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The Effectiveness of Swale Drainage in Terms of Pollutant Removal and Rate of Infiltration

(Keberkesanan Saliran Berumput dari segi Pembuangan Pencemaran dan Kadar Penyusupan)

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ABSTRACT

Swale drainage is a broad and shallow drainage that is able to filter runoff before flowing to the main drain and river. This study is focused on the effectiveness of the swale drainage compared to concrete drainage, in terms of pollutant removal and its relationship with the infiltration rate. The chosen site is at Astaka field, in Selangor. The water quality of the outflow was tested to determine the water quality classes when compared to the Interim National Water Quality Standards (INWQS) for Malaysia. Chemical oxygen demand (COD), total suspended solid (TSS), ammonia nitrogen, pH and turbidity are the five parameters that were tested in the water quality test. The study of infiltration rate of swale outflow was done by using the Mini Disk Infiltrometer and was compared with that of the field without swale. Swale proved to be effective to remove about 40%-60% TSS, 10-70% COD and 30-80% ammonia nitrogen compared to the regular concrete drain. The water turbidity of the outlet is higher than that of the inlet for both types of drainage. Results show that swale has negligible effects towards the pH value. The pH value obtained shows signs of alkalinity of the water outflow. The water quality of the outflow at swale outlet achieved Class II according to the INWQS for Malaysia. Swale at Astaka field had a rate of infiltration of 1.8-2 cm/hour which indicates a smaller rate than the field without swale.

Keywords: Swale; water runoff; pollutant removal; infiltration rate

ABSTRAK

Saliran berumput adalah saliran yang luas dan cetek yang mampu menapis air larian sebelum ia mengalir ke dalam saliran utama dan kemudiannya ke sungai. Kajian ini memberi tumpuan kepada keberkesanan saliran berumput berbanding dengan saliran konkrit, dari segi penyingkiran pencemar dan hubungannya dengan kadar penyusupan. Tapak kajian yang dipilih adalah Padang Astaka, Selangor. Kualiti air di aliran keluar telah diuji untuk menentukan kategori kualiti air jika dibandingkan dengan Piawai Kualiti Air Kebangsaan (INWQS) untuk Malaysia. Permintaan oksigen kimia (COD), pepejal terampai (TSS), ammonia nitrogen, pH dan kekeruhan merupakan lima parameter yang diuji dalam ujian kualiti air. Kajian kadar penyusupan dilakukan dengan menggunakan alat 'Mini Disk Infiltrometer' dan perbandingan dilakukan dengan padang tanpa saliran berumput. Saliran berumput terbukti berkesan untuk menyingkirkan lebih kurang 40-60% TSS, 10-70% COD dan 30-80% Nitrogen Ammonia berbanding saliran konkrit. Kekeruhan air di aliran keluar pula adalah lebih tinggi daripada aliran masuk bagi kedua-dua jenis saliran. Keputusan menunjukkan saliran berumput tidak memberi kesan terhadap nilai pH. Nilai pH yang diperolehi menunjukkan tanda kealkalian pada aliran keluar. Kualiti aliran keluar saliran berumput mencapai Kelas II mengikut INWQS untuk Malaysia. Saliran berumput di Padang Astaka mempunyai kadar penyusupan sebanyak 1.8-2 cm/jam yang menunjukkan kadar penyusupan yang lebih rendah berbanding padang tanpa saliran berumput.

Kata kunci: Saliran berumput; air larian; penyingkiran pencemaran; kadar penyusupan

INTRODUCTION

Impervious area increases with rapid urban development. Therefore, water infiltration rates in the soil are becoming increasingly reduced, which results in more runoff (Zaiedy et al. 2016). Renewal of drainage such as replacing the drainage surface with pervious areas can promote water infiltration. The existing drainage is not efficient because the surface is built of concrete and only serves to drain water but there is no kind of filtration for the water runoff. Swales are open vegetated (generally grass) drains, which provide stormwater filtration prior before being discharged to downstream drainage systems or receiving rainfall (Deletic & Fletcher 2006). Generally, swale drainage works by reducing and filtering runoff. Hydraulically, the swales operate in three phases: completely infiltrating about a minimum 40% of storm events, reducing the total runoff volume for an additional 40% of storm events, and simply performing as flow conveyance with negligible volume attenuation for the maximum 20% of events (Stagge et al. 2012). According to Davies et al. (2012), the diminution in volume caused by filtration and the water quality is an important consideration because this contributes to the decrease of the entire mass of swale drainage pollutant. Yu et al. (2001) also stated that the main mechanism for reducing pollution in swale drainage is filtration by vegetation, particle settling and infiltration into the sub-surface zone. Swale drainage has been shown as one of the effective mediums that can reduce runoff pollution (Yu et al. 2001; Deletic & Fletcher 2006; Stagge et al. 2012; Mohamed et al. 2014). The removal of pollutant in the water from the runoff can improve the water quality of the river.

The work by Yu et al. (2001) is a study that compared the effectiveness of two swales in removing pollutant. The study tested swale drainages located in Taiwan and Virginia. To make a comparison, the experiments of the swale were also made with and without the presence of a check dam. Based on Yu et al. (2001) findings, TSS removal showed the highest percentage compared with other parameters. In addition, swale that has a check dam showed a higher percentage of TSS removal compared with one that has no check dam.

Besides total suspended solid (TSS), total nitrogen (TN) and total phosphorus (TP) are other parameters to measure the level of water pollution. Removal of nutrients in recent studies shows variant results. This is likely referable to the vegetation factor that is applied as the medium for filtration itself. High variability in nutrient removal can be ascribed, in part, as an external organic material, such as forage or other plants, which can get rid large quantities of nutrients (Yu et al. 2001).

Infiltration is one the most important criteria that have made swale the Best Management Practice (BMP) to manage urban stormwater. A higher infiltration rate allows a reduction in the runoff volume. Deletic (2001) developed a mathematical model in estimating sediment movement through grass. The sensitivity analysis demonstrated that the quantity of runoff primarily depends on the length of grass and soil hydraulic conductivity.

In an effort to find the infiltration capacity of five swales in Canada, Abida and Sabourin (2006) used a Single-Ring Infiltrometer to the swale which has perforated pipes within. According to Abida and Sabourin (2006), the infiltration capability of the swale decreased exponentially with time until a constant value was achieved. The range of initial infiltration rate of the swale was 3 to 13 cm/h and reached a constant rate range of 1 to 3 cm/h after 15-20 minutes.

Although there are many previous studies focusing on swale effectiveness in reducing non-point source pollutions and flow control (Bäckström, 2002; Lloyd et al. 2002; Stagge et al. 2012; Shafique et al. 2018), there are not many studies made on swale in a field. Past researches are focused on swale at side streets or highways. This has resulted in this study being carried out to look at the effectiveness of swale at a field. While there are similarities in terms of components, the difference of locations is likely to convey different results either in terms of the reduction of pollution or the rate of infiltration. Therefore, the aim of this study is to check the effectiveness of the swale drainage compared to concrete drainage, in terms of the pollutant removal and its relationship with the infiltration rate.

METHODOLOGY

SITE DESCRIPTION

The site for the experiment is Astaka field located at Petaling Jaya Landscape Department, the Petaling Jaya City Council (see Figure 1 and Figure 2). The Petaling Jaya Landscape Department is responsible for the implementation of the aforementioned swale drainage. The swale is designed based on the advisory they gained from Universiti Sains Malaysia (USM). This is one of the reasons that explains the similarity of the swale drainage in USM (Figure 3) and Astaka field. The construction method for both swales is similar. However, these swales have different dimensions as they are constructed at two different places.

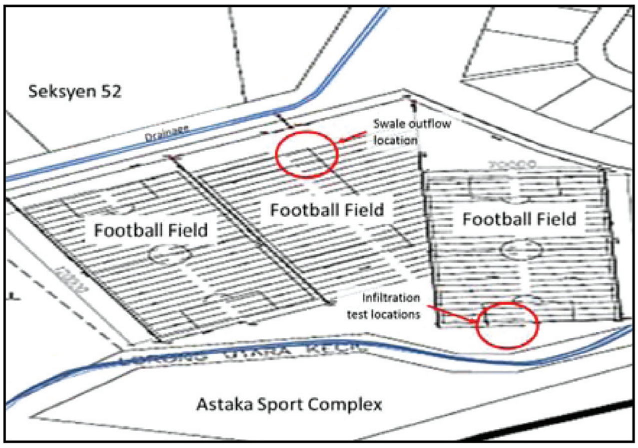

FIGURE 1. Location of Astaka field

FIGURE 2. Swale drainage at Astaka field

FIGURE 3. Swale drainage at USM (Mustaffa et al. 2016)

Swale drainage located in Astaka field consists of two modules that work as filtering tools. Both modules are installed side-by-side at the bottom layer of the swale. The modules (Figure 4) used in swale are made of polypropylene that has been recycled and will then be enfolded with rich filtering hydronet (geotextile). The filtering fabric hydronet has a rate of permeability of about 9.30 mm/s. To enhance the filtering process in the swale, sand was also placed on the modules. This allows the water filtering process to be performed by the sand river prior to filtering by geotextile. Once the module is installed, the swale components are complete. The type of grass used on top of the swale field is 'native cow grass'. The installation procedures of the swale can be found in Ghani et al. (2004) paper.

FIGURE 4. Type of module used in the swale (Ghani et al. 2004)

There were four swales at Astaka field. Each two swales were connected to an outflow drain. Therefore, there were two outflow drains placed at the tank (see Figure 5). This water runoff will stagnate in the tank before it was drained into the main drain. Although there were four swales at the Astaka field, only one swale was reviewed in this research paper due to the assumption that each swale had the same outflow and characteristics. Therefore, the comparison between the two swales was irrelevant. Astaka field also has existing drainages located at the edge of the field. Comparison between the existing drainage and swale was made to get the result for the review of the effectiveness of this grassy drainage.

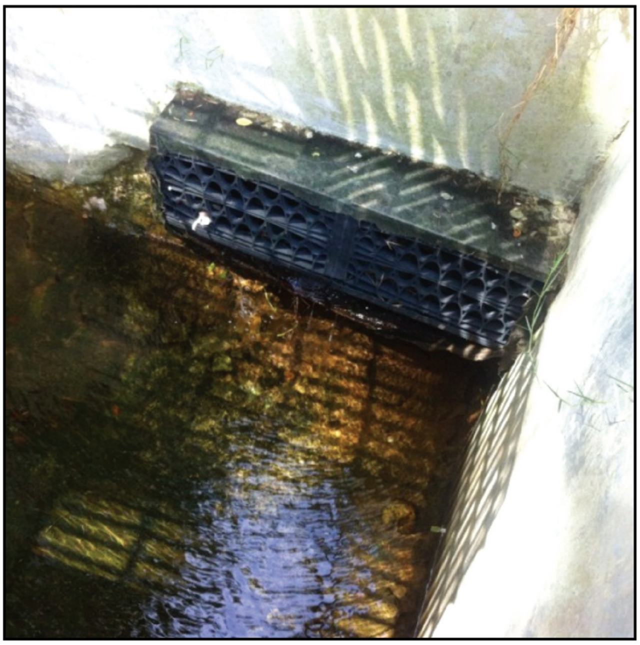

FIGURE 5. Outflow drains from swales at Astaka field

FIELD TEST

Fieldwork was carried out to measure the water infiltration rate in the swale drainage soil. This test was carried out in the swale drainage during a non-rainy day. This is because this test was to assess the level of water seeping into the ground. Mini Disk Infiltrometer tool used to measure the infiltration rate of the swale drainage is shown in Figure 6. The tool was filled with water and the volume of water seeping into the ground with time was recorded. This procedure was continued until a constant value was obtained. The constant value indicated the basic infiltration rate of the soil. Then, the infiltration rate was calculated using Equation (1).

$$I = \frac{\sqrt[3]{V_i - V_t}}{t} \tag{1}$$

where,

I = Infiltration rate (cm/s);
V_i = Initial reading of water (ml);
V_t = Volume of water at time t (ml);
t = Time (s).

FIGURE 6. Mini-Disk Infiltrometer used to get the infiltration rate

LABORATORY EXPERIMENT

Water samples of runoff were taken only after the rainfall was ended. This is because high pollution content was expected to be available after the rainfall ended. Higher pollution content was needed to assess the effectiveness of the swale drainage. Water samples were taken manually at the inflow and outflow of the swale in a period of 15 minutes, 30 minutes and 60 minutes later after the rain. The reason for taking the water samples according to the time mentioned was to allow time for the infiltration of runoff into the swale.

Natural storm runoff was used because of site restriction as the field is open for public. Thus, using synthetic runoff would cause many difficulties. The collected water samples were then tested in laboratories for five pollutant parameters, namely total suspended solid (TSS), chemical oxygen demand (COD), ammonia nitrogen, pH and turbidity. The outflow of the runoff from the swale was tested and compared with the outflow of the runoff from the existing concrete drain around the field, in which both were taken 60 minutes after the rainfall. Besides that, the swale and the non-swale outflows were then compared with the Interim National Water Quality Standards for Malaysia (INWQS) by the Department of Environment Malaysia (DOE 1985) as shown in Table 1, to indicate the water quality classes.

RESULTS AND DISCUSSION

SWALE AND EXISTING DRAIN

The concentration of the water quality parameters in the outflow of the existing concrete drain was much higher than the concentration of the water quality parameters in the outflow of the swale. Table 2 depicts the comparison of the swale and existing drain in which the samples were both taken 60 minutes after rainfall ended. Based on the table, TSS is shown to be the parameter that found the most effective parameter eliminated in the swale. On the contrary, no filtration occurred in the existing drain. Therefore, the TSS concentration was high in the concrete drain, depending on the location of the water sampling.

TABLE 1. Interim National Water Quality Standards for Malaysia (INWQS) classification for five parameters

		Classes					
Parameter	Unit	I	IIA	IIB	III	IV	V
TSS	mg/L	25	50	50	150	300	300
COD	mg/L	10	25	50	50	100	>100
Ammonia-Nitrogen	mg/L	0.1	0.3	0.9	0.9	2.70	>2.70
pH	-	6.5-8.5	6.0-9.0	6.0-9.0	5.0-9.0	5.0-9.0	-
Turbidity	NTU	5	50	50	-	-	-

TABLE 2. Comparison of water quality parameters of the swale and existing drain

Parameter	Unit	Swale	Existing Drain	Difference of Percentages (%)
Percentages (%)				
TSS	mg/L	16.67	188.57	91.2
COD	mg/L	29.60	150.96	80.4
Ammonia nitrogen	mg/L	1.40	2.24	37.5
pH	-	7.07	6.08	-
Turbidity	NTU	19.8	93.8	78.9

Swales were less effective to remove ammonia nitrogen. This was also proven by the previous studies, where they indicated that swale has limited effectiveness and high variability in removing nutrients (Mohamed et al. 2014; Yu et al. 2001). The pH unit also demonstrated the effects that can be disregarded because it did not have much difference. The pH was not affected by the presence of the swale. Turbidity also had a high percentage of the difference between swales and drain, as the percentage difference for TSS between both was high. This is because both turbidity and TSS parameters were interdependent.

WATER QUALITY CLASSES OF SWALE OUTFLOW

Table 3 shows the water quality classes of the swale outflow according to INWQS. The results also show the differences of outflow parameters concentration and water quality classes between different times after the rainfall ended. It was evident that TSS has been reduced and achieved class IIA when the time taken for water sample was 15 minutes after the rain. The TSS content of the swale outflow showed that the value was lower with the increasing time after the rain. Therefore, the water quality improved from Class IIA to Class I with time. According to Bäckström (2002), this can be due to the greater size of the particles contained in the water. Therefore, the removal of particles was governed by the law of Stokes and related to both the hydraulic residence time and particle size.

TABLE 3. Water quality parameters of the swale outflow according to INWQS classes

Parameter	Time after Rainfall event was ended (min)	Pollutant Concentration (mg/L)	INWQS Classe
TSS	15	25.33	IIA
	30	24	I
	60	16.67	I
COD	15	73.20	IV
	30	47.37	III
	60	29.60	IIB
Ammonia nitrogen	15	0.22	IIA
	30	0.78	IIB
	60	0.84	IIB
pH	15	7.80	I
	30	7.70	I
	60	7.07	I
Turbidity	15	23	IIA
	30	30	IIA
	60	19.8	IIA

Similar result was observed for COD as the classification of swale outflow was improved from Class IV to Class IIB when the time taken for the water sample was increased. The concentration of COD was lower with the increase of time after the rainfall. On the other hand, Ammonia Nitrogen quality changed to worse, which was from Class IIA to Class IIB. This was unlike any other parameters, where ammonia nitrogen indicated that the concentration of pollutants was higher when the time taken for water sample was increased.

In the event of a natural storm runoff, most of the nutrients (and other pollutants) are attached to the sediment. Therefore, the TSS reduction will have a direct effect on the removal of nutrients in runoff in a real situation (Mohamed et al. 2014). There was no significant change in pH over water sampling time. Water quality of the outflow was neutral in pH and in Class I. The turbidity was classified as IIA class when it was compared with the INWQS for Malaysia. Logically, water turbidity reduces when the suspended solids are decreasing. Therefore, the results obtained were related to the concentration of TSS.

INFILTRATION RATE OF SWALE AND FIELD WITHOUT SWALE

Figure 7 shows the infiltration rate of field with swale and field without swale. The infiltration rate of swale was increased to 5 cm/h in the first 90 seconds; then, the infiltration rate was decreasing until it achieved a constant rate of 3 cm/h. The dramatic increased in infiltration rate for the first 90 seconds was due to the wicking effect when the Mini-Disk Infiltrometer tool was first placed in the dry soil surface. According to Bhave and Sreeja (2013), initial compaction conditions of the soil, such as water content and dry density, could influence the infiltration characteristics of the soil.

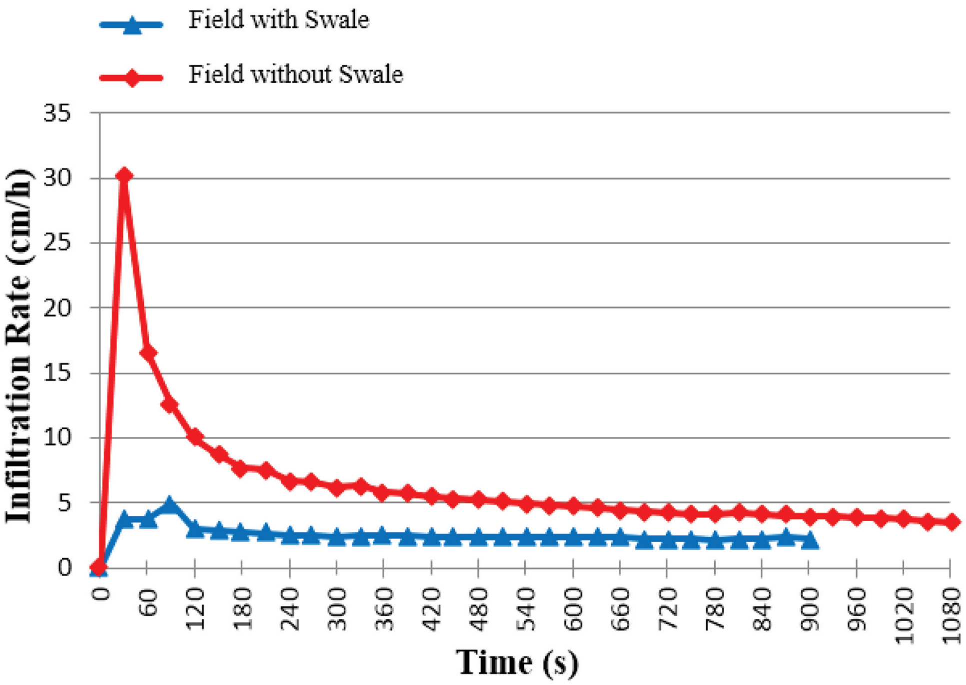

FIGURE 7. Infiltration rate of swale and field without swale

The rate of infiltration of the field without swale also showed the same reading form. Established along the graph, it can be seen that the rate of infiltration of the field was dramatically increased and then decreased over time as the soil conditions became more saturated. The rate of infiltration of the field without swale was increased from 0 cm/h to 30 cm/h in the first 30 seconds, then decreased to 6 cm/h after 330 seconds. However, constant infiltration was achieved at about 3.6 cm/h when the time reached 1,050 seconds.

The field without swale had a higher infiltration rate than the field with swale. This entailed that the water permeated faster into the soil without swale compared with the swale. This was in all probability due to the soil conditions and the module effect. A lower infiltration rate is good for the swale because it permits a longer time for the filtration process to occur.

CONCLUSIONS

TSS proved to be the most effective parameter to be reduced by the swale with a difference percentage for pollution concentration of 91.2%. However, a swale is less effective in reducing the amount of nutrient in the water. Difference of percentage for ammonia nitrogen concentrations in the outflow of the swale compared to that of the existing drain was lower by 37.5%. The pH value can be considered unaffected by the presence of the swale. This is because there was no substantial alteration in the pH values for both sites. Swale proved to be efficacious in reducing contamination. Swale infiltration rate showed a lower rate which was about 2 cm/h compared to that of the field without swale which was about 3.6 cm/h.

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