Effect of Different Aggregate Size on Sediment Concentration and Hydraulic Parameters in Overland Flow

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Abstract. This study is about the impact of the rainfall on different aggregate size by using the rainfall simulator. The objectives of this study are to estimate the runoff, sediment concentration production, hydraulic parameters on different aggregate size and to investigate the relationship between sediment concentration and different hydraulic parameters. The hydraulic parameters including flow velocity, flow depth, shear stress and stream power. The different aggregate size, D0.6mm and D1.18mm, were set up under the rainfall simulator on a flat surface and slope angle 20°. The rainfall simulator was adjusted to the rainfall intensity 10 Lmin⁻¹. The average rainfall intensity was a constant variable for this experiment. The runoff flow was collected at several intervals (30, 60, 90 and 120 min) for 2 hours. Then, the hydraulic parameters, runoff discharge and sediment concentration were measured. As the result, the average of sediment concentration increased as the slope also increased, from 335.667 to 1365.333 gm⁻³ and 173.767 to 555.333 gm⁻³ for aggregate size D0.6mm and D1.18mm, respectively. The measured of sediment concentration was higher as the flow depth and shear stress was decreased. On the other hand, flow velocity and unit stream power were increased when directly relate between the sediment concentrations. In general, the precision of the hydraulic parameters in anticipating sediment concentration was: flow velocity > stream power > shear stress > unit stream power > flow depth.

1. Introduction
Research on erosion and sediment has been started long ago to improve the erosion that commonly happen or take place on a development site. Soil erosion is one of the major natural disaster that occur around the world. The soil erosion leads to loses of soil particles on the slope surface. Soil erosion is one of the major environmental problems in the arid and semiarid regions [1] which can lead to the reduction of soil productivity, water pollution, and an increase in the sediment transport. The soil erosion process affects the topography of the area and can lead to the landslide in the sloping area. Rain is the ordinary dynamic movement of water that differs spatially and temporally under the intensities and volumes. Rain is one of the most key erosion factors under all the natural conditions in terms of erosive and destructive power to cause soil particle detachment and movement from the soil surface [2].

The size of particles that make soil move over a wide extend of soils and large are called rock, sand, build up or earth depending upon predominant measure of particle interior the earth. To depict soil by their particle size, some affiliations have made atom estimate course of action. Slope gradient is essential variables that control soil erosion on hill slopes due to overland flow. The steepness of the slope gradient really affects the hydraulic parameters. As the example, the overland shear stress increasing as the slope gradient becomes steeper [3].
The concentration of sediment is due to the fact that the movement of the detachment of soil particles from the soil surface is due to few factors. Sediment concentration strongly associated with erosion. Reciprocal overburden for foliar erosion and infill erosion areas are landslides and soil runoff affected by rains. Fine material is easier to transport than coarse material, thanks to factors such as the decomposition of the mixture and, consequently, the development of the superficial crust which also causes an increase in the flow of the finest material [4].

Unit of hydraulic parameters necessary for the study of the transport of water and matter. There are many hydraulic parameters of the surface unit, such as flow rate, cut-off voltage, flow depth, stream power and unit power. From these parameters, the sediment concentration will be determined by characterizing the erosive power of the Earth's flow. Only few studies have investigated on effects of different aggregate size on sediment concentration and hydraulic parameters in overland flow. Therefore, in this study, rainfall was applied on different aggregate size by using the rainfall simulator. The main objectives of this study were the following: (1) to estimate the runoff and sediment concentration production on different aggregate size (2) to estimate the hydraulic parameters on the different aggregate size (3) to investigate the relationship between sediment concentration and different hydraulic parameters.

2. Methodology
This research is on the experimental study on different type of aggregate size on sediment concentration and hydraulic parameters. Three scientific laboratories are involved in this study. First of all, the geotechnical laboratory, wherever the sieve analysis is completed, allows to induce totally different aggregate sizes which pass the metric linear unit of the sieve by 1.18 mm and 0.6 mm. The second is the hydrology laboratory. During this scientific laboratory, the experiment is about to begin with the use of a precipitation apparatus, while general information about sediment production in the flow was collected and tested in the environment laboratory anywhere Total Suspended Solid (TSS).

2.1. Soil samples
The soil sample is taken from the slope around the Universiti Pertahanan Nasional Malaysia (UPNM). Then, the samples sieved using the dry sieve agitator under dry conditions. The surface unit of the sieved samples was collected from the aggregates which passed through the 2 mm sieve and held on the 1.18 mm sieve and used the 0.6 mm sieve and held on the 0.3 mm sieve. Using this technique, the composition of 2 aggregated sizes was collected and prepared under the names D_{1.18mm} and D_{0.6mm}. Samples collected up to the quantity of samples fill the dimensions of the container.

2.2. Experimental framework
Several experiment involves in this research regarding to investigate the objectives of the experiment. First experiment is the sieve analysis, to get two different aggregate sizes. Besides that, to obtain the surface runoff, the soil sample need to experimented using the rainfall simulator. In addition, the hydraulic parameters also measured using the rainfall simulator. In the rainfall simulator, the soil sample will have compacted in the tray and arrange properly. The rainfall event will take 2 hour period and for each 30 minute of time lapse the surface runoff will have collected in different container. Last experiment for the research is Total Suspended Soil test (TSS) where the surface runoff collected will filtered using the filtering apparatus. This test is to diverge the water and sediment after the sample was dried in the oven for 1 hour under temperature of 105°C. So after finish all the experiment the runoff discharge, Q (m³s⁻¹), and sediment concentration, Qs (gm³), will be determined.

2.3. Detachment tray
The compacted samples inside the tray were 67 cm long × 23 cm wide × 18.8 cm high. The tray consisted of a hole that is located only in the upper part of the sample. The outlet is connected to the pipeline to collect the flow of water from the land stream [5]. The sand filled up until the hole that is 8 cm high. The plastic instrument tray and had changed to comply with the procedural factors.
2.4. Rainfall simulator

A rainfall simulator was used to study the different rainfall intensities. The overall dimension of this rainfall simulator is approximately 2.4 m long × 1.0 m wide × 1.8 m high and electricity is required to run the electric pump. The soil which is sieved are compacted within the tray and set beneath the rain simulator. In this test, all rectangular tray has one hole at the top of the tray associated to PVC pipe to channel eroded soil to a bucket that will be set at its outlet for collection of water that runoff the surface and water that moves through the soil. The sum of runoff was measured after 30 minutes of the most rainfall occasion after allowing sediment to settle. The bucket expelled from the tray and being weighed. After that, the sediments collected at the foot of each tank will be dried within the oven until it is totally dry and was weighed again. The data were collected three times after the most rainfall occasion for each aggregate size. The physical properties of the sediment production were measured and recorded. The slope angle will be altering after the collection of data from 0° to 20° respectively. The Figure 1 shows the sample set up with the incline steepness of $\theta = 20^\circ$. Then, the normal rainfall is set under escalated $10 \text{ Lmin}^{-1}$ to 250 mmhr$^{-1}$.

![Sample set-up at $\theta = 20^\circ$](image)

Figure 1. Sample set-up at $\theta = 20^\circ$

2.5. Determination of hydraulic parameters

By referring Figure 2 shows on how the data were collected. The overland flow and infiltration flow are collected at interval of 30 minutes for 2 hours. Bucket of water is used to collect the water and change every 30 minute. The collected samples measured in lab with various methods. Total suspended solid test (TSS) was tested after collecting the sample due to the aspect of the sediment is non-filterable residues. The filtered sediment was dried using oven under 105$^\circ$C for 1 hour. From the weight of the dried sediment and water that separate from the sediment, the sediment concentration, $Q_s$ (gm$^{-3}$), and discharge of runoff flow, $Q$ (m$^3$s$^{-1}$) can be determined.

![Analysis steps of Hydraulic Parameters](image)

Figure 2. Analysis steps of Hydraulic Parameters

From the equation (1) the runoff discharge, $Q$ (m$^3$s$^{-1}$), could be measured. From the total suspended solid test, we can obtain the volume of runoff flow, $V$ (m$^3$) that is the water that we separated from the
sediment. For overall of the sediment that collected, time is recorded too as the time interval. As an example, this experiment time interval, $t$ (s), is 30 minutes for 2 hours meaning when converted to seconds unit will be 1800 s.

$$Q = \frac{V}{t} \quad (1)$$

The determination of sediment concentration, $Q_s$ (gm$^{-3}$), is by using equation (2) as below. The mass of the sediment, (g), is the sediment that filtered through the TSS test and dried in the oven while the volume of water collected, $V$ (m$^3$), is depend on the water collected for each soil covers.

$$Q_s = \frac{m}{V} \quad (2)$$

The most important parameter that will often use to find other hydraulic parameters is the flow velocity, $v$ (ms$^{-1}$) where it will depend with the discharge of the flow and slope gradient. For the first hydraulic parameters that is the mean flow velocity or average flow depth, $D$ (m), will be declare through as equation (3) using method [6]. The length of the tray was 67 cm, while the rain is flowing over the surface of the soils, the inconsistent of average unit flow discharge per unit width, $q$ (m$^2$s$^{-1}$), value along the length of tray were assumed as negligible [5] and the $v$ (ms$^{-1}$), measured the flow velocity.

$$D = \frac{q}{v} \quad (3)$$

Second hydraulic parameters are the shear stress. From the equation (4), the shear stress could be measured. The value of density of water that flow, $\rho$ is 1000 kgm$^{-3}$ [7], gravitational acceleration, $g = 9.81$ ms$^{-2}$ and tangent value of bed slope degree, $S$.

$$\tau = \rho gDS \quad (4)$$

Lastly the unit power of stream. From equation (5) we can find the unit power of stream, $U$ (ms$^{-1}$), [6]

$$U = vS \quad (5)$$

3. Results and Discussions

3.1. Runoff

Figures 3 shows the result of runoff that collected for slope ($\theta = 20^\circ$) for both soils. The runoff discharge for both soils were increasing by time. It shows a linear relationship. The runoff produced slightly higher on $D_{0.6}$mm. We can conclude that finer particles produce higher amount of runoff compared to bigger particles. The plausible reason for lower hydraulic parameters in soil $D_{1.18}$mm may be attributed to the existence of larger aggregates and the subsequent larger pores in this soil, which enable water to pass easily through the soil and generate less overland flow [8]. Moreover, the runoff discharge for both soils $D_{0.6}$mm and $D_{1.18}$mm seems to increase until 90 minutes. At 120th minute the runoff discharge for both soils slightly decrease. This is because it attained the maximum level of infiltration rate after 90 minutes. So the capacity of soil to hold the water reached its maximum limit. In the initial phases of storm, when the soil is dry, a rainfall intensity less than infiltration rate produces no surface runoff. Gradually, as the rain progresses, the soil saturates and the infiltration rate reduces to a steady rate.
Figure 3. Relationship between runoff discharge and time taken at (θ = 20°) slope

3.2. Sediment concentration

Figure 4 below shows the relationship between sediment concentration and time taken for both soils D_{0.6mm} and D_{1.18mm} at slope 20°. Highest sediment was collected at 60th minute and it starts to decreases by time at both slope. At 60th minute at slope 20° identified a coarsening in the particle size composition of the transported material due to the increase in water discharge and sediment concentration.

Figure 4. The changes of sediment concentration at 20° slope for soil D_{0.6mm} and D_{1.18mm}

The comparison of sediment concentration between the soils shows that sediment concentration was greater at steeper slopes. For soil D_{0.6mm}, as slope steepness is 20 %, the measured sediment concentration increased from 335.667 to 1365.333 gm⁻³ under rain intensity 62.39 mmh⁻¹. The obtained values of sediment concentration for soil D_{1.18mm} under rain intensity of 62.39 mmh⁻¹ increased from 173.767 to 555.333 gm⁻³ when slope steepness increased from 0 to 20% and correspondingly decreased from 228 to 110 gm⁻³ at 90th minute. This is because when all possible particles are washed away with, the flow becomes direct water seepage ultimately, and the sediment concentration at the same position in the water decreases over time. Defersha et al. [9] found that rain intensity and slope gradient had significant influences on sediment concentration. Slope gradient is important as more soil particles are...
splashed down-slope than up-slope [10-11]. In fact, slope gradient has a significant influence on the down-slope splash loss [12] as well as total splash rate [13].

Comparison of sediment concentration between the studied soils showed that soil D0.6mm exhibited higher values of sediment concentration than soil D1.18mm. However, flow hydraulic conditions determine the erosive forces acting on the eroding surface, although soil properties can also control these conditions, most notably through the aggregate stability influencing on surface roughness [8]. In fact, soil properties affect rain-induced over-land flow through soil detachability by distributing erosive forces and water infiltration into the soil [14].

3.3. Hydraulic parameters
Table 1 shows minimum, maximum and average values of hydraulic parameters for rainfall intensity 62.39 mmhr⁻¹ for θ = 20°. As general the aggregate size of D0.6mm obtained higher values for flow velocity and unit stream power when compared to aggregate size D1.18mm because large particles tend to slow the flow more than small ones and the discharge, or volume of water passing a point in a unit of time. But the aggregate size of D0.6mm obtained smaller values of flow depth and shear stress compared to aggregate size D1.18mm. Majid [15] also states that greater values of the parameters were obtained for smaller soil compared to bigger soil indicating higher erositivity of overland flow generated on the soil containing finer particles. The mean flow velocity of aggregate size D0.6mm varied from 0.00695 ms⁻¹ to 0.011065 ms⁻¹ as the slope changed to 20°. Same goes to D1.18mm, it varied from 0.00457 ms⁻¹ to 0.00692 ms⁻¹. From this, we know that higher slope gradient is directed to stronger stream powers of overland flow that increase the value of velocities thus decreasing the flow depth.

| Parameters               | Soil D0.6 mm | Soil D1.18 mm |
|-------------------------|--------------|---------------|
|                         | Max          | Min           | Average       | Max         | Min           | Average       |
| Flow velocity (ms⁻¹)    | 0.01188      | 0.01025       | 0.011065      | 0.00798     | 0.00561       | 0.00679       |
| Flow depth (m)          | 0.01188      | 0.01025       | 0.021506      | 0.00361     | 0.00337       | 0.03494       |
| Shear stress (Pa)       | 95.262       | 58.311        | 76.7865       | 182.027     | 67.483        | 124.755       |
| Unit stream power (ms⁻¹)| 0.04324      | 0.03731       | 0.040275      | 0.001696    | 0.001631      | 0.001664      |

3.4. Relationship between sediment concentration and hydraulic parameters
Figure 5 show the relationship between the measured sediment concentration and hydraulic parameters for aggregate size D0.6mm at θ = 20°. As graphed from the Figure 5 (a) and (d), sediment concentration had a positive relationship between the flow velocity and unit stream power. In contrast, flow depth (Figure 5 (b)) and shear stress (Figure 5 (c)) had a negative relationship with the sediment concentration. The steeper slope can transport the sediment easily than flat slope. In fact, an increase in flow depth decreases the rate at which sediment was transported by flow, consequently leading to a decline in sediment concentration. It was also found that all the studied hydraulic parameters had a significant relationship with the measured sediment concentration. Shih and Yang [16] concluded that gravity is the significant driving force for overland flow and the unit stream power dominates sediment concentration among all hydraulic parameters.
Figure 5. Relationship between Sediment Concentration and Hydraulic Parameters for Soil D$_{0.6mm}$ at slope ($\theta = 20^\circ$) (a) Flow velocity; (b) Flow depth; (c) Shear stress; (d) Unit stream power.

Figure 6 show the relationship between the measured sediment concentration and hydraulic parameters for aggregate size D$_{1.18mm}$ at $\theta = 20^\circ$, separately. The graphs below reported that the relationship between the sediment concentration and hydraulic parameters (flow velocity and stream power) has a positive relationship. Also, the result indicated that the sediment concentration had greater values at slope ($\theta = 20^\circ$) as hydraulic parameters (except flow depth) increased with increasing slope steepness.

Among the different hydraulic parameters, flow velocity and unit stream power exhibited a linear relationship with sediment concentration, whereas the other parameters showed nonlinear (power) relationships. Cao et al. [17] found a linear relationship between the soil loss on loess road surface and stream power. Sirjani and Mahmoodabadi [18] reported that the nonlinear relationships make the determination of erodibility and critical values disputable, while in a linear trend, these two process-based parameters can be determined more easily and accurately.
Figure 6. Relationship between Sediment Concentration and Hydraulic Parameters for Soil $D_{1.18\text{mm}}$ at slope ($\theta = 20^\circ$) (a) Flow velocity; (b) Flow depth; (c) Shear stress; (d) Unit stream power.

4. Conclusion

Based on the experiment conducted to investigate effects of different aggregate size on sediment concentration and hydraulic parameters, there are a few critical conclusions may well be obtained. For aggregate size $D_{0.6\text{mm}}$, there was a direct relationship between the sediment concentration with flow velocity and unit stream power but contrarily relationship with the flow depth and shear stress. For total estimate $D_{1.18\text{mm}}$, sediment concentration has directly relationship with the hydraulic parameters. The sediment concentration was higher in finer total size compared to bigger aggregate size since of the infiltration rate expanding between the little pore between the aggregates. As increasing the slope gradient, the sediment concentration moreover expanding with increasing the hydraulic parameters. The flow velocity was the leading hydraulic parameter to show the sediment concentration.

The result of this study has little scale since of the as well little of rainfall force that's particular with the natural rainfall which has higher precipitation escalated. Besides, the experiment was run within the little scale of separation tray so the making of the silt concentration and the values of hydraulic parameters may be distinctive from the continuous field scale.

5. References

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