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EFFECTS OF RAINFALL INTENSITIES AND AGGREGATE SIZE ON SEDIMENT CONCENTRATION AND HYDRAULIC PARAMETERS

Zuliziana Suif[a,*], Maidiana Othman[a], Nordila Ahmad[a], Mohd Asri Md Nor[a], Siti Zulaikha Baharom[b]

[a] Department of Civil Engineering, Faculty of Engineering, National Defence University of Malaysia, Sungai Besi Camp, 57000 Kuala Lumpur, Malaysia
[b] Royal Engineer Regiment, Kuala Lumpur, Malaysia

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ABSTRACT

The aim of this study was to investigate the relationship between the effects of rainfall intensity and aggregate sizes on sediment concentration and hydraulic parameters. Flow velocity, flow width, shear stress and stream power are the hydraulic parameters. The impact of various rainfall intensities with differing aggregate sizes ($D_{1.18\ mm}$ and $D_{2.00\ mm}$) was also studied. Under the rainfall simulator, the different aggregate sizes, $D_{1.18\ mm}$ and $D_{2.00\ mm}$, were set up at a slope angle of 20°. The flow of runoff was collected for 2 hours at several intervals (30, 60, 90 and 120 min). Then, the hydraulic parameters and concentration of the sediment were measured. As a result, the increased rate of rainfall creates a higher concentration of sediment on a steep slope from 7.988 to 3233.569 gm^{-3} and 2.954 to 976.736 gm^{-3} for aggregate sizes $D_{1.18\ mm}$ and $D_{2.00\ mm}$, respectively. Generally, as the flow depth and shear stress were reduced, the estimated sediment concentration was higher. On the other hand, flow velocity and unit stream power were directly related to the sediment concentrations.

1.0 INTRODUCTION

The concentration of sediment is the movement of the separation of soil particles from the surface of the soil because of the few variables [1]. The sediment concentration mostly related to the soil erosion in term of erosive and destructive. The mutually responsible for sheet and interrail erosion areas are rain-impacted soil detachment and flows [2]. The primary distribution of particle size produced by rain-impacted flows is finer (including nutrient and chemical particles) than the distribution in the soil matrix [3]. Fine material is more easily transported and increase in the discharge than coarse material because of the factors such as aggregate breakdown and the development of the surface crust [4].

Rainfall is one the real agent of soil erosion by the water [5]. Rainfall intensity is defined as the duration of the valves that were plotted in the logarithmic coordinates and states that increased in rainfall duration will minimize the average intensity. Those can trigger shallow slope failures decreases linearly [6]. The variation in rainfall intensity can affect the soil erosion. It falls as drops in the spherical shape as assumed [7] and causes sediment that related to the disasters annually [8]. The downstream movement of the soil particles is triggered by the raindrop impact and surface flow [2]. The actual rainfall intensity data are collected from the auto weather station data [5].

Hydraulic parameters are necessary for the study of water and solute transport. The practical or financial constraints become the bar for the hydraulic parameters often cannot be measured. Many methods exist to determine soil hydraulic parameters or properties. One of the current methods is a broad array that can be determined in the field or in the laboratory. There are several hydraulic parameters such as flow, depth, flow velocity, shear stress and unit stream power. From these parameters, the sediment concentration can be characterizing by determining the erosive power of the overland flow. These parameters also can estimate the sheet flow based on the surface erosion rate [9].

*Corresponding Author | Suif, Z. | zuliziana@upnm.edu.my

Means that the higher erosive powers are because of due to greater flow rates and the increasing of sediment concentration [10].

The main objective of this study was to: (1) describe the effect of rainfall intensity and different aggregate sizes on sediment production and hydraulic parameters; and (2) investigate the relationship between sediment concentration production and hydraulic parameters.

2.0 METHODOLOGY

2.1 Soil Sample

The sample of soil is collected from the slope of failure around the region of National Defence University of Malaysia. Then, by the process of sieve analysis, the samples are sieved using a sieve shaker under dry conditions [11]. By this method, the two aggregate sizes composition were collected and prepared under named D_{2mm} and $D_{1.18mm}$. The aggregate samples are collected until the volume of the samples fill the dimension of the tray. The samples then were compacted as same as the actual field. The samples are compacted in the tray of 30 cm long × 10 cm wide × 10 cm high. The samples are compacted as compact as the real site. The tray consisted of one hole only that is at the top of the sample. The hole is connected to the pipe to collect the water flow of the overland flow [12]. The tray from the plastic container and had modified to fulfil the criteria of the experimental procedure.

To run the experiment, the soil was sieved to obtain the aggregate size that retained on sieve 1.18 mm and retained on sieve 600 μm. The samples are compacted in the tray before placing the samples under rainfall simulator. A brick is placed under the tray as a basement to control the slope steepness. When to get the slope steepness of θ = 20°, the height of the end tray from brick must be 7.3 cm height. Then, the rainfall is set under intensity 0.004 $mmhr^{-1}$ or 0.044 $mmhr^{-1}$. The rainfall is run for 2 hours with taken the discharge water every 30 minutes. To run for the next experiment, the sample must be completely dry and sieve again to get the needed aggregate sizes. This to avoid any error that may be occurred.

2.2 Experimental Works

The relationship between sediment concentration and various hydraulic parameters is to be explored in an experiment setup. The aggregate sizes represent the sediment concentration while the rainfall intensities will be the controlled variables in this experiment. There are three laboratories are involved in this experimental work. Firstly, Geotechnical Laboratory where the sieve analysis is done to get the two different aggregate sizes which are passing sieve 2.00 mm and passing 1.18 mm. Secondly is Hydrology Laboratory. In this lab, the experiment is set up by using a rainfall simulator. While the total suspended solid data from the overland flow, were collected and testing in the Environmental Laboratory where Total Suspended Solid test (TSS) is run.

For every rainfall event, the sediment overland flow is collected with an interval of 30 minutes for 2 hours. Then, the collected sediment is volumetrically measured [12]. The collected sediment undergoes the total suspended solid Test (TSS) because the sediment is non-filterable residues. The collected sediments are filtered to separate from water and were oven dried at 105°C for 1 hour [10]. From that, the runoff discharge, Q (m^3s^{-1}), and sediment concentration, Q_S (gm^{-3}), is determined.

2.3 Hydraulic Parameters

By having reference to Figure 1 will show how the data is gathered. For a span of 2 hours, the overland flow and infiltration flow are obtained every 30 minutes.

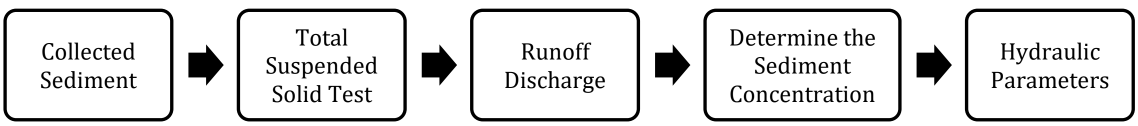


Figure 1. Flow of hydraulic parameters measures

The runoff discharged is calculated by using the (1) as below. The volume of runoff flow, V (m^3), is obtained from the total suspended solid test. Time duration, t, is taken at when the sediment is collected (time interval). For example, when the sediment is collected at time interval 60 minutes, the t is 60 minutes then convert to second.

$$Q = V/t \tag{1}$$

Where Q is the runoff discharge (m^3/s), V is the volume of runoff flow (m^3), and t is the time duration when the sediment is collected. To determine the sediment concentration, Q_S (g/m^3), use (2). The mass of the dry sediment, m (g), is obtained from the TSS Test.

$$Q_S = m/V \tag{2}$$

Where Q_S is the sediment concentration (g/m^3), m is the mass of dry sediment (g), and V is the volume of water collected (m^3). The flow velocity, v (ms^{-1}), is the important parameter to calculate the other hydraulic parameters. This parameter is depending on the flow discharge and slope gradient [13]. For the average depth flow, D (m), was determined as (3) [12]. Since the length of the tray was short, which is 30 cm, while rain was applied on the entire surface of the soil, it was presumed that the changes of q over the length of the tray were negligible [12].

$$D = q/v \tag{3}$$

Where D is the average flow depth (m), q is the average unit flow discharge per unit width (m^2s^{-1}), and v is the flow velocity (ms^{-1}). The next hydraulic parameter is shearing stress (τ). The shear stress was calculated as (4) [14]. The density of water flowing, ρ is 1000 kgm^{-3} [12], while the gravitational acceleration, g = 9.81 ms^{-2}. Where, D is average flow depth (m) and S is the tangent value of bed slope degree (fraction).

$$\tau = \rho g D S \tag{4}$$

Unit stream power is one of the hydraulic parameters. Use (5) to calculate unit stream power, U (ms^{-1}), [15]:

$$U = vS \tag{5}$$

Where, U is Unit stream power (ms^{-1}), v is the flow velocity (ms^{-1}), and is the S is the tangent value of bed slope degree (fraction).

3.0 RESULTS AND DISCUSSION

3.1 Hydraulic Parameters

Figure 2 to Figure 5 shows the result of hydraulic parameters for aggregate size $D_{1.18mm}$ for lowest and highest rainfall intensities at different time interval. The Figure 2 defined the flow depth from 0.17669 to 0.17677 m and 0.17680 to 0.17686 m as the time interval increasing for rainfall intensities of 0.004 $mmhr^{-1}$ and 0.044 $mmhr^{-1}$ respectively. But, from Figure 3 shows that the flow velocity was uniformly graphed when there is increasing from minute 30 to minute 60 and decreasing starting from minute 60 to minute 120 for rainfall intensity 0.004 $mmhr^{-1}$. So, the range is 0.000317 to 0.000336 ms^{-1}, and 0.000355 to 0.000360 ms^{-1} for rainfall intensities 0.004 $mmhr^{-1}$ and 0.044 $mmhr^{-1}$ respectively. Apparently, when increasing the flow velocity, the flow depth is decreasing [12].

According to Figure 4, the obtained shear stress ranged from 632.443 to 633.138 Pa for rainfall intensity of 0.004 $mmhr^{-1}$ and from 632.928 to 633.285 Pa for rainfall intensity of 0.044 $mmhr^{-1}$. Also, the unit stream power increasing ranged from 0.000116 to 0.000122 ms^{-1} and 0.000130 to 0.000132 ms^{-1} under rainfall intensity of 0.004 $mmhr^{-1}$ and 0.044 $mmhr^{-1}$, respectively (Figure 5).

*Corresponding Author | Suif, Z. | zuliziana@upnm.edu.my

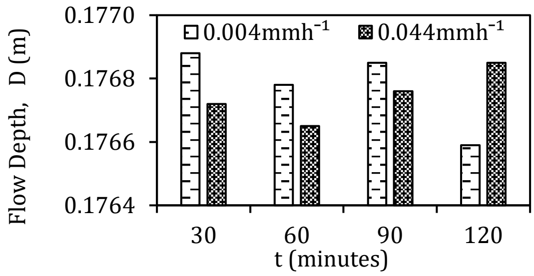


Figure 2. Flow depth for $D_{1.18mm}$

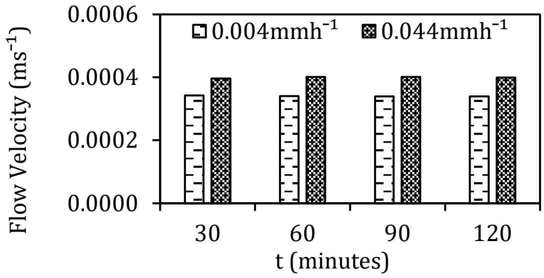


Figure 3. Flow velocity for $D_{1.18mm}$

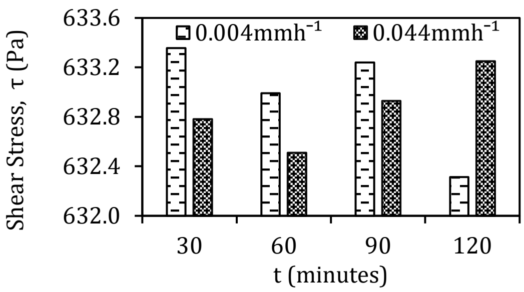


Figure 4. Shear stress for $D_{1.18mm}$

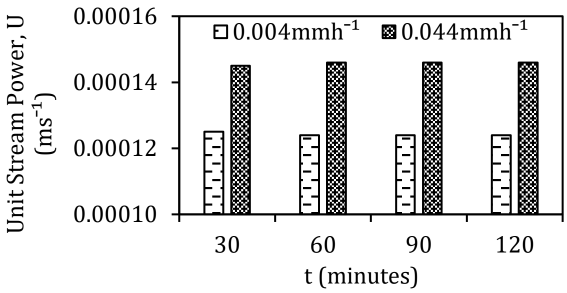


Figure 5. Unit stream power for $D_{1.18mm}$

Consequently, the maximum values of hydraulic parameters were obtained at the higher rainfall intensity which is 0.044 mmhr^{-1} except for flow depth. These results suggest that the higher rainfall intensity contributed to the stronger unit stream power of the overland flow. From Figure 6 to Figure 9 were reported about the result of hydraulic parameters for aggregate size $D_{2.00mm}$. The Figure 6 shows the result of flow depth falling from minute 30 to minute 90 then increasing to minute 120. The ranged 0.17677 to 0.17858 m for rainfall intensity 0.004 mmhr^{-1}. While for rainfall intensity of 0.044 mmhr^{-1} ranged from 0.17665 to 0.17685 m. Furthermore, Figure 7 displays the flow velocity under rainfall intensity 0.044 mmhr^{-1} and 0.044 mmhr^{-1} that increasing from 0.000317 to 0.000333 ms^{-1} and 0.000352 to 0.000357 ms^{-1}, respectively.

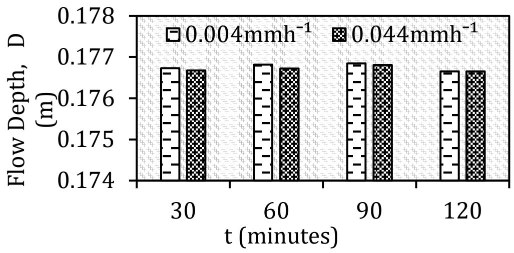


Figure 6. Flow depth for $D_{2.00mm}$

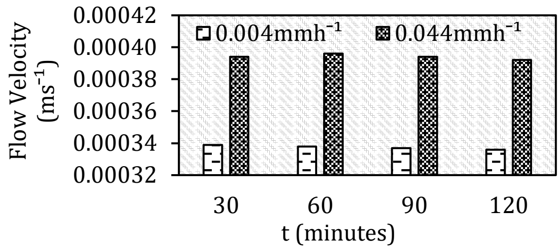


Figure 7. Flow velocity for $D_{2.00mm}$

The data of shear stress were shown in Figure 8. The graph showed the same pattern as the flow depth graph. For a rainfall intensity of 0.004 mmhr^{-1}, shear stress value from 632.954 to 639.442 Pa while under rainfall intensity of 0.044 mmhr^{-1}, the value ranged from 632.537 to 633.237 Pa. According to Figure 9, unit stream power increasing and remained constant under rainfall intensity of 0.004 mmhr^{-1} with fluctuated from 0.000116 to 0.000122 ms^{-1}. For rainfall intensity 0.044 mmhr^{-1}, the data distributed as a pyramid in ranged from 0.000129 to 0.0001300 ms^{-1}.

*Corresponding Author | Suif, Z. | zuliziana@upnm.edu.my

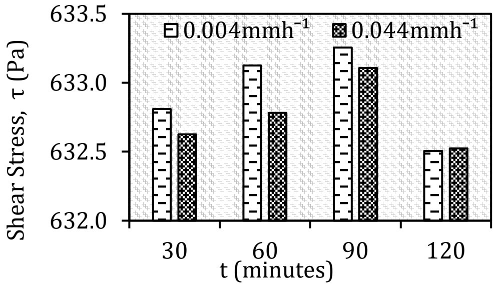


Figure 8. Shear stress for $D_{2.00mm}$

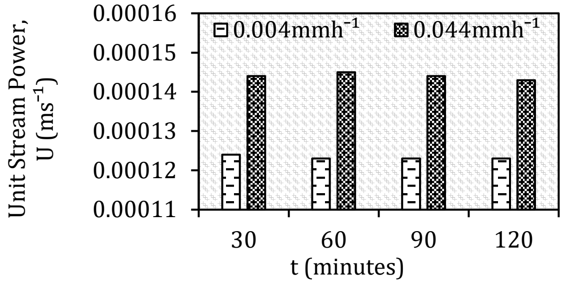


Figure 9. Unit stream power for $D_{2.00mm}$

3.2 Sediment Concentration

When compared both aggregate sizes, $D_{1.18mm}$ (Figure 10) and $D_{2.00mm}$ (Figure 11), the result showed a finer aggregate ($D_{1.18mm}$) has greater measured hydraulic parameters, flow depth, flow velocity, shear stress and unit stream power, than aggregate size $D_{2.00mm}$. The overland flow produced is not affected by the rainfall intensity and steepness of slope but is also affected by the distribution of soil aggregate sizes [12]. It claimed that the proportion of the larger aggregate size at the surface of the soil can regulate the overland flow velocity and flow stream power [16-17]. The reason for the higher values of hydraulic parameters in $D_{1.18mm}$ may be because of the finer aggregates credited with the presence of smaller aggregates and the following smaller pores in this soil. Therefore, smaller pores unable water to pass quickly through it and produce more overland flow.

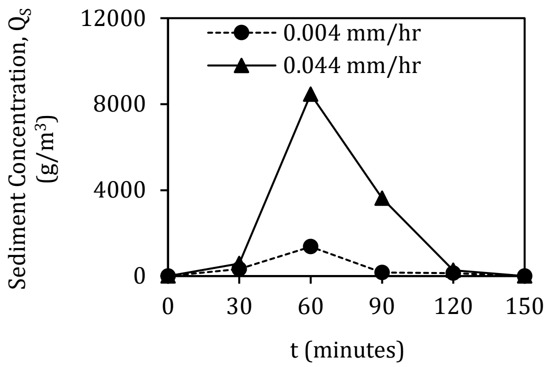


Figure 10 The changes of sediment concentration at different rainfall intensities for aggregates size $D_{1.18mm}$

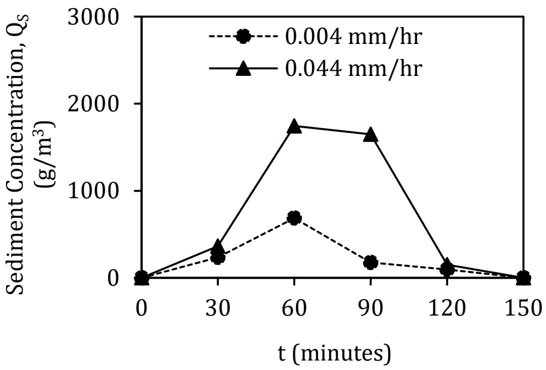


Figure 11: The changes of sediment concentration at different rainfall intensities for aggregates size $D_{2.00mm}$

3.3 Relationship Between Sediment Concentration And The Hydraulic Parameters

Figure 12 and Figure 13 indicates the relationship between the measured sediment concentration and hydraulic parameters of aggregate size $D_{1.18mm}$ and $D_{2.00mm}$, respectively. As graphed in Figure 12 (a) and (d), there was a positive relationship between the flow velocity and unit stream power on sediment concentration production. While, flow depth and shear stress, by comparison, had a negative relationship with the concentration of the sediment. From Figure 13 reported that the relationship between the sediment concentration and hydraulic parameters (flow velocity, flow depth, shear stress and unit stream power) has positive relationship. But, from the Sara and Majid [12], reported that sediment concentration had a positive relationship with the flow velocity, shear stress, stream power, and unit stream power while flow depth had negative relationship. The different results may cause from the difference misconduct the experiment such as when changing the bottle when collected the overland flow. The different laboratory setup and rainfall intensity induced also may become the reason why contradicting of result.

*Corresponding Author | Suif, Z. | zuliziana@upnm.edu.my

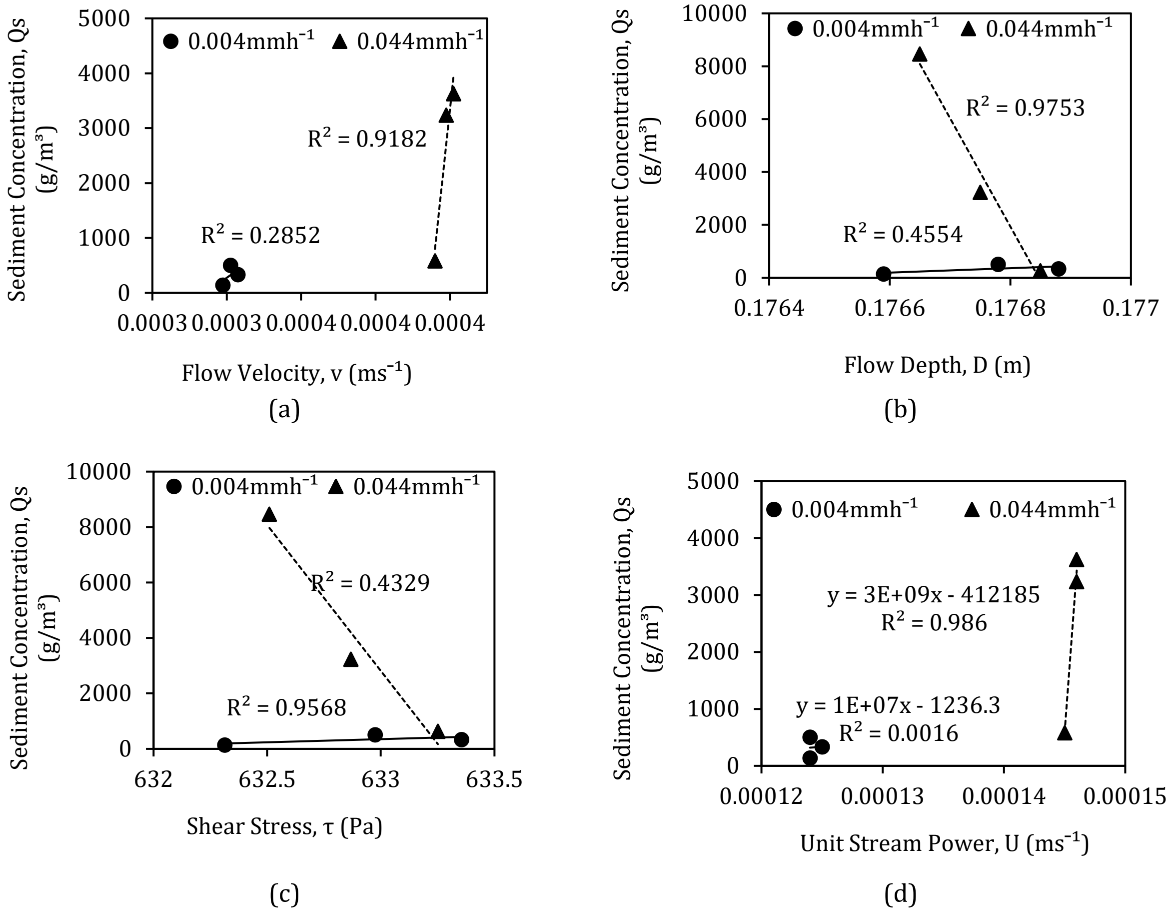
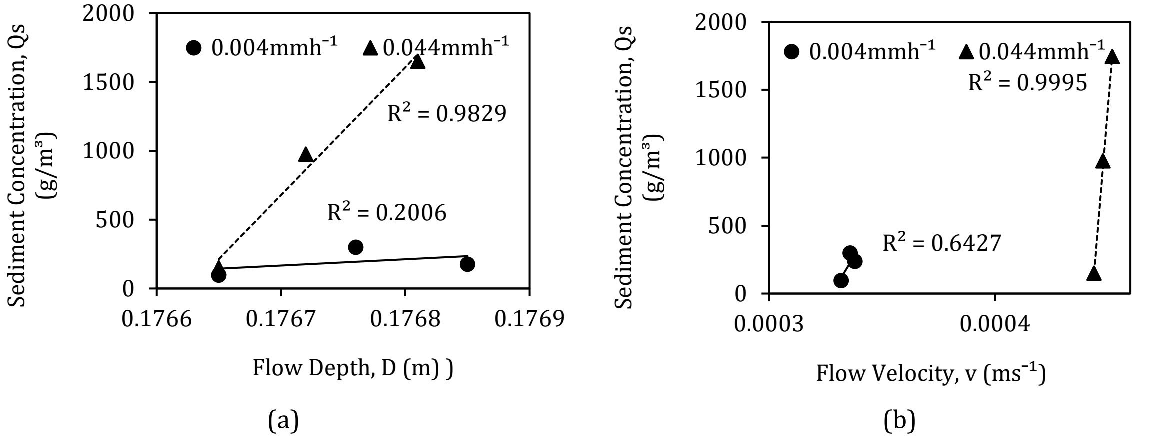
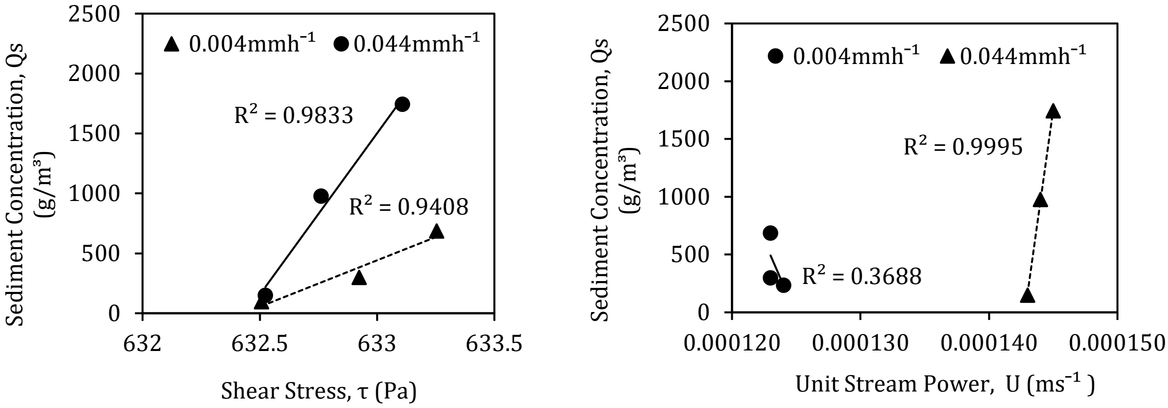


Figure 12. The relationship between sediment concentration and hydraulic parameters including flow velocity (a), flow depth (b), shear stress (c) and unit stream power (d) for aggregate size $D_{1.18mm}$



*Corresponding Author | Suif, Z. | zuliziana@upnm.edu.my



(c) (d)

Figure 13. The relationship between sediment concentration and hydraulic parameters including flow velocity (a), flow depth (b), shear stress (c) and unit stream power (d) for aggregate size $D_{2.00mm}$

4.0 CONCLUSION

There are several important results that could be obtained based on the experiment conducted to examine the effects of rainfall intensities and aggregate size on sediment concentration and hydraulic parameters. From the research, there was a direct relation between flow velocity and unit stream power on sediment concentration for aggregate size $D_{1.18\ mm}$, but an inversely related relationship for sediment concentration with flow depth and shear stress. The sediment concentration has a linear relation to the hydraulic parameters for aggregate size $D_{2.00\ mm}$. The sediment concentration production was higher in finer aggregate size compared to larger aggregate size because of the infiltration rate to increase when smaller pore was produced between the aggregate particles in the tray. The sediment content also increases as the rainfall rate increases, with the hydraulic parameters increasing.

5.0 ACKNOWLEDGEMENT

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*Corresponding Author | Suif, Z. | zuliziana@upnm.edu.my

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*Corresponding Author | Suif, Z. | zuliziana@upnm.edu.my