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Importance of vetiver grass system to reduce the impacts of landslide hazard in Katteri watershed, Nilgiris District, India

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Key words: Landslide hazard mitigation, Kattery watershed, Nilgiris, Vetiver grass, Shear strength

Abstract

This article explores the scope of the vetiver system as a natural solution to mitigate landslide hazard in the Katteri Basin, Nilgiris District, Western Ghats of India. Landslides are one of the most common problems worldwide and also in India. The district of Nilgiris, located in the Western Ghats in southern India, is prone to high to heavy landslides. This area makes it clear that the future occurrence of landslides in the district is diverse and catastrophic. Many researchers have quantified the danger and risk of landslides in these areas; however there are not many studies on landslide planning, environmental and social issues. Numerous landslides/ landslides have taught a lesson and created the need and urgency to address these issues. In connection with the existing landslide risk scenario, the beginnings of landslide risk reduction in the district and the study area to be processed in the Nilgiris district were examined and recommendations were made to overcome these problems. Scientists, planners and policymakers on landslide containment practices in Nilgiri District.

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Introduction

The landslide hazard is one of the major hazards that various parts of India are faced with each year during the rainy season. The frequency of landslides varies in different mountain ranges. India's Landslide Hazard Zoning Atlas published by Building India's Materials and Technology Promotion Council (BMTPC) has classified the Nilgiris district in Tamil Nadu state as one of the areas prone to severe to very high landslides. The district is known for the risk of landslides. Recently, landslide losses and damage have increased in the Nilgiri Hills, teaching the lesson of the need and urgency for the safety of habitats in landslide prone areas.

Vegetation is used as a millennia-old practice to protect slopes as it improves the shear strength of the soil. Over the centuries, these techniques were used in ancient times to protect flat slopes from irrigation and water sources such as tanks, canals and lakes (Petrone and Preti 2010, Genet *et al.,* 2010, Schwarz *et al.,* 2010). The plants used for this also differed depending on the suitability of the location from place to place. Engineering techniques such as building retaining walls (Devkota *et al.,* 2006, Petrone and Preti 2010) are not only ecological, but can also have certain limitations, such as z et up to 2010). Different root types and different types of root plants show different performances in improving soil shear strength in different geographic locations (Burylo *et al.,* L 2007). Shear strength, a main parameter for slope stability, is directly proportional to the fiber area ratio (Gray and Ohashi 1983), the discrete randomness of the fibers (Maher and Gray 1990, Prabhakar and Sridhar, 2002) and naturally inherited technical properties. Fiber (Rao and Balan 2000, Sivakamar and Vasudevan 2008). Among the various natural plants, the vetiver and the sisal are the most widespread anti-soil erosion vegetation in subtropical countries such as India, China, the Philippines and Indonesia (Erskine 1992). Vetiver root system composed of fibrous roots extending to a depth of 3. 0 m below the Surface and serves as a necessary anchor to protect the loss of surface soil and therefore its use has been promoted by the World Bank, and the roots of vetiver plants also take up water and evaporate into the atmosphere through stem and grass systems. Biospecies by many researchers was also attempted in this study to improve the shear strength parameters of the slopes in order to minimize the susceptibility to landslides (BhandarI 2006, Ganapathy *et al.,* 2009, 2010, GSI 1993, Thanavelu and Chandrasekaran 2008, BMTPC 2003, Rajarathnam, Ganapathy. 2006, Seshagiri *et al.,* 1982, Jaiswal and Van Westen. 2009, UNDRO 1991, IDNDR 1999, Leven thal and Withycombe, 2009, Saunders and Glassey 2009, David 2003, Schiechtl *et al.,* 1980, Lewis 2000, Lewis *et al.,* 2001, Gray and Leiser 1982, WSDOT 2012, Bhoop Singh, 2006, NDMA 2009).

In the present study, the soil required for plant growth was collected from sites where landslides have historically occurred from the slopes of the Nilgiri Hills in the Western Ghats of India. Vetiver grass was grown above ground at different predetermined arbitrary distances. Over time, increases in root zone depths were observed and the shear strength of the soil in different root zone depths was determined using the shear box test (direct cut test) according to IS 2720 Part 131986, and the soil shear strength was optimized and the plant spacing optimized in order to achieve maximum soil shear strength (Fig. 5).

Study area and methodology

Study area

Nilgiris district comprises 75 macro watersheds and 176 micro watersheds. Kateri watersheds of nilgiri district codified as 7A/75 which falls between lattitudes 110 16' 19" N to 110 24' 40" N and longitude 760 40' 40" E to 760 49' 25" E. The watershed comes in the survey of India topo sheets 58 A/11 and A/15 published on 1:50000 scale. This watershed is located at about 9 kms from Coonoor in Ooty-Coonoor highway at a maximum elevation of 2480m MSL and an area of 2919 hectares. The site specific study area ketti micro watershed is situated on the northern side of this watershed with an AISLUS codification of 4B2O5B2B2B3A. This micro watershed partly lies on the Ooty- Coonoor highway itself. With a GPS location 110 23 '3''N and longitude 760 44 '0`` E.

The micro watershed is characterized with moderate to steep slope, laterite soils and coarse drainage pattern. The present land use is of annual crops, forests and tea cultivation. Improper agricultural and construction practices have triggered soil erosion in the past decades, silting up the katteri reservoir at the drainage point. The dam was desilted in early 1980s and in 2015 at a huge cost. The watershed had undergone major loss of life and natural resources in the past, the recent one being 2001 (Fig. 1 and 2).

Landslide susceptibility assessment

Landslide is a regularly occurring activity in the Nilgiris district of Tamil Nadu state, India because of high intensity rainfall. Landslides occur both in remote, unpopulated as well as in the populated areas. Most of the landslides occur in the places where deforestation, plantation, urbanization and shifting cultivation take place. In such places, more rain water may infiltrate into various soil layers and lead to landslides. As site specific study related to landslides, Landslide susceptibility assessment (LSA) was done for Ketti micro- watershed, using remote sensing and GIS techniques. Various thematic maps based on the data and field study with GIS application the following maps of Ketti micro watershed were prepared.

1. Watershed map, 2. Present Land use map, 3. Drainage map, 4. Slope map, 5. Soil Map, 6. Elevation & Contour Map.

Pertaining to this work was prepared from Survey of India topographic maps and satellite imageries. The prepared maps were justified in the field during field investigations. Finally, all the thematic maps were integrated using GIS applications to prepare landslide susceptibility maps of ketti micro watersheds (Fig. 3) (BhandarI 2006, Ganapathy *et al.,* 2009, 2010, GSI 1993, Thanavelu and Chandrasekaran 2008, BMTPC 2003, Rajarathnam, Ganapathy. 2006, Seshagiri *et al.,* 1982, Jaiswal and Van Westen. 2009, UNDRO 1991, IDNDR 1999, Leventhal and Withycombe, 2009, Saunders and Glassey 2009, David 2003, Schiechtl *et al.,* 1980, Lewis 2000, Lewis *et al.,* 2001, Gray and Leiser 1982, WSDOT 2012, Bhoop Singh, 2006, NDMA 2009).

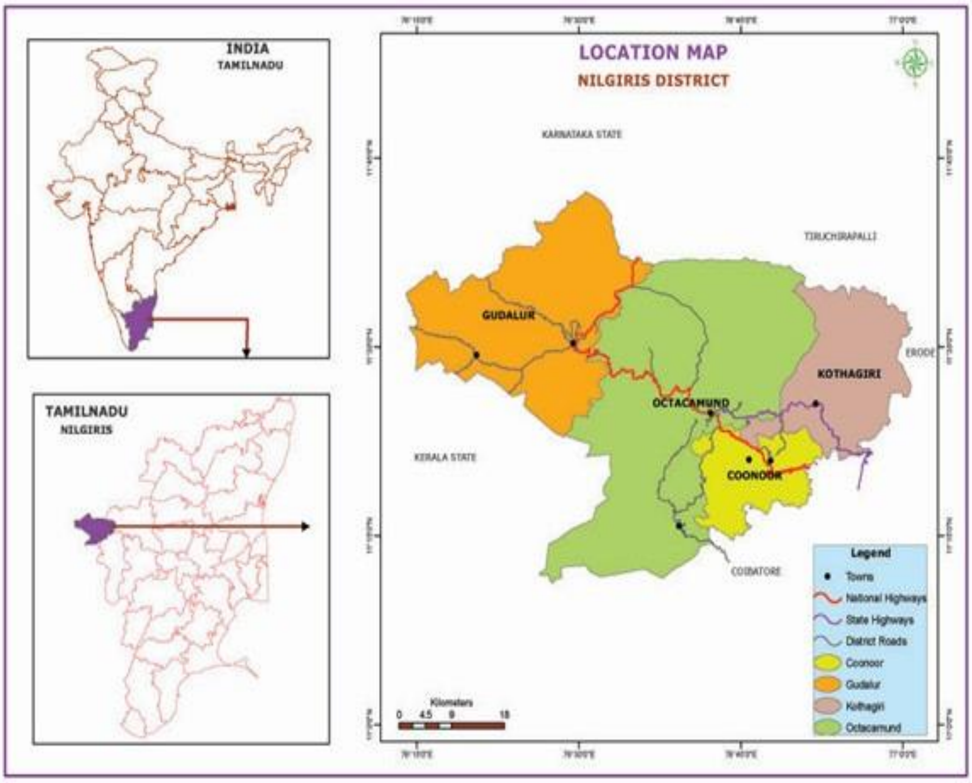

Fig. 1. Study Area Location map.

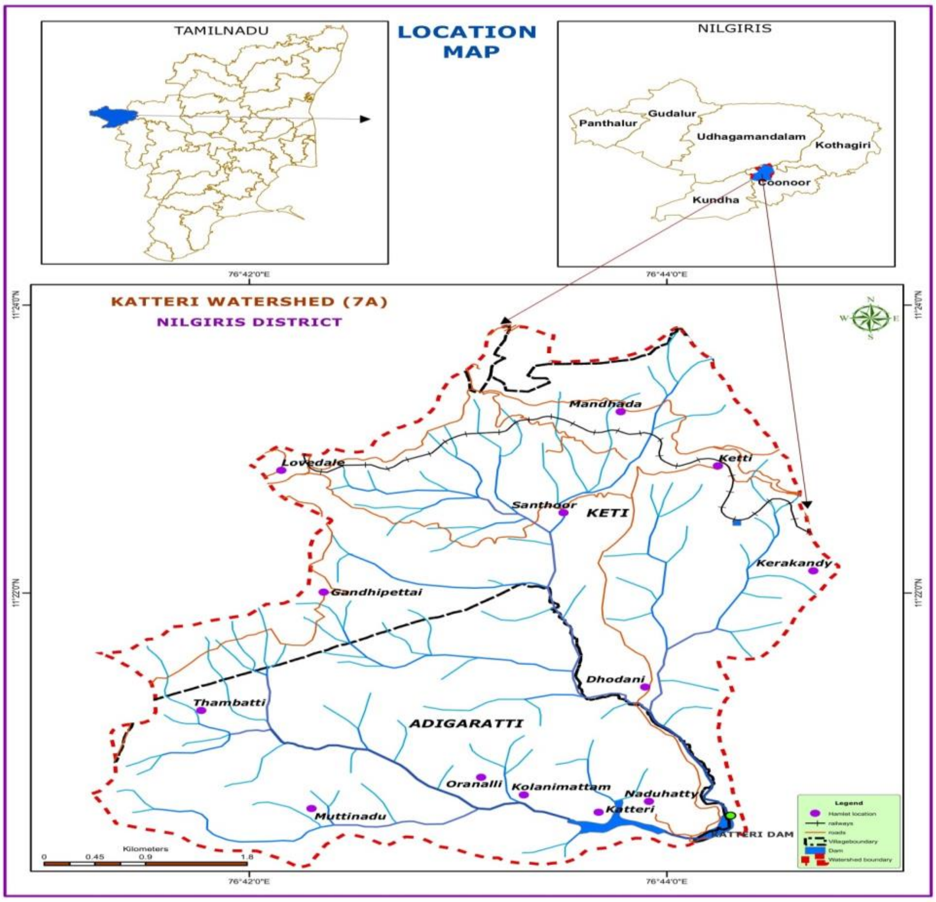

Fig. 2. Katteri watershed location map.

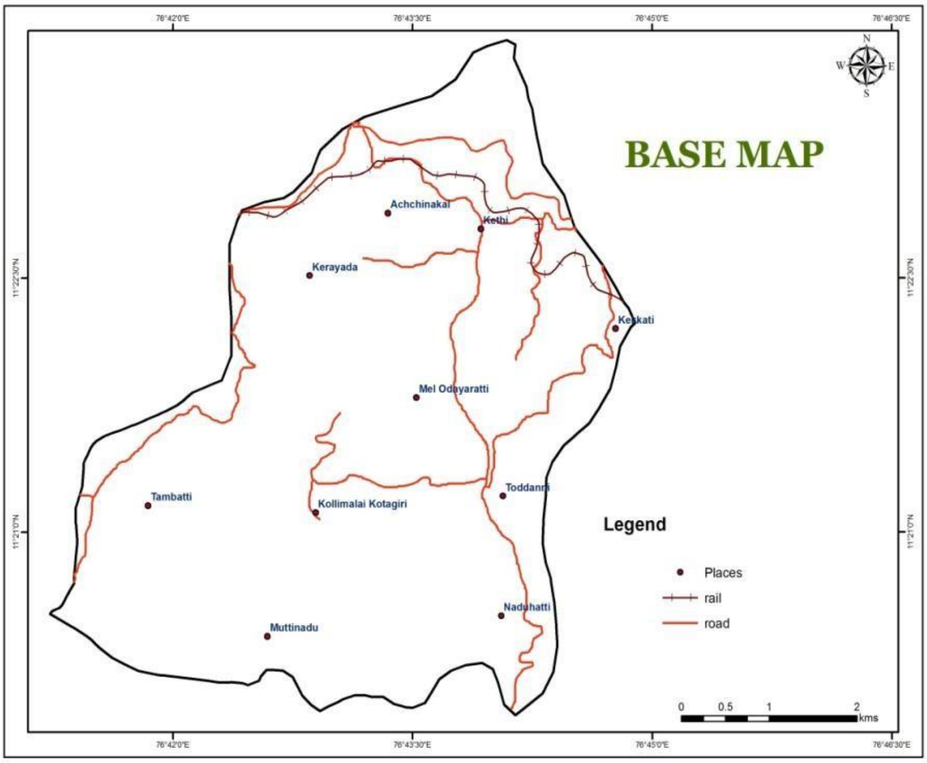

Fig. 3. Base map of Kateri watershed Landslide susceptibility assessment.

Advanced computer tools have been found to be useful in mapping hazard from landslide studies. One of these important tools is Geographic Information Systems (GIS). With the help of GIS it is possible to integrate geodata from different layers in order to determine the influence of parameters on the occurrence of landslides. Since the early 1970s, many scientists have tried to assess landslide hazards and create vulnerability maps that depict their spatial distribution using many different GIS-based methods. The results of the published articles show that landslides. They have become very effective tools for planners and decision makers. Most attempts have been made to start with the intensity and dimension of landslides versus the temporal frequency of landslides. These types of landslide hazard assessments are expressed under the term landslide susceptibility assessment (LSA). This landslide sensitivity rating is based on the following causal factors in the Ketti micro basin. Slope, geomorphology, drainage, linear, land use, appearance and lithography thickness [121]. The subjects were assigned rank and weight according to their susceptibility to landslides. All maps have been integrated and overlaid to create the final landslide endangered map of the Ketti micro-basin. The susceptibility index is derived from the combined weight of all factors, which is the sum of the product of the rank and weight of each overlapping item (Fig. 4).

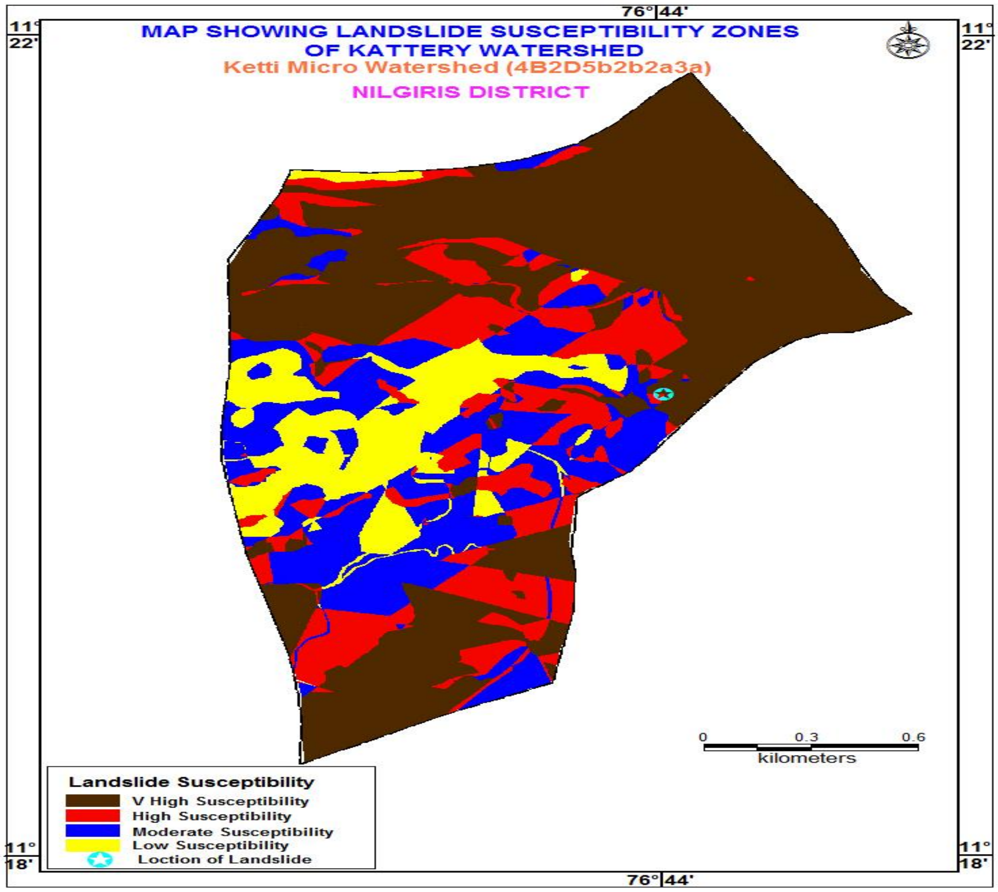

Fig. 4. Landslide susceptibility.

Valuation of the landslide susceptibility map has been validated in comparison with field investigations of locations of previous major landslides within the study area. For validation of the prepared map, the past landslides occurrence data from GSI (pub no: 57, 1982) was taken. There is good correlation between areas defined as highly susceptible and moderately susceptible zones and the known landslides. The study area comes under highly landslide susceptible zone.

Landslide hazard mitigation through cost effective technology

Strengthening buildings and infrastructure should lead to a reduction in vulnerability. However, the vulnerability of buildings and infrastructure to a landslide is almost 100 percent greater in cases, regardless of the quality of the construction. Therefore, the vulnerability of structures cannot be reduced. Therefore, the option for landslide prone areas is not very relevant. The principles of planning a landslide risk study are: 1) gather accurate hazard information; 2) plan to avoid hazards before developing and subdividing; 3) take a risk-based approach in areas likely to be developed or subdivided; and 4) communicate the risk of hazards, In this paper, however, the simple and inexpensive technology of soil biotechnology is discussed (BhandarI 2006, Ganapathy *et al.,* 2009, 2010, GSI 1993, Thanavelu and Chandrasekaran 2008, BMTPC 2003, Rajarathnam, Ganapathy. 2006, Seshagiri *et al.,* 1982, Jaiswal and Van Westen. 2009, UNDRO 1991, IDNDR 1999, Leventhal and Withycombe, 2009, Saunders and Glassey 2009, David 2003, Schiechtl *et al.,* 1980, Lewis 2000, Lewis *et al.,* 2001, Gray and Leiser 1982, WSDOT 2012, Bhoop Singh, 2006, NDMA 2009).

Use of Soil Bio Engineering for Landslide hazard mitigation

Soil bioengineering is the use of plant material, live or dead, to alleviate environmental problems such as shallow, rapid landslides and erosion of slopes and stream banks. The effectiveness of vegetative structures is limited to a total of 0.5 to 1.0 meters and complements conventional engineering structures. For deep faults, biotechnological structures cannot be stabilized directly, but can contribute indirectly to engineering structures by protecting the soil surface by using locally available nature Materials and minimal equipment and can provide road managers with an inexpensive way to solve local environmental problems, Soil biotechnology can be an effective means of treating sites where steep slopes and soil instability lead to greening problems. Rather than replacing civil engineering, bioengineering provides engineers with a range of tools that complement tools already available for solving a wide variety of flat embankment problems. The functions of soil bioengineering work in a similar way to civil engineering structures. The six most important technical functions that biotechnological structures have are: catching (holding /stopping falling soil particles on the surface), armoring (shielding the slope surface from rain splashes and erosion), supports (holding the mass from below), anchors (loose particles anchoring) to solid ground), Reinforce (reinforcement of the soil by increasing the shear strength) and Drain (improvement of the drainage capacity of poorly permeable soil) (BhandarI 2006, Ganapathy *et al.,* 2009, 2010, GSI 1993, Thanavelu and Chandrasekaran 2008, BMTPC 2003, Rajarathnam, Ganapathy. 2006, Seshagiri *et al.,* 1982, Jaiswal and Van Westen. 2009, UNDRO 1991, IDNDR 1999, Leventhal and Withycombe, 2009, Saunders and Glassey 2009, David 2003, Schiechtl *et al.,* 1980, Lewis 2000, Lewis *et al.,* 2001, Gray and Leiser 1982, WSDOT 2012, Bhoop Singh, 2006, NDMA 2009).

Bioengineering solution for shear strength improvement

Soil Sample

The soil for this study was collected from the up to 2m high slopes of Nilgiris Hill, where the landslide occurred in the past. The physical parameters such as density, cohesion, angle of internal friction were determined and shown in Table 1. The hills are about 50 degrees; the soil medium to support vetiver growth was prepared in a tank with a soil slope of 50 degrees as shown in Fig. 7.

Fig. 5. Direct shear tests to determine shear parameters.

Fig. 6a Vetiver grass.

Fig. 6b. Vetiver grass root.

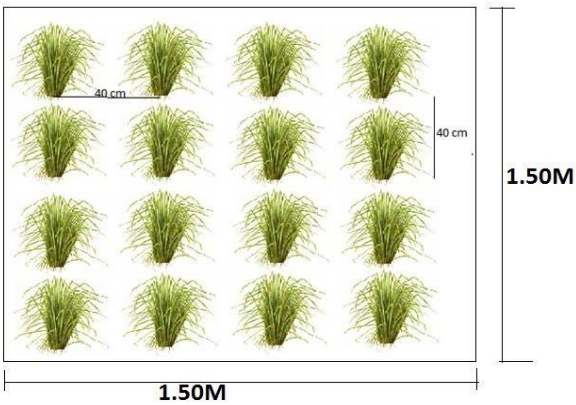

Fig. 7. Vetiver Plant with 40cm centre to centre spacing.

Table 1. Properties of natural soil.

SN	Properties	Value
1.	Specific gravity	2. 344
2.	Gravel content	0. 00%
3.	Sand content	90. 8%
4.	Silt content	7. 00%
5.	Clay	2. 2%
6.	Liquid limit	31%
7.	Plastic limit	11. 5%
8.	Optimum moisture Content	12. 5%
9.	Maximum dry density	1. 91g/cc
10.	Cohesion	4. 84 kN/m^2
11	Angle of Internal friction	30. 5^0
12	Soil type	Silty sand

Vetiver Grass

Vetiver grasses obtained from Tamil Nadu Agricultural University"s nursery was planted with four types of spacing as 10cm centre to centre, 20cm centre to centre, 30cm centre to centre and 40cm centre to centre in 4 rows with 4 species per row. The growth of Vetiver plant has been monitored for 200 days in which growth beyond 150 days were not much significant. Therefore, the testing programme was optimised with 150-day growth of Vetiver grass root. At the end of150 days of plant growth, diameter of root system and depth of root penetration were measured and undisturbed soil samples from root zone were collected in four depths viz at 25cm deep, at 50cm deep, 75cm and 100cm and subjected to direct shear test with shear test box (Fig. 5, 6a. 6b and 7).

Testing

All the specimens were tested in a conventional direct shear testing apparatus of size of 60mm x 60mm to obtain the shear strength parameters under three over burden pressures of 15 kPa, 25kPa and 35 kPa in undrained condition. Load was applied at a controlled strain rate of 1. 25mm per minute (Fig. 5 and Table 1).

Results and discussions

Comprehensive experimental results obtained from direct shear test in terms of shear strength, cohesion, angle of internal friction with reference to sampling depth and spacing of Vetiver species are presented in Table. 2. Results are synthesized and discussed in terms of effect of depth of soil sample and effect of Vetiver grass species spacing on shear strength.

Table 2. Shear Strength Parameters of Vetiver Reinforced Hill slope soil.

SN	Vetiver Species Spacing	Depth	Cohesion kPa	Angle of Internal Friction in Degrees	Maximum Shear Strength in kPa	Shear Strength Ratio SR= $\frac{\tau RS}{\tau Soil}$
1	Bare Soil	0	4. 84	30. 5	14. 15	1. 00
2	10	25cm	5. 24	31. 0	17. 42	1. 231
3	10	50cm	5. 62	32. 5	21. 85	1. 544
4	10	75cm	5. 89	35. 5	29. 94	2. 116
5	10	100cm	5. 38	34. 0	24. 82	1. 754
6	20cm	25cm	6. 40	30. 5	22. 82	1. 613
7	20cm	50cm	7. 12	34. 5	38. 48	2. 719
8	20cm	75cm	9. 29	36. 5	44. 25	3. 127
9	20cm	100cm	8. 27	33	42. 17	2. 980
10	30cm	25cm	6. 56	32. 0	28. 26	1. 997
11	30cm	50cm	7. 38	35. 5	31. 88	2. 253
12	30cm	75cm	8. 72	37. 5	39. 23	2. 772
13	30cm	100cm	6. 88	37. 0	34. 34	2. 427
14	40cm	25cm	5. 97	34. 0	26. 51	1. 873
15	40cm	50cm	6. 42	34. 5	29. 79	2. 105
16	40cm	75cm	7. 61	36. 0	37. 09	2. 621
17	40cm	100cm	8. 09	33. 0	32. 36	2. 287

Effect of Soil Depth on Cohesion of Root Reinforced soil

The influence of soil depth on soil cohesion is shown in Fig. 8. In general, the cohesion increases with increasing soil depth and this trend continues to a depth of 75cm and then decreases. The minimum cohesion is given as 5. 24 kPa if the soil depth is 25cm and vetiver The distance between plants is 10cm. The maximum cohesion was improved to 29 kPa at 75cm soil depth and 20cm plant spacing. In all cases, the soil reinforced with roots shows greater cohesion than the soil, the cohesion value of which is 4. 84 kpa. The maximum cohesion of the soil reinforced with roots has increased by 91. 94% compared to the raw soil. From this it can be concluded that the root reinforcement improved the cohesive property of the soil to this extent. The optimum values for ground clearance and ground depth were found to be 20cm and 75cm, respectively.

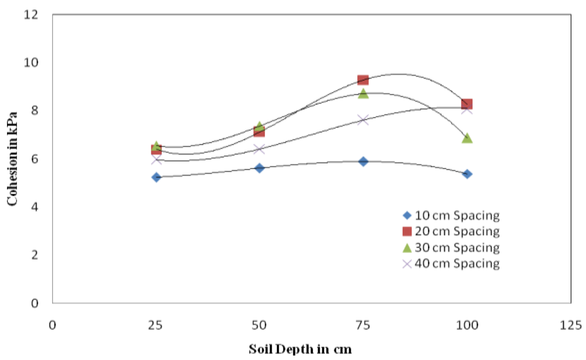

Fig. 8. Effect of Soil Depth on Cohesion of Soil.

Effect of Soil Depth on Angle of Internal Friction of Root Reinforced Soil (Ø)

Fig. 9 shows the relationship between soil depth and internal friction angle (ø) of root-reinforced soil. It can be seen from this Fig. that the angle of internal friction of the soil increases as the depth of the soil increases. This trend continues up to 75cm deep in the ground as with cohesion and beyond that the value of ø decreases. Unfinished floor indicated 30.5 degrees as the internal angle of friction. After reinforcement of vetiver grass, the minimum value of ø of 30.5 degrees at a soil depth of 25cm with a distance of 20cm was observed. The maximum ø value improved to 37.5 degrees with a floor depth of 75cm and a distance of 30cm. This is an increase of approximately 22.9% due to the introduction of vetiver plant reinforcement, so the conclusion clearly shows that the improvement in internal angle of friction is due to the presence of root inclusions in the surrounding soil, which is 75cm deep from the surface.

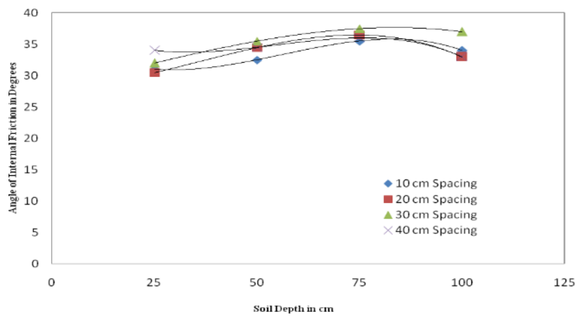

Fig. 9. Effect of Soil Depth on Angle of Internal Friction.

From this it can be concluded that the Vetiver reinforcement improves the angle of shearing resistance of the soil and the optimum soil depth and plant spacing are 75cm and 30cm respectively.

Effect of Soil Depth on Shear strength of Root Reinforced Soil

The shear strength of soil is the measure of the sliding resistance of soil. Fig. 10 shows the variation of shear strength with respect to the soil depth. From this Fig., it can be observed that the shear strength improves with increase in soil depth. This is mainly because of the increase in the overburden pressure of soil.

The Vetiver plant root reinforced soil showed minimum shear strength of 17. 42 kPa as against the raw soil"s shear strength of 14. 15 kPa. This is an increase of 23. 10% than that of raw soil. The maximum shear strength reported to be 44. 25 kPa which is an increase of 212. 7% than that of raw soil at 75cm depth of soil at 20cm Vetiver plant spacing.

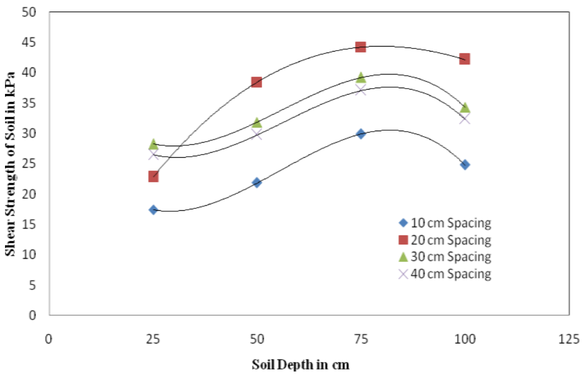

Fig. 10. Effect of Soil Depth on Shear Strength of Soil.

Therefore, it is proved that the Vetiver plant root system improved the shear strength of soil 3. 127 times that of raw soil i. e. without plant reinforcement. The optimum depth and plant spacing of this case would be 75cm and 20cm respectively.

Effect of Vetiver Plant Spacing on Cohesion of Soil

The Fig. 11 is refers to the effect of Vetiver plant spacing on the cohesion of soil. The trend shows an initial increase of cohesion with the increase in Vetiver plant spacing of 20cm beyond which the cohesion value decline.

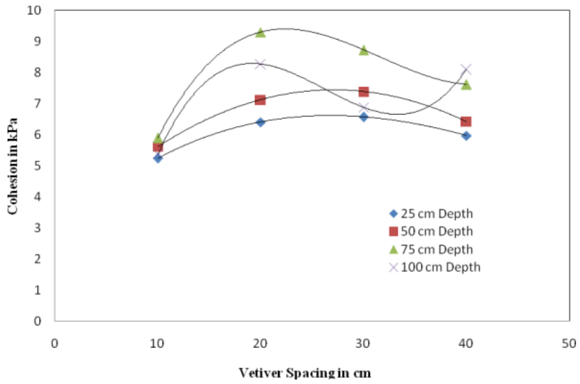

Fig. 11. Effect of Vetiver Plant Spacing on Cohesion of Soil.

The minimum and maximum values of cohesion have been reported as 5.24 kPa and 9.29 kPa respectively. The optimum Vetiver plant spacing has been observed as 20cm spacing at 75cm soil depth. The reason for this trend being the concentration of root zone at 20cm spacing beyond which no such effect have seen. From this observation, it can be concluded that at the optimum plant spacing of 20cm, the maximum cohesion values have obtained. However, beyond 20cm spacing yield reduction in the cohesion value.

Effect of Vetiver Plant Spacing on Angle of Internal Friction of Soil

Fig. 12 illustrate the effect of Vetiver plant spacing on angle of internal friction of soil. It is very clear that the increase in the Vetiver plant spacing increases the angle of internal friction of soil. This trend follows till the plant spacing of 30cm beyond which it decreases.

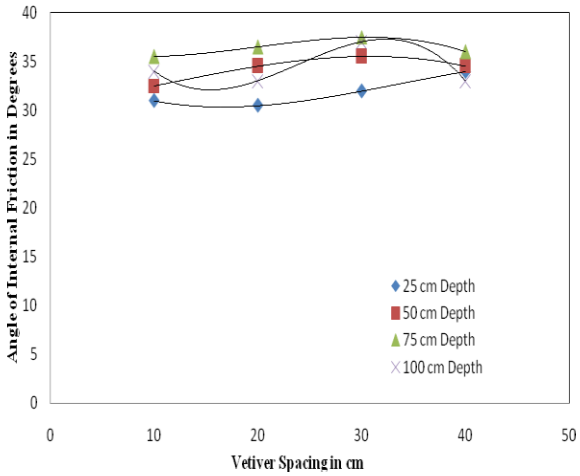

Fig. 12. Effect of Vetiver Plant Spacing on Angle of Internal Friction.

The major reason for this increase in the angle of internal friction is presence of confinement and root zone concentration in the soil. When the spacing increased beyond 30cm, the soil confinement by the plant root gradually reduced and thereby the angle of internal friction reduces. From this it can be observed that the Vetiver plant spacing, up to 30cm spacing increases the angle of internal friction of soil.

Effect of Vetiver Plant Spacing on Shear Strength of Soil

The effect of Vetiver plant spacing on the shear strength of soil has been furnished in the Fig. 13.

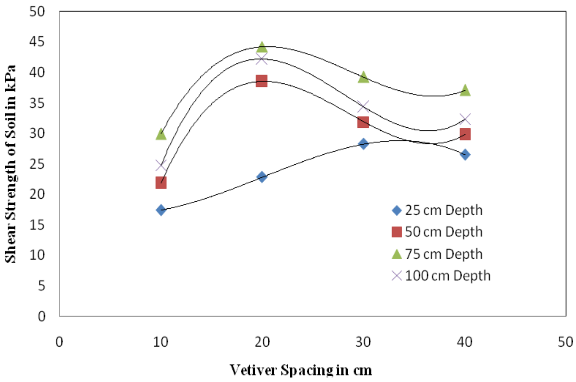

Fig. 13. Effect of Vetiver plant spacing on shear strength of soil.

In general, up to 20cm Vetiver plant spacing increases the shear strength of soil and reduced beyond which. The minimum and maximum shear strength increase has been observed as 17.42 kPa and 44.25 kPa respectively. This shows a minimum percentage of increase of 23.10% and the percentage of maximum increase of shear strength is 212.72%. From this, it can be referred that the increase in the Vetiver plant spacing increases the shear strength of soil till 20cm spacing and the spacing can improve the shear strength up to 3.127 times than that of the raw soil.

Shear Strength Ratio of Plant Reinforced Soil

The shear strength ratio is the ratio of the shear strength of reinforced soil to raw soil, which is an indicator of increased soil strength. In addition, the shear strength ratio is an indicator of the lateral resistance of the soil. Fig. 14 shows the influence of the soil depth. The shear strength ratio increases with increasing soil depth up to 75cm and then decreases. cm. The maximum ratio of the shear strength was given as 3.127 at a soil depth of 75cm with a distance of 20cm. In this way it can be seen that the shear strength ratio increases as the depth of the soil increases. This shear strength ratio of the plant-reinforced soil in turn improves the lateral strength of the soil and thus the resistance to landslides.

Fig. 15 shows the variation in the shear strength ratio as a function of the distance between the vetiver plants. Similar to the effect of soil depth, the vetiver-plant spacing also improves the shear strength ratio of the soil.

A maximum shear strength ratio of 3. 127 was achieved for 20cm plant spacing at 75cm soil depth. Beyond the 20cm plant spacing, the shear strength coefficient decreases, but in all cases it is observed that the shear strength factor is greater than 1, which means that the shear strength factor of the soil reinforced with vetiver plants is always greater than that of raw soil.

From this study it can be concluded that the vetiver root system improves cut resistance parameters such as cohesion and the internal angle of friction of the soil. In addition, the soil reinforced with vetiver plants showed up to a 2, 127-fold increase in shear strength compared to ordinary raw soil.

Therefore, planting vetiver on the slopes of Nilgiri Hill can be recommended as a protective measure against landslides as it improves the shear strength of the soil up to a maximum of 3 times compared to raw soil (BhandarI 2006, Ganapathy *et al.,* 2009, 2010, GSI 1993, Thanavelu and Chandrasekaran 2008, BMTPC 2003, Rajarathnam, Ganapathy. 2006, Seshagiri *et al.,* 1982, Jaiswal and Van Westen. 2009, UNDRO 1991, IDNDR 1999, Leventhal and Withycombe, 2009, Saunders and Glassey 2009, David 2003, Schiechtl *et al.,* 1980, Lewis 2000, Lewis *et al.,* 2001, Gray and Leiser 1982, WSDOT 2012, Bhoop Singh, 2006, NDMA 2009).

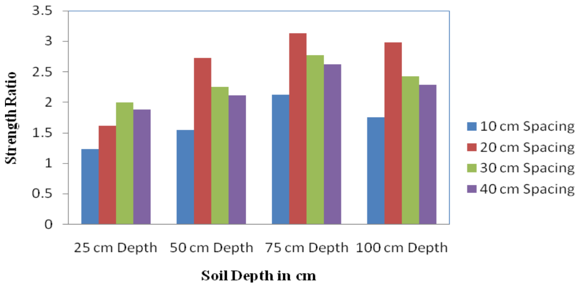

Fig. 14. Effect of Soil Depth on Shear Strength Ratio of Plant Reinforced Soil.

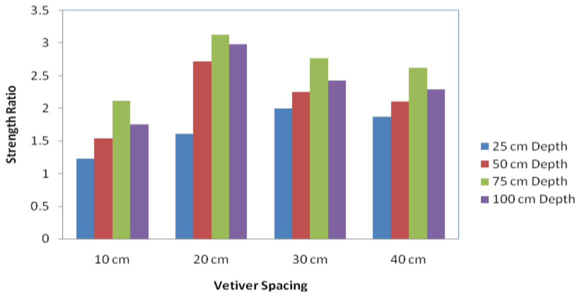

Fig. 15. Effect of Vetiver Plant Spacing on Shear Strength Ratio of Soil.

Conclusion and recommendations

A study conducted by the Tamil Nadu government shows that landslides are accelerating from 1978 onwards and if the current trend continues, the likelihood of landslides occurring will increase from 70% to 100% in the next 10 years. Illiteracy is a major driver of population migration to high risk areas. In recent landslides damaged around 3, 785 huts belonging to the poor and the uneducated in the district. The poor drainage in built-up areas is the other cause of since most of the drainage has been clogged and people have built houses over the river drains and abruptly diverted the watercourse, it is the number one cause of roadside landslides in any engineering degree. The study recommended using soil biotechnology for slope stabilization whenever possible of tools that complement those already available to solve a wide variety of flat embankment problems. The tasks of soil biotechnology work also play a role similar to that of engineering structures. The effort for implementing this technology is also significantly lower than for civil engineering work. Also, the natural beauty of the hills would remain on the slopes of the hills. Soil biotechnology offers improved landscape and habitat values. Suitable for all locations and situations, a detailed site-specific investigation is recommended before implementing this technique. Susceptibility to landslides Soil planted with vetiver has shear strength of 44.25 kPa versus bare ground shear strength of 14.15 kPa, which is approximately 127 times that of bare ground. This clearly provides for the planting of vetiver grass in the study and is therefore recommended. It was observed at 20cm from center to center, and the optimum depth of the ground at which the maximum cutting resistance was observed is 75cm from the surface. Resistance was observed after 150 days of plant growth. Therefore, in practice, a distance of 20-30cm from the vetiver plant has been recommended in order to improve the soil shear strength and in turn to reduce the susceptibility to landslides.

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