Chapter 4

SOILS OF SIKKIM

Sikkim enjoys a wide range of climate, mapped, physiographic, geology and vegetation that influence the formation of different kinds of soils. These soils have been mapped described, analyzed, characterized and classified under 5 broad physiographic units.

Table 4.1 Major physiographic units and dominant soils found in Sikkim

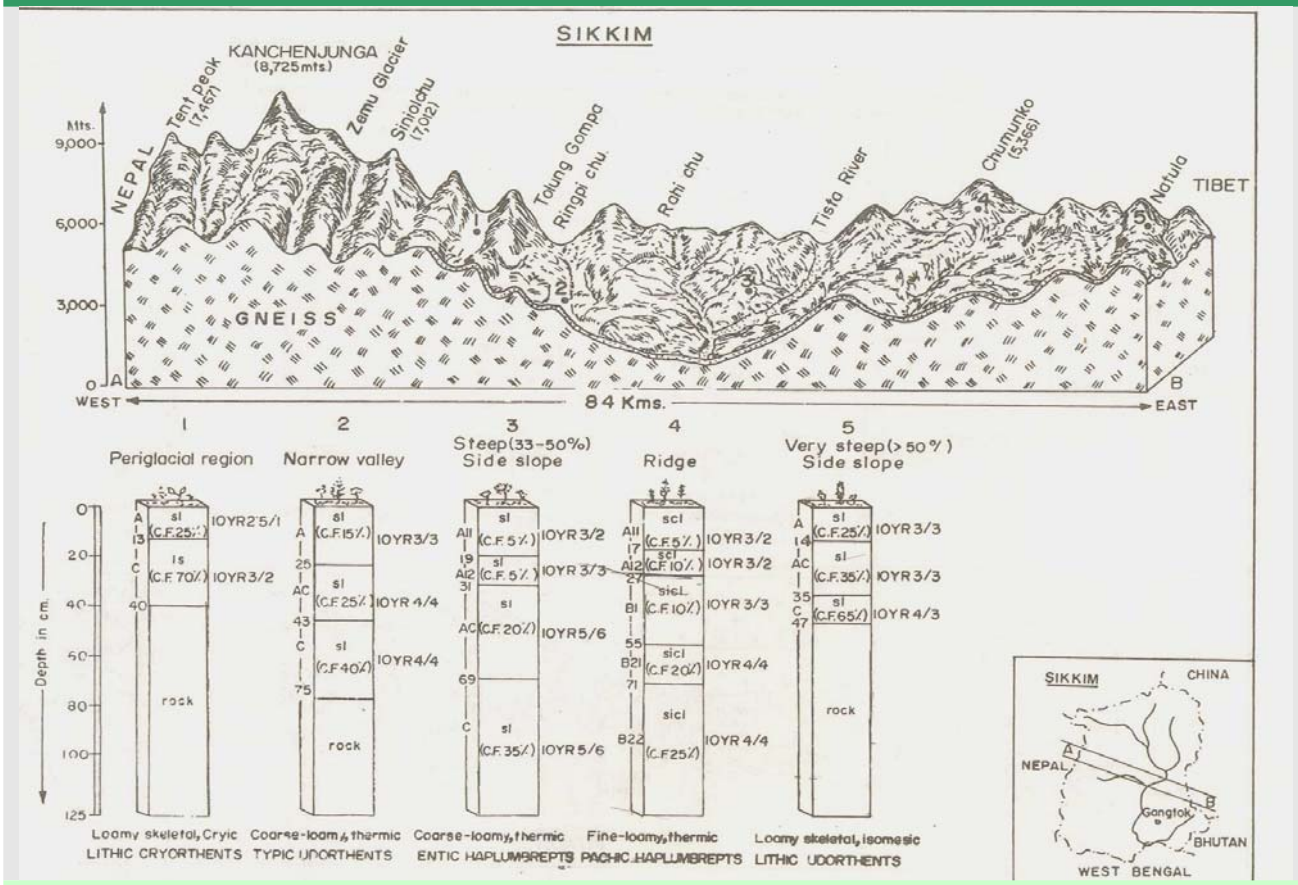
SL. No	Physiographic Units	Area (ha.)	% of TGA	Dominant Soils(Subgroup)
1	Summit and ridge (<30%)	31459.45	4.43	Typic Haplumbrepts Typic Hapludolls Pachic Haplumbrepts Typic Udorthents
2	Side slope of hills	213100.01	30.03	Typic Hapludoll
2.1	Very steeply sloping (>50%)			Entic Hapludolls Dystric Eutrochrepts Lithic Cryorthents
2.2	Escarpments (>50%)	30480.73	4.30	Typic Udorthents Entic Hapludolls Umbric Dystrochrepts
2.3	Steeply sloping (30 - 50%)	214641.28	30.24	Umbric Dystrochrepts Typic Hapludolls Typic Argiudolls Cumulic Haplumbrepts Entic Cryumbrepts
2.4	Moderately steep sloping (15-30%)	16024.82	2.26	Fluventic Eutrochrepts Mollic Udarents Typic Argiudolls Cumulic apludolls
3.	Valleys (15-30%)	9683.36	1.37	Typic Haplumbrepts Aquic Udorthents Cumulic Hapludolls
4	Rocky cliffs and Precipitous slope	85700.29	12.08	Lithic Udorthents Lithic Haplumbrepts
5.	Glacier/Perpetual snow	108510.06	15.29	

IDENTIFIED SOILS

Soils occurring in different landforms are studied in respect of their morphology, physical and chemical characteristics. In accordance with the physiographic sequence of the terrain features, 78 soil families were identified in Sikkim State and mapped into 69 mapping units. It revealed that soils of Sikkim belong to 3 orders, 7 suborders, 12 great groups and 26 subgroups. It is observed that Inceptisols are dominant (42.84%) followed by Entisols and Mollisols occupying 42.52% and 14.64% respectively.

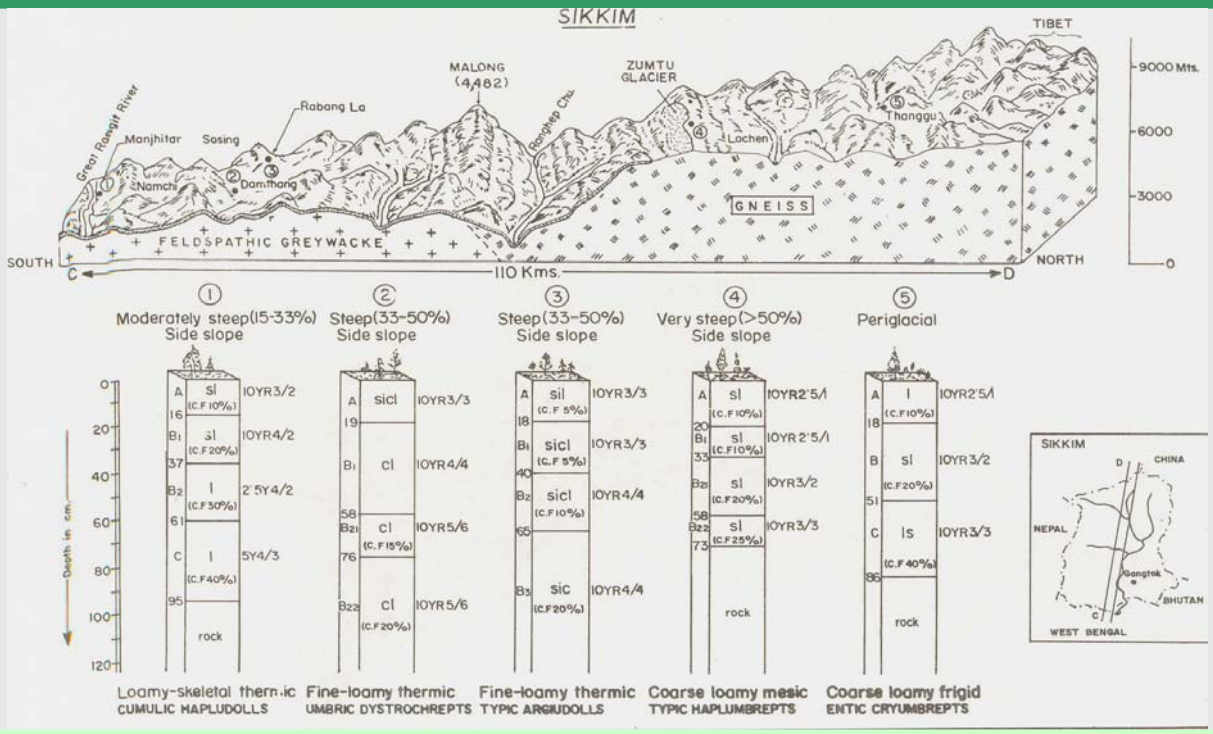
Sikkim has been divided into five broad physiographic units. The relationship between these physiographic units and their soils are established and discussed under the following heads.

Map 4.1 Soil Depth of Sikkim (West-East)



Source : Agriculture Department, Govt. of Sikkim

Map 4.2 Soil Depth of Sikkim (South-North)



Source : Agriculture Department, Govt. of Sikkim

SOILS OF SUMMITS AND RIDGES

Soil variation on summits and ridges is markedly influenced by degree of slope and climate. The climate of the area is characterized with mild summer and cool winter. Mean annual rainfall exceeds 2000 mm in most of the parts in state. Soil moisture and temperature regime are udic and thermic respectively.

Ridges with 30% Slope : Soils developed in these areas are deep, somewhat excessively drained, fine-loamy with loamy surface, have slight stoniness and moderate erosion. These soils are classified as Typic Haplumbrepts and Pachic Haplumbrepts. They occur in association with moderately deep, somewhat excessively drained, coarse-loamy Typic Udorthents with loamy surface, having slight stoniness and moderate erosion. Associated soils lack profile development. They have moderate to high base saturation. These soils occupy an area of 11435 ha. representing 1.6 1% of the total geographical area. The major land use is pre-dominantly under forest; paddy and maize are cultivated to a limited extent. Erosion and Soil acidity are the major constraints associated with these soils.

Ridges with 15-30% Slope: Soils are deep, well to somewhat excessively drained, coarse-loamy to fine with loamy surface, having slight stoniness and slight to moderate erosion. They are classified as Typic Hapludolls and Umbric Dystrochrepts. Soil are moderately acidic in nature and rich in humus content and have medium base saturation. They occur in association with moderately shallow to deep, somewhat excessively drained, coarse- loamy Typic Udorthents with slight to moderate stoniness and moderate erosion. These soils cover an area of 15388 ha. representing 2.17% of the total geographical area. The major land use is predominantly under forest; paddy and maize are cultivated to a limited extent. Erosion, Soil depth and Surface stoniness are some of the constraints.

Ridges with <15% slope : Soils are deep, well drained, fine-loamy soils with loamy surface, having slight stoniness and moderate erosion. They show a slight degree of profile development and are classified as Cumulic Haplumbre and Pachic Haplumbrepts. They occur in association with moderately deep, coarse soils with loamy surface having slight stoniness and moderate erosion. Associated soils are classified as Typic Udorthents and Typic Haplumbrepts. They comprise an area of 1974 ha. representing 0.28% of total area. Most of the area is under paddy cultivation; limited extent is under temperate forest. Erosion and surface stoniness are some of the constraints.

SOILS OF SIDE SLOPES OF HILLS

Formation of soils on side slopes is influenced by the steepness of the slope as it controls surface run-off and erosion. The area experiences a wide variation in climate. In the extreme north, most of the year, area is covered with snow and precipitation received through snowfall only. Soil temperature is identified as isofrigid. Areas above 2700 m in altitude and nearer to isofrigid region, experience cold climate. Temperature varies from 7.8-17°C and rainfall varies from 821 mm (at Thangu) to 1652 mm (at Lachen). Soil moisture and soil temperature regime are identified as mesic and perudic respectively. Rest of Sikkim experiences mild summer and cool winter. Rainfall varies from 2197 mm (at Damthang) to 3494.5mm (at Gangtok). Soil moisture regime in subtropical and temperate climatic regions is Udic and per Udic respectively. Soil temperature regime is thermic.

Very steeply sloping (>50%)

Thermic soil temperature regime: These soils are moderately deep to deep, developed on very steeply sloping hill side. They are somewhat excessively drained, coarse-loamy to fine-loamy soils with slight surface stoniness and moderate erosion. They are classified as Typic Hapludolls, Typic Dystrochrepts and Entic Hapludolls. Soils are moderately acidic, dark brown to dark yellowish brown and rich in humus (Das et al 1996). Base saturation is moderate to high. Soils show a good profile development. They occur in association with deep, coarse-loamy soils with moderate surface stoniness and severe erosion. Soils are Dystric Entrochrepts, Typic Udorthents, Mollic Udarents under stable terraces. But unterraced lands are susceptible to severe erosion. They cover an area of

1,02,378 ha. representing 14.43% of total geographical area. Land use is largely under temperate forest cover and partly under maize cultivation. Soil acidity, soil erosion, steepness of the slope and surface stoniness are some of the constraints.

Mesic soil temperature regime: These soils are moderately shallow to moderately deep, developed on very steeply sloping side hill slopes. They are somewhat excessively drained, loamy-skeletal to coarse- loamy soils with moderate surface stoniness and moderate erosion. Dominant soils are Typic Haplumbrepts and Fluventic Hapludolls. They occur in association with moderately shallow to shallow, somewhat excessively drained coarse- loamy to loamy-skeletal soils with strong surface stoniness and severe erosion. Associated soils are classified as Typic Udorthents and Lithic Haplumbrepts. Soils are highly acidic and low in base saturation. They show poor soil profile development. The soils cover an area of 32,593 ha. representing 4.59% of total geographical area. They occur mainly in North district of the State. Land use is largely under temperate forest cover; some patches are under maize cultivation. Soil acidity, soil depth, soil erosion and surface stoniness are constraints.

Escarpments: These soils have developed under Thermic soil temperature regime and udic soil moisture regime. They are moderately deep, excessively drained, loamy-skeletal soils with slight surface stoniness and moderate to strong erosion. Dominant soils are classified as Typic Udor thents and Umbric Dystrochrepts. They occur in association with excessively drained coarse loamy soils with slight surface stoniness and severe erosion. Soils are Entic Hapludolls. They cover an area of 40922 ha. Representing 5.76% of total geographical area. Land use is largely under coniferous forests and alpine pastures, some patches are under cereal cultivation. Soil depth, Soil erosion and Steepness are some of the constraints.

Steeply sloping hilt sides (30-50%): Soils under steeply sloping hill side experience a wide variation of temperature and rainfall. Two soil moisture regimes viz. udic and perudic prevail in these areas. Soils under perudic moisture regime in North districts rethains wet throughout the year due to heavy rainfall and very low evapotranspiration caused by foggy weather. Three soil temperature regimes viz. thermic, mesic and isofrigid have been identified here.

Thennic soil temperature regime: These soils are moderately shallow to deep, developed on steeply sloping hill side. They are well drained to somewhat excessively drained, fine-silty to fine-loamy soils with slight to moderate surface stoniness and moderate erosion. Soils are Typic Hapludolls, Cumulic Hapludolls, Typic Argiudolls and Typic Paleudolls. These show a considerable degree of profile development. They are associated with deep, well drained, strongly acidic, fine-loamy soils with slight surface stoniness and moderate erosion which are classified as Umbric Dystrochrepts and Typic Dystrochrepts. Land use is largely under cultivation of paddy and maize and partly under temperate forest. Soil acidity, soil erosion, surface stoniness are constraints.

Mesic soil temperature regime: These soils are shallow to moderately shallow, somewhat excessively drained, coarse- loamy with gravelly-loamy surface and severe erosion. They are moderate to strongly acidic and rich in humus. They are Typic Hap and Lithic Udorthents. They show a lack of profile development. They occur in association with Lithic Haplumbrepts. Associated soils are shallow, somewhat excessively drained, loamy-skeletal with slight surface stoniness and moderate erosion. They predominantly occur in North district of the state and cover an area of 91036 ha. rep resenting 12.83% of total area. Land use is largely under forest cover with very limited areas under maize cultivation. Soil erosion, soil acidity and stoniness are constraints.

Isofrigid soil temperature regime: These soils are shallow, somewhat excessively drained, loamy-skeletal with gravelly loamy surface, moderate surface stoniness and moderate erosion. They are classified as Lithic Cryorthents and Lithic Cryumbrepts. These occur in association with moderately shallow, somewhat excessively drained, loamy-skeletal, Typic Cryorthents. The soils dominantly occur in high relief, periglaciated land in North and West district of the State. They cover an area of 78464 ha. representing 11.06% of total area. Alpine pastures is the main land use. Soil depth and stoniness are constraints.

Moderately steep sloping hill sides (15-30%)

Thennic soil temperature regime: These soils are moderately deep to deep, developed on moderately steep slope. They are well drained coarse-loamy to fine-loamy soils with slight surface stoniness and moderate erosion. These soils are classified as Typic Hapludolls, Typic Argiudolls and Fluventic Eutrochrepts. They occur in association with moderately deep, well drained, fine-silty, Typic Haplumbrepts and Umbric Dystrochrepts with slight surface stoniness and moderate erosion. They are moderately acidic and medium in base saturation. They dominantly occur in East and South district. They cover an area of 15717 ha. representing 2.2% of total area. Land use is under cultivation of paddy, maize, ginger and fruits. Soil erosion and soil acidity are constraints.

SOILS OF VALLEYS

Valleys of Tista river are very narrow with moderately steep slope (15-30%). They experience a wide variation of climate. Southern area receives annual rainfall of 2500 mm (at Rango). Its soil temperature and soil moisture regimes are thermic and udic respectively. The northern portion experiences mild summer and cold winter. Soil temperature and moisture regimes are mesic and perudic respectively.

Thermic soil temperature regime: These soils are moderately deep to deep, developed on moderately sloping to moderately steep slopes on Tista bank. They are somewhat excessively drained, loamy-skeletal soils with slight surface stoniness and moderate erosion. These soils are classified as Cumulic Hapludolls, Typic Haplumbrepts. They are acidic and rich in humus. They occur in association with moderately shallow, somewhat excessively drained, coarse-loamy soils which are classified as Typic Udorthents. They occur in an area of 5448 ha. representing 0.77% of total land area. Land use is under cultivation of cereals and tropical fruits in southern part. Soil acidity and stoniness are constraints.

Mesic soil temperature regime: These soils are moderately deep, developed on moderately steep slopes on the banks of river Tista and its tributaries in North district. They are somewhat excessively drained coarse-loamy soils with slight stoniness and moderate erosion. They are Typic Haplumbrepts. They are associated with moderately shallow, somewhat excessively drained, loamy-skeletal Typic Udorthents. They cover an area of 3225 ha. representing 0.45% of total area. Land use is largely under temperate forests; some patches are under cultivation of cereals, potato and temperate fruits. Soil acidity, surface stoniness and soil erosion are constraints.

SOILS OF CLIFF AND PRECIPITOUS SLOPES

Thermic and mesic soil temperature regimes are identified on this physiographic unit.

Thermic soil temperature regime: These soils are shallow, excessively drained, loamy-skeletal with moderate surface stoniness and very severe erosion. They are classified as Lithic Udorthents and Lithic Haplumbrepts. Exposed rocks are very common. They cover 16692 ha. representing 2.35% of total area. Land use is permanent fallow. Soil depth, surface stoniness and soil erosion are constraints.

Mesic soil temperature regime: These soils are extremely shallow, excessively drained, loamy-skeletal with strong surface stoniness and very severe erosion. They are classified as Lithic Udorthents. They dominantly occur in periglacial region of North district. Ex posed rocks are common. They cover 69874 ha, representing 9.85% of total area. Land use is barren/alpine pasture. Steepness of slope and soil depth are constraints.

SOILS OF GLACIAL DRIFTS/ MORAINES/STONES

These soils comprise of moraines and boulders. They are shallow, excessively drained, loamy-skeletal with much surface stoniness and severe erosion. They cover 25468 ha. representing 3.59% of total area. Soils are Lithic Haplumbrepts and Typic Haplumbrpts. Land use is forest vegetation. Soil depth, soil erosion and steepness of slope are constraints.

SOIL SURVEY INTERPRETATIONS

The soil resource map of Sikkim on the scale of 1:50,000 has brought out the basic information on physiography, soils, their extent, characteristics and classification. The analysis of the data-base generated by soil resource mapping, reveals different classes of slope, internal drainage system, degree of soil erosion, soil depth and surface texture which are of consider able importance for effective land use planning (Das et al 1993).

SURFACE FORM

Surface form is the resultant of the present and past climate in the areas under natural condition. Land surface tends to change with human Intervention resulting in deformation of terrain. Six types of land forms have been identified in Sikkim. Among them steep to very steep land covers in maximum areas of 458222 ha (64.6%).

Table 4.2 Surface Form classes

Class	Area (ha)	(%)
i) Ridge	31459.4	4.4
ii) Moderate sloping land	16024.8	2.2
iii) Steep to very steep land	458222.0	64.6
iv) Valley	9683.4	1.4
v) Cliff	85700.3	12.1
vi) Miscellaneous land including snow cover	108510.1	15.3

SOIL EROSION

Soil erosion is one of the major soil degradation processes in hills. Steep lands with high rainfall are often subjected to soil loss by water erosion and land slides or land slips. Four erosion classes have been identified in Sikkim viz, slight erosion, moderate erosion, severe erosion and very severe erosion. They needs immediate attention for soil and water conservation. A total area of 7627.00 ha (1.07%) is under slight erosion. Severe to very severe erosion affects 103270.0 ha (14.55%). Coarse textured skeletal soils on cliffs and precipitous slopes are primarily subjected to very severe erosion. Nearly, 123504.0 ha (17.41%) are under moderate erosion, It needs appropriate soil conservation measures to check soil degradation process. Improper management of agricultural land and indiscriminate deforestation leads to soil erosion. Attention should be given to preserve vegetation cover on land surface of very steep hills for preventing further depletion of natural resources.

Table 4.3 Area affected by different classes of Erosion

Sl. No.	Description	Area (ha)	% of TGA
1.	Slight	7627.00	1.1
2.	Moderate	123504.00	17.4
3.	Severe to Very	103270.00	14.6
4.	severe Rock	43360.25	6.1
5.	Glacier& Misc.	108510.06	15.3

SOIL DEPTH

Effective soil depth is an important soil parameter which decides the type of vegetation and its performance. The occurrence of limiting layer in soil which is impenetrable to roots is indicated by introduction of term Lithic (Suggesting a soil depth of less than 50cm). Nearly, 151870.31 ha are covered by rock, glacier and river etc. Shallow soil groups (very shallow and shallow) occupy 173214.0 ha (24.40%). They dominantly occur on cliffs and precipitous slopes with thermic and isomesic soil tem perature regimes. Shallow soils have serious management problems and need to he preserved permanently under vegetative cover. Medium soil groups (moderately shallow and moderately deep) occupy maximum area in the State covering 258881.82 ha (36.48%). These soils need special care in management and selection of species suited to each category of soil for best land use. Deep soils cover an area of 125633.90 ha (17.71%). They dominantly occur on ridges and moderately steep hill side slopes. Deep soils on lower slopes can he brought under more intensive use with adequate management. Out of five soil classes, those affecting crop growth have been identified which call for special attention. Problem soils have been described in Table 5.3 and their proportionate distribution is given in Fig.

Table 4.4 Area affected by different classes of Soil Depth

Sl. No	Description	Area(ha)	% of TGA
1.	Very shallow	44239.4	6.2
2.	Shallow	128974.6	18.2
3.	Moderately shallow	140035.0	19.7
4.	Rock	43360.3	6.1
5.	Glacier & Misc.	108510.1	15.3

SOIL DRAINAGE

Internal soil drainage governs the air and water movement within the profile. Plant growth depends upon the drainage condition which also influences the growth of micro flora and fauna. Sikkim is wholly steep mountainous state. Poor and imperfect drainage condition is very uncommon here. Somewhat excessive drainage condition is observed in 258828 ha (36.5%). Well drained and moderately well drained soils cover 69600 ha (9.81%) and 5197 ha (0.73%) respectively. Excessive drainage occurs in 214105 ha (31.58 These differences in internal soil drainage call for a serious consideration in the proper planning of agricultural crops, tree crops, agro-forestry systems, plantations etc. The area covered by those drainage classes which adversely affect soil and crop management are given in Table below.

Table 4.5 Area affected by different classes of Drainage

Sl. No	Description	Area(ha)	% of TGA
1.	Somewhat excessive	258828.0	36.5
2.	Excessive	224104.7	31.6
3.	Rock	43360.3	6.1
4.	Glacier & Misc.	108510.1	15.3

SURFACE TEXTURE

Somewhat excess, Excessive Soil texture is a nearly permanent characteristic of soil. It has an important role in crop production from the stage of sowing seeds upto the maturity of crops. Out of four textural classes inventoried, those which hinder crop growth are described. They are sandy, gravelly loam and Rocky. The area affected by these textural classes are given in Table below

Table 4.6 Area affected by different classes of Surface Texture

Sl No.	Description	Area(ha)	% of TGA
1.	Gravelly loam	254359.8	35.9
2.	Sandy	1742.3	0.2
3.	Rock	43360.3	6.1
4.	Glacier & Misc.	108510.1	15.3

LAND CAPABILITY CLASSES

Land capability classes depict the capability of the soils for proper utilization of land on sustained basis. Soils in the state are grouped under six land capability classes (Table 5.6). Due to abrupt rise of landform from the drainage channel, lands of capability classes I - III are very rare. It is observed that majority of the soils can be grouped under IV - VIII class lands and it calls serious consideration in the proper use of land for tree crops, agro-forestry system, plantation and forestry.

Table 4.7 Areas under different Land Capability Classes

Class	Area	%
IIIe	16024.8	2.3
IVec	118956.4	16.8
Vec	41121.8	5.8
VIecs	124161.9	17.5
VIIcs	215124.7	30.3
VIIIcs	85700.3	12.1
Misc. and snow cover	108510.1	15.3

SOIL DEGRADATION

Assessment of Soil Degradation in Sikkim was done by GLASOD methodology. Soil degradation refers to adverse change in soil quality resulting in productive capacity due to human induced intervention like deforestation to meet the demand of increasing population. This has resulted in over exploitation of natural resources with little consideration of maintaining the eco-balance resulting in drought, ac celerated soil erosion etc. Such processes in turn reduce agri-productivity. For assessing the type and severity of degradation problem, a modified method (Sehgal and Abrol, 1994) is followed. Soil degradation status data for Sikkim show that out of 709600 ha. of total geographical area, about 234401 ha (33.03%) is affected by water erosion causing low, medium, high and very high severity class of degradation. Soils affected by water erosion causing loss of top soils occupy an area of 228331 ha (32.18%). Water erosion also results in terrain deformation of 6070 ha (0.85%).

Table 4.8 Status of Soil Degradation in Sikkim					
Soil Degradation	Degree of degradation				Total
	Slight	Moderate	Strong (‘00ha)	Extreme	
WATER EROSION					
Loss of top Soil (Wt)	7.627	123.504	91.34	5.86	228.331 (32.18)
Terrain deformation(Wd)	-	-	6.07	-	6.07 (0.85)
Total area(‘000 ha) (%)	7.627 (1.07)	123.504 (17.41)	97.41 (13.72)	5.86 (0.83)	234.401 (33.03)

Stable Terrain

Under natural conditions	214.979 (30.30)
Rock-outcrops & cliff	81.67 (1150)
Land with no degradation problems	88.19 (12.43)
Misc. area (Ice cap)	90.36(12.74)
Total area	709.6 (100.0)

Table 4.9 Severity of soil degradation in Sikkim					
Soil Degradation Type	Severity class				Total area
	Low	Medium	High (‘00ha)	Very high	(%)
Water erosion(Wt)	9.53	28.87	104.031	85.80	228.331 (32.18)
Terrain deformation(Wd)	-	-	6.07	-	6.07 (0.85)
Total area (‘000 ha) (Percent)	9.53 (1.34)	28.97 (4.08)	110.101 (15.52)	85.80 (12.09)	234.4 (33.03)

SOIL FERTILITY STATUS

The soil pH varied from 4.3 to 6.4. The organic carbon contain ranged from 0.36 to 5.6 while sand, silt and clay content of the soils were 55.098.0%, 7.0-29.0% and 4.0-24.0%, respectively. The available nitrogen, phosphorus and potassium content of the soils varied from 10.0-280.0, 4.0- 175.0 and 45.0-490.0 ppm, respectively. The total Zn, Cu, Mn, Fe, Band Mo content of the soil varied widely. The soils are rich in available Zn, Cu, Mn and Fe however; about 94% of the soil could be rated as deficient in available boron and 85% in available molybdenum. In order to correct the pH of he soil liming is being done. However with the application of enough organic manure and fertilizers also sowed improvement in Soil pH as well as the fertility status has also improved.

INTERGRATED TREATMENT OF LANDSLIDE AND SOIL EROSION IN SIKKIM

Whole state of Sikkim is hilly and cris-crossed by number of streams. Soi1 erosion is one of the major problems. Lots of nutrients are washed away along with soil. 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 the term landslide includes a wide range of ground movement, such as rock falls, deep failure of slopes and shallow debris flows.

Photo: Landslide Hazard for Communication

The proposed project draws its logic from the SIKKIK HUMAN DEVELOPMENT REPORT 2001, which states *"In a geologically fragile state like Sikkim, an integrated approach to landslide prevention is required. This should incorporate Afforestation in blank areas, checking run-off, souring as well as light engineering structures and the disposal of run – off through catch water drains"*

Forest Survey of India Report emphasizes the gravity of the problems and calls for a positive action. It says:

"The high intensity of rainfall in Sikkim often causes extensive soil erosion and heavy losses of nutrients of land by leaching. Sikkim being a hilly state with heavy rainfall, occurrence of landslide and erosion of land by water fall and river during heavy rains are quite common. In order to safe guard the human lives and natural resources of the State, flood protection works; waterfall training works and erosion works are necessary"

Photo: Slope Failure

Further National Bureau of Soil Survey and Land Use planning (Indian Council of agriculture Research) in its reports on soil of Sikkim mention the urgency of the situation. It states *"Soil erosion is one of the major soil degradation process in hills. Steep lands with high rainfall are often subjected to soil loss by water erosion and landslides or landslips. Four erosion classes have been identified in Sikkim. They need IMMEDIATE* ***ATTENTION*** *for soil and water conservation"*

The hydroelectric power generation is the thrust area of the Government of Sikkim. The health of the reservoir and dams would depend upon the silt load in the water from the catchment. In this scenario when lots of power development projects are coming in the state, it becomes imperative to work on Soil conservation for the long term sustainability of the power projects.

In the proposed project, attempt has been made to treat the landslides and soil erosion in an integrated way as they have a mutual relationship even though this may not be a direct one. The project envisages checking the erosion & landslides by way of engineering and biological measures. In addition, plantation has been proposed in the river source and surrounding area for overall environmental improvement. Although gravity acting over steeped slope is the primary reason for a landslide, there are other contributing factors such as

- Erosion by river glacier
- Rock and soil slopes are weakened by thorough saturation by snowmelt or heavy rain
- Earthquakes create stress that can make weak slopes fail
- Earthquakes of 4 and above have been known to trigger landslides
- Excess weight *from* accumulation of rain or snow, stockpiling of rock or manmade weight

The slope material that becomes saturated with water may develop a debris flow or mud flow. The resulting slurry of rock or mud may pick up trees and houses etc thus blocking bridges and tributaries causing flooding along its path. Landslides usually occur throughout whole of Sikkim but the areas that are generally prone to landslide are the ones having an existing old landslide.

Photo: ***Slope failure due to heavy surface runoff***

Landslides or slope movements in Sikkim can be classified in many ways. There are many attributes used as criteria for identification and classification including:

- Rate of movement: This ranges from very slow creep (millimeters /year) to extremely rapid (meters/second).
- Type of material: Landslides are composed of bedrock, unconsolidated sediment and/or organic debris.
- Nature of movement: The moving debris can slide, slump, flow or fail

  - Slide: movement parallel to planes of weakness and occasionally parallel to slope.
  - Slump: complex movement of materials on a slope; includes rotational slump.
  - Topple : the end-over-end motion of rock down a slope.
  - Fall : material free falls
  - Flow : viscous to fluid-like motion of debris.
  - Torrent : a sporadic and sudden channelized discharge of water and debris.

SOIL STRUCTURE AND GEOLOGY

Sikkim is a part of lesser Himalayan terrain of eastern sector. *Tectonostratigraphically it has been classified under for tectonic belts (i) Foothil belt (ii) Inner belt (iii) axial belt and (iv) transaxial belt.* The state is predominantly covered by the unfossliferous metamorphic and crystalline rocks grouped under the inner and axial tectonic belts. The inner belt is essentially made up of precambrain Daling and Darjeelling group of metasediments and minor development of Buxa group of rocks. The axial belt exposes the crystallines of Central region and intrusive granites. There are two predominant zones viz. gnessic and Daling group. The entire state is a young mountain system with highly folded and faulted rock strata at many places. It encompasses the lesser Himalayas, Central Himalayas and Tethys Hima1ays. Great mountains ranging from 3000 meters to 8500 meters in height separate the state from its surroundings. In fact, it has no flat piece of land of good size anywhere. Major portion is covered by the pre-Cambrian rock and is much younger in age. The rock type consists of phyllite and schists and therefore, the slopes are highly susceptibie to weathering and prone to erosion and landslides. The northern portion of the state is deeply cut in to steep escarpments. Southern Sikkim is lower, more open and fairly well cultivated. The western portion of the state is constituted of the hard massive gneissose rocks capable of resisting denudation. The southern portion is formed of comparatively soft, thin, slaty and half schist ore rocks, which denude very easily. The trend of the mountain system is in a general east west direction.

The southern and western portion of the state primarily consists of gneissose rock and half-schistose rocks. The soil developed form the gneissose group of rocks is a brown day, generally shallow and poor. They are typically coarse often with ferric concentrations, neutral to acidic with poor organic/mineral nutrients. They tend to carry most of evergreen and deciduous forest with Sal (Shorea robusta) as dominant species. The high intensity of rainfall often causes extensive soil erosion and heavy looses of nutrients of land by leaching.

An idea of the problem of the intensity of erosion can be judged from the reports of the forest Survey of India which says that in West Sikkim 7.13% of the area is heavily eroded, 10.95% of the area is moderately eroded and 74.85% of the area is mildly eroded. Similarly in South Sikkim 2.27% of the area is heavily eroded, 14.33% of the area is moderately eroded and 74.22 % of the area is mildly eroded.

Table 4.10 Statistics of Erosion

Sl. no.	Description	Area (ha)	% of TGA*
1	Slight	7627.00	1.1
2	Moderate	123504.00	17.4
3	Severe to very severe	103270.00	14.6
4	Rock	43360.25	6.1
5	Glacier and Misc.	108510.06	15.3

It needs appropriate soil conservation measures to check soil degradation process. Improper management of agricultural land and deforestation leads to soil erosion. Poor and imperfect drainage condition is very common in Sikkim. Somewhat excessive drainage condition is observed in 258828 ha (36.5%). Well drained and moderately drained soils cover 69600 ha (9.81%) and 5197 ha (0.73%) respectively. Excessive drainage occurs in 214105 ha (31.58%). These differences in internal soil drainage call for a serious consideration in the proper planning of agricultural crops, tree crops, agro-forestry systems, Plantations etc.

Soil degradation status data for Sikkim show that out of 709600 ha of total geographical area, about 234401 ha (33.03) is affected by water erosion causing low, medium, high and very high severity class of degradation. Soils affected by water erosion causing loss of top soil occupy an area of 228331 ha (32.81 %).

**TGA= Total Geographical Area*

CLIMATIC CONDITION

The climate of the state varies generally from sub-tropical to alpine depending upon the elevation of the place. Within the same catchment watershed of a stream, sub-tropical or even tropical climate is often observed at the lower end of the watershed in the valley, while temperate climate prevails inth eupper reaches of the stream. Climatically Sikkim experiences variable temperature with burning summers in the foothills to freezing winter on high mountains. The climate of the state has been roughly divided in to the tropical, temperate and alpine zones. For most period in year, the climate is cold and humid as rainfall occurs in each month. Temperature varies with altitudes and slope aspects- it generally decreases with increase in altitude. Three soil temperature classes have been identified- Thermic, Mesic and Isofrigid. Throughout the year the relative humidity remains above 70% in most of Sikkim. The area experiences a heavy rainfall due to its proximity to the Bay of Bengal The mean annual rainfall varies from 2000mm to 5000mm with intensity ranging from drizzling to torrential rain. Rainfall is heavy and well distributed from May to September during which July is the wettest month in most of the places. Rainfall is moderate in the months of April to October. It is generally low during the months of November to February. Rainfall pattern is essentially monsoonal. Due to wide variation of sharp edged mountains present throughout the state, there is a large variation of rainfall and temperature. There are two zones receiving maximum rainfall i) in South-East quadrant including Mangan, Singhik, Dikchu, Gangtok, Ronglli, Gnathang ii) In the south west comer including Hilley. In between these two regions there is low rainfall region viz. Namchi area. Rainfall in this area is half the former area. The state receives an average annual rainfall of 500 cm which is the highest in the Eastern Himalayas. The high intensity of rainfall causes extensive soil erosion and frequent landslides.

APPROACH AND METHODOLOGY

The approach to tackling the problem would consist of geological investigations and devising and testing a suitable, engineering, biological or bioengineering measure. Emphasis win be on social fencing but where urgently required some barbed wire fencing will also be done. Apart from landslide investigation and survey, the methodology of landslide treatment will be as below;

In the current project more emphasis is given on soil bioengineering since it is an excellent tool for stabilizing soil erosion. These methods are not, however, the only solution to erosion problems. *In* soil bioengineering methods, shrubs certainly have a draining and stabilizing effect, especially when they consist of pioneer plants that rapidly produce a root system of high tensile strength. Since some of theses plants have a limited life span on slopes (as compared to those growing at flowing water), woody successor plants are required to sustain and foster the plant population. The basic purpose of these bioengineering measures is to

- Reduce slope angle
- Reduce surface erosion (rills and gullies)
- Trap sediment
- Capture and utilize both surface and sub-s1Ulrface water
- Retard runoff
- Provide additional slope protection for critical areas above gullies
- Reconstruction of slope by refilling localized 0caHsed slump

Benefits of Soil **Bioengineering in Sikkim include**

- Projects usually require less heavy equipment excavation. As a result, there is less cost and less impact
- Erosion areas often begin small and eventually expand to a size requiring costly traditional engineering solutions. Installation of soil bioengineered systems whine the site problem is small will provide economic savings and minimize potential impacts to the road and adjoining resources.
- Use of native plant materials and seed may provide additional savings. Costs are limited to labor for harvesting, handling and transport to the project site. Indigenous plant species are usually readily available and well adapted! to local climate and soil conditions.
- Soil bioengineering projects may be installed during the dormant season of late fall, winter, and early spring. This is the best time to install soil bioengineered work and it often coincides time wise when other construction work is slow.
- Soil bioengineering work is often useful on sensitive or steep sites where heavy machinery is not feasible.
- Years of monitoring has demonstrated that soil bioengineering systems are strong initially and grow stronger with time as vegetation becomes established. Even if plants die, roots and surface organic litter continues playing an important role during reestablishment of other plants.
- Once plants are established, root systems reinforce the soil mantel and remove excess moisture from the soil profile. This often is the key to long-term soil stability.
- Soil bioengineering provides improved landscape and habitat values.

However, there are certain limitations of soil bioengineering namely:

- 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, hydromulching, or spreading of a protective layer of weed-free straw may be satisfactory and l*ess* costly than more extensive bioengineering treatments.
- On areas of potential or existing mass wasting, it may be best to use a geotechnically - engineered system alone or in combination with - soil bioengineering.
- Project areas require periodic monitoring. On highly erosive sites, maintenance of the combined system will be needed until plants have established.
- Established vegetation can be vu1nerab1e to drought, soil nutrient and sunlight deficiencies, road maintenance side cast debris, grazing, or trampling and may require specia1 management measures to ensure long-term project success.