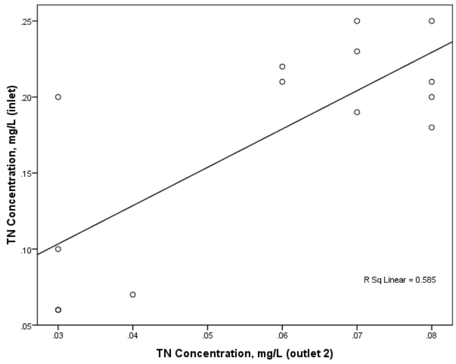

Fig.17 Correlation of TN Concentration at inlet with TN Concentration at Outlet 1

Figure 15 displays that the removal efficiency of TN ranged from 49.62% to 94.96% at Outlet 1 and 45.31% to 84.89% at Outlet 2. Compared to other parameters of water quality, the removal efficiency of TN was low. Based on statistical analysis, there was a weak correlation between the inlet and Outlet 1 and strong correlation between the inlet and Outlet 2. From Figure 16 and 17, it can be observed that R^2 values are 0.379 and 0.585 for Outlet 1 and Outlet 2. This is such as the TN concentration at the inlet had slightly effected the TN concentration at the two outlets.

Table 3 shows the comparison of removal efficiency through TP and TN performance between UNITEN, Malaysia and previous researches that were based on field studies. The performance of nutrients was found to be not consistent. In terms of removing nutrients, Davis et al. (2006) and Hatt et al. (2009) reported that the removal of nitrogen was poor and it was found that sometimes the outflow concentration was higher than inflow concentration [4],[16]. Nutrients compounds are essentials required for plant growth. Conversely, excess amount of nutrients could threaten aquatic habitat.

Table 3.Comparison of Bioretention Field Studies on TP and TN Performance

Authors	Location	Percentage of TP Performance	Percentage of TN Performance
Chen, 2013 [17]	Lenexa, Kansas	-	56%
Brown and Hunt, 2011 [10]	Rocky Mount, North California	-10%	58%
Debusk and Wynn, 2011 [11]	Blacksburg, Virginia, United States	99%	99%
Li and Davis, 2009 [13]	College Park, Maryland Silver Spring, Maryland	-36% 100%	-3% 97%
Passeport and Hunt, 2009 [18]	Graham, North Carolina	58-63%	54%
Brown and Hunt, 2008 [15]	Rocky Mount, North California	72%	80%
UNITEN	Malaysia	76.06%-97.09%	45.31%-94.96%

V. CONCLUSION

Bioretention systems on a local scale in UNITEN is a pilot study that has a great potential to improve stormwater management in tropical climates. Preliminary results indicated that bioretention systems have the ability to remove TSS, turbidity, TP and TN significantly. Additional monitoring and analysis will be made for the long-term performance in terms of water quality and hydrologic aspects. With this conclusion, it is hoped that this research will help to support the design procedure and criteria of bioretention facilities as outlined in the MSMA, 2nd Edition with some recommendations to overcome the problem in implementing the bioretention system in Malaysia.

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