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COMPARISON OF THE SLOPE STABILITY ENHANCEMENT MEASURES FROM BANGLADESH PERSPECTIVE - A REVIEW

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ABSTRACT

Slope failure is a common natural hazard in Bangladesh, especially in the hilly region, because of the specific geotechnical properties of hilly terrains and illegitimate hill cutting. Slope failures need to be minimized as much as possible to prevent their risks to human lives and natural resources. Many researchers have previously studied shallow slope failures based on different methods of enhancing slope stability and how they can benefit. The research works came up with numerous solutions, including applying vegetation using vetiver (Vetiveria zizanioides), recycled plastic pin, biochar, grassland slopes, bioengineering using jute geotextiles, soil-nailing and self-drilling anchors. Notably, different approaches are suitable for slopes of different regions due to differences in soil material and engineering properties, including the grain size distribution, permeability, shear strength parameters. For example, while nailing along with vegetation was found quite effective for sandy hill slope protection, vegetation with vetiver was more effective for stabilizing slopes with clayey soils. In Bangladesh, to ensure sustainability and minimize maintenance needs, different stabilizing methods are needed in different locations to provide slope stability as per soil properties and geological status. This paper presents a critical review of existing slope stability enhancement measures analyzing the usefulness and limitations of different methods considering location, availability of raw materials, required skilled labourers and underlying assumptions from Bangladesh's perspective. Each technique was scrutinized considering soil composition, region-based soil behaviour, rainfall event, and unpredictable factors keeping the safety and economy as prime requirements. Moreover, further research scopes for the potential applications of these methods have been discussed.

Keywords: *Landslide in Bangladesh; Slope stability measures; Hilly soil properties; Soil anchoring; Vegetation*

1. INTRODUCTION

In the last decade, landslides have been one of the significant fatal annual disasters in the hilly and tract areas, especially in the southeastern part of Bangladesh (Ahmed, 2014). After analyzing the history of landslide events of the last 19 years, it is seen that eight districts of the country, i.e., Chattogram, Rangamati, Cox's Bazar, Bandarban, Khagrachari, Sylhet, Habiganj, and Moulvibazar, have been identified as the Landslide-prone Districts (LPDs). The southeastern region (Chattogram, Cox's Bazar, Rangamati, Khagrachari, and Bandarban) has experienced more landslide episodes than the other parts (Sultana, 2020). According to Bangladesh Landslide Database (BDLS-DAT) (2000-2018), a total of 367 landslides occurred in the north, and southeastern part of Bangladesh (Sultana, 2020), whereas only in 2017, five districts of the hilly south-east were affected by several landslide events that caused the death of 164 people victimizing around 15,000 families (Chowdhury, M., 2017). Different studies show that between 2007 and 2018, landslides episodes have increased every year, exposing new places (Froude & Petley, 2018; Haque et al., 2019). As Sultana (2020) stated, the existing government policies of Bangladesh are usually emergency response (such as relocation, rescue & relief works) oriented. Some preventive relocation policies have been developed in the high-risk zone to reduce the risk by resettling 2,00,000 vulnerable people in Chattogram (Sarker & Rashid, 2013). However, due to the Chattogram Hill Tracts Peace Accord-1997, this act can not be applied successfully. Also, according to the participants, relocation strategies are not suitable for the tribal people's culture and lifestyles (Sultana & Tan, 2021). The local administration also implements a landslide Early Warning System (EWS) (Intrieri et al., 2012). However, according to 15 out of 45 officials (9 out of 16 Upazilas), the existing mitigation strategies are insufficient (Sultana & Tan, 2021). It should be reformed into various structural interventions (i.e., slope stabilization, drainage, vegetation management, physical barriers, escape routes, relocation, excavation, construction and dwelling codes) to minimize the frequency and intensity of landslide hazards (Lacasse et al., 2009). Slope stabilization is an effective way that helps to resist the force that comes along the slope (Jeet, A. A., 2020). Different slope stabilization methods are available such as vegetation, soil-nailing, grassland slope, biochar, plastic-pin, soil-anchor etc. However, their implementation depends on the soil type, slope characteristics, rainfall, cost, and maintenance. Study shows that in Chattogram hilly areas, soil samples are consist of medium (37%) to very fine (57%) sand with a small amount of silt and clay (Islam et al., 2014), whereas, in Rangamati, hilly areas are covered with siltstone with subordinate shale, sandy shale and sandstone (Begum et al., 2020). Tertiary hill sediments in Chattogram, Sylhet, and Mymensingh districts mainly comprise sand quartz 70-90% of the total(Huq, S., Shoaib, J., 2013). Moreover, as per laboratory analysis and field investigation in Chattogram division, low cohesion value, low internal friction angle, and greater slope angle from that of the angle of internal friction are the leading causes of rainfall-triggered landslides in the hills. Also, deforestation, cutting down of hills, inappropriate agricultural activities in hilly areas make the area more vulnerable to landslides if the slope angle of the hill is greater than the limit (30°) (Mia A. F., Farazi A. H. and Mahmud M. I., 2017). On the other hand, in the Rangamati district, landslide events occur mainly due to hill cutting (22%), de-vegetation (4%), heavy rainfall (21%), earthquake (12%), steeper hill (4%), and house construction (6%) (Kafy, Hasan, et al. 2017). Depending on the soil type, different methods have been analyzed to prevent shallow landslides, such as vegetation using vetiver to prevent landslides due to rainfall (Islam, M.A., Islam, M.S., Chowdhury, M.E. et al.,2021), recycled plastic pins for hillslope stabilization (Jeet, A., 2020), use of biochar to increase the mechanical strength (Chen, XW., Wong, J.TF., Ng, C.WW., et al.,2015), slope stabilization using self-drilling anchors (Singh, P. and Mittal, S., 2018). In this review paper, the available methods will be discussed, analyzed considering geographic conditions and the suitability of applications of the methods in different locations of Bangladesh.

2. STUDY AREA

This review paper focuses on the hilly areas of Bangladesh in the Chattogram and the Sylhet division. In the Chattogram division, the low hills (100 m-300 m) are made up of unconsolidated Dupi Tila and Dihing sandstones and shales, while the high hills (300 m-1200 m) are made up of consolidated Tipam and Surma siltstones and sandstones (Brammer, H., 1996). In the north and east, yearly rainfall is 2540 mm, whereas it is 2794–3777 mm in the south-west. The monsoon period (June to October) is the most hazardous season, with heavy rainfall causing 86 % of landslides (Sultana, N., & Tan, S., 2021).

3. METHODOLOGY

3.1. Vegetation

Vegetation is a process of covering the land using plant communities to stabilize the soil using the root's hydrological and mechanical properties (Islam & Rahman, 2019). The plant root adds an interlocking property to the soil material and helps remove the water, thus providing shear strength to the soil (Saifuddin and Osman 2014). Available materials for slope reinforcement are grass, shrubs, herbs, and trees with different root structures, mechanical properties, cost, maintenance, and establishment period

(Islam & Rahman, 2019). Previous studies on Acacia forest land show that such vegetation (Acacia auriculiformis, Acacia Mangium, Gmelina Arborea, etc.) improves soil's overall physical and chemical properties by adding relatively higher content of organic matter, total nitrogen, exchangeable cations, and CEC but, these plants require a long time to establish and slow-growing (Akhtaruzzaman et al., 2020). However, deep-rooted trees perform better for stabilizing slopes where the wind speed and risk of a cyclone are low as the Factor of Safety falls drastically (Gupta, 2016). On the contrary, the surface-mat effect of herbaceous vegetated slopes decreases with depth. The vegetation is not much affected by the hydrological dynamics of soil, thus preventing shallow slope failure, which is primarily related to high moisture content (Löbmann et al., 2020). Vetiver grass (*Vetiveria zizanioides*), a graminaceous plant with fibrous roots that can grow up to 3 meters, is effective to reduce top-soil erosion and protecting shallow depth slope failure with low cost, only US$ 4.7 per square meter (Islam et al., 2013) and attains enough height in a short period (Islam. M. S. & Islam. M. A., 2018). Studies also show that vetiver grass in slope reduces the surface runoff volume 18-71% (for different vegetation intervals) and decrease the cumulative sediment yield by 312% compared to the bare slope, which will indeed reduce the rainfall-induced slope failures (Islam et al., 2021). This lesser surface runoff can result in less soil erosion, but this also increases the rate of infiltration (35% higher for a closed experimental setup) by adding permeability to the soil, and in the hilly areas, rainwater infiltration and steep slope are two of the significant causes of slope failure (Islam M. A. et al., 2021, Islam M. S. & Rahman, 2019). Analyzing the soil type and growth rate of vetiver grass, Nasrin (2013) stated that the growth rate is higher in silty soil than in clayey soil, which is very similar to another experiment by Islam M. S. and Islam M. A. (2018). The percentage of FoS due to vetiver also can rise to 48% in silty soil, whereas about 5–35% value is obtained in the case of clayey soil (Suhatril et al., 2019). In Bangladesh, some bioengineering techniques such as vegetation have been applied on some sample sites applying artificial grass treatment using vetiver, and the participants in the programme accepted vegetation as an effective way to mitigate landslides (Dhungana et al., 2020). Also, in Cox's Bazar district, Bangladesh Forest Department (BFD) has launched a project of afforestation and reforestation in the hilly region called “Sustainable Forests and Livelihoods Project (SUFAL)” in 88 hectors areas (Sultana & Tan, 2021). According to Baten et al., Community-managed Village Common Forest (VCF) should be implemented besides the local government for an effective forest management programme against all the odds of the regional groups and tribal communities (2010).

3.2. Biochar

Biochar is a carbon-rich substance created by heating biomass such as wood, leaves, manure, and sludge at low temperatures (700 ºC) (Stockmann, 2011) in the presence of little or no oxygen supply (Lehmann and Joseph,2009). Research works of biochar are classified into five significant aspects. They are contaminants control, greenhouse gas control, plant response, soil biology and soil physical and chemical properties (Chen, XW., Wong, J.TF., Ng, C.WW., *et al.*,2015). Researches have shown that hydraulic conductivity (Yaghoubi, p., 2012), water retention (Cao et al., 2014) and water content (Hseu, Z. Y., Jien, S. H., Chien, W. H., & Liou, R. C.,2014) and resisting capacity against erosion (Fang et al., 2013) are increased in biochar amended soil. A study has shown that soil treated with biochar decreases soil loss during rainfall in calcareous and non-calcareous soil. Moreover, in non-calcareous soils, using biochar reduces bulk density, thus increasing the infiltration rate, whereas in calcareous soils, using the same quantity of biochar does not affect bulk density (Abrol, V. et al., 2016). According to Bangladesh Biochar Initiative, no research works has been done on slope stability using biochar in Bangladesh. Slope stabilization using biochar has both advantages and disadvantages. Research works have been done to estimate the cost of application on different methods; among them, broadcast-and-disk and trench-and-fill are easy to apply. In broadcast application, at saturation rates of 2.5, 5, 10,25 and 50 tons per acre, the cost of application is $29, $44, $72, $158, and $300 respectively, while in trench-and-fill method, for saturation rate 5, 10, 15, 25, 50 and 75 tons per acre, with 2 feet deep trenches with an application rate of 15 feet per minutes, the cost of application is $34, $85, $171, $341, and $512 respectively (Williams, M. M., & Arnott, J. C., 2010).

3.3. Recycled Plastic Pin

Recycled Plastic Pin (RPP) is manufactured from recycled plastic materials and some other wastes (such as fly ash, polymers, sawdust) to provide shear strength to soil mass (Hossain J. & Hossain M. S., 2012). Hossain J. & Hossain M. S. (2012) also reported that RPPs are lightweight, can be modified with conventional equipment and are highly resistant to extreme environmental conditions such as a biochemical attack, UV ray, and freeze-thaw acidic-alkaline condition. This is an eco-friendly and cost-effective method. In Bangladesh, about 3000 tons of industrial plastic waste per day results in 800,000 tons of plastic waste annually, which threatens our environment (Jeet, 2020). Thus, a significant amount of plastic can be recycled commercially to manufacture RPPs at a cheaper rate and protect our environment from the threatening plastic waste. An experimental study by Khan et al. (2017) shows that RPP installation gives higher FoS of a slope (greater than two at critical slope height lower than 9.91 m) for constant soil parameters. A parametric study conducted with different RPP lengths (ranging from 8 ft to 12 ft) shows that an increase in RPP length results in higher FoS (Khan et al., 2014). Jeet (2020) recommended the spacing between 1m to 2 m, whereas Khan et al. (2014) suggested it be up to 1.5 m for better reinforcement. Besides adding shear reinforcement to the soil, RPPs have sufficient stiffness and strength to withstand the stress while installing, making them more user-friendly (Bowders et al., 2003). Different installation methods are available, but according to the study by Sommers et al. (2000), the mast-mounted hammer system is highly preferable because of its effectiveness, accuracy, less skill requirement and cheaper installation cost (317 pins were installed in four days for a total installation cost of $5,250 including labour). Khan et al. (2017) reported that RPPs could add an excellent reinforcement to the clayey soil as higher cohesion values of soil (8.07 kPa) yields more excellent Factor of Safety (between 1.93 and 3.76), except that FoS tends to decrease when the slope height exceeded 8.38 m (27.5 ft). Another numerical analysis by Jeet (2020) on the effect of RPPs installation in clayey sand shows a moderate increase in FoS (up to 1.67), thus providing versatile use of RPPs. Also, a combination of RPPs and modified moisture barrier has a significant impact in controlling the rainfall-induced cyclic wetting and drying that lower (3 times less) lateral deformation of soil (Sapkota et al., 2019). Despite having a promising scope, there has not been any implementation of RPPs in Bangladesh yet. As RPPs are made from waste plastic at a cheaper cost and require no maintenance (Jeet, 2020), this method can thus serve as a significant slope stabilizing method in our country.

3.4. Jute Geotextile

Geotextiles have been utilized as a method of ground improvement to improve soil performance for several years in several sectors of geotechnical engineering. Natural fibres including jute, coir, sisal, kenaf, and ramie, as well as other low-cost natural materials such as palm leaves, wood, and split bamboo, are utilized in geotechnical applications like soil stabilization, erosion control, and soil reinforcement in the hilly areas (Desai & Kant, 2016). For Bangladesh as a major producer of jute fibres and an exporter of geojute (commercial name: "soil saver"), a cost-effective and straightforward solution to rain-induced erosion control problems might be anticipated (Rahman and Khan, 2009). Geo-jute is a popular open mesh jute geotextile made in Bangladesh, and they usually last two monsoons before degrading (Khan & Binoy). There are three basic types of JGT based on constructional features, (i)Woven, (ii) Open weave, (iii) Nonwoven (Sanyal, 2017). A study by Sanyal (2017) states that jute fibre has physical properties of high tenacity, high initial modulus, low elongation at break, highly hydrophilic, high roughness coefficient, excellent spinnability and very high thermal stability that make jute an excellent geotextile compared to synthetic fibre. Laboratory study shows that it increases slope stability during rainy weather when there is no vegetation cover, and the top-soil erosion can be reduced by 95% (Khan & Binoy, 2012). It is recommended to use 500 and 700 GSM open weave jute geotextiles with tea and grass plants respectively (up to 90% of the slope) to effectively stabilize hill slopes (Manivannan et al., 2019). A field test on embankment reported that the factor of safety after implementing jute geotextile was found to be 1.26 (increased 51%). After seven months, the factor of safety was found to be 3.2 (Sanyal, 2017). According to Khan & Binoy (2012), the application of jute geotextile on sandy soil shows excellent success in stabilizing slopes and controlling top-soil erosion. In Bangladesh, five river bank sites were selected in different geographical regions (Panchagarh, Rangpur, Rajbari, Gopalganj and Khulna) by BWDB, BUET and JDPC to apply jute geotextile and investigate. The project was done in 2013, and there was no disturbance reported for many years (Khan, 2016). Locally manufactured jute geotextile in Bangladesh costs BDT 2.30 to 3.0 per sft slope for 500 gsm (Hossain, 2018). This shows the potentiality of jute geotextile in various slope stabilization fields.

3.5 Soil nailing

Soil nailing implies reinforcing and strengthening existing structures by placing closely spaced steel bars, known as 'nails,' into a slope as work progresses from top to bottom (Tan, Y. C., & Chow, C. M., 2004). This procedure produces a strengthened portion that is both stable and capable of retaining the ground underneath it (Tan, Y. C., & Chow, C. M., 2004). In Malaysia, soil nailing has become popular in road construction and hillside development projects because of its simple construction and low maintenance requirements (Chee-Meng, C., & Yean-Chin, T., 2006). In Bangladesh, soil nailing has not gained much popularity in slope stabilization but it can be a solution in preventing landslides (Islam et al., 2017). Elahi, T. E., Islam, M. A., and Islam, M. S. in 2019 showed that in the sandy soil of Rangamati, FoS is increased by 61% if the slope is reinforced with soil nailing and vegetation, and in clayey soil, FoS is increased by only 13%. According to Shaw-Shong, L. (2005), the following soil types are suitable for soil nailing

- Stiff fine/cohesive soil.
- Cemented granular soil.
- Well-graded granular soils having a minimum apparent cohesiveness of 5kPa, as measured by capillary suction, and enough moisture content.
- Most residual soils and weathered rock mass without unfavorable geological conditions (such as poor day-lighting discontinuities, extensively fractured rock mass) exposed during the staged excavation.

In hill slopes, the soil is eroded due to extensive rainfall (Islam and Islam, 2018). Research conducted by Mittal, S. in 2006 showed that soil nailing is be a helpful method for protecting the slope during rainfall. The materials used for soil nailing are available in Bangladesh as Bangladesh is much sufficient in manufacturing steel reinforcement. According to Tan, Y. C., & Chow, C. M. (2004), materials used for soil nailing should be-

1. Steel Nail reinforcement. BS 4449 or equivalent standard.
2. Steel welded wire fabric. BS 2283 or equivalent standard.

From Bangladesh's perspective, hill slopes reinforced with vegetation and soil nailing will effectively stabilize the hill slopes because of the easy availability of raw materials and low maintenance cost.

3.6 Soil anchoring

Soil anchoring is a technique similar to soil nailing. Anchors/nails are inserted to increase the soil's tensile and shear strength and constrain its displacements (Singh, P., & Mittal, S., 2018). In our country, no research work or application of soil anchoring has been made in slope stabilization. The conventional approach for protecting hill slopes is to construct RC retaining walls and masonry walls, which are expensive in Bangladesh (Elahi, T. E., Islam, M. A., & Islam, M. S., 2019). The existing RC retaining wall and masonry wall can be upgraded by inserting steel anchors through the walls. Soil anchoring with steel bars is also effective when the vertical load alone or above the slope is increased that results in improvement of the shear resistance along the slip surface (Hobst and Zajic 1983; Bromhead 1994).

4. COMPARATIVE ANALYSIS AMONG DIFFERENT METHODS

To understand the suitability and efficiency of the available slope stabilizing from Bangladesh perspective, Table-1 represents the comparison considering the soil type, material, cost and maintenance.

Table 1: Comparison among differnt slope stabilization methods.

No	Methods	Suitable Soil Type	Raw materials	Cost	Maintenance
1	Vegetation	1. Silty Sand 2. Clayey Soil	1. Vetiver grass (Vetiveria zizanioides)	Cost of vetiver plantation US$ 4.7 per square meter	Low cost of maintenance
2	Application of Biochar	1. Soils with less hydraulic conductivity. 2. Non-calcareous soil.	1. Solid by-products of Pyrolysis 2. Pyrolysis raw materials: animal feedings, crop residues, agricultural materials, food wastes, woody materials, animal litters and solid wastes.	1.In broadcast application at saturation rate of 2.5, 5, 10 ,25 and 50 tons per acre the cost of application is $29, $44, $72, $158, and $300 respectively. 2. In trench-and-fill application method, for saturation rate 5, 10, 15, 25, 50 and 75 tons per acre, with 2 feet deep trenches with an application rate of 15 feet per minutes, the cost of application is $34, $85, $171, $341, and $512 respectively.	Re-application of biochar after 2-3 years.
3	Recycled plastic pin	1. Clayey soil 2. Clayey sand	1. Recycled plastic materials. 2. Fly ash, polymers, sawdust.	1. Mastmounted hammer system: Install 317 pins in four days for a total cost of $5,250, including labour.	Requires no maintenance.
4	Jute geotextile	1. Sandy soil 2. Clayey soil	1. Natural fibres are jute, coir, sisal, kenaf, ramie, palm leaves, wood, and split bamboo.	BDT 2.30 to 3.0 per sft slope for 500 gsm	Re-application after every two monsoons.
5	Soil nailing	1. Sandy soil 2. Cemented granular soil 3. Most residual soil and weathered rock mass 4. Cohesive soil.	1. Steel Nail reinforcement. BS 4449 or equivalent standard. 2. Steel welded wire fabric. BS 2283 or equivalent standard	N/A	Low cost of maintenance
6	Soil anchoring	Same as soil nailing			

5. CONCLUSION AND RECOMMENDATIONS

The current study has been conducted to analyze different methodologies of hilly slope stabilization and their suitability for our country in terms of soil types, rainfall event, availability of raw materials, cost and safety factors. As vetiver grass, jute geotextile and soil nailing perform comparatively better in sandy soil, they are compatible to be implemented in Chattogram, Sylhet and Mymensingh hilly regions. Jute geotextile along with vegetation could be a great measure to stabilize Rangamati landslide prone areas considering its silty soil composition and heavy rainfall every year. Application of biochar has potential for our study area for its non-calcareous soil composition to increase mechanical strength. Also, for clayey soil using biochar and RPP respectively is a reliable method. Hill slope reinforcement with vegetation at first to increase cohesion in soil and then implementing soil nailing will work as an effective tool to increase the factor of safety. For existing retaining walls on some sites, applying soil anchoring could add more stability and durability in slope reinforcement.

In Bangladesh only the implementation of vegetation and jute geotextile has been evidently found. Further research is needed to analyze the soil composition of Bangladesh's different hilly and tract areas for selecting the most suitable slope stabilizing method. A comprehensive cost-benefit analysis of the available methods needs to be reported from Bangladesh's perspective to assist the policymakers.

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