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Research paper

Removal of total suspended solids and turbidity within experimental vegetated channel: optimization through response surface methodology

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Abstract

Vegetation plays an important role in transport and settling of suspended sediment in natural waterways. In this study, effectiveness of emergent vegetation in an open channel for the removal of Total Suspended Solids (TSS) and turbidity is empirically investigated. To this end, response surface methodology (RSM) was applied to optimize three variables of vegetated channel including flow velocity at the entrance, density of vegetation, and the length of vegetation zone. Analysis of Variance (ANOVA) was employed to verify the precision of the mathematical models and their relative parameters. Optimum values generated by RSM were compared with experimental results of percentage TSS and turbidity removal and good agreement was observed.

Keywords: Vegetated channel; Total suspended solids; Turbidity; Response surface methodology; Analysis of variance

1. Introduction

Nowadays, huge land areas in Malaysia as well as in other developing countries are being used for development areas such as residential house, commercial building, institution, agriculture, livestock, and industrial areas. During the development, huge land areas will become active construction sites with large quantities of exposed earth. During the rainfall, stormwater runoff from construction site can be the major contribution to stormwater pollution. Sedimentation and nonpoint pollution from the construction site enter into the rivers. This can degrade water quality and habitat, thus affecting aquatic and wildlife. While sediment moves either as bed load or suspended load, it causes many problems in irrigation canals, navigation channels, lakes, reservoirs, and etc. In addition to that, excessive generation of sediment has detrimental impacts especially on fauna and flora. The more important problem related to sediment transport involves fine sediment particles carried in suspension. There is a definite effect of suspended sediment on the size and population of fish in stream. Furthermore, sediment in transport affects the quality of water and its suitability for human consumption and industrial usage (Garcia, 2008; Vanoni, 2006). In order to predict natural process of erosion, transport, and deposition of solid particles and also better comprehension of the interaction between sediment and water, several research studies have been done (GU et al., 2011; Jha and Bombardelli, 2011; Huang et al., 2006; Rodrigues et al., 2006).

Total suspended solids (TSS) is a measurement of water quality. Removal of suspended solids from water body has long been studied because of its adverse impacts on water quality. In order to manage natural resources of a water body through activities such as water quality control, prediction of suspended sediment concentration is very important. Therefore, controlling, measuring, and the removal of suspended solids are absolutely vital for the clarity of water (Altunkaynak, 2010;

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Mulligan et al., 2009). Turbidity is a darkness of water brought about by distinct particles such as suspended solids. One of the most important tests to enhance water quality control is turbidity estimation. The unit of turbidity from a calibrated nephelometer is called Nephelometric Turbidity Unit (NTU) (Australia, 2002; Myre et al., 2006).

There is an increase awareness of the importance of vegetation in the ecological environment of a river system. Although there are unfavorable effects of vegetation on rivers such as reduce conveyance and increase river resistance, vegetation enhances geomorphic stability and diminish the erosion hazard (Rhee et al., 2008; Tanaka and Yagisawa, 2010; Tsujimoto, 1999). It is claimed that vegetated area such as channels and wetlands are useful to entrap suspended sediment in the flow (Huang et al., 2008; Jang and Shimizu, 2007). By baffling the flow and reducing bed-stress vegetation creates region of sediment retention. In some channels vegetation has been shown to retain up to 80% of the sediment in transit downstream (Cotton et al., 2006; Tsujimoto and Shimizu, 1994; Zong and Nepf, 2010). The magnitude of the effects on trapping suspended load not only depends on the characteristics of the flow, but also depends on vegetation characteristics including size, shape, flexibility, concentration, and density (Fu-sheng, 2008; Järvelä, 2005; Sharpe and James, 2007; Wang and Zhu, 2006). In shallow waterways emergent vegetation is observed to have a significant effect on transport of sediment (Leonard and Reed, 2002). Most field studies have shown that emergent vegetation decreases suspended sediment concentrations (Braskerud, 2001; Leonard and Reed, 2002), either by increasing sediment deposition rates or by direct trapping of sediment on stems and leaves (Saiers et al., 2003; Palmer et al., 2004; Huang et al., 2008; Kothyari et al., 2009). The removal of suspended sediment is the result of reduction of transport capacity due to presence of vegetation (Elliott, 2000). The goal of using vegetated channel is to prevent erosion and improve water quality by settling sediments before it flows into permanent stream like river. Flows are reduced by roughness of vegetation and water quality is furthered improved (DID, 2000).

In this research, the effectiveness of emergent vegetation on TSS and turbidity removal was studied within a laboratory flume. In order to reduce the number of experiments, evaluate the effects of various parameters, and find the optimum conditions for desirable responses, the widely used technique for experiment design known as response surface methodology (RSM) was used in this study (Khuri and Cornell, 1996; Zaroual et al., 2009). Moreover, analysis of variance (ANOVA) allows this research to assess suitability of the models by producing the statistical results and diagnostic checking test. While many studies have been done to remove TSS and turbidity using RSM in wastewater treatment, those regarding to water treatment have been limited (Bukhari, 2008; Ghafari et al., 2009; Sadri Moghaddam et al., 2010). To fill this gap in research work, RSM is applied to establish a mathematical correlation involving the flow velocity, vegetation density, and the length of vegetation zone and finally optimize these parameters in order to maximize TSS and turbidity removal. There are many advantages of using RSM over the other methods such as fuzzy logic approach and adaptive neuro-fuzzy inference system (ANFIS). Perhaps one of the most serious advantages of this method is the reduced number of experiments required to establish an appropriate model and consequently acceptable results. In addition to that, RSM is able to evaluate multiple parameters and their interactions. Moreover, the RSM approach has a number of attractive features: 3D graphs, contour plots, and a wide variety of other graphical illustrations.

2. Material and methods

2.1. Flume

The experiments were done at UPM Hydraulic Laboratory, Faculty of Engineering in a straight toughened glass flume with the dimension of 10 m long, 0.303 m wide, and 0.40 m deep. For all the experiment cases the bed slope S_o was kept constant at 0.005. The flume was not recirculating type in this experiment and flow was conveyed to outdoor. Fig. 1 shows the flume configuration used in the test. The discharge and entrance flow velocity were controlled by a flow meter and the water level was adjusted by a gate system setting at the end of the flume. In all the experimental runs the water level was trying to keep approximately in 0.15 m. In order to measure the entrance flow velocity, first of all the flow meter sensor was installed near to the channel inlet on the channel bed. Since flow meter is able to measure the discharge and the water level, by setting the channel width, 0.303 m, into the flow meter it shows the velocity on its screen. It should be noted that the entrance discharge and the water level were already adjusted by pump and gate systems, respectively.

2.2. Vegetation characteristics

The vegetation selected for this study is Lepironia Articulata or by the local name Rumput Purun. This grass is widespread in the tropics and subtropics as it adapts well to the more humid tropical climate. Reed-like leafless plant is up to 2 m tall (in this study less than 1 m) with tubular, hollow, septate bluish green stem of 2 mm in diameter. The reason for this choice was that the grass is considered as emergent vegetation and its ecological function can reduce suspended solids and chemical pollutants and biodegrade organic pollutants in water.

2.3. Total suspended solids (TSS) and turbidity measurement

For TSS and turbidity measurement, in each run a certain amount of soil sample was added and mixed with water in another tank in which an automatic stirrer was installed to mix the soil and water uniformly. The mixture of water and soil were conveyed to the channel via inline flow meter. The water samples of approximately 200 ml were collected at sampling points. The glass microfiber filter paper (GF/C), circles 47 mm Whatman was used to filter the sediment. TSS was measured