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Reduction of Landslide Risk and Water-Logging Using Vegetation

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Abstract. Landslide is a major concern in Bangladesh. The Hill Tracts of Bangladesh are highly vulnerable to rain-cut erosion because of their geological formation, soil characteristics (sedimentary) and deforestation. The cracks in the sandstone allow water to permeate through the layers which causes decrease in shear strength of hill soils leading to landslides. Eroded soil causes clogging in drains and canals in nearby urban areas. Subsequently, in a view to investigate the erosion potential of hill slopes, soil samples were collected from Chittagong and Rangamati hills. The soil is mostly silty or clayey sand which is susceptible to erosion. In this context, bio-engineering technique using vetiver has been selected to reduce erosion potential and water-logging. Efficacy of vetiver in soil erosion has been studied using a model for vegetated slope constructed with hill soil. Performance of slope against rain-cut erosion has been premeditated under uniform artificial rainfall for both bare and vegetated slopes. The sediment yield for bare soil is found to be 47.8 kg/m^2 which is almost four times higher compared to the sediment yield for rooted slope (11.6 kg/m^2). Therefore, vetiver is effective in reducing erosion, which eventually decreases landslide vulnerability and water-logging in the nearby city areas.

1 Introduction

Landslide is one of the most significant natural disasters in Chittagong Hill Tracts (CHT) of Bangladesh [1]. Rapid urbanization and human development activities such as building and road construction through deforestation and excavation of hill slopes have increased landslides in densely populated cities located in mountainous areas [2]. In addition, heavy rainfall makes uncovered slope prone to erosion [3]. Water-logging in Chittagong city is a great concern. One of the main reasons for water-logging is clogging of the drains and canals which is mainly caused by eroded soil load from the nearby hills.

The hill areas are underlain by tertiary and quaternary sediments that have been folded, faulted and uplifted, then deeply dissected by rivers and streams. These areas consist of thick sandstones, shale and siltstone which have less stability. The yellowish orange

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coloured sand particles are fine and loose in state. In between the sandstone layers, there is shale which comes due to the soaking of water. In addition, there are some cracks in the vertical line, which makes it easy for the rain to permeate therein. Hence, the bedrock and soil structure of these hills become unstable and highly prone to erosion.

Vegetation is currently a well-recognized method in the world to stabilize slopes. Vegetative cover not only increases the stability of the slopes but also decreases the soil loss due to rain-cut erosion. Specially, vetiver grass (*Vetiveria zizanioides*) which is a graminaceous plant having fibrous roots reported to reach depths up to 3 m is very popular in slope stabilization [4]. It is a low cost and environment friendly method for erosion control [5-7]. Previous studies have reported on the growth and use of vetiver grass in its natural environment [8]. Shear strength of rooted soil matrix [9-10] and performance of vetiver grass on the coastal embankment stabilization of Bangladesh has been studied [8]. Studies have indicated that a homogeneous slope under rainfall conditions is prone to suffer from surface erosion or shallow landslides [11] whereas deep seated failures are often induced by rainfall in slopes with weak layers. The most obvious way in which vegetation enhances mass stability is via root reinforcement. The combination of deep roots with soils improves the shear strength of soil which makes vetiver grass an ideal plant for stabilizing steep and unstable slopes. The shoot of vetiver effectively absorbs the impact energy of rainfall. In addition, the root system acts as a filter to trap erosion sediment, creates natural terraces and reduces the velocity of rainfall runoff. Vegetation has also effects on infiltration capacity of soil. It is found that vegetative barriers with longer and thicker roots and significantly higher dry weight and volume can make the soil profile more porous and permeable than bare soil condition, resulting in greater channelling and infiltration of runoff [12]. Thus, the Vetiver System (VS) when applied to erodible slopes significantly reduces the probability of land slippage and reduces the need for “hard solutions”.

Physical measures are often combined with bio-engineering approaches to obtain the benefit for erosion control and slope protection [13-14]. Although different model studies have been conducted all around the world, the investigation on hill slopes of Bangladesh is needed to be investigated. This study aims to determine the soil properties of CHT and understand the behaviour of rooted soil through model study. Effect of vetiver on infiltration and erosion potential of hill slopes have also been investigated.

2 Materials and methods

2.1 Study site

Mountains of Bangladesh are located in the southern, eastern and northern part of the country including the Chittagong Hill Tracts (CHT). The area of CHT is 13,184 km^2 which is approximately one-tenth of the total area of Bangladesh. These hills are underlain by unconsolidated or little-consolidated beds of sandstones, siltstones and shale. In order to characterize the hill soil and geometry of hills, two locations were selected: Chittagong and Rangamati. The slope angle and hill height were observed as 45^0~60^0 and 15~35 m, respectively. Disturbed samples were collected from two locations of Rangamati. Undisturbed samples were collected from Rangamati using Shelby tube from a depth of 1 m. Then the Shelby tube was waxed both at top and bottom in order to maintain the moisture content as same as the field condition. The study sites and locations of soils samples collected are shown in Fig. 1.

2.2 Soil Properties

Physical and engineering properties of collected hill soil samples were determined through extensive laboratory tests. Atterberg limit test, grain size, permeability test and direct shear test (CU) have been performed according to ASTM standards. Grain size distribution of the two soil samples collected are presented in Fig. 2. Table 1 presents the properties of the soils. Based on the index properties, soils were classified as SC and SM according to Unified Soil Classification System (USCS).

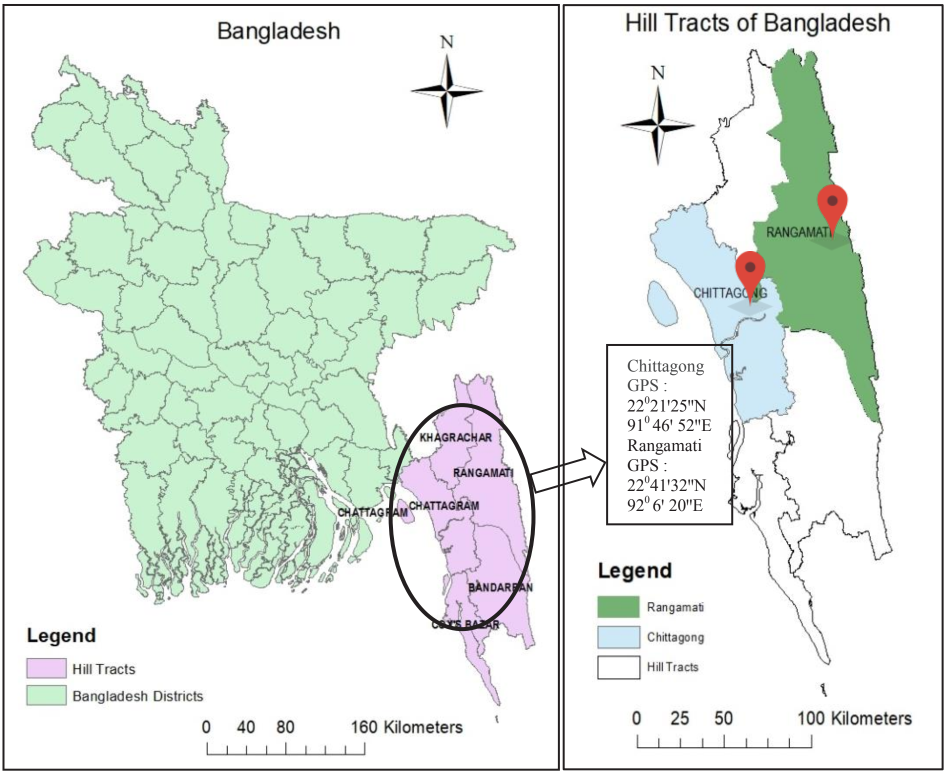

Fig. 1. Locations of the collected soil samples

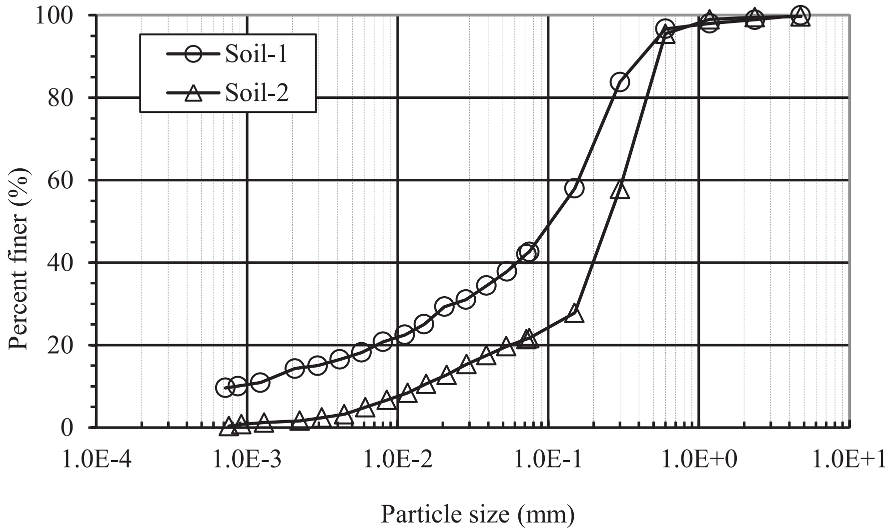

Fig. 2. Grain size distribution of the soil collected from hill tracts

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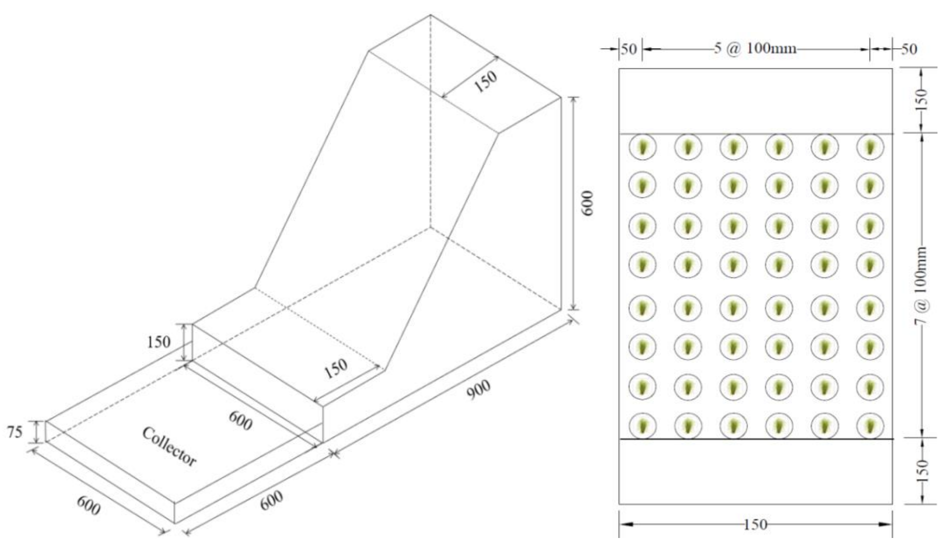
Table 1. Properties of hill tracts soil

Properties	Soil-1	Soil-2
Natural moisture content, w_n (%)	15.46	13.34
Specific gravity, G_s	2.75	2.66
Bulk density, γ (kN/m^3)	16.80	18.50
Liquid Limit (%)	24	28
Plastic Limit (%)	17	24
% Finer No. 200 sieve	42.60	21.70
Soil Classification (USCS)	SC	SM
Void ratio, e	0.85	0.59
Cohesion, c (kN/m^2)	1.80	0
Angle of internal friction, ϕ (^{0})	30.20	39.60
Permeability, k (cm/s)	5.25×10^{-6}	1.93×10^{-5}

2.3 Experimental setup

2.3.1 Model construction

A physical model was constructed to assess the erosion potential of hill slopes. A trapezoidal glass module was manufactured with a slope of 1V:1H. The length, width and height of the model were 900 mm, 600 mm and 600 mm, respectively. The schematic diagram of the glass model is shown in Fig. 3(a). The model was filled with soil collected from Rangamati with a uniform density. The density of the slope model was kept similar to the field condition from where the soil had been collected. To achieve the density in model slope, soil was compacted by a hammer (according to standard proctor test specification) weighing 2.5kg and the drop height was 304.8 mm. The compaction was achieved by several trials. The soil was weighed and placed in the glass chamber and then compacted in every 75 mm thick layer with the use of the hammer. Thus, the whole soil in the model was compacted in total 8 layers.



(a) **(b)**

Fig. 3. (a) Isometric view of the glass model used for rain-cut erosion test, (b) Layout of plantation

scheme of vetiver tiller (dimensions are in mm)

After preparation of the model, the slope was measured as 1V:2.5H. Two similar models were made to simulate two conditions, one for bare soil and the other one was rooted soil with vegetation. For the rooted soil model, vetiver sapling was sowed on mid-December, 2017 with a center to center spacing of 100 mm as shown in Fig. 3(b).

2.3.2 Rainfall simulator

For artificial rainfall simulation, a portable perforated steel tray rainfall simulator (1220mm ×910mm×50mm) was designed (Fig. 4). This drip-type artificial rainfall simulator includes a 1.11 m^2 rectangular tray made of mild steel with a pipe supply-based water connection system, enabling it to simulate any artificial rainfall on a structure (physical model) having an area equal or less than 1.11 m^2. It can produce 188 mm/h rainfall intensity from a height of 3 m above the bottom of the slope with a drop size distribution slightly greater than natural rainfall (median diameter, D_{50}=4.18 mm). Detailed design and calibration are available in Chowdhury et al., 2017 [14].

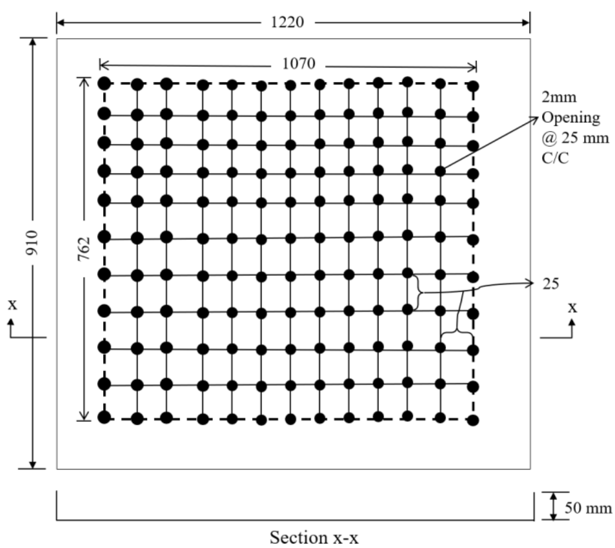


Fig. 4. Schematic diagram of the rainfall simulator (dimensions are in mm)

2.3.3 Collection of eroded soil

After application of artificial rainfall, the portion of rainfall infiltrates into the soil and rest causes direct runoff. Because of direct runoff, some soil particles got washed away which caused surficial soil erosion. To quantify the amount of erosion, the runoff water was collected in a tray and the volume of the runoff water was measured. Then, the soil and water mixture were filtered through filter paper to separate the soil mass from water. Finally, the collected moist soil was dried in oven at 106^0 C for 24 hours to get the dry soil weight.

3 Results and discussions

3.1 Growth of vegetation

In order to study the growth rate of vetiver in hill slopes, vetiver grass have been planted on a model and nurtured on a regular basis. After completion of erosion test, shoot length, root length, clump diameter etc. have been measured. Vetiver grasses have been pulled out from the slopes to observe the physical condition after growth in 90 days. The average root and shoot length was measured as 35.6 cm and 84 cm, respectively. Obtained results have been compared to other values determined by other researchers and presented in Fig. 5. It is observed that growth rate is maximum for dredge sand and minimum for silt. The growth of vetiver in dredge sand [16] was conducted in a model study where enough care and nurturing had been maintained properly. On the contrary, growth in silty soil of road slope [17] was conducted in a field study where it was not possible to nurture the plants properly and hence growth of vetiver in silt [17] was found less compared to the growth in sand [16]. Nasrin, 2013 [19] found that growth rate of vetiver grass in silty sand is higher than that of in clay soil which is very similar to the results of present study and other literature [16-18].

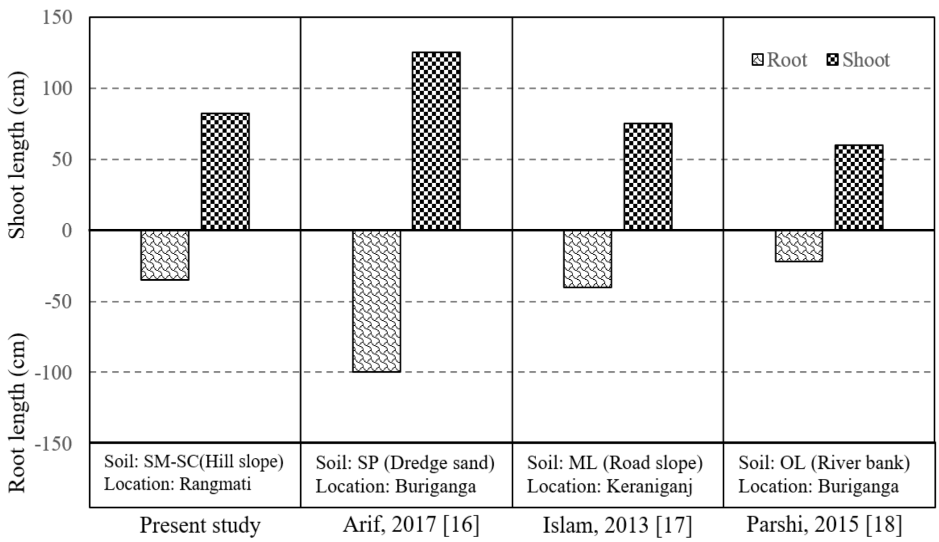


Fig. 5. Comparison of vetiver growth among different study

3.2 Efficacy of vetiver grass in top soil erosion

3.2.1 Effect of vegetation on infiltration

The efficacy of vetiver under artificial rainfall has been tested. Fig. 6 shows the comparative result of soil erosion and condition of bare and vegetated slopes. It can be seen from the clear view of the glass model that the root system has reached the bottom of the model which is 50 cm from the ground surface. The root architecture is also robust in nature. Since vetiver root system absorbs and retains moisture, the water content at the bottom of the model is found higher than the water content at the top of the model. Moreover, the model was confined at the bottom and the infiltrated water could not go deeper compared to the natural slope. Hence, moisture content was found higher at the bottom. Although, the pull-out capacity of the root system has not been measured quantitatively, it is found much higher comparing to the other plant's root system.

From Fig. 7, it is observed that the volume of infiltrated water decreases with time having the same amount of surface water runoff. It is caused due to the decrease in water retention within the soil with time under rainfall. Moreover, confinement of the soil area with trapezoidal glass module may contribute to the increase in retained water; not allowing the water to spread in a large area. Thus, the proportion of the infiltrated water decreases resulting in greater surface runoff water volume.

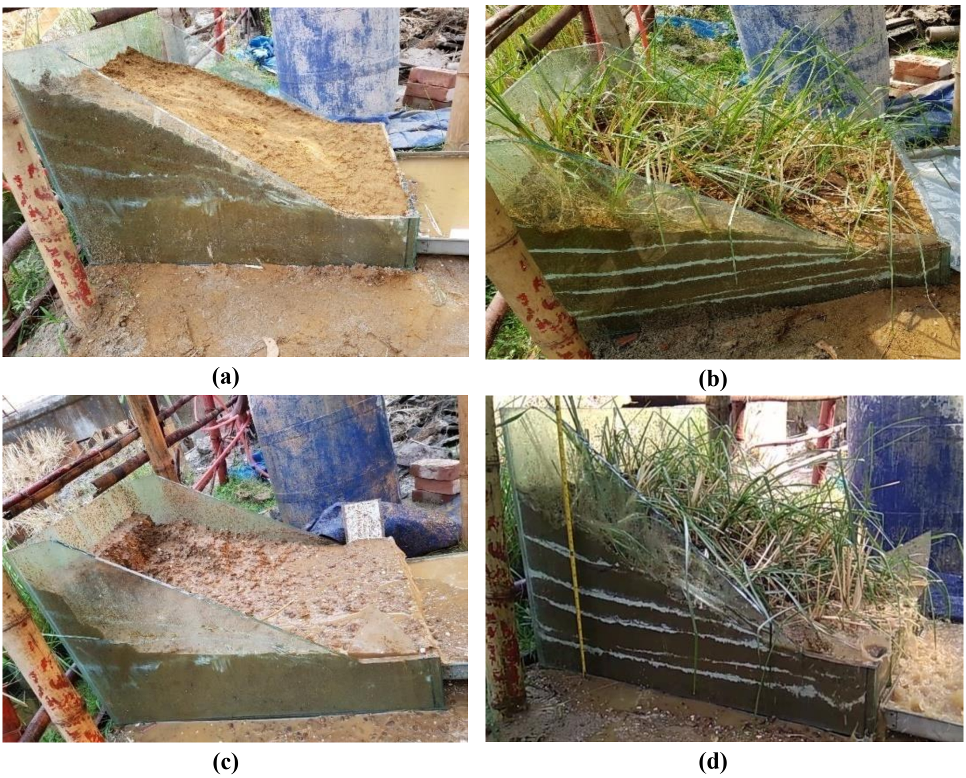


Fig. 6. Rain-cut erosion: (a) bare soil before rainfall; (b) rooted soil before rainfall; (c) bare soil model after 30 min of rainfall; (d) rooted soil model after 30 min of rainfall for bare soil

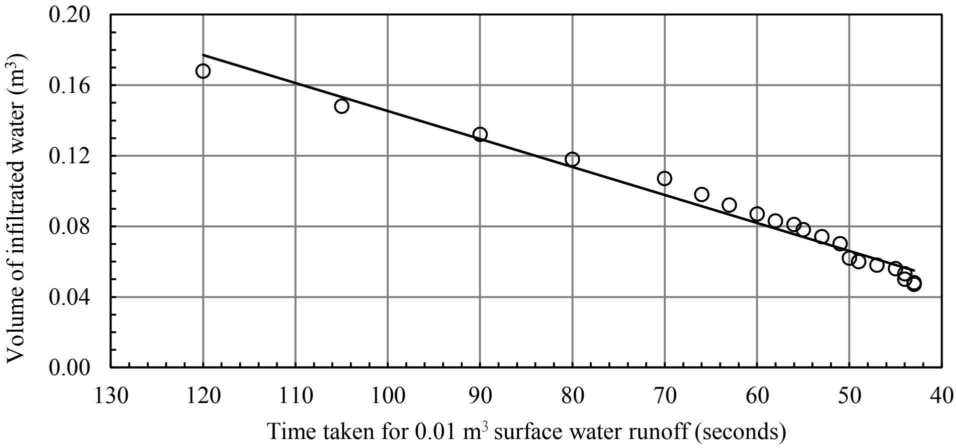


Fig. 7. Volume of infiltration vs. time taken for 0.01m^3 surface runoff

3.2.2 Effect on surface erosion

From the Fig. 8, the cumulative dry weight of eroded soil (under rooted condition) initially (2 minutes~10 minutes rainfall) increases with the increase in time, but the increment rate decreases in the later part (10 minutes~30 minutes) of rainfall, observed from the decreasing slope of the graph with time compared to the initial part. The cumulative dry weight of eroded soil (for bare condition) exhibits an exponential increase with time which signifies that vetiver is quite effective in preventing soil erosion compared to bare soil condition. From Fig. 9, the sediment yield for bare soil is found 47.8 kg/m^2 which is almost four times higher compared to the sediment yield for rooted slope (11.6 kg/m^2). In case of the vegetative slope, the erosion was stopped after 60 mm of rainfall. Since the sediment yield decreases, the sediment load for drains and canals will also be decreased and thus it will reduce water-logging.

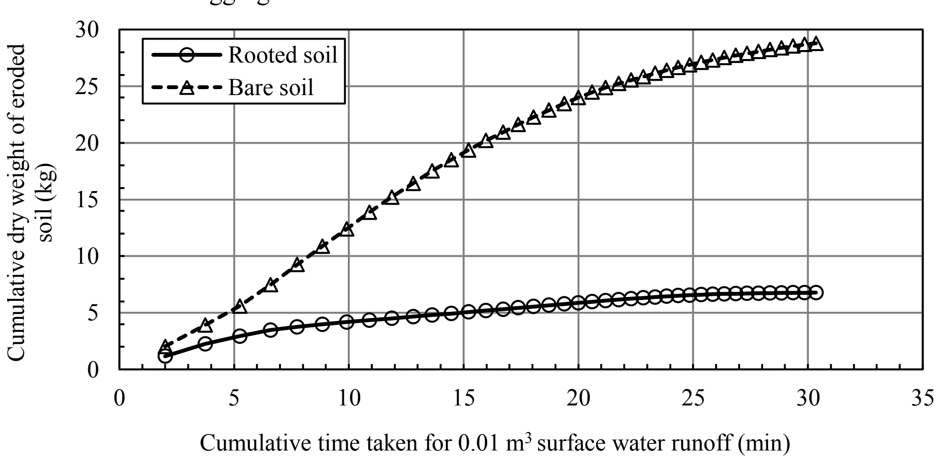


Fig. 8. Cumulative dry weight of eroded soil vs. cumulative time taken for every 0.01m^3 surface water runoff

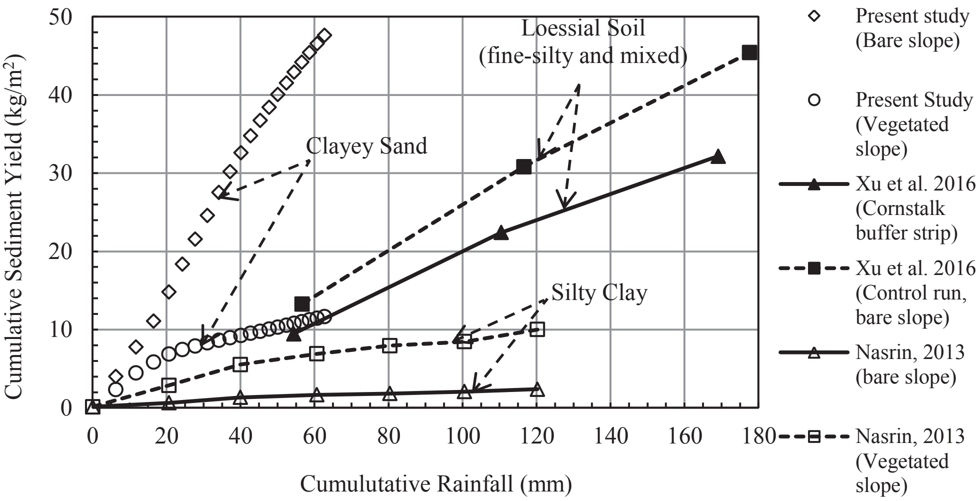


Fig. 9. Comparison of cumulative sediment yield due to rainfall for this study and experiment conducted by Xu et al. (2016) and Nasrin (2013) for bare and vegetated slope

3.2.3 Validation of the model

The study of erosion potential of vegetated slope has been compared with other studies. Xu et al., 2016 [20] simulated rainfall experiment which was designed to investigate how a cornstalk buffer strip affected soil erosion. The data obtained from Xu et al. (2016) have been compared with the present study and illustrated in Fig. 9. Although the present study was conducted by a rainfall simulation only for 30 minutes, the trend of the result can be compared with Xu et al. (2016). It is observed that the performance of the vegetated slope of the two studies for erosion control is quite similar. Though Xu et al. (2016) conducted their study for four different cases of cornstalk buffer strip; comparison was done with only continuous cornstalk buffer strip condition as it was conducted on maximum vegetative soil condition resulting in minimum sediment yield. The slope of cumulative sediment yield decreases gradually with rainfall for both the studies which indicates that after some rainfall the slope erosion decrease which will eventually tend to zero. Moreover, trend of the cumulative sediment yield of this study approaches towards the data of Xu et al. (2016). However, there is a difference for bare soil in which the result from the present study gives higher cumulative sediment yield. The present results are also compared with the results obtained from Nasrin, 2013 [19] in which the slope was 1V:1.5H. Cumulative sediment yield of the present study is quite similar to the results obtained from Nasrin, 2013 [19].

4 Conclusion

In hill slopes, soil erodes mainly due to rain-cut erosion. To quantify the effect of soil erosion under rainfall both field survey and reduced scale models have been conducted for vegetated and bare slope. From this investigation, the followings can be concluded.

a) Because of deforestation, rapid urbanization and human activities, the hill slopes become bare. The hill soils are composed of different layers of sandstones and shales which are easy for the rain to permeate. Thus, the shear strength of hill soil decreases during heavy rainfall in monsoon and causes rain-cut erosion and landslides.

b) The soil properties of hills have been determined and it is found that the soils are mainly silty or clayey sand. Sandy hills are mainly prone to erosion. Hence, water clogging occurs because of eroded soil loads in nearby Chittagong metropolitan areas.
c) From the model study, it is found that cumulative sediment yield reduces significantly for vegetated slopes compared to bare slope. Thus, vetiver grass plantation is effective in reducing the top soil erosion and protection of shallow depth slope failure. Reduction in erosion also decreases the water-logging of the nearby city area.

Vegetation is a cost-effective, sustainable and eco-friendly method for erosion control. For overall stability of hill slopes, vegetation associated with other measures like soil nailing, grouting, geotextiles and geogrid etc. can be used. Pilot studies are being conducted to investigate the effectiveness of the proposed method in Chittagong Hill Tracts.

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