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Full Length Research Paper

Removing sediment transport in open channel with submerged aquatic vegetation: Laboratory study

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Vegetation affects fluvial processes and is key role in river management in particular sediment transport. Vegetation characteristics such as vegetation's density, height and distributions have significant effect on sediment transport in vegetated channel. This paper studied the role of aquatic vegetation characteristics in sediment transport. Laboratory experiments were conducted in a fabricated channel with real vegetations (*Hydrilla verticillata*) planted on its bed. The total suspended solid (TSS) was applied for sediment rate measurement. As results, it is found that vegetation density and distribution has significant impact to the sediment entrapment capacity of the vegetation. An increased coverage of the vegetation from 33 to 66% of the flow area has increased the sediment trapping capacity in average by 15%. To sum up, the present study was designed to determine the effect of the vegetation properties on sediment transport rate.

Key words: Sediment transport, aquatic vegetation, Flow, vegetation open channel.

INTRODUCTION

Traditionally, vegetation is the leading cause of reduction in discharge capacity in open channel waterways. Maintenance work has been typically carried out to remove bank and open channel vegetation for this reason (Järvelä, 2005). However, recent developments in the field of river and wetland management have led to a renewed interest in vegetation because of costly and ecological harmful procedures of removing channel vegetation. Vegetation provides ecological services that make it an integral part of a river ecosystem such as increase in bank stability, reduction in erosion and water turbidity, provide aquatic and terrestrial wildlife, provide retention to flood, supply ecological and aesthetic values, and filter pollutants carried by runoff (Afzalimehr et al., 2010; Ali, 2010; Folkard, 2011; Green, 2005; Liu and Shen, 2008; Luhar, 2008; Takahiro Shionoa et al., 2010).

Sediment transport in non vegetated channels is controlled by the channel boundary roughness and flow characteristics (Järvelä, 2004). In the presence of vegetation, the roughness is mainly governed by the drag provided by the vegetation (Nepf and Vivoni, 2000). Vegetation acts as baffles which reduces the mean flow and thus increases the flow depth and residence time and hence promotes sediment accumulation (Folkard, 2005). The capability of vegetation to entrap sediment depends on vegetation characteristics such as vegetation structure, roughness of the leaves and stems, size, density and distribution (Nepf and Ghisalberti, 2008).

Despite, a lot of study investigated flow structure in vegetal channel, far too little attention has been paid to field studies or experiments on the impact of vegetation to sediment transport (Liu and Shen, 2008; Nepf and Ghisalberti, 2008). To our knowledge, there are some studies on sediment transport using non-natural vegetation with limited experimental properties (DUNN, 1996; Folkard, 2005; Schmid et al., 2005; Tsujimoto, 1999). Due to diverse characteristics of vegetation, it is quite challenging and time consuming to tests various types and characteristics of vegetation. Thus, this short study just focused on one type of aquatic vegetation and several significant vegetation characteristics. The aim of this study was to evaluate effects of selected real tropical aquatic vegetation to the suspended sediment transport in an open channel through experimental works.

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Abbreviation: TSS, Total suspended solid.

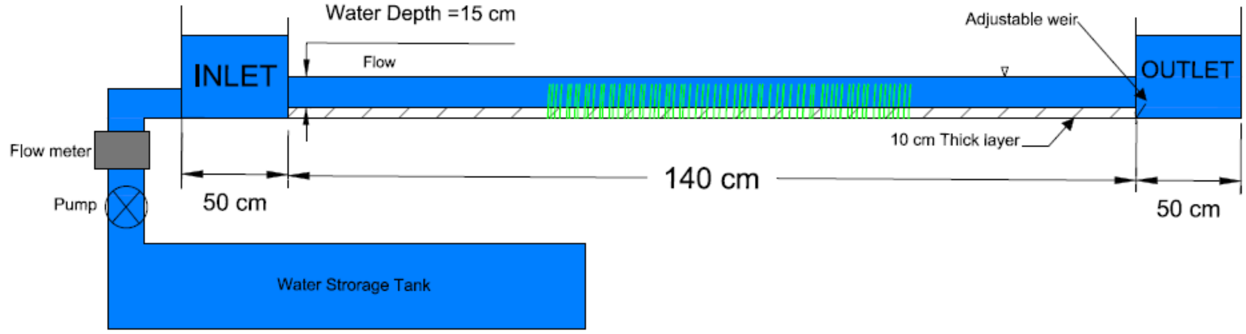

Figure 1. Experimental set-up.

(a) (b) (c)

Figure 2. a) Magnify picture of *Hydrilla Verticillata*, **(b)** Sample of Hydrilla Verticillata in the lab., **(c)** Schematic structure of *Hydrilla verticillata.*

MATERIALS AND METHODS

The study to determine the sediment trapping capacity of a selected aquatic plant was conducted in a fabricated channel of 240 cm length, 50 cm width and 50 cm height. The channel consists of 3 sections that are the inlet, the channel section (test area) and the outlet (Figure 1). The channel bed was covered with 10 cm thick of fine sand for easy planting of the plant. A mixture of water and clay of average particle size of 8.15 μm and specific gravity of 2.52 was pumped from the storage tank to the channel at a controlled discharge of 0.018 m^3/s and a flow depth of 15 cm. The clay particles size and the specific gravity were determined by means of hydrometer test and density bottle method, respectively.

For the plant, *Hydrilla verticillata* was selected due to its structure and roughness which seemed to favour sediment entrapment. Furthermore, it can be easily found and grown in Malaysian waterways especially that with low flow (MASMA, 2000). *H. verticillata* is a submerged aquatic plant with heavily branched stems towards the water surface. Stems are slender and flexible and can grow up to 1–2 m long with each leaf of 5–20 mm long and 0.7–2 mm broad (McCutcheon and Schnoor, 2003). The leaves are strap-shaped with pointed tips and saw-tooth edges and are arranged in whorls of two to eight around the stem. The vegetation structure is shown in Figure 2.

The stems of the *H. verticillata* were cut to the desired lengths of 10, 20 and 30 cm and fastened into bunches by using sponges and rubber band with 10 stems per bunch. The plants were then planted at the sand bed in three different densities and distributions, one at a time. In the first distribution, 24 bunches of the plants were arranged at the centre of the channel section (Figure 3a). In second distribution, 36 vegetations were arranged at both sides of the channel (Figure 3b) and in the third distribution, 48 plants were arranged covering the whole cross section (Figure 3c).

Water samples approximately 50 ml each were collected at the inlet, at the region before (Region 1) and after the vegetation (Region 2) (Figure 3), and at the outlet at time interval of 5, 10 and 15 min after the water started to flow from the outlet of the tank. The amount of suspended sediment in the samples was then determined by total suspended sediment (TSS) standard method.

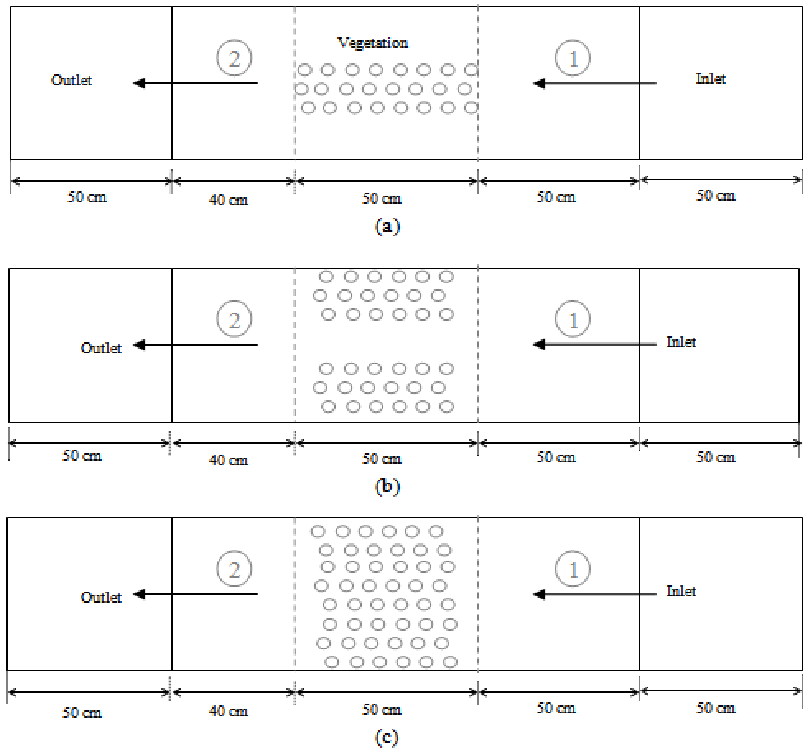

Figure 3. Vegetation distribution for (a) 24 stems (first distribution) (b) 36 stems (second distribution) and (c) 48 stems (third distribution).

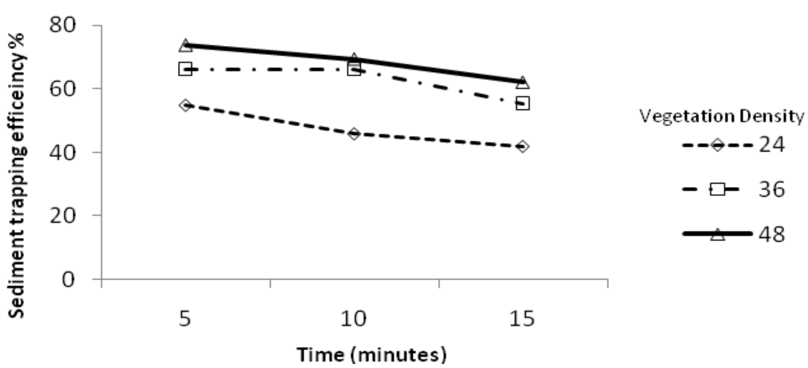

Figure 4. Effect of different density of vegetation on trapping efficiency.

The percentage sediment trapping efficiency, T, for each test were hence calculated using Equation (1):

$$T = \frac{TSS_1 - TSS_2}{TSS_1} \times 100 \quad (1)$$

Where TSS_1 and TSS_2 are the average total suspended load (mg/l) in region 1 and region 2 (Figure 3), respectively.

RESULTS AND DISCUSSION

In this study factors affecting the trapping efficiency of suspended sediment by the vegetation were evaluated, that are vegetation density, distribution, vegetation height as well as time factor.

The effect of vegetation density on sediment trapping capacity

The results of sediment trapping capacity of three different vegetation densities and vegetation height of 30 cm are presented in Figure 4. The total sediment trapping was plotted versus time. Although the flow rate was kept constant, the sediment inflow concentration was not

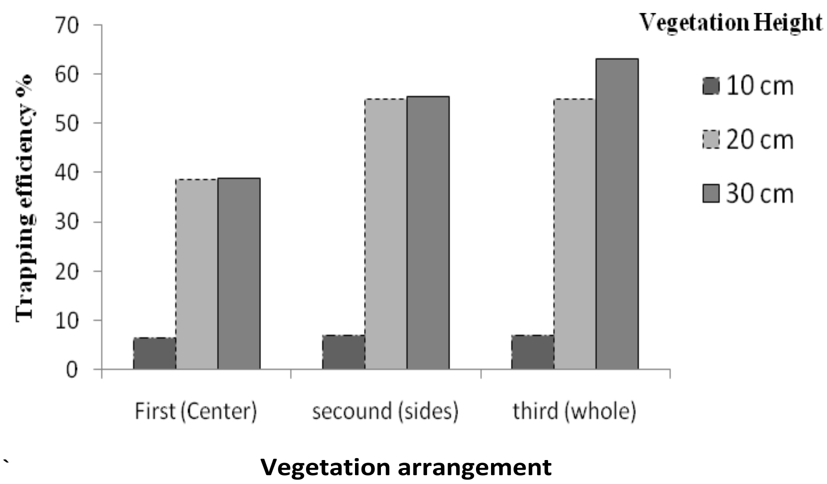

Figure 5. Effect of different arrangements of vegetation on trapping efficiency.

steady due to the sedimentation that was happening in the tank upstream of the plant and in the mixing tank, which was not controllable. There was a time lag in sediment propagation.

Vegetation trapped the largest amount of sediment concentration in the first 5 min for all plant densities. Sediment trapping capacity of the vegetation decreased exponentially with time but increased with vegetation density. Strong evidence of effect of different distribution and density was found. These finding has good agreement with other same work (Järvelä, 2005). This result is also in agreement with those of Righetti (2008) and Nepf and Ghisalberti (2008). They reported high density vegetation is more effective in sediment trapping compare to low density since dense vegetation provide higher roughness that promotes more sediment settlement and accumulation. When the time increased more sediment are expected to flow into the region before the vegetation and through the vegetation but the vegetation capability of trapping the sediments either remains the same or reduced, thus the sediment trapping capacity of the vegetation decreased with time. From the results, it is also found that increased coverage of vegetation from 33 to 66% of the flow area has increased the sediment trapping capacity in average by 15%, while increased coverage to 100% has raised the sediment trapping capacity in average to 21%.

The effect of vegetation arrangement on sediment trapping capacity

In order to study the effect of vegetation distribution on sediment trapping capacity, three different arrangements as shown in Figure 3 with three different vegetation heights (10, 20 and 30 cm) in each arrangement have been tested. Figure 5 shows the percentage of sediment trapping efficiency for different distributions using different heights of vegetation. In general it can be said that the third and second distribution in which the vegetation covered the whole cross section and at both sides of the channel, respectively, provided better trapping efficiency compared to the first distribution (vegetation at the centre of the channel). This was observed for vegetation height of 20 and 30 cm. However, the third distribution did not always give better trapping efficiency compared to the second distribution. For vegetation height of 20 cm, the third and the second distribution performed equally in term of sediment trapping capability. While for vegetation height of 10 cm the different of vegetation distributions seemed do not have any effect on sediment trapping efficiency. It is clear that vegetation arrangement has significant effect on flow structure. The findings of the current study are consistent with Järvelä (2004) who found effect of different vegetation arrangements on flow resistance up to 50%.

The effect of vegetation height on sediment trapping capacity

Figure 6 presented the trapping efficiency of the vegetation with different heights and distributions. The vegetation heights (h) that have been used were 10, 20 and 30 cm. The tests were carried out in the condition where the vegetations were submerged with the flow depth (y) of 15 cm. The results show that the minimum trapping efficiency was when the vegetation height was 10 cm. The increase of vegetation height from 20 to 30 cm did not have much effect on the sediment trapping capacity. This trend is observed for all vegetation densities and distributions. At vegetation height of 10 cm ($h/y < 1$), the sediment can be transported easily through unblock layer above the vegetation. At vegetation height of 20 and 30 cm (greater than the flow depth), top end of the vegetations were bent in the direction of flow and

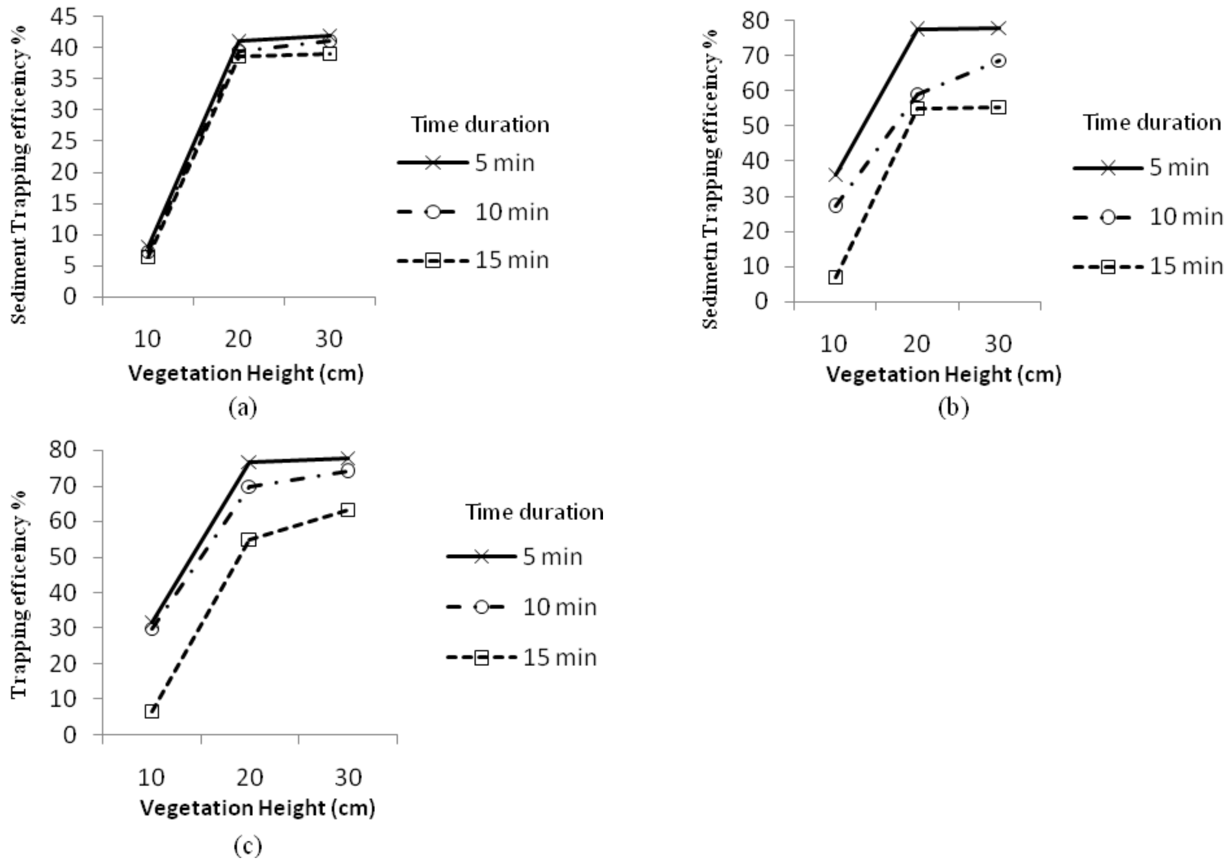

Figure 6. Effect of vegetation height on trapping efficiency (a) 24 vegetations, (b) 36 vegetations and (c) 48 vegetations.

floated on the water surface. Thus height of vegetation in this case (h/y >1) did not play much role in trapping the sediment. It can be concluded that the sediment trapping capacity is dependent on the ratio of h/y rather than on the vegetation height alone.

Conclusions

The results from experiment clearly show the importance of vegetation density and distribution as well as vegetation height-flow depth ratio to elucidate the interaction between suspended sediment transport, aquatic vegetation and flow characteristics. The trapping efficiency of suspended sediment with the third distribution of vegetation in which the flow area is the most covered was significantly higher than that of first and second distribution. Also, in the case of submerged flexible vegetation like H. *verticillata,* it can be said that the longer the vegetation height or length the better the sediment trapping capability. The results cannot be applied to other cases directly, because the vegetation's sediment trapping capability much depends on the vegetation characteristics as well as the flow and sediment characteristics. Due to diverse characteristics and types of aquatic vegetations it is recommended that similar tests are carried for other types of aquatic plant.

REFERENCES

Afzalimehr H, Najfabadi EF, Singh VP (2010). Effect of Vegetation on Banks on Distributions of Velocity and Reynolds Stress under Accelerating Flow. J. Hydrol. Eng., 1(130).

Ali F (2010). Use of vegetation for slope protection: Root mechanical properties of some tropical plants. Int. J. Phys. Sci., 5(5): 496-506.

Dunn CL (1996). Mean flow and turbulence structure induced by vegetation: Experiments. Urbana, USA: University of Illinois at Urbana-Champaign.

Folkard AM (2005). Hydrodynamics of model Posidonia oceanica patches in shallow water. Limnol Oceanogr. 50(5): 1592-1600.

Folkard AM (2011). Vegetated flows in their environmental context: a review. Proceedings ICE – Eng. Comput. Mech., 164(EM1).

Green JC (2005). Modelling flow resistance in vegetated streams: review and development of new theory. Hydrol. Process,. 19(6): 1245-1259.

Jarvela J (2004). Flow resistance in environmental channels: focus on vegetation. PhD, Helsinki University of Technology Water Resources Publications.

Jarvela J (2005). Effect of submerged flexible vegetation on flow structure and resistance. J. Hydrol., 307(1-4): 233-241.

Liu C, Shen Y-m (2008). Flow structure and sediment transport with impacts of aquatic vegetation. J. Hydrodynamics, Ser., 20(4): 461-468.

Luhar M, Rominger J, Nepf H (2008). Interaction between flow, transport and vegetation spatial structure. Environ. Fluid Mech., 8(5-

6): 423-429.
MASMA (2000). Urban Stormwater Management Manual for Malaysia Kuala Lumpur: Department of Irrigration and Drainge Malaysia.
McCutcheon SC, Schnoor JL (2003). Phytoremediation: transformation and control of contaminants: Wiley-IEEE.
Nepf H, Ghisalberti M (2008). Flow and transport in channels with submerged vegetation. *Acta. Geophysica,* 56(3): 753-777.
Nepf HM, Vivoni ER (2000). Flow structure in depth-limited, vegetated flow. J. Geophys. Res., 105(C12):28: 547-28-557.
Righetti M (2008). Flow analysis in a channel with flexible vegetation using double-averaging method. *Acta Geophysica.* 56(3): 801-823.
Schmid BH, Stephan U, Hengl MA (2005). Sediment deposition in constructed wetland ponds with emergent vegetation: laboratory study and mathematical model. Water Sci. Technol., 51(9): 307-314.
Takahiro S, Noburo H, Kuniaki M (2010). Evaluation of a grass field for reduction of sediment runoff from agricultural areas. Desalin. Water Treat., 19: 198-204.
Tsujimoto T (1999). Fluvial processes in streams with vegetation. J. Hydraul. Res., 37(6): 789-803.