Report on

TREATMENT OF LAND SLIDE AND EROSION CONTROL PROJECT UNDER TDET - SOUTH SIKKIM

2004-05 to 2007-08

Conducted by

ENVIS CENTRE SIKKIM

On Status of Environment & its Related Issues

Under the Supervision of

C. Lachungpa, IFS
Conservator of Forests (Land Use & Env.)
Forests, Env. & Wildlife Management Department
Government of Sikkim

Report on

TREATMENT OF LAND SLIDE AND EROSION CONTROL WORK UNDER "TDET" PROJECT - SOUTH SIKKIM

2004-05 to 2007-08

Conducted by

ENVIS CENTRE SIKKIM

On Status of Environment & its Related Issues

Under the Supervision of

C. LACHUNGPA, IFS
Programme Coordinator (ENVIS Centre Sikkim) –cum-
Conservator of Forests (Land Use & Env.)
Forests, Env. Wildlife Management Department
Government of Sikkim

Acknowledgement

The support of Ministry of Rural Development, Department of Land Resources, Government of India for the sanction of "Treatment of Landslide Erosion Control activities" under TDET program is a prioritized appropriate policy which may develop specific technology to combat the specific problem of landslide and erosion control measure in the country.

We acknowledge the expert inputs of many Institutes & Research Centers, and also Individual scientist whose studies and findings have been referred to and suitably incorporated in preparing this report.

There are still others who have significantly contributed in the design and documentation of this report whose names could not be included. Land Use & Environment Circle, Forest Environment & Wildlife Management Department express gratitude to all of them.

Finally, LU & E Circle, Forest Environment Wildlife Management department, Government of Sikkim with deep sense of gratitude, thanks all the Team Members and its own staff for their sincere effort to produce this Report without which the completeness of the same would not have been achieved.

STUDY TEAM	
C. Lachungpa, IFS Conservator of Forests LU & E Circle Forests, Env. & W/L Mgt. Deptt.	Project Coordinator
Divisional Forest Officer South Sikkim	Implementing Agency
Tshering Tashi Bhutia Additional Director Mines, Minerals and Geology Govt. of Sikkim	Geologist
P. D. Lepcha Deputy Director, Soil Testing Laboratory, Agriculture Department, Govt. of Sikkim	Soil Scientist
Narpati Sharma, Sr. Research Scholar, Science & Technology, Govt. of Sikkim	GSI Expert
Rajen Pradhan, Programme Officer, ENVIS Centre Sikkim, Forests, Env. & W/L Mgt. Deptt.	Report Editor
Garap Dorjee Bhutia Technical Project Associate ENVIS Center, Forests, Env. & W/L Mgt. Deptt.	Botanist/ Technician
Laxuman Darnal, I.T. Assistant ENVIS Center, Forests, Env. & W/L Mgt. Deptt.	Report Designer
N.P. Gautam Assistant Conservator of Forest, South Sikkim	Coordinator Assistant
N B. Chettri Range Officer, LU&E, South Sikkim.	Field Guide

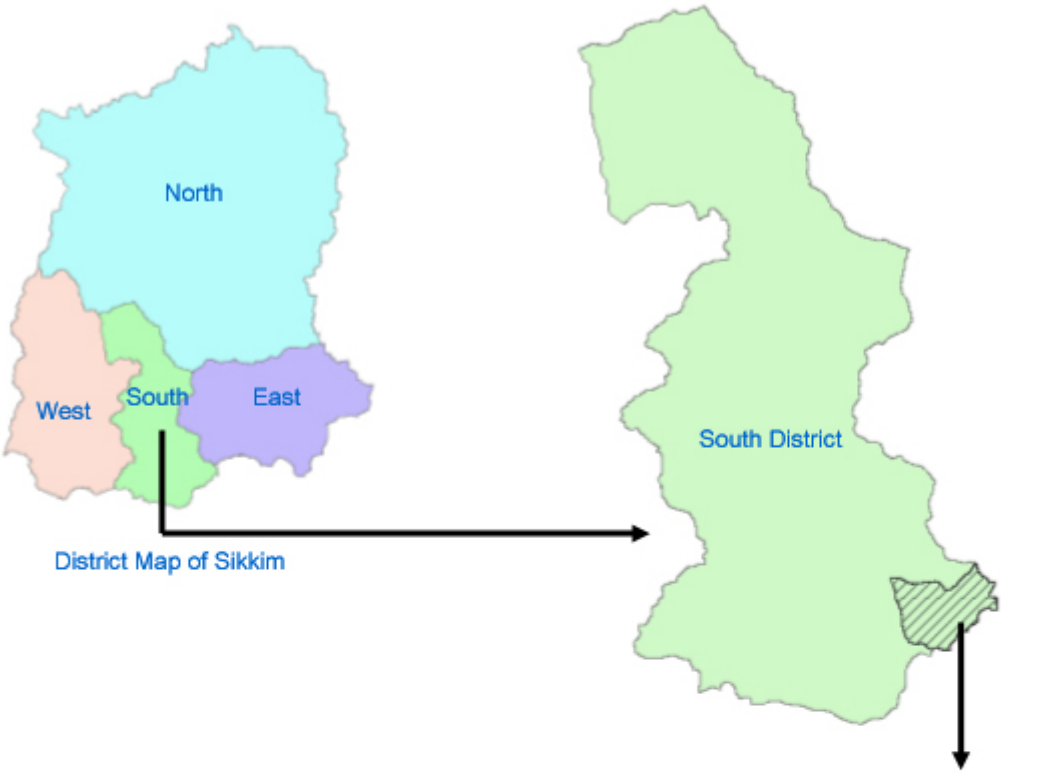
Index

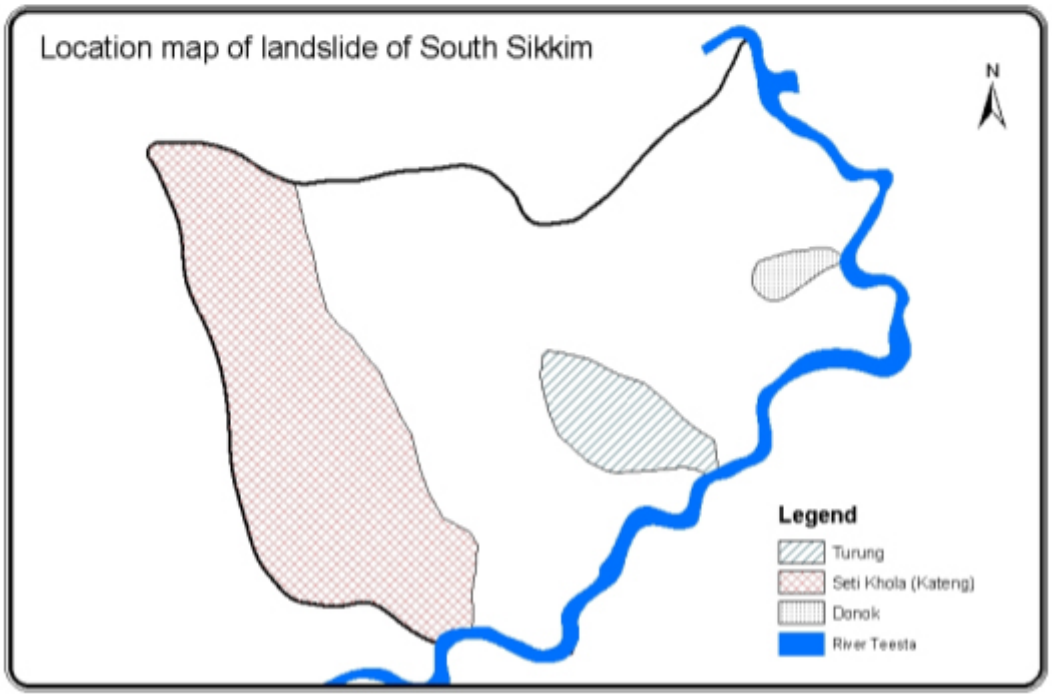
1. Introduction

Since the earth first appeared, it has been shaped by erosion and for over 7000 years human beings have tried to defend there lands against the assaults of rain and runoff energies. Like wise today, Sikkim is also facing great challenge to protect our natural resource from land degradation and erosion. The whole state of Sikkim is hilly and cris-crossed by number of streams. Soi1 erosion is one of the major problems. The hills of Sikkim mainly consist of gneissose and half-schistose rocks, making their soil brown clay, and generally poor and shallow.

The soil is coarse, with large amounts of iron oxide concentrations, ranging from neutral to acidic and has poor organic and mineral nutrients. This type of soil tends to support evergreen and deciduous forests. A large portion of the Sikkim territory is covered by the Precambrian rock and is much younger in age than the hills. The rock consists of phyllites and schists and therefore the slopes are highly susceptible to weathering and prone to erosion. This combined with the intense rain, causes extensive soil erosion and heavy loss of soil nutrients through leaching. As a result, landslides are frequent, isolating the numerous small towns and villages from the major urban centers. Lots of nutrients are washed away along with soil.

It is a common experience that the soil is liable of removal from one place to another whenever there is physical force such as storm or flood (or running water). The dust blows along with wind or flows in runoff water, usually after rains. This is called erosion. The term 'erosion' is derived from the Latin word *Erodere* which means to 'gnaw away' or 'tear away'. Rama Rao (1962) called soil erosion as creeping death of the soil. Soil erosion refers to physically detaching soil particles from their original place and transporting them to some other place. Thus, though it takes a very long time to build the soil, its erosion by the forces of rain and runoff water, wind action, etc., is a rapid process. Volume and intensity of precipitation, slope conditions, vegetation cover and wind speed are some important factors of soil erosion. Soil erosion is one of the major soil degradation processes in the hills.


North
West
South
East
District Map of Sikkim
South District


Location map of landslide of South Sikkim
N
Legend
Turung
Seti Khola (Kateng)
Donok
River Teesta

The proposed project intends to arrest the soil erosion & landslides in few selected areas in all the four districts of Sikkim and develop demonstration models for technology extension. In the current project under TDET, study of vegetation and soils of four severe erosion of South Sikkim has been carried out for the guidelines to implements the technical inputs in order to combat the problem of soil erosion.

Undergoing project entitled **"The Treatment of Land Slide & Erosion Control Work"** under Technology Development Extension & Training Scheme (TDET) could be long termed research based project seeing the range of devastation case by land degradation.

Active landslide of South Sikkim

The studied landslides are still very active and indeed needs extensive scientific research prior to the implementation of any conservation and recreation measures. So within target severe landslides, scientific analysis of vegetation density, enumeration of soil profile, and study of streams origin and its runoff velocity has been carried out during field visit.

2. History of Soil Erosion

2.1 Status of Turung Landslide

Seeing the range of devastation, Turung erosion of South Sikkim is classified as very severe erosion. History reveals that erosion occurred in October 1968 due to heavy rainfalls and floods. As per the recent survey, approximately 25.36 ha forest land is under the erosion slide. The erosion is extending approximately 279 m in elevation and 909 m in breadth. The slide is sandwich between 88 ^{0} 33' 29" and 88 ^{0} 33' 49" East latitudes and 27 ^{0} 09' 32" and 27 ^{0} 09' 38" North longitudes.

Degraded land due to Soil Erosion

In due course of survey, it is fairly noticed that the condition of slop is very stiff and erosion continuous, most probably due to three downward streams which intersect the slide longitudinally at different intervals. As a result many gullies are formed, however parameters like intensity of rainfall, velocity of wind, temperature, edaphic factor are also responsible for erosion. The streams were originated at the top of slide and rapid run off erodes the soil debris which ultimately mingles with the Teesta River at bottom nearby. The slide was so severe that the top-most fertile soil was completely washed away so that the probability of plantation is almost null even though cutting of many bamboo species, trees like *Anthocephalus cadamba, Erythrina indica, Bischofia javanica, Terminalia myriocarpa* were planted within the slides seeing the appropriate land.

2.2 Streams of Turung Landslide

Turung erosion itself is the origin of three streams. It was observed that under ground water sprout out naturally from the erosion which later turns into high potential runoff streams. Two streams flow longitudinally downward bordering the erosion slide from side-wise and one stream flows just through mid vein dissecting the slide.

Streams of Turung Landslide

All streams finally meet at the base line and mix with the river Teesta. Average Speed of runoff has been calculated as 20 Km/hr, 19 Km/hr, and 25 Km/hr respectively in the month of December however velocity does not remain constant throughout the year because during monsoon season, naturally runoff velocity increases due to either heavy rainfall or over seepage of waste water from different sources. The speed of runoff also depends upon the condition of slop, turning of stream, etc.

2.3 Vegetation status of Turung Landslide

Vegetation study of tree species reveals that *Schima wallichii* has highest density and abundance which is followed by *Alnus nepalensis* and *Shorrea* sp., The slide also contains important medicinal plants like *Treminalia chebula, Spondias axillaries, Rhus emialata* etc.

Vegetation study of landslide by botanist of Forest Department

So conservation of these plants along with the landslide is important concern for this project. Among the shrubs *Lantana camara* which is also exotic plant has highest density and abundance. This plant is so far known for the good binder of soils. Plants like *Buddleia asiatica, Woodfordia fruticosa* also has stable community within the erosion slide.

Most of Herbs were seasonal, however good density of herbs likes *Eupatorium odoratum, Eupatorium adenophorum, Cynodon dactylon* provide result in conservation strategies for soil erosion.

Table No. 1: ***Record of Tree species in Turung (sample plotting 10m x 10m)***

Checklist of plant species	No. of individuals in quadrant number 1,2,3,….10	Total no. of individuals	Total no. of quadrats of occurrence	Total No. of quadrats studied	Abundance	Density
Alangium begoniaefloium	1	1	1	10	1	0.1
Albizza procera	1+1	2	2	10	1	0.2
Alnus nepalensis	3+1+2	6	3	10	2	0.6
Bauhinia purpurrea	1	1	1	10	1	0.1
Betula alnoides	2	2	1	10	1	0.2
Bombax cieba	1	1	1	10	1	0.1
Castanopsis tribuloides	1	1	1	10	1	0.1
Chuckrassia tabularis	1	1	1	10	1	0.1
Dysoxlum procerum	1+1	2	2	10	1	0.2
Engelhardtia spicata	1+1	2	2	10	1	0.2
Erythrina indica	1	1	1	10	1	0.1
Ficus bengamina	1	1	1	10	1	0.2
Grewia vestita	1+1+1	3	3	10	1	0.3
Litsae polyantha	1	1	1	10	1	0.1
Meliosma thomsonii	1	1	1	10	1	0.1
Oroxylum indicum	1	1	1	10	1	0.1
Populus gambali	1+1+1	3	3	10	1	0.1
Premna barbata	1	1	1	10	1	0.1
Rhus emialata	1	1	1	10	1	0.1
Rhus succedanea	1	1	1	10	1	0.1
Shorea robusta	1+2+1	4	3	10	1.3	0.4
Spondias axillaries	1	1	1	10	1	0.1
Schima wallichii	1+3+3+1+2+3	16	6	10	2.6	1.6
Treminalia chebula	1	1	1	10	1	0.1
Vitex negundo	1	1	1	10	1	0.1

Note: Abundance is described as the number of individuals per quadrate of occurrence. Density is number of individuals per quadrate.

Table No. 2: ***Record of Shrubs Species in Turung (sample plotting 5m x 5m)***

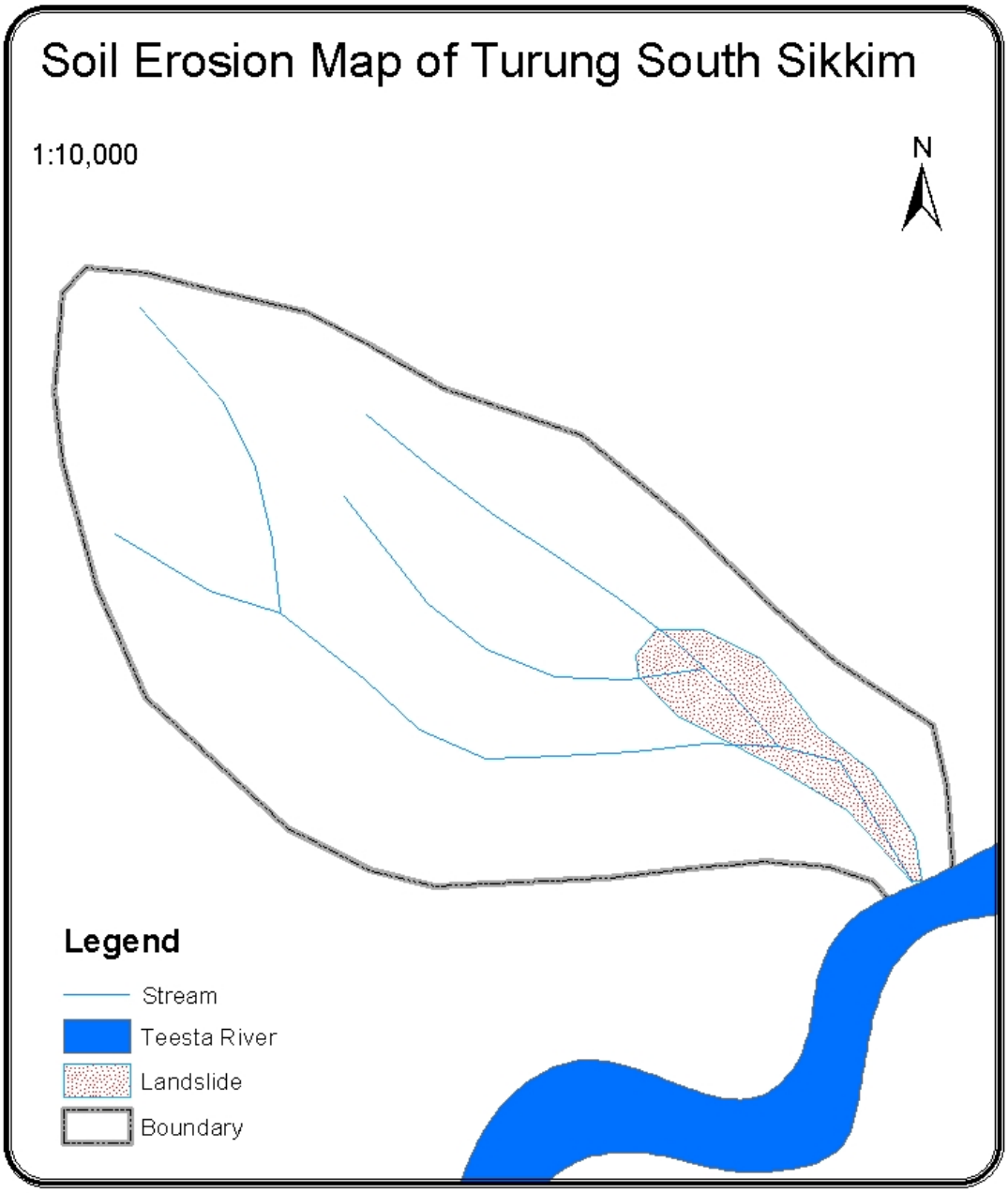
Checklist of plant species	No. of individuals in quadrant number 1,2,3,….10	Total number of individuals	Total no. of quadrats of occurrence	Total No. of quadrats studied	Abundance	Density
Boehmeria macrophylla	1+3	4	2	5	2	0.8
Buddleia asiatica	5+3+4	9	3	5	3	1.8
Datura surveolens	2	2	1	5	1	0.4
Debregeasia velutina	3+1	4	2	5	2	0.8
Lantana camara	10	10	1	5	10	2
Maesa chisia	1	1	1	5	1	0.2
Mezoncurcum cullatum	1	1	1	5	1	0.2
Mimosa himalayana	1	1	1	5	1	0.2
Sacchraum spontanium	1	1	1	5	1	0.2
Woodfordia fruticosa	1+3+2+1	7	4	5	1.7	1.4

Note: Abundance is described as the number of individuals per quadrate of occurrence. Density is number of individuals per quadrate.

Table No. 3: ***Herbs species recorded in Turung (sample plotting 2m X 2m)***

Checklist of plant species	No. of individuals in quadrant number 1,2,3,….10	Total number of individuals	Total no. of quadrats of occurrence	Total No. of quadrats studied	Abundance	Density
Ageratum conyzoides	10+7+5+3	25	4	10	6.25	2.5
Artimesia vulgaris	3+1	4	2	10	2	0.4
Axnopus compressus	10	10	1	10	10	1
Bidens pilosa	5+3+2	10	3	10	3.3	1
Cissampelos panira	3+1	4	2	10	2	0.4
Cissus adnata	1	1	1	10	1	0.1
Cissus repanda	15+4+6+3	28	4	10	7	2.8
Commulena bengalensis	3+2	5	2	10	2.5	0.5
Cynodon dactylon	5+6+7	18	3	10	6	1.8
Digitaria sangunalis	37+15	52	2	10	26	5.2
Drymaria cordadta	5+4	9	2	10	4.5	0.9
Dryopteris fillixanus	4	4	1	10	1	0.4
Eupatorium adenophorum	7+10+3+4	24	4	10	6	2.4
Eupatorium odoratum	20+5+6+9+10+11	61	9	10	6.7	6.1
Dioscorea deltoidea	2	2	1	10	1	0.2
Glaphylopteriopsis erubescens	3+4+3	10	3	10	3.3	1
Imperata cylindrical	23	23	1	10	23	2.3
Nephrolepsis cordifolia	21+5+2	28	3	10	9.3	2.8
Neyraridia madagascariensis	3	3	1	10	3	0.3
Pauzolzia viminea	1+8+3+2	14	4	10	3.5	1.4
Pogonatherum paniceum	3+4+7	14	3	10	4.6	1.4
Ricinus communis	1+11	12	2	10	6	1.2
Solanum khasianum	2	2	1	10	2	0.2
Salima chrysopogon	17	17	1	10	17	1.7
Thysanolaena maxima	2+5	7	2	10	3.5	0.7

Note: Abundance is described as the number of individuals per quadrate of occurrence. Density is number of individuals per quadrate.


Soil Erosion Map of Turung South Sikkim
1:10,000
N
Legend
Stream
Teesta River
Landslide
Boundary

3. Donok Landslide

"Donok" soil erosion of South Sikkim occurred in 1968 due to heavy rainfalls and is included in severe erosion which dragged off approximately 6.925 ha forest land. This landslide is being continuous threat for the inhabitants of Bimbung village situated just at the top of landslide.

Degraded Forest Land in Donak, South Sikkim

The erosion slide is sandwich between 88 ^{0} 30' 65" and 88 ^{0} 33' 81" East latitudes and 27 ^{0} 09' 21" and 27 ^{0} 09' 05" North longitudes. Recently the slide has got approximately the elevation of 351.6 m and approximately spread out 197m in breadth. The zone of the side is completely guided from both sides by the dense forest *of Tectona grandis* and *Shorea robusta* so the chances of spreading erosion are minimized. It was noticed that slide is just mass movement of soil devoid of stone due to seepage of underground water from unknown sources and the rapid run off of Bimbung stream. The slope condition is stiff though soil fertility was retained which favours the plantation but very small work has been done so far in order to check the erosion. The another cause of erosion is paddy cultivation at the top of slide in private sector but now this type of cultivation practices have been already checked and obscured.

3.1 *Streams of Donok Landslide*

History reveals that Donok erosion occurred due to heavy rainfall of 1968; however that was only limited to initial cause of landslide. Also today, landslide is active due to runoff energies of streams. In due course of investigation, it was fairly noticed that downward stream which flows from the Bhimbung Busty transect the slide from the middle and erodes the bulk of soil debris creating the gullies. At last this stream merge with the river Teesta.

Streams of Donak landslide with Baseline of Teesta river

During the month of December, this stream flows with the average speed of 15 Km/hr but speed is mainly depended upon the slope steep, bending of stream, and mass of water. The stream velocity increases as it approaches the monsoon season. If water of this stream is diverted from the source by constructing catch water drain to other arid places then erosion can be controlled to some extent.

3.2 *Vegetation Status of Donok Landslide*

The density and abundance of plants like *Schima wallichii, Alnus nepalensis, Shorea robusta, Eupatorium odoratum, Buddleia asiatica, Woodfordia fruticosa* are quite healthy under this slide.

Vegetation of Donok Landslide

Important medicinal plants like *Macaranga denticulate, Artemisia vulgaris, Terminalia chebula,* are well adaptated in the environment of slide. Most of plants were exotic but still these plants are fighting to protect the soil lost by mechanical stress.

Ripened fruit of medicinal plant Trichosanthes sp.

Table No. 4: ***Tree species recorded in Donok (sample plotting 10m X10m)***

Checklist of plant species	No. of individuals in quadrant number 1,2,3,….10	Total number of individuals	Total no. of quadrats of occurrence	Total No. of quadrats studied	Abundance	Density
Alnus nepalensis	1+1+2+1	5	4	10	1	0.5
Caruga pinnata	1	1	1	10	1	0.1
Durbanga grandiflora	1+1	2	2	10	1	0.2
Macaranga denticulate	1	1	1	10	1	0.1
Rhus succedane	1+1	2	2	10	1	0.2
Schima wallichii	3+1+4+2+1	10	5	10	2	1
Symplosos caudasts	1	1	1	10	1	0.1
Shorea robusta	2+2	4	2	10	2	0.4
Terminalia chebula	1	1	1	10	1	0.1
Terminalia myriocarpa	1	1	1	10	1	0.1
Tectona grandis	1+1	2	2	10	1	0.2

Table No. 5: ***Recorded shrubs species in Donok (sample plotting 5m X 5m)***

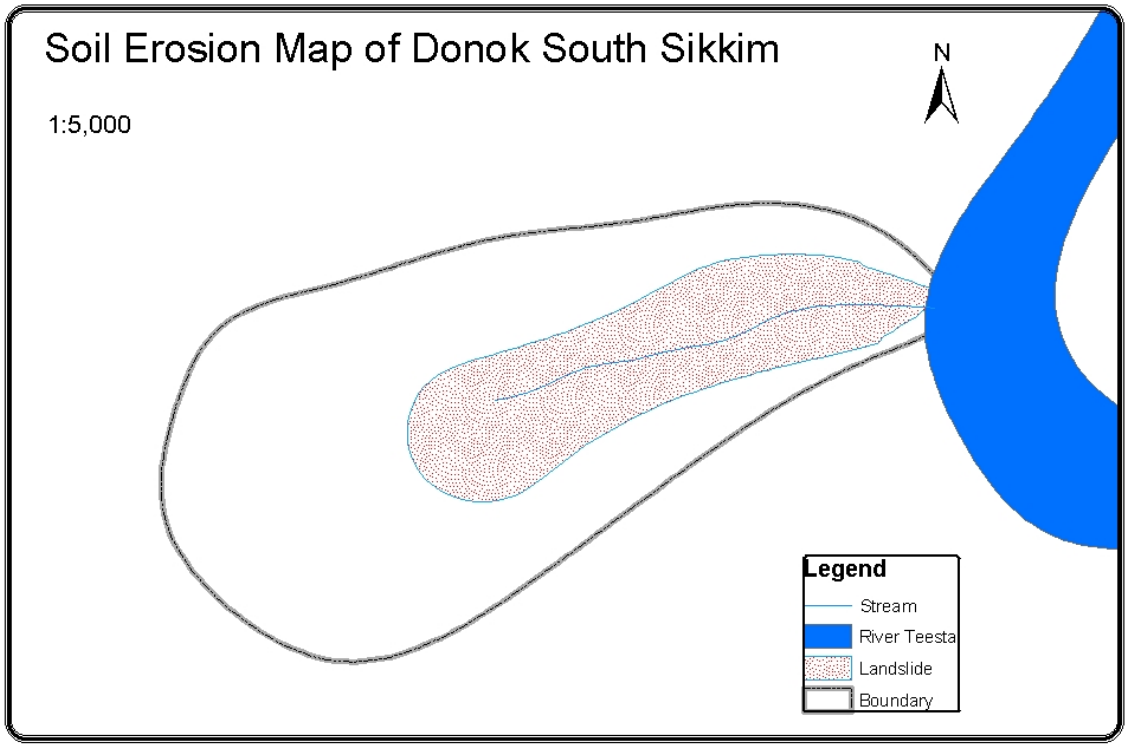
Checklist of plant species	No. of individuals in quadrant number 1,2,3,….5	Total number of individuals	Total no. of quadrats of occurrence	Total No. of quadrats studied	Abundance	Density
Boehmeria macrophylla	2+1	3	2	5	1.5	0.6
Buddleia asiatica	1+4+3+2	10	5	5	2	2
Debregesia velutina	3	3	1	5	3	0.6
Datura surveolans	2	2	1	5	2	0.4
Debregeasia velutina	3	3	1	5	3	0.6
Lantana camara	12+5	17	2	5	8.5	3.4
Woodfordia fruticosa	1+2+1+1	5	4	5	1.3	1

Note: Abundance is described as the number of individuals per quadrate of occurrence. Density is number of individuals per quadrate.

Table No. 6: ***Herbs species recorded in Donok (sample plotting 2m X 2m)***

Checklist of plant species	No. of individuals in quadrant number 1,2,3,….10	Total number of individuals	Total no. of quadrats of occurrence	Total No. of quadrats studied	Abundance	Density
Ageratum conyzoides	3+4+2	9	3	10	3	0.9
Artemisia vulgaris	1+2	3	2	10	1.5	0.3
Axnopus compressus	3+2+1+1	7	4	10	1.8	0.7
Barleria cristata	1+1	2	2	10	1	0.2
Bidens pilosa	5+1+2+1	9	4	10	2.3	0.9
Chrysopogon gryllus	10	10	1	10	10	1
Eupatorium odoratum	15+7+3+2+5	32	5	10	6.4	3.2
Glaphylopteriopsis erbescens	3	3	1	10	3	0.3
Hibiscus cannabinus	1	1	1	10	1	0.1
Muelhenbergia varidissima	1+1	2	2	10	1	0.2
Neyraridia madagascariensis	5	5	1	10	5	0.5
Nephrolepsis cordifolia	7+3	10	2	10	5	1
Oxalis corniculata	20+17+5	42	3	10	14	4.2
Osbeckia crinita	2	2	1	10	2	0.2
Pogonatherum paniceum	5+9+3	17	3	10	5.6	1.7
Salima crysopogon	20	20	1	10	1	2
Thomsonia napaulensis	1	1	1	10	1	0.1

Note: Abundance is described as the number of individuals per quadrate of occurrence. Density is number of individuals per quadrate.


Soil Erosion Map of Donok South Sikkim
1:5,000
N
Legend
Stream
River Teesta
Landslide
Boundary

4. Status of Seti Khola Landslide

"Seti Khola" land slide is so far considered as biggest and very severe erosion of South Sikkim which haul approximately 87.65 hector forest land. Traced back to history, it was revealed that slide occurred in 1968 due to over rainfall and panic floods. This slide provoked peril situation for the inhabitants of the Katang Busty situated just at the top of slide. Seeing the range of devastation caused by slide, many houses were evacuated for safety. The erosion Slide is sandwich between 88 ^{0} 28' 18" and 88 ^{0} 28' 51" East latitudes and 27 ^{0} 08' 51" and 27 ^{0} 08' 31" North longitudes. Main cause of erosion is Seti Khola which flows diagonally from the side and comes at the middle in the baseline of slide. In rainy season this stream roars with the flood and drags the soils from the bottom of slide. Some portion of slide is very stiff and rocky so establishment of climax plant succession is very much disallowed naturally.

Seti Khola landslide South Sikkim

The weathering of rock is very prominent within this slide due to hydraulic pressure caused by heavy rains which increases the weight of the rock at clefts which comes under gravitational force and finally slips or fall off. This slide itself is the origin of several springs from where underground water spout out naturally which flows downwards creating the gullies and eventually turns to streams by approaching the baseline.

4.1 *Streams of Seti-khola Landslide*

Though South Sikkim receives less rainfall as compared to other places of Sikkim, unexpected seasonal rainfall of 1968 was the main cause of Seti-Khola landslide. Since then number of streams originated within the slide and made the erosion very much active. In Nepali terminology “Khola” means river and Seti-Khola flows diagonally from the slide and ultimately reach at the mid-base of slide. This river flows with very high speed of 30 Km/hr throughout the year even one can generate the electricity from this river. The velocity reaches optimum during spring season. The runoff energies of this river drags the soil debris from the bottom, so occupational land and many villagers were evacuated from the top of the slide. If cemented wall is constructed along the river bank then it will guard the further dragging of soil from bottom and give proper channel to the water flow.

Downwards Streams of Seti Khola

4.2 *Vegetation Status of Sati Khola Landslide*

Seti Khola slide is the biggest of all slides, so in term of diversity, it has got more diverse plant species but relatively very low in term of density and abundance. Adaptation of tree species like *Alnus nepalensis, Grewia vestita, Schima wallichii, Shorea robusta,* are fairly noticed but density of these trees is very thin. Herbs belonging to poaceae family like *Axnopus compressus, Chrysopogon gryllus , Neyraridia madagascariensis, Saccharum spontanium* are very common due to arid condition of slide.

Sample plotting for tree species

Table 7: Tree species recorded in Seti Khola (sample plotting 10m X10m)

Checklist of plant species	No. of individuals in quadrant number 1,2,3,….10	Total number of individuals	Total no. of quadrats of occurrence	Total No. of quadrats studied	Abundance	Density
Albizza procera	1+1	2	2	10	1	0.2
Alnus nepalensis	3+1+1	4	3	10	1.3	0.4
Bombax cieba	1+1	2	2	10	1	0.2
Chukrassia tabularis	1	1	1	10	1	0.1
Dysoxlym procerum	2	2	1	10	2	0.2
Erythrina indica	1+1	2	2	10	1	0.2
Duadanga denticulate	2	2	1	10	1	0.2
Engilhardtia spicata	1+2	3	2	10	1.5	0.3
Grewia vestita	2+1+1	4	4	10	1	0.4
Macaranga denticulate	1	1	1	10	1	0.1
Oroxylum indicum	1	1	1	10	1	0.1
Casuarinas sp.	2	2	1	10	2	0.2
Populus gamblei	5+2+3+1	11	4	10	2.7	1.1
Rhus semialata	1+2	3	2	10	1.5	0.3
Rhus succedanea	2	2	1	10	1	0.2
Schima wallichii	3+2+2+1+5	14	5	10	2.8	1.4
Shorea robusta	2+1+2	5	3	10	1.6	0.5
Terminalia myriocarpa	2+1	3	2	10	1.5	0.3

Table 8: Herbs species recorded Seti Khola (sample plotting 2mX2m)

Checklist of plant species	No. of individuals in quadrant number 1,2,3,….10	Total number of individuals	Total no. of quadrats of occurrence	Total No. of quadrats studied	Abundance	Density
Ageratum conyzoides	5+2+3	10	3	10	3.3	1
Artemisia vulgaris	10	10	1	10	1	1
Axnopus compressus	11+7	18	2	10	9	1.8
Bidens pilosa	3+2+1	6	3	10	2	0.6
Cissus repanda	15+10+4+5	34	4	10	8.5	3.4
Chrysopogon gryllus	50+23	73	2	10	36.5	7.3
Eupatorium adenophrom	5+2+7+3	17	4	10	4.3	1.7
Eupatorium odoratum	100+9+15+20+5	149	5	10	29.8	14.9
Glaphylopteriopsis erbescens	5+3	4	2	10	2	0.4
Muelhenbergia varidissima	5+4+1	10	3	10	3.3	1
Neyraridia madagascariensis	6	6	1	10	6	0.6
Nephrolepsis cordifolia	12+5+3	20	3	10	6.6	2
Oxalis corniculata	13	13	1	10	13	1.3
Pogonatherum paniceum	6+2+15	23	3	10	7.6	2.3
Thomsonia napaulensis	2	2	1	10	1	0.2
Saccharum spontanium	15+10+3+2+1	31	5	10	6.2	3.1

Table 9: Recorded shrubs species Seti Khola (sample plotting 5m X 5m)

Checklist of plant species	No. of individuals in quadrant number 1,2,3,….10	Total number of individuals	Total no. of of quadrats of occurrence	Total No. of quadrats studied	Abundance	Density
Bambusa nutans	4	4	1	5	4	0.8
Boehmeria macrophylla	3	3	1	5	3	0.6
Buddleia asiatica	5+3	8	2	5	4	1.6
Datura surveolens	2	2	1	5	1	0.4
Lantana camara	12+5	17	2	5	8.5	3.4
Mezoncurcum cullatum	1	1	1	5	1	0.2
Mimosa himalayana	1	1	1	5	1	0.2
Rubus ellipticus	1	1	1	5	1	.02
Woodfordia fruticosa	3+2+1	7	3	5	2.3	1.4

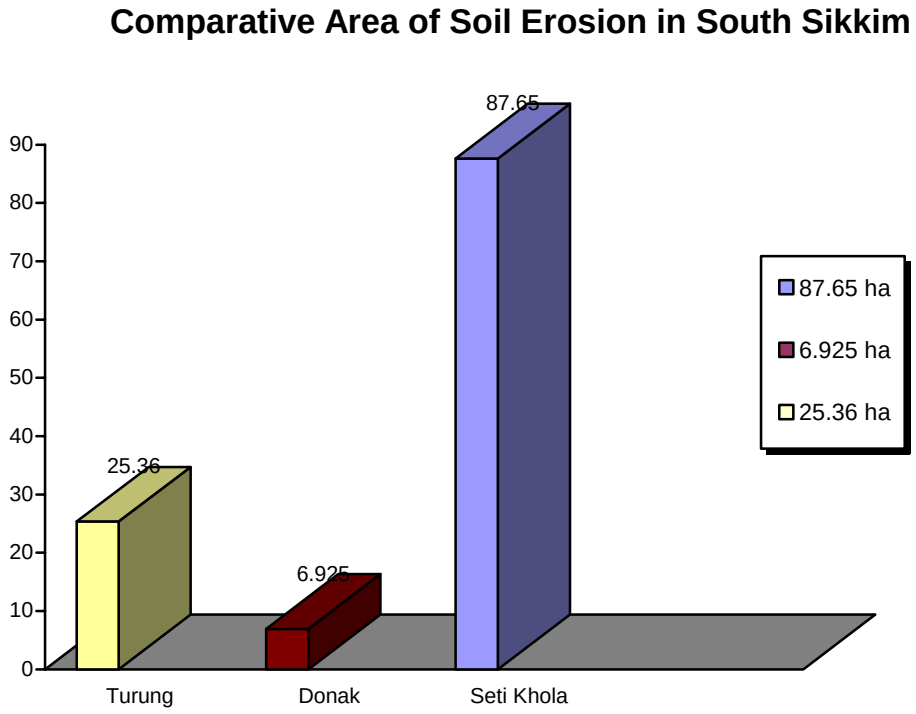
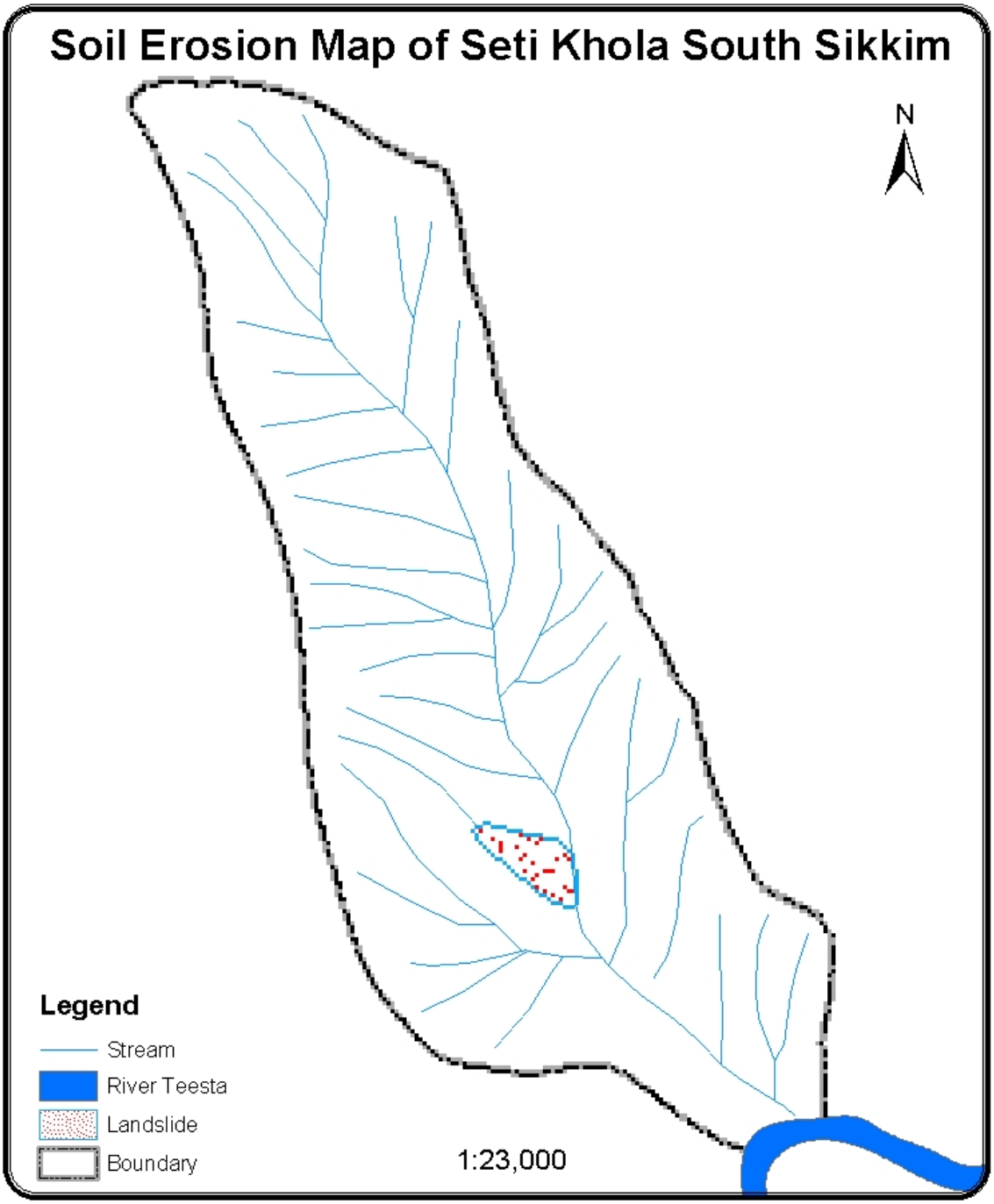


Fig. 1. As per the survey of 2007, conducted by the Forest Department, Government of Sikkim, the total area under severe Soil erosion in South Sikkim is approximately 119.935 ha.


Soil Erosion Map of Seti Khola South Sikkim
N
Legend
Stream
River Teesta
Landslide
Boundary
1:23,000

5. Critical Analysis and Scientific Approach of Vegetation

After scientific investigation, it is found that the density of *Alnus nepalensis* is very high in every fresh degraded landslide. The prolific and unsurpassable growth rate of this tree in harsh nutrient deficient habitats of the region is primarily attributed to its ability to fix the nitrogen in the soil and also accelerates the P cycle. Biological approach of some scientist reveals that root of this plant have association of bacteria called *Frankia* and VAM fungi which improve the fertility status of soil and also help them in physiological process like photosynthesis. This plant is susceptible to diseases like leaf spots and severe damping –off. So seed sowing of these plants in degraded land brings drastic changes in fertility status which in turn supports the invasion of other plant species.

The cuttings of *Jatropa* sp. is also an ideal plant in the rain-fed degraded land like in South Sikkim because cuttings initiate root very easily in dry land and also have high growth rate which efficiently binds the soil in proper place. The herbs like *Eupatorium odoratum, Lantana camere* known as common weeds of field, due to their high adaptability in the adverse environmental condition. Transplantation of such plants may easily survive in the nutrient defecate slide to check the soil lost. The C*yanodon dactlon* grass of Poaceae is very common which forms the sod and covers all ground thus prevent soil lost. There is dearth of information that this grass is being used by many countries to defend their fertile land from erosion. Plantation of *Populu*s sp. could be ideal material to check the soil erosion because it can grow in very fast rate with extensive root system and survive in adverse condition of environment. However, plantation of many bamboo species and plant like *Anthrocephalus cadamba, Erythrina indica, Bischofia javanica, Terminalia myriocarpa, Agave americana,* was done in afforestation zone of erosion slide.

Acclimatization of Poaceae grasses in degraded nutrient deficient landslide

The outcome survivalists of plantation is nearly 80% but soil is very acidic and nutrient deficit, so once approaching to unfavorable seasonal condition, vegetation could change to nude land. In this condition, if seed of *Schima wallichii* was sown then it can withstand in the acidic soil with prolong dryness. Plantation of any leguminous plants in the degraded land may enrich the soil with nitrogenous fertilizer. Scientific approach behind this reason is that these plants produced root nodule association with the nitrogen fixing bacteria which fix the nitrogen to soil and enhance the fertility status. This all includes in biological and eco-friendly method to implement for the conservation of soil erosion.

6. Chemical properties of soil

Good soil produces enormous vegetation to support the ecosystem of particular area. The sustainable propagation of vegetation is totally determined by the chemical properties of soil which included inorganic and organic contents of soil. Soil pH is another parameter which is also ecologically significant for the plant propagation in any bare land. Plants regarded as calcicole usually occur in soil with pH 6.5, whereas calcifuges occur in soil with pH below 3.8-4.

The acidity, alkalinity and neutral of soils are described in term of hydrogen ion concentration or pH values. Soil above ph 6.5 are generally cation saturated (those containing free $CaCO_3$ called calcareous soil) whereas soil below pH 3.8-4 contain a considerable contents of exchangeable hydrogen. Highly acidic or highly alkaline soils often remain injurious to plant growth, microorganism etc. soil ph affect the microbial activities as at below pH 5, bacterial and fungal activities are reduced which could be either nitrogen fixer or decomposer. In regards of this scientific approach soil testing has been done.

Table10: Fertility Index

Chemical evaluation	Name of erosion slide		
	Turung slide	Donok slide	Ssati khola slide
pH	5.7	5.6	5.0
N	154.00 kg/Ha (low)	56.0 Kg/Ha (low)	168.00kg/Ha (low)
P_2O_5	68.70kg/Ha (medium)	84.73 Kg/Ha (Medium)	64.12kg/ha (medium)
k_2O	202.50 Kg/Ha (medium)	175.5 Kg/Ha (medium)	189.00 Kg/Ha (medium)
Organic matter content	0.31kg/Ha (low)	0.31 Kg/Ha (low)	0.31kg/Ha (low

7. Soil sampling procedure and *seive analysis* report

Prior to the collection of soil samples, four pits of 5m X 5m was dough out at toe, foot, middle and top of the erosion slide respectively. Next different layer of soil was collected separately from the each pit and sample is tag with the name as Ao for the top most layers. Bt1, Bt2, Bt3 was assign to the name of other layers next to top layer respectively as we proceed through the top to bottom. Finally sieve analysis was done in the laboratory.

It was found that percentage of gravel and sand is very high in each of the sample and fertility status is also very low due to this reason, vegetation propagation is very difficult even though we can seek out some measures to improve the soil profile either through biological or mechanical method. Recent finding of many scientists reveals that some plants fixed nitrogen in soil for e.g. leguminous plants which can be grown in such arid zone of gravel and sand.

Main aim to study the soil profile is to know what type of soil may prone to erosion and what type of vegetation may introduce in such land for forestation.

Toppled Gravelly Loamy Sand partially checked by bally benching

8. Scientific Approach for Quality Improvement of Soil Profile

After fertility test and soil profile analysis, it was found that “Gravelly Loamy” sand is predominant through the catchment area of erosion slides in South Sikkim. Due to the highest percentage of gravel and sand, water holding capacity of soil is very negligible and hence average moisture contains of soil is restricted to only 7% per gram of soil sample through the landslide. Gravel percentage is very high and water can easily pass through it, as a result flush of rain may erode huge mass of gravel with sand in slope. It is known from the Soil fertility test that soil is also NPK deficit with acidic condition. So, this poor condition of soil does not permit the growth of any vegetation in erosion slide even Xerophytic plant can hardly survive. Plants like *Alnus nepalensis* is very dominant in landslide of Sikkim because it has got ability to fix the atmospheric nitrogen in soil which finally converted to nitrate fertilizer with the help of some bacteria encysted inside the root nodule of this plant even though this plant also got very less density around the landslide of South Sikkim.

In order to improve the fertility status and soil profile in South Sikkim, mulching method is applied in the erosion slide in extensive manner. Mulches of leaves, stubbles, straw etc. totally covers the surface layer of the soil which prevents the organic top layer from being washed away by rainfall. Mulches decay afterwards due to the microbial activities which enhance the organic content of soil and also help in the retention of moisture in soil. So, the method of mulching is significant in various ways to enhance the fertility status.

Application of organic manure could be eco-friendly method to increase the organic content of soil in erosion slide but it is very expensive. Applications of inorganic synthetic fertilizer also help to improve the soil quality but it can evoke several environmental problem like algal bloom, biomagnifications etc. So, in another way round, selection of some plant species which have ability to fix the atmospheric nitrogen in the soil is necessities to combat the soil erosion The leguminous plant could be ideal material for planting and sowing in the degraded land. This plant contains nitrogen fixing bacteria in their root nodules.

In field we are selecting such plant which can easily survive and withstand in acidic and nutrient deficit condition of soil in erosion slide. Therefore, after study of vegetation density and their adaptation in the erosion slide, following tree species were selected and sown in the field in order to check the landslide and to improve the soil fertility status. Result is outstanding, nearly 80% vegetation survive in Afforestation zone near by erosion slide despite of having nutrient deficit soil.

1. *Anthrocephalus cadamba ,*
2. *Erythrina indica,*
3. *Pischofia javanica ,*
4. *Terminalia myriocarpa,*
5. *Agave americana,*
6. *Schima wallichii,*
7. *Alnus nepalensis*
8. *Bambusa nutants*
9. *Dendrocalamus hemlintonii*
10. *Cephalostachym capitatum*
11. *Populus* Sp.

Many sod forming grasses like *Cynodon dactylon, Imperata* sp., *Chrysopogon* sp. *Thysanolaena maxima* was already selected and planted in erosion slide. These plants actually forms sod and cover the whole area so that top most soil is prevented from erosion. Most of the sod forming grasses is seasonal. It decays to add the organic nutrient to soil and again reappear on return of favorable seasonal condition covering surface. Vegetation propagation is also depending upon the moisture content of soil which is very low in South Sikkim. In order to raise the moisture level in soil, tillage method is applied in many slides and result is satisfactory.

Since from the implementation of project, it was fairly notice that biomass is drastically improved either in term of vegetation invasion or in fertility status, because almost all the degraded land is covered by the vegetation. However some part of landslide is very stiff and rocky, which need mechanical method as control measures.

Sample from the top pit of slide
Top layer: Ao, 3 inch (thickness of layer)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	49.44	49.44	50.32
2.36	13.03	13.03	37.29
1.18	11.78	11.78	25.51
0.600	8.67	8.67	16.84
0.425	3.36	3.36	13.48
0.300	3.32	3.32	10.16
0.150	5.03	5.03	5.13
0.075	2.46	2.46	2.67
Pan	2.67	2.67	0.00

Gravel= 62.47% Sand=32.16% Silt=2.46% Soil & Clay=67%
Moisture content = 4.34% IS: 2720(part 2)-1973
Soil Colour: (Moist) 10 YR 4/4, Brown
Soil name: Gravelly Loamy Sand

Next to Ao is Bt1 layer (thickness 1.8 ft)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	46.54	46.54	53.22
2.36	15.87	15.87	37.35
1.18	12.5	12.5	24.85
0.600	8.1	8.1	16.75
0.425	3.01	3.01	13.74
0.300	3.35	3.35	10.39
0.150	5.14	5.14	5.25
0.075	2.46	2.46	2.79
Pan	2.79	2.79	0.0

Gravel= 62.41%Sand=32.1% Silt=2.46% Soil & Clay=2.79%
Moisture content=8.23% IS: 2720(part 2)-1973
Soil Colour: (Moist) 7.5 YR 5/6, Bright Brown
Soil name: Gravelly Loamy Sand

Next to Bt1 is Bt2 layer (thickness 1.8 ft)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	52.65	52.65	46.98
2.36	13.65	13.65	33.33
1.18	12.03	12.03	21.3
0.600	6.56	6.56	14.74
0.425	1.93	1.93	12.81
0.300	2.08	2.08	10.73
0.150	3.51	3.51	7.22
0.075	3.39	3.39	3.83
Pan	3.83	3.83	0.0

Gravel= 66.30%Sand=26.11% Silt=3.39% Soil & Clay=3.83%
Moisture content=2.11% IS: 2720(part 2)-1973
Soil Colour: (Moist) 5 Y 7/1, Light Grey
Soil name: Gravelly Loamy Sand

Sample from the middle pit of slide
Top layer: Ao, 1ft (thickness of layer)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	42.54	42.54	57.26
2.36	12.82	12.82	44.44
1.18	11.6	11.6	32.82
0.600	9.04	9.04	23.8
0.425	3.78	3.78	20.02
0.300	4.25	4.25	15.77
0.150	7.14	7.14	8.63
0.075	3.94	3.94	4.69
Pan	4.69	4.69	0.00

Gravel= 55.36%Sand=35.81% Silt=3.94% Soil & Clay=4.69%
Moisture content=9.93% IS: 2720(part 2)-1973
Soil Colour: (Dry) 10 YR 4/2 Grayish Yellow Brown
Soil name: Gravelly Loamy Sand

Bt1 layer (thickness 4.3 ft)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	19.13	19.13	80.39
2.36	19.51	19.51	60.88
1.18	20.85	20.85	40.03
0.600	13.75	13.75	26.28
0.425	4.45	4.45	21.83
0.300	4.91	4.91	16.92
0.150	7.32	7.32	9.6
0.075	4.45	4.45	5.15
Pan	5.15	5.15	0.00

Gravel= 38.64%Sand=51.28% Silt=4.45% Soil & Clay=5.15%
Moisture content=9.15% IS: 2720(part 2)-1973
Soil Colour: (Moist) 5Y 6/4, Olive Yellow
Soil name: Gravelly Loamy Sand

Bt2 layer (thickness 2ft)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	47.87	47.87	51.82
2.36	17.24	17.24	34.58
1.18	10.45	10.45	24.13
0.600	5.55	5.55	18.58
0.425	2.55	2.55	16.03
0.300	3.12	3.12	12.91
0.150	5.33	5.33	7.58
0.075	2.69	2.69	4.89
Pan	4.89	4.89	0.00

Gravel= 65.11%Sand=27.00% Silt=2.69% Soil & Clay=4.89%
Moisture content=5.40% IS: 2720(part 2)-1973
Soil Colour: (Moist) 2.5Y 6/6, Bright Yellowish brown
Soil name: Gravelly Loamy Sand

Bt3 layer (thickness 7 inch)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	18.02	18.02	81.4
2.36	20.53	20.53	60.87
1.18	24.98	24.98	35.89
0.600	14.1	14.1	21.79
0.425	3.66	3.66	18.13
0.300	4.5	4.5	13.63
0.150	6.33	6.33	7.3
0.075	3.58	3.58	3.72
Pan	3.72	3.72	0.00

Gravel= 38.55%Sand=53.75% Silt=3.58% Soil & Clay=3.72%
Moisture content=8.41% IS: 2720(part 2)-1973
Soil Colour: (Moist) 5Y 7/4, Light Yellow
Soil name: Gravelly Sand

Sample from the foot pit of slide
Top layer: Ao, 8 inch (thickness of layer)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	18.49	18.49	81.00
2.36	24.45	24.45	56.55
1.18	17.69	17.69	38.86
0.600	11.8	11.8	27.06
0.425	4.41	4.41	22.65
0.300	4.85	4.85	17.8
0.150	8.44	8.44	9.36
0.075	4.27	4.27	5.09
Pan	5.09	5.09	0.00

Gravel= 42.94%Sand=47.19% Silt=4.27% Soil & Clay=5.09%
Moisture content=9.85% IS: 2720(part 2)-1973
Soil Colour: (Dry) 10 YR 4/2, Grayish Yellow Brown
Soil name: Gravelly Loamy Sand

Bt1 layer (thickness 9 inch)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	25.9	25.9	73.75
2.36	15.75	15.75	58.00
1.18	15.32	15.32	42.68
0.600	12.00	12.00	30.68
0.425	5.58	5.58	25.10
0.300	6.23	6.23	18.87
0.150	9.71	9.71	9.16
0.075	4.23	4.23	4.93
Pan	4.93	4.93	0.00

Gravel= 41.65%Sand=48.84% Silt=4.23% Soil & Clay=4.93%
Moisture content=10.77% IS: 2720(part 2)-1973
Soil Colour(Moist) 10 YR 5/4, Dull Yellowish Brown Soil name: Gravelly Loamy Sand

Bt2 layer (thickness 2 inch)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	47.87	47.87	51.82
2.36	17.27	17.27	34.58
1.18	10.45	10.45	24.13
0.600	5.55	5.55	18.58.
0.425	2.55	2.55	16.03
0.300	3.12	3.12	12.91
0.150	5.33	5.33	7.58
0.075	2.69	2.69	4.89
Pan	4.89	4.89	0.00

Gravel= 65.11%Sand=27% Silt=2.69% Soil & Clay=4.89%
Moisture content=5.80% IS: 2720(part 2)-1973
Soil Colour: (Moist) 2.5Y 6/6, Bright Yellowish brown
Soil name: Gravelly Loamy Sand

Sample from the (Toe) pit of slide
Top layer: Ao, 5 inch (thickness of layer)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	30.13	30.13	69.6
2.36	19.41	19.41	50.19
1.18	14.49	14.49	35.7
0.600	12.03	12.03	23.67
0.425	4.99	4.99	18.68
0.300	4.95	4.95	13.73
0.150	7.51	7.51	6.22
0.075	3.24	3.24	2.98
Pan	2.98	2.98	0.00

Gravel= 49.54%Sand=43.97% Silt=3.24% Soil & Clay=2.98%
Moisture content=8.68% IS: 2720(part 2)-1973
Soil Colour: (Dry) 5 YR 4/1, Brownish Grey
Soil name: Gravelly Sand

Bt1 layer
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	35.54	35.54	63.89
2.36	14.43	14.43	49.46
1.18	14.52	14.52	34.94
0.600	9.24	9.24	25.7
0.425	4.16	4.16	21.54
0.300	4.58	4.58	16.96
0.150	8.07	8.07	8.89
0.075	4.08	4.08	4.81
Pan	4.81	4.81	0.00

Gravel= 49.97%Sand=40.57% Silt=4.08% Soil & Clay=4.81%
Moisture content=13.01% IS: 2720(part 2)-1973
Soil Colour: Moist) 10 YR 5/6, Yellow Brown
Soil name: Gravelly loamy Sand

Bt2 layer (Toe)
Wt. of sample 100 gm

IS sieves size (mm)	Wt. of retained sample (gm)	Sample retained (%)	Sample passing (%)
4.75	31.39	31.39	67.83
2.36	16.75	16.75	51.08
1.18	17.32	17.32	33.76
0.600	9.6	9.6	24.16
0.425	3.22	3.22	20.94
0.300	3.97	3.97	16.97
0.150	6.62	6.62	10.35
0.075	3.94	3.94	6.41
Pan	6.41	6.41	0.00

Gravel= 48.14%Sand=40.73% Silt=3.94% Soil & Clay=6.41%
Moisture content=6.84% IS: 2720(part 2)-1973
Soil Colour: (Moist) 2.5Y 6/6, Bright Yellowish brown
Soil name: Gravelly loamy Sand

9. Year Wise Physical and Financial Target

The fund released under TDET by the Government of India, Mo RDD of Land Resources to the Divisional Forest Officer (Land Use &Environment) Namchi, South Sikkim is being use for the various conservation activities to arrest soil erosion within South Sikkim. By the end of 2007, 3rd years financial and physical target lay out in the chart below has been achieved. Still lots of scientific investigation are going on which deals with the study of vegetation density and their adaptability, soil testing, evaluation of runoff velocity of streams, in collaboration with Mines, Minerals and Geology Department, Gov. of Sikkim.

Table 11:Years wise physical targets and financial outlay

Sl. No.	Activity	Rate in Rs.		Year wise physical and financial (Rs. In Lakhs) target									
			Unit	1st year		2nd year		3rd year		4th year		Total	
				Phy	Fin.	Phy	Fin	Phy	Fin	Phy	Fin	Phy	Fin
1	Protective works												
(a)	H.P stone wall inside sausage in landslide area	4400	RMT	1200	52.80	1200	52.80	600	26.40	-	-	300	132
(b)	Stream training works												
(i)	H.P. stone wall inside sausage for river training	4400	RMT	600	26.40	600	26.40	300	13.20	-	-	1500	66
(ii)	GI sausage wall with 1:2:4 PCC lining	6400	RMT	-	-	96	6.144	96	6.144	48	3.027	240	15.36
2	Soil and moisture Conservation	33000	Ha	-	-	64	21.12	64	21.12	32	10.56	160	52.80
3a	Afforestration	20340	Ha	-	-	100	20.34	100	20.34	50	10.17	250	5085
3b	Maintenance of afforestration	3700	Ha	-	-	-	-	100	3.7	100	3.70	-	7.4
4	Bamboo plantation with seed broadcasting	25700	Ha	-	-	84	21.59	84	21.59	42	10.79	210	53.97
5	Bole Benching	24850	Ha	-	-	24	5.96	24	5.96	12	2.98	60	-
6	Application of geo synthetics and polymers	185	Sq.ft.	-	-	-	-	5000	9.25	5000	9.25	10000	18.5
7	Regarding of slope	55	Cu.m	-	-	-	-	7500	4.13	7500	4.13	15000	8.26
8	Anchoring /Shoteeting	6500	M	-	-	-	-	20	1.30	80	5.20	100	6.5
9	Supervisors	72000	Per person p.a	1	0.72	1	0.72	1	0.72	1	0.72	-	2.88
	Sub total of works				79.92		155.08		133.85		60.57		429.42
10	**Adm. Overheads (15%)**				22.536		20.26		16.534		5.08		64.41
	Grand total				102.452		175.34		150.384		65.65		493.83
	DoLR Share				99.956		172.84		147.884		63.15		483.83
	Beneficiary contribution				2.50		2.50		2.50		2.50		10

10. CONSERVATION OF SOIL EROSION

Principles of soil conservation

The soil conservation depends on the following principles : (i) protection of soil from impact of rain drops, (ii) to prevent water from concentrating and moving down the slope, (iii) to slow down the water movement when it flows along the slope, (iv) to encourage more water to enter the soil, (v) to increase the size of soil particle, (vi) reduction in the wind velocity near the ground by growing vegetation cover, ridging the land, and (vii) to grow the strips of stubble or other vegetation cover which help to catch and hold the moving particles of soil.

Plantation of cuttings across the slopes of landslide

10.1 Agronomic Soil Conservation measures -

Use of Vegetation: Vegetation which covers the ground surface well and has extensive root system was used to reduce soil erosion in South Sikkim. Plant canopy was planted along the contour of landslide to protect the soil from the adverse effect of rainfall. The grasses and legumes are transplanted in degraded land which has potential to produce dense sod to check the further erosion. This vegetation also provide organic matter to the soil. As a result, the fertility of soil increases and the physical condition of soil is improved. Following cropping systems has been implemented to controlling soil erosion -

Crop rotation and dry farming: This method could be very effective in checking erosion of occupational land surrounding the landslide. It has been observed that on the top of Turung and Donok landslide, people are practicing crop rotation in traditional way because most of the people in Sikkim relied upon seasonal occupation. So in one sense, people are maintaining fertility status and productivity of soil.

Occupational land just above the landslide

Land Use & Environment Circle of Forest Department is conducting awareness campaign to assist crop rotation and dry farming in all occupational land surrounding the erosion slide. In occupational land, people are practicing good seasonal crop rotation which includes the sowing of maize, followed my millet, beans, etc. Cultivation of leguminous plant like bean, pea, increases the yield of nitrogen content of soil because most of these plants contain nitrogen fixing bacteria. Aqua culture of any things was already detained in the surrounding area of erosion by providing appropriate compensation for the source income through such land.

Strip Cropping: Erosion permitting crop was grown in alternate strips in the slope of landslide to check the erosion. Strip cropping employs several good farming practices including crop rotation, contour cultivation, proper tillage, stubbles mulching, cover cropping etc.

It is very effective and practical means for controlling soil erosion in hilly area like Sikkim, especially for gently slopping land. It may be of different types as follows:

- **Contour strip Cropping**: Applying this method, culitvation of erosion permitting and erosion resisting crops is being practiced alternately in strips across the slope and on the contour line in order to check the soil erosion. This practice is useful because it checks the fast flow of run-off water; increases the infiltration of water in the soil and prevents soil erosion.
- **Field Strip Cropping:** Growing of crops in parallel strips to the general slope of the landslide is being practiced to check the soil erosion.
- **Wind Strip Cropping:** Growing of crops across the direction of wind regardless of contour of landslide has been practiced.
- **Buffer Strip Cropping:** The severally eroded portion of land was permanently kept under grass and contour strip cropping has been practiced in the rest of the landslide area.

There is a special type of contour strip cropping in which care is taken to check soil erosion.

Cultivation of dense plant and grasses: Sod forming grass such *cynodon sp*., *Cissus adnata, Commulena bengalensis Oxalis corniculata, Chrysopogon gryllus* cover the surface of the land and their roots bind the soil particles to form soil aggregates, thus preventing soil erosion.

Afforestation: **A**ll slides are situated under forest area and very challenging for crop cultivation within erosion slide so afforestation is economically best method to implement for the conservation purpose of erosion. Afforestation means growing of forests where there were no forests before owing to lack of seed trees or due to adverse factors such as unstable soil, aridity or swampiness. Along with afforestation, reforestation should be undertaken which means replanting of forests at places where they have been destroyed by uncontrolled forest fires, excessive felling and lopping. Afforestation is the best means to check the soil erosion.

Bamboo plantation in landslide

Advantage of afforestation is as follows:-

- Infiltration of water is favoured due to high porosity of soil under vegetation. Percolation of water helps in preventing the soil moisture which accelerates further growth of the vegetation.
- Surface accumulation of organic matter increases the water holding capacity of the underground soil.
- Root system of vegetation holds the soil mechanically and provides stability of the underground soil.
- It gives the protection against wind. The forest vegetation shields the soil from direct effect of drought, snow and rain.

Aforestation zone has been already created within the slide and plantation of bamboo sp, *anthrocephalus cadamba ,erythrina indica, bischofia javanica ,Terminalia myriocarpa, Agave americana,* etc was done mostly in Turung slde. Soil of all erosion slides is slightly acidic so seed showing of acid loving plants *like schima wallichii, alnus nepalensis* could turn to better result in term of adaptation and soil erosion conservation. Trees as windbreaks are planted in arid region which check the velocity of wind. Plantation of trees in short blocks are called wind breaks. Extensive plantation of trees is called shelter belts.

Plantation around the landslide area to create afforestation zone.

Windbreaks are planted across the area at 90° to the prevailing wind. They check the blowing away of the fertile top soil. Windbreaks are planted in several rows. Some herbs like *Imperata cylindricall, Chrysopogon gryllus* are good binder of top soil in hilly area of Sikkim. Shrubs like *Lantana camara, Artimesia vulgaris, Eupatorium adenophorum, Thysanolaena maxima, Neyraridia madagascariensis, Antidesma acuminattum, Rubus calycinus* etc. are also enlisted for the conservation of soil erosion. The roots of the plants (which are used in windbreaks or shelter belts) bind the soil and protect it from erosion.

Mulching: Mulching was done in extensive manner in every landslide at South Sikkim and obtained good result in the improvement of fertility status and moisture retention capacity of soil. Mulches of different kinds such as leaves, straws, paper, stubbles, etc. were used to cover nutrient deficit landslide. As a result evaporation was minimized and moisture absorption capacity of was enhanced. Top soil layer was also protected against the beating action of rain drops. Later on they decay to form humus which improves the physical condition of soil. Natural mulching also helps in the infiltration of water and the reduction of evaporation.

Bally benching: Bally benching was done in many places within the slides using the cuttings of *Jatropa* sp., *Anthrocephalus cadamba, Erythrina indica to* minimize the flow of soil debris. Bally benching was more or less successful however some slide is so severe so that it washed away many such fencing. Seeing the severity of slide seed dispersion could be best method for reforestation.

Bally benching in the landslide to arrest the soil erosion and vegetation regeneration

Control of grazing: Grazing increases the soil erosion so, grazing is checked more or less in erosion slide but the grazing cannot be completely stopped in all areas. The restricted and rotational grazing may be helpful in checking soil erosion to some extent. The area open to grazing for sometimes should be closed for the following year to facilitate regeneration of forests and to maintain thick ground vegetation.

Good tillage: Tillage is the mechanical manipulation of soil by different kinds of implements. Tillage was done by plouging and harrowing in slope of degraded land to make the soil loose and friable which helps in retention of water. The special method of tillage practice was followed for the conservation purposes..

10.2 Mechanical Soil Conservation measures -

Mechanical measures include various engineering techniques and structure was implemented to check the soil erosion. This practices aim at some objective as follows:

- To divide a long slope of land into a series of shorter ones in order to reduce the velocity of run off water.
- To retain the water in the land for long period so as to allow maximum water to be absorbed and held in the soil and less water flows down the slope of the land at non-erosive velocity.
- To protect the soil against erosion by water.

Damaged wall due to over flood within landslide and portion has been protected

The important mechanical soil conservation measures are as follows:

Contour bunding: Earthen embankment was constructed at intervals across the slope and along the contour line of the many landslides in South Sikkim. A series of such bund is very useful in dividing the area into strips and act as barrier to the flow of water. As a result, the amount and velocity of run-off are reduced, resulting reducing the soil erosion. Contour bunding is made on landslide where the slope is not very steep and the soil is fairly permeable. Contour bunds are also called level terraces, absorption type terraces or ridge type terraces. Contour bunding works are carried out over wide areas in many parts of India, notably in Andhra Pradesh, Gujarat, Karnataka, Maharashtra and Tamil Nadu. The significant of contour bunding is enormous to combat the erosion, so, this method is also inherited in our state.

Terracing: A terrace is an embankment of ridge of earth constructed across the slope to control run off and to minimize soil erosion. A terrace reduces the length of the hill side slope, thereby reducing sheet and rill erosion and prevents formation of gullies. There are different types of terraces implemented for the project as follows:

Bench terracing: Relatively steeps land was transformed into a series of level or nearly level strips or steeps running across the slope of many landslides in South Sikkim. The soil materials that are excavated from the upper part of the terrace is used in filling the lower part and a small bund is also raised along the outer edge of the terrace to check the downward flow of rainwater and also soil erosion.

Channel terrace wide but shallow channels across the slope of the landslide either exactly on contour line or with a slight grade was constructed in many landslides. In this process, the excavated soil is placed along the lower edge of the channel in the form of low ridge.

Narrow based terrace number of narrow based ridges or bunds at a distance of 1m to 2m across the slope of the many landslides was built.

Broad based ridge terrace wide but low bunds were also constructed on the contour lines by excavating soils from both sides of terrace. This method was practiced in landslide where the rainfall is relatively low.

Contour trenching: series of deep pit (i.e. 2ft. wide and 1ft. deep) or trenches across the slope at convenient distance was built within the landslide of South Sikkim. The soil excavated from the trenches was deposited on the lower edge of the trenches where forest trees were planted.

Hand packed stone walls inside sausage (gabion) in landslide areas. Preference was given to sausage wall among the mechanical method in every landslide of South Sikkim and every landslide was nearly checked by applying sausage wall. In this method the stone wall was covered with G.I sausage to hold the loose stones in place. During field visit, it was observed that most of the erosions are active due to downward streams which loosen and mobilize the soil, so massive bulk of soil began to move down wards. Therefore damage of sausage wall is also very common within the landslide

The Movement of stone debris and boulders across landslide has been partially checked by sausage wall albeit heavy destruction

Construction of CC M Jhora*:* Most of the slide has origin of streams within their body and there is no proper diversion plan for such streams however run off water can be canalized by the construction of CCM Jhoras and drains. However this method is yet to implement.

Catch water drains. The basic purpose of these catch water drains is to collect the run off and dispose it safely to other way so that the seepage is prevented and also the loose upper soil is prevented from erosion. This method is best for such slide which is bisected by stream flowing from long way from the top of slide. The water can be diverted from the origin before approaching to the landslide area. This method is also yet to implement in the field.

Rock Bolting and Grouting

Rock bolting method is used to tie potentially unstable rock structures into the slope. There are static and tensioned rock bolts:

- Tensioned rock bolts should be used only where a force is needed to counteract the forces making the structure unstable.
- In most cases static bolts should be used.

The logic behind a static bolt is that if the structure is safe enough to drill into and install rock bolts, it already has an inherent factor of safety. If the stability of the structure is adversely affected in the future the static bolt will automatically go into tension with the exact amount of force and in the exact location. Large funding is needed to implement such technology because we need machine and expert in this regards.

Rock Slope Netting

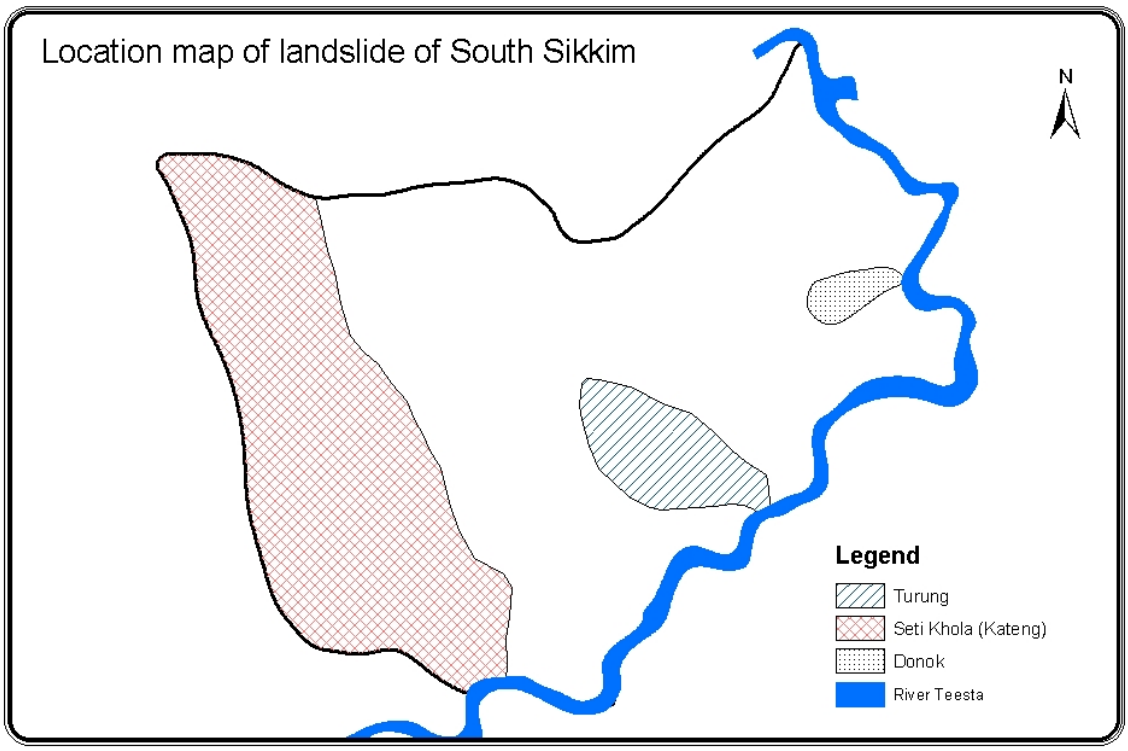
Rock Netting is used to cover an entire area of unstable rock. The **slope netting** can be either draped or bolted in each corner of each panel. Rock netting is used where the unstable rock is big and blocky but not big enough to make bolting the only option. This is very new technique implementing in foreign country but we can also implement this technique in our landslide.

11. Biomass fluctuation and Achievements.

At the initial stage of the implementation of project, each landslide was just bared degraded land devoid of any vegetation. Since then after three years, almost all the landslide is invaded by the different type of plant species. In aforestation zone of landslide, nearly 80% of vegetation was regenerated. All the planting material was well adapted and survived; this is due to selection of planting through vegetation and soil study made by different scientist and expert. During recent field visit, it was noticed that density of plant like *Schima wallichii, Alnus nepalensis, Shorea robusta, Eupatorium odoratum, Buddleia asiatica, Woodfordia fruticosa* was much enhanced in the landslide area. However, plant like *Terminalia chebula, Terminalia myriocarpa, got* very low density.

After mulching of different erosion slide, it was observed that fertility status was also enhanced in each landslide; as a result many species of weeds and fodder grasses like *Lantana camara, Artimesia vulgaris, Eupatorium adenophorum, Thysanolaena maxima, Neyraridia madagascariensis, Antidesma acuminattum, Rubus calycinus* were invaded naturally in landslide. Moisture content was much enhanced as compared to earlier study. So, we are successfulin designing the soil in most of the landslide either for plantation or for implementing any mechanical method.

Most of soil erosion in south Sikkim became slightly stable today. Implementation of mechanical method like sausage wall across the slope of landslide played significant role to stabilize the erosion in Turung landslide. This slide is almost stable now. Still we are implementing new scientific measure in many landslides and hoped for good output.


Location map of landslide of South Sikkim
N
Legend
Turung
Seti Khola (Kateng)
Donok
River Teesta

12. Conclusion

For seven thousand years, humanity has left records of the battle with soil erosion, soil degradation and runoff, trying to improve soil fertility and water management. Likewise, today Sikkim is under the laps of huge devastation caused by soil erosion. Topographically Sikkim is a fragile hilly state; obviously, soil erosion is most prominent and severe. Every year many villagers have to evacuate their occupational land and village. The sanction of "Treatment of Landslide and Erosion Control Project" under TDET is a appropriate approach towards the conservation of natural resources through specific technology development to strengthen and control of soil erosion and Landslide.

The extent of Landslide and erosion is so vast occurring over stretches of the watershed in the project area thereby it may not possible to attend the entire problem area of the project site with the sanction amount of the project. However, it is possible to establish benchmarks of Biological and soil conservation engineering technology to be applied to other similar problem area of the state.

During the course of the study of the soil erosion and landslide treatment activities, it was observed that the heavy gabion structure in highly severe loosen and fractured faulted configuration area required heavy foundation with G.I. wire sausage stonework combined with cement concrete works to strengthen the pressure of heavy surface runoff added with loose conglomerates and slope gravitational forces. The edge effect of gradual stabilization of landslide with Afforestation of highly adoptable and hardly species renders good impact. Several species of flora both tree and herbs and shrubs have been identified for same purpose.

This project has severe landslides and soil erosion zone which were identified as newly formed or old erosions. In this regards, the team worked with great interest in contending the problem of erosion and landslide control in the area. In due course of survey number of landslides, scientific finding on vegetation status, stream bank erosion, rate of runoff speed, soil profile and fertility status were made, which may be considered scientific measures to promote stabilization of the erosion and Landslide.

After critical analysis, many scientific measures were developed in order to arrest the landslide and control erosion. The scientific finding like soil testing and vegetation study give ideas for the selection of planting material which could be best fitted with the soil and prevailing environmental condition of landslide zone. Rock bolting and grouting is very effective to stabilize hard rock in the slope but require heavy financial provisions. Various measures like afforestation, sausage wall, terracing, catch water drain seed sowing, bamboo plantation, bally benching were carried out to both in severe land slides as well as gentle slope of private and government land to establish impact of treatment. The outputs and result of landslide and erosion control studies can be tried in similar sites in the state in the first instance and further may improve for replication to other hilly stations in the country.

It is also experienced that Treatment of Landslide and erosion control implementation required ardent and spontaneous support of the fringe dwellers of the problem area to restrict their faulty agriculture and traditional network of activities in the fragile Landslide ecosystem. In order to sanitize and educate and bring awareness about the risk and unforeseen threat of Landslide it was noted that several awareness campaign, training of inhabitants at Turung, Setikhola, Manrang, Donak and other surrounding area were carried out by the PIA and his team before the project commencement and also during implementation. The package of this programme should be extended in other nearby areas too.

Further, the findings of the report was presented to the Advisory Technical Committee constituted under the "**Technology Development Extension & Training"** (TDET) project on landslide and erosion control.

13. References

1. **Journal of Hill Research** *vol. 19 nos. 1 June 2006*
2. **The Indian Forester** *(Journal) vol.133 June 2007*
3. **Web Search**