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The Effect of Grass Block Paving on Runoff Coefficient

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Abstract The growth of urban areas is overgrowing, which has an impact on changes in land use. Green land that functions as rainwater catchment is covered with an impermeable surface, so runoff will increase and infiltration capacity will decrease. The method that can be done to reduce runoff is by using an impermeable cover with green plants. The pavement model used is an environmentally friendly pavement that can function to reduce surface runoff. The surface runoff coefficient is an indicator of land conditions. Surface land with the pavement will produce a large runoff coefficient while on natural land the runoff coefficient will be small. The grass block paving experimental model allows it to be used more widely because it has pores that can reduce runoff and increase the volume of water that enters the soil. The test results show differences in the runoff coefficient resulting in the tested land cover variations. The average runoff coefficient on land with a sandy loam texture without pavement is 0.41. Meanwhile, the average runoff coefficient for grass block paving is 0.43. On land with impermeable pavement, the runoff coefficient ranges from 0.50 to 0.70.

Keywords Pavement, Grass Block, Coefficient, Runoff

1. Introduction

Flooding is a problem that is often encountered in various urban areas. One of the factors that influence the occurrence of flooding is the impact of changes in land use. Green open land has turned into residential areas, offices, industrial areas, and other uses [1]. In urban areas, in general, most of the land surface is land with good pavement, asphalt, concrete, and generally in the form of paving blocks. Various impacts that can arise from changes in land use due to pavement are increased surface runoff, inundation, flooding, and decreased infiltration capacity. Paving Block is a current trend used to arrange public areas because it has advantages compared to other materials.

The advantages of using paving blocks are that the installation process is fast, cheap, has a variety of shapes, and is easy maintenance. The impact of installing paving blocks is a reduced area of rainwater infiltration, decreased infiltration rate and capacity, and increased inundation [2]. The occurrence of flooding is also caused by changes in the water balance on the surface due to pavement [3]. This happens because most of the rainwater that falls on the surface will become runoff while the water that enters becomes reduced infiltration. If this process continues for a long time, it will cause a decrease in the groundwater level because the capacity of the water that enters the soil is minimal.

In an effort to maintain water balance in urban areas, it is very important to develop the use of porous pavement because it can increase infiltration capacity [4-6]. One of the porous pavements that can be developed is environmentally friendly paving blocks. Environmentally friendly paving blocks are in the form of paving blocks that provide space for rainwater to enter the ground. The paving being developed is in the form of porous/perforated paving blocks with fillers in the form of grass plants in the paving block holes. The grass installation in the paving block holes is intended to inhibit surface water flow so that rainwater that falls on the paving surface will enter the ground through the paving block holes. Developing porous pavement will reduce inundation due to rain, increase infiltration, reduce surface runoff coefficients, and reduce urban flood peak heights [7,8]. Likewise, according to [9], pavement with porous paving blocks can inhibit surface flow rates. Flooding in an urban area is generally due to high rain runoff that flows over the pavement surface. The runoff coefficient (C) is almost above 0.8, indicating that nearly 80% of rainwater becomes runoff and only 20% enters the soil. Coupled with the condition of the area where the drainage system is not available or not functioning, every time it rainfall, it will be followed by flooding. The runoff coefficient is the ratio between the flow during rain and the total volume of rain in a certain period [10,11]. Runoff coefficients for different types of land cover, asphalt, concrete, soil, and vegetated land [12]. Vegetated land cover has a smaller runoff coefficient than land cover with the pavement. The more vegetation on the land with coefficient runoff (C), the better so that the surface runoff will be smaller while the capacity of water that enters the soil will be greater. The runoff coefficient of a watershed varies greatly depending on land use conditions and other flow parameters [13,14]. In reducing the amount of surface runoff to reduce the occurrence of flooding, it is better for pavement construction to use porous materials [15-17]. Furthermore, according to [18] providing channels on the pavement with concrete paving blocks can also reduce the occurrence of surface runoff because the water flows directly into drainage channels.

2. Material and Methods

2.1. Grass Block Paving

The material used in this research is grass block paving in the shape of a hexagon (hexagon) which is given a hole inside that functions as a place for grass plants. The dimensions of the paving are the length of each side: 10 cm and the height: 6 cm. The grass block paving material used is shown in Figure 1.

Figure 1. Grass block paving

2.2. Sandy Clay Soil

The soil used in the study is sandy loam soil. Sandy clay soil is included in soil with a slow ability to pass water as shown in Figure 2.

Figure 2. Sandy clay soil

2.3. Grass

Figure 3 shows the grass used as a pore filler for block paving is Korean Lawn Grass (Zoysia Japonica). Besides its aesthetic function, this grass also quickly absorbs water so that it can avoid standing water. Japanese grass is popular and widely used as a top choice in garden grass. In general, grass has long size, but this grass is uniformly short with a rough texture.

(a)

(b)

Figure 3. (a) (b) Korean lawn grass (Zoysia Japonica)

2.4. Rainfall Simulator

Rainfall simulator consisting of a test basin with a size of 200 cm x 100 cm x 35 cm and a water reservoir connected to a pipe network as rain output. The depth of rain in the rainfall simulator is measured using a manual rain gauge. The model of the rainfall simulator is shown in Figure 4.

2.5. Rainfall Intensity

Rainfall intensity is the amount of rain expressed in rain height or volume per unit of time (mm/hour, mm/min, mm/sec) that occurs during a period of concentrated rainwater. The amount of rainfall intensity varies depending on the duration of the rainfall and the frequency of occurrence. High-intensity rainfall generally lasts for a short duration and covers a small area. Rain covers a large extent, rarely with high intensity, but can last for quite a long time. The combination of high-intensity rain with long duration rarely occurs, but if it happens, it means that a large volume of water is being poured out of the sky. To get the amount of rain intensity obtained from a rain simulation tool (rainfall simulator), the equation is used:

$$\mathrm{I} = \frac{d\ (mm)}{t\ (jam)} \tag{1}$$

$$\mathrm{d} = \frac{V\ (mm^3)}{A\ (mm^2)} \tag{2}$$

With:
I: rainfall intensity (mm/hour)
d: rainfall depth (mm)
t: time (hour)
A: rainfall area (m^2)
v: water volume (mm^3)

Figure 4. Rainfall simulator

2.6. Surface Runoff

Surface runoff is rainwater that flows over the land surface into rivers, lakes, or the sea. Runoff occurs when the soil can no longer infiltrate surface water because the soil is saturated. Runoff can also occur when rain falls on an impermeable surface such as pavement. The various factors that influence surface runoff can be grouped into those related to climates, such as rainfall, and those related to watershed characteristics.

The effect of vegetation and farming methods on surface runoff can be explained by the fact that vegetation slows down the runoff, increases the amount of water retained above the soil surface, and decreases the runoff rate. In urban areas, the coefficient of surface runoff is strongly influenced by pavement conditions. Pavement material has a role as a cause of urban flooding.

2.7. Runoff Coefficient

Surface runoff coefficient (C) is a value that shows the ratio between the amount of flow and the amount of rainfall. The flow coefficient value is one indicator to determine a watershed's physical condition [12]. The value of C ranges from 0 to 1. The value of C = 0 indicates that all rainwater is intercepted and infiltrated into the soil, while C = 1 indicates that all rainwater flows as runoff. In good watersheds, C values are close to zero (0); the more damaged a watershed is, the closer C prices are to one [1]. The surface runoff coefficient (C) can be calculated using the following formula and Table 1 shows the value of the coefficient C for various land covers

$$Q = C \times I \times A \tag{3}$$

$$C = \frac{Q\ (mm^3/jam)}{I\ (mm/jam)\ \times\ A\ (mm^2)} \tag{4}$$

With:
Q: discharge (mm^3/jam)
C: runoff coefficient
I: rainfall intensity (mm/jam)
A: rainfall area (m^2)

Table 1. The runoff coefficient of different land types

Land Type	Runoff Coefficient
Building surface, concrete, or asphalt pavement road	0.85 – 0.85
Large rubble paved road, or gravel road with an asphalt surface	0.55 – 0.65
Gradation macadam road	0.40 – 0.50
Masonry brick or gravel road	0.35 – 0.40
Unpaved soil road	0.25 – 0.35
Garden or green land	0.10 – 0.25

Source: Zhifeng Li, et al, [19]

3. Results

3.1. Rainfall Depth

Rainfall depth values were carried out by modeling on a rain simulator with a duration of 15, 25, 40, and 60, minutes. Rain depth for each duration of rainfall is recorded with a manual rain gauge.

Table 2. Rainfall depth average

Durasi (Minute)	Running Test	Rainfall Depth (mm)	Average (mm)
15	1	35,561	38,548
	2	41,716	
	3	38,369	
25	1	63,168	64,103
	2	66,443	
	3	62,700	
40	1	104,344	102,160
	2	99,197	
	3	102,940	
60	1	154,410	153,630
	2	150,199	
	3	156,282	

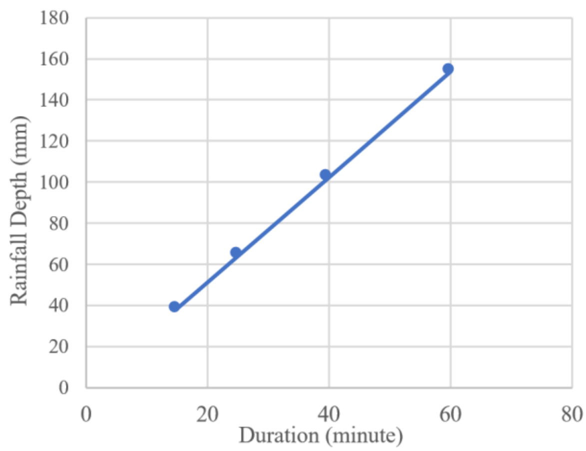

Figure 5. Relationship between duration and rain depth

Table 2 and Figure 5 show that the recorded rainfall depth has a linear pattern. This is because the rain outflow from the rainfall simulator is set constant to obtain depth in a fixed time function.

3.2. Runoff

The runoff volume on grass block land is larger than on land without pavement. Land without rainwater pavement can be infiltrated immediately, whereas with grass blocks rainwater enters the soil surface through the paving holes. Figure 6 shows that surface runoff only occurs after the rain duration reaches 60 minutes. So that the addition of Japanese grass to paving blocks is very influential in reducing runoff volume and can increase infiltration capacity.

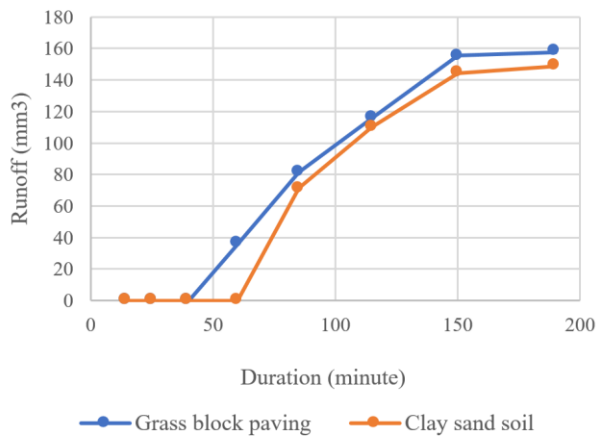

Figure 6. The trend of surface runoff volume on a grass block

3.3. Rainfall Intensity

The intensity of rain shows the ratio between the depth of rain obtained from measuring the height of rain divided by the time of occurrence of rainfall. At each increase in the duration of rainfall, the depth of rain recorded on the rain gauge also increases. The rainfall intensity used in this study is an average of 153 mm/hour. The recording of rain intensity values is shown in Table 3 below.

Table 3. Average rainfall intensity

Durasi (Mnt)	Test	Rainfall Depth (mm)	Rainfall Intensity (mm/hr)	Average (mm/hr)
15	1	35,561	142,245	153,475
	2	41,716	164,704	
	3	38,369	153,475	
25	1	63,168	151,603	153,849
	2	66,443	159,464	
	3	62,700	150,480	
40	1	104,344	156,516	153,241
	2	99,197	148,795	
	3	102,940	154,410	
60	1	154,410	154,410	153,630
	2	150,199	150,199	
	3	156,282	156,282	

3.4. Runoff Coefficient

The surface runoff coefficient is calculated using equations (2.3) and (2.4). The runoff coefficient value indicates the ratio between the runoff volume with the rain intensity and the test area. The average runoff coefficient on sandy loam soil is 0.41, while on grass block paving it is 0.43. Meanwhile, according to [19] the runoff coefficient in areas covered with paving ranges between 0.35 – 0.40. The magnitude of the runoff coefficient on sandy loam soil and grass block paving is shown in Table 4 and Figure 7.

Table 4. Runoff coefficient clay sand soil and grass block paving

Rainfall Duration (Minute)	Coefficient Runoff (C)	
	Clay Sand Soil	Grass Block Paving
15	0.39	0.41
25	0.39	0.42
40	0.40	0.44
65	0.42	0.43
80	0.43	0.44
100	0.43	0.44

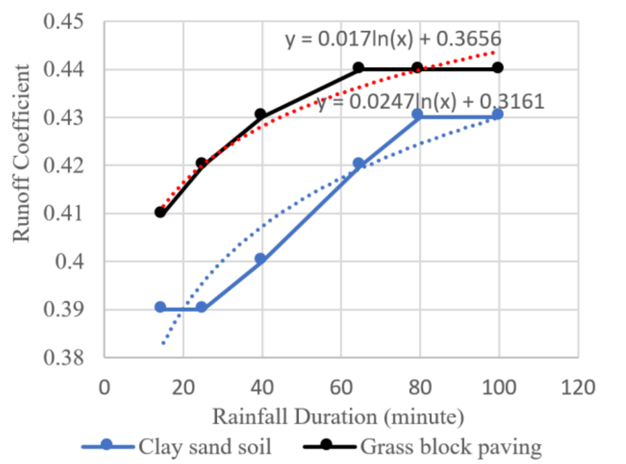

Figure 7. Trend coefficient runoff

Based on Table 4 and Figure 7, grass block paving significantly reduces surface runoff. This is indicated by the runoff coefficient which is almost close to the runoff coefficient of sandy clay soils.

4. Discussion

Grass blocks have advantages over other pavements because they are able to reduce surface runoff to subsurface flow through an infiltration process. The surface runoff coefficient is smaller because rainwater is retained by the grass and enters the ground through the holes in the paving blocks. The value of the runoff coefficient on the grass block is also influenced by the type of subgrade soil. Sandy soil has a structure and texture in the form of granules with large cavities so that sand can absorb water. In contrast to sandy soil, sandy loam soil has a denser structure and texture so this soil is relatively slow in absorbing water. This study used sandy loam soil so that the runoff coefficient is greater than sandy loam without pavement. However, surface runoff on grass blocks begins to occur after the rain duration ranges from 40-60 minutes. After that duration, the runoff coefficient increased and reached constant at 80 minutes of rain duration. The constant runoff coefficient is 0.44, while in sandy loam soil, it is 0.43. This shows that almost 44% of the rain that falls on the surface of the grass block becomes subsurface flow while 54% becomes surface runoff. This shows a very significant value that grass block paving is very effectively used for pavement and can increase infiltration capacity. The utilization of grass block paving has very high effectiveness in reducing surface runoff with the resulting smaller runoff coefficient. Planning for the development of urban areas is expected that the land that will be used as a parking lot use grass block paving in addition to reducing flooding aesthetically has a high aesthetic value.

5. Conclusions

From the results of the analysis, several conclusions can be drawn as follows:

a. Grass Block Paving is very good for land that is given pavement because it can reduce the volume of surface runoff and can increase the volume capacity of infiltration
b. Surface runoff on grass block paving only occurs after the duration of rain reaches 50 minutes
c. The surface runoff coefficient for grass block paving is 0.43, almost close to the runoff coefficient for sandy clay soil, while for paving without grass, the coefficient value is 0.50 – 0.70.

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