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ECO DRAINAGE MODEL USING POROUS PAVING BLOCK WITH SIEVE WASTE CORAL FILLER AND PUMICE STONE

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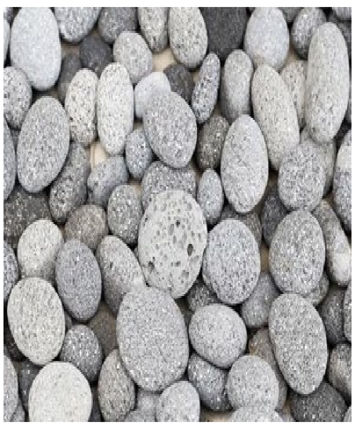
Graphical abstract



Abstract

Environmental problems in the form of changes in land use have an impact on the degradation of land carrying capacity. Rapid urban growth with various paving materials causes various problems such as reduced water absorption, increased surface runoff and puddles and reduced infiltration and percolation capacity. The most extreme condition of paving use is flooding. In overcoming the problem of reducing the impact on waterproof pavement in residential, office and industrial areas, pavement modification with the eco-drain concept is needed. The eco-drain concept is to use porous paving blocks with fillers. The paving blocks used are grass blocks whose cavities/pores are filled with natural stone in the form of sifted waste rock and pumice. The purpose of the study is to obtain an environmentally friendly pavement model that can reduce surface runoff, prevent puddles and conserve groundwater. The modeling results show an average reduction in surface runoff on paving blocks with sieved waste filler of up to 20%, while with pumice filler the reduction in runoff is greater, up to 25 - 30%. The value of the surface runoff coefficient (C) for hexagonal paving block land cover ranges from 0.327 - 0.492. While the value of the runoff coefficient for porous paving blocks with sieved waste stone filler is: 0.302 - 0.411 and for paving block land cover with pumice filler is 0.267 - 0.396.

Keywords: paving, grass block, waste, pumice, runoff coefficient.

1.0 INTRODUCTION

Land use change in urban areas has a very wide impact, especially the increase in the frequency of flood events [1]. The land changes that occur are very extreme, as shown by the reduction of green areas to become the center of urban growth, settlements, and industrial areas [2]. Various consequences caused by these changes are in the form of reduced water infiltration due to land surface pavement [3,4]. The pavement used is in the form of waterproof pavement with concrete, asphalt, and paving materials so that rainwater that falls on the surface is mostly runoff. By using a waterproof surface layer, the infiltration capacity becomes very small [5]. Almost 80% of rainwater that falls on the waterproof surface layer will be runoff and only 20% have the chance of infiltration [6]. Surface flow occurs when the intensity of rain exceeds the soil infiltration capacity, in which case the soil has been saturated with water, causing inundation or flooding problems. With a decrease in infiltration, when the intensity of rainwater is high, it will certainly trigger the problem of inundation or flooding which can hinder activities and even be detrimental. Sustainable drainage systems can reduce the occurrence of inundation in built-up or developing areas [7].

A solution to this problem is to accelerate the infiltration of rainwater into the soil by increasing the rate of infiltration into the soil, opening pores in the fields that have been concreted by replacing them with permeable pavement, thereby reducing the surface flow that is a factor in the problem of the occurrence of a puddle [8]. The paving block is a building material made from a mixture of Portland cement or similar hydraulic adhesives, water, and aggregate with or without other additives that do not reduce the quality of concrete [9]. The variation in the shape of paving blocks has different abilities in reducing surface runoff, as well as the spacing/distance between paving blocks affects the amount of surface runoff. According to [10]; paving blocks can reduce surface runoff by 40 – 67 %.

To support SDG 6, namely Clean and Water Sanitation, especially in reducing flood disasters, the green drainage system method (eco drain) uses porous pavement [5]. Porous paving blocks with the use of natural waste materials as fillers are one of the most appropriate ways to overcome surface runoff and groundwater preservation. So this method is very suitable for use in settlements, office yards, industries, and other public spaces that use pavement. The method of pavement with porous paving blocks with natural rock filler is a new solution to utilize waste to reduce surface runoff on land with pavement, in addition to technically functioning in construction, it can also be used as a means of preservation/conservation of groundwater/groundwater [11]. The process of surface flow is rainfall that falls on the ground surface in an area. First, the rain will enter the ground as infiltration water [12]. Infiltration will take place continuously as long as the water is still below the saturation capacity. If the rain continues, and the saturation capacity has been met, then the excess rainwater will remain infiltrated which will then become location water and part of it will be used to fill the ground surface basin as surface storage (depression storage), then after the surface storage is met, the excess water will become a puddle called surface mooring (detention storage). Before becoming a surface flow (overland flow), the excess rainwater above partially evaporated (evaporation) even though the amount was very small [13].

According to the available holes in the paving block have a significant influence on increasing the infiltration capacity, the larger the hole, the smaller the surface runoff and the greater the infiltration capacity. The addition of grass between paving blocks can also affect surface runoff. In paving blocks without adding grass, mini elephants have a larger coefficient value. The resulting runoff coefficient includes: soil with runoff coefficient values ranging from 0.39 - 0.44, paving block stacking bricks with runoff coefficient ranging from 0.42 - 0.46, paving block woven mats ranging from 0.41 - 0.45, paving block with brick stacking pattern with the addition of mini elephant grass with runoff coefficient ranging from 0.40 - 0.45, and paving block pattern woven mat with the addition of mini elephant grass with runoff coefficient ranging from 0.36 - 0.41 [14]. The characteristics of each land cover material used affect the surface flow discharge that occurs. The study was conducted with variations in rain intensity of 50 mm/hour, 55 mm/hour, and 60 mm/hour. The slope of the land used is 5%, 10%, and 15% with the type of square paving and hexagon paving [14]. The results show that the use of paving blocks can reduce surface runoff by 40% to 67%. Each type of paving has a different ability to reduce surface flow and the amount of infiltration is influenced by the amount of spacing resulting from the installation of paving [10]. The use of pavement with porous paving blocks with fillers in the form of sieve rock waste and pumice stone will be able to reduce the volume of surface runoff and reduce the runoff coefficient.

2.0 METHODOLOGY

2.1. Paving Block

The paving is on the market, is commonly used by the public, and meets technical specifications for pavement with K200 compressive strength. In this experimental modeling, hexagonal paving and grass blocks with dimensions of 10 cm in length on each side and 6 cm thick.

2.2. Waste Stone Sieve And Pumice Stone

The filler material used is waste material in the form of sieved rock waste and pumice waste. The diameter of the filler material is not uniform, namely 1 -3 cm. The filler material is inserted into the paving block hole so that surface runoff will enter the soil through the cavity of the filler material. Figures 1 and 2 show the filler material used in the modeling.

Figure 1 Waste rock sieve.

Figure 2 Waste pumice stone

2.3. Sand

Sand material is used as a thin layer under the paving block so that the surface of the paving block becomes flat. The thickness of the sand layer is 5 cm thick.

2.4. Rainfall Simulator And Rainfall Recorder

Rainfall simulators are used as a tool to perform modeling. The series of simulators consists of water reservoirs, runoff collection gutters, runoff reservoirs, infiltration and percolation reservoirs as well as porous paving block placement tubs. Rainfall recorders are used to measure the intensity of rainfall.

2.5. Rainfall Uniformity Analysis

The coefficient of Uniformity (CU) is one of the factors that indicate the distribution of water distribution. The CU has a significant influence on the distribution of rain that occurs in modeling. Research on uniformity in sprinkler irrigation systems was first carried out by [15], therefore until now the equation is known as uniformity coefficient (CU). The value of the CU is shown in Table 1.

Table 1 Uniformity coefficient (CU) values and their classifications.

Coenfficient Uniformity	Classification
91% - 100%	Exellent
90% - 81%	Good
80% - 71%	Pretty good
70% - 56%	Not good
<55%	Not eligible

The value of CU must reach a figure above 70%, with the diameter of the rain approaching the field, which is 1 mm to 7 mm, which means that the rainfall simulator works well. The CU value = 100% is impossible to achieve where this value indicates that the emission is completely uniform. The CU can be calculated using the following equation 1.

$$CU = \frac{\text{Mean Rainfal Intensity} - \text{Mean Deviation}}{\text{Mean Rainfall intensity}} x\ 100\% \quad (1)$$

$$\text{Mean deviation} = \frac{\sum|X - \bar{X}}{N} \quad (2)$$

with: X = data value, $\bar{X}$ = average of data , N = amount of data

2.6. Runoff coefficient (C)

The runoff coefficient (C) is defined as the ratio between the peak rate of surface flow to the intensity of precipitation. The main factors that affect the C value are soil infiltration rate, ground cover crops, and rainfall intensity [16] The main factors that affect the C value are the rate of soil infiltration or the percentage of impermeable land, the slope of the land, the land cover crops and the intensity of rainfall. The runoff coefficient also depends on the nature and condition of the soil. Other factors that affect the value of the runoff coefficient are groundwater, soil density, and soil porosity [17]. A small C value indicates that a watershed is still in good condition, on the contrary, a large C value indicates a watershed that has been damaged. The value of the runoff coefficient (C) from the above definition can be translated into the following rational formula :

$$Q = C.I.A \quad (3)$$

with: Q = flow discharge (litre/second), I = rain intensity (mm/hour), A = test area (cm^2), C = runoff coefficient

2.7. Installation Of Paving Blocks

Eco-Dranase by utilizing pavement using porous paving is installed with the same standard pattern as hexagon paving, but the porous or perforated paving in the paving hole is filled with waste material in the form of natural sieve waste and pumice waste. The waste is an unused material which is very large. By filling the paving pores, utilizing the waste will be able to reduce surface runoff and increase infiltration. Thus, many benefits are obtained, namely: reducing flooding/inundation, increasing infiltration, groundwater conservation, and environmental conservation. The eco-drain installation system is shown in Figures 3 and 4 below.

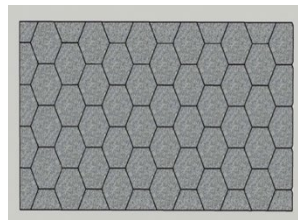


Figure 3. Installation pattern hexagon paving

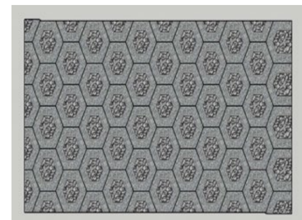


Figure 4. Installation pattern paving with filler

3.0 RESULTS AND DISCUSSION

3.1. Type of soil

The purpose of this test is to determine the type of soil that will be used as the base layer of paving blocks. The results of the soil grain gradation test are shown in Table 2.

Table 2. Percentage of grain gradation

Type of soil	%
Gravel	3.8
Dust	50.4
Clay	1.8
Sand	44

Based on the data presented in Table 2. above, the analysis results show that the percentage of soil grains is as follows: gravel at 3.8%, dust at 50.4%, clay at 1.8%, and sand at 44%. With the percentage data available, the next step is to describe the results in a soil texture chart to identify the soil type from the samples taken.

3.2. Uniformity Of Rainfall Intensity

Based on the results of measuring the uniformity of rainfall intensity in the modeling, the average rainfall intensity produced is 152 mm/hour with a 2 mm/hour deviation. The uniformity coefficient value achieved was 99% with excellent criteria. The uniformity coefficient shows that the magnitude and distribution of rainfall intensity at each test point have almost uniform values. The analysis of the uniformity value of rainfall intensity is shown in Table 3 below.

Table 3 Uniformity coefficient

Number of test	Rainfall Intensity (I) (mm/hour)
1	153
2	152
3	154
4	150
5	151
Mean	152
Mean Deviation	2.00
CU	99 %

3.3. Rainfall Intensity

Rain intensity shows the relationship between the depth of rain and the duration of rain. The calculation of rain intensity is obtained from the results of measuring the average depth of rain divided by the duration of the rain event. The results of the analysis of rain intensity with durations ranging from 15 minutes, 30 minutes, 45 minutes, 60 minutes, 80 minutes, 100 minutes, and 120 are shown in Figure 5.

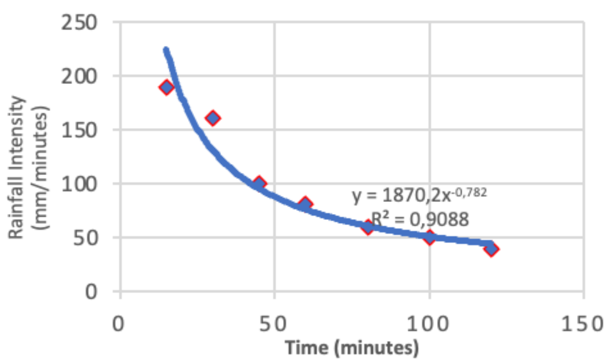


Figure 5 Rainfall intensity in modeling

3.4. Surface Runoff

The use of waste sieves and pumice as fillers in porous paving blocks can reduce surface runoff and increase the volume of water entering the soil very significantly. The average reduction in surface runoff on paving blocks with waste sieve filler is up to 20%, while with pumice filler the reduction in runoff is greater, up to 25-30%. This shows that eco-drainage by utilizing porous paving blocks with fillers is very effective, environmentally friendly, and increases groundwater conservation as shown in Figure 6. The reduction in runoff volume of 20% - 30% is due to an increase in infiltration and percolation capacity through the pore holes in the paving block. The role of waste rock sieves and pumice waste as a space for water to enter the soil in greater quantities. This is due to the availability of cavities in the filler rock which causes runoff to enter the soil without obstruction.

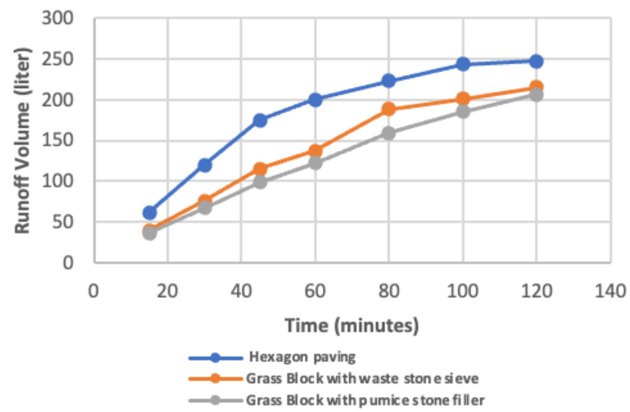


Figure 6 The volume of runoff of each paving block.

3.5. Runoff coefficient

The runoff coefficients in hexagon and grass block paving blocks with sifted waste rock filler and pumice stone showed very significant differences. Hexagon paving provides an opportunity for water to enter small soil but this is because part of the paving surface is closed. Grass blocks with siltstone filters, sieves, and pumice stones have the advantage that surface runoff water can enter the soil more quickly and in a very fast time. Rainwater that falls on the surface of the grass block can be drained through the grooves available on the grass block to the pores filled with waste stones, sieves, and pumice. Using equation 3, the value of the runoff coefficient in each paving block is obtained as shown in the following figure 7.

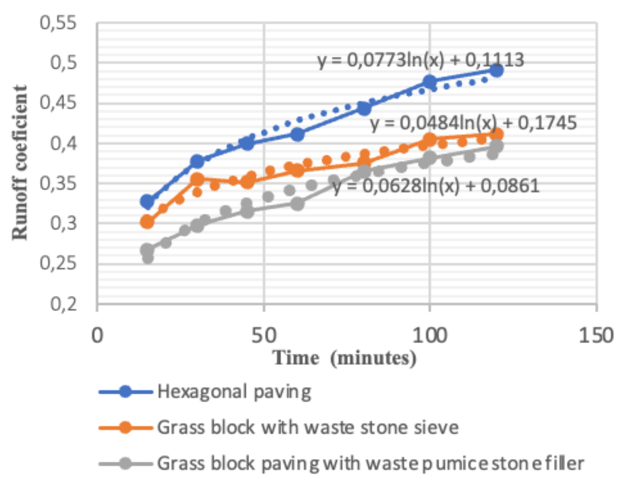


Figure 7 Surface runoff coefficients on each paving

Based on figure 7 shows using paving blocks for pavement requires special treatment to be able to increase the occurrence of infiltration into the soil, in addition to reducing the occurrence of inundation or flooding, it can also be used for groundwater conservation and increase the elevation of groundwater level. The surface runoff coefficient in the paving block shows that the presence of holes on the surface plays a role in providing opportunities for water to enter the soil. The holes on the surface of the paving block are filled with natural materials as a filtration medium to cover the holes so that they are not dangerous to pedestrians. The value of the surface runoff coefficient (c) in the paving block is for hexagonal paving block with an impermeable surface, which ranges from: 0.327 – 0.491, porous paving block with sieve waste rock filler, which is: 0.302 – 0.411, and paving block with pumice stone filler, which is: 0.267 – 0.396. Meanwhile, according to Gueen (1989), the value of the runoff coefficient for paving blocks ranges from 0.5 to 0.7. Based on the runoff coefficient value produced from porous paving blocks with fillers, the results are smaller than the standard paving block runoff coefficient set.

4.0 CONCLUSION

Based on the results of the research, several things can be concluded, including the following:

1. The surface layer on the paving block has a very significant contribution to producing surface runoff
2. The average reduction of surface runoff on paving blocks with sieve waste filler is up to 20%, while with pumice stone filler, the reduction in runoff is greater, which is up to 25-30%.
3. The surface runoff coefficient (c) in porous paving blocks with filler material shows a very small runoff coefficient value compared to the runoff coefficient in impermeable paving blocks. The value of the runoff coefficient in hexagonal paving blocks is: 0.327 – 0.491, porous paving blocks with sieve waste rock filler, namely 0.302 – 0.411, and paving blocks with pumice stone filler, namely 0.267 – 0.396.
4. This research is still limited to the basic soil, namely sandy clay and it is very necessary to research soils with other textures.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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