Journal of Agroecology and Natural Resource Management
Print ISSN: 2394-0786, Online ISSN: 2394-0794, Volume 1, Number 2; November-January, 2014 pp. 56-62

http://www.krishisanskriti.org/janrm.html

Bio-Engineering Slope Protection: Urgent Need of the Himalayas

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Abstract: *It has been long recognized that slopes under vegetation are much more resistant to soil erosion process compared to bare soils and improves the slope stability. Planting or preserving vegetation in areas vulnerable to erosion and shallow mass movement is therefore considered to be a very effective soil erosion control and slope stability measure. Re-vegetation strategies for erosion control rely in most cases on the effects of the above-ground biomass in reducing water erosion rates, whereas the role of the below-ground biomass is often neglected or underestimated. While the above-ground biomass can temporally disappear in semi-arid environments, roots may still be present underground and play an important role in protecting the topsoil from being eroded and also increases the soil shear strength by holding the soil together with the network of roots and hence increases the stability of the slope. One of the important mechanical characteristics of root is that they are strong in tension. Soils, on the other hand are strong in compression and weak in tension. A combined effect of soil and roots results in reinforced soil. This measure is based on Community based Disaster Management with provision of social, economic and environmental benefits, which makes this technique more sustainable.*

This paper discusses the urgent need of adoption of bio engineering techniques in Himalayas due to massive land degradation and unplanned development. It justifies the adoption of this measure compare to conventional engineer structures. It also describes how the use of this technique could probably reduce the impacts of recent past disasters. This paper concludes with the comparison between the results of various slope failure parameters between a bio-engineered stabilized slope and a non bio-engineered stabilized slope.

Keywords: *Bio-engineering, Erosion, Slope Stability, Community Based Disaster Management.*

1. INTRODUCTION

Since from a very long time, it has been recognized that the slopes under vegetation are much more resistant to soil erosion and shallow mass movement as compared to bare soils. Planting plants or preserving vegetation in areas vulnerable to erosion and slope instability is therefore considered to be a very effective counter measure against erosion andslope destabilization. Re-vegetation strategies for erosion control rely in most cases on the effects of the above-ground biomass in reducing water erosion rates.While the above-ground biomass can temporally disappear in semi-arid environments, roots which are the below-ground biomassmay still be present and play an important role in protecting the slope from shear failure till they decay[1].

Vegetation and slope stability are interrelated by the ability of the plant life growing on slopes to both promote and hinder the stability of the slope as well. The relationship is a complex combination of factors like type of soil, the rainfall regime, the plant species present, the slope aspect, and the steepness of the slope. Knowledge of the underlying slope stability as a function of the soil type, its age, horizon development, compaction and other impacts is a major underlying aspect of understanding how vegetation can alter the stability of the slope[2]. There are four major ways in which vegetation influences slope stability: wind throwing, the removal of water, mass of vegetation (surcharge), and mechanical reinforcement of roots.

Bioengineering measures, has been defined as ‘the use of living vegetations, either alone or in conjugation with non-living plant material and civil engineering structures, to stabilize slopes and reduce erosion’ and ‘the use of any form of vegetation, weather a single plant or collections of plants, as an engineering material’ [3].

This type of slope stabilization measures are used to reduce the environmental consequences of slope stabilization mitigation measures. When used for landslide remediation or mitigation works, conventional earth retaining structures made up of steel or concrete are not visually pleasing or environmentally friendly. Nowadays, these traditional “hard” remedial measures are increasingly supplemented worldwide by vegetated composite structures that are environmentally friendlier [3].

The primary objective of this technique is to provide self-sustaining protection to natural terrain affected by erosion and to prevent shallow to medium depth mass movement at low-cost and environmentally sensitive approach. Soil bioengineering systems are generally strong initially and grow stronger as vegetation becomes established [4]. Even if the plant dies, roots and surface organic matter continues to plan an important role during reestablishment of other plants. Once plants are established, root system reinforces the soil mantel and removes excess moisture from the soil profile through evapotranspiration. This is often the key to long-term slope stability. Soil bioengineering measures provides improved landscape and habitat values. This system work by fulfilling the engineering functions required for protection and stabilization of the slope. Also the maintenance cost is less as compared to other conventional slope stabilization methods [5].

The use of indigenous plant species will not only help in stabilization of the slope but the established vegetations will also provide firewood, fodder, flower, fruits, resin and other forest products to the local community. Thus this type of technique for slope stabilization will have more community support than the conventional concrete remedial measures and will help in achieving the concept of Community Based Disaster Management [6].

2. PRESENT SCENARIO OF HIMALAYAN REGION

2.2 Landslides:

Most of the slope failureoccurs during the monsoon (June to September) when excess rainwater pushes the soil triggering a chain of events intensified by man-made constructions and deforestation. According to the Geological Survey of India (GSI), roughly 15% of India's landmass is highly vulnerable to landslides. India's National Disaster Management Authority (NDMA) – an autonomous federal institution responsible for disaster management and preparedness in the country – lists the Himalayan states, Arakan-Yoma belt in the north east, the Meghalaya plateau, Western Ghats and Nilgiri hills as most landslide-prone areas.

Of late, it has been felt seriously about the need of stabilizing the Himalayan slope. According to **Defense Terrain Research Laboratory**, "Landslides rank third in terms of number of deaths due to natural disasters. While, Himalayan Landslides kill one person per 100km. The estimated average losses due to landslides in the Himalayas costs 200 lives and Rs 550 crore every year. Whereas, this hazard affects over 0.49 million km^2 i.e. over 15 % of our country's area [7].Some of the major landslides and their statistical details in Himalayan region in past 25 yrs are given in table 1 and 2 respectively.

Table 1: Major Landslide in Himalayas

Place	Year	Death
Sunkoshi, Nepal	2 Aug 2014	156
Kedarnath Uttarakhand	16 June 2013	5,700
Sikkim	24 Sep 2012	27
Gilgit-Balisthan, Pakisthan	4 Jan 2010	20
Leh	Aug 2010	500
Baglung and Bajura, Nepal	12July 2007	35
Dharla Himachal Pradesh	14Aug 2007	62
Kashmir	Oct 2005	1350
Malpa, Uttarakhand	11-17 Aug 1998	400
Okhimath, Uttarakhnad	14 Aug 1998	69
Nagaland	Aug 1993	500
Kalimpong, West Bengal	Aug 1993	40
Itanagar	July 1993	25
Assam	July 1991	300

Table 2: Statistical details of all major slope failures in past 25 years in the Himalayan region(Source: EM-DAT)

No of major events	395
Deep seated slips	118
Shallow seated slips (Debris)	277
No of people killed	139,393
Average killed per year	4,807
No. of people affected	1,506,749,740
Average affected per year	51,956,439
Economic damage (US $ X 1,000)	45,184,830
Economic damage per year (US $ X 1,000)	1,558,098

The present condition of Himalayan slope is found out to be very unstable owing to various reasons like clearing of forests, blasting during road construction, diversion of natural waterways, over population of humans and cattle, under cutting of slopes etc [8].

2.3 Erosion

Eastern Himalaya has a higher erosion rate (2.9mm/yr.) as compared to the Western Himalaya (2.1mm/yr.). The total Himalayan erosion is estimated to be 2.19 mm/yr [9]. This is likely a function of different erosional conditions within the range such as the lithology, the morphology, the climate, vegetation cover and the rate of uplift. In the absence of major morphological and lithological differences between the two portions of the range, the eastward increase of the erosion rate suggests that the intensity of the monsoon, which is much higher over the eastern Himalaya, determines the erosion rate[9].

2.4 Population

The Himalayas recorded 65.57 million persons in 2001 [10]. The Indian Himalayas registered 36.32 million persons, while the kingdom of Nepal and Bhutan recorded 27.07 and 2.18 million persons respectively. The Central Himalayas recorded 54% population, while Western Himalayas and Eastern Himalayas had a concentration of 25% and 21% population respectively. The Himalayas have recorded a decadal population growth of 25% during 1991-2001 as compared to 21.34% for India as whole. The kingdom of Nepal and Bhutan also registered a decadal growth rate of 22.30% and 21.12% respectively

Since 1950, tourism has emerged as a major growth industry in the Himalayas. Nearly 1 million visitors come to the Himalayas each year for mountain trekking, wildlife viewing, and pilgrimages to major Hindu and Buddhist sacred places [10]. The number of foreign visitors has increased in recent years, as organized treks to the icy summits of the Great Himalayas have become popular. While tourism is important to the local economy, it has had an adverse impact on regions where tourist numbers exceed the capacity of recreational areas.

2.5 Economics

Economic conditions in the Himalayas partly depend on the limited resources available in different parts of this vast region of varied ecological zones. The principal activity is animal husbandry, forestry, trade, and tourism is also important. The Himalayas abound in economic resources. These include pockets of rich arable land, extensive grasslands and forests, vast floral resource (medicinal and aromatic plants), workable mineral deposits, easy-to-harness waterpower, and great natural beauty [11]. The explosive population growth that has occurred in the Himalayas and elsewhere in the Indian subcontinent since the 1940s has placed great stress on the forests in many areas. Deforestation to clear land for planting and to supply firewood, paper, and construction materials has progressed up steeper and higher slopes of the Lesser Himalayas, triggering environmental degradation. Only in Sikkim and Bhutan are large areas still heavily forested.

- **Agriculture:** The agricultural practices of the hill communities have adapted to overcome problems like low availability of irrigational water (in cold desert regions like Ladakh and Lahaul and Spiti), small land-holdings and limited time for cultivation in the form of one short growing season. The agricultural patterns differ according to regions. In Arunachal Pradesh and the highlands of Sikkim, shifting cultivation, popularly called "jhoom cultivation" is prevalent where farmers clear a tract of forestland for cultivation purposes. The farmers move from area to area, clearing the forest and rotate among each piece of land in a rotational manner, allowing the vegetation of the region to regenerate. Earlier, the rotation period was approximately 10 years and has rapidly decreased to an unsustainable 2-3 years in present times. In Nepal, Uttarakhand and the lowlands of Himachal Pradesh, the hillsides are defined into terraces, to maximize the land under cultivation and minimize loss of soil with runoff. Several crops are grown for commercial purposes: cereals like wheat, rice and maize, vegetables like potatoes and peas and horticultural crops like apples, walnuts, oranges, apricots and cherries. In conjunction with the significant produce of horticultural crops from the area, several processing industries (juices, jams, alcoholic beverages etc.) have developed. In the eastern region, tea is grown on the foothills (Darjeeling, Assam). Several vegetables are also grown for personal consumption. Nowadays, mountain agriculture is in a phase of transition from traditional methods of cultivation to a more intensive, demand driven system [12].
- **Animal husbandry:** To overcome the harsh conditions of the area, communities have largely depended upon animal energy for transportation, trade and agricultural activities like ploughing. Thus, many tribes in the Himalayas are fully or partially engaged in animal rearing activities. Many communities in the region are completely pastoralist in nature. Animals like the yak and Bactrian camel are synonymous with the Himalayas as beasts of burden. Yaks, goats, sheep and cows are kept for milk and its products, and also for their wool and meat. The wealth of a family is often quantified by the number of animals it has and animal products serve as important sources of income. Most pastoral communities move with their animals and families to the high altitude rangelands during summer, returning to the lowlands in the winter months. Semi-pastoral communities also practice agriculture as an alternate source of income [12].
- **Trade:** Traditionally, trade among hill communities followed the barter system. Trade fairs would be organized wherein animals, utensils, grains, fruits and vegetables etc. would be exchanged without any monetary transactions. Although such practices are still prevalent, they are fast eroding and modern commercial transactions involving money are practiced with increasing frequency. The introduction of markets has however, led to a decrease in local self-sufficiency. People have shifted from mixed sustenance cropping to cultivation of cash crops like potatoes and apples. Thus, local populations are slowly being weaned from their traditional trading methods and are relying on external sources to meet their basic consumption [12].
- **Tourism:** The tourism sector is rapidly expanding in the Himalayan region and offers income-generating options to the local communities. Annually, over a million tourists come to the region for trekking, sightseeing, wildlife viewing and pilgrimages; ensuing income generation from tourism has immense scope. Apart from conventional jobs like hoteliers or tour guides, new sustainable initiatives like eco-tourism and home-stays are being adopted [12].

3. NEED FOR ADOPTION OF BIO-ENGINEERING TECHNIQUES IN THE HIMALAYAN REGION

There are two types of slips or mass movements that affect stability of Himalayan slopes. These are: deep seated slips and shallow seated slips. Deep seated slip problems (depth of surface of failure is more than 3m) are geotechnical or geological in nature. It can only be address by taking into account the slope geometry, soil strength, climatic condition, groundwater characteristics etc. and can be ascertained by slope stability analysis. For the shallow seated slip (depth of surface of failure is less than 3m) the problem is somewhat difficult to quantify [13]. Shallow slips of 1-3 m depth, on the other hand, comprise the majority of the landslide that are being faced by the Himalayan people especially in region with prolonged and heavy rainfall (Table 2). This problem still arises despite of the fact that the results of the slope analysis technique might have shown a slope to have adequate factor of safety [14]. To tackle this problem, engineers conventionally rely on the use of ‘hard’ or ‘inert’ material such as concrete retaining structures, mortared riprap, shotcrete or like to seal off the slope to prevent water infiltration that is deemed to be the cause of the slippage in the first place. However, not in all cases they succeed. An alternative solution to this problem is to resort to vegetation to help strengthen the surficial 1-3 m layer that is prone to slippage.

Benefits of Bio engineering measure [15]:

- Prevention of scour erosion: This is done by strengthening the surface so that gullies cannot be formed. Also roots strengthen the surface layers of soil.
- Reduction of shallow planer land sliding: This is done by the roots adding strength to the surface soil layers and increasing the shear strength of the soil. Vegetation also reduces the extent of shallow failure by binding the surface together laterally.
- Channeling of runoff to alter slope hydrology: Lines of grass or cuttings can channel water into gullies or down the slope, so that infiltration is reduced. At the same time, the plants strengthen the surface and prevent erosion from starting.
- Providing support to the base of the slope and trapping material moving downwards: Vegetation can be used in this way to form a kind of flexible, growing retaining structure.
- Establishment with fewer disturbances: Projects usually require less heavy equipment excavation. As a result, there is less cost and less impact. In addition, limiting crews to one entrance and exit route will cause less soil disturbance to the site and adjoining areas.
- The provision of environmental and social benefits with improved landscape and habitat values.
- Installation in Economical: Use of native plant materials and seed may provide additional savings. Costs are limited to labor for harvesting, handling, transport to project site and installing.
- Limitations of bioengineering methods include [15]:
- Soil bioengineering has unique requirements and is not appropriate for all sites and situations. On certain surface erosion areas, for example, distribution of grass and forb seed mixes, hydro-mulching or spreading of a protective layer of weed-free straw may be satisfactory and less costly than more extensive bioengineering treatments.
- On areas of potential or existing mass wasting, it may best to use a geotechnically-engineered system alone or in combination with soil bioengineering.
- It works effectively in areas having North or North East slope aspect.
- This approach doesn’t work effectively in rocky slope or slopes greater than 50-60^0.
- Project areas require periodic monitoring. On highly erosive sites, maintenance will be needed until plants are established.
- Established vegetation can be vulnerable to drought, soil nutrient and sunlight differences, road maintenance side cast debris, grazing or trampling and may require special management measures to ensure long term project success.
- Installation season is often limited to plant dormant seasons, when site access may be limited.
- Installers may be unfamiliar with bioengineering principles and designs, so upfront training may be required.
- Alternative practices are aggressively marketed and often more widely accepted by society and contractors.

Bio technical measures are often used as part of a broad design, in conjunction with a number of standard civil engineering measures. These include- check dams, prop walls, toe walls, wire bolsters, jute netting. However, it is stressed that bio technical measure should always be used as a part of the overall design when resolving any particular slope problem. It must always be integrated in such a way that it complements and enhances any other measures [16].

3.1 Role of vegetation in erosion control and slope stabilization:

Bio engineering if employed carefully can prevent minor problems from developing into larger and complex ones. Vegetation affects both the surficial and mass stability of slopes in significant and important ways. The stabilization or protective benefits of vegetation depend both on the type of vegetation and type of slope degradation process. In case of mass stability, the protective benefits of woody vegetation range from mechanical reinforcement and restraint by the roots and steams to modify the slope hydrology as a result of soil moisture extraction via evapotranspiration.

Benefits of vegetation in preventing surficial erosion [17]:

- Catching material that is moving down a slope.
- Interception foliage and plant residues absorb rainfall energy and prevent soil compaction.
- Restraint root systems physically bind or restrain soil particles while above ground residues filter sediment out of runoff.
- Retardation above ground residues increase surface roughness and slow runoff velocity.
- Transpiration depletion of soil moisture by plants delay onset of saturation and runoff.

Benefits of vegetation in slope stabilization [17]:

- Roots mechanically reinforce a soil by transfer of shear stress in the soil to tensile resistance of the roots thus limiting the extent of slope failure by binding soil vertically and laterally.
- Soil moisture modifications, evapotranspiration and interception in the foliage limit buildup of soil moisture stress. Vegetation also affects the rate of snowmelt, which in turn affects soil moisture regime.
- Anchored and embedded stems can act as buttress piles or arch abutments in slope, counteracting shear stresses.
- Large trees planted at the toe of the slope may anchor into firm strata providing support to the upslope soil mantle through buttressing and arching.

3.2 Mechanical reinforcement by roots:

Roots reinforces the soil through growing across failure planes, root columns acting as piles, and through limiting surface erosion [18, 19].When roots grow across the plane of potential failure there is an increase in shear strength by binding soil particles vertically as well as laterally. The roots anchor the unstable surficial soil into the deeper stable layers or bedrock.

Bio engineering techniques: Best suitable for Himalayan region:

Table 3: Chemical and geographical properties of Himalayan Regions Slope

Propety / Region	Total Nitrogen	Available Phosphorous	Available Potassium	Organic Carbon	Soil Organic Matter	pH	C:N ratio	Base Saturation	Slope (0)	Soil Type	Yearly avg. rainfall (mm)	Aspect
Kashmir Himalayas	11–15 µg/gm	14–35 µg/gm	102-195 mg/kg	2.6–4.45 %	4.5–7.67 %	6.1-6.58		35-60%	30-85	Clayey	600-800	South Eastern
Ladakh, Himalayas	200-410 kg/ha	30-55 kg/ha	10-40 kg/ha	0.66-0.97 %	1.24-1.67 %	7.4-8.5		30-50%	35-80	Sandy-silt and loamy	90-110	South
Shiwalik, Himachal	0.54-0.12 moles/kg	3.14-16.5 ppm	0.09–0.48 moles/kg	0.10–1.0 CaCO3	3.21-7.9 %	5.8-8		57–80%	30-80	Silty-clay	900-2350	North Eastern
Eastern Himalayas	0.03–0.51 %	15-110 kg/ha	0.09–1.06 Milli eq./100g	0.26–8.33 %	4.5-8.3 %	3.8–5.3		40-95%	25-75	Coarse loamy to clay loam	800-4500	North
Kumaun, Uttarakha	0.48–0.76 %	4.5–17 kg/ha	100–199 kg/ha	0.33–1.05 %	0.57–1.81%	6.7–7.7		36–55%	25-70	Silt-clay-loam	1000-2000	North Eastern
Garhwal, Uttarakhan	0.17-0.45 %	2.73–20.17 ppm	40.67–261.17	2.29–4.31 %	3.95–7.43 %	5.47–6.67	8.12 – 14.49	35-55%	35–80	Sandy-silt-clay	1428-2845	North Eastern

One of the important mechanical characteristics of roots is that they are strong in tension. Soils, on the other hand, are strong in compression and weak in tension. A combined effect of soil and roots results in reinforced soil. When shearing the soil, roots mobilizes their tensile strength whereby shear stress that develop in the soil matrix are transferred to the root fibers via interface friction along the root length [20] or via the tensile resistance of the roots. Thus it has been seen that soil containing effective network of roots in them fails at a higher shear force than soil deprived of it. In other words, roots increase the soil shear strength in which they grow [21]. It does so directly by mechanical reinforcing and indirectly through water removal by transpiration. From research it is also known that the finer the roots, the higher are their tensile strength [20, 22]. It can therefore be hypothesized that a large number of small roots will contribute more to soil reinforcement as compared to a small number of thick roots.

There is great opportunity available for installation of bio engineering measures. Some of the favorable conditions prevailing in the Himalayan region for bioengineering are (as seen in table 3):

- Soil: The soils of most of the Himalayan region except the Ladakh region are good for plant growth. It contains enough nitrogen, phosphorous, potassium and organic carbon to sustain plant growth. Also majority of the slopes are either made up of soil or debris (soil and gravel).
- Slope: The slopes are in between 25-85^0. The less to moderate slopes up to 50-55^0 are generally found in the sub Himalayan foot hills and terai planes and continues up to Middle and Lesser

Himalayas. This region has the highest density of population in IHR.And through this technique this regions can be stabilize.

- Plant: The Indian Himalayan Region (IHR) has about 18,440 species of plants (25.3% species endemic), 1748 species of medicinal plants (MAP) and 675 species of wild edibles [24]. The vegetation mainly comprises of tropical, sub-tropical, temperate, sub-alpine and alpine types. Most of the MAPs are used in the Indian Systems of Medicines and pharmaceutical and oil industries. About 118 species of MAPs of IHR yield essential oils [24]. With the increasing demand of MAPs in the Indian Systems of Medicines, and pharmaceutical and oil industries, the wild populations of the MAPs are facing high pressures, can be installed in slopes.

- Labor: Easy availability of labor in Himayalan region having fair knowledge about indigenous local plants and soil.
- Monitory Need: As stated earlier, Bio-engineering slope stabilization measures are economical as compared to conventional civil engineered structures [5].
- Livelihood opportunities: By installing these measure, we will not only able to stabilize the slope and prevent the rate of erosion but also provide livelihood options to the local community in terms of firewood, fodder, flower, fruits, resin and other forest products [6].
- Previous Results: Bioengineering slope stabilizations has been installed at various unstable slope around the world and in Himalayan region also in order to stabilize it and this measures are working well till today(table 3), with no further soil slip after installation, reduced soil erosion rate and soil creep and improved livelihood of the locals. Some examples of slopes stabilizations are: Sahastradhara Hill, Dheradun, Uttarakhand India by Central Soil and Water Conservation Research and Training Institute, Dehradun and Varunavat Parvat, Uttarkashi, Uttarakhand, India by Geological survey of India [25].

Table 3: Comparisons between bioengineering and conventional slope stabilization technique

Property	Bioengineering	Conventional
Increase soil shear strength	Yes [1]	No
Support Livelihood	Yes [6]	No
Wildlife protection	Yes [6]	No
Economical	Yes [5]	No
Counterstrength	Increase with time [1]	Remains same

4. CONCLUSION

Soil Erosion and landslide calamity may be avoided or at least minimized by applying appropriate remedial measures or set or remedial measures at the initial stage of development scheme(table 3, [25]). Bioengineering is a suitable technique to protect slopes against surface erosion, reduce the risk of planer sliding and improve surface drainage. It is a technique that can be applied nearly everywhere in the world, provided that suitable plants and auxiliary materials are available on site. At the present state of condition, the Himalayas need this to be installed urgently. The success of this system dependson the growth performance of plants as at installed sites. The length and quantity of shoots and roots is anexcellent indicator for biomass development, factor which indicates their suitability interms of soil and climate for the area and also improved living condition of the local community [5, 25].

5. ACKNOWLEDGMENTS

This work was supported by scholarship provide by MHRD for M.Tech. Wethank institution like NIDM, Delhi; CSWCRTI, Dehradun; FRI, Dehradun for providing support and all necessary information. We also thank to all known and unknown persons who helped in documentation of this parer.

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