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Effect of Different Types of Soil Covers on Sediment Concentration and Hydraulic Parameters

(Kesan Pelbagai Jenis Penutup Tanah pada Kepekatan Mendakan Sedimen dan Parameter Hidraulik)

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ABSTRACT

Soil erosion issue is common among construction sites. The phenomena usually takes place on sloped areas with no soil cover. The main objectives of the research are to determine the sediment concentration of rain induced on different types of covers and also to determine the hydraulic parameters. Besides that, the research also has to investigate the relation of the sediment concentration with hydraulic parameters. This research will take place in rainfall simulator using soil sample collected from sloped areas. The hydraulic parameters of this experiment consist of flow velocity, flow depth, shear stress, and unit stream power. Soil sample will be placed on four trays with different types of covers and properly arranged in the rainfall simulator with slope of 20 º. The sample will undergo rainfall event for two hours. The surface runoff collected and the sediment concentration measured using Total Suspended Solid (TSS) testing. The result shows the stream power of dry leaves is higher among those four covers with 0.0046 ms⁻¹ followed by grass cover with 0.0033 ms⁻¹ than gravel with 0.0023 ms⁻¹, and lastly bare soil cover with 0.0008 ms⁻¹. However, sediment concentration and surface runoff that were produced by bare soil is the highest followed by gravel, then leaves, and lastly grass. Generally, the sediment production in descending order started with the bare soil, gravel, dry leaves, and grass. From the research shown, rain induced on vegetation cover can be used as a low-cost initiative to control the soil erosion on construction slope area.

Keywords: Soil erosion; rainfall simulator; hydraulic parameter; sediment concentration; runoff discharge

ABSTRAK

Isu hakisan tanah adalah perkara biasa di tapak pembinaan. Fenomena ini biasanya berlaku di kawasan cerun tanpa penutup tanah. Objektif utama penyelidikan adalah untuk menentukan kepekatan mendakan sedimen pada jenis penutup yang berbeza dan juga untuk menentukan parameter hidraulik. Penyelidikan ini dilakukan dengan menggunakan simulator hujan dan sampel tanah yang dikumpul dari kawasan cerun. Selain itu, penyelidikan juga menyiasat hubungan kepekatan mendakan sedimen dengan parameter hidraulik. Parameter hidraulik untuk penyelidikan ini terdiri daripada halaju aliran, kedalaman aliran, tekanan rumput, dan kuasa aliran unit. Sampel tanah akan diletakkan di atas empat dulang dengan pelbagai jenis penutup dan disusun di dalam simulator hujan dengan kecerunan 20 o. Sampel akan didedahkan kepada hujan selama dua jam. Larian permukaan yang dikumpulkan dan kepekatan mendakan sedimen diukur menggunakan ujian Jumlah Pepejal Terampai (TSS). Hasil kajian menunjukkan kuasa aliran daun kering adalah lebih tinggi di antara empat penutup dengan 0.0046 ms⁻¹ diikuti dengan penutup rumput dengan 0.0033 ms⁻¹ daripada kerikil dengan 0.0023 ms⁻¹, dan penutup tanah yang terakhir terdedah dengan 0.0008 ms⁻¹. Walau bagaimanapun, kepekatan mendakan sedimen dan air larian permukaan yang dihasilkan oleh tanah yang terdedah adalah yang tertinggi diikuti dengan kerikil, kemudian daun, dan rumput adalah yang terakhir. Secara amnya, pengeluaran mendakan *sedimen dalam susunan menurun bermula dengan tanah yang terdedah, kerikil, daun kering, dan rumput. Daripada kajian, ia menunjukkan bahawa hujan yang disebabkan oleh perlindungan tumbuhan boleh digunakan sebagai inisiatif kos rendah untuk mengawal hakisan tanah di kawasan cerun pembinaan.*

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. This phenomenon usually takes place during the preliminaries phase where before the structural work begins which is during the earthwork phase. During the earthwork phase where cut and fill process occur, after the ground level has been excavated and filled, the soil cover will be disturbed and causes major problem when the soil has no top cover. During rainfall, the erosion will start from the upper bank where the rain water will start to flow with initial velocity and comes down with the sediment that eroded from the surface.

Generally, when too much sediment flows into the drainage, the sediment will become settled thus causing the drainage volume to decrease (Dimoyiannis et al. 2001). Besides that, in other cases when rain flows with the sediment that flows with the drainage path with high velocity will be bunged up at certain point. To overcome this problem, this research has provided a solution by using different types of soil covers which are bare soil cover, grass cover, leaves cover, and gravel cover.

Rain water induced overland flow describe the situation of the rain water flow on land surface. What can be described here is there are many probabilities either it influences by the surface of the soil or the infiltration capacity or depression storage capacity has exceeded its limit. This research will compare the suitable cover that can be applied to slopes on construction site or slope areas by testing the soil samples under simulated rainfall event.

The significance of plant cover in controlling water erosion is generally accepted. In the short term, vegetation influences erosion mainly by intercepting rainfall and protecting the soil surface against the impact of rainfall droplets, and by intercepting runoff. For a long period of time, vegetation influences the fluxes of water and sediments by increasing the strength soil-aggregate and cohesion as well as by improving water infiltration (Hugo 2008).

One of the advantageous influence of vegetation on soil erosion is root reinforcement. The roots mechanically reinforce a soil by transfer of shear stresses in the soil to tensile resistance in the roots (De Baets et al. 2006; Gyssels & Poesen 2003). Vegetation also made soil moisture modifications as the process of evapotranspiration and interception in the foliage limit build-up of soil moisture stress. These occurrences would tend to increase soil saturation and runoff.

The vegetation development and plant growth depend on some factors such as climate, conditions of soil, and types of land use. Other than that, natural and non-natural disturbances, such as global climate changes, deforestation, afforestation, and other human activities give impact to the vegetation development (Suif et al. 2017; Suif et al. 2018). Vegetation dynamics also affects the process of soil erosion (Zhu 2016: Zhou, Shangguan & Zhao 2006).

The main objectives are to determine the runoff and sediment production, to determine the hydraulic parameters and also to investigate the relationship between sediment production and hydraulic parameters on different types of soil covers. From experimental results, it will help other researchers by obtaining the range data value of hydraulic parameters and sediment concentration for modelling work.

METHODOLOGY

This research is on the experimental study on different types of soil covers on sediment concentration and hydraulic parameters. Three scientific laboratories are involved in this study. First, the geotechnical laboratory, where the sieve analysis is completed, allows to induce different aggregate sizes which passes the metric linear unit of the sieve size. The second is the hydrology laboratory. In this scientific laboratory, the experiment is begins with the use of a precipitation apparatus, while general information about sediment production in the flow was collected and tested in the environment laboratory Total Suspended Solid (TSS).

SOIL SAMPLES

The soil sample used in this research was from slope in arid region near to a construction site in Universiti Pertahanan Nasional Malaysia (UPNM). There will be four plant pots with dimension of 67 cm × 23 cm × 18.8 cm shown in Figure 1 and will have four different covers. There will be a pipe that is cut into half that acts as drainage to collect the surface discharge in the middle of the tray presented in Figure 2 with diameter 2.5 cm and another pipe on the bottom tray that acts as the drainage to collect the infiltration flow. The sample collected is according to the volume of the tray itself. The soil sample will be compacted as the soil condition of the actual field. The sample that have been collected will dry under the sun to ensure it is saturated before undergoing the rainfall using the rain simulator. To analyse the soil profile, it is shown that the soil sample is weighed for initial data which is 1 kg not including the weight of the tray. After that, the soil sample will be placed in the sieve to get the soil profile.

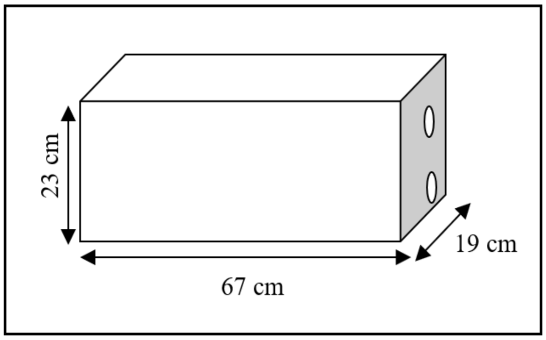

FIGURE 1. The dimension of tray

FIGURE 2. Arrangement of pipe as drainage

EXPERIMENTAL FRAMEWORK

Several experiments involved in this research to investigate the objectives of the experiment. The first experiment is the sieve analysis. To clarify the soil profile, the soil sample needs to be sieved and classified by using the Unified Classification System method. Besides that, to obtain the surface runoff, the soil sample needs to be tested using the rainfall simulator. In addition, the hydraulic parameters were also measured using the rainfall simulator. In the rainfall simulator, the soil sample will be compacted in the tray and arranged properly. The rainfall event will take a 2-hour period and for each 30 minutes of time lapse the surface runoff will be collected in different containers. Last experiment for the research is Total Suspended Soil test (TSS) where the surface runoff collected will be 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 the temperature of 105 o. After all the experiments are finished, the runoff discharge, Q (m3 s^{-1}), and sediment concentration, QS (g m^3), will be determined.

DETERMINATION OF HYDRAULIC PARAMETERS

The hydraulic parameters that were used in this research is flow velocity, V (m s^{-1}), depth flow, D (m), shear stress, τ (Pa), and unit stream power, U (m s^{-1}).

From Equation (1), the runoff discharge, Q (m3 s^{-1}), could be measured. From the total suspended solid test, we can obtain the volume of runoff flow, V (m^3), which is the water that we have separated from the sediment. For the overall sediment collected, time is recorded as the time interval. For this experiment, time interval, t (s), is 30 minutes and the experiment lasted for 2 hours.

$$Q = {}^{V}\!/_{t} \quad (1)$$

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

$$Q_S = {}^{m}\!/_{V} \quad (2)$$

The most important parameter that is oftenly used to find other hydraulic parameters is the flow velocity, V (m s^{-1}), where it depends on the discharge of the flow and slope gradient.

For the first hydraulic parameter that is the mean flow velocity or average flow depth, D (m), will be declared through Equation (3) using method stated by Sirjani & Mahmoodabadi (2012b). 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 (m2 s^{-1}), value along the length of tray were assumed as negligible reported by Majid & Sara (2015) and the V (m s^{-1}), measured the flow velocity.

$$D = {}^{q}\!/_{V} \quad (3)$$

Second hydraulic parameter is the shear stress. From Equation (4), we could measure the shear stress, τ (Pa). The value of density of water that flows, ρ is 1 000 kg m-3 shown by Nearing et al., (1997), gravitational acceleration, g = 9.81 m s^{-2} and Tangent value of bed slope degree, S.

$$\tau = \rho g D S \quad (4)$$

Lastly the unit power of stream. From Equation (5), we can find the unit power of stream, U (m s⁻¹), stated by Sirjani & Mahmoodabadi (2012b).

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

RESULTS AND ANALYSIS

RUNOFF

Figure 4 shows the result of runoff collected for the slope steepness of 20 o for all of the soil covers. Both of the slopes show different results since slope steepness does affect the runoff discharge of runoff. For both slopes, bare soil collects the most of surface runoff since the top of the soil has no cover. Bare soil does not consist of any water flow resistant on it. The gravel cover consists gravel all over the soil that may disturb the rainfall that flows on the soil surface, so the water flow from upper hill to the channel is not directly comparable to bare soil. Next cover will be leaves cover for both slopes. The leaves cover contains dry leaves spread all over the soil. The dry leaves may absorb rain water until the water storage of the leaves are at its limit. Lastly, the grass cover. The grass cover consists grass vegetation. Vegetation consists root system where it may be another passage for the water to flow beside of overland flow compared to the other covers. Grass is the cover that has a high volume of infiltration flow compared to the other covers.

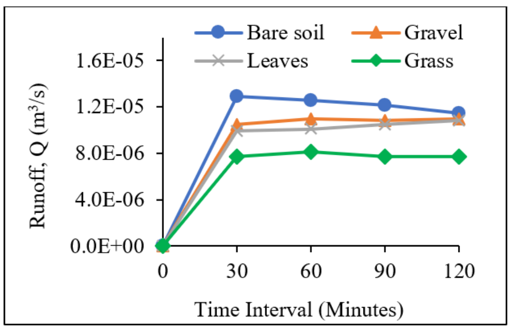

FIGURE 4. The effect of different soil covers on runoff at θ = 20 °

SEDIMENT CONCENTRATION

From the result for sediment concentration as presented in Figure 5 for wider scope, we can conclude that bare soil produces large amount of sediment for both slope situations. This may be caused from bare soil not having resultant overland flow, so the rainfall water easily impacts the soil and deforms the soil surface thus flowing directly to the drainage. The second highest sediment production produced by the gravel cover. By having gravel on the surface, it will be the only resultant to overland flow not just by interrupting the flow velocity but also functions as a wall for the sediment to flow over it. Dry leaves cover took the third highest sediment production. Logically, the sediment under the leaves may find it hard to flow after the leaves absorbs the rain water and increase in weight. Lastly, the grass cover will be the cover that produces the lowest sediment production. The value of production is almost near to zero. The grass will be the best suggested cover in preventing sediment concentration and reducing flow velocity.

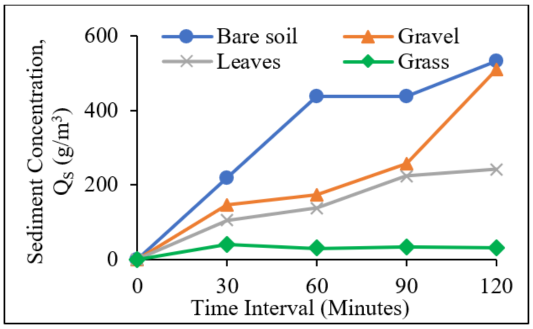

FIGURE 5. The effect of different soil covers on sediment concentration at θ = 20 °

HYDRAULIC PARAMETERS

Figure 6 shows the results of flow velocity for different covers. The highest flow velocity is the bare soil cover with 0.01266 ms-1 for slope steepness of 20 o. Next, the gravel cover has the second highest of the flow velocity with speed 0.00900 ms-1 for slope steepness of 20 o. After that, dry leaves cover shows it may reduce the flow velocity with the dead leaves compacted over the soil better compared to gravel with a speed of 0.00637 ms-1 for slope steepness of 20 o. Lastly, the best resultant overflow is grass cover. The root system is one of the factors that affects the speed of overland flow at 0.00222 ms-1 for slope steepness of 20 o. The steeper slope produces higher result for flow velocity.

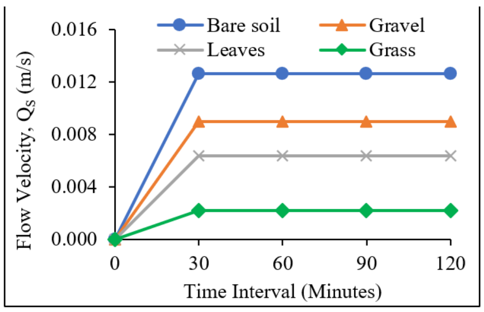

FIGURE 6. The effect of different soil covers on flow velocity at θ = 20 °

From the result of flow depth for all covers shown in Figure 7, we could describe that the grass has the deepest depth that increased from 0.01848 m in minute 30 to 0.01964 m in minute 60 and started to decrease slightly to 0.01862 m throughout the experiment for slope steepness of 20 o. Following close after grass is dry leaves, where the depth rises slowly from 0.00869 m in minute 30 to 0.00939 m throughout the experiment. In minute 30 the gravel has the thinnest flow depth with 0.00767 m compared to the bare soil where it took to 0.00635 m. Eventually bare soil decreased in depth to 0.00431 m in minute 120 while the gravel swapped place with bare soil by being second thinnest flow depth with an increase in depth slightly to 0.00667 m in minute 120 m. The grass may have the deepest flow depth since the root system of the grass could open another flow path for the water to infiltrate.

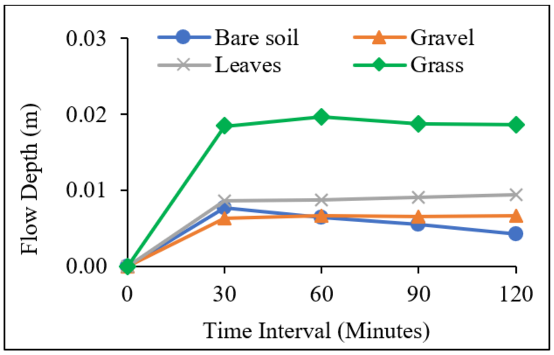

FIGURE 7. The effect of different soil covers on flow depth at $\theta = 20^{o}$

Result for shear stress on the four different covers in Figure 8 shows that the highest shear stress produced by grass followed by leaves, gravel, and bare soil. Shear stress has the similarity to the flow depth result since the formula used are the flow depth data and factor to gravitational force, density of water flow, and tangent for bed slope degree. All of the factors are constant for all soil covers except for flow depth that has different value for each slope and produces different result for shear stress.

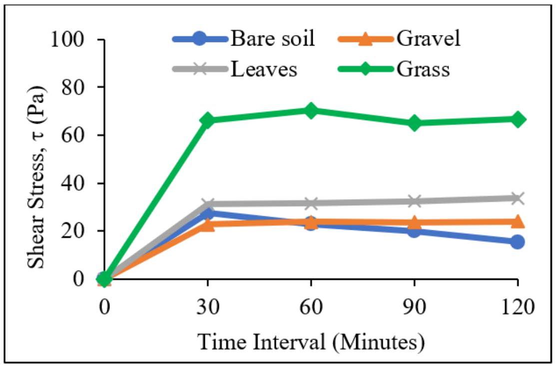

FIGURE 8. The effect of different soil covers on shear stress at $\theta = 20^{o}$

Lastly, by referring to the result of unit stream power in Figure 9, bare soil consists the highest unit stream power under the slope steepness of 20o. Since it has no resultant overland flow, it creates a strong stream to flow over its surface with the power of 0.00461 ms^{-1}. Second highest stream power is gravel where the gravel texture can reduce the stream power compared to bare soil with the power of 0.00327 ms-1. Followed by the dry leaves cover with the power of 0.00232 ms^{-1}, and lastly the weakest stream power will be grass cover where it consists live vegetation cover compared to dry leaves cover with the power of 0.00081 ms^{-1}.

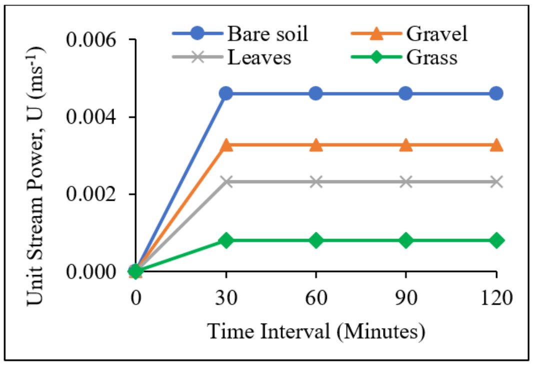

FIGURE 9. The effect of different soil covers on unit stream power at $\theta = 20^{o}$

RELATIONSHIP BETWEEN SEDIMENT CONCENTRATION AND HYDRAULIC PARAMETERS

Based on the relation between sediment concentration and flow velocity for all covers (Figure 10), it shows a positive relation between the flow velocity and sediment production. Bare soil with the steepest slope produced huge sediment production compared to the flat slope. Same goes to gravel cover, leaves, and grass. Grass consists the lowest flow velocity and produced the lowest sediment production. Logically, steep slope produces high flow velocity and it also creates high sediment concentration. Soil covers also play an important role as resultant overland flow. For the relation between flow velocity and sediment concentration, it depends on each value, but if it is influenced by soil cover, the value will be larger.

From the graph of the relation of sediment concentration and flow depth (Figure 11), an observation that can be made between both variables is that it has positive relation where the deeper the flow depth, the lower sediment production produced. Grass for flat slope only shows the negative relation when it produces almost the same amount of sediment production with grass cover on slope steepness of 20 o but a have depth ranges among the bare soil cover, gravel cover and leaves cover. Bare soil on flat slope produced highest sediment production followed by gravel cover. Bare soil on slope steepness of 20 o proved the thinnest flow depth will produce a high sediment concentration.

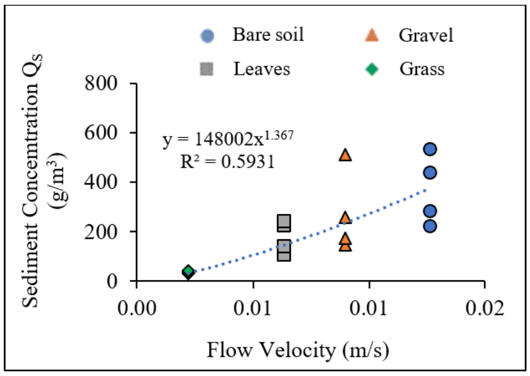

FIGURE 10. The relation between sediment concentration and flow velocity of slope θ = 20 °

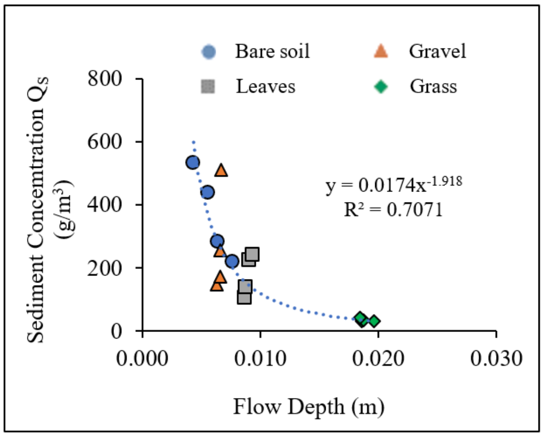

FIGURE 11. The relation between sediment concentration and flow depth of slope θ = 20 °

Figure 12 shows the relation between sediment concentration and shear stress. Eventually, for all soil covers on flat slope has no shear stress since the tangent of the slope is absolute zero. Shear stress occurs when there is a presence of slope. However, the graph shows the positive relation between those two variables. Grass cover on slope steepness of 20 o has the largest stress where it can prevent rainfall from deforming the soil. For covers that have weak shear stress, the soil is unable to hold the soil from deformation caused by the rainfall impact. The vegetation on the grass cover have gripped the soil with its root system and it is hard for rainfall to deform the soil near it. Bare soil is the cover with the weakest shear stress. Rainfall impact and overflow could easily deform the sediment to flow with it.

Lastly, the result of the relation of sediment concentration and unit stream of power (Figure 13) also had to neglect the flat slope since there is no power stream on a flat surface. From Figure 13, it shows positive relation between those two variables where soil cover with the lowest stream power produces less sediment production. The grass has the lowest stream power where the stream of rainfall water interrupted by the vegetation on the cover. Same goes for leaves cover, the difference between grass cover and leaves cover is the condition of the vegetation. As for grass, it has live vegetation while the dry leaves only have dead vegetation. For bare soil, it consists strong stream power and produces large sediment concentration. High stream power does influence sediment production by the strength of the overland flow until it may deform the sediment that flows over it.

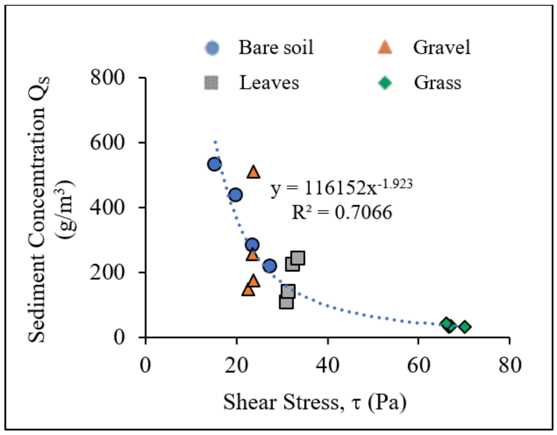

FIGURE 12. The relation between sediment concentration and shear stress of slope θ = 20 °

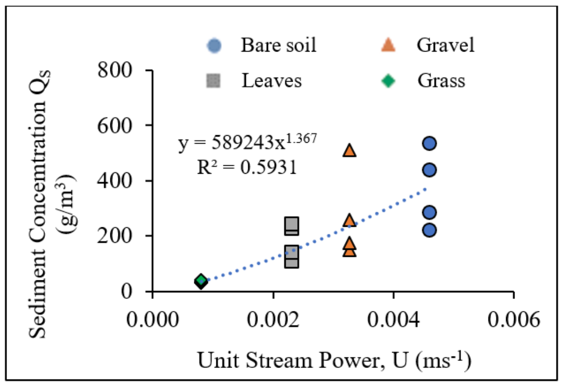

FIGURE 13. The relation between sediment concentration and unit stream power of slope θ = 20 °

Lastly, the result of the relation of sediment concentration and unit stream of power (Figure 13) also had to neglect the flat slope since there is no power stream on a flat surface. From Figure 13, it shows positive relation between those two variables where soil cover with the lowest stream power produces less sediment production. The grass has the lowest stream power where the stream of rainfall water interrupted by the vegetation on the cover. Same goes for leaves cover, the difference between grass cover and leaves cover is the condition of the vegetation. As for grass, it has live vegetation while the dry leaves

only have dead vegetation. For bare soil, it consists strong stream power and produces large sediment concentration. High stream power does influence sediment production by the strength of the overland flow until it may deform the sediment that flows over it.

CONCLUSION

In this research, the aim is to study the relationship between sediment concentration and hydraulic parameters of rain induced overland flow on different types of covers. The overall result displays positive relationship between sediment concentration and hydraulic parameters (flow velocity, shear stress, flow depth, and unit stream power). The slope steepness also influenced the sediment production. Besides that, the different cover shows the resultant overland flow plays an important factor that also may influence the sediment production. Nevertheless, the value of sediment concentration increased as the slow velocity and stream power increases on the steepest slope and a clear soil surface with no resultant overland flow.

The consequence of the research mentioned that sediment concentration curtailed in the soil that has vegetation on the surface and the vegetation needs to prevent it from perishing. Hydraulic parameters that have a linear relation with sediment concentration is flow velocity and stream power considering that the other parameters show nonlinear contact. Flow velocity and stream power are the suggested parameters that may forecast the sediment concentration.

To conclude, the preference in the application of hydraulic parameters was high flow velocity and stream power create high shear stress and flow depth. Due to the mini scale of the rainfall area that was performed in the simulator, the soil surface was supposedly entrained by overland stream powers but due to the low erosivity, the stream power was sufficient to transit the sediment pre-deformed by the raindrop contact. From this finding, the study has shown eventhough the rainfall was experimented in mini scale, it can be used as modelling precisely referring to the flow velocity and stream power if the experiment was experimented on a sloped surface. The flow velocity and stream power need to be measured frequently throughout the experiment.

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DECLARATION OF COMPETING INTEREST

None

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