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A Performance Review of Grass Swales Channel in Malaysia

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Abstract: Grass swales is a series of vegetated open channel that are designed specifically to treat and attenuate stormwater runoff for a specified water quantity volume. The aim of this research is to study the hydraulics characteristics of grass swales and to study the flow attenuation and the flow conveyance of swale. Studies showed that grass swales are very efficient in stormwater quality control by reducing volume and peak flowrate. The previous studies the performance of grass swales in term of stormwater quantity control have been analyzed from the article and journal. The method that have been used including Mean-Section Method for measuring the flow discharge and Manning's equation to determine the hydraulic roughness. Rational method has been used to calculate the peak discharge, peak flow to determine the performance of swales as stormwater quantity control. Based on the review, the Manning coefficient has been studies and compared according to MSMA (2012) which is higher than 0.050. Besides, Grass swale in UTHM and USM Engineering Campus are very capable to attenuate the flow and convey stormwater runoff. At the end of the study, will be able to find out the hydraulic characteristics of grass swale and the flow attenuation and conveyance capacity of swale and whether the application of grass swale suitable to be applied as one of the best management practices (BMP) in mitigating flash flood in Malaysia.

Keywords: Storm Water Quantity, Drainage, Flood, Swales

1. Introduction

Malaysia is undergoing significant growth in the proximity of urban areas to meet the nation's economic development ambition. Major developments have led to massive migration of rural residents and migrants to those urban areas, putting pressure on local and state governments to create land for infrastructural development and housing for the expansion of urban populations. However, the increase of urbanization also has negative consequences on urban watershed ecosystems which has caused surfaces in natural ecosystems to shift to impervious surfaces. The constantly increasing impervious surface area resulting in an increasing in rainfall runoff volume and peak discharge [1]. In order to solve this issue, new urban drainage manual known as Storm Water Management Manual for Malaysia were introduced by Department of irrigation and Drainage (DID) [2].

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Grass swales has been identified as the best BIOECODS approach means to control stormwater runoff beside enhance the purification capability through vegetated filtration, and reducing the risk of flash flood in many cities such as roads and residential area. Grass swale can be characterized as an open channel mainly lined with grasses to treat, capture, and convey stormwater runoff [3]. According to [4], grass swale also capable of providing open space advantages as well as enhancing natural hydrological component of infiltration and evapotranspiration. In general, grass swale is a shallow open channel that can reduce stormwater volume and runoff rate due to permeable surface, and also act as living filters and shallow runoff through glass blades and across soils that provides better condition for particulate pollutant removal. Moreover, the ecological diversity and aesthetic appeal of urban settings are also can be improve by the application of grass swales. Therefore, grass swale can be the main solution for sustainable drainage system that have greater benefit toward ecological system and can be alternative solution to conventional drainage system.

1.1 Problem Statement

The rate of land urbanization in Malaysia has risen dramatically over the last decades and is expected to grow as Malaysian populations continue to rise. According to Department of Statistics Malaysia (DOSM) [5], urban population in Malaysia increase 71 percent in 2010 and projected to rise as more rural people migrate to cities because of economic factor. A study by [6] concluded that urbanization was identified as the major cause of increasing flash flood because of higher peak flow and lower of infiltration process that can damage the hydrologic cycle. Land clearing due to urbanization process has created many impervious surfaces such as sidewalk, road, and parking lots that will cause significant change to the hydrologic cycle in particular watershed area. The rapidly changing climate also threatens by the increase of extreme weather. Malaysia is often prone to flash floods since it situated along the path of southwest and northeast monsoon rains. A study by [7] found that there are rising high rainfall duration and intensity especially during north east monsoon season which raises the chances of flash floods. According to [8], the low efficiency of conventional drainage system also contributes to the increasing of flooding in urban area. The older conventional drainage system usually drains stormwater rapidly into the rivers resulting in river bank’s overtopping that cause flash floods. The application of grass swale is expected to reduce the risk of flash flood besides being able to improve water quality of watershed.

1.2 Scope of Study

The scope of study is focusing on the performance of grass swale as stormwater quantity control. This study reviews the previous research that have been conduct by another researcher from Malaysia and abroad. The location of this study are limited in Universiti Tun Hussein Onn Malaysia (UTHM) and USM Engineering Campus, Universiti Sains Malaysia (USM) since both location have applied the grass swales as the main drainage system. The parameter that involved in this study are the hydraulic characteristics of grass swales and the flow attenuation and conveyance capacity of swales.

2. Methodology

2.1 Data Collection

A comprehensive review of the worldwide literature source was conducted and reviewed systematically. Various search engines or repositories had been used including Science Direct, Scopus, Google Scholar, Springer Link, articles, technical reports, and thesis. The recorded articles collected are sorted based on the title and author to removes the duplicate article. All the articles collected have been screened based on the keywords and abstract.

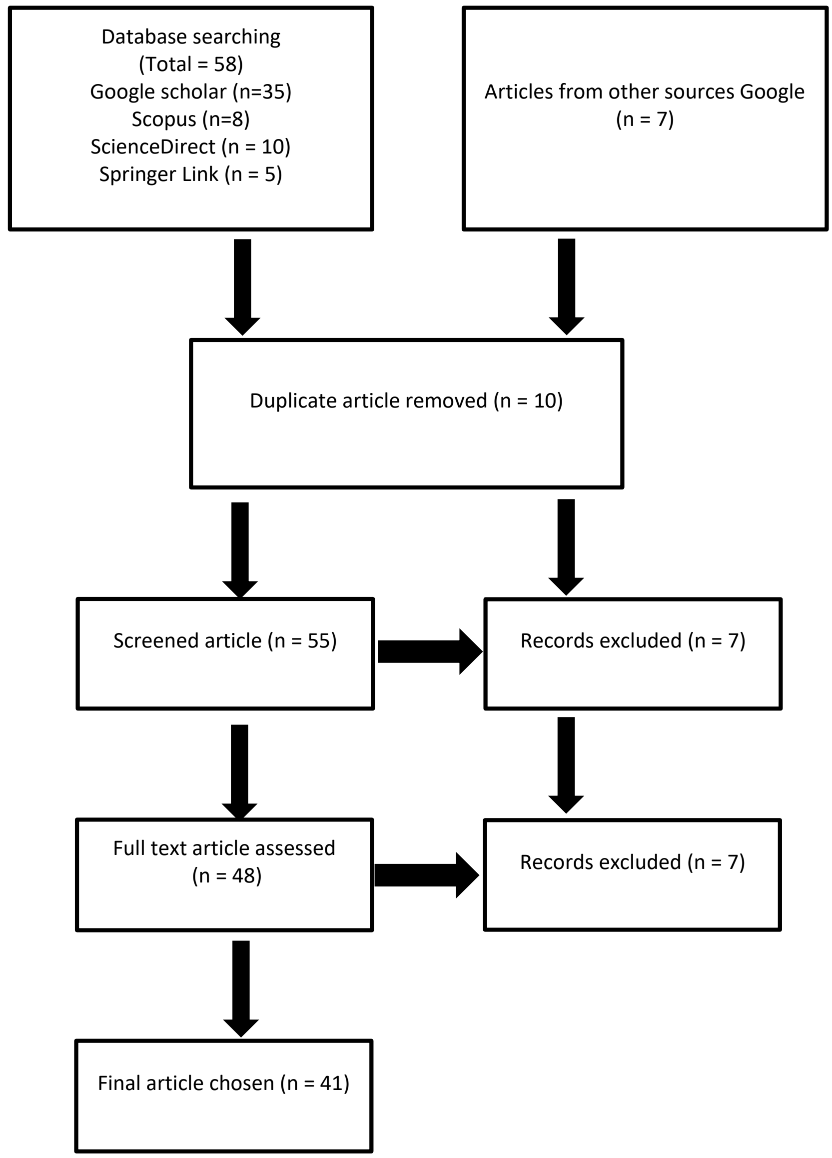

Figure 1: Flow of data collection from previous studies

2.2 Data Quality

The accuracy of the data utilised for these studies can be assessed based on the assumption of that these data are trustworthy and reliable. The validity of the data can be determined by the instrument used being accurate. The measurement was taken repeatedly to ensure the data is very precise. The precision of the data determines the reliability of the data.

2.3 Method

Method that it used to conduct this study is by using Mean Section Method. This method have been used to for estimating flow discharge when there is irregularity in the shape of swale. The continuity equation is by measuring flow rate (Q). To obtain the flow rate, simple formula that relates the average velocity of section (V) and the cross-sectional area of the flow (A). The formula is:

$$Q = VA \tag{1}$$

the calculation of profile average velocities was made dividing section into more subsection, and each subsection's edge are known as verticals. The example of calculation for subsection 1-2 shall be calculated:

For the calculation of cross-sectional area of subsection 1-2:

$$A = \left(\frac{y_1+y_2}{2}\right)(T_1) \tag{2}$$

For the calculation of average velocity in Subsection 1-2:

$$V = \left(\frac{V_1+V_2}{2}\right) \tag{3}$$

For the calculation of flow rate in Subsection 1-2:

$$Q = \left(\frac{y_1 + y_2}{2}\right)(T_1)\left(\frac{V_1+V_2}{2}\right) \tag{4}$$

For the estimation of peak flow discharge, the rational method has been used. Rational method is the process in which the maximum surface runoff in a drainage area is determined. To obtain the peak flow rate, Rational Method is very suitable due to its simple and systematic urban hydrology methods to computing storm water flows from rainfall. Application of the Rational Method is based on a simple formula that relates peak flow (Q), average rainfall intensity (I), runoff coefficient (C), and Drainage area (A). The formula can be expressed as:

$$Q = \frac{CiA}{360} \tag{5}$$

3.0 Results and Discussion

3.1 Design Criteria of grass swales

The proper design of grass swales is very important to enhance the performance and efficacy of grass swales as a stormwater quantity control. According to MSMA (2012), the most recommended design of cross section of swale in Malaysia is trapezoidal shape design. Table 1 below shows the swales profile of grass swales in different literature source in Malaysia.

Table 1: Swales profile of grass swales in different literature source in Malaysia

Literature Source	Location	Geometrical Properties		
		Flow Depth (m)	Top Width (m)	Bed Slope, S_o
Aliza *et al*. (2012) [10]	USM	0.731 – 0.742	3.100	0.001 – 0.002
Aliza *et al*. (2011) [11]	USM	0.283 – 0.327	3.100 – 3.00	0.001– 0.002
N Mustaffa *et al*. (2015) [12]	UTHM	0.085 – 0.390	1.800– 2.100	–
N Mustaffa *et al*. (2016) [13]	UTHM	0.390 – 0.225	1.800 – 3.00	0.002

Based on table 1, the geometrical properties from different swales location are compared with the design recommended by MSMA (2012). The table 1 above show the different range of flow depth. The maximum allowable flow depths according to MSMA (2012) should below 1.2 m included least freeboard of 50 mm. Based on the table 1 shows all the flow depth is in the range of 0.085 m – 0.742 m, means less than 1.2m which are in the allowable range. As for the top widths of swales, no guideline stated by MSMA (2012). All the swale's top width is in the range 1.8 m – 3.1 m. For designing of longitudinal slope, the slopes should be in the range of 0.001 – 0.005. According to table 1, both locations are in the allowable range which is 0.001- 0.002. Based on the criterion above, it can be concluded that grass swale at UTHM campus and USM Engineering campus has comparable design as recommended by MSMA (2012).

3.2 The Effect of Cross-Sectional Area on Flow Discharge

The performance of grass swales can be measured by the efficiency in lowering the flow discharge between cross-sections of swales. This study is conducted by [13]. The table below shows Table 2 below show the sectional area of swale, velocity, and flow discharge at three sections of swale.

Table 2: Velocity, and flow discharge at three sections of swale for three days

Section	Date	Area, A (m^2)	Velocity, V (m/s)	Flow discharge, Q (m^3/s)
A	31 March 2015	0.452	0.0270	0.01200
B	31 March 2015	0.496	0.0340	0.01700
C	31 March 2015	0.285	0.0800	0.02300

The larger cross-sectional area on 31st March 2015 indicate the possibilities of higher rainfall intensity during that day. The result shows the section B which has smaller area has the highest velocity and flow discharge. It can be concluded that larger area of swale can reduce the velocity and discharge of the swale.

3.3 The Variation of Roughness Coefficient of Swale

Roughness coefficient can be defined as friction that applied along the flow by the water channel. Previous study has revealed numerous factor that influencing velocity in a grass swales, including water area, maximum depth, maximum surface velocity, wetted perimeter, water surface slope, and coefficient of roughness. This study is conducted by [10]. Figure 1, 2, and 3 shows the graph of Manning's n against flow depth, velocity, and flow discharge.

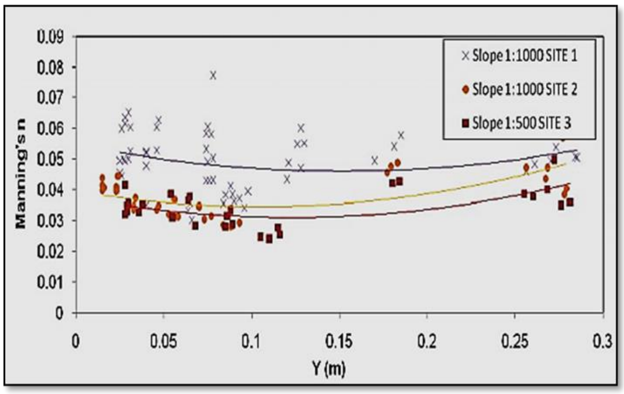

Figure 2: Graph of Manning's n against flow depth

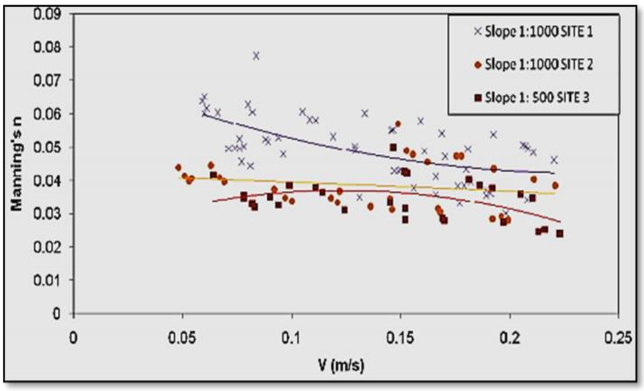

Figure 3: Graph of Manning's n against velocity

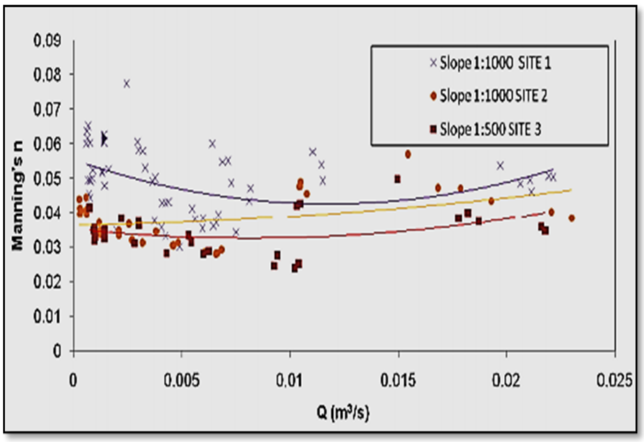

Figure 4: Graph of Manning's n against flow discharge

Figure 4 shows the manning coefficient's n relationship with flow depth, velocity, and flow discharge. The result shows the increasing of flow depth resulted in a lower Manning's coefficient value. The result also shows the Manning's coefficient decrease with the increase of velocity and flow discharge. However, Manning's n was observed to rise after flow depth beyond 0.10 m because of numerous factors related to the swale irregularities [13]. This can be concluded flow depth, velocity, and flow discharge can influence Manning's coefficient value.

3.4 Flow conveyance of swale

Flow conveyance is successful in reducing flash flood by reducing the volume of rainfall received by each swale. The performance of swale as a flow conveyance has been reported by [14] by comparing the flow discharge of swale with the peak flow. The table 3 shows result of flow discharge and peak flow of each swale.

Table 3: Result of flow discharge and peak flow of each swale [14]

Site	Runoff coefficient, C Minor system (≤ 10-year ARI)	Rainfall intensity, I (mm/hr)	Flow Discharge, Q (m^3/s)	Peak Flow, (m^3/s)
Swale 1	0.83	162.85	0.477	0.285
Swale 2	0.61	146.45	0.316	0.154

The results of Table 3 show flow discharge are larger than peak flow indicates that swales are highly effective in controlling stormwater runoff. As accordance to MSMA (2012) [2], the effectiveness of swales at the UTHM campus in collecting and transporting storm water runoff is between 48.7% – 59.7%, which suggests that swales at UTHM are capable of accommodating the quantity of precipitation each swale receives.

3.5 Peak Flow Attenuation of Swale

Peak flow attenuation is very important to evaluate the efficiency of swale in term of hydraulic capabilities. The performance of peak flow attenuation of swale has been reported by [15]. The table 4 below shows the reduction of volume and peak flow.

Table 4: The reduction in volume and peak flow [15]

Rain Event (2003)	Intensity (mm/hr)	ARI	Location Channel	Peak flow (l/s)		Volume (m^3)		Percentage Reduction (%)	
				Inlet	Outlet	Inlet	Outlet	Peak Flow	Volume
24/6	11	3 month	Surface	128	91	418.5	246.6	28.9	41.1
			Subsurface	79	32	134.1	16.2	59.5	87.9
26/6	31.6	6 month	Surface	45	22	105.6	31.2	51.1	70.5
			Subsurface	53	53	53.1	31.2	0	41.2
30/8	14.5	3 month	Surface	59	26	388.8	123.6	55.9	66.6
			Subsurface	41	50	119.1	90.9	0	23.7
8/9	13.8	5 year	Surface	59	26	4043.1	3043.2	55.9	24.1
			Subsurface	70	51	160.2	83.1	27.1	48.1
4/10	6.18	2 year	Surface	201	167	2202.9	1560	16.9	29.2
10/10	33.6	2 year	Surface	226	168	1711.8	1380.3	25.7	19.4
3/11	44.2	1 year	Surface	172	120	1134.6	599.4	30.2	47.2
			Subsurface	41	23	108.9	11.7	43.9	89.2
8/11	9.3	6 month	Surface	115	75	607.8	357.9	34.8	41.1

Based on table 4.5, the result shows the volume reduction for surface channels is in the range of 19.4% and 69.8 %, whereas the of peak flow decrease between 16.9% and 55.9%. This result shows that grass swales is very effective as stormwater quantity control.

3.6 Performance Comparison of Grass Swales in Malaysia and Abroad

Table 5 shows the comparison of runoff volume and peak flow reduction from different literature source at different location and Figure 5 shows the graph comparison of maximum range of volume and peak flow reduction from different literature source.

Table 5: The comparison of runoff volume reduction and peak flow reduction from different literature source at different location

Literature Source	Location	Runoff volume reduction (%)	Peak flow reduction (%)
A. Ainan *et al*. (2003)	USM Engineering Campus, Malaysia	19.4%- 69.8%	28.9% - 55.9%
Lucke et al. (2014)	University of the Sunshine Coast Campus, Australia	52%	61%
Stagge (2006)	Maryland, USA	46%-54%	50%-53%
Zaqout and Andradóttir (2021)	Gardabaer, Iceland	22%	13%

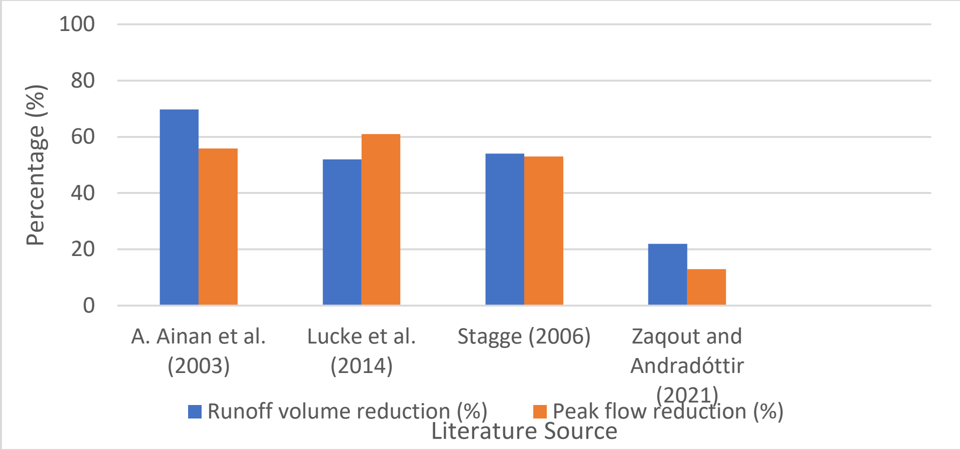

Figure 5: Graph comparison of maximum range of volume and peak flow reduction from different literature source

Based on this figure 5, the higher percentage of volume reduction reported by [15] shows the higher efficiency of grass swale in attenuating stormwater runoff. This is probably due to the design criteria and geometry of grass swale. The higher percentage of peak flow reduction reported by [16] is due to the infiltration factor. According to [16], the study was found higher infiltration rate due to minimal soil moisture content which decrease the peak flow. The previous finding [18] show the lowest percentage of volume reduction and peak flow attenuation which are 22% and 13% respectively. As stated by [18], the decrease in the swale's performance was mostly due to the accumulation of frost or snow during winter season. This study has concluded that the weather condition can influence the grass swale’s hydraulic capability to manage stormwater runoff.

4. Conclusion

A grass swale is one of the components of Bio-Ecological Drainage System (BIOECODS) that capable to convey stormwater runoff. Grass swale is very beneficial for human as well for the environment because it can enhance the water quality of water catchment area besides can mitigate the flash flood. Based on this study, the Manning coefficient for both location are higher than recommendation by MSMA (2012) which is 0.050. The performance for the flow attenuation of stormwater runoff has been proven by the reduction of flow discharge by each section of studies swale and flow conveyance of swales also has been proven according to MSMA (2012) that flow discharge are higher than peak flow. The comparison between case study area in Malaysia and abroad shows that grass swales is very suitable to be applied in Malaysia for alternative of conventional drainage system.

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