Concentration of Total Suspended Solids (TSS) Influenced by the Simulated Rainfall Event on Highway Embankment

S. M. H. Shah, K. W. Yusof, Z. Mustaffa, and A. Mustafa

***Abstract*—A model was constructed in compliance with the real conditions to study the behavior of total suspended solids (TSS) on the partially covered road side slopes. The study was performed in Perak, Malaysia where the average high rainfall intensity was found to be 52 mm/hr from the year 2005 to 2011. The results attained showed fluctuations in the TSS concentration observed from the partially covered soil surfaces that could have happened due to several reasons which are discussed in the paper. A sandy loam on a slope gradient of 30˚ was observed. Four plots were prepared namely, fully grass covered surface (plot A), bare soil surface (plot B), 50% of the grass covered surface (plot C), and 30% of the grass covered surface (plot D). The concentration of TSS was found to be very severe, attained from the bare soil surface (plot B). However, the maximum TSS values obtained from plot A, C, and D were found to be 22.29%, 45.62%, and 78.90% respectively of the maximum TSS value observed from the bare soil surface.**

***Index Terms*—Highway embankment, simulated rainfall, total suspended solids.**

I. Introduction

In the last few decades, the demand of fresh water has increased due to the tremendous increment in the population growth. On the other side the worsening of the water channels have raised through different polluting agents in the form of effluents and the generated runoff obtained from the surrounding areas [1].

In the year 2010, the river water quality standards of the Malaysian rivers were monitored. Out of 1055 stations, 50% of stations were reported clean whereas; the remaining 50% were found polluted. The status of the clean rivers was 54% in the year 2009, which slightly declined by the year 2010. Several polluting agents were reported liable to the worsening of clean rivers among which the concentration of the suspended solids was stated to be a threating agent [2] which was received from the numerous sources like the road construction activities, industrial activities, deforestation, overgrazing, and urbanization [3]. In order to attain sufficient knowledge and information about the factors affecting the water body it is necessary to properly gather and examine the water samples [4].

The urban population in the developing countries is predicted to increase by about 9.5 billion in the year 2050 where the water quality concerns are increasing. Among several construction activities, road construction is considered to be the major contributor of soil loss which increases the concentration of the suspended solids in the flowing runoff during a storm event [5]. During the rainfall events, the generated storm water flow makes it way towards the small rivers which are among the major environmental issues as it carries the hazardous pollutants in the form of organic compounds, heavy metals, and other suspended solids to receiving body [6]. Together with the suspended solids, the generated runoff delivers the toxic pollutants and disruptive nutrients to the water channels [7] which not only affects the water quality but are considered responsible to cause harmful impacts on the flora and fauna [8]. The concentration of these solids in the water body deteriorates the water quality for which higher cost of water treatment is required [9].

The impact of rain splash erosion is considered to be the most common type of soil erosion on the exposed soil surfaces for which re-vegetation is suggested to be the most viable erosion control technique which takes time to grow [10]. Therefore, the use of grass sod to control the surface erosion on the disturbed lands associated with the highways, is very common as an immediate soil shelter [11]. No doubt, the fully grass covered surface provides the best protection. However, this study aimed to observe the immediate response of a partially covered native grass patches against the soil loss during the phase of embankments construction. If an optimum percentage of cover provides nearly the same results as for the fully grass covered surface for a particular rainfall event, then it would be best recommended as an economical and immediate soil conservation approach. Once the soil loss is reduced, the concentration of the suspended solids towards the catchment area will also decrease.

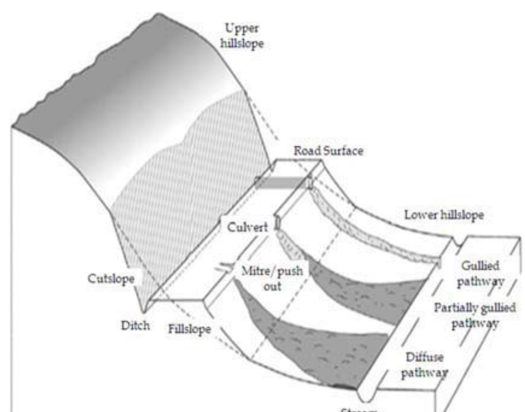

Fig. 1. Road features and runoff conduits [12].

II. Literature Review

A. Road Features and Runoff Conduits

A road is constructed to support the mode of

Manuscript received January 26, 2014; revised March 12, 2014.
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communication. Road surfaces can be crowned, in-sloped, and out-sloped. The crowned road surface distributes the runoff to the fill slopes and the ditches. The in-sloped road surface delivers the generated runoff towards the ditches only whereas; the out-sloped road surface delivers it to the fill slopes. A culvert is a structure provided beneath the road surface and is connected with the ditch to deliver the runoff on the upper hill side slope whereas; a push out is an excavated structure which allows the generated runoff to flow onto a fill-slope area. Fig. 1 shows the features of a road surface which describes that how the generated runoff reaches the stream channels through the embankments [12].

B. Bare Embankments

Nearly 50% of the sediments load that influx into the streams is contributed by the road surfaces [13]. During the last few decades, the capacity of the water channels have been greatly influenced by the sediments load due to the rapid development activities [14]. Majority of the construction spoils occur during the development phase, which are received at the catchment basins in the form of sediments [15]. This gives rise to siltation and worsens the water quality [16]. Among the several general causes responsible for the worsening of the embankments, the improper maintenance of the bare embankments is suggested to be one of the vital agents which lead the sedimentation phenomenon [17].

C. Sedimentation

The process of sedimentation occurs when the eroded soil is detached, transported, and deposited to another place [18]. Once detached, the particles are then carried away by the generated runoff and find its ways to the bottom of a water body where it either settles or remain in suspension depending on its density [19]. Fig. 2 illustrates the way that how sediments settling process occurs. The cohesive particles flocculate through the inter-particle bonding forces whereas; the non-cohesive particles are easily separable due to the large diameter. The silt particles possess both the qualities and remain in suspension for longer than sand grains. Once settled, it then forms the bed load [18], [20] which affects the water carrying capacity of the channels.

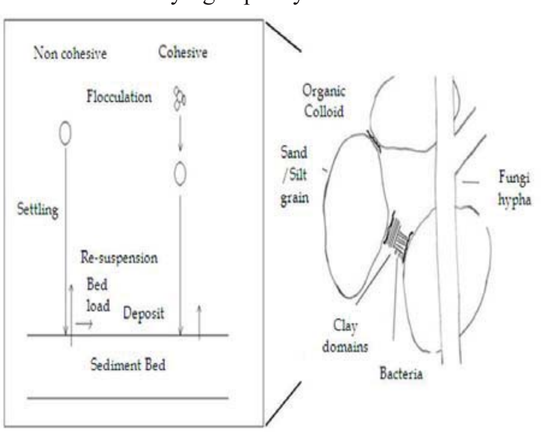

Fig. 2. Settling process [18], [20].

III. HAZARDS OF TSS

The rain water runoff carries away variety of pollutants. It washes away the pollutants and the contaminated heavy metals from the road surface emitted by the busy daily traffic which influx into the water body without proper treatment [21].

Concentration of suspended solids is life threatening for fish species, which causes troublesome infection among which the abrasion of gills is severe. The food finding ability of the fish is also reduced due to the hindrance caused by the solids moving in suspension which further makes these species available to predators [22].

The dissolved oxygen present in the water is greatly influenced by the presence of suspended particles. The sunlight absorbed by the suspended particles, increases the water temperature which reduces the oxygen holding capacity of the warm water and disturbs the cold water species [23].

The existence of TSS further reduces the production of oxygen as it disturbs the light penetration which is necessary for photosynthesis by plants [24].

IV. METHODOLOGY

A. Experimental Setup

The study was performed at Universiti Teknologi PETRONAS, Perak Malaysia. Four plots were separately observed with similar soil conditions, rainfall events, plot size, and slope gradients of 30°. The percentage of grass cover on each plot was varied to form coverage area of 0, 30, 50, and 100%, as shown in Fig. 3. The water samples were collected at 15 minutes intervals for a period of two hours to study the variation of total suspended solids observed from each plot. The water samples were precisely collected at the catchment outlet. The samples were collected without disturbing the settled solids as the study concerns with the presence of total suspended solids only. Later, the samples were taken to the environmental lab for determining the concentration of the TSS observed from each sample.

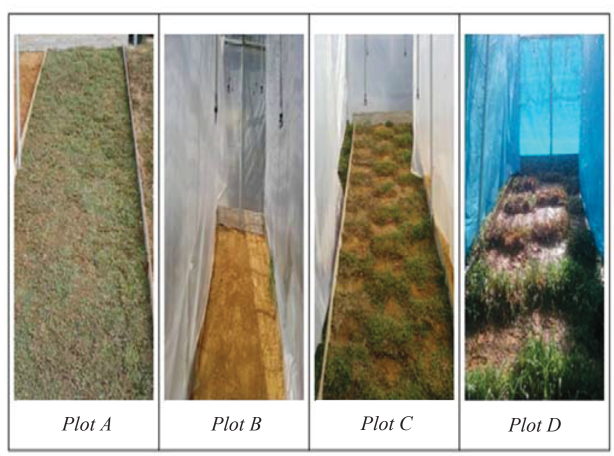

Fig. 3. Front view of the experimental setup showing different grass coverage area for Plot A, B, C, and D.

B. Laboratory Procedures

Thirty two (32) water samples were collected from the four plots to examine the concentration of TSS. The presence of TSS was determined by weighing the dry weight of the residue which was left on the filter paper collected from the sub-sample of a known volume of sediments-water mix [25]. The filter papers were first washed and kept in the oven for 24 hours at 105°C as illustrated in Fig. 4(a). After 24 hours, the dried filter papers were placed in the desiccators for 20 minute and weighed as shown in Fig. 4(b). The samples were stirred before dilution as mentioned in Fig. 4(d). From each water sample, three sub-samples of 10 ml (the dilution used was 1 in 10) were selected to obtain the average TSS value. Next, the filter paper reservoir was removed and the filter paper was placed on the filter support. The vacuum was then kept on and the diluted samples were filtered. The residues left on the filter paper were then dried for one hour in the oven at 105°C and placed in the desiccators for 20 minute as shown in Fig. 4(e). The difference was then observed and the concentration of TSS was determined as mentioned in Fig. 4(f). The TSS was determined using equation (1):

$$TSS= [W_2\ (mg) – W_1\ (mg)] / 0.1\ (L) \quad (1)$$

Where, TSS is the total suspended solids, W_1 is the weight of dried empty filter paper, W_2 is the weight of the dried filter paper containing suspended particles, and 0.1 is the sample volume in liters.

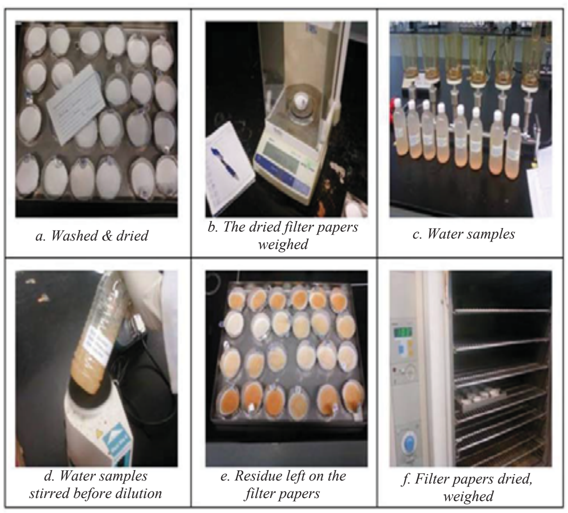

Fig. 4. Laboratory procedures to determine total suspended solids (TSS).

V. Results and Discussion

The results of TSS concentration at different time intervals from all the plots under the rainfall intensity of 52 mm/hr are shown in Fig. 5.

The trend line observed from all the plots showed variations in the TSS concentration for which several factors have been accounted responsible. The results attained showed that the TSS concentration was very high as observed from Plot B (control plot), followed by Plot D, Plot C, and Plot A. The results obtained from Plot B and Plot D nearly lies in the same range. The reason for such proximity is suggested that Plot D was only 30% covered and 70% exposed. Moreover, the reduced percentage of cover increased the spacing between the grass patches which allowed the generated runoff to take away the detached soil particles with the flowing velocity. Therefore, the concentration of TSS as observed from Plot D and Plot B was found to be very near. However, Plot B being fully exposed caused the maximum TSS concentration among all the plots.

The maximum TSS value observed from Plot A was found to be 13 mg/L. Due to complete surface protection the samples collected from plot A were fairly clean. The water samples collected from Plot B were very turbid due to the excess soil loss. The exposed soil surface was influenced by the rain drop impact which raised the runoff flow received in the bottom container. The increased surface water discharge affected the suspended particles in the catchment outlet. Therefore, the maximum TSS value observed from Plot B was found to be 58.3 mg/L. The TSS value observed from Plot C was comparatively lower than Plot B. The closely spaced grass patches reduced the flow velocity, restricted the soil detachment and the amount of suspended solids in the water, collected at the catchment outlet. The maximum TSS value observed from Plot C was found to be 26.6 mg/L. The soil loss observed from Plot D was high compared to Plot A and Plot C. Due to the reduced percentage of cover, the distance between the grass patches increased which allowed the detached sediments to flow with the generated runoff. The maximum TSS value observed from Plot D was found to be 46 mg/L. The TSS concentration observed from Plot A, Plot C, and Plot D was nearly 22%, 46%, and 79% respectively of the TSS concentration observed from Plot B.

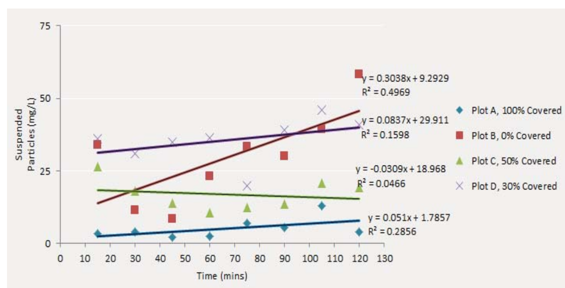

Fig. 5. TSS concentration results for different plots under rainfall event of 52 mm/hr.

VI. Conclusions

The study aimed at recommending the optimum grass cover percentage necessary for the immediate soil protection on the bare road embankments in Perak under the average high and medium rainfall events. Together with the soil loss, water discharge, turbidity, and TSS values were also observed. However, this paper mainly focuses on the TSS values attained from all the plots. It is obvious that the percentage of cover influences the soil particle detachment which in turn affects the concentration of TSS values. The fluctuations in the TSS values showed that the flow velocity has strong impact in picking up the soil particles and disturbing the solids which remain in suspension. Moreover, the density of an individual particle plays a vital role in determining the concentration of TSS in a given water sample. The water samples were collected after every 15 minute which could have allowed the heavy particles to settle at the bottom. The samples examined were precisely collected from the top in the bottom container without disturbing the settled particles.

The study recommends that rather than leaving the embankments bare during the construction phase. It is essential to cover it at least by 50% of the grass covered surface so that it shelters the soil loss on the embankments to an extent for the particular rainfall events and mitigates the concentration of the total suspended solids in the water ways.

ACKNOWLEDGMENT

The author would like to express his sincere gratitude to Universiti Teknologi PETRONAS, Malaysia for providing the Graduate Assistantship and the platform to conduct the study. The author is further thankful to URIF (University Research Incentive Funds) code # 22/12 for supporting and funding the project.

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