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The Impact of Providing Surface Cover on the Soil Loss and Water Discharge under the Moderate Rainfall Event

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Abstract

A nation's development purely relies on the good road infrastructure which is necessary to promote the economic growth of the country. On the other side, the detrimental effects in the form of soil loss caused by its construction cannot be neglected. Roads, regardless of their small areal periphery are equally responsible to induce higher rates of erosion when compared with the agricultural lands. This study aimed to shelter the exposed soil surface once the gradients are constructed to mitigate undesirable siltation which raises water muddiness and worsens water carrying capacity of the stream channels. To cope with this issue a full scale field test was conducted on three plots which resembles the road embankments (~30°) provided with the different percentage of land covers i.e. Plot A (fully grass covered surface), Plot B (bare surface), and Plot C (50% of the grass covered surface). The soil loss examined was sandy loam. The sediment loss was observed manually at the catchment outlet of each plot whereas, the volume rate of water flow was observed in the designed bottom container. The runs were conducted for 2 hours under the simulated rainfall events of 52 mm hr^{-1}. The impact of simulated rainfall on the soil loss was nullified by Plot A, the soil loss was severe for Plot B, and Plot C showed preeminent results in restricting soil from flowing away. Whereas, the values of water discharge were found varying for all the plots at different time intervals which are further discussed in this paper.

Keywords: erosion by water, water discharge, exposed soil surface, land cover, simulated rainfall

1. Introduction

Soil erosion is a process which sweeps away the bits of soil sediments from the inclined planes that deplete the land and make it unproductive thus affecting the eco-environment (El Kateb et al., 2013). The term "erosion" varies with various topographies, erosion patterns, soil type, and cropping practices and systems. It is a serious environmental, social, and economic problem which has received increasing emphasis as it is not only responsible for the loss of soil productivity and severe land degradation but it also threatens the sustainable development of a society (Wang et al., 2013). The term soil erosion is associated with the on-site and off-site impacts. On-site impacts are considered to have taken place when the land is degraded due to the loss of nutrient rich top layer causing adverse impacts to the soil quality resulting in the decline of crop production. The off-site impacts are liable to water contamination and increased turbidity which are responsible for the environmental degradation and economic losses (Delmas et al., 2012).

The raindrop capacity to erode the soil depends on the velocity and mass of the raindrop striking the soil surface and the intensity of the rainfall (Angulo-Martinez et al., 2012). The detachment process of soil erosion relates with the energy required to soak the soil surface. Diverse effects have been observed on soil detachment caused by the impact of direct kinetic energy and dissipated kinetic energy (Rienzi et al., 2013).

Roads are among the foremost infrastructures for the economical development of a country by means of trade and communication. Its construction however influences the local environment causing offsite impacts (Dong et al., 2012) as roads are considered to be the major contributors of soil erosion (Cerda et al.,2007) which leads to siltation in the reservoirs, worsens the water capacity of the stream channel, and undermines the road utilities which is very costly to repair (Sekitar, 1996).

For determining the hydrological and erosion response at inter rill scale and to analyze the runoff-infiltration process and soil particle detachment, rainfall simulators are best recommended. The use of simulation gives qualitative information due to the facility of repeating the experiments and recording the data in a short period of time (Martinez-Murillo et al., 2012).

2. Problem Statement

During the phase of roads construction, the embankments usually remain bare and are given little attention in terms of soil loss. Moreover, the nutrient rich top soil is removed which is necessary for the plant re-growth. Due to the lack of cover, the detached soil sediments from the embankments are directed towards the stream channels by means of surface runoff which aggrades the channel capacity, contaminates water quality, and leads to the increased turbidity.

3. Research Objectives

Primarily, the study aimed to observe the response of partially covered grass patches as an immediate protection cover against soil loss for the given rainfall intensity. Specifically, the water discharge was observed to study the behavior of the flow rate for the particular rainfall event.

4. Literature Review

The need of road construction is increasing due to the economic development of the state which contributes to soil loss and causes detrimental effects on the surrounding environment. The construction phase involved in building roads includes unpaved road surface, construction spoil deposits, cut and fill areas, and embankments (Dong et al., 2012). The road embankments usually remain bare once the road is constructed which are then available for soil erosion that leads to the degradation of the roads and reservoir siltation (Cerda et al., 2007). The newly constructed road embankments restrict the plant growth and vegetation development because of the loss of the nutrient rich top soil. The top soil protects the soil from the raindrop impact and provides shelter to the soil particles (De Ona et al., 2011).

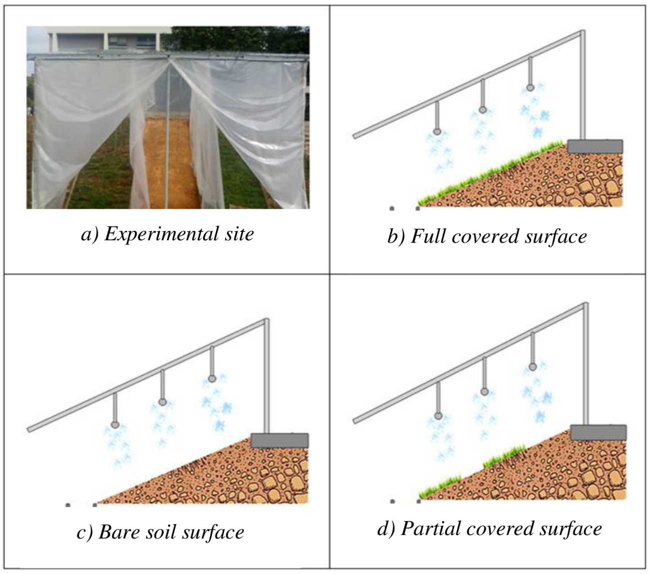
The erosion activities originated from the roads are equal to half of the erosion observed from the logging operations. During the phase of road construction, majority of the erosion occurs during the first rain when the soil is more exposed and disturbed. Humid regions are considered to be severe victim of the road construction activities which worsens the risk of erosion. When cities grow new highways are developed which contributes to the severe runoff and soil loss from the construction activities. This raises the process of sedimentation which is among the most problematic non point source of water pollution (Bakr et al., 2012).

The prediction of erosion rates and its remediation measures are necessary for the road embankments. The embankments usually get damaged by water erosion on the road side slopes which is difficult to maintain and is very costly (Xu et al., 2009). It is such a process which cannot be eliminated completely; however it can be mitigated by applying several structural and soil bio-engineering management practices including mulches, vegetated buffers, retention basins and ponds, hydro seeding, silt fence, porous pavement materials and natural fiber mats. Land cover is therefore mostly preferred as it intercepts rain drop impact, reduces the kinetic energy and decreases the water discharge reaching the water body (Bakr et al., 2012).

5. Methodology

The study was conducted at Universiti Teknologi PETRONAS, Malaysia with the different percentage of land covers on the inclinations having slope angle of 30˚ (represents the gradient of road side slopes) and the plot area of (2 meters x 6 meters) as shown in Figure 1. Each plot was observed under the simulated rainfall of 52 mm hr^{-1} for a period of two hours at the time intervals of 15 min. The rainfall data was collected and analyzed from the Meteorological Department Malaysia for Perak from the year 2005 to 2011.

After every 15 min the soil loss was collected in the plastic bags. The soil samples were then taken to the soil lab and placed in the oven for 24 hours at 105˚C which gave the dried weight of the detached soil particle at each interval. The soil loss was then accumulated and the soil loss per square meter was attained. The volume rate of water flow was also observed in the designed container of known volume (V-notch weir). The water head was noticed after every 15 min in the bottom container for 2 hours. The discharge was then calculated for each interval.



a) Experimental site *b) Full covered surface*

c) Bare soil surface *d) Partial covered surface*

Figure 1. The study area

Figure 2 (a, b) shows that how the eroded soil was received at the bottom catchment outlet which was then oven-dried for assessing the soil loss per square meter and Figure 2 (c, d) shows the water level in the bottom container which was noticed to calculate the water discharge observed from the V-notch weir.

For V-notch weir the discharge is given by,

$$Q = C_d\ 8/15\ (2g)^{1/2}\ \tan \Theta/2\ h^{5/2} \qquad \text{(I)}$$

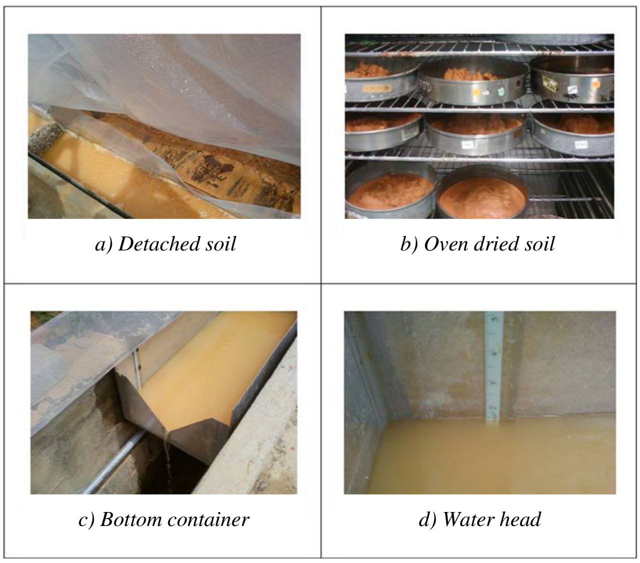
Where:

Q= flow rate (m^3/sec)

C_d= discharge coefficient (0.581)

Θ= degree of opening of the weir (90˚)

h= head on the weir



a) Detached soil *b) Oven dried soil*

c) Bottom container *d) Water head*

Figure 2. The experimental procedure

6. Results and Discussions

6.1The Eroded Soil

Figure 3 shows the accumulated values for the dried soil eroded from Plot A, Plot B, and Plot C at the time interval of 15 min, 30 min, 45 min, 60 min, 75 min, 90 min, 105 min, and 120 min under the simulated rainfall intensity of 52 mm hr^{-1}.

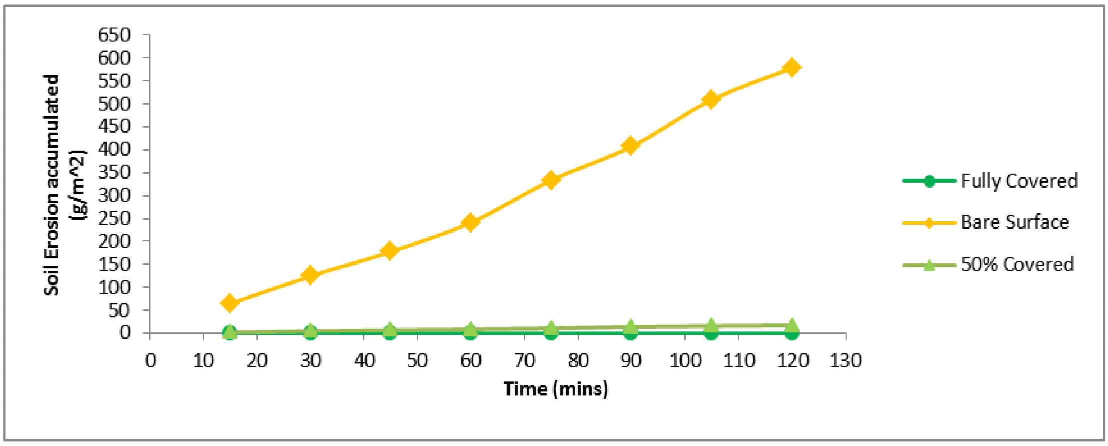


Figure 3. The eroded soil

The soil loss was found negligible from the fully grass covered surface which sheltered the soil particles from flowing away. The impact of raindrop was nullified by the presence of complete grass cover. The soil loss observed from the bare soil surface was drastic because of no surface cover. The exposed soil particles were affected by the striking force of the direct raindrop. The detached soil particles were then taken up by the surface runoff from their point of origin to the catchment outlet. The soil loss observed from 50% of the grass covered surface was very little compared to the bare soil surface. The grass patches did not allow the surface runoff to carry away the detached soil particles. Although, the soil was detached but it was restricted by grass patches which acted as a filter and hindered the particles to flow.

6.2The Water Discharge

The values observed for the water discharge from Plot A, Plot B, and Plot C at the time interval of 15 min, 30 min, 45 min, 60 min, 75 min, 90 min, 105 min, and 120 min under the simulated rainfall intensity of 52 mm hr^{-1} are shown in Figure 4.

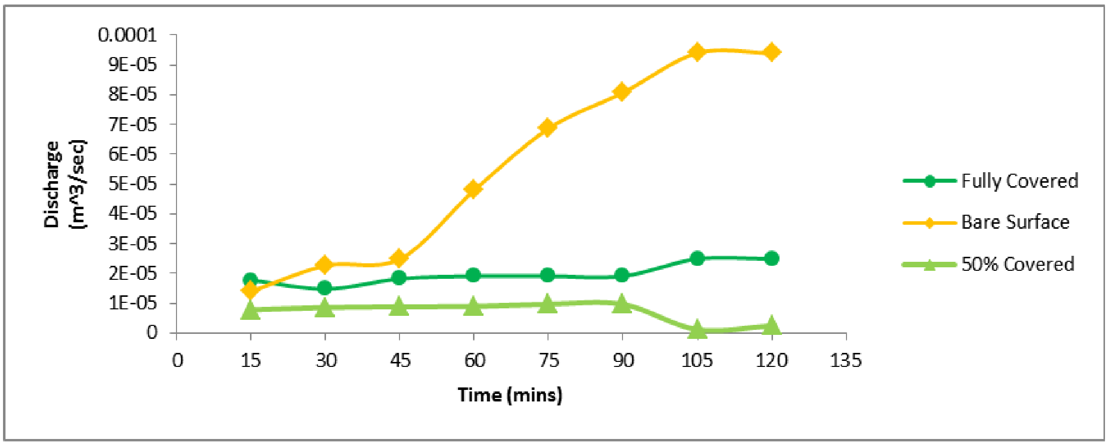


Figure 4. The water discharge

For the water discharge, the maximum values observed from the fully grass covered surface, bare soil surface, and 50% of the grass covered surface were found to be 2.49 x 10^{-5} $m^3 sec^{-1}$, 9.39 x 10^{-5} $m^3 sec^{-1}$, and 9.73 x 10^{-6} $m^3 sec^{-1}$ respectively. The water discharge observed from 50% of the grass covered surface was found to be low as compared to fully grass covered surface and bare soil surface. The reason for which is suggested that the grass patches dissipated the runoff flow, which scattered the water direction due to which the impact of flowing water on the soil particles was reduced and the velocity of the flow was affected. The discharge rates were found adequate from the fully grass covered surface whereas for the bare soil surface the discharge was observed to be drastic because of no surface cover. The discharge observed from the bare soil surface increased smoothly for the initial 45 min which then suddenly arose for which the reason is suggested that the pore capacity of the soil got filled which did not allow further penetration of the water into the soil.

7. Conclusions

It was observed that 50% of the grass covered surface is adequate enough for the immediate soil protection under the moderate rainfall event of 52 mm/hr. The study can be considered to interpolate the optimum percentage of cover necessary for the protection of bare road embankments which have been reported repeatedly in aiding the process of soil erosion and siltation for the similar rainfall events. It was further observed that the water discharge was reduced by placing 50% of the grass covered surface. The presence of grass patches scattered the flow direction and reduced the flow velocity. However, it is suggested that this study may assist the areas where the rainfall is intermittent and moderate and the embankments are exposed.

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