POTENTIALITY OF BIOENGINEERING TECHNIQUES TO STABILIZE THE LANDSLIDES OF NAGARKOT AND TATHALI VDCs OF BHAKTAPUR

A DISSERTATION

Submitted to Central Department of Environmental Science

In partial fulfillment of requirements of Masters Degree in Environmental Science

Submitted by:

Prajjwal Babu Gongal

T.U. Regd. No.: 5-1-20-349-97

Exam Roll No.: 1719

Central Department of Environmental Science

Tribhuvan University, Kirtipur

Kathmandu, Nepal

TRIBHUVAN UNIVERSITY
(Institute of Science and Technology)
CENTRAL DEPARTMENT OF ENVIRONMENTAL SCIENCE
Kirtipur, Kathmandu, Nepal
Phone No.: 01-4332711, 4332147

Central Department of Environmental Science Kirtipur

Ref. No. **Date: June 3, 2007**

LETTER OF RECOMMENDATION

This is to certify that the dissertation entitled "Potentiality of Bioengineering Techniques to Stabilize the Landslides of Nagarkot and Tathali VDCs of Bhaktapur" being submitted to Central Department of Environmental Science, T. U., Kirtipur, Nepal by Mr. Prajjwal Babu Gongal in partial fulfillment of the requirement for the completion of Masters degree in Environmental Science is a bonafide record of work carried out by him under my supervision and guidance.

The results presented in this dissertation are original and has not been accepted for any other degree. I, therefore, recommend his work for the approval.

....

Prof. Dr. Siddhi Bir Karmacharya
(Supervisor)
Former Head
Central Department of Environmental Science
Tribhuvan University
Presently: Department of Botany
Tri-Chandra Multiple Campus, TU
Kathmandu, Nepal

TRIBHUVAN UNIVERSITY

(Institute of Science and Technology)

CENTRAL DEPARTMENT OF ENVIRONMENTAL SCIENCE

Kirtipur, Kathmandu, Nepal

Phone No.: 01-4332711, 4332147

Ref. No.

Central Department of Environmental Science Kirtipur

Date: June 26, 2007

LETTER OF APPROVAL

This dissertation prepared by Mr. Prajjwal Babu Gongal entitled **"Potentiality of Bioengineering Techniques to Stabilize the Landslides of Nagarkot and Tathali VDCs of Bhaktapur"** has been accepted as a partial fulfillment of the requirement for the completion of Masters Degree in Environmental Science.

Prof. Dr. Uma Kant Raya Yadav
(Head of Department)
Central Department of Environmental Science
Tribhuvan University
Kirtipur, Kathmandu, Nepal

Head of the Department

Prof. Dr. Siddhi Bir Karmacharya
(Supervisor)
Former Head
Central Department of Environmental Science
Tribhuvan University
Presently: Department of Botany
Tri-Chandra Multiple Campus, TU
Kathmandu, Nepal

Mr. Kabiraj Paudyal
(Co-supervisor)
Lecturer
Central Department of Geology
Tribhuvan University
Kirtipur, Kathmandu, Nepal

Dr. Dinesh Pathak
(External Examiner)
Lecturer
Department of Geology
Tri-Chandra Multiple Campus, TU
Kathmandu, Nepal

ABSTRACT

Bioengineering offers a number of opportunities that encompass environment friendly, sustainable, cost effective, easily available, highly adaptable, multipurpose in use, easily repairable, community participation, use of local resources and locally manageable to stabilize the landslides.

In Nepal, bioengineering is favorable because of its topography and fragility, climatic condition, national economy, availability of indigenous material, local human resources, and need for the protection of the natural environment.

The objective of this study is to suggest the appropriate bioengineering techniques to stabilize the landslides of Nagarkot and Tathali VDCs of Bhaktapur. The study is based on the field work, map work and the analytical methods for determination of geological, vegetation and physico-chemical parameters.

The study sites both the Nagarkot Phedi and Tathali Phaidhoka lie on the Midlands of Lesser Himalayan zone. They are the parts of the Hanumante sub-watershed of Bagmati watershed.

The Nagarkot landslide is the type of translational slide and the Tathali slide is the earthflow. The major causes of Nagarkot landslide are presence of fault above the site, extreme pore water pressure built on silty sand and the presence of streamlet and the prominent gulley. The major causes of Tathali earthflow are due to the distinct sediment profile of sand, silt and clay layers and the seepage above from the clay layers and the higher moisture content and human disturbance near to the base.

In Nagarkot Site, *Alnus nepalensis* (Utis) and *Schima wallichii* (Chilaune) have the highest densities i.e. 0.0166 individuals/m^2 and 0.0022 individuals/m^2 and relative densities i.e. 58.36% and 7.86% respectively. In Tathali Site, *Alnus nepalensis* (Utis) and *Melia azederach* (Bakenu) have the highest densities i.e. 0.0061 individuals/m^2 and 0.0029 individuals/m^2 and relative densities i.e. 53.26% and 25.06% respectively. The species diversity and species evenness are optimum on the both sites which refers to stability.

The Physico-chemical analysis shows that the soils of both the Nagarkot and Tathali sites are rich in nitrogen, phosphorus and potassium. These sufficient amounts of NPK and the other Physico-chemical parameters support that these sites are suitable for growing of the plants for the bioengineering purpose.

The site moisture factors (altitude, aspect, soil moisture content and others) indicate that the Nagarkot site is warm and dry whereas there is high tendency towards the damp site in case of Tathali. Hence, the plant species of bioengineering grown on the warm and dry site should be selected for stabilization of Nagarkot site and the plant species of bioengineering grown on damp site should be selected in case of Tathali.

Renovation and construction of Gabion retaining wall and backfilling, Stone pitching, Bamboo plantation, Tree plantation and Diagonal grass plantation are the proposed bioengineering systems to stabilize the Nagarkot landslide site. It costs about Rs. 4,61,962 for the implementation of these bioengineering systems. To stabilize the Nagarkot road side, the Tree plantation and the Diagonal grass plantation should be done on the both sides of the road.

Surface drain, Stone pitching, Gabion wall construction and backfilling, Jute netting, Grass seeding and Vertical grass plantation are the proposed bioengineering systems to stabilize the Tathali earthflow. It costs about Rs. 2,27,392 for the implementation of these bioengineering systems.

Bioengineering is the most appropriate and essential way to control the mass movements in the mountainous country like Nepal with fragile geology.

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Prajjwal Babu Gongal

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CHAPTER 1

1. INTRODUCTION

1.1 Background

The Himalaya is the most active and fragile mountain range in the world. It is a 'live mountain' with active tectonics. The inherently weak geological characteristics of the rocks make the Himalaya fundamentally very fragile. The combination of weak geology and a monsoonal climate makes Nepal vulnerable to the landslides.

Bio-engineering is the use of living vegetation, either alone or in conjunction with civil engineering structures and non-living plant material to stabilize slopes and/or reduce erosion. It offers a number of opportunities that encompass environment friendly, sustainable, cost effective, easily available, highly adaptable, multipurpose in use, easily repairable, community participation, use of local resources and locally manageable. Hence, in Nepal, bioengineering is the appropriate technique to stabilize the landslides because of its topography, climatic condition, national economy, availability of indigenous material, local human resources and need for the protection of the environment.

Bioengineering techniques must be used in an appropriate way so that the benefits outweigh potential disadvantages. Selecting the technique best suited to fulfill the required engineering function is an important step for the implementation of bioengineering system. In addition to that, the choice of plant species should be made with consideration that products are of potential use to local people as far as possible. Hence, the selection of appropriate bioengineering techniques to control the mass movement is the crucial task.

1.2 Bioengineering

1.2.1 Introduction

Bioengineering may be defined variously as " the use of living vegetation, either alone or in conjunction with non-living plant material and civil engineering structures, to stabilize slopes and/or reduce erosion; and the use of any form of vegetation, whether a single plant or collection of plants, as an engineering material (i.e. one that/has quantifiable characteristics and behaviour) (Morgan and Rickson, 1995).

Bioengineering is the use of living plants for engineering purposes (GEU, 1997). It is usually used in combination with civil engineering structures. It does not normally replace the use of civil engineering structures, instead of that; it offers the engineer a new set of tools.

The civil engineering structure controls the slope failure or erosion initially whereas the vegetation will increase in strength over time making bioengineering attractive over time. In bioengineering, the vegetation provides one or more of the roles of- Catching debris, Armouring the surface, Reinforcing the soil, Anchoring the surface layer, Supporting the slope or Draining the material.

Bioengineering protects almost all slopes against erosion, reduces the instances of shallow planar sliding and can be used to improve surface drainage and reduce slumping.

1.2.2 Potentialities of Bioengineering

The bioengineering technique offers a number of opportunities that encompass environment friendly, sustainable, cost effective, easily available, highly adaptable, multipurpose in use, easily repairable, community participation, use of local resources and locally manageable.

The potential advantages of ecoengineering can be summed up as follows: better performance, less cost, multiple benefits and better acceptance. Natural disaster prevention/ pollution control, tourism and recreation fees, production of marketable products and aesthetically pleasing and biodiversity conservation are the major benefits (Mitsch and Jorgensen, 1989).

The bioengineering

-Improves the environment.

-Limits the lateral extent of instability.

-Supplies useful product as thatch, fruit, firewood from the locally available materials as vegetation & rock and

-Provides seasonal employment opportunities and scenic and touristic value of the land.

Bioengineering techniques alone may be adequate on protection of shallow planar failure and erosion. However, it is more often closely integrated with civil engineering structures.

The potential uses of bioengineering techniques are as follows.

- Protection of bare soil areas, embankments, cut face slopes and bare surfaces of rehabilitated landslides.
- Stabilization of gullies.
- Rehabilitation of quarries, borrow pits and camp compounds.
- Protection against debris blocking side drains and coming on to the carriageway.
- Reduction of minor rock falls and debris creep.
- Protection of civil engineering structures.

1.2.3 Functions of Bioengineering

The six main functions of both civil engineering and bioengineering techniques of slope stabilization are as follows.

1. Catch eroded material moving down the slope due to gravity alone or with the aid of water as well.
2. Armour the slope against erosion from runoff and rain splash.
3. Reinforce the soil by physically strengthening its resistance to shear.
4. Anchor surface material to deeper layers by soil pinning to reduce mass movements at greater depths.
5. Support the soil mass by buttressing.
6. Drain the excess water from the slope.

The choice of stabilization techniques depends on an identification of the functions needed to stabilize and protect the slope.

1.2.4 Limitations of Bioengineering

i) It cannot stabilize deep seated slope failure.

ii) Suitable for the site where immediate heavy landslide is not possible for one or two seasons.

iii) Appropriate in the site where slope angle is less than 60 degree.

1.2.5 Suitability of Bioengineering in Nepal

Bioengineering is generally considered to be suitable for Nepal in its present stage of development, mainly because it offers more comprehensive solutions to a wide range of slope suitability problems when combined with appropriate civil engineering measures. There also appear to be cost reductions using locally available materials and skills. The introduction of bioengineering was made to augment the use of other civil engineering works, and thereby increases effectiveness (Dhakal et al., 1999).

In Nepal, bioengineering is favorable because of its topography, climatic condition, national economy, availability of indigenous material, local human resources, and need for the protection of the environment.

1.2.6 Bioengineering techniques

The main bioengineering techniques appropriate in Nepal are described as follows.

1. Planted grass lines: Contour/Horizontal

In this technique, grass slips (rooted cuttings), rooted stem cuttings or clumps grasses from seed are planted in lines across the slope or along the contour. They protect the slope with their roots and, by providing a surface cover, reduce the surface runoff and catch debris. The main engineering functions are to catch, armour and reinforce.

This technique can be applied on almost any slope less than 65^0. It is mostly used on dry sites, well drained materials where increased infiltration is unlikely to cause problems. It can be used on cultivated slopes less than 35^0 to avoid soil loss. It is essential for the cultivation on slopes greater than 35^0. Plants should be spaced at 100 mm centres within rows normally. Row spacings: slope < 30^0: 1000 mm; slope 30-45^0: 500 mm; slope > 45^0: 300 mm. The time to maturity is 2 seasons.

The main limitation of Contour grass lines is it can increase the infiltration rate to the point of liquefaction on poorly drained materials, particularly on steeply sloping, fine textured debris.

2. Planted grass lines: Downslope/Vertical

Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted in lines running down the slope or towards drainage lines. They maximize surface drainage by channeling runoff and minimizing infiltration. The main engineering functions are to armour against erosion, reinforce the slope and drain.

This technique can be applied on almost any slope less than 65^0. It is mostly used on damp sites and poorly drained materials where increased infiltration can lead to liquefaction of the soil. Plants should be spaced at 100 mm centres within rows normally. Row spacings: 500 mm. The time to maturity is 2 seasons.

The main limitation is runoff can become damaging on impermeable materials and grass plants can suffer from drought. Rills can develop down the side of the plant line.

Figure 1: Vertical grass plantation (Howell, 1999a)

3. Planted grass lines: Diagonal

Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted in lines diagonally across the slope. They armour and reinforce slopes effectively and can also drain and catch materials. This technique combines the best features of both horizontal and vertical planting in the majority of sites.

It can be applied on almost any slope less than 65^0. It is mostly used on poorly drained materials and also on damp sites. It should be used whenever there is doubt about the grass line planting system. Plants should be spaced at 100 mm centres within rows normally. Row spacings: 500 mm. The time to maturity is 2 seasons.

The main limitation is diagonal planting should not be used on the places where the specific advantages of horizontal or vertical planting patterns are critical.

4. Planted grass lines: Random planting

Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted at random on a slope. They armour and reinforce slopes with their roots and by providing a surface cover. This technique is particularly used in conjunction with standard mesh jute netting.

It can be applied on almost any slope less than 60^0 that allows grass planting. It is normally used with jute netting on slopes steeper than 45^0 and less than 15 metres in length where moisture is not a serious problem. Plants should be spaced at 100 mm centres normally (i.e. 100 plants per square metre). No spacing should exceed 200 mm.

The main limitation is random planting should not be used on the places where the specific advantages of horizontal, vertical or diagonal planting patterns are critical.

5. Grass Seeding

Grass seeds are spread evenly over the surface. This technique is often used in conjunction with mulching and jute netting. Grass seeding armours surfaces effectively and reinforces slopes after a few years of growth.

It can be applied on almost any bare site with slopes up to 45^0. It is mostly used on well-drained materials where increased infiltration does not increase the problems. The time to maturity is 2 seasons.

The main limitation is this technique gives none of the structural advantages of grass slip planting. Plants take longer to develop from seeds than from slips. The heavy rain just after sowing can wash the seeds off the slope or damage the very small seedlings.

Figure 2: Grass seeding, the seeds or grass seed heads are spread liberally over the slope. Ideally, the whole surface should be very lightly covered in seed material.

6. Turfing

Shallow rooting grass and the soil it is growing in, is placed on the slope. It is commonly used on gentle embankment slopes. Turfing armours slopes, it gives a complete instant surface cover. It can be used on gently sloping site (less than 30^0) and mostly used on well drained materials with minimal risk of slumping.

Turfing is relatively costly and creates equal bare areas at the source of the turf. There is a discontinuity between on turf and the under-lying material.

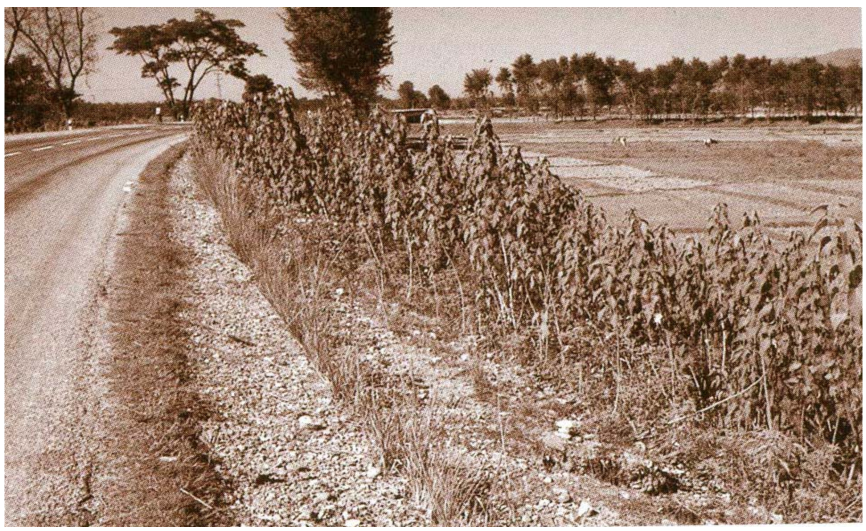


Figure 3: Turfing- It provides instant surface protection, as used on this road shoulder (the embankment has been treated with grass lines and brush layering).

7. Shrub and Tree Planting

Seedlings of shrub or trees are planted at regular intervals on the slope. Planting shrubs and trees reinforces and anchors the slope by establishing a community of larger plants. They also support the slope in the long term.

This method can be applied on almost any slope up to 30^0. It can be used on slopes between 30^0 and 45^0. Normally, a spacing of 1 x 1 metre is necessary, requiring 10,000 plants per hectare. Unless a different pattern is needed for specific bioengineering requirements, plants should be planted in off-set rows or in an appropriate manner.

The main limitation of this method is seedlings take about five years to contribute significantly to slope strengthening. Care and protection are required in the first three years. The grown up trees should be trimmed time to time up to certain suitable height which protects the slope as well as wood and fodder can be obtained. It is a part of conservation i.e. protection along with utilization.

Figure 4: Tree plantation of Utis- It is established enough to reinforce and anchor the roadside slope.

8. Shrub and Tree Seeding

Shrub or tree seeds are applied directly to the site. This technique allows very steep, rocky and unstable slopes to be revegetated where cuttings and seedlings cannot be planted. There are two methods: i) Direct sowing and ii) Broadcasting. In the first, seeds are placed individually whereas the second involves throwing the seed all over the site. These provide good reinforcement and anchorage on any slope, however rocky, establishing a community of larger plants.

This method can be applied on any steep, rocky or unstable sites. It is particularly useful on fractured rock slopes. Direct seeding can be practiced on very steep slopes up to about 60^0 and is rarely necessary to practice on slopes more gentle than 45^0. Broadcasting seeds can be done on any slopes up to 45^0, but is usually less successful on slopes steeper than 30^0.Seeds are normally sown or broadcast to give coverage of one plant every 250 mm, centre to centre. The actual seeding rate should be increased to three seeds for every plant required to give a reasonable survival rate.

Seedlings take about five years to contribute significantly to slope strengthening. Care and protection are required in early years.

9. Large Bamboo Planting

Large clumping bamboos are planted usually near the base of the slope. They are usually planted either by traditional planting method or by planted root cuttings from a nursery. They establish a very strong line of plants reinforcing, supporting the slope and catching debris moving down the slope.

Bamboos are planted mostly at the base of slopes and in gullies with slope segment less than 30^0. Individual bamboo is planted with space of 2-3 m intervals in a single row or in off-set rows and rows are 2 m apart.

It takes about five years for bamboos to strengthen the slope. So, protection is required in early years. Bamboos need cool, moist sites. They do not thrive on hot, dry and excessively stony sites. They can surcharge upper slope areas.

The fully grown bamboos should be harvested time to time so that it prevents from slumping as well as bamboos can be utilized. It is a part of conservation i.e. protection along with utilization.

Figure 5: Bamboo plantation: a stand of large bamboos can catch debris and support the base of a slope.

10. Brush Layering

Lines of woody cuttings are laid in trenches across the slope, usually following the contour. These form a strong barrier preventing the development of rills and trap material moving down the slope. Brush layering provides a very strong and low cost barrier especially on debris slopes. It armours and reinforces the slope, catches debris and if angled, helps to drain.

It can be widely applied on the sites up to about 45^0. It is particularly effective on debris sites, fill slopes and high embankments. This technique cannot be used on poorly drained materials and sites with high rates of small scale slumping.

Spacing depends on the steepness of slope. Slope < 30^0: 2m interval; Slope 30-45^0: 1m interval. Cuttings laid in double rows should be at 50 mm centres. It takes one season if planted early and watered, for maturity.

The main limitation is that construction gives rise to considerable level of disturbance to the slope.

Figure 6: Brush layering- The first layer of cuttings is laid along the terrace, with a 50 mm interval between the cuttings(far left); a second layer of cuttings is placed on top (above left); layers are positioned at 1 to 2-metre intervals up the slope (above middle) and small terraces are developed in the long term (above right).

11. Palisades

Woody cuttings are planted in lines across the slope, usually following the contour. Palisades provide a very strong and low cost barrier with minimum disturbance to the slope. They armour and reinforce the slope, catch debris and if angled, help to drain.

Spacing depends on the steepness of slope.
Slope < 30^0: 2m interval;
Slope 30-45^0: 1m interval.
Within the palisade lines, cuttings should be at centres of between 30 and 50 mm. It takes two seasons for the maturity of palisades.

Palisades are not as strong as brush layering.

Figure 7: A completed palisade (left) and a Simali palisade excavated after one growing season to show the development of roots (right).

12. Live Check Dams

Large woody cuttings are planted across a gully, usually following the contour. These form a strong barrier and trap material moving downwards. The main engineering functions are to catch debris, to armour and to reinforce the gully floors. They are effective low cost structure to reduce erosion in smaller gullies and can be used in between masonry check dams.

This technique can be used widely on the gully sites with slopes up to 45^0. Spacing between check dams depends on the steepness of the gully slope and the profile of the gully floor. Live check dams should normally be at intervals of between 3 and 5 metres. Within the check dams, cuttings should be about 30 to 50 mm apart.

Large and very active gullies require stronger measures than can be provided by vegetation alone.

Figure 8: Live check dams form a strong barrier on a wide range of gully sites, on slopes up to 45^0.

13. Fascines

Bundles of live branches are laid in shallow trenches in this technique. They put out root and shoots forming a strong line of vegetation. Fascines armour and reinforce the slope, catch debris and if angled, provide drainage and useful on a variety of sites.

They are best used on consolidated debris or soft cut slopes. The maximum slope is about 45^0. Contour fascines are used on well-drained materials and herringbone pattern is used to improve drainage. Spacing depends on the steepness of slope. Slope $< 30^0$: 4m interval; Slope $30\text{-}45^0$: 2m interval. Within the fascines, there should be at least four but no more than eight cuttings. The time to maturity is 3 seasons. Fascines do not form a physical barrier immediately as brush layers. Construction causes disturbance to the slope.

Figure 9: Fascines- They are effective on consolidated debris and put out roots and shoots which develop into a strong line of vegetation.

14. Vegetated Stone Pitching

Slopes are strengthened by a combination of dry stone walling or cobbling, and vegetation planted in the gaps between the stones. The two distinct uses are: 1) reinforced toe walls and 2) protected gully beds. This technique provides a very strong form of armouring and is particularly useful for gully floors carrying large flood discharges.

It can be applied on steep, low slope toe walls of up to 2 meters in height, and gully floors with a maximum slope of 45^0. Plants should be established at 250 mm centres initially, on a random pattern.

The main limitation is that over a large area it becomes costly. However, it's relatively less costly than many toe walls and other forms of gully control.

Figure 10: Vegetated stone pitching providing strong armouring

15. Jute Netting.

It is a temporary surface cover to aid grass establishment on very steep slopes. A locally made geotextile of woven jute netting is placed on the slope. Jute netting is of two types: 1) Standard mesh jute netting (mesh size about 40 x 40 mm) and 2) Wide mesh jute netting (mesh size about 150 x 450 mm). The first one is for the protection the surface, armouring against erosion, catching debris, holding and germination of seeds, improvement of microclimate and for mulching after its decay. Whereas, the second one in mainly used to hold mulch on slopes that have been seeded.

Standard netting is used on steep, hard slopes with slope angles of 45 to 60^0. Wide mesh netting is normally used on any site where plant seeds have been covered in mulch, with the slope angle between 30 and 45^0.

For the spacing of Standard netting, the affected area should be completely covered with netting, anchoring pegs spaced at 500 to 1000 mm centres. Whereas, in case wide-mesh, mulch is covered with netting and anchoring pegs are placed at 500 mm centres.

Standard mesh jute netting is a very effective aid to establish permanent grass cover on hard, dry materials on steep cut slopes. The main limitation is that if the material has poor internal drainage, it can lead to liquefaction as jute netting forms the mulch.

Wide mesh jute netting ensures the position of mulch on the slope with the seeds underneath germinate and establish a complete vegetation cover. Its limitation is that mulch cannot normally be held on slopes steeper than 45^0.

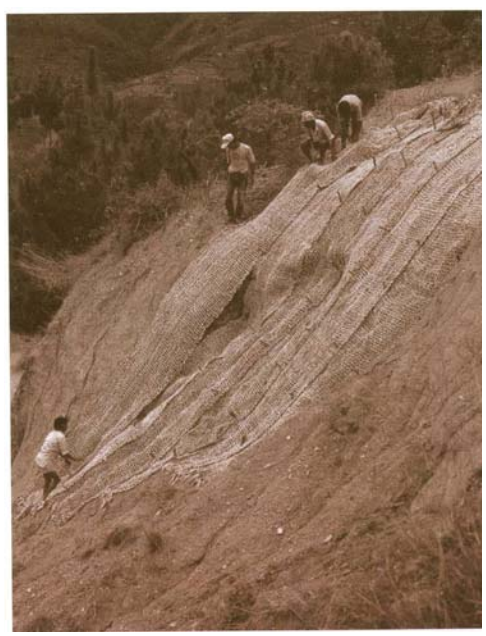


Figure 11: Jute netting to enhance the establishment of vegetation

1.2.7 Civil engineering techniques

The main civil engineering structures used for slope stabilization and erosion control in conjunction with bioengineering are as follows.

1. Retaining Walls

Retaining walls help to support the mountainside slopes, road or slope segments. They are designed to stop active earth pressure. Toe walls are considered to be a type of retaining wall found at the base of slope or slope segment. The general types of retaining walls and their characteristics are shown on Annex 15. However, the design must always be site specific.

Retaining walls function on any slope with deep seated (>500 mm) instability problem or where the steepness of the slope makes benching impractical.

Bioengineering techniques should be used in conjunction with retaining walls, according to site characteristics, as follows:

i) Protection of backfill,

ii) Protection from scour and undercutting of the foundations and sides.

iii) Flexible extension to the wall by planting large bamboos, shrubs or trees above the wall, increasing the catch function.

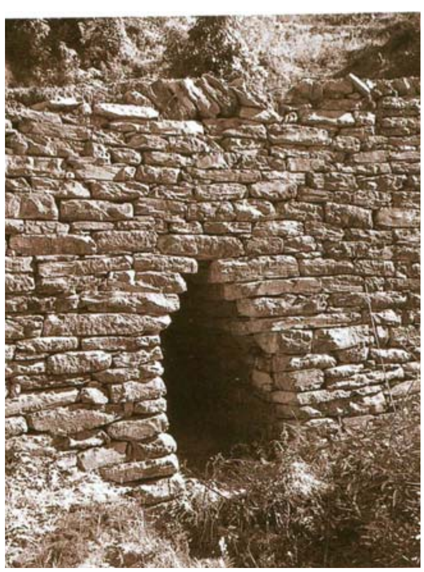


Figure 12: A dry masonry retaining wall with a scupper culvert (Howell, 1999a)

2. Revetment Walls

Revetment walls protect the base of a slope from undermining or other damage, such as grazing by animals. They are not used on large, unstable slopes, where substantial retaining structures may be required. Breast walls are the types of revetment walls.

They are constructed along the base of inherently stable cut slopes where seepage erosion can destabilize the base of large slopes; along the foot of abandoned spoil tips which have reached their angle of repose; along the foot of large fill sites.

Bioengineering techniques should be used in conjunction with revetment and toe walls as follows:

i) Protection of backfill,

ii) Protection from scour and undercutting of the foundations and sides.

iii) Flexible extension above the wall by planting large bamboos, shrubs and trees increasing the catch function.

Figure 13: A revetment toe wall, protected by grasses planted on the slope

3. Prop Walls /Dentition

Prop walls are used on very steep cut slopes to support blocks of harder rock where they are underlain by softer rock bands. They stop the erosion of softer bands below harder band supported on them.

They are constructed on steep cut slopes. This technique is particularly useful in bands of alternating hard and soft rocks, such as are common in the Churia ranges.

According to the necessity for additional protection, bioengineering techniques should be used as protection from scour and undercutting of the foundations and sides.

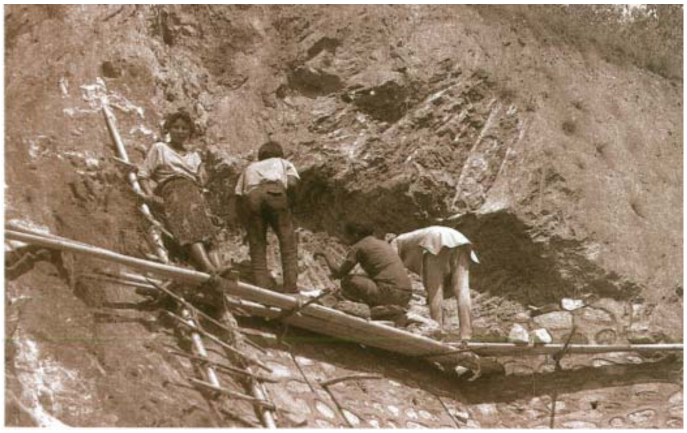


Figure 14: Construction of Cement masonry dentition wall to prevent undercutting of the upper part of a steep cut slope in differentially weathered gneiss.

4. Check Dams

Check dams are physical constructions to prevent the down cutting of runoff water in gullies. They ease the gradient of the gully bed by providing periodic steps of fully strengthened material.

Generally, check dams can be constructed on any slope where there is a danger of scour from running water. Particularly, they are used on any loose or active gully or in any rill that threatens to enlarge.

Bioengineering techniques should be used in conjunction with check dams as follows:

i) Protection of backfill and gully floor above check dam.

ii) Protection from scour and undercutting of the foundations and sides.

iii) Construction of live check dams between civil check dams, to reduce water velocity in the gully and improve stability or lining the gully bed with vegetated stone pitching.

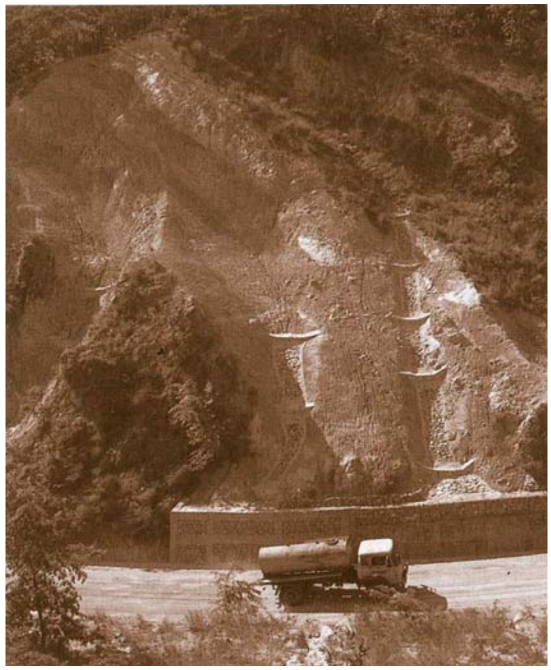


Figure 15: Check dams at frequent intervals- They are effective even in very steep gullies.

5. Surface and Sub-Surface Drains

Surface drains are installed in the surface of a slope to remove surface water quickly and efficient. Surface water drains often use a combination of bioengineering and civil engineering structures. Cascades are surface drains designed to bring water down the steep slope.

Sub-surface drains are installed in the slope to remove ground water quickly and efficiently. They can be installed to a maximum of 1 to 1.5 metres in practice. Sub-surface drains do not normally use bioengineering measures.

They are installed on any site less than 35^0. Certain drain types (e.g. drains using gabion wire) can be used on slopes up to 45^0. Cascades are normally used on slopes steeper than 45^0.

Figure 16: Stone-pitched surface drains on a wet landslide scar

The same site, two years later, following establishment of the protective grass cover between the drains

6. Stone Pitching

It is a strong stone covering which armours the slope with free drain withstanding considerable water velocities. It forms a strong and long-lasting method of reinforcing a slope surface and stopping gully development.

Stone pitching can be applied on any slope up to 35^0. It is particularly useful on slopes with a heavy seepage problem, in flood-prone areas or where vegetation is difficult to establish, such as in urban areas. It is also useful on gully floors between check dams and for scour protection by rivers.

Bioengineering techniques should be used in conjunction with stone pitching as follows which strengthens the stone pitching:

i) Planting grass slips in the gaps between stones.

ii) Inserting live cuttings of shrubs into the gaps between stones.

Vegetated stone pitching is an example.

7. Wire Bolster Cylinders

A gabion tube of 300 mm diameter filled with stone is laid in shallow trenches across the slope. Wire bolster cylinders form the strongest and long-lasting method of armouring a slope surface and preventing surface scour and gully development. Bolsters can be laid in two ways: (1) along the contour; or (2) in a herringbone pattern (slanted) to double as a surface drainage system.

Wire bolster cylinders are laid on most long, exposed slopes between 35^0 and 50^0 with risk of scour or gullying on the surface. Contour bolsters are used on well drained materials whereas slanted bolsters are used on poorly drained material with risk of slumping.

Appropriate bioengineering techniques should be treated in the spaces between the bolsters as soon as the subsequent rains have broken as follows:

i) Plantation of shrub and small tree seedlings between wire bolster cylinders at 1000 mm centres throughout the slope treated.

ii) Plantation or seeding with grass between cylinders
if a more complete surface protection is required.

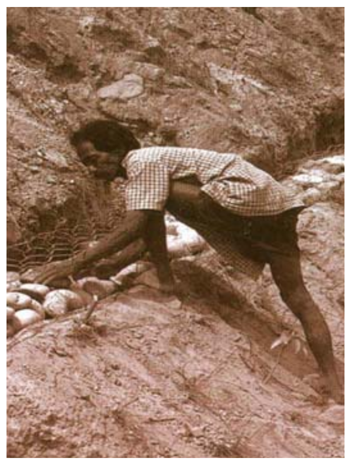


Figure 17: Construction of a wire bolster cylinder

8. Other civil engineering techniques

Wire netting, Cement slurry, Reinforced earth; Soil nailing and other civil engineering techniques can be applied according to site characteristics to stabilize the slope.

1.2.8 Relative strength of civil and bioengineering systems

As the relative strength of engineering structures decreases, the relative strength of plant structures increases.

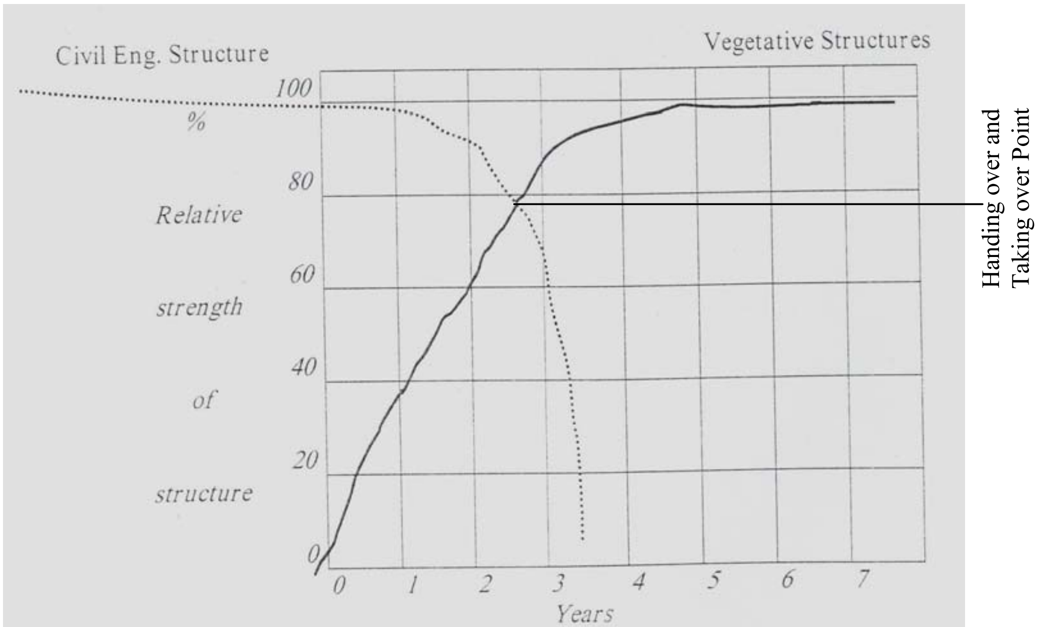


Figure 18: Life span of small civil engineering and vegetative structures (DSCWM, 2005)

The above graph relates to the performance of each type of structure separately. For example, Jute net and grass can both be used to perform a catching function. In the beginning, the fine soil retaining capacity of the jute net is very high and each small square behaves as mini check dam. With time the jute decays which weakens the net and consequently its soil retaining capacity decreases. Ultimately the net will fail to carry out any retaining function. The grass slips grow up with time and start to retain soil on the slope due to the development of root and shoot systems. When grass is fully grown, it stays at 100% relative strength. As the relative strength of the jute net declines the relative strength of the grass increases. The soil retaining function of the jute net is handed over to the grass. That’s how the civil engineering structure hands over the soil retaining/ protective function to the vegetative structure at handing over and taking over point and the slope becomes stabilized.

1.2.9 Steps for the Stabilization of Slopes

The steps required to implement the civil and bioengineering works for the slope stabilization are gradually as follows.

1. Make an initial plan
2. Prioritize the works
3. Divide the site or slope into segments
4. Assess the site
5. Determine civil engineering works
6. Choose the right bioengineering techniques
7. Design the civil and bioengineering works
8. Select the species to use
9. Calculate the required quantities and rates
10. Finalize priority against available budget
11. Plan plant needs
12. Arrange implementation and prepare documents
13. Prepare for plant propagation
14. Make the necessary site arrangements
15. Prepare the site
16. Implement the civil engineering works
17. Implement the bioengineering works
18. Monitor the works
19. Maintain the work

The annual calendar of Civil and Bioengineering works is shown on Annex 19.

Site Assessment is the most important step for the implementation of bioengineering technique. It consists of the determination of following factors.

1. Erosion and failure processes- The common types of erosion and slope failures are:

   a) Surface erosion

   b) Gully erosion

   c) Translational landslide

   d) Rotational landslide

   e) Slumping

   f) Debris fall

   g) Debris flow

The causes and dimensions of these failures should be determined.

2. Physical factors affecting the slope- The main potential physical factors affecting the slopes are as follows.

a) Fault lines	e) Landslides	i) Khet and kulo
b) Springs	f) River flooding	j) Construction activities
c) Slip planes	g) Catchments	
d) Large gullies	h) Drain discharge	

3. Slope angle- The slope angles should be recorded and the slope segments should be assigned of one of the three classes: a) $<30^0$ b) 30^0-45^0 c) $>45^0$. Slopes of less than 30^0 need only mild soil conservation treatment whereas others need more stabilization.

4. Slope length- A slope length of 15 metres represents a practical dividing line between 'big' and 'small' site segments. Slope segments longer than 15 metres are prone to greater risks of gullying and deep-seated failures. So, the slope lengths can be categorized as: a) <15 metres and b) >15 metres.

5. Material drainage- It relates to the internal porosity of soils and the likelihood of their reaching saturation, losing cohesion and starting to flow. Materials with poor drainage are prone to shallow slumping. It can be categorised as: a) Good drainage and b) Poor drainage; for the convenience, Annex 16.

6. Site Moisture- The entire site moisture regime must be considered although this can only be estimated in the field. Broadly, the sites can be categorised as: a) Damp sites and b) Dry sites. Annex 17 summarizes the main factors.

7. Altitude- It is the main determinant of temperature and regulates the local climate to a large extent. It is necessary to know for the selection of species for bioengineering works.

1.3 Landslide

1.3.1 Introduction

Landslide is the downward and outward movements of slope forming material along surfaces of separation (Varnes 1978). It is a quick mass wasting process. Terms such as mass movements, mass wasting, slope movement, slope failure, etc, are closely related to landslides. The various types of down slope movements of coherent masses of rock, debris or earth material either slowly or quickly due to the force of gravity are collectively known as "Mass wasting" or "Mass movement". Landslides consist of all varieties of slope-forming soils, rocks, artificial fills, or combinations of these, moving out and down the slopes; and often involving little or even no actual sliding over a long period of time, or sudden, and sometimes catastrophic, movements caused by gravity (Monkhouse 1988).

1.3.2 Types of Landslides

Varnes (1978) classified landslides on the basis of the types of movements and material.

Table 1. Classification of landslides (Varnes 1978)

<table>
<tr><th colspan="3" rowspan="3">Type of movement</th><th colspan="3">Type of material</th></tr>
<tr><td rowspan="2">Bedrock</td><td colspan="2">Engineering soil</td></tr>
<tr><td>Predominantly coarse</td><td>Predominantly fine</td></tr>
<tr><td colspan="3">Falls</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="3">Topples</td><td>Rock topples</td><td>Debris Topples</td><td>Earth topples</td></tr>
<tr><td rowspan="3">Slides</td><td>Rotational</td><td>Few units</td><td>Rock slump</td><td>Debris slump</td><td>Earth slump</td></tr>
<tr><td rowspan="2">Transnational</td><td rowspan="2">Many units</td><td>Rock block slide</td><td>Debris block slide</td><td>Earth block slide</td></tr>
<tr><td>Rockslide</td><td>Debris slide</td><td>Earth slide</td></tr>
<tr><td colspan="3">Lateral spread</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="3" rowspan="2">Flows</td><td rowspan="2">Rock flows (Deep creep)</td><td>Debris flow</td><td>Earth flow</td></tr>
<tr><td colspan="2">(Soil creep)</td></tr>
<tr><td colspan="3">Complex</td><td colspan="3">Combination of two of more Principle Types of movement</td></tr>
</table>

Movement types are divided into five main groups; falls, topples, slides, spreads, and flows and a sixth group of complex slope movement which includes combinations of two or more of the other types of movements. Materials are divided into two classes: rocks and engineering soil. Soil is further subdivided into debris and earth, based on the grain size (Varnes 1978).

1. Falls - Falls are abrupt movements of masses of geologic materials that become detached from steep slopes or cliffs by free-fall, bouncing and rolling. Rock falls are sudden and rapid free fall leaping, rolling and or bouncing of detached blocks and solid bed rock materials in very steep slopes especially cliff and in steep hillside following the law of free fall bodies. All types of falls are enhanced by undercutting, differential weathering, excavation or stream erosion.

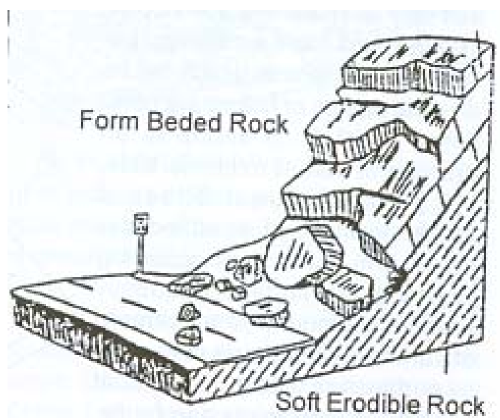


Figure 19: Rock fall (After Varnes, 1978)

2. Topple - A topple is the overturning or tilting of a block of rock on a pivot or hinge and then separates from the main mass falling on the slope. Toppling occurs when the weight vector, which passes through the centre of gravity of the block, falls outside the base of the block. The danger of a slope toppling increases with increasing slopes as well as discontinuity angle. Toppling is common in vertically jointed rocks.

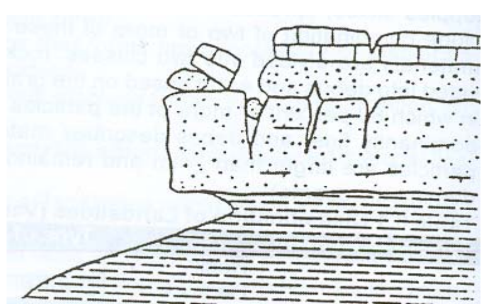


Figure 20: Rock Topple

3. Slides - Slides are movements of rock and or unconsolidated materials along a distinct surface of rupture or zone of weakness separating the slide material from the more stable underlying materials. The two major types of slides are rotational slides and translational slides.

i. Rotational slide - A rotational slide is one in which the surface of rupture is curved concavely upwards (spoon shaped) and the slide movement is more or less rotational about the axis that is parallel to the contour of the slope. It occurs on slopes of homogeneous clay or shale or soil slopes. The depth is usually greater than 1.5 metres.

Slump is an example of rotational slide. It occurs where material is poorly drained or has low cohesion between particles and liquefaction is reached. It is commonly caused by high ground water pore pressure deep in the hillside, and the slip circle usually goes several metres deep.

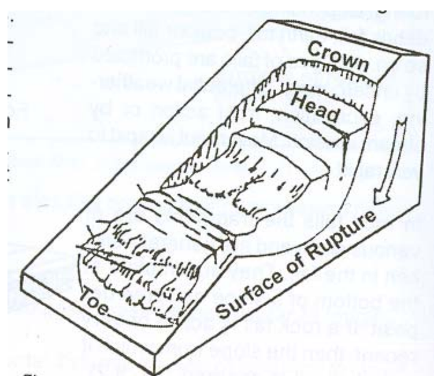


Figure 21: Rotational Slide (After Varnes, 1978)

ii. Translational slide - A translational slide is the downward and outward mass movement along a relatively planar surface. The mass involved in the movement becomes dislodged because the force of gravity overcomes the frictional force resistance along the slip surface.

Translational slide is frequently quite shallow (i.e. one metre deep or less). It can be caused by ground water pore pressure along a slide plane, or by weathering or undercutting of the slope. It can be shallow or deep, according to the structure of the superficial layers. Block slides are translational slides in which the moving mass consists of a single unit of rock block that moves down slope.

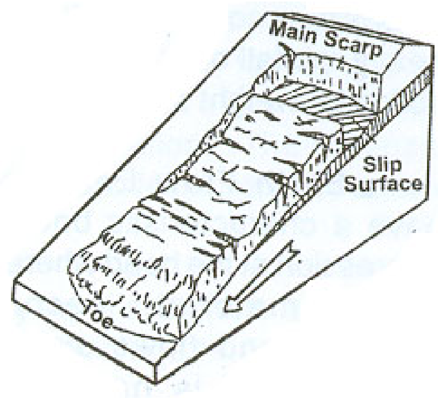


Figure 22: Translational Slide

4. Spreads- Spreads are the failures caused by liquefaction, the process whereby saturated, loose, cohesionless sediments (usually sands and silts) are transformed from a solid into a liquefied state.

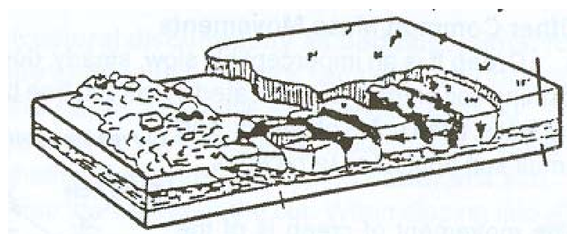


Figure 23: Lateral Spread

5. Flows- The various forms of flows are:

a) Creep- Creep is the imperceptibly slow, steady downward movement of slope-forming soil or rock which is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences and small soil ripples or terraces.

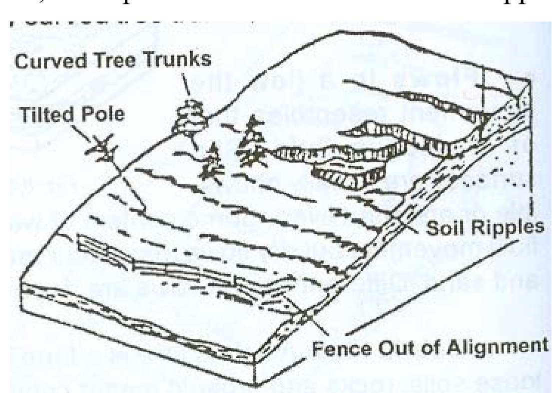


Figure 24: A Creep

b) Debris flow- A debris flow is a form of rapid mass movement involving high percentage of coarse fragments as loose soil, rocks and organic materials along with entrained air and water to form slurry. In gullies and small, steep river channels, debris flow can occur following intensive rain storms.

c) Earth flow- Earth flow is a process in which the cohesive or fine grained slope materials become liquefied and flows out leaving bowl like depression at the head. Earth flows are composed of clay-rich materials that swell when wet, causing a reduction in friction between the soil particles. When saturated, the fine-grained, clay-rich matrix may carry larger, more resistant boulders with them in slow, creeping movements. Slide materials erode easily, resulting in gullying and irregular drainage patterns. The irregular, hummocky ground characteristic of earth flows is generally bare of trees. Failures commonly occur on slopes that are gentle to moderate, although they may also occur on steeper slopes where vegetation has been removed. Undercutting of the toe of an earth flow is likely to reactivate downslope movement. The central area of earth flow is narrow and usually becomes wider as it reaches the valley floor.

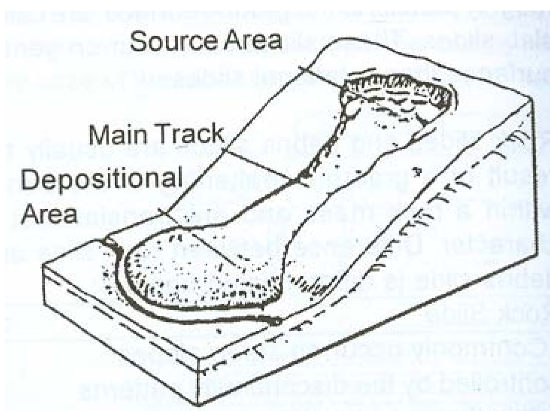


Figure 25: Earth flow (Varnes 1978)

d) Mud flow- A mud flow is an earth flow which consists of material that is wet enough to flow rapidly and that contains at least 50 percent sand, silt and clay sized particles.

6. Complex movements- They include two or more principal types of movements.

1.3.3 Parts of a Typical Slide:

a. Crown- The upper still in place from which solid rock and soil materials are torn away from the rest of the slope.
b. Scarp- The step wall of the undisturbed material below crown around the periphery of the slide material.
c. Head- The upper part of the slide material.
d. Slip Plane- The shear surface, the surface of movement down hill of the slide material.
e. Flanks- Side of a slide. Left flank- Right flank.
f. Transverse Ridges- Terrace or step like pressure or compression ridges.
g. Foot- The line of intersection of the lower part of the slip plane and the original ground surface.
h. Toe- The lower portion in which the rock or soil material is heaped up.
i. Length- Horizontal distance from crown to toe.
j. Width- Horizontal distance from flank to flank.
k. Height- Vertical distance from crown to toe.
l. Depth- Thickness of the slide mass between crown and foot.

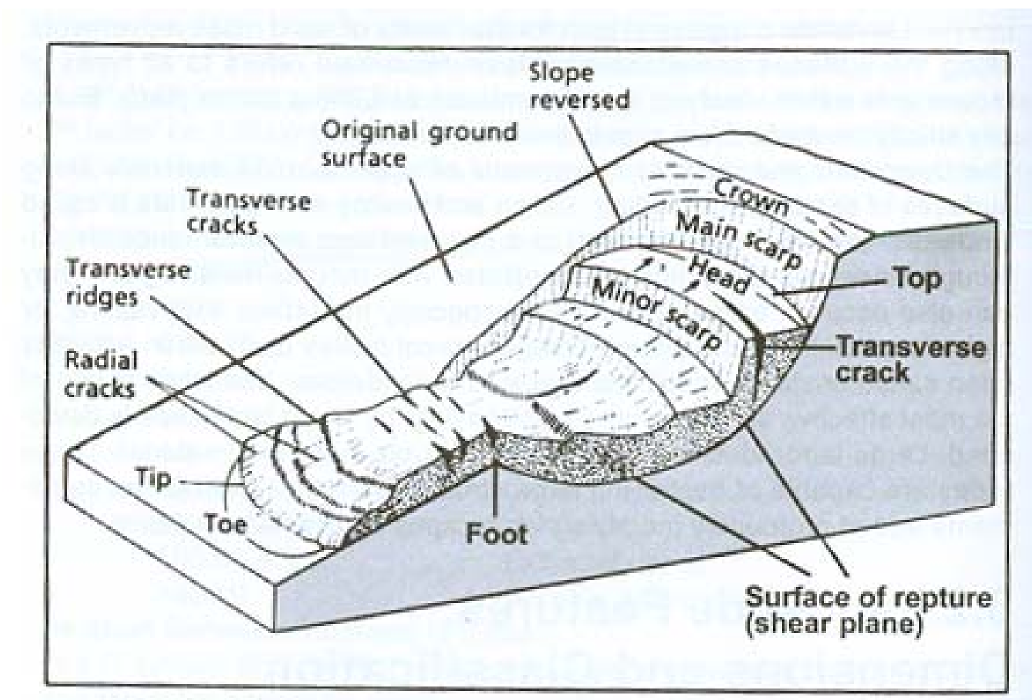


Figure 26: The Main Features of a Rotational Slide (After Varnes, 1978)

1.3.4 Causes of Landslides

The causes of landslides can be categorised as-

1. Natural factors- It includes:
   - High relief or steep slopes
   - Undercutting of the banks by deeply incised rivers and streams.
   - Extensive development of weak rocks such as phyllites, slates and schists, presence of calcareous inter layers in the rocks which leads to high porosity and void formation due to leaching and dissolution.
   - Heavily fractured rocks because of intense folding and faulting.
   - High weathering of rocks.
   - Concentrated precipitation.
   - Seismic activity

2. Anthropogenic factors- It includes-
   - Deforestation
   - Improper land use
     - a. Agricultural practices on steep slopes
     - b. Irrigation on steep and vulnerable slopes
     - c. Overgrazing and
     - d. Quarrying for construction material without considering the conditions of the terrain.
   - Unmanaged and improper construction activities

In another way, the causes of landslide can be grouped as:

1. Primary causes- Factors which are long-lasting and inherent in the constituent rock and soil. The important factors are gravity, rock and soil type and strength, rock structure (folds, faults, joints, foliation, bedding), soil depth, porosity and permeability.

2. Secondary causes (Triggering factors) - Factors which are variable or short lived. The secondary causes are seismicity, precipitation, land use, natural slope conditions, rock and soil weathering conditions, presence of gullies, streams and rivers and groundwater conditions.

1.3.5 Mechanisms of Slope Stability/ Landslide

The stability of the slope or the occurrence of landslide relates with two types of forces.

a. Driving force- Force which tends to move earth materials down a slope. The most common driving force is the downslope component of the weight, of the slope material such as vegetation, fill material, buildings. The causative factors of landslide increases the driving force.

b. Resisting force- Force which tends to oppose the down slope movement. The most common resisting force is the shear strength of the slope material acting along potential slip planes. It is the function of cohesion and internal friction.

Slope stability is evaluated by calculating the safety factor (SF). It is the ratio of the Resisting force to the Driving force. If the safety factor is greater than one, the resisting force exceeds driving force and the slope is stable. Instead of that, if the safety factor is less than one, the driving force exceeds the resisting force and the slope failure/ landslide occurs. Driving and resisting forces are not static; they tend to change with time. Thus, depending on the changes in local conditions, the safety factor may increase or decrease.

It can be shown mathematically by (Paudyal, 2005):

Driving Force (DF) = $w\sin\beta$ ---- (1)

Resisting Force (RF) = Shearing strength (τ)

We know, $\tau = C + \sigma \tan\Phi$

$\therefore$ RF = $CA + w\cos\beta \tan\Phi$ ----- (2)

Where, C = Cohesion,

β = Angle of inclination,

Φ = Angle of internal friction of the mass,

A = Area of block at the contact.

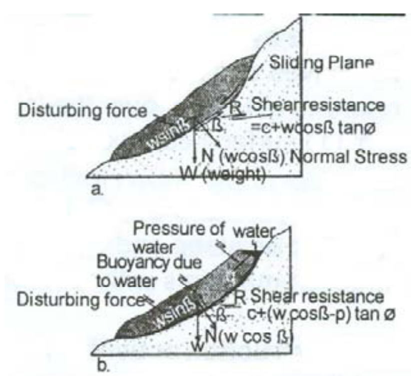


Figure 27:a. Relationship of Shear strength with Shearing stresses
b. Role of water for landsliding
(After Valdiya, 1987)

$$\text{Factor of Safety (FS)} = \frac{\text{Sum of forces available to resist failure}}{\text{Sum of forces tending to induce failure}}$$

$$= \frac{CA + w\cos\beta \tan\Phi}{w\sin\beta}$$

Conditions:

1. If RF = DF, FS = 1 i.e. Equilibrium condition

    i.e. $CA + wCos\beta\ Tan\Phi = wSin\beta$

2. If RF > DF, FS > 1 i.e. Stable condition

    i.e. $CA + wCos\beta\ Tan\Phi > wSin\beta$

3. If RF < DF, FS < 1 i.e. Unstable condition

    i.e. $CA + wCos\beta\ Tan\Phi < wSin\beta$

There are three main factors that play important roles in the fate of slopes.

1. Role of Geology: The orientation of the rocks in the slopes gives vital information about the stability of the slope. When the dip direction of rocks is towards the hill, the slopes tend to be more stable than when they are towards the face of the slope. The presence of folds and faults also determines the stability of slopes. Their presence greatly reduces the strength of the slope by making the fold materials highly shattered and weathered. Other factor deciding the fate of slope is the type of rock on the slopes. Hard rocks like Quartzite do not weather or break easily making the slopes highly stable, but slopes with rocks of soft and moderate strength like Shale, Mudstone, Phyllite and Schist readily break making the slopes highly vulnerable.

2. Role of Slopes: Steep slopes are more vulnerable to failure while slopes with hill slope angles less than 30 degrees are less vulnerable. The increase in the steepness of the slope increases the driving force which is given by the Sin angle and simultaneously decreasing the resisting force given by the Cos angle. But angle is not a deciding factor for all sorts of materials.

Most materials are stable up to a certain angle of slope, which is called the critical angle of slope or also called angle of repose. It varies from 35^0 for unconsolidated sediments to 90^0 for perfectly crystalline unjointed rocks. For jointed rocks, it may range from 60^0-90^0. Angle of repose is considerably important in determining the stability, which is why clayey soils can be stable at great angles whereas silty and sandy soil cannot be stable at greater angles.

3. Role of Water: Much importance is attached to the role of water- both surface and subsurface in causing mass movement. Water may act directly to reduce the shearing strength of a rock or soil mass in a number of ways. It may also play an indirect role in promoting the instability conditions for land masses. Some general cases are described below one briefly.

i. Water that percolates the soil and rocks move into the pores of the mass may uplift pore pressure and reduce the normal stress of the mass affecting its shearing strength adversely. The reduced shearing strength would be

$\tau = C + (\sigma - p) \tan\Phi$

Where, τ = Shearing strength and

p = pore pressure

ii. Water that accumulates at the back of a rock mass and inside the pores exert pressure reducing the factor of safety by increasing the driving force.

$$FS = \frac{CA + (wCos\beta - p) \tan\Phi}{WSin\beta + P}$$

Where, p = pore water pressure and

P = directed water pressure

iii. A different way by which water may weaken soil is by repeated change of state where its change from liquid to solid form results into increment of volume inducing a great amount of pressure when present in voids of cracks on rock surfaces.

iv. By acting as a lubricant, water helps the plane on the upper layer to slide over the base. It also helps this sliding by helping to wash out the cementing material that binds the two planes together.

Furthermore studies have shown that the strength of the soil affecting its behaviour on load bearing, compaction and tillage and root penetration tend to increase with increasing bulk density and decrease with increasing water content. One reason for this is that bonds that hold the particles together in structural units are weakened as more water is absorbed. Strength is imparted by bonds linking by crystals into packets and the packets into aggregation. These include Van der Waal's forces, attraction between oppositely charged surfaces, organic matter in various forms and inorganic cements.

The bond strength is reduced by water through the softening of cements and the increased separation of particles as water is absorbed. Two other mechanisms also affect the relationship between water content and strength. A negative pressure in its pore water may strengthen soil. Cracking acts in an opposite way to the general trend by weakening soil as it dries.

When a saturated soil is loaded its shear strength depends on whether the water is able to drain from as it consolidates. Under conditions where drainage is prevented, pressure will develop in water and the applied load will not be wholly supported by particles. On the other hand, if the drainage allows the pressure to dissipate, more of the load will be carried by the particles, which will then be under greater inter-granular stress at contact points, giving it greater shear strength.

1.3.6 Major Causative factors of Landslides in Nepal

1. Lithology-

It is one of the primary factors causing landslides. The most common types of mass rock movement in the Himalayas are rockslides, rockfalls, rock toppling, and wedge failure. Dhital (1991) described the common rocks and their susceptibility to respective slope failures.

- Fractured slate: This type is found in a large portion of the Midlands and breaks easily into long pencil shaped or small flat polygonal chips which cleave off the bed even in the dry season. Slate is susceptible to wedge failure, gully erosion and toppling.

- Interbedded Quartzite/Sandstone and Shale: These types of rock are found north of the MBT as well as inner part of the lesser Himalayas. The interbedding of resistant quartzite or sandstone with weak slate or mudstone contributes significantly to mass movement. Huge rockslides and smaller wedge failure are common.

- Interbedded Limestone/Dolomite and Slate: The most common types of mass movements on these rocks are rockslides parallel to the bedding/joint planes and wedges failures. Thick beds of dolomite fail along the discontinuity planes. On the other hand, rock fall is likely if the slope is steep.

- Massive Limestone, Dolomite, Marble or Quartzite: Under normal conditions, these rocks are quite stable but when strongly jointed, wedge failure or rock fall is possible.

- Interbedded Soft Sandstone and Mudstone: This type of rock is found in the Siwalik Zone. Occasionally, it forms high cliffs. Large-scale wedge failures and plane rockslides often occur in the wet areas and areas with deep gully erosion.

- Massive Granite, Gneiss and Crystalline Rocks: These rocks are found in the lesser and Himalayan zones. Generally, these rocks are quite stable. They form steep cliffs and narrow gorges. Rock falls, rock avalanches, boulder gliding, talus cones and wedge failures are seen at higher altitudes and along fault zones.

- Phyllite and quartzite Alternation: Generally, a thick succession of the phyllite and quartzite alternation is found in the midlands. Large anticlines and synclines with numerous small- scale folds also occur in this rock unit. The main mass movements associated with this rock unit are debris slides, wedge failures and gully erosion. Large- scale rotational slides may occur in the weathered or crushed zones.

- Deeply weathered Residual or Colluvial Soils: After rock weathering and disintegration, various kinds of soils are formed on slopes. Generally, transitional and rotational slides are common on these soils. If the slope is gentle (less than 25 degrees), it may be quite stable. However, depending upon the intensity of precipitation, gully erosion may occur and badlands may develop.

- Alluvial Soil: Alluvial soil is found along the riverbanks and in the proximal areas. It is of two types: the old consolidated (cemented) river terrace type and the recent terrace type with loose gravel and fines. Often, in the old terraces, vertical joint develop which may be toppling and fall. On both types of terraces, deep gully erosion, rotational and transnational slides also occur.

2. Rock Structure-

Numerous small and big landslides occur along the major thrusts and faults with several weak and crushed zones. Also, the orientation of folds, bedding, foliation and joints in the rock also play the major role in landsliding. The MFT, MBT and other active faults are characterized by the parallel alignment of small and large landslides.

3. Weathering-

Mechanical and Chemical weathering change the strength of rock and soil considerably. In many landslide events, chemical alterations, such as hydration and ion exchange in clay have contributed to trigger off the landslides (Zaruba and Mencl, 1982).

4. Geotechnical properties of soil-

The geotechnical properties of soil are the main factors contributing to soil slopes failures. Soil composition, depth, shear strength (which depends on density, cohesion, plasticity and angle of internal friction), porosity, permeability, grading, packing, moisture content and organic material content are some of the important geotechnical parameters for soil study. Genetically, the soils on the hill slopes of the Himalayas can be classified as colluvium and as residual soils, in addition to the alluvium found along the river and stream banks in the form of terraces.

Debris slides are observed in coarse-grained soils with steeper (35-45 degrees) slopes and rotational slides are characteristic of fine- grained and thick soils with gentler slopes (less than 35 degrees).

5. Groundwater-

Flowing groundwater exerts pressure on soil particles thus impairing slope stability. Flowing groundwater flushes out fine particles in fine sand and silt and the strength of the slope is reduced by the cavities formed in the process (Zaruba and Mencl 1982).

6. Precipitation-

Rainfall is one of the main factors controlling the frequency of landslides. Rain and melt water penetrate the joints and produce hydrostatic stress in the rocks. Rain increases the pore water pressure on soils and consequently decreases the shear resistance. Rainfall measurements have shown that recurrent slopes movements occur during periods of exceptionally high rainfall (Zaruba and Mencl 1982).

7. Monsoon and Rainstorm Events in Nepal-

The climate of Nepal is essentially controlled by monsoon winds and the physiography. The monsoon winds result from an inland low pressure that develops in summer and they are accentuated by a northward migration of air from the southern hemisphere. These are south to southwesterly winds, which carry moisture from Indian Ocean to Nepal (Nelson *et al.* 1980). The wet season is from June to September. Generally, in Nepal, the precipitation decreases from east to west during the summer monsoon whereas the winter monsoon shows the reverse trend. Approximately 80 per cent of the total annual rainfall occurs between June and September with relatively limited precipitation from November to February. Rains brought by these winds are characterized by strong seasonality, variation in the amount of precipitation and high intensity at lower altitudes.

Measured values of mean annual precipitation in Nepal range from approximately 250mm in the stations north of the Great Himalayas to over 3000mm in numerous other stations. The mean annual precipitation in the 114 stations considered was 1,627mm (Alford 1992). It is not uncommon for 10 days of the rainy season (Alford 1992). Such uneven distribution plays an important role in triggering landslides.

8. Natural Slopes-

Change in the slope gradient is one of the principal factors causing landslides. An increase in the slope gradient produces a change in the internal stress of the rock or soil mass and equilibrium conditions are distributed by an increase in shear stress (Zaruba and Mencl 1982). Generally, in the Nepal Himalayas, slope gradients between 30 and 40 degrees are most critical failures. However, landslides occur on gentler as well as on steeper slopes (Dixit 1994 a,b; Deoja *et al.* 1991; DPTC/TU, 1994 a,b).

9. Vegetation-

Vegetation plays a vital role in slope stability and the soil erosion process. Generally, the vegetation cover increases the shear strength of the soil with its root network and protects the slope from landslides. The hydrological and mechanical effects of vegetation on slope stability are shown on Annex 18.

10. Glacier Lake Outburst Floods (GLOF)-

A Glacier Lake Outburst Flood is a catastrophic surge of water and debris caused by the sudden outburst of glacial lakes. The transportation of sediments during a GLOF is exceptionally great and material is eroded from river banks, terraces, and slopes. As a result, several slope instabilities are triggered.

Some of the well recorded events in Nepal are the GLOFs along the Bhote Koshi-Sunkoshi (Zhangzangbo) in 1964 and 1981; and the GLOFs along the Arun River (1964) and the Tamur River (1980) (Mool 1995).

11. Earthquakes-

Movement of the earth's crust is accompanied by major deformations of the ground surface and destruction of mountain slopes (Zaruba and Mencl 1982). As the

Himalayan range lies in a high seismicity belt, landslides due to earthquakes are very common.

1.3.7 Effects of Landslides in Nepal

Landslides are very common occurrences in Nepal and are also one of the main natural hazards. Many hill slopes in Nepal are situated on or adjacent to unstable slopes and old landslides, which are reactivated from time to time. In Nepal, on an average 260 people lose their lives every year and about 30,000 families are affected annually. In 2002, from the mid July to late September, 52 districts affected by landslides and floods, 444 people were killed, about 44 were missed, more than 100 were injured, more than 55,000 families were affected (UNDP,2002).

Table 2. Loss of life and properties due to landslides and floods in Nepal, between 1992-1995 (UNDP, 2002)

	Average annual
Families affected (no.)	33,000
Persons killed (no.)	416
Persons injured (no.)	69
Houses damaged completely (no.)	6,100
Houses damaged partially (no.)	7,500
Cattle-shed damaged (no.)	89
Animal killed (no.)	6,700
Bridge damaged (no.)	127
Canal damaged (no.)	13
Drinking water project damaged (no.)	27
Irrigation project damaged (no.)	24
Office building damaged (no.)	159
School building damaged (no.)	3
Suspension bridge damaged (no.)	4
Temple damaged (no.)	1
Water mills damaged (no.)	49
Agricultural land loss (ha)	18,500
Total estimated amount lost (USD)	2,450,000

1.4 Geology of Nepal

The Himalaya is the most active and fragile mountain range in the world. It is a 'live mountain' with active tectonics. It is still rising and its rocks are under constant stress as the northward moving Indian Plate pushes against the more stable Tibetan block. This pressure forces the Himalaya to rise and move horizontally southward along major thrusts. The active nature of the range is also manifested in frequent earthquakes. The inherently weak geological characteristics of the rocks make the Himalaya fundamentally very fragile.

Nepal is situated in the central part of the Himalaya, which extends for about 2,400 km from the Punjab Himalaya in the west to the North Eastern Frontier Area or Assam Himalaya in the east. The middle strip of 820 km constitutes Nepal. Triggering factors such as rainfall and earthquakes make the mountains highly vulnerable to landslides and other mass-wasting processes. The combination of weak geology and a monsoonal climate makes Nepal unique in its vulnerability to landslides.

Nepal can be divided into eight distinct physiographic units (Hagen, 1969):

1. The Terai	5. The Midlands
2. The Siwalik (Churia) Range	6. The Fore Himalaya
3. The Dun Valleys	7. The Higher Himalaya and
4. The Mahabharat Range	8. The Inner and Trans Himalayan Valleys

Each of these units has distinct altitude, topography, climate and vegetations.

Geologically, Nepal can be divided into five major tectonic zones (Gansser 1964, Hagen 1969):

1. The Terai Zone
2. The Sub-Himalayan Zone (Siwaliks)
3. The Lesser Himalayan Zone
4. The Higher Himalayan Zone and
5. The Tibetan- Tethys Zone

Each of the tectonic zones is characterized by its rock types, age, metamorphism, structures and geological history.

The study sites lie on the Midlands of Lesser Himalayan Zone.

The Lesser Himalayan Zone

It is bordered to the south by the MBT and to the north by the Main Central Thrust (MCT). Three physiographic units i.e. The Mahabharat Lek, Midlands and frontal parts (southern part) of the Fore Himalaya belong to the Lesser Himalayan zone. The zone is made up of mostly of unfossiliferous metasedimentary and metamorphic rock such as shale, sandstone, limestone, dolomite, slate, phyllite, schist, marble and quartzite, ranging in age from Precambrian to Eocene. The rocks in this zone are highly folded and faulted, hence have developed very complicated structures.

The Lesser Himalayan zone of Nepal shows much variation in stratigraphy, structure and magmatism. Topographically, the Mahabharat range has rugged terrain but the Midlands, in contrast to other physiographic division exhibit a mature topography.

The main hazards in Lesser Himalayan zone are:

1. Landslide i.e. mainly slope failure and debris flow,
2. Soil erosion and
3. Toe cutting action of rivers.

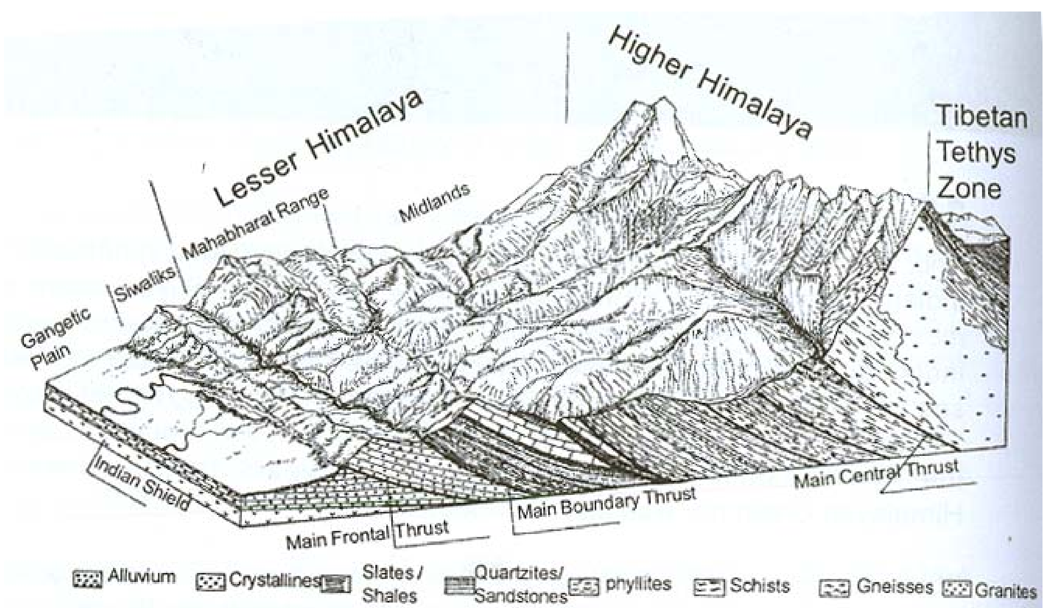


Figure 28: Physiographic and Geological Division of Nepal (After Dhital, 1991, ICIMOD)

1.5 Statement of the Problem

Kathmandu valley is one of the topmost fertile valleys in the world. The intense monsoonal rainfall and its geo-environment lead to the dominant hazardous process, mass wasting (landslide, earthflow) and the soil erosion. As a result, large amount of top fertile soil is being lost from the valley affecting the stability of slopes and the economic value of the land. Also, the physical infrastructures and properties are being damaged due to the landslides every year. In addition to that, a number of people have to lose their lives. In Nepal, on an average 260 people lose their lives every year and about 30,000 families are affected annually (UNDP Nepal, 2002).

Nagarkot is a popular hill station in Nepal. The study area lies on the way to the station. The road is very busy with high number of traffic and pedestrians. Due to the landslide, the road was blocked, six families were affected and the agricultural land downwards was also deteriorated. The landslide may create more adverse effects on the road, agricultural land and to the people. In Tathali site, there is the problem of loss of soil and the agricultural land becomes deteriorated.

To overcome such problems, it is necessary to identify and implement the landslide preventing and controlling techniques. Bioengineering is one of the most appropriate techniques for this.

1.6 Objectives of the Study

General objective

- Suggest the appropriate bioengineering techniques to stabilize the landslides of Nagarkot and Tathali VDCs.

Specific objectives

1. To identify the natures and causes of landslides.
2. To conduct the vegetation analysis.
3. To estimate the soil nutrients using soil quality assessment method (testing NPK).
4. To propose the appropriate small scale civil engineering and bioengineering systems for further stabilization of landslides.
5. To estimate the cost for bioengineering application.

1.7 Limitations of the Study

1. The scope of this study has been limited to a definite time frame as it is a part of academic degree of M.Sc. in environmental science.
2. The study is limited to the Nagarkot and Tathali VDCs of Bhaktapur.
3. During the geological study, the hydrometer analysis of the soil could not be performed for the fine size particles.
4. The grass/ herb vegetation is not considered during the vegetation study.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Bioengineering

1. Mitsch and Jorgenson (1989) reported the well known application of ecological engineering on watershed treatment, stream banks/shoreline stabilization and stream and riparian restoration.

2. Florineth and Gerstgraser (1998) stated that the time factor for implementing vegetation for slope stabilization works depends on the technique of the soil bioengineering measure and the type of plant. Cuttings and rooted plants should only be used during the dormant season and sodding techniques should be used during the vegetation season. Choosing the right method depends on various factors such as the position of slope, ground and available method.

The soil bioengineering measures described for the hill and slope stabilization in South Tyrol (Italy) and Austria are: seeding, slope planting, brush layering, drain and slope fascines, planted toe wall, live slope grid, live wooden cribwall, vegetated stone wall and vegetated gabion.

3. Barrett (1999) reported that ecological engineering holds great promise to provide better more cost-effective solutions to today's environmental problems. However, it requires new sets of skills and techniques which are still being developed. In this new philosophy, the engineer collaborates with nature to develop solutions to society's problems and needs.

4. Barker (1999a) described the use of bioengineered composite structures combining vegetation and inert materials for protecting and stabilizing very steep slopes (50^0-75^0) formed along highways in weathered granitic regolithic soils in the Inner Islands of Seychelles in Philippines.

The composite structures included vegetation installed on a range of techniques into galvanized wire mesh structures to form composite gabion retaining or toe walls (with rock or soil fill), rock mesh sheets for slope retention with coir blanket underlay, soil permeated rock fined revetments or reno mattresses, tubular gabions for gully backfilling, wire wedge structures or Terra fences, erosion control using coir blankets, fish-net retained organic waste materials together with slope grooming in combination with slope planting are other techniques which have been introduced. The paper briefly described the strategy adapted for implementation of landslide repairs.

5. Barker (1999b) introduced the humid tropics ground and water bioengineering techniques for erosion control and slope stabilization. It includes bioengineering studies and project work carried out in south and south East Asia over the last decade and work on highways in the tropics stretching over 35 years.

The rapid growth in the economies and the infrastructural development has created many opportunities for the bioengineering in the Asia-Pacific region over the last 10-15 years. Whilst landslides have closed roads and led to loss of life as well as loss of performance of public and private investments, bioengineering mitigating approaches and techniques have been adopted only slowly by owners and designers of transportation facilities.

6. Chant et al. (1999) described the importance of bioengineering in the rehabilitation design and selection of appropriate plant species for the bioengineering design and inexpensive plant propagation trails carried out in Philippines.

7. Hengchaovanich (1999) stated that the conventional 'hard' approach for solving the problems of rainfall induced erosion, shallow mass movement or deep seated stability problems is gradually giving way to 'soft' or 'bioengineering' approach due to concern over the degradation of the environment coupled with the fact that more knowledge on vegetation, especially from the engineering aspects, has now come on light.

The massive root system of Vetiver (*Vetiveria zizanioides*) (vertically downward up to 3-4 m depth and average tensile strength of 75MPa) increases the shear strength of soil, thereby enhances slope stability significantly in particular the shallow slip zone. Use of dead vegetation (e.g. Bamboo) as a soil-reinforcing element (similar to geogrid) in steep embankments to counter deep-seated stability problems is also described. The control of surface movement by grassing and/or leguminous cover crops and mitigation of shallow-seated instabilities (shallow mass movement) by shrub and tree planting is explained.

8. Huq (1999) stated that the ecological agriculture has proven that use of organic fertilizer, crop rotation and green manures and the recycling of crop residue increased the yield protect the soil fertility instead of chemical fertilizer and pesticides and is slowly improving the socio-economic condition of poor farmers of Bangladesh.

9. Khisa, Alam and Siddiqi (1999) gave a brief account of the botany, ecology, phenology, mode of propagation, cultivation, management and socio-economic aspects of broom grass, *Thysanolaena maxima* (Roxb)O. Ktze. The effect of broom grass hedge on soil conservation and slope stabilization was studied. They stated cultivation of T.maxima in hedges will protect soils from erosion, stabilize slopes and will thus protect the environment. Systematic cultivation will also ensure sustainable production and regular marketing and thus employment generation and poverty alleviation.

10. Samra (1999) based on the case study in India, stated vegetative barriers alone can be used in farming situations up to 4% slope keeping in view rainfall, agro-climatic niche and requirements of local communities. Beyond that, especially in high rainfall zones, they need to be supplemented with some structural measures up to 9 or 10% slope. Initial dose of mechanical measures help on quicker establishment of vegetation on mass eroded sites and later on vegetation conserves on sustainable basis.

11. Sauli (1999) discussed the possibility of transferring the most widely used soil bioengineering techniques- a list of which is given- from temperate climate areas to low-altitude areas both in humid tropical zones and in arid zones.

12. Shoaib (1999) synthesized the practical experiences based on the results/observation on bioengineering measures to control soil erosion, rehabilitation/stabilization of debris of degraded area due to landslide. It has been found that establishment of hedgerow along contour can arrest significant amount of

eroded soil, which is about 6 t/ha/yr with green bio-mass yield from hedge about 26 t/ha/yr against 42 t/ha/yr without any bio-mass yield from shifting cultivation. Small and medium gullies were successfully controlled by constructing cross barriers either by vegetatively propagated plants or earthen check dam with jute-geo textile treated with bitumen followed by vegetatively propagated plants/shrubs etc. (where only vegetative cross barriers are not suitable). Rehabilitation or quick re-vegetation of debris and geo-technically stable landslide area of road side by jute geo-textile (JGT) in Bangladesh environment is found effective and low cost.

2.2 Bioengineering and its study in Nepal

1. Carson (1986) found that an increasing population of soil loss is attributable to accelerated erosion induced by an increased population pressure on a limited land resource. Forest clearing, overgrazing, poorly maintained marginal arable lands and fire have greatly altered the natural vegetation of Nepal, leaving the soil open to degradation. Accelerated erosion has been characterized by the loss of topsoil by sheet and rill erosion.

2. Luintel (1994) emphasized on the effective people's participation in bioengineering technique as it is more labor intensive than mechanical and capital intensive. This technique is very useful in making the infrastructure sustainable by designing the developmental projects free from erosion and compatible with the environment.

3. Partap and Watson (1994) mentioned the findings of experimental trails on sloping agricultural land technology (SALT) by the International Centre for Integrated Mountain Development (ICIMOD) shows that biological soil conservation measures are quite effective in most cases.

4. Batajoo et al. (1995) mentioned that the bioengineering techniques play major role in the low cost stabilization of extreme slopes in the road sector of Nepal. The Department of Roads is currently expanding its capabilities. The use of indigenous large grass species planted in different configurations is becoming a simple and highly effective means for erosion control and also affects the shallow slope hydrology. The bioengineering works in combination with small scale, relatively low cost engineering

works are solving numerous erosion and shallow landslide problems. Its use will be expanded more over the next few years.

He also mentioned that the bioengineering has also been used to reduce erosion and protect other infrastructure in Nepal (eg Sthapit and Tennyson, 1990; Nepal SPWP, 1992). It was mentioned that the use of vegetation in slope stabilization (or bioengineering) on Nepal's roads has become well documented (eg Meyer, 1987; ITECO, 1990; Howell *et al*, 1991; ICIMOD, 1991; Shrestha, 1991; Clark, 1992; ERRM, 1993).

5. Shrivastava (1996) studied the physio-chemical properties of soil on Shivapuri and the erosion problem for soil conservation. Erosion of soil is inter-related with organic matter content. So, if organic matter in the soil is high, the soil is less susceptible to erosion. It also increases water holding capacity of the soil. For conserving soil, the soil should be properly covered with vegetation which provides organic matter to the soil by decomposition. It also increases infiltration capacity of the soil and provides nutrients to the soil.

6. DOR (1997) stated private planting (management) is the most direct and perhaps, the easiest way to maintain the bioengineering systems. The site is often close to farmers' house which is convenient for both the farmer and the project. There should be social fencing instead of barbed wire fencing.

7. Karmacharya (1997) mentioned that the concept of Bioengineering is not new for Nepalese people from time immemorial, only they may not be using in systematic and scientific way. Nowadays, private and public sector have realized the necessity of Bioengineering application along highway slopes and other landslide areas. The effort launched by DOR/HMG will ultimately reduce the maintenance costs of roads and stabilize the fragile slopes improving the environment. He added the importance of local people participations to achieve the goal.

He studied the role and function of grasses in the bioengineering process with growth relation to physiography and climate, method of plantation, engineering function of grasses and interaction of grasses with small civil engineering structures.

8. Dhakal et al. (1999) described the process by which the Department of Roads of His Majesty's Government of Nepal had introduced the use of bioengineering throughout the national strategic road network. The specific types of bioengineering used were outlined and the process of institutional development employed to introduce them throughout the national road sector was defined.

The introduction of bioengineering techniques has been made by use of demonstration, awareness-raising, information provision, training, budget programming and provision of technical advice. The use of bioengineering measures has now become routine in the road sector of Nepal.

9. Sharma (1999) documented the important indigenous techniques and their effectiveness to combat erosion and stabilize slopes in the hills and mountains of Nepal. Terracing is considered and the most effective technique. The indigenous bioengineering techniques such as vegetative techniques and farming system approach are also found effective to mitigate erosion and land slip problems. The widely used indigenous vegetation types include amliso (*Thysanolaena maxima*), kaans (*Sachharum spontaneum*), kettuke (*Agava Americana*), simali (*Vitex negundo*), sajiwan (*Jatrofa curcas*), baans (*Bambusa spp*), and utis (*Alnus nepalensis*) which are environment friendly and cost effective.

10. Karmacharya (2001a) stated that the selection of plant species for plantation in the site is very critically important. If the right selection of species is not done and haphazardly the plant species are planted, the result will be adverse i.e. negative instead of positive result expected. Therefore, it is highly recommendable to apply the prescribed bioengineering measures very carefully to get the positive results.

11. Karmacharya (2001b) described the role of Bhujetro (*Butea buteiformes*) in bioengineering technique. Bhujetro can be considered as the best example for the function of anchoring at different suitable sites, protecting the site from shallow and deep-seated movement to some extent, maintaining the environment. Most of the part of Dharan-Dhankuta road sector, Naubise-Pokhara road sector, Barhabise-Kodari road sector of Arniko highway and other road sectors of mid-hills are being planted by this species.

12. Regmi (2002) performed the engineering, geological study of landslides of Sindhupalchowk district, Central Nepal, lesser Himalaya and suggested the application of appropriate bioengineering system in stabilization of the landslides during the fulfillment of requirement for MSc. Geology, TU as dissertation.

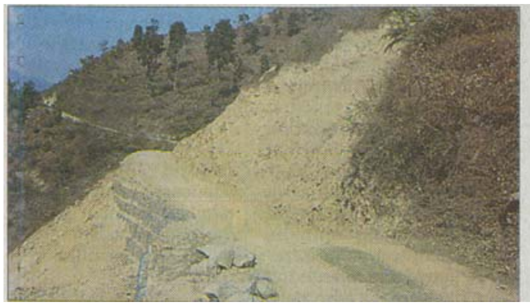
13. Government of Nepal, Ministry of Works and Transport, Department of Roads has published the guidelines of the Use of Bioengineering in the Road sector and studied in the sector of bioengineering more. Similarly, Ministry of Forest and Soil Conservation, Department of Soil Conservation and Watershed Management, Bagmati Integrated Watershed Management Programme, ICIMOD (INGO for mountain development) and MREU (Mountain Risk Engineering Unit with collaboration of ICIMOD and Geology Department, TU) have studied the sector of bioengineering a lot.

2.3 Some Bioengineering Practices in Nepal

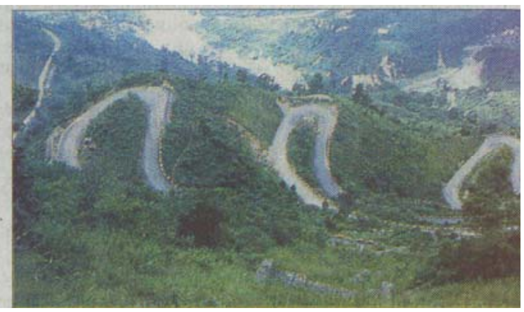
Sharma (1999) stated the general practice of applying more bioengineering techniques on the riser (kanlo) of bari land (sloping terraces where upland crops are grown), whereas such practices are not much applied to the riser (kanlo) of khet land (level terraces where low land paddy is grown). Hence terraces constructed on bari lands can be considered as a good example where bioengineering techniques have been applied.

The bari risers are used for growing various grass and non-grass species, including woody plants, used for fodder, fuel and building materials, medicinal herbs, brooming material, and thatch for roofing and mulching. The bari risers play a very important role to stabilize the slopes (Zurick, 1990). The traditional planting of bamboos is a great example of application of bioengineering technique for erosion control and slope stabilization. The existing indigenous techniques in the hills and mountains of Nepal that include largely bioengineering methods are centuries old.

Bioengineering is applied and found to be effective in controlling the slope failure along the roadside of different road sectors of our country such as Dharan- Dhankuta- Hile- Basantapur, Arniko- highway, Lamosangu- Jiri, Kathmandu- Naubise, Naubise- Mugling, Mugling Pokhara, Pokhara- Baglung (Karmacharya, 2000).




Sidhupalchowk before bioengineering | Sindhupalchowk after bioengineering

Dharan-Dhankuta road before | Dharan-Dhankuta road after


Road-shoulder before | Road-shoulder after


Ramechhap before | Ramechhap after

Figure 29: Some Bioengineering practices in Nepal (Shrestha, 2006)

Howell (1999b) stated that in Nepal, bioengineering is used more widely, on account of the extreme terrain conditions and the need for extensive low-cost techniques for protecting slopes and stabilizing shallow-seated failures.

Department of Water Induced Disaster Prevention, DWIDP (2004) has implemented Disaster Mitigation Support Project (DMSP) (from Sept. 1, 1999- 31 Aug. 2004) with the technical cooperation of JICA. To promote appropriate countermeasures for water induced disaster mitigation, DMSP has developed two model work sites. One is Girubari khola Sabo Model Site in Nawalparasi district and another is Dahachowk Sabo Model Site in Kathamandu district.

The main causes of landslide in the Dahachowk area are due to the combined effects of natural (rugged and steep topography, fragile geological conditions, soft and thin soil cover, high intensity rainfall in a short period) and human induced factors (unscientific land use practices, increased population pressure (overgrazing), extensive deforestation (bare land), lack of awareness, unscientific and unplanned development of infrastructures).

The landslide is controlled by the implementation of many structural countermeasures like check dams, drainage channel, earth removal and bioengineering works like plantation, nursery operation, bamboo fencing, jute netting and straw matting. Along with these, promotion and education of participatory disaster mitigation activities, cooperation and collaboration with users' group and warning and evacuation system are implemented.

Landslide area (April 2000)

Landslide area (August 2004)

Figure 30: Dahachowk Sabo Sites before and after use of Bioengineering (DWIDP, 2004)

2.4 Landslide Studies

1. Sharma (1966) studied the damage occurred on the Morang Hydroelectric powerhouse in the Chisang Khola by a landslide in 1964, since which time the unit is lying idle. The causes of sliding and was described and the effect and damage inflicted on the reservoir by the landslide was mentioned. The disaster could have been avoided if proper measures had been taken before the installation of the powerhouse.

2. Brunsden *et al.* (1975) prepared a geomorphological map of a part of the Dharan-Dhankuta Road (Leoti Khola-Mulghat sector). This map showed various unstable zones along the alignment. As a result, the originally proposed alignment was rejected and a new alignment, with several hairpin stacks on a relatively stable slope, was selected.

3. A considerable amount of land subsidence occurred in 1975 during the monsoon season. As a result, the building and approach road were severely damaged. In 1975, a part of Tahamalla Tole of Bhaktapur municipality was damaged by slumping.

4. Pandey (1976) carried out surface and subsurface investigations of the Swayambhu landslides and found that the weathering of the jointed sandstone, presence of strike slip faults, and presence of weak shale horizons in the section contributed to the development of slip circles due to the stress caused by the massive structure of the temple.

5. Kojan (1978) studied the landslide problems in Far-western Nepal along the Godavari to Dandeldhura Road.

6. Sharma (1981) reported that a landslide dam was formed at Labu Besi, Central Nepal, on August 1 1968, and it blocked the entire Budhi Gandaki River and created a 60m deep lake for 29 hours. After the breaching of dam, the debris flow and flood washed away most of the houses and bridges in the low lying areas. Arughat Bazaar suffered heavily; many lives were lost and property destroyed due to this incident.

7. Wagner (1983a) carried out a survey of erosion and instability potentials along parts of the Lamosangu-Jiri road and concluded that the geological structure, lithology, topography, and relief of the area were the predominant factors responsible for the debris and rockslide hazards along the road.

8. Wagner (1983b) studied more than 100 landslides along the roads, rivers, and hill slopes of South Central Nepal. He studied the geological, geomorphological, morphostructural, and groundwater conditions contributing to the occurrence of landslides in the area and prepared a hazard map.

9. Younger et al. (1984) studied the landslide along the Godavari-Dadeldhura Road in Far-western Nepal. They observed that rotational and planar slides, block falls, wedge failures, and gully erosion were common along the road alignment. They proposed a relationship among the rock type, weathering conditions, and type of landslide and also proposed various stabilization measures.

10. Dikshit (1985) studied the landslides of Dolkha District in Central Nepal. Most of landslides here were of the debris slide-debris avalanche types. The main factors causing these landslides were very steep slopes, high moisture content, deforestation, and unsound agricultural activities. He also recommended large-scale afforestation on the hill slopes.

11. Marui (1985) described the landslide situation in Nepal and conducted field surveys in a few prominent landslide areas. Ramsay (1986) reviewed existing information on hill slope processes including mass movements and erosion in the Nepal Himalayas. Zimmermann et al. (1986) studied the mountain hazards in the Khumbu Himal and prepared a mountain hazard map of the area on a scale of 1:50,000. Gurung and Khanal (1987) studied the slope failures on the Churia Range in Central Nepal. They analysed and evaluated the landscape processes and studied the cause and extent of failures in the region.

12. Marston and Miller (1987) studied the mass-wasting phenomena in the Manaslu-Ganesh and Langtang-Jugal Himal region. They applied the chi-square statistical procedure to test several hypotheses regarding the spatial distribution of the 272 mass

wasting scars and concluded that human activities do not account for a disproportionate share of mass wasting. Deforestation is prevalent, although the nature and extent vary from one region of Nepal to the next and, at the same time, devastating mass wasting is occurring. However, the logic linking these two phenomena could not be supported by the data in the study area.

13. Wagner *et al.* (1988) developed a computer progamme for rock and debris slide hazard mapping for personal computers. They concluded that rock and debris slides in the Nepalese foothills are directly related to the rock structure, topography, and hydrogeology of the slopes. They also subdivided the slope into 'rocky' (if steeper than 35 degrees) and 'non-rocky' (if dipping 35 degrees or less).

14. Karmacharya (1989) collected and analysed the data on landslides and evaluated the cost of damage by landslides in Nepal from 1970 to 1980. He also carried out a field study along the Butwal-Palpa Road in Western Nepal. He study indicated that most of the landslides along the road were triggered by river cutting.

15. Yagi *et al.* (1990) mentioned that in 1988, a huge landslide at Darbang (approximately 200km WNW of Kathmandu) killed 109 people and temporarily dammed the Myagdi Khola. The landslide occurred in the Main Central Thrust Zone. About 62 years ago, the same landslide had buried Darbang Bazaar and killed about 500 people.

16. Nepal (1992) studied the landslides in Kulekhani Watershed in Central Nepal and prepared land use, landslide distribution and hazard zonation maps.

17. The Department of Roads (DOR) carried out an environmental impact study of the Pokhara-Baglung Road and prepared geological engineering and hazard maps of the entire road alignment (DOR 1992).

18. Karmacharya (1993) studied the landslide at Bungamati, which was creating several problems by breaking the water supply pipeline during the rainy season. The landslide was studied by installing extensometers. The main cause of failure was porewater pressure developed by infiltration from a gravel layer. She suggested that

the pipeline be supported by constructing gabion pillars founded below the slip surface, of the shallow slide.

19. The damage caused by heavy rainfall in East Central Nepal during the period from 19^{th} to 21^{st} July 1993 was also assessed by Dhital et al. (1993), Dangol et al. (1993), UNDP/HMG (1993), and the World Bank/HMG (1994). There were numerous rock and soil slides, alluvial fans, and debris flows along the Tribhuvan Highway, Prithvi Highway, Kulekhani- Kunchhal Road, as well as instabilities along the stream and river banks and canals. The event had an adverse impact on the Kulekhani Reservoir and caused severe damage to the penstock pipe in Jurikhet Khola. The newly-completed Bagmati Barrage was also heavily damaged.

20. Ito et al. (1993) prepared a technical proposal for landslide control and management in the Hindu Kush-Himalayan Region for ICIMOD and concluded that the occurrences of landslide in HKH region is related to the fragile geology, high precipitation, deeply weathered rock material, unconsolidated soil characteristics, slope configuration and steepness, as well as human activities.

21. Shrestha (1990 and 1994) carried out landslide inventory mapping in parts of Mustang, Gorkha and Palpa districts and Shrestha and Shakya (1990) carried out a reconnaissance inventory survey along the roads and highways in the areas of Nuwakot, Dhading, Lamjung, Tanhun, Nawalparasi, Chitwan, and Makawanpur districts.

22. The Water Induced Disaster Prevention Technical Centre (DPTC) and the Central Department of Geology, Tribhuvan University (DPTC/TU 1994a, 1994b) carried out preliminary surveys on debris flows and landslides in Palung Khola and Manahari Khola in Makawanpur District, and Agra Khola, Belkhu Khola, and Malekhu Khola in Dhading District. The focus was mainly on the impact of the July 19-21 1993 disaster in the area. These studies are among the few comprehensive studies carried out on landslides and debris flows caused by high intensity precipitation in Nepal.

23. Upreti and Dhital (1996) focused on the landslides, causes and their mitigation. Review of landslide studies in Nepal is also done.

CHAPTER 3

3. STUDY AREA

3.1 Nagarkot Phedi Site

3.1.1 Location

The study area lies in the Nagarkot VDC of Bhaktapur district. Nagarkot is a popular hill station in Nepal and the study area lies on the right of the way to the station. It is situated between an altitude of 1460m and 1520m from the sea level. Geographically the area is bounded by latitudes $27^0 42' 14.92''$ N to $27^0 42' 28.37''$ N and longitudes 85^0 27' $38.05''$ E to 85^0 27' $40.1''$ E. Physiographically, it is the part of Midlands on the north eastern part of Kathmandu valley. Politically, the area is enclosed by Chhaling VDC on the west and Bageswori VDC on the south whereas the northern and western parts are the further continuation of Nagarkot VDC. Nagarkot road is a true representation of busy Mountain road of Nepal.

3.1.2 Accessibility

It is about 8 km north east from the Kamalbinayak bus park of Bhaktapur and 21 km east of Kathmandu. Regular bus services are available from Kamalbinayak, Bhaktapur (Kamalbinayak- Telkot route) and Kathmandu (Kathmandu-Nagarkot route).

The road to Nagarkot was metalled during the Coronation of the Late King Birendra Bir Bikram Shah Dev (1975 AD) so that the Royal guests coming from more than 100 nations would witness the most spectacular sunrise and sunset over the Himalayas, from the best vantage point (Gyawali, 2005). All the visitors should pass through the Telkot/ Nagarkot Phedi road to reach Nagarkot, one of popular destination for world tourists.

Nagarkot is a better location for unsurpassed view of Mt. Everest and the unobstructed panaroma of the Snow Mountains stretching from the Dhaulagiri in the west to Kanchanjunga in the east. Nagarkot is a popular holiday resort for the breathtaking sunrise over the gorgeous Himalayas and equally glorious sunset behind the beautiful Kathmandu valley. The spellbound view of the Indrawati river valley to the east and Kathmandu valley to the west is inevitably appreciable. The important religious and historical places are Mahadev Pokhari, Mahakal, Kalidevi Temple, Lhodim Khasyor Chhyorden Remborche Gumba, Panchakanya Temple and Jalpadevi Temple. Overall, the hill resort is equally popular among the tourists, dignitaries, diplomatic and Nepalese as well (Pradhan, 1995).

3.1.3 Geology

The study site, Nagarkot Phedi lies on Kulekhani Formation which belongs to the hard rock group (shown on Engineering and Environmental Geological map at Annex 6). It consists of greenish to grey biotite schist with schistose quartzite. It is relatively resistant to weathering. Quartz veins are present with some base metal mineralization. The thickness of this formation is up to 2000 m. A fault passes above the landslide which may be one of the major causes for instability and also for the occurrence of that slide.

The study site lies on the Bhimphedi series which consists of Phyllites, Schists and quartzites (shown on Geological map at Annex 7). It lies on the Midlands of Lesser Himalayan Zone.

3.1.4 Hydrology

The drainage pattern is dendritic (shown on drainage map of study area at Annex 2). A narrow streamlet (2.5 m width and 3 m depth) passes along the base of the slide which is originated from the Nagarkot hill and mixes with Tabyakhusi stream and then to Hanumante watershed which is the subwatershed of Bagmati river. The streamlet is ephemeral.

3.1.5 Climate

Nagarkot has sub-tropical to warm-temperate climate for four seasons generally. The spring or pre-monsoon (February to May) is windy, dry but pleasant with little or no precipitation. Summer or monsoon starts from June and ends around mid of the September. It is humid and hot with heavy rainfall. The autumn or post-monsoon starts from mid-September and ends the November. It is dry but sunny. The winter, November to mid-February is cool and foggy with short but sometimes precipitation. Sometimes the temperature drops below 0^0C and high peak Nagarkot is covered with snow for short period. The mean annual temperature is 18^0 C. Normally, the temperature of this area ranges from 2.6^0 C to 12.0^0 C in winter and 15.4^0 to 23.3^0 C in summer. The average total annual rainfall of Nagarkot is 2045 mm (average of 1972 to 1996, Nagarkot station at an altitude of 2173m).

Nagarkot is at higher altitude than Kathmandu city area so the temperature is lower than the city area. As this area stands in front of a mountain, wind blows in the morning and evening. In the winter season, sometimes snow falls for short period in Nagarkot. In the winter, temperature rarely drops below 0^0 C with short but heavy precipitation. Even in the hot season, one does not feel hot.

Figure 32: Nagarkot Phedi Site showing the road and gully at the base of landslide

Figure 33: Nagarkot Phedi Landslide and the debris

Figure 34: Small Landslide at the base of major slide

3.2 Tathali Phaidhoka Site

3.2.1 Location

The study area lies in the Tathali VDC of Bhaktapur district. The landslide is located on the hillock at Phaidhoka on the left side of Chyamasinha to Nala road. It is situated between an altitude of 1352m and 1392m from the sea level. Geographically, the area is bounded by latitudes 27^0 $40'$ $0.94''$ N to 27^0 $40'$ $1.43''$ N and longitudes 85^0 27' $35.95''$ E to 85^0 27' $36.51''$ E. Physiographically, it is the part of Midlands on the north eastern part of Kathmandu valley. Politically, the Tathali VDC is enclosed by Bhaktapur municipality on the east, Sudal VDC on the north, Chittapol VDC on the south and Kavrepalanchowk district on the west.

3.2.2 Accessibility

It is about 4 km east from the Chyamasinha bus park of Bhaktapur and 17 km east of Kathmandu. Regular bus services are available from Chyamasinha, Bhaktapur (Chyamasinha – Tathali- Nala route).

3.2.3 Geology

The study site, Tathali Phaidhoka lies on Gokarna Formation which belongs to the slightly consolidated sediment (shown on Engineering and Environmental Geological map at Annex 6). It consists of light to brownish grey; fine laminated and poorly graded silty sand. Intercalations of clay of variable thickness are present.

The study site lies on the Kathmandu valley deposit which consists of Mountain wash and Talus (shown on Geological map at Annex 7). It lies on the Midlands of Lesser Himalayan Zone.

3.2.4 Hydrology

The drainage pattern is dendritic (shown on drainage map of study area at Annex 5). A narrow streamlet (1.5m width and 20 cm depth) passes along the base of the slide which joins with Chakhu stream and then to Hanumante watershed which is the subwatershed of Bagmati river. The streamlet is ephemeral.

3.2.5 Climate

Tathali falls in warm-temperate humid climate zone. The average total annual rainfall of Tathali is 1502.57 mm (Department of Hydrology and Meteorology (DHM) average of 1972 to 1996, Bhaktapur station at altitude 1330m). More than 80% of the rainfall is concentrated during the four months of the year, June through September. The mean annual temperature is 18.2^0 C.

Figure 34: Tathali Phaidhoka Site showing the landslide and earth flow

Figure 35: Tathali Phaidhoka Site showing the landslide

Figure 36: Tathali Phaidhoka Site showing the earth flow and vegetation

CHAPTER 4

4. METHODOLOGY

4.1 Field Work

Geo-Environmental survey of the study sites was done. The geological study of the area along with the environmental consideration was carried out. The study of land mass, rock materials, drainage pattern, vegetation type, soil type and infrastructure was done. Route map of Nagarkot phedi road, 500m upwards and 500m downwards of the landslide site was prepared with the help of Brunton compass and measuring tape.

Detail study of landslides was done by field surveys and observations. Landslide assessment forms were filled up (form shown on Annex). Slopes were measured with Brunton compass and the length, breadths and heights were measured with the help of measuring tape. Schematic diagrams of the studied landslides were prepared and the sections of the slides were drawn. Vegetation study was also performed.

Field surveys/ visits/ studies were done on June, July, September, November months of 2005 and January, February and June of 2006.

4.2 Map Work

The landslide sites were marked on the topographic map. Following maps of the study areas were traced/ prepared with the help of following sources.

1. Topographic and Drainage Maps of Nagarkot and Tathali Sites.
   Source- Topographic map of Bhaktapur, Scale 1: 25000. Sheet No. 2785 06B
   Government of Nepal, Survey Department. First edition 1994.
2. Engineering and Environmental Geological map of the study area.
   Source- Engineering and Environmental Geological map of the Kathmandu valley, scale 1: 50 000, Kathmandu 1998
   Published by Department of Mines and Geology in Cooperation with Aundesanstalt fur Geowissenchaften und Rohstoffe
   (Federal Institute for Geosciences and Natural Resources, Hannover, Germany).

3. Geological map of the study area.
Source- Geological Map of Kathmandu valley, Department of Mines and Geology, 1966, scale 1: 63 360.

Following maps/ diagrams were prepared through field survey and observation.

1. Route map of Nagarkot Phedi Road, scale 1: 1000
2. Schematic diagram of Nagarkot Phedi landslide, scale 1: 500
3. Section of Nagarkot Phedi landslide, scale 1: 500
4. Schematic diagram of Tathali Phaidhoka earthflow, scale 1: 500
5. Section of Tathali Phaidhoka earthflow, scale 1: 500
6. Proposed Bioengineering techniques to stabilise Nagarkot Phedi landslide, scale 1: 500
7. Proposed Bioengineering techniques to stabilise Tathali Phaidhoka earthflow, scale 1: 500

4.3 Analytical Methods

4.3.1 Soil sampling

The spots were selected and 25 cm ‘v’ shaped ditch was made and 3cm slice was cut with the help of kuto. 500 gm of soil samples were thoroughly mixed and put in the polythene bag and tagging was done. Such samples are called as composite soil samples. It was immediately brought to the laboratory. Drying, grinding, and sieving of the composite soil sample were carried out. The soil was spreaded in the tray and was dried at room temperature for 2 to 3 days (air drying). Air dried samples were separately crushed under mortar. This sample was used in various physical and chemical analyses after appropriate sieving, specific to methods used.

4.3.2 Geo-Environmental Survey

Geo-Environmental survey is the geological study of the area along with the environmental consideration. It includes the study of land mass, rock materials, drainage pattern, vegetation type, soil type, infrastructure etc. The aim of geo-environmental survey is to have the state of risk information (vulnerability) on existing infrastructure as well as for the proper planning of the infrastructure to be built.

4.3.3 Principles

4.3.3.1 Geological Parameters

1. Soil texture

It refers to the relative proportion of various particles sizes in a soil. Clay particles affects the soil properties to a large extent than either silt of sand. That's why silt and sand are called skeletons of soils and clay particles are called the active portion of soil. The texture of soil horizon is its most nearly permanent characteristic but modified through the ploughing as it removes the surface horizon (Rai, 2002).

In a fine texture, there is tendency of higher nitrogen content. Water holding capacity and mineral availability to plants is greater in soils of moderately fine textured soil than in coarser one. To improve soil texture clay or compost had been added artificially for better plant growth. The texture plays an important role to increase organic carbon and available nitrogen and decrease phosphorus availability (Singh and Singh 1973).

2. Sieve Analysis

The soil is sieved through a set of sieves. Sieves are generally made of spun brass and phosphor bronze or stainless steel sieve cloth. According to IS: 1498-1970, the sieves are designated by the size of square opening, in mm or microns (1 micron = 10^{-6}m = 10^{-3}mm). Sieves of various sizes ranging from 80 mm to 75 microns are available. The diameter of the sieve is generally between 15 and 20 cm.

The sieve analysis is done for coarse-grained soils. The coarse-grained soils can be further sub-divided into gravel fraction (size>4.75 mm) and sand fraction (75μ< size <4.75 mm). The set of sieves, consisting of the sizes of sieve 2 mm, 1 mm, 600 μ, 425 μ, 212 μ, 150 μ and 75 μ is used for sieving the sand fraction. The selection of the required number of sieves is done to obtain a good particle size distribution curve. The sieves are stacked one over the other, with decreasing size from the top to the bottom. A lid or cover is placed at the top of the largest sieve. A pan which has no opening placed at the bottom of the smallest sieve.

(a) Dry Sieve Analysis

The soil sample is taken in suitable quantity according to the particle size. The larger the particle size, the greater is the quantity of soil required. Generally, 300 gm soil is taken if the particle size is less than 4.75 mm. The soil should be oven-dry. It should not contain any lump. If necessary, it should be pulverized. If the soil contains organic matter, it can be taken air-dry instead of oven dry.

The sample is sieved through a 4.75 mm IS sieve. The portion retained on the sieve is the gravel fraction and is sieved through the set of coarse sieves. The sand fraction (minus 4.75 mm fraction) is sieved through fine set of sieves (2 mm, 1 mm, 600 μ, 425 μ, 212 μ, 150 μ and 75 μ arranged as described above). The sample is placed in the top sieve and the set of sieves is kept on a mechanical shaker and the machine is started. Normally, 10 minutes of shaking is sufficient for most soils. The weight of the retained soil in each sieve and the pan is noted with the help of electronic balance and calculating the finer percentage according to size, particle size distribution curve is plotted on semi log graph paper. Dry sieve analysis is suitable for cohensionless soil, with little or no fines.

3. Particle Size Distribution Curve

The particle size distribution curve, also known as a gradation curve, represents the distribution of particles of different sizes in the soil mass. The percentage finer, N than a given size is plotted as ordinate (on natural scale) and the particle size as abscissa (on log-scale).The semi-log plot for the particle size distribution has the following advantages over natural plots.

1) The soils of equal uniformity exhibit the same shape, irrespective of the actual particle size.

2) A log scale is required as the range of the particle size is very large, for better representation.

4. Grading of Soils

The distribution of particles of different sizes in a soil mass is called grading. The grading of soils can be determined from the particle size distribution curves. The particle size distribution curves of different soils are shown on Annex 23.

A curve with a hump, such as curve B, represents the soil in which some of the intermediate size particles are missing. Such a soil is called gap-graded or skip-graded. The flat *S*-curve, such as curve A, represents a soil which contains the particles of different sizes in good proportion. Such a soil is called a well-graded/ uniformly graded soil. The steep curve, like C indicates a soil containing the particles of almost same size. Such a soil is called uniform soil.

The particle size distribution curve also reveals whether a soil is coarse-grained or fine-grained. Generally, a curve situated higher up and to the left (curve D) indicates a relatively fine-grained soil whereas a curve situated to the right (curve E) indicates a coarse-grained soil.

The uniformity of a soil is expressed qualitatively by a term called uniformity coefficient, C_u, given by (Arora, 1997):

$C_u = D_{60}/ D_{10}$

Where, D_{60} = particle size such that 60% of the soil is finer than this size;

D_{10} = particle size such that 10% of the soil is finer than this size.

D_{10} size is also known as the effective size. In figure of Annex 23, D_{60} and D_{10} for the soil A are respectively, 0.08 mm and 0.004 mm. Therefore, $C_u = 0.08/ 0.004 = 20$

The larger the numerical value of C_u, the more is the range of particles. Soils with a value of C_u less than 2 are uniform soils. Sands with a value of C_u of 6 or more are well-graded. Gravels with a value of C_u of 4 or more are well-graded.

The general shape of the particle size distribution curve is described by another coefficient known as the coefficient of curvature (C_c).

$C_c = (D_{30})^2 / (D_{60} \text{ X } D_{10})$

Where, D_{30} is the particle size corresponding to 30% finer.

For a well-graded soil, the value of the coefficient of curvature lies between 1 and 3. For the soil shown by curve A in figure of Annex 23, the particle size D_{30} is 0.025 mm. Therefore, $C_c = (0.025)^2 / (0.08 \text{ X } 0.004) = 1.95$

5. Uses of Particle Size Distribution Curve

The particle size distribution curve is extremely useful for coarse-grained soil. Its use for fine-grained soil is limited as the behavior of fine-grained soils (<75μ) depends upon the plasticity characteristics and not on the particle size.

1) The particle size distribution curve is used in the classification of coarse-grained soils.

2) The coefficient of permeability of a coarse-grained soil depends to a large extent on the size of the particles. An approximate value of the coefficient of permeability can be determined from the particle size.

3) The particle size is used to know the susceptibility of a soil to frost action.

4) The particle size distribution curve is required for the design of drainage filters.

5) The particle size distribution provides an index to the shear strength of the soil. Generally, well-graded, compacted sand has high strength.

6) The compressibility of a soil can also be judged from its particle size distribution curve. A uniform soil is more compressible than a well-graded soil.

7) The particle size distribution curve is useful in soil stabilization and for the design of pavements.

8) The particle size distribution curve may indicate the mode of deposition of a soil. For example, a gap-graded soil indicates deposition by two different agencies.

9) The particle size distribution curve of a residual soil may indicate the age of the soil deposit. With increasing age, the average particle size decreases because of weathering. The particle size distribution curve which is initially wavy becomes smooth and straight with age.

4.3.3.2 Vegetation Characters

Biotic community is defined as an assemblage of several populations (plants and/ or animals) living together with mutual tolerance/ adjustment. It is a complex assemblage of microbial community, plant community and animal community. Community characters are of two types: 1) Quantitative and 2) Qualitative. The quantitative characters include density, frequency and abundance.

Species is a natural biological unit tied together by the sharing of a common gene pool. Species diversity refers to the variety of living organisms on the earth. Simply, the variability of species within a community is called the species diversity of the community. Allopatric speciation and/ or sympatric speciation cause/s speciation and the development of species diversity..

Species diversity has three aspects or levels. They are as follows:

a) Species richness or species variety or species abundance: Species richness refers to the total number of species in a community. It is denoted by d or S.R. It ignores the commonness or rarity of the species.

b) Species equitability or species evenness: It refers to the relative abundance of species in a community. It is denoted by e. It depends on the apportionment of individuals among the species.

c) Species dominance: It refers to the most dominant species in a community. It is denoted by c.

Shannon- Weiner diversity index is one of the important indices for the determination of species diversity.

4.3.3.3 Soil Physico- Chemical Properties

1. pH

Technically, pH is the negative logarithm of activity of H^+ ions in the soil solution. Thus, each unit charge in pH represents a ten fold change in the activity of the H^+ and OH^- ions. Soil acidity is common in all regions where the precipitation is high to leach appreciable amounts of exchangeable bases from the surface level of the soils. In general humid regions soils dominated by silicate clays and humus are acidic. In the process of organic matter decomposition, both organic and inorganic acids are formed.

Soil alkalinity occurs when there is comparatively high degree of base saturation. The process of soluble salts of Ca, Mg, and Na carbonates also gives OH^- ions in the soil solution. Bacteria and actinomycetes generally found better in mineral soils at intermediate and higher pH values. As pH value drops below 5.5, fungi are versatile, flourishing satisfactory at a wide range of pH. The oxidation and N_2 fixation mostly occurs in organic soils at lower pH values but also takes place vigorously in mineral soils only at P^h value well above 5.5.

Texture of soils also controls the acidity. Particularly clay contents have been found directly proportional in relation to pH. The lower pH reduces the intensity of organic matter decomposition and nitrogen mineralization. For a better growth of plants in general a pH range of 6.5-7.5 is supplied to be ideal (Singh 1980).

2. Soil water: (Soil moisture)

Water is held in the soil pores with varying degrees of tenacity depending on the amount of water present and the pore size. When the soil moisture content is optimum for plant growth, the water in the large and inter-radiate sized pores can move in the soil and can be used by plants. The movement can be in any direction, downward in response to gravity, upward as water moves to the soil surface to replace that lost by evaporation and in any direction toward plant roots as they absorb the important liquid. Mostly, water movement in soils is from a soil saturated with water (High free energy) to a dry soil (low free energy). The clay soil holds much more water at a given tension level than does loam or sand, much of the water hold by clay soils is held so tightly that it cannot be removed by growing plants. As the soil dries, plants become to wilt during the day time, especially in high temperature and wind movement and the soil moisture content at this stage is called the wilting stage. Nitrification is markedly influenced by soil water content, the process being retarded by both very high and very low moisture condition.

3. Soil organic matter:

Soil organic matter comprises an accumulation of partially disintegrated and decomposed plants and animal residues and other organic compounds synthesized by the soil microbes as the decay occurs. The influence of organic matter on soil properties and consequently on plant growth, is for greater than low percentage would indicate.

Organic matter binds mineral particles into granules that are largely responsible for the loose (good aeration) easily managed condition of productive soils and increase the amount of water a soil can hold. It is a major source of phosphorous, and sulphur and the primary source of N_2 which is essential for plant growth. The various growth promoting compounds such as vitamins, amino acids and auxins are developed as organic matter decays and stimulated both higher plants and micro-organisms. It also increases the CEC (Cation Exchange Capacity).

4. Soil Nitrogen:-

Plant absorbs combined nitrogen in the form of NH_4^+ or NO_3^- ion from the spoil solution. N_2 fixing bacteria present in the nodules of leguminous plants converts atmospheric nitrogen into organic nitrogen compound. The main source of nitrogen is organic matter. 2 to 3 % N_2 present in organic matter is available to plants. Symbiotic fixation of N_2 varies widely and depends upon a number of factors like soil aeration, drainage, moisture etc.

N_2 is constituent of chlorophyll, amino acids, proteins, protoplasm, nucleotides, phosphatides and alkaloids and present in many vitamins, enzymes and hormones. Hence it is essential for plant growth.

5. Phosphorus

The main source of phosphorus in soil is apatide mineral. Soils contain some phosphorus in organic combinations such as phytin and nucleic acid which release phosphates on decomposition. The phosphorus availability is maximum when soil is neither acidic nor basic. Phosphate is a critical component of RNA and DNA. Both organic and inorganic forms of phosphorus occur in soils and both are important to plants as source of this element.

6. Potassium

Potassium is absorbed as K^+ ion. The main sources of K are potash bearing minerals in soil. Potash mica, biotite, muscovite etc. it plays a vital role in the synthesis of amino acids and proteins from NH_4^+ ions.

7. C: N Ratio

C: N ratio shows the state biodegradability. When C: N ratio is more than 35:1, it is susceptible to further and rapid decomposition and slow nitrification (Tamhane et al., 1970). The C: N ratio decreases on further decomposition of organic matter generally till 10:1 or lower.

4.3.4 Procedures

4.3.4.1 Geological Analysis

Soil texture

300 gm of grinded soil sample was put in the top most sieve, arranged in the standard series .then it was vigorously shaken through electric vibrator for 15 minutes which separates the soil into different groups according to sieve size. The content of soil retained in each sieve was weighed. With the help of Grain size analysis tables and graphs (shown on Annex), the soil samples were grouped according to laboratory criteria for unified soil classification system (Annex 22) and their characteristics were studied.

4.3.4.2 Vegetation Analysis

Total counting of all the individuals of the species was done. Representative samples of the species unidentified on the field were collected on polythene bags and later they were identified with the help of book by Shrestha (1998) and expert. The areas of the study sites were calculated by measuring the lengths and breadths. Then the densities, relative densities and species diversities are calculated by applying respective formulae mentioned as follows.

1. Density: Density is defined as the number of individuals of a species per unit sampling area. It can be calculated as (Zobel et al., 1987):

$$\text{Density of a species} = \frac{\text{Total no. of individuals of a species in a site}}{\text{Total area of that site}}$$

The unit of density is No.of individuals/ m^2.

2. Relative density: It is the density of a species with respect to the total density of all species under the study. It can be calculated as:

$$\text{Relative density (\%)} = \frac{\text{Density of a species in a site}}{\text{Total density of all species}} \times 100$$

3. Diversity index: Shannon- Weiner diversity index is one of the important indices for the determination of species diversity. It is given by:

$H = -\sum \frac{n_i}{N} \log \frac{n_i}{N}$ Where, H= Shannon-Weiner index, n_i = No. of individuals of species

N = Total no. of individuals of all the species

4.3.4.3 Physico-Chemical Analysis

For the analysis of soil samples, the manual of soil analysis by Pradhan (1996) published by NARC (Nepal Agricultural Research Council) and by Trivedi and Goel (1986) were used and the different parameter analyzed with their methods are given..

1. pH:

20 gm of the air-dried soil was taken in a clean beaker and 100 ml distilled water was added to it and stirred. pH meter (Digital pH meter, pH-008 High accuracy portable pH meter) was dipped into the soil solution and readings were taken. The pH meter was calibrated by using buffer solution.

2. Conductivity:

20 gm of soil was taken in 100ml of aerated distilled water so as to prepare 1: 5 soil suspension. The suspension was then shaken for one hour. The conductivity of the soil suspension was then measured with the conductivity meter (Digital Conductivity meter, Wagtech Company) by dipping the cell directly into the suspension.

3. Soil Moisture:

10 gm of fresh soil was taken in the porcelain basin and kept in an oven for 24 hours. The temperature was adjusted at 105^0C. The constant final weight of the soil sample was noted by cooling on desiccators. The hygroscopic soil moisture percentage is calculated as:

$$\text{Soil Moisture (\%)} = \frac{\text{Weight of fresh soil - Weight of dry soil}}{\text{Weight of dry soil}} \text{ X } 100$$

4. Organic Matter:

0.5gm of the soil sample was weighed which was passed through the 0.2mm sieve.10 ml of 1N $K_2Cr_2O_7$ solution was added to it in a 500 ml conical flask. 20 ml of concentrated sulphuric acid was added and mixed by gentle rotation for 1 minute, to insure complete contact of the reagent with the soil. The mixture was allowed to stand for 30 minutes. A standardization blank (without soil) was run in the same way. After half an hour, about 200 ml of distilled water, 30 drops of diphenylamine indicator and about 0.2 gm of orthophosphate was added to it. The solution was titrated with ferrous ammonium sulphate (FAS) solution. The color then changed from dull green to turbid blue. At the end point this color sharply shifted from to a brilliant green.

Calculation:

$$O.M\ (\%) = \frac{(B - S)\ X\ 3\ X\ 100\ X\ 100\ X\ 100}{Wt.\ of\ the\ soil\ X\ 1000\ X\ 77\ X\ 58} = \frac{(B - S)\ N}{Wt.\ Of\ soil}\ X\ 0.67$$

Where, B= Volume of FAS solution used up for blank titration

S= Volume of FAS solution used up for sample

N= Normality of FAS from blank titration

5. Total Nitrogen:

1gm of the soil was weighed and put in 50 ml Kjeldhal flask and 2gm catalyst digestion mixture followed by 10 ml concentrated sulphuric acid and few pieces of broken porcelain was added to it. 10 ml of distilled water was added and left for 30 minutes before adding digestion mixture and sulphuric acid for fine textured soil. The mixture was then heated in the low heat until frothing stops. The heat was gradually increased until the acid boils. The flask was swirled at intervals and digested until the color of the mixture changes to green-blue or gray color and continued it for 1-1.5 hours more.

The flask was cooled and about 20 ml of distilled water was added to it before the solution started to crystallize. The solution was then transferred to a 100 ml volumetric flask, leaving the sand in the digestion flask. 20 ml of aliquot was taken in the distilling flask and 20 ml of 40 % NaOH was added to it and is then distilled, collecting the liberated NH3 in 10 ml 4 % boric acid solution containing 2 drops of mixed indicator in 125 ml conical flask. It was then titrated with 0.01N HCL.

Calculation:

$$\%\ N = \frac{7\ X\ n\ X\ (T - B)}{S}$$

Where, n= Normality of acid

T= Volume of acid used in titration

B= Volume of acid used in blank.

S= Sample weight

6. Available Phosphorus:

The fresh soil was sieved through 2mm screen. Its moisture content was then determined by drying it in oven at 105^{o}c. The fresh sample was then taken equivalent to 1.0 gm of oven-dried soil in a conical flask and 200 ml of 0.02 N H_2SO_4 was added to it. The suspension was then shaked for ½ hour. Then it was filtered to get the clear soil solution.

To obtain the standard curve of absorbance vs. concentration, phosphate at different concentrations were prepared by diluting the stock solution at different strength. To 50 ml of each dilution, 2 ml ammonium molybdate and 5 drops of stannous chlorides ($SnCl_2$) solution was added. The solution was then left undisturbed for about 5 minutes to develop blue colonies. Within the absorbance was noted down at 690nm in the spectrophotometer. Then, 50 ml sample was taken in 1 clean conical flask. The colloidal impurities& colour were removed by the addition of activated charcoal. Then, 2 ml of ammonium molybdate & 5 drops of stannous chloride was added. The absorbance was noted after blue colour fully developed between 5 minutes-12 minutes time period usually within the same time as before. Then the concentration of phosphorus in sample soil solution was directly found out by plotting the absorbance of the sample against the standard curve prepared earlier.

Calculation:

$$\%\ \text{available P} = \frac{\text{mg P/L soil solution}}{50}$$

Phosphorus (P_2O_5) in Kg/ha = Ppm Phosphorus in Soil X 2.24 X 2.3

where, Ppm Phosphorus in Soil =Ppm Phosphorus in Solution (from std. curve) X 100

7. Exchangeable Potassium:

Exchangeable potassium was determined in ammonium acetate following flame photometric method by using the reagents:

a) Ethyl alcohol, 40%, b) Absolute Alcohol and c) Ammonium acetate solution 1N

50g of air dried soil was taken in 500ml beaker & added about 100ml of 40% alcohol. It was shaken well & kept for 15 minutes. The suspension was filtered through Whatman No. 50 filter paper using Buchner funnel & vacuum pump. The soil was washed 4-5 times with 50ml portions of 40% alcohol. The final washing was performed with 50ml of absolute alcohol to dry the soil. The filter paper was removed & scarped the soil in 250ml beaker. The Buchner funnel & filter paper was washed with 100ml ammonium acetate solution for removing any adhered portion of the soil. The soil extract was prepared by leaching with 1N ammonium acetate solution, & the suspension was filtered & finally filtered the soil, with additional ammonium acetate through Whatman No. 42 filter paper using Buchner funnel & vacuum pump. The soil was leached 4-5 times with more ammonium acetate & the final volume of the filtrate was made up to 500ml in a volumetric flask.

The concentration of K is found out by following photometric method.

$$K\% = \frac{\text{mg K/L of Soil extract x V}}{\text{10000 x S}}$$

Where, V = total volume of Soil extract prepared (500 ml)

S = Weight of taken Soil (50g)

Potassium (K_2O) in Kg/ha = Ppm Potassium in Soil extract (from std. curve) X 26.88

8. C: N Ratio:

C: N ratio shows the state biodegradability. When C: N ratio is more than 35:1, it is susceptible to further and rapid decomposition and slow nitrification (Tamhane, R.V. et al., 1970). The C: N ratio decreases on further decomposition of organic matter generally till 10:1 or lower.

Calculation:

$$\text{C: N ratio} = \frac{\text{Carbon \%}}{\text{Nitrogen \%}} \quad \text{Where, Carbon \%} = \frac{\text{Organic matter \%}}{1.724}$$

The factor 1.724 is based on the assumption that carbon is only 58% of the organic matter.

CHAPTER 5

5. RESULT AND ANALYSIS

5.1 Dimensions of Slides

5.1.1 Nagarkot Phedi Landslide / Site A

Width- 52.2 m

Length- 57.1 m

Area- 52.2m*57.1m = 2980.62 m^2

Depth (approx) - 4m

Table 3: Slope measurement of Nagarkot Landslide

S.No.	Slope angle	Slope length	Distance from base
1.	4^0	2m	2m
2.	34^0	15.1m	17.1m
3.	75^0	2m	19.1m
4.	25^0	34m	53.1m
5.	75^0	4m	57.1m

Average angle of slope- 42.6^0

5.1.2 Nagarkot Phedi Roadside / Site B – The Route map of Nagarkot Phedi Road 500m upwards and 500m downwards of the landslide site was prepared which is shown on Annex 3. The average slope angle of the road side is 30^0.

5.1.3 Tathali Phaidhoka Slide / Site C

Width- 70 m

Length- 40 m

Area- 40m*70m = 2800 m^2

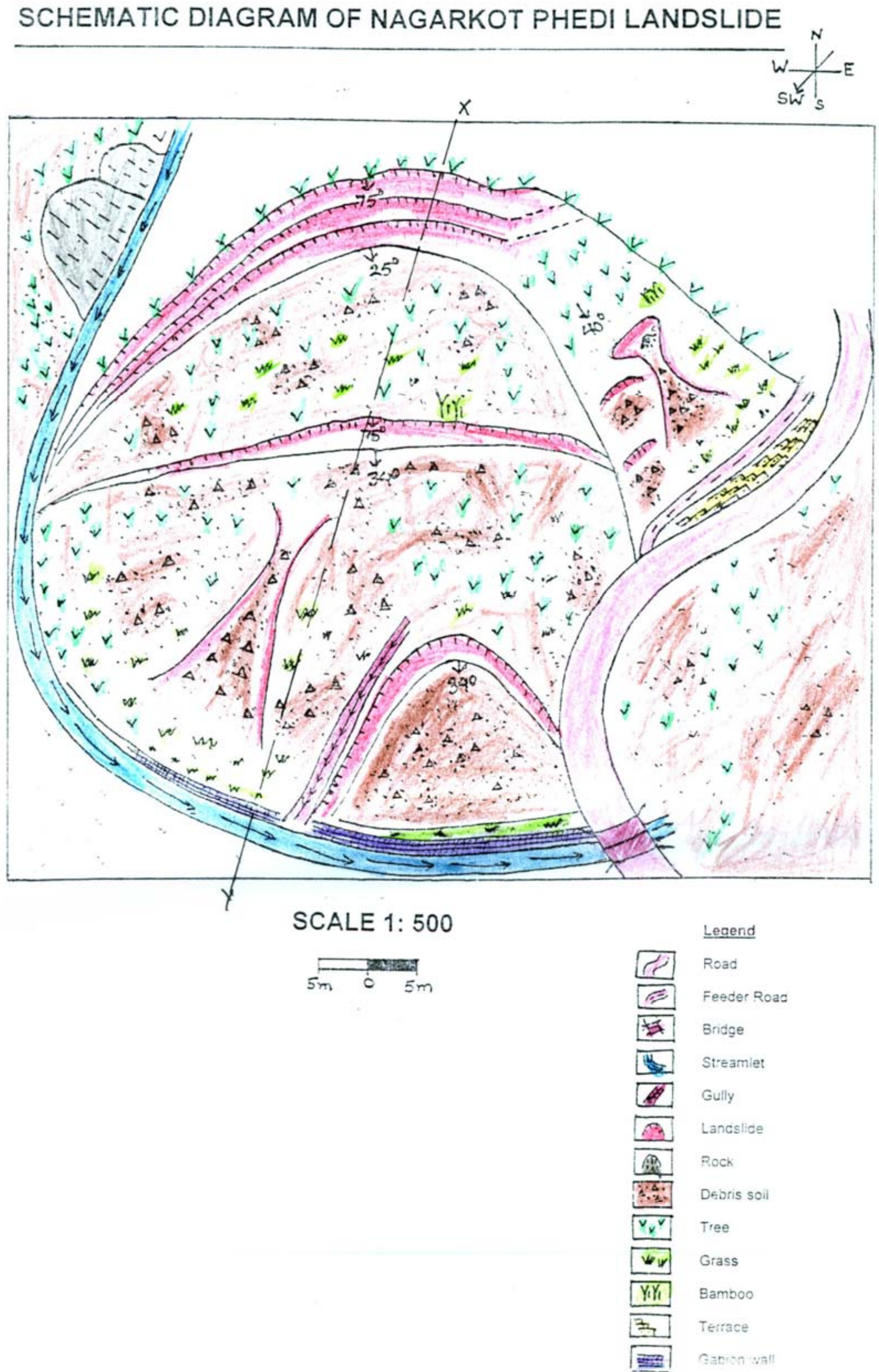
Depth (approx) - 4m

Table 4. Slope measurement of Tathali Landslide

S.No.	Slope angle	Slope length	Distance from base
1.	25^0	24.5m	24.5m
2.	49^0	4.5m	29m
3.	87^0	11m	40m

Average angle of slope- 54^0

Figure 37:



SCHEMATIC DIAGRAM OF NAGARKOT PHEDI LANDSLIDE
N
W
E
SW
S
X
75°
25°
40°
15°
34°
33°
Y
SCALE 1: 500
5m
0
5m
Legend
Road
Feeder Road
Bridge
Streamlet
Gully
Landslide
Rock
Debris soil
Tree
Grass
Bamboo
Terrace
Gabion wall

Figure 38:

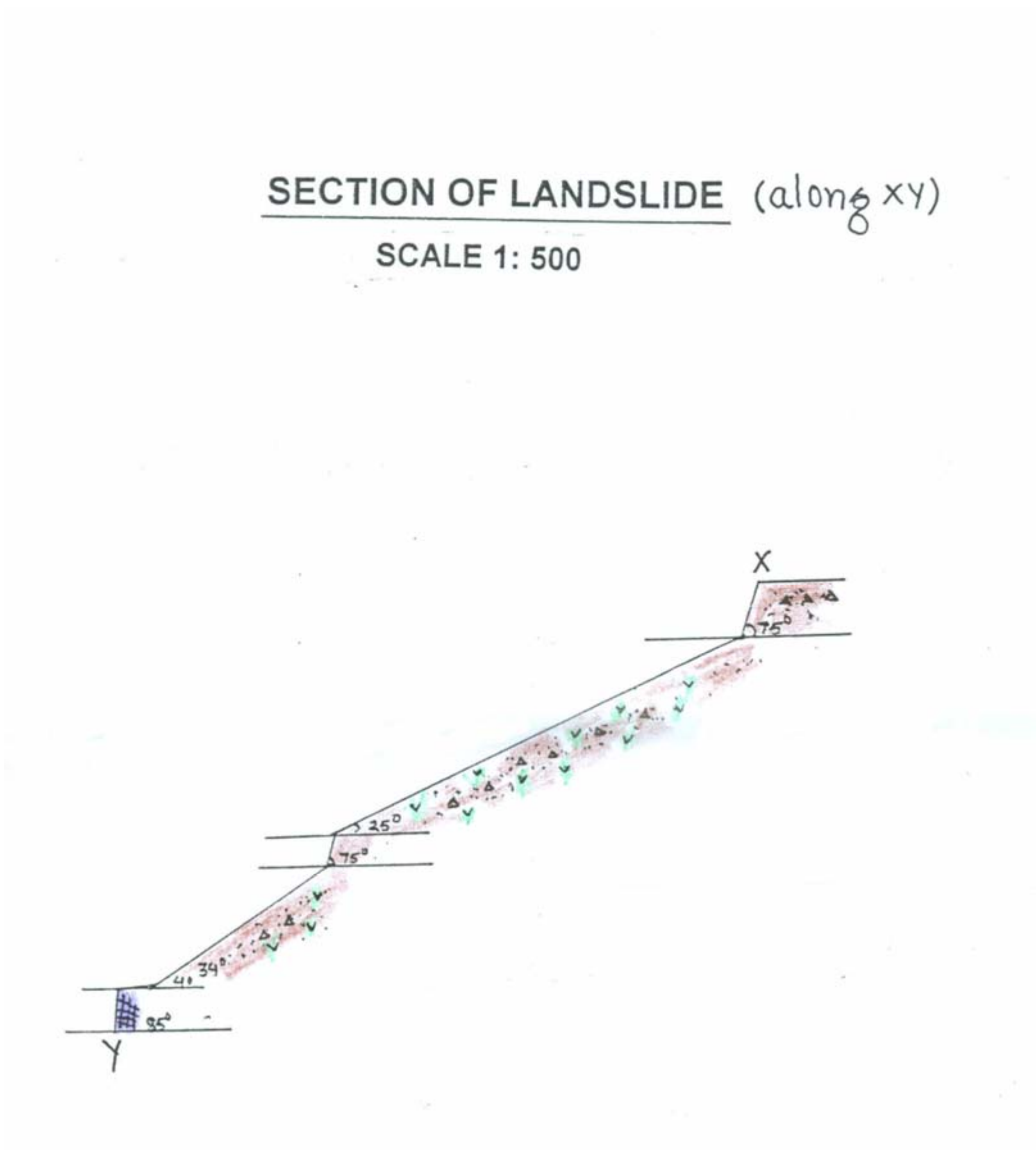
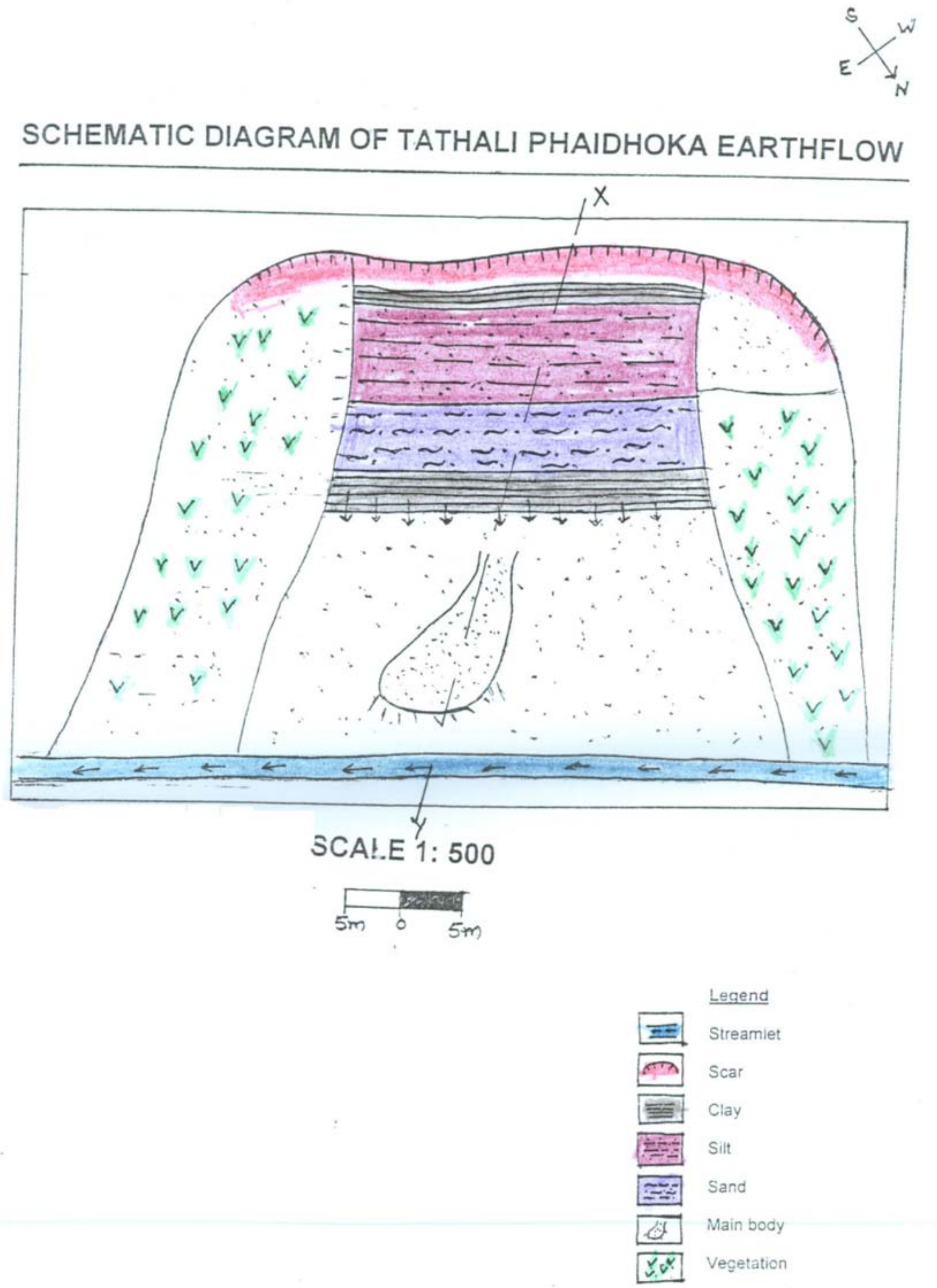
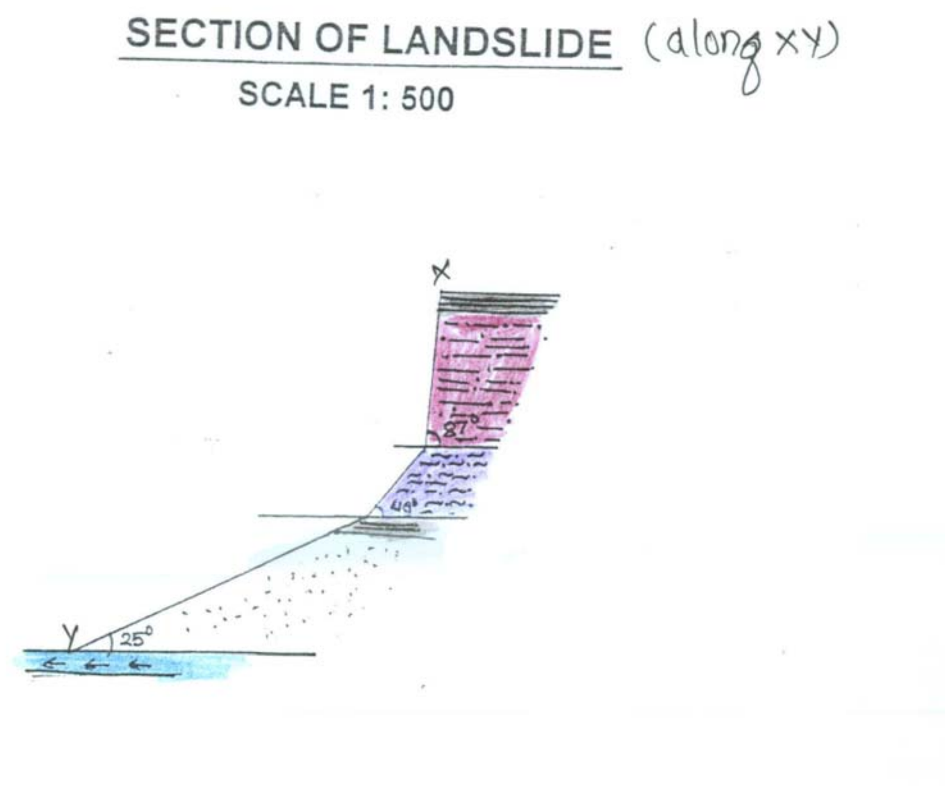


Figure 39:



S
W
E
N
SCHEMATIC DIAGRAM OF TATHALI PHAIDHOKA EARTHFLOW
X
Y
SCALE 1: 500
5m
0
5m
Legend
Streamlet
Scar
Clay
Silt
Sand
Main body
Vegetation

Figure 40:



5.2 Causes of Landslides

5.2.1 Nagarkot Phedi Landslide / Site A

The slip surface of the landslide is roughly parallel to the ground surface. There is the downward and outward mass movement along a relatively planar surface. It is composed of different soil masses usually varying from clay to boulders though the soil type is silty sand. Hence, it can be categorised as the translational slide.

A fault line is passed above the site (shown on Engineering and Environmental Geological map at Annex 6). A prominent gulley of 12.5m * 2m is present at the right part of the landslide. An ephemeral streamlet of width 2.5m is flowing at the left and base of the slide. The pore-water pressure is developed on the silty sand. Also the heavy rainfall during monsoon and the steep slope at the top of the slide also triggered the landslide. There was also stone quarrying on the south east aspect of the slide which was the human cause for slide. Hence, the major causes of the landslide are:

1. Presence of fault above the site.
2. The prominent gulley at right part,
3. The streamlet at the left and base,
4. Extreme pore water pressure built on silty sand,
5. Heavy rainfall during monsoon and steep slope at the top of slide and
6. Quarrying on the south east aspect of the slide.

5.2.2 Tathali Phaidhoka Slide / Site C

The sediment profile is distinctly developed on the landslide at the top. The silt, sand and clay layers are separated clearly. The water enters the silty and sandy soil layers but due to less infiltration capacity, it can't penetrate through clayey layer. Hence, the leaching or seepage occurred. At the base, the slope is gentle i.e. 25^0 and the slope materials consist fine grained materials, i.e. fine sand, silt and clay. There is the slow flowing of the slope materials. The bowl like depression is formed at the head, the central area is narrow and it became wider as it reached the valley floor. Hence, the slide can be termed as the earth flow.

There is lack of vegetation on the steep slope at the top of slide. The slope faces towards the north east direction. The soil is saturated with moisture and a streamlet of

1.5m width and 20 cm depth is flowing at the base. Near to the base, there is encroachment of land for the agricultural purpose and for the brick factory.

Hence, the major causes of the earthflow are:

1. The distinct sediment profile of sand, silt and clay layers and the seepage from the clay layers,
2. Steep slope at the top and gentle slope at the base consisting of the fine grained materials,
3. Higher moisture content, north east facing slope and the streamlet at the base.
4. Human disturbance near to the base.

5.3 Site Characteristics

Table 5. Environmental factors indicating site moisture characteristics

Site Moisture Factor	**Nagarkot Site / Site A**	**Tathali Site / Site C**
Aspect	Facing SW, S and SE	Facing NE
Altitude	1460 m- 1520 m	1352 m- 1392m
Topographical location	Gully present; Average slope angle is 42.6^0.	Moisture accumulation and seepage areas. Average slope angle is 54^0.
Regional rain effects	Absent	Absent
Rain shadow effect		
Stoniness and soil moisture holding capacity	Few stones; gravels and silty sand soil, soil moisture content is 16.54%.	Fine sand, silt and clay, soil moisture content is 104.94%.
Winds	Site exposed to wind	Site not exposed to wind
Dominant Vegetation	*Schima wallichii* (Chilaune) *Alnus nepalensis* (Utis)	*Melia azederach* (Bakenu), *Alnus nepalensis* (Utis)

Table 6. Calculation of Slope site Drought factor for Site A			
S. No.	Parameters		Score
1.	Slope angle	42.6^0	4
2.	Stoniness, Fines %	20-25%	2
3.	Altitude	1460 m- 1520 m	3
4.	Aspect	South-west	10
5.	Annual rainfall	2044.59 mm	2
		Total	21

In case of site A, the aspect, altitude, soil moisture percentage and exposure to winds (Table 5) indicate the tendency towards the dry site. In addition to that, the scoring system of roadside slopes according to the dryness recommended by Department of Roads, Geo-Environmental unit shows the total scoring of 21 (Table 6) indicates that the site lies on the warm and dry class. Hence, the Nagarkot site is warm and dry and the plant species of bioengineering grown on the dry sites should be selected.

In site B, on the Nagarkot road side, the above soil moisture factors are similar to the site A. Only, there is less amount of tree vegetation. The site is also warm and dry site. Hence, the tree and grass plantation should be enhanced on the both sides of the road to stabilize the road and the whole hill as in the site A.

Table 7. Calculation of Slope site Drought factor for Site C			
S. No.	Parameters		Score
1.	Slope angle	$>49^0$	6
2.	Stoniness, Fines %	>25%	1
3.	Altitude	1352 m- 1392m	4
4.	Aspect	North-east	2
5.	Annual rainfall	1502.57 mm	3
		Total	16

In case of Site C, the aspect facing NE, the site not exposed to winds, fine texture (fine sand, silt and clay content), high moisture content and dominance of Utis (Table 5) indicates that there is tendency towards damp site though the scoring system shows that the site lies on the moderately dry class (Table 7). Hence, the plant species of bioengineering grown on the damp sites should be selected.

5.4 Vegetation analysis

1. Nagarkot Phedi Site (Site A)

Table 8. Determination of Density and Relative density

S.N.	Name of the species	No. of individuals of species	Density of the species	Relative density of the species
1.	*Alnus nepalensis*	52	0.0166	58.36
2.	*Schima wallichii*	7	0.0022	7.86
3.	*Litsea monopelata*	5	0.0016	5.61
4.	*Betula alnoides*	2	0.0006	2.24
5.	*Bambusa arundinaceae (Retz.) Wild.*	2	0.0006	2.24
6.	*Bambusa arundinaceae Wild.*	2	0.0006	2.24
7.	*Lagestroemia parviflora*	1	0.0003	1.12
8.	*Castonopsis indica*	4	0.0013	4.49
9.	*Hygrocybe conica*	1	0.0003	1.12
10.	*Ficus nerifolia*	3	0.0010	3.37
11.	*Ficus auriculata*	2	0.0006	2.24
12.	*Choerospondias axillaris*	1	0.0003	1.12
13.	*Lyonia ovalifolia*	5	0.0016	5.61
14.	*Prunus cerasoides*	2	0.0006	2.24

* Local names of the plants are given on Annex 20.

From the above table, *Alnus nepalensis* (Utis) and *Schima wallichii* (Chilaune) have the highest densities i.e. 0.0166 individuals/m^2 and 0.0022 individuals/m^2 and relative densities i.e. 58.36% and 7.86% respectively. Both of these plants are suitable for bioengineering purpose. As the site already consists of these species, to enhance the bioengineering functions, the density of these plants should be increased by planting these species.

Table 9. Calculation of Species diversity

S.N.	Name of the species	No. of individuals of species/m^2 (ni)	ni/N	log ni/N	ni/N log ni/N
1.	*Alnus nepalensis*	0.0166	0.5836	-0.2339	-0.1365
2.	*Schima wallichii*	0.0022	0.0786	-1.1048	-0.0868
3.	*Litsea monopelata*	0.0016	0.0561	-1.2509	-0.0702
4.	*Betula alnoides*	0.0006	0.0224	-1.6488	-0.0370
5.	*Bambusa arundinaceae (Retz.) Wild.*	0.0006	0.0224	-1.6488	-0.0370
6.	*Bambusa arundinaceae Wild.*	0.0006	0.0224	-1.6488	-0.0370
7.	*Lagestroemia parviflora*	0.0003	0.0112	-1.9499	-0.0219
8.	*Castonopsis indica*	0.0013	0.0449	-1.3478	-0.0605
9.	*Hygrocybe conica*	0.0003	0.0112	-1.9499	-0.0219
10.	*Ficus nerifolia*	0.0010	0.0337	-1.4727	-0.0496
11.	*Ficus auriculata*	0.0006	0.0224	-1.6488	-0.0370
12.	*Choerospondias axillaris*	0.0003	0.0112	-1.9499	-0.0219
13.	*Lyonia ovalifolia*	0.0016	0.0561	-1.2509	-0.0702
14.	*Prunus cerasoides*	0.0006	0.0224	-1.6488	-0.0370
		∑ni=N= 0.0284		∑ni/N log ni/N= -0.7245	

Shannon-weiner species diversity index (H)= -∑ni/N log ni/N= -(-0.7245) = 0.7245

Pielou's evenness index (e) = H/logS

Here, S= 14

∴ e= 0.7245/log 14 =0.6321

The species diversity of trees in the given community by using Shannon-weiner index is 0.7245 which is optimum i.e. normal. The optimum species diversity of trees refers to normal food chain and not so complex food web. Optimum diversity refers to stability. It is apparent that the ecosystem is somewhat diversified and not so complex.

Moreover, species diversity tends to be low in physically controlled ecosystems (i.e. subjected to strong physico-chemical limiting factors) and high in biologically controlled ecosystems. Hence, the optimum diversity in the community may be due to more or less equal control of physico chemical and biological factors.

The species evenness for trees in given community by using Pielou's evenness index is 0.6321 which is normal or optimum. It shows the distribution of trees is not so unequal. As in natural condition, only the species *Alnus nepalensis* has high number of individuals and others have low number. This kind of distribution is normal or optimum because naturally, all the speciess in the community are not equally important in determining the value and function of the whole community. Only a few species or species groups out of hundreds or thousands kinds generally exert the major controlling influence on the others.

2. Tathali Phaidhoka Site (Site C)

Table 10. Determination of Density and Relative density

S.N.	Name of the species	No. of individuals of species	Density of the species	Relative density of the species
1.	*Alnus nepalensis*	17	0.0061	53.26
2.	*Melia azederach*	8	0.0029	25.06
3.	*Prunus cerasoides*	2	0.0007	6.27
4.	*Toona ciliata*	3	0.0011	9.40
5.	*Bambusa arundinaceae*	2	0.0007	6.27

* Local names of the plants are given on Annex 21.

From the above table, *Alnus nepalensis* (Utis) and *Melia azederach* (Bakenu) have the highest densities i.e. 0.0061 individuals/m^2 and 0.0029 individuals/m^2 and relative densities i.e. 53.26% and 25.06% respectively. Utis is suitable for bioengineering purpose. As the site already consists of this species, to enhance the bioengineering functions, the density of this species should be increased by planting this.

Also, the dominance of Utis indicates the site is damp. It refers for the selection of suitable plants for bioengineering purpose grown on damp sites.

Table 11. Calculation of Species diversity

S.N.	Name of the species	No. of individuals of species/m^2 (ni)	ni/N	log ni/N	ni/N log ni/N
1.	*Alnus nepalensis*	0.0061	0.5326	-0.2736	-0.1457
2.	*Melia azederach*	0.0029	0.2506	-0.6010	-0.1506
3.	*Prunus cerasoides*	0.0007	0.0627	-1.2030	-0.0754
4.	*Toona ciliata*	0.0011	0.0940	-1.0269	-0.0965
5.	*Bambusa arundinaceae*	0.0007	0.0627	-1.2030	-0.0754
	∑ni=N= 0.0114			∑ni/N log ni/N= -0.5436	

Shannon-weiner species diversity index (H) = -∑ni/N log ni/N

` = - (-0.5436) = 0.5436

Pielou's evenness index (e) = H/logS

Here, S= 5 ∴ e= 0.5436/log 5 = 0.7777

Similar to the site A, the species diversity and species evenness are optimum to this Site too. Comparatively, the species diversity of site C is lower than that of site A. It may be due to low pH (more acidic soil), high moisture content (saturated condition) and low organic matter.

The species evenness is comparatively higher in case of site C than site A. It is due to the low number of species. Different physico-chemical parameters are responsible for this as mentioned above.

5.5 Geological analysis

The study site, Nagarkot Phedi lies on Kulekhani Formation which belongs to the hard rock group (shown on Engineering and Environmental Geological map at Annex 6). It consists of greenish to grey biotite schist with schistose quartzite. Though it is relatively resistant to weathering, the presence of fault above the site decreases the stability. It may be one of the major causes for the landslide.

The next study site, Tathali Phaidhoka lies on Gokarna Formation shown on annex 6. It is slightly consolidated sediment. It consists of light to brownish grey; fine laminated and poorly graded silty sand. Intercalations of clay of variable thickness are present. . The distinct sediment profile of sand, silt and clay layers and the seepage from the clay layers is the major cause of the earth flow.

5.5.1 Grain Size Analysis

Through the study of grain size distribution curve of the soil samples of the Nagarkot Phedi site and Tathali Phaidhoka site, the soils of both sites are found as silty sand. According to the laboratory criteria for Unified Soil Classification system (Krahenbuhl and Wagner, 1983, Annex 22), the soils of the study areas are silty sand or sand- silt mixtures whereas the group symbol is SM.

From the grain size analysis tables from Annex, the percentages of soils passing the sieve with opening of 0.106mm for the soils of top (A1), middle (A2) and bottom (A3) of Nagarkot landslide site are 51.1%, 49.38% and 53.09% respectively whereas the percentages of soils passing the sieve with opening of 0.053mm for these A1, A2 and A3 soils are 21.62%, 23.96% and 21.78% respectively.

These data reveal that less than 50% of the soils pass the sieve with openings of 0.074 mm or No. 200 sieve which clarifies that the soil of this site is coarse grained soil. In addition to this, more than half of the coarse fraction passes the No. 4 sieve size or sieve with openings of 4.76 mm which indicates the soil is of sand group.

The above percentages passing through the sieves of openings 0.106mm and 0.053 mm support that more than 12% of the soils passing the No.200 sieve size (sieve of openings 0.074mm). Hence, from the Unified soil classification system (Annex 22) and the grain size analysis curves, it reveals that all the soil samples A1, A2 and A3 of the Nagarkot landslide site are the silty sand. So, the soil of Nagarkot landslide site is Silty sand. The pore water pressure developed on the silty sand causes the instability of the site.

Similarly, the soil samples taken from the Road site of Nagarkot (B) and the Tathali Phaidhoka site (C) follow the similar above criteria which indicate that the soils of that Road site as well as of Tathali are also Silty sand.

In case of Tathali, the percentages of the soil passing through the sieves of openings 0.106 mm and 0.053 mm are 64.68% and 36.82% respectively which are comparatively higher than those of Nagarkot sites. Hence, the soil of Tathali is finer than that of Nagarkot.

The percentages of soils passing the sieve of openings 0.053mm (which is less than the No. 200 sieve size) for A1, A2, A3, B and C are 21.62%, 23.96%, 21.78%, 20.68% and 36.82% respectively which are more than 5%. Also, the Hagen's Uniformity coefficient ,Cu for the soils A1, A2, A3, B and C are 3.25, 3.75, 2.93, 2.68 and 3.21 respectively which are less than 4 and Centre of Curvature, Cc for soils A1, A2, A3, B and C are 0.889, 0.662, 0.806, 0.908 and 0.803 which don't lie in the range of 1 to 3. So, these all data also support that the soils are Silty sand.

According to Discroll (1979), the Silty sand soil has cohesion of 0.5 to 0.2 t/m^2. The engineering use chart for soils classified by Unified Soil Classification System, USCS (adapted from Krahenbuhl and Wagner 1983) shows that the silty sand (SM group) belongs to semi-pervious to impervious permeability when compacted, good shearing strength when compacted and saturated, low compressibility when compacted and saturated and fair workability as a construction material.

Krahenbuhl and Wagner 1983 have given following ratings of Silty sand soil for relative desirability for following purposes.

1. Canal sections- a. Erosion resistance- 8 b. Compacted earth lining- 5
2. Foundation- a. Seepage important- 3 b. Seepage not important- 7
3. Roadways- a. Fills
   -Frost important- 8 - Heave possible- 10
   b. Surfacing- 6

In the ratings, no. 1 is most desirable and no. 14 is least desirable. It shows that for the foundations, seepage is important in this soil.

5.6 Physico-Chemical analysis

Table 12. Physico-Chemical parameters

1. pH

Sites	Soil	pH			Mean values	
Site A	A1	5.34	5.54	5.10	5.33	5.51
	A2	5.44	5.48	5.40	5.44	
	A3	5.70	5.70	5.91	5.77	
Site B	B	5.93	5.98	6.00	5.97	5.97
Site C	C	4.67	4.68	4.68	4.68	4.68

2. Conductivity us/cm

Sites	Soil	Conductivity µs/cm			Mean values	
Site A	A1	57	58	58	57.67	48.22
	A2	40	43	40	41.00	
	A3	45	46	47	46.00	
Site B	B	39	39	42	40.00	40.00
Site C	C	712	705	713	710.00	710.00

3. Hygroscopic moisture of Soil (Moisture content on the basis of dry soil) in %

Sites	Soil	Moisture content %			Mean values	
Site A	A1	8.11	8.20	7.60	7.97	16.54
	A2	23.49	23.27	23.46	23.41	
	A3	18.79	16.90	19.08	18.26	
Site B	B	2.40	2.31	2.15	2.28	2.28
Site C	C	108.68	101.21	104.92	104.94	104.94

4. Organic Content %

Sites	Soil	Organic Content %			Mean values	
Site A	A1	7.35	7.14	7.24	7.24	6.38
	A2	8.85	8.63	8.73	8.74	
	A3	3.10	3.20	3.15	3.15	
Site B	B	3.99	4.10	4.04	4.04	4.04
Site C	C	6.20	6.16	6.15	6.17	6.17

5. Nitrogen %

Sites	Soil	Nitrogen %			Mean values	
Site A	A1	0.27	0.29	0.31	0.29	0.26
	A2	0.31	0.36	0.30	0.32	
	A3	0.19	0.17	0.17	0.18	
Site B	B	0.25	0.22	0.27	0.25	0.25
Site C	C	0.38	0.36	0.29	0.34	0.34

Note: A1= Soil Sample from Top of site A, A2= Soil sample Middle of Site A, A3= Soil sample from Bottom of Site A

B= Soil Sample from Site B
C= Soil Sample from Site C

6. Phosphorus %

Sites	Soil	Phosphorus %			Mean values	
Site A	A1	0.0052	0.0054	0.0054	0.0053	0.0033
	A2	0.0020	0.0021	0.0021	0.0021	
	A3	0.0025	0.0025	0.0025	0.0025	
Site B	B	0.0062	0.0060	0.0060	0.0061	0.0061
Site C	C	0.0084	0.0080	0.0086	0.0083	0.0083

7. Phosphorus (P2O5) in Kg/ha

Sites	Soil	Phosphorus (P2O5) in Kg/ha			Mean values	
Site A	A1	143.31	148.82	148.82	146.98	91.01
	A2	56.22	57.88	58.98	57.69	
	A3	68.90	67.80	68.35	68.35	
Site B	B	170.87	165.36	165.36	167.20	167.20
Site C	C	231.50	220.48	237.02	229.67	229.67

8. Potassium %

Sites	Soil	Potassium %			Mean values	
Site A	A1	0.0195	0.0200	0.0210	0.0202	0.0201
	A2	0.0140	0.0150	0.0150	0.0147	
	A3	0.0250	0.0246	0.0265	0.0254	
Site B	B	0.0290	0.0300	0.0300	0.0297	0.0297
Site C	C	0.0350	0.0340	0.0360	0.0350	0.0350

9. Potassium (K2O) in Kg/ha

Sites	Soil	Potassium (K2O) in Kg/ha			Mean values	
Site A	A1	524.16	537.60	564.48	542.08	539.09
	A2	376.32	403.20	403.20	394.24	
	A3	672.00	658.56	712.32	680.96	
Site B	B	779.52	806.40	806.40	797.44	797.44
Site C	C	940.80	913.92	967.68	940.80	940.80

10. Carbon %

Sites	Soil	Carbon %			Mean values	
Site A	A1	4.26	4.14	4.20	4.20	3.70
	A2	5.13	5.01	5.06	5.07	
	A3	1.80	1.86	1.83	1.83	
Site B	B	2.31	2.38	2.34	2.34	2.34
Site C	C	3.60	3.58	3.57	3.58	3.58

11. C:N ratio

Sites	Soil	%C	%N	C:N	Mean
Site A	A1	4.20	0.29	14.48	13.50
	A2	5.07	0.32	15.84	
	A3	1.83	0.18	10.17	
Site B	B	2.34	0.25	9.36	9.36
Site C	C	3.58	0.34	10.53	10.53

1. pH

The soils of all the three sites show acidic in nature varying from 4.68 to 5.97 and this pH range is suitable for plant growth. Similar findings have been mentioned by Wilde (1933) and Shrivastava (1996). Most plants growing on mineral soils do well at pH range of 6.0-7.0. The high acidity on the soil of Site C may be due to leaching away of the exchangeable basic cations (Ca^{++}, Mg^{++}, Na^{+}, K^{+}) and many of them are replaced by H^{+} from carbonic acid formed in water by dissolved carbondioxide and then by $Al(OH)_2^{+}$ due to surface runoff and precipitation. In the process of organic matter decomposition, both organic and inorganic and acids are formed especially fulvic acid in wet condition (Shrestha, 1979). As clay content is more in the soil of Site C, acidity is increased.

2. Conductivity

Conductivity of soil of Site C is highest (710 $\mu S/cm^{-1}$) followed by Site A (48.22 $\mu S/cm^{-1}$) and Site B (40 $\mu S/cm^{-1}$). The high conductivity in Site C may be due to high salt concentration and the flowing condition of the soil in Site C.

3. Moisture content

The soil of site C is wetter than the soils of the Sites A and B. It may be due to high clay content or more percentage of finer texture. As the infiltration rate is very low in clayey soil, the water is accumulated on the upper surface. Also the slope faces towards the North east direction which lacks the exposure of direct sunlight. Hence, the site C contains higher percentage of moisture on the soil. This saturated moisture condition is mainly responsible for the earthflow in that site.

In the sites A and B, the texture is comparatively coarser. The infiltration is high in the silty sand soil than clayey soil. So, the sites A and B are comparatively drier. Site B is the driest site among three. It may be due to lack of tree vegetation on that site.

Much of the clay fraction has colloidal properties. It has adsorption capacity due to which it holds the nutrients supplied to the soil firmly and prevents leaching. Because of the colloidal properties, clay retains water. As it attracts and absorbs water, the clay swells and in saturated condition it starts to flow. The similar phenomenon has occurred in case of Site C.

4. Organic Content

Organic matter influences physical properties of soil such as structure, water holding capacity and resistance to erosion. It may be due to absorptive property of colloidal organic matter which holds water tightly, increasing water holding capacity of the soil. Also, the soil productivity is determined primarily by organic matter (De 2000). Organic content is the source of plant nutrients, especially nitrogen and phosphorus. Hence, the soils of Site A and C are more productive and beneficial by the view of organic content as they bear comparatively more organic content than the site B. The less organic content in the Site B may be due to absence of tree vegetation.

5. Nitrogen

Nitrogen promotes the growth of the plants. It is part of many important compounds, including protein and chlorophyll. According to Pradhan(1996), in the hilly region of Nepal, the nitrogen content is low if less than 0.075%, medium within the range of 0.075 to 0.15% and high if it exceeds 0.15% for the agricultural point of view. Hence, the nitrogen content is noted high in all three sites as they possess 0.26%, 0.25% and 0.34% nitrogen for sites A, B and C respectively. The soils of all these sites are rich in nitrogen which is suitable for growing of the plants for the bioengineering purpose.

6. Phosphorus

Phosphorus is part of genetic material involved in plant reproduction and cell division. Soil phosphorus is provided by the weathering of minerals like apatite, a calcium phosphate mineral. As apatite weathers, it releases anions that can be used by plants. These anions are primary orthophosphate and a secondary orthophosphate. Between pH 4.0 and 6.5, phosphorus reacts with aluminium.

According to Pradhan (1996), in the phospahate amount, P_2O_5 is low if less than 26 kg/ha, medium within the range of 26 to 55 kg/ha and high if it exceeds 55 kg/ha for the agricultural point of view. Hence, the amount of phosphate is noted high in all three sites as they possess 91.01 kg/ha, 167.20 kg/ha and 229.67 kg/ha phosphate for sites A, B and C respectively. The soils of all these sites are suitable for growing of the plants for the bioengineering purpose by phosphate point of view.

Also, with reference to the rating chart for soil test data in India, (Muhr 1963), the available phosphate, P_2O_5 for all three sites are high as these exceed 50 pounds per acre i.e. 56.09 kg/ha. These high values indicate there is lesser possibility of obtaining a profitable response from the use of fertilisers on soils or in other words, there is already sufficient amount of phosphate.

7. Potassium

Potassium is necessary for the development of thick cell walls and strong, rigid plant stems. It is involved in the gas exchange needed for photosynthesis and in transpiration.

According to Pradhan (1996), NARC, in the potassium content, K_2O is low if less than 110 kg/ha, medium within the range of 110 to 280 kg/ha and high if it exceeds 280 kg/ha for the agricultural point of view. Hence, the amount of potassium is noted high in all three sites as they possess 539.09 kg/ha, 797.44 kg/ha and 940.8 kg/ha potassium for sites A, B and C respectively. The soils of all these sites are suitable for growing of the plants for the bioengineering purpose by potassium point of view.

Also, with reference to the rating chart for soil test data in India, (Muhr 1963), the available phosphate, K_2O for all three sites are high as these exceed 300 pounds per acre i.e. 336.55 kg/ha. These high values indicate there is lesser possibility of obtaining a profitable response from the use of fertilizers on soils or in other words, there is already sufficient amount of potassium.

8. C: N Ratio

When fresh plant residues are added to the soil, they are rich in carbon and poor in nitrogen. Upon decomposition, the organic matter of soils changes to humus and have an approximate C: N ratio of 10:1.

Low ratios of carbon to nitrogen (10:1 or smaller) in soil organic matter generally indicate an advance stage of decomposition and resistance to further microbial decomposition. A wide ratio of C: N (35:1 or more) indicates little decomposition, susceptibility to further and rapid decomposition and slow nitrification.

Here, the C: N ratios of sites A, B and C are 13.5, 9.36 and 10.53 respectively. These low C: N ratio indicates the faster rate of decomposition. The low C: N ratio in Site B may be due to less amount of organic matter due to lack of tree vegetation.

9. Correlation between the soil parameters

Table 13. Correlation between different soil parameters

S.No.	Soil parameters	Correlation Coefficient (r)
1	pH and Moisture	-0.8794
2	pH and Organic matter	-0.4961
3	Moisture and Conductivity	0.9790
4	Organic matter and moisture	0.1462
5	Organic matter and Nitrogen	0.8200
6	Organic matter and Phosphorus	-0.0878
7	Organic matter and Potassium	-0.5884

There are significant positive correlations between moisture and conductivity (r=0.9790) and organic matter and Nitrogen (r=0.8200). There is positive correlation between organic matter and moisture (r=0.1462).

There are significant negative correlations between pH and moisture (r=-0.8794) and organic matter and Potassium (r=-0.5884) whereas negative correlations between pH and organic matter (r=-0.4961) and organic matter and Phosphorus (r=-0.0878).

5.7 Proposed Bioengineering Systems for the studied landslides

5.7.1 Nagarkot Phedi Landslide / Site A

Gabion retaining walls help to support the slope segments and are designed to stop active earth pressure. So, the gabion retaining wall was constructed at the base of the slide on the left bank of streamlet which is in degraded condition. The gabion wall should be renovated and constructed along the bank of streamlet at the base and the backfilling is necessary. Near to the base, a small landslide occurred on the left side. Gabion wall should be constructed along the base of that slide and backfilling is necessary. Gabion wall should be constructed also on the south east aspect of the site and backfilling is necessary. Stone pitching should be done on the surface of the gulley developed at the right side of the slide to prevent further scouring.

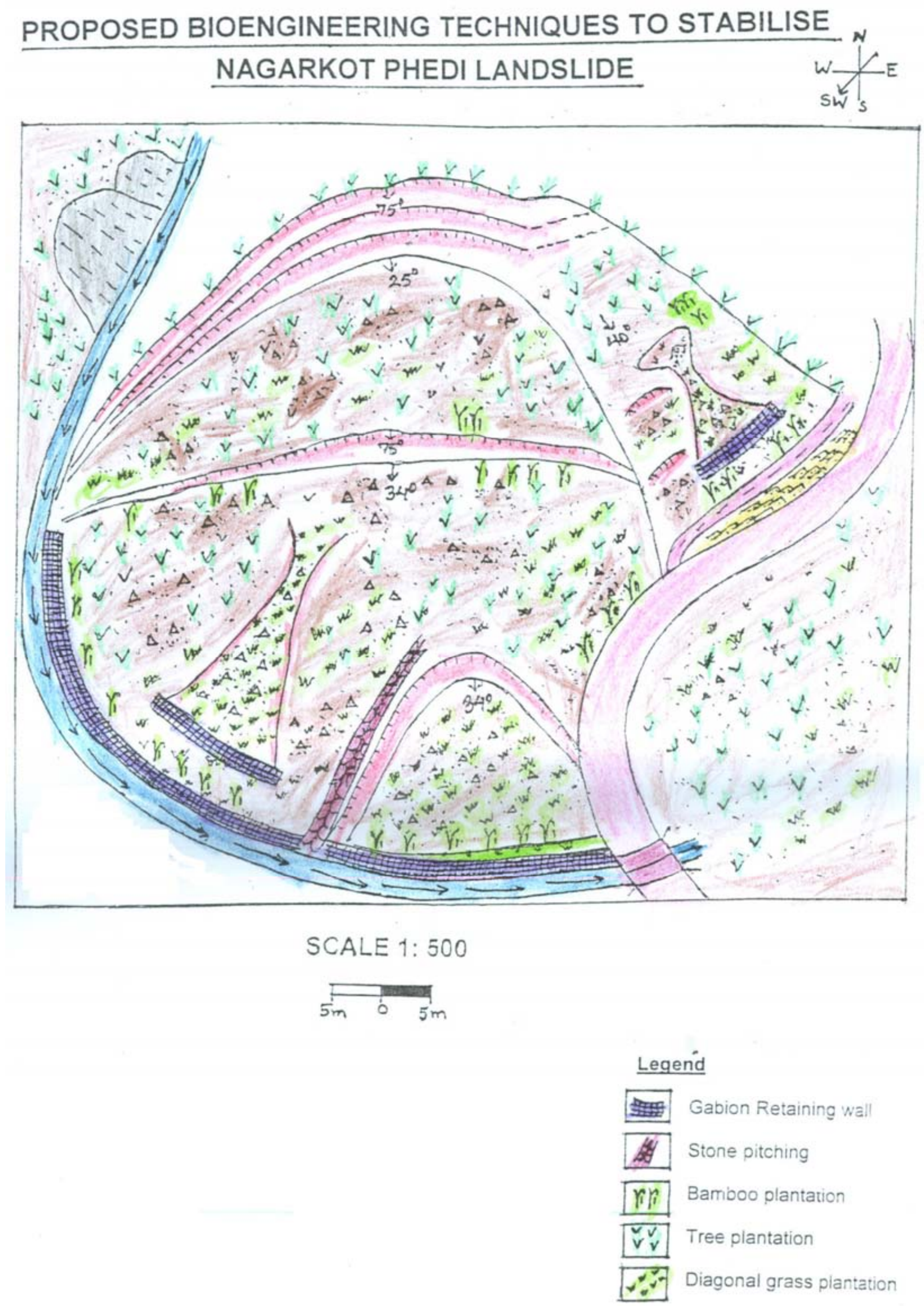
Bamboo plantation should be enhanced at the middle of the slide as few bamboos are already grown which indicates the suitability for bamboo and this plantation also helps to catch the debris moving down the slope and supports to prevent the further sliding. In addition to that, few bamboos should be planted on the base of the slide to support the whole area.

As different species of tree are grown, the tree plantation should be increased selecting the species appropriate for bioengineering purpose. It reinforces and anchors the slope by establishing the community. Diagonal grass plantation should be practiced on the unconsolidated slope materials of the smaller landslide zones on the base at right and left for draining as well as catching the materials of the slope.

5.7.2 Nagarkot Road side / Site B

Through the study of route map prepared (annex 3), the site characteristics (soil moisture, texture, altitude, vegetation etc.) are similar to the site A, landslide site. The site is the damp and the average slope angle of the road side is 30^0. Hence, the appropriate species of tree and grass vegetation of bioengineering functions as in site A should be planted on the both sides of the road for further stabilization of the road and the whole area. Planting shrubs and trees reinforces and anchors the slope by establishing a community of larger plants. They also support the slope in the long term.

Figure 41:


PROPOSED BIOENGINEERING TECHNIQUES TO STABILISE
NAGARKOT PHEDI LANDSLIDE
N
W
E
SW
S
75°
25°
40°
75°
34°
34°
SCALE 1: 500
5m
0
5m
Legend
Gabion Retaining wall
Stone pitching
Bamboo plantation
Tree plantation
Diagonal grass plantation

5.7.3 Tathali Phaidhoka Slide / Site C

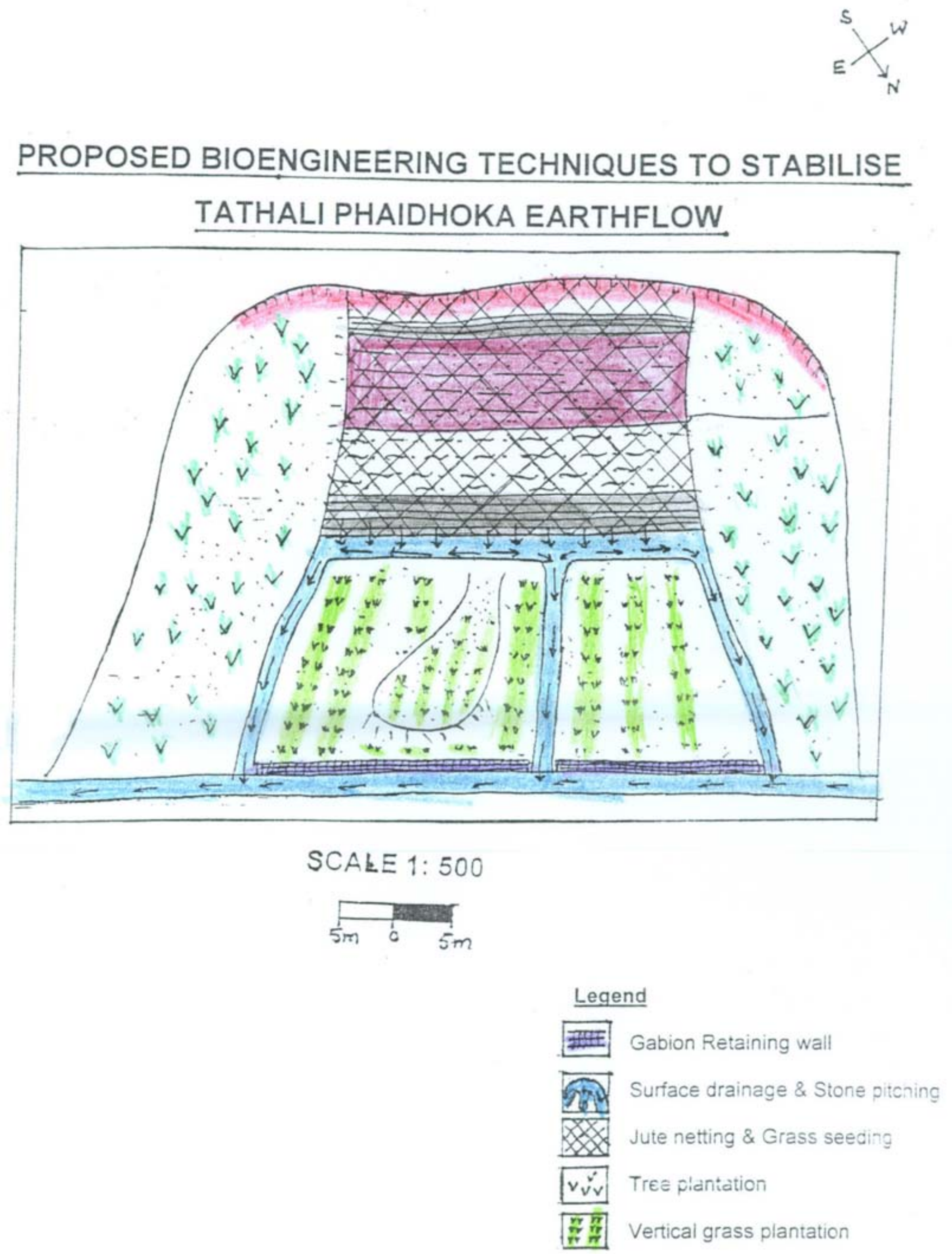
The major cause of the slide is the seepage of water from the clayey layer of soil. Water enters the sand and silty soil layers but can not infiltrate through the clayey layer due to low infiltration capacity. So, the drainage management is the best solution to stabilize the slide or earthflow.

Surface drain should be constructed below the clayey layer horizontally (along the width). The water from seepage can be collected on that drain and it can be drained through the vertical sub drains to the streamlet. Stone pitching should be done on the surface drains. Gabion wall should be constructed on the bank of streamlet to prevent further scouring and backfilling is necessary.

Jute netting can be done on the upper part of the slide as the slope is so steep and the grass seeding should be taken together. Vertical grass planting should be practiced below the horizontal drain which catches the slope materials and also assists in draining the water. The gentler slope (25^0) favours for the vertical grass planting.

As the trees are already grown on the both sides of the slide, the number of trees should be increased on the lower gentler slope by planting the suitable species for bioengineering purpose.

Figure 42



S
W
E
N
PROPOSED BIOENGINEERING TECHNIQUES TO STABILISE
TATHALI PHAIDHOKA EARTHFLOW
SCALE 1: 500
5m
0
5m
Legend
Gabion Retaining wall
Surface drainage & Stone pitching
Jute netting & Grass seeding
Tree plantation
Vertical grass plantation

5.8 Selection of Appropriate Plant species for Bioengineering

Bioengineering techniques should be used in an appropriate way so that the benefits outweigh potential disadvantages. The selection of plant species should be suited to fulfill the required engineering function. The choice of species should be made with consideration that products are of potential use of local people as far as possible. The selection should be on the basis of site characteristics. The appropriate plant species for bioengineering on the study sites are as follows.

1. To stabilize the Nagarkot Sites (Both on Sites A and B)

Almost all, 11 out of 13 species (i.e. Utis, Chilaune, Dudhilo, Kutmero, Saur, Taru Bans, Tama Bans, Katus, Nebharo, Lapsi amd Painyu) of the site A are recommended for bioengineering by Department of Road. Hence, the number of these tree species should be increased to stabilize the site except Dudhilo and Nebharo due to high grazing risk. As the landslide lies on the side of the road, and the main objective is to protect the road, following plant species are more appropriate for bioengineering on the basis of site moisture characteristics, altitude (Tables 6 & 7) and recommendation from Department of Roads.

Table 14: Appropriate Grass species selected/ recommended for bioengineering particularly for roadside areas (Nagarkot sites) and their characters

S. N.	Local Name	Botanical Name	Character	Best propagation	Remarks
1.	Amliso	*Thysanolaena maxima*	Large clumping	Slip cuttings	Best in damper areas
2.	Dhonde	*Neraudia reynaudiana*	Large clumping	Steam/slip cuttings/seed	15,520,000 seeds/kg
3.	Kans	*Saccharum spontaneum*	Large clumping and spreading	Slip cuttings	Very tough on all sites
4.	Katara khar	*Themeda species*	Large clumping	Slip cuttings/ seeds	
5.	Khar	*Cymbopogon microtheca*	Medium-large clumping	Slip cuttings/ seeds	1,681,000 seeds/kg

6.	Narkat ∗	*Arundo clonax*	Large clumping and spreading	Steam/slip cuttings	
7.	Phurke	*Arunduella nepalensis*	Medium-sized clumping	Slip cuttings/ seeds	1,809,000 seeds/kg
8.	Tite nigalo bans	*Drepanostachyum intermedium*	Large clumping (small stature bamboo)	Large slip cuttings	Drier sites than padang

∗ - Already available in study area

Table 15: Appropriate Shrubs/ Small trees selected/ recommended for bioengineering particularly for roadside areas (Nagarkot sites) and their characters

S. N.	Local Name	Botanical Name	Character	Best propagation	Remarks
1.	Areri	*Acacia pennata*	Small thorny tree, up to 5m	Seeds/ polypots	36,000 seeds/kg
2.	Bhujetro	*Butea minor*	Shrub up to 4m high	Direct seeding	450 seeds/kg, including separate pod segments
3.	Dhanyero	*Woodfordia fructicosa*	Shrub up to 3m high	Seeds/ polypots	
4.	Kanda phul	*Lantana camara*	Shrub up to 2m high	Hardwood cuttings	Not hard cut slopes
5.	Kettuke	*Agave americana*	Large cactus; sub-species with & without thorns	Root suckers	Grows well on south facing slopes
6.	Namdi phul	*Colquhounia cocinea*	Shrub up to 3m high	Hardwood cuttings	
7.	Simali	*Vitex negundo*	Small tree, up to 6m high	Hardwood cuttings	Very versatile; pollards well

Table 16. Appropriate Large clumping bamboos selected/ recommended for bioengineering particularly for roadside areas (Nagarkot sites) and their characters

S. N.	Local Name	Botanical Name	Character	Best propagation	Remarks
1.	Choya/ tama bans ∗	*Dendrocalamus hamiltonii*	Thin culm, heavy branching	Culm cuttings	
2.	Dhanu bans	*Bambusa balcooa*	Thin culm, heavy branching	Culm cuttings	
3.	Kalo bans	*Dendrocalamus hookeri*	Heavy branching, brown hairs	Culm cuttings	
4.	Mal bans	*Bambusa nutans*	Strong, straight culms	Traditional method	sub-sps *cupulata*
5.	Nibha/ ghopi/ lyas bans	*Ampelocalamus patellaris*	Smaller, bluiesh culms	Traditional method	

∗ - Already available in study area

Table 18. Appropriate Large trees selected/ recommended for bioengineering particularly for roadside areas (Nagarkot sites) and their characters

S. N.	Local Name	Botanical Name	Character	Light	Coppicing	Best propagation	Seeds/ kg	Remarks
1.	Chilaune *	*Schima wallichi*	Large evergreen tree	Bears shade	Can be looped	Seeds/ polypots	160,000	Can colonise existing plantations
2.	Dhale Katus *	*Castonopsis indica*	Large tree	Light or shade	Coppices	Seeds/ polypots	1,300	Grows best in higher rainfall areas
3.	Khanyu (khosro)	*Ficus semicordata*	Small stature, heavy branching	Full light	Coppices well	Seeds/ polypots	1,500,000	
4.	Lapsi *	*Choerospondias axillaris*	Medium to large deciduous tree	Strong light	Can be looped	Seeds/ polypots	300	
5.	Painyu *	*Prunus cerasoides*	Medium-sized flowering tree	Bears shade	Coppices	Seeds/ polypots	2,500	
6.	Phaledo	*Erythrina species*	Three fodder species	Light	Can be looped	Seeds/ hardwood cuttings up to 2m	2,000	Long cuttings are very successful
7.	Rato siris	*Albizia julibrissin*	Medium-sized deciduous tree	Light or shade	Coppices well	Seeds/ polypots	24,000	Fast growing in damp sites
8.	Saur *	*Betula alnoides*	Small tree	Full light		Seeds/ polypots	5,000,000	Natural coloniser
9.	Utis *	*Alnus nepalensis*	Large broadleaved tree	Full light	Probably does not coppice	Seeds/ polypots	500,000	

* - Already available in study area

2. To stabilize the Tathali Site (Site C)

All the species present in Phaidhoka Tathali site bear the bioengineering functions. So, their number should be increased for the stabilization of the site. These plant species and their characters are mentioned in the following tables. In addition to that, the appropriate plant species selected for bioengineering on the basis of site moisture characteristics, altitude and others (Tables 6 & 8) are also shown as follows.

Table 18. Appropriate Grass species selected/ recommended for bioengineering in Tathali site and their characters

S. N.	Local Name	Botanical Name	Character	Best propagation	Remarks
1.	Amliso	*Thysanolaena maxima*	Large clumping	Slip cuttings	-Best in damper areas -Recommended for roadside areas
2.	Kans	*Saccharum spontaneum*	Large clumping and spreading	Slip cuttings	-Very tough on all sites -Recommended for roadside areas
3.	Katara khar	*Themeda species*	Large clumping	Slip cuttings /seeds	-Recommended for roadside areas
4.	Khus	*Vetiver zianioides*	Medium-large clumping	Slip cuttings	-Fill slopes only; 1,712,000 seeds/ kg -Recommended for roadside areas
5.	Narkat	*Arundo clonax*	Large clumping and spreading	Steam/slip cuttings	-Recommended for roadside areas
6.	Sito	*Neyraudia arundinaceae*	Large clumping	Slip cuttings /seeds	-Higher rainfall areas: 16,390,000 seeds/ kg -Recommended for roadside areas
7.	Tite nigalo bans	*Drepanostachyum intermedium*	Large clumping (small stature bamboo)	Large slip cuttings	-Drier sites than padang

Table 19. Appropriate Shrubs/ Small trees selected/ recommended for bioengineering in Tathali site and their characters

S. N.	Local Name	Botanical Name	Character	Best propagation	Remarks
1.	Ainselu	*Rubus ellipticus*	Thorny shrub up to 2m high	Seeds/root cuttings	
2.	Namdi phul	*Colquhounia cocinea*	Shrub up to 3m high	Hardwood cuttings	- Recommended for roadside areas

Table 20. Appropriate Large clumping bamboos selected/ recommended for bioengineering in Tathali site and their characters

S. N.	Local Name	Botanical Name	Character	Best propagation	Remarks
1.	Choya/ tama bans	*Dendrocalamus hamiltonii*	Thin culm, heavy branching	Culm cuttings	
2.	Dhanu bans	*Bambusa balcooa*	Thin culm, heavy branching	Culm cuttings	
3.	Kalo bans	*Dendrocalamus hookeri*	Heavy branching, brown hairs	Culm cuttings	
4.	Nibha/ ghopi/ lyas bans	*Ampelocalamus patellaris*	Smaller, bluiesh culms	Traditional method	
5.	Tharu bans	*Bambusa nutans*	Strong, straight culms	Traditional method	Subspecies *nutans*

Table 22. Appropriate Large trees selected/ recommended for bioengineering in Tathali site and their characters

S. N.	Local Name	Botanical Name	Character	Light	Coppicing	Best propagation	Seeds/ kg	Remarks
1.	Bakeno *	*Melia azedarach*	Medium to large deciduous tree	Demands light	Coppices well	Seeds/ polypots	1,200	Needs deep soil for really fast growth
2.	Chilaune	*Schima wallichi*	Large evergreen tree	Bears shade	Can be looped	Seeds/ polypots	160,000	Can colonise existing plantations
3.	Dhale Katus	*Castonopsis indica*	Large tree	Light or shade	Coppices	Seeds/ polypots	1,300	Grows best in higher rain area
4.	Jamun	*Syzygium cumini*	Medium-sized evergreen tree	Bears shade	Coppices well	Seeds/ polypots	1,000	
5.	Kapur	*Cinnamomum camphora*	Evergreen tree (exotic)		Coppices well	Seeds/ polypots	3,500	
6.	Lankuri	*Fraxinus floribunda*	Large deciduous tree	Prefers light	Coppices well	Seeds/ polypots	60,000	
7.	Painyu *	*Prunus cerasoides*	Medium-sized flowering tree	Bears shade	Coppices	Seeds/ polypots	2,500	
8.	Phaledo	*Erythrina species*	Three fodder species	Light	Can be looped	Seeds/ harwood cuttings up to 2m	2,000	Long cuttings are very successful
9.	Rato siris	*Albizia julibrissin*	Medium-sized deciduous tree	Light or shade	Coppices well	Seeds/ polypots	24,000	Fast growing in damp sites
10.	Tooni *	*Toona ciliata*	Large deciduous tree	Light or shade		Seeds/ polypots	125,000	
11.	Utis *	*Alnus nepalensis*	Large broadleaved tree	Full light	Probably does not coppice	Seeds/ polypots	500,000	

* - Already available in study area

5.9 Cost estimation/ Rate analysis of Proposed Bioengineering System

Table 22. Cost Estimation for Nagarkot Phedi Site / Site A

S.N.	Bioengineering Structure and System	Unit Rate	Quantity	Total Cost (Rs.)
1.	Gabion retaining wall	Rs.1083.76	360 m^3	3,90,153.60
2.	Backfilling	Rs.69.31	360 m^3	24,951.60
3.	Stone pitching	Rs.66.39	25 m^2	1,659.75
4.	Bamboo plantation	Rs.153.77	12 No.	1,845.24
5.	Tree plantation	Rs.4	15 No.	60
6.	Diagonal grass plantation	Rs. 64.53	600 m^2	38,718
			Total	Rs. 4,57,388.19
			Contingency (10%)	4,573.88
			Grand Total	Rs. 4,61,962.07

Hence, it costs about Rs. 4,61,962 for the implementation of proposed bioengineering system.

Table 23. Cost Estimation for Tathali Phaidhoka Site / Site C

S.N.	Bioengineering Structure and System	Unit Rate	Quantity	Total Cost (Rs.)
1.	Gabion retaining wall	Rs.1083.76	70 m^3	75,863.2
2.	Backfilling	Rs.69.31	70 m^3	4,851.70
3.	Surface drainage stone pitching	Rs.66.39	92.5 m^2	6,141.08
4.	Standard Jute netting	Rs.128.03	675 m^2	86,420.25
5.	Grass seeding	Rs.9.57	675 m^2	6,459.75
6.	Tree plantation	Rs.4	10 No.	40
7.	Vertical grass plantation	Rs.64.53	703 m^2	45,364.59
			Total	Rs. 2,25,140.57
			Contingency (10%)	2,251.40
			Grand Total	Rs. 2,27,391.97

Hence, it costs about Rs.2,27,392 for the implementation of proposed bioengineering system.

Note: The cost estimations are based on the costs calculated on bioengineering work in Balephi landslide, Sindhupalchowk and the DoLIDAR (2002) norms. The costs should be calculated according to economic inflation/deflation declared by Nepal Rastra Bank at the period of implementation.

CHAPTER 6

6. CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The study site, Nagarkot Phedi lies on Kulekhani Formation which consists of greenish to grey biotite schist with schistose quartzite. The next study site, Tathali Phaidhoka lies on Gokarna Formation which belongs to the slightly consolidated sediment and consists of light to brownish grey, fine laminated and poorly graded silty sand. Both the study sites lie on the Midlands of Lesser Himalayan Zone. They are the parts of the Hanumante sub-watershed of Bagmati watershed.

The Nagarkot landslide is the type of translational slide and the Tathali slide is the earthflow. The major causes of Nagarkot landslide are presence of fault above the site, extreme pore water pressure built on silty sand and the presence of streamlet and the prominent gulley. The major causes of Tathali earthflow are due to the distinct sediment profile of sand, silt and clay layers and the seepage from the clay layers and the higher moisture content and human disturbance near to the base.

In Nagarkot Site, *Alnus nepalensis* (Utis) and *Schima wallichii* (Chilaune) have the highest densities i.e. 0.0166 individuals/m^2 and 0.0022 individuals/m^2 and relative densities i.e. 58.36% and 7.86% respectively. The species diversity of trees in the given community by using Shannon-weiner index is 0.7245 which is optimum i.e. normal which refers to stability. The species evenness for trees in given community by using Pielou's evenness index is 0.6321 which is normal or optimum. It shows the distribution of trees is not so unequal and almost all the organisms in the community are not equally important in determining the value and function of the whole community.

In Tathali Site, *Alnus nepalensis* (Utis) and *Melia azederach* (Bakenu) have the highest densities i.e. 0.0061 individuals/m^2 and 0.0029 individuals/m^2 and relative densities i.e. 53.26% and 25.06% respectively. Similar to the Nagarkot site, the species diversity and species evenness are optimum to this site too.

The Physico-chemical analysis shows that the soils of both the Nagarkot and Tathali sites are rich in nitrogen, phosphorus and potassium. The Nitrogen content of Nagarkot sites are 0.26% and 0.25% whereas that of Tathali site is 0.34%. The Phosphorus amount of Nagarkot sites are 91.01 kg/ha, 167.20 kg/ha phosphate whereas that of Tathali site is 229.67 kg/ha phosphate. The Potassium content of Nagarkot sites are 539.09 kg/ha and 797.44 kg/ha whereas that of Tathali site is 940.8 kg/ha potassium. These sufficient amounts of NPK and the other physico-chemical parameters support that these sites are suitable for growing of the plants for the bioengineering purpose.

The site moisture factors (altitude, aspect, soil moisture content and others) indicate that the Nagarkot site is warm and dry whereas there is high tendency towards the damp site in case of Tathali. Hence, the plant species of bioengineering grown on the warm and dry site should be selected for stabilization of Nagarkot site and the plant species of bioengineering grown on damp site should be selected in case of Tathali.

Renovation and construction of Gabion retaining wall and backfilling, Stone pitching, Bamboo plantation, Tree plantation and Diagnol grass plantation are the proposed bioengineering systems to stabilize the Nagarkot landslide site. It costs about Rs. 4,61,962 for the implementation of these bioengineering systems. To stabilize the Nagarkot road side, the Tree plantation and the Diagnol grass plantation should be done on the both sides of the road.

Surface drain, Stone pitching, Gabion wall construction and backfilling, Jute netting, Grass seeding and Vertical grass plantation are the proposed bioengineering systems to stabilize the Tathali earthflow. It costs about Rs. 2,27,392 for the implementation of these bioengineering systems.

Bioengineering is the most appropriate and essential way to control the mass movements in the mountainous country like Nepal with fragile geology.

6.2 RECOMMENDATIONS

1. The existing civil engineering structures like gabion wall, cement masonry wall should be maintained periodically and such structures should be constructed on the roadside as per required.
2. Stone quarrying on the south east aspect of the Nagarkot landslide should be stopped.
3. The study area, Nagarkot Phedi site can be promoted as ecotourism area.
4. Human disturbances like extracting the soil at base in Tathali site and using it for brick factory should be strictly prohibited.
5. Formulating the long term plans to stabilize such slides is essential and their implementation is must and the institutional/ organizational capacity should also be incorporated.
6. Trainings and researches related to Bioengineering and Landslide prevention, control and mitigation measures should be managed through government level, NGOs, INGOs and from student level.
7. Public participation should be increased for the implementation of bioengineering techniques and stabilization of the areas.
8. Landslide mainly occur in the summer monsoon season so all the civil engineering structure, bioengineering and other maintenance should be done before this according to schedule but should not wait till the severe situation arises.

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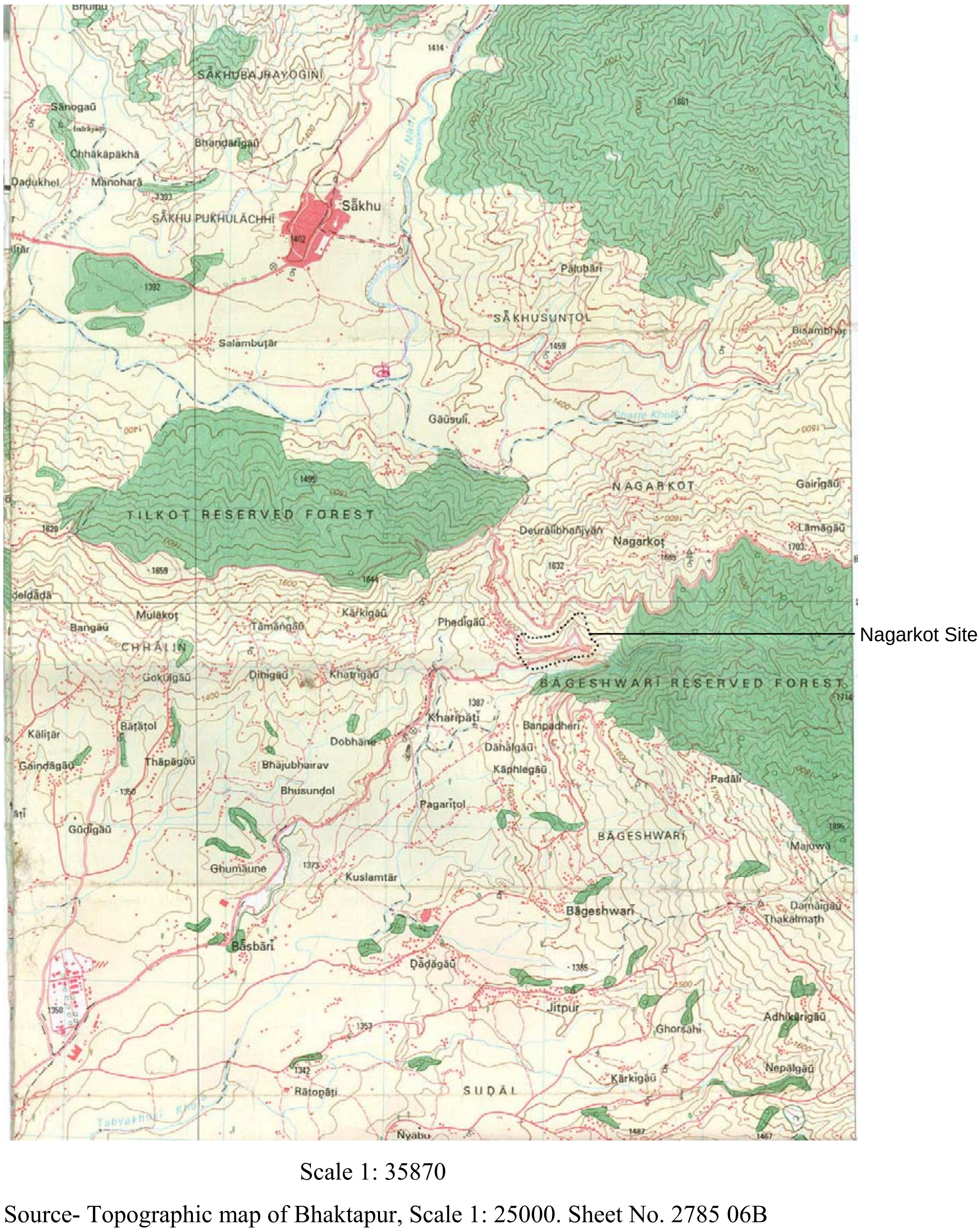
ANNEXES

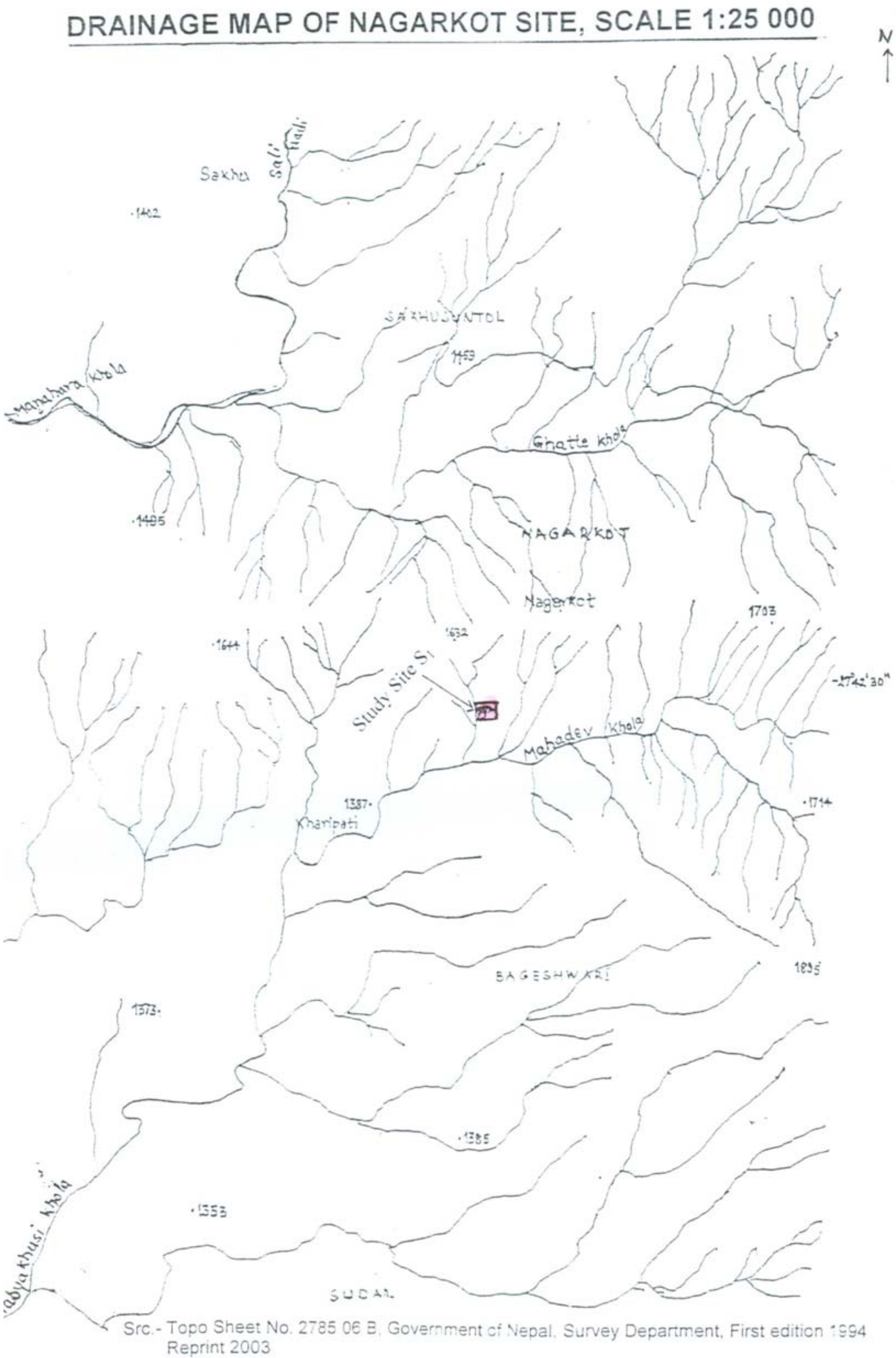
Annex 1: Topographic map of Bhaktapur showing Nagarkot Phedi Site



Scale 1: 35870

Source- Topographic map of Bhaktapur, Scale 1: 25000. Sheet No. 2785 06B Government of Nepal, Survey Department, First Edition 1994.

Annex 2:



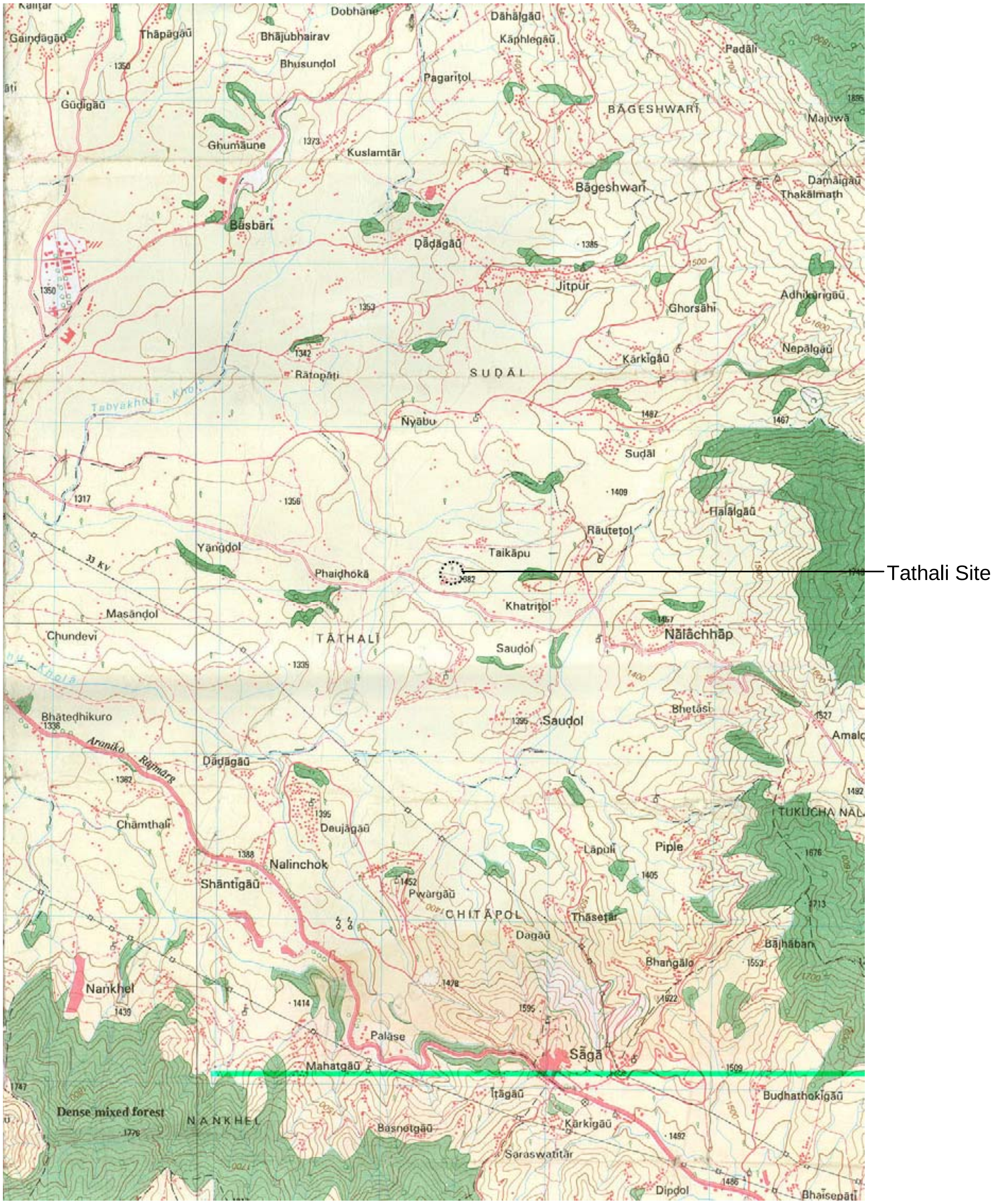
Src.- Topo Sheet No. 2785 06 B, Government of Nepal, Survey Department, First edition 1994 Reprint 2003

ROUTE MAP OF NAGARKOT PHEDI ROAD, BHAKTAPUR

SCALE 1 : 1000

PREPARED BY:
PRAJJWAL BABU GONGAL

Annex 4: Topographic map of Bhaktapur showing Tathali Site



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Source- Topographic map of Bhaktapur, Scale 1: 25000. Sheet No. 2785 06B

Government of Nepal, Survey Department, First Edition 1994.

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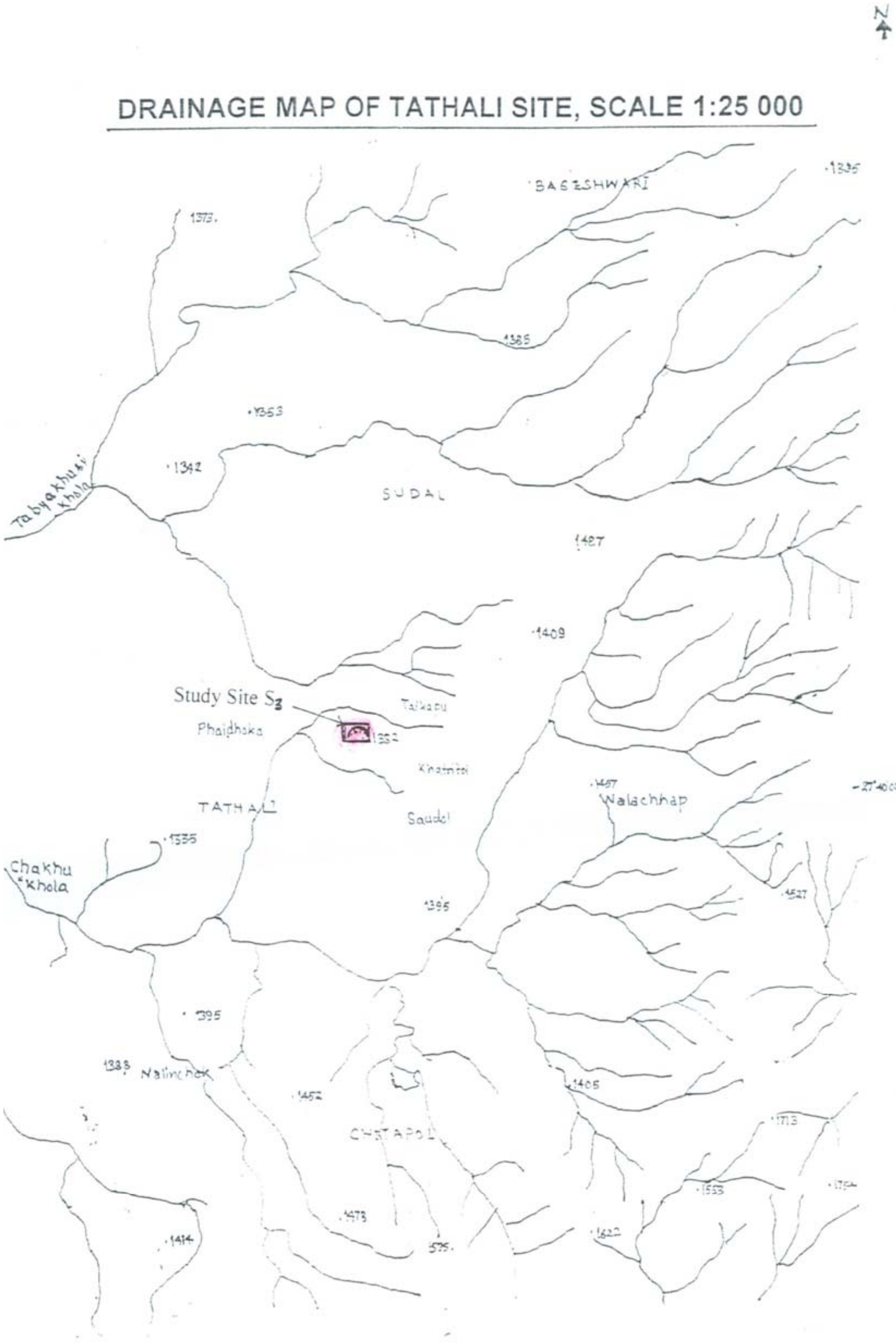
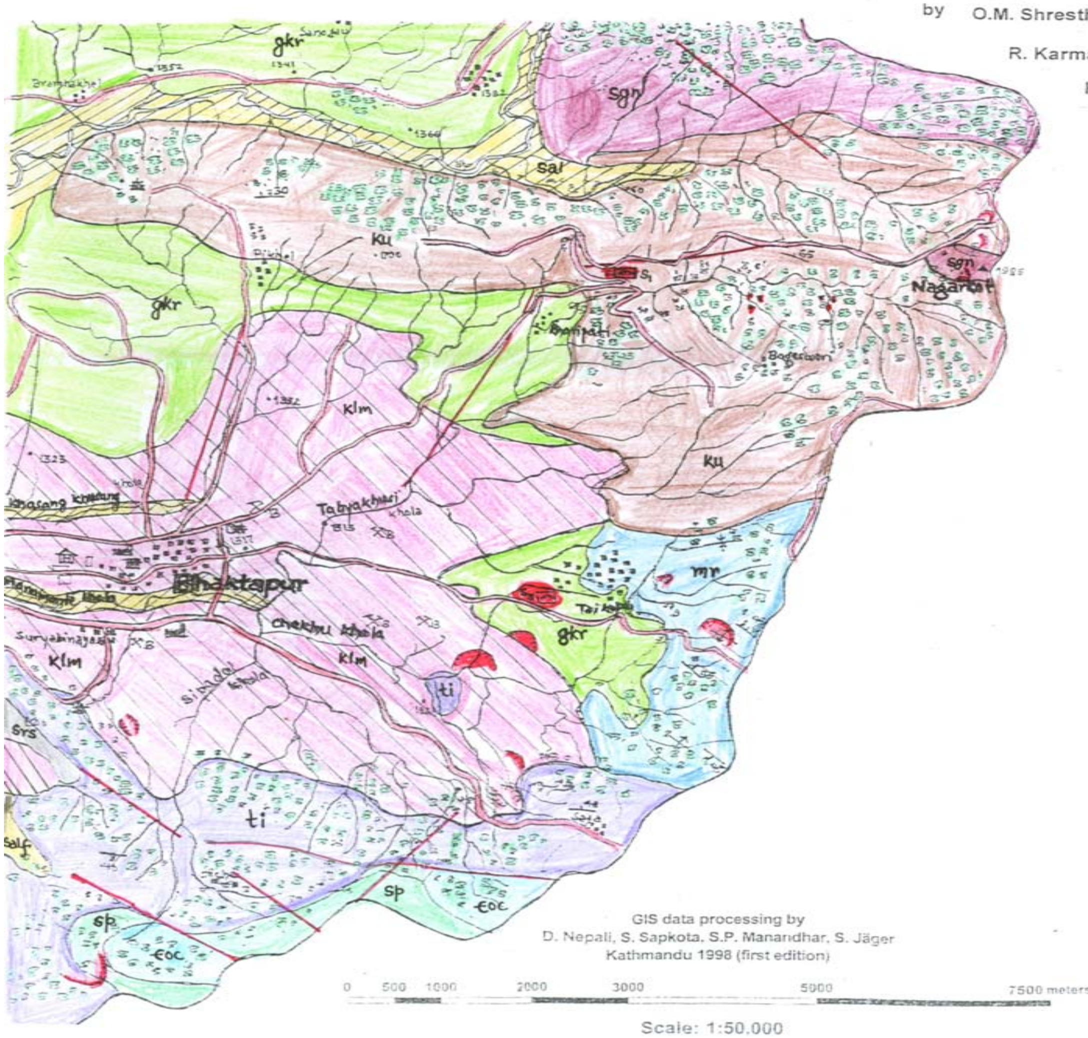


Src.- Topo Sheet No. 2785 06 B. Government of Nepal, Survey Department, First edition 1994
Reprint 2003

ENGINEERING AND ENVIRONMENTAL GEOLOGICAL MAP OF THE STUDY AREA, SCALE 1 : 50 000

COPIED FROM- ENGINEERING AND ENVIRONMENTAL GEOLOGICAL MAP OF THE KATHMANDU VALLEY, SCALE 1 : 50 000

by O.M. Shrestha, A. Koirala, S.L. Karmacharya, U.B. Pradhananga, P.M. Pradhan, R. Karmacharya with contributions from J. Hanisch, M. Kerntke, P.R. Joshi, L. Steiner, K. Busch, B.M. Jnawali, N.D. Maske, G.B. Tuladhar and K.P. Kaphle



EXPLANATORY LEGEND

S_1	Nagarkot Landslide
S_3	Tathali Landslide

FORMATION

Quaternary — Unconsolidated material/ sediment

sal	Recent alluvial soil	Recent sediments of flood plains and lower alluvial terraces. In northern part: sand and gravel deposits up to boulder size. In central and southern part: clay, sand, and fine gravel.
srs	Residual soil	Humic silty loam to sandy gravel of thickness 1 - 3 m, at places and occur on slopes.
salf	Alluvial fan deposit	Gravel, sandy gravel, sand, and silt. Thickness increases towards the centre of the fan. Finer grained material towards the margin.

Plio-Pleistocene — Slightly consolidated sediment

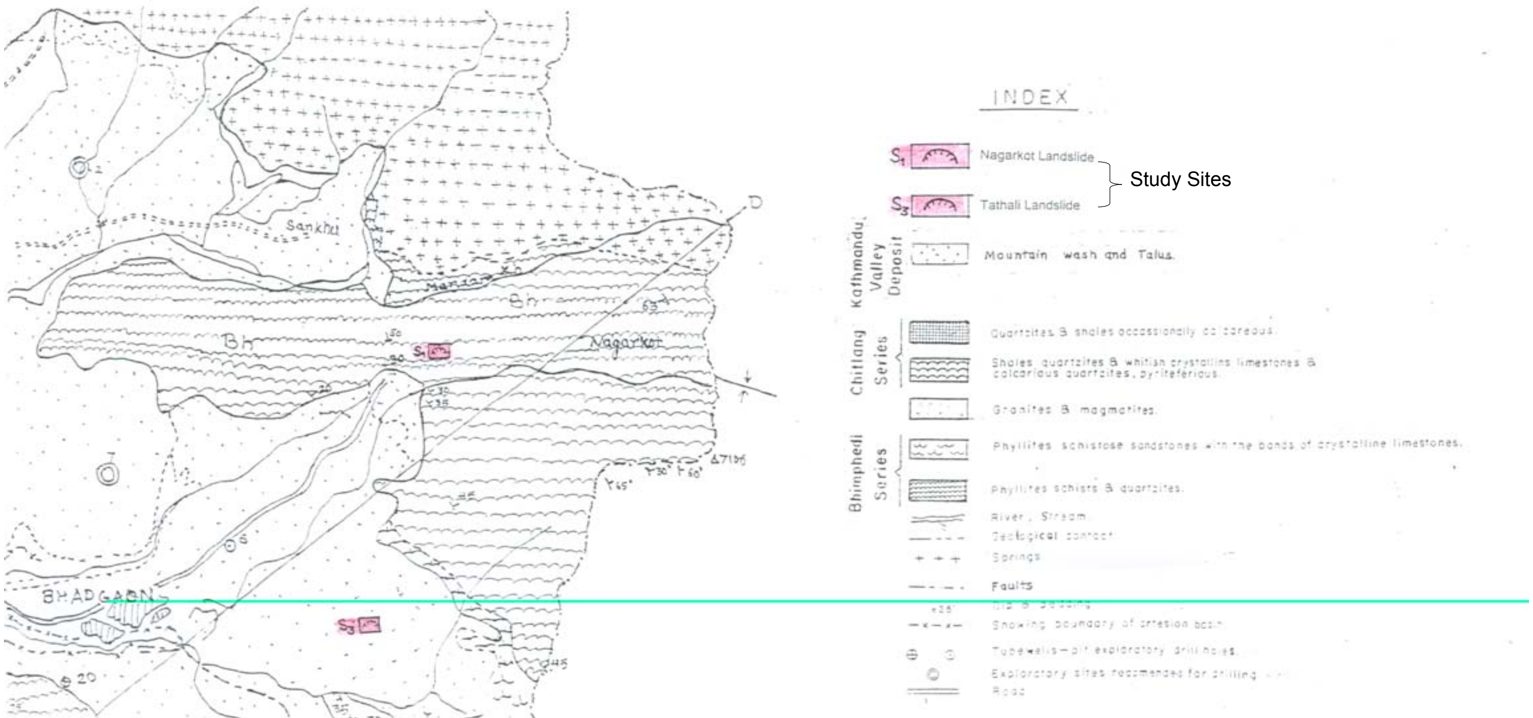
gkr	Gokarna Formation	Light to brownish grey fine laminated and poorly graded silty sand. Intercalations of clay of variable thickness as well as in upper part: white Thimi diatomite (1 m) present. Total thickness up to 300 m or more.
klm	Kalimati Formation	Grey to dark silty clay and clayey silt, at places calcareous nature and phosphate mineral (vivianite). Organic clay, fine sand beds and peat layers common. Occasionally lignite seams up to 2 m. In Kharipati area quartzitic and biotite schist boulder beds with sandy gravel and minor clayey and sandy silt layers present. Total thickness up to 450 m or more.

Precambrian to Devonian — Hardrock

€oc	Chandragiri Formation	Pale bluish grey to brown, medium to thick bedded, massive and finely crystalline limestone, at places with sandstone and phyllite, locally siliceous or dolomitic limestone. At places sporadic lead/ zinc mineralization. Total thickness up to 2000 m.
sp	Sopyang Formation	Dark, thinly bedded calcareous slate. Yellowish to brown when weathered. Total thickness up to 200 m.
ti	Tistung Formation	Greenish grey to brown, fine grained phyllite and slate interbedded with meta-sandstone and quartzite containing thin bands of argillaceous limestone. Total thickness up to 3000 m.
mr	Marku Formation	Highly folded sericitic quartzite with interbedding of phyllitic schist and few marble bands and quartz veins. Sand formed from quartzite when weathered. Thickness up to 1000 m.
ku	Kulikhani Formation	Greenish biotite schist with schistose quartzite. Relatively resistant to weathering. Quartz veins with some base metal mineralization. Thickness up to 2000 m.
sgn	Sheopuri gneiss	In southern part Mica gneiss and biotite schist with intrusions of muscovite granite intensively weathered at surface. In northern part: Medium to coarse grained muscovite granite with intercalations of mica gneiss and dark biotite schist. Tourmaline and beryl present at places.

GEOLOGICAL MAP OF THE STUDY AREA

SCALE 1 : 63360



Source:-

HMG / DEPARTMENT OF MINES AND GEOLOGY		
GEOLOGICAL MAP OF KATHMANDU VALLEY		
Author: S. P. Nautiyal & P. N. Sharma. (Geological Survey of India)		Topo. No.
Draftsman B. R. Tuladhar	Checked by:	Date 1966/4/24
Ref. No. [illegible]	Scale 1: 63360	Report Fig. No.

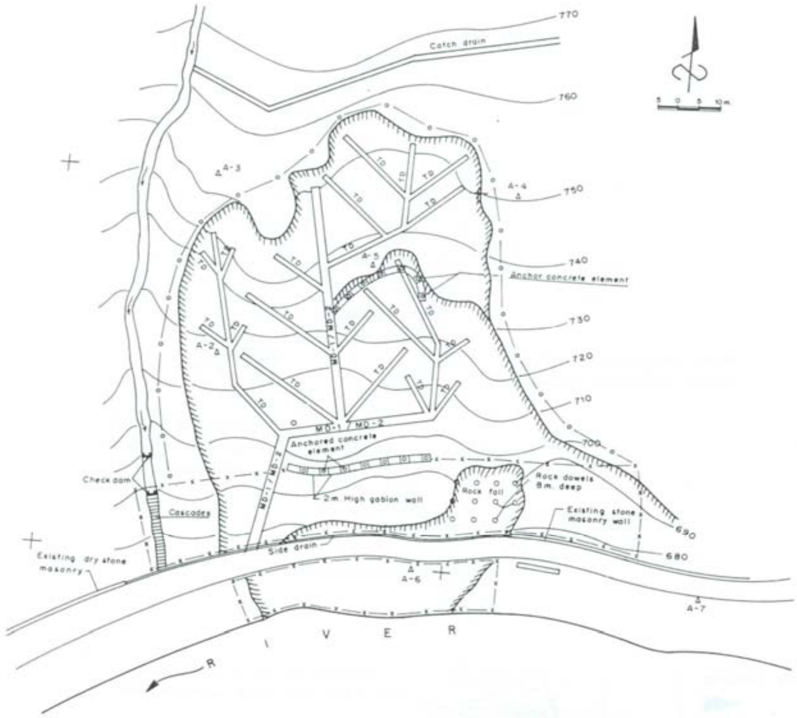
Annex 8: Nagakot Phedi Landslide and the measurement of slope angle

Annex 9: Nagarkot Phedi Landslide with debris and vegetation

Annex 10: A streamlet flowing on the base of Tathali Phaidhoka slide

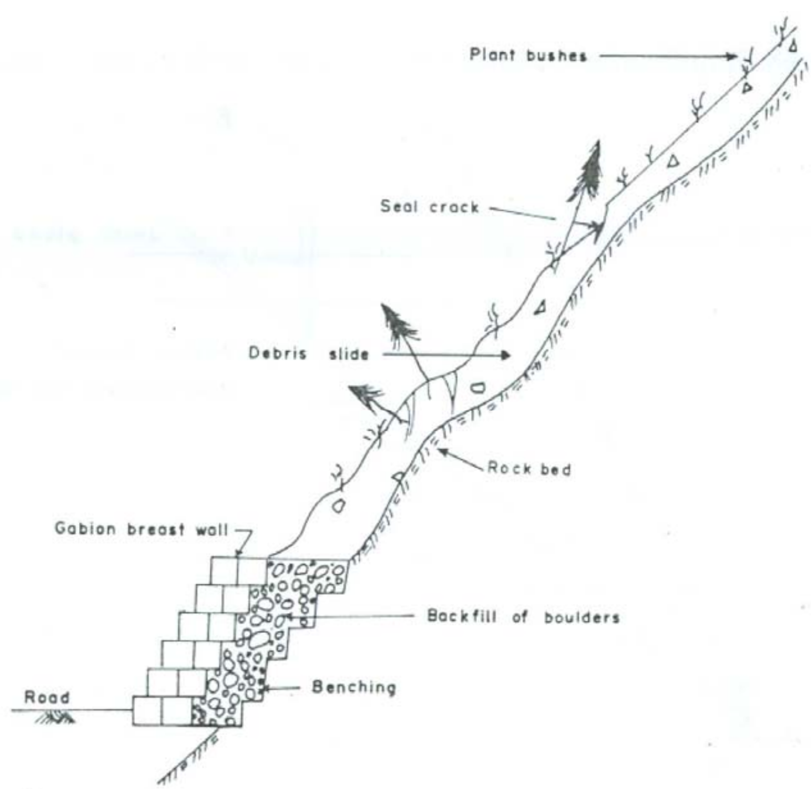
Annex 11: Maize cultivation on the slope of the slide.

Annex 12: Landslide stabilization by sub-surface pipe drains



Source: Road Flood Rehabilitation Project, DOR, HMG Nepal, 1991 (Deoja et al., 1991)

Annex 13: Stabilization of minor landslides by gabion breast walls



Annex 14: Main engineering functions of structures with appropriate techniques

Function	Civil engineering techniques	Bioengineering techniques	Combination of Both
Catch	Catch walls Catch fences	Contour grass lines or brush layers Shrubs and large bamboo clumps	Catch wall with densely planted shrubs Catch wall with bamboo clumps planted above
Armour	Revetments Surface rendering	Mixed plant storey giving complete cover Grass carpet	Vegetated stone pitching Jute netting with planted grass
Reinforce	Reinforced earth Soil nailing	Densely rooting grasses, shrubs and trees Most vegetation structures	Wire bolster cylinders and planted shrubs or trees Jute netting with planted grass
Anchor	Rock anchors Soil anchors	Deeply rooting trees	Combination of soil anchors and deeply rooting trees
Support	Retaining walls Prop walls	Large trees and large bamboo clumps	Retaining wall with a line of large bamboo clumps planted above
Drain	Masonry surface drains Gabion and French drains	Downslope and diagonal vegetation lines Angled fascines or brush layers	Herringbone-pattern wire bolster cylinders and angled grass lines French drains and angled grass lines

Annex 15: Comparison of Retaining wall types

Wall Type	Maximum Safe Height	Width : Height Ratio	Advantages / Limitations
Dry Masonry	4 metres	1:1 to 0.6:1	Well drained; flexible; relatively low cost; low strength threshold
Composite masonry	8 metres	0.75:1 to 0.5:1	Better drained than mortared masonry, but with reduced strength
Mortared masonry	10 metres	0.75:1 to 0.5:1	Easier to construct on steep terrain, can't tolerate settlement; poor drainage
Gabion	10 metres	Width = ½ h+0.5	Flexible without rupturing; tolerates poor foundations; well drained; relatively low cost for strength
Reinforced earth	8 metres	Depends on design	Reinforcing expensive or difficult to obtain; difficult to achieve tension
Reinforced concrete	10 metres	Depends on design	Relatively costly; requires advanced technical skills to build; poor drainage

Annex 16: Common characteristics of Well drained and Poorly drained soils

Material Drainage Characteristics	Tendency towards Good drainage	Tendency towards Poor drainage
Overall drainage	Freely draining material; dries quickly after rain storms	Slowly draining material; tends to remain wet for long periods after rain; behaves like firm curd
Soil particle size	Coarse textures; loams and sandy soils	Fine textures; clays and silts
Porosity	Larger inter-connecting pores	Small pores
Material types	Stony colluvial debris; fragmented rock; sandy and gravelly river deposits	Residual soils of fine texture; debris from mud flows, slumps etc; red clay loam soil (rato mato)
Slope types	Fill slopes; cut slopes in stony debris (colluvium)	Cut slopes in original consolidated ground

Annex 17: Environmental factors indicating site moisture characteristics

Site Moisture Factor	Tendency towards Damp Sites	Tendency towards Dry Sites
Aspect	Facing N, NW, NE and E	Facing S, SW, SE and W
Altitude	Above 1500 metres; particularly above 1800 metres	Below 1500 metres; deep river valleys surrounded by ridges
Topographical location	Gullies; lower slopes; moisture accumulation and seepage areas	Upper slopes; spurs and ridges; steep rocky slopes
Regional rain effects	Eastern Nepal in general; the southern flanks of the Annapurna Himal	Most of Mid Western and Far Western Nepal
Rain shadow effect	Sides of major ridges exposed to the monsoon rain-bearing wind	Deep inner valleys; slopes sheltered from the monsoon by higher ridges to the south
Stoniness and soil moisture holding capacity	Few stones; deep loamy and silty soils	Materials with a high percentage volume of stones; sandy soils and gravels
Winds	Sites not exposed to winds	Large river valleys and the Terai
Dominant Vegetation	e.g. amliso, nigalo, bans, chilaune, katus, lali gurans, utis	e.g. babiyo, khar, dhanyero, imili, kettuke, khayer, salla

Annex 18: Effects of Vegetation on Slope Stability (Greenway 1987)

Hydrological Mechanism	Influence
1. Foliage intercepts rainfall, causing absorptive and evaporative losses that reduce rainfall available for infiltration.	B
2. Roots and stems increase the roughness of the ground surface and the permeability of the soil, leading to increased infiltration capacity.	A
3. Roots extract moisture from the soil which is lost to the atmosphere via transpiration, leading to lower porewater pressure.	B
4. Depletion of soil moisture may accentuate desiccation cracks in the soil, resulting in a higher infiltration capacity.	A
Mechanical Mechanisms	
5. Roots reinforce the soil, increasing the soil shear strength.	B
6. Tree roots may anchor into firm strata, providing support to the upslope soil mantle through buttressing and arching.	B
7. Weight of the trees surcharges the slope, increasing normal and downhill force components.	A/B
8. Vegetation exposed to the wind transmits dynamic forces into the slope.	A
9. Roots bind soil particles in the surface of the ground, reducing their susceptibility to erosion.	B

A- Adverse to stability, B- Beneficial to stability

Annex 19: Annual calendar of Civil and Bioengineering works

Fiscal Year		**First Year**												**2nd Year**	
Activities	**Months**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**
1. Make an initial plan			■												
2. Prioritise the works				■											
3. Divide the site or slope into segments				■	■										
4. Assess the site				■	■										
5. Determine civil engineering works				■	■										
6. Choose the right bioengineering techniques				■	■										
7. Design the civil and bioengineering works					■	■									
8. Select the species to use					■	■									
9. Calculate the required quantities and rates						■									
10. Finalise priority against available budget						■									
11. Plan plant needs						■									
12. Arrange implementation and prepare documents						■									
13. Prepare for plant propagation						■	■	■	■	■	■	■	■		
14. Make the necessary site arrangements							■								
15. Prepare the site								■							
16. Implement the civil engineering works									■	■	■				
17. Implement the bioengineering works												■	■	■	
18. Monitor the works													■	■	■
19. Maintain the works															■

Note:

Month 4= Shrawan
Month 5= Bhadra
Month 6= Aswin
Month 7= Kartik
Month 8= Mangsir
Month 9= Poush
Month 10= Magh
Month 11= Falgun
Month 12= Chaitra
Month 1= Baisakh
Month 2= Jestha
Month3= Ashad

Annex 20: Local names of plant species found on Nagarkot site

S.N.	Name of the species	Local Name	Family Name
1.	*Alnus nepalensis*	Utis	Betulaceae
2.	*Schima wallichii*	Chilaune	Theaceae
3.	*Litsea monopelata*	Kutmero	Lauraceae
4.	*Betula alnoides*	Saur	Betulaceae
5.	*Bambusa arundinaceae (Retz.) Wild.*	Taru Bans	Gramineae
6.	*Bambusa arundinaceae Wild.*	Tama Bans	Gramineae
7.	*Lagerstroemia parviflora*	Hade	Lythraceae
8.	*Castonopsis indica*	Katus	Fagaceae
9.	*Hygrocybe conica*	Vala	Hygrosphoraceae
10.	*Ficus nerifolia*	Dudhilo	Moraceae
11.	*Ficus auriculata*	Nimaro	Moraceae
12.	*Choerospondias axillaris*	Lapsi	Anacardiaceae
13.	*Lyonia ovalifolia*	Angeri	Ericaceae
14.	*Prunus cerasoides*	Painyu	Rosaceae

Annex 21: Local names of plant species found on Tathali site

S.N.	Name of the species	Local Name	Family Name
1.	*Alnus nepalensis*	Utis	Betulaceae
2.	*Melia azederach*	Bakenu	Meliaceae
3.	*Prunus cerasoides*	Painyu	Rosaceae
4.	*Toona ciliata*	Tooni	Meliaceae
5.	*Bambusa arundinaceae*	Bans	Gramineae

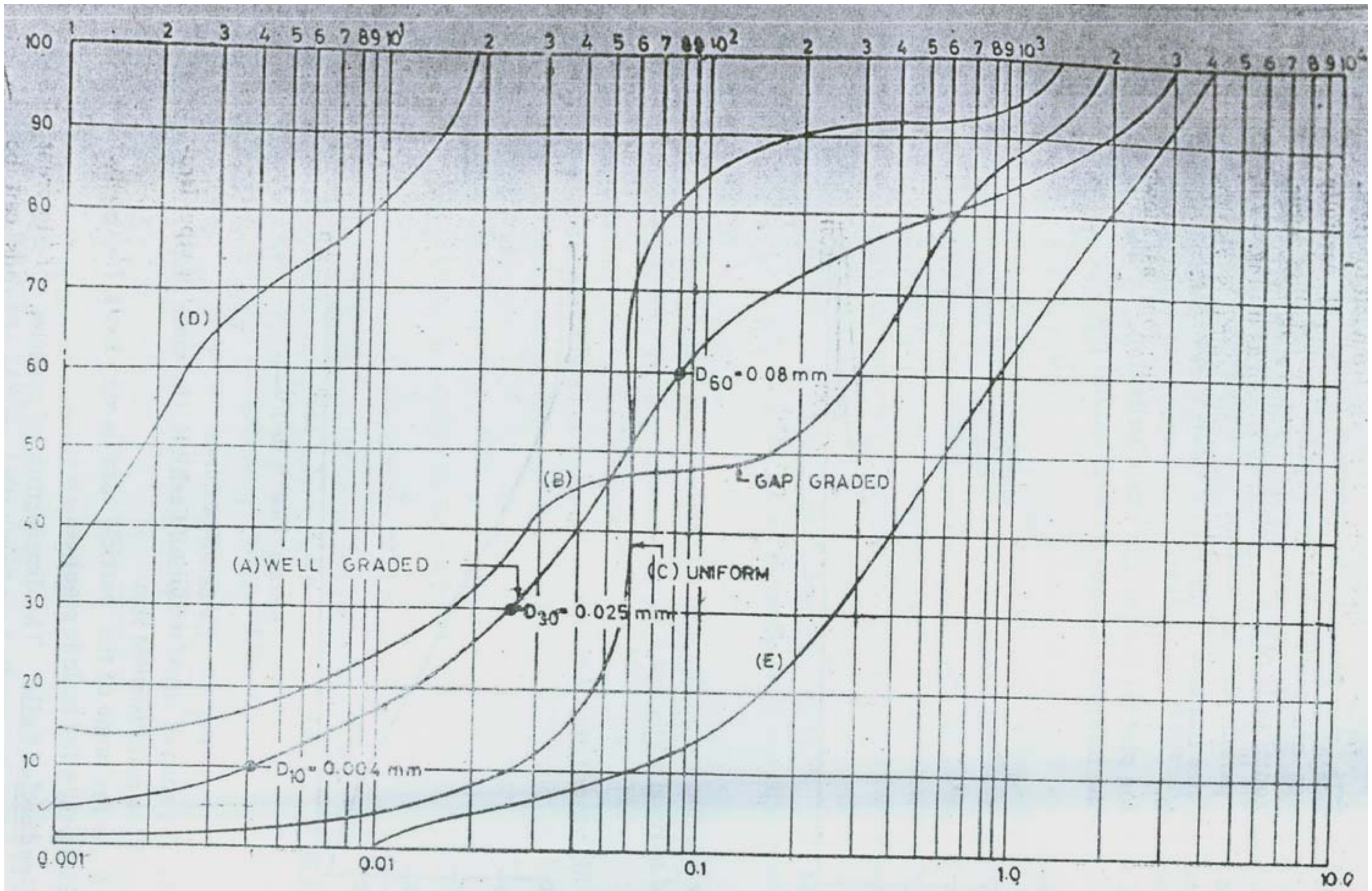
Annex 22:

<table>
<tr><th colspan="9">LABORATORY CRITERIA FOR UNIFIED SOIL CLASSIFICATION SYSTEM</th></tr>
<tr><th colspan="7">LABORATORY CLASSIFICATION CRITERIA[1]</th><th>GROUP SYMBOLS</th><th>TYPICAL NAMES[2]</th></tr>
<tr><td rowspan="8">Coarse Grained Soils Less than 50% passing No. 200 sieve</td><td rowspan="8">Sands and Gravels</td><td rowspan="4">GRAVELS
Less than half of the coarse fraction passes the No. 4 sieve size</td><td rowspan="2">Less than 5% passing the No. 200 sieve size</td><td rowspan="4">Borderline cases requiring the use of dual symbols (i.e. SW-SC)</td><td colspan="2">$C_u = D_{60} / D_{10}$ Greater than 4;
$C_c = (D_{30})^2 / (D_{60} X D_{10})$ Between 1 and 3</td><td>GW</td><td>Well graded gravels, gravel-sand mixtures, little or no fines</td></tr>
<tr><td colspan="2">Not meeting both C_u and C_c requirements above</td><td>GP</td><td>Poorly graded gravels, gravel-sand mixtures, little or no fines</td></tr>
<tr><td rowspan="2">More than 12% passing the No. 200 sieve size</td><td rowspan="2">Above "A" line with PI between 4 and 7 requires the use of dual symbols (GC-GM)</td><td>Atterberg limits below "A" line, or PI<4</td><td>GM</td><td>Silty gravels, gravel-sand-silt mixtures</td></tr>
<tr><td>Atterberg limits above "A" line, or PI>7</td><td>GC</td><td>Clayey gravels, gravel-sand-clay mixtures</td></tr>
<tr><td rowspan="4">SANDS
More than half of the coarse fraction passes the No. 4 sieve size</td><td rowspan="2">Less than 5% passing the No. 200 sieve size</td><td rowspan="4">5% to 12% passing the No. 200 sieve size</td><td colspan="2">$C_u = D_{60} / D_{10}$ Greater than 4;
$C_c = (D_{30})^2 / (D_{60} X D_{10})$ Between 1 and 3</td><td>SW</td><td>Well-graded sands, gravelly sands, little or no fines</td></tr>
<tr><td colspan="2">Not meeting both C_u and C_c requirements above</td><td>SP</td><td>Poorly graded sands, gravelly sands, little or no fines</td></tr>
<tr><td rowspan="2">More than 12% passing the No. 200 sieve size</td><td rowspan="2">Above "A" line with PI between 4 and 7 requires the use of dual symbols (SC-SM)</td><td>Atterberg limits below "A" line, or PI<4</td><td>SM</td><td>Silty sands, sand-silt mixtures</td></tr>
<tr><td>Atterberg limits above "A" line, or PI>7</td><td>SC</td><td>Clayey sands, sand-clay mixtures</td></tr>
<tr><td rowspan="6">Fine Grained Soils More than 50% passing No. 200 sieve</td><td rowspan="6">Silts and Clays</td><td rowspan="6">GO TO PLASTICITY CHART</td><td colspan="4" rowspan="5"></td><td>ML</td><td>Inorganic silts and very fine sands, rock flour silty or clayey fine sands with slight plasticity</td></tr>
<tr><td>CL</td><td>Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays</td></tr>
<tr><td>MH</td><td>Inorganic silts, micaceous or diatomaceous, fine sandy or silty soils, elastic silts</td></tr>
<tr><td>CH</td><td>Inorganic clays of high plasticity, fat clays</td></tr>
<tr><td>OL</td><td>Organic silts and organic silt-clays of low plasticity LL<50</td></tr>
<tr><td colspan="4">Below "A" line and $\frac{LL\ (oven\ dry\ soil)}{LL\ (air\ dry\ soil)} < 0.75$</td><td>OH</td><td>Organic clays of medium to high plasticity LL>50</td></tr>
<tr><td colspan="3"></td><td colspan="4">Visual identification only</td><td>PI</td><td>Peat or other highly organic soils</td></tr>
</table>

[1] Work from left to right across chart
[2] Typical names not necessarily appropriate for individual soil description

Sourrce: Krahenbuhl and Wagner 1983

Annex 23: Particle size distribution curves of different soils



PERCENTAGE FINER- P

DIAMETER- D (mm)

Sourrce: Arora, 1997

Annex 24: Calculation of Highway Slope Site Drought Factor

Department of Roads
Geological-Environmental Unit

BIO-ENGINEERING FOR ROAD OVERSEERS

HIGHWAY SLOPE SITE DROUGHT FACTOR **Session OV -31**

This is a simple scoring system which classes roadside slopes according to the seriousness of the dryness. There are five factors to consider:

a. Slope angle;
b. Stoniness;
c. Altitude;
d. Aspect;
e. Annual rainfall.

a. Slope angle

Slope	Score
$<30^0$	1
30 - 34^0	2
35 - 39^0	3
40 - 44^0	4
40 - 49^0	5
$>49^0$	6

b. Stoniness

Fines	Score
>25%	1
20 – 25%	2
15 – 19%	3
10 – 14%	4
5 – 9%	5
<5%	6

c. Altitude

Altitude	Score
> 2500m	1
2000 -2500	2
1500 – 1950m	3
1000 – 1450m	4
500 – 950m	5
< 500m	6

d. Aspect

Aspect	Score
North	0
North-east	2
North-west	4
East	6
West	8
South-east	10
South-west	10
South	12

e. Annual Rainfall

Rainfall	Score
> 2500 mm	1
2000 – 2490 mm	2
1500 – 1990 mm	3
1000 – 1490 mm	4
500 – 990 mm	6
< 500 mm	8

Classes

Score	Class	Definition
< 6	I	Cool, moist sites
6 – 11	II	Damp sites
12 – 17	III	Moderately dry sites
18 – 23	IV	Warm, dry sites
24 – 30	V	Very hot and dry sites
> 30	VI	Very severely hot and dry sites

Annex 25:

Landslide Assessment form

Date of survey:

Site:

Field Supervisor:

Chainage:

Side of Road: Hill/ Valley/ Right/ Left

1. Geometry

Extent:

Width of slope at toe [ ] m

Depth (approx) [ ] m

Length of slope failure [ ] m

Slope angle range [ ] deg.

Average angle of slope [ ] deg

Fig. Schematic Diagram of Landslide

Fig. Section of Landslide

2. Geological Characteristics

Composition of landslide mass

Alluvium ☐ Colluvium ☐ Lake Deposit ☐ Others ( )

Characteristics of Gravel/ Sand/ Silt/ Clay/ Peat/ Others ( )

Rock type

Soft Rock- Siltstone/ Phyllite/ Slate/ Clay stone/ Schist/ Other ( )

Hard Rock- Quartzite/ Granite/ Gneiss/ Lime Stone/

Sand Stone/ Dolomite/ Other ( )

Size Big ☐ Small ☐

Tone (Colour) Site ☐

Weathering condition High- H ☐ Moderate- M ☐ Low-L ☐

Others (Mention) – rock characteristics and structure

3. Geomorphological Characteristics

Scarp Y/ ☐ N ☐

Existing if Y, Length: ☐ m Height: ☐ m Gradient ☐

Tension Crack Y/ ☐ N ☐

if Y, Length: ☐ m Height: ☐ m Number: ☐

Gully Y/ ☐ N ☐

if Y, Number: ☐

Other Remarks:

4. Hydrological Information

Ground water condition

Dry ☐ Wet ☐ Flowing ☐ Discharge ☐

Number of gullies No ☐ Few ☐ Many ☐

Surface water run-off Y ☐ N ☐

Type/ Condition of existing drainage ☐

Remarks (rainfall pattern)

☐

5. Vegetation/ Land use

Vegetation Type Tree ☐ Shrubs ☐ Grass ☐

Tree inclination

Towards Toe ☐ Towards Scarp ☐ Several Bending ☐

Land use (Mention)

Forest ☐ Residential area ☐ Khet ☐ Bari ☐

Vegetation density Thick ☐ Moderate ☐ Sparse ☐ Barren ☐

6. Damage to the facilities, Structures

Cultivated land Y ☐ N ☐

if Y, Cropping pattern ☐

Damage ☐ ha/Ropani

Road surface Y ☐ N ☐

if Y, Pavement Crack/ Slide/ Depression Damage: ☐ m

Shoulder Crack/ Slide/ Depression Damage: ☐ m

Residence Y ☐ N ☐

if Y, No. of houses ☐

Type of damage ☐

Water channel Y ☐ N ☐

if Y, Damage: ☐ m

Others:

☐

7. Remarks:

a. Seismicity:

b. Megastructure of geology:

c. Man-made causes:

d. History of Landslide:

e. Others:

Source: Paudyal, 2005

Annex 26:

TRIBHUVAN UNIVERSITY

Central Department of Environmental Science
Kirtipur, Kathmandu, Nepal

Grain Size Analysis

Mechanical Method

Project: Soil Analysis

Location of the Project: Nagarkot Phedi Landslide area, Site A at top

Bore Hole No:

Description of Soil:

Date of Testing: 2062-08-11

Depth of Sample: 15cm

Type of Analysis: Wet Dry √

Soil Sample No: S_1

Mass of Total Soil Sample taken for analysis (gm) = 250 gm

Sieve No.	Sieve Opening (mm)	Mass of Sieve (gm)	Mass of Sieve+Soil (gm)	Mass of Soil Retained (gm)	Cumulative Mass of Soil Retained (gm)	Cumulative % of Soil Retained	% Passing
1	2	3	4	5	6	7	8
	2			10.66	10.66	4.27	95.73
	1			10.15	20.81	8.34	91.66
	0.85			4.65	25.46	10.20	89.9
	0.45			17.1	42.56	17.05	82.95
	0.212			25.0	67.56	27.06	72.94
	0.106			54.52	122.08	48.90	51.1
	0.053			73.58	195.66	78.38	21.62
	Pan			53.98	249.64	100	0
			Total	249.64			

Remarks: % error = $\frac{250 - 249.64}{250}$ x 100 = 0.14 %

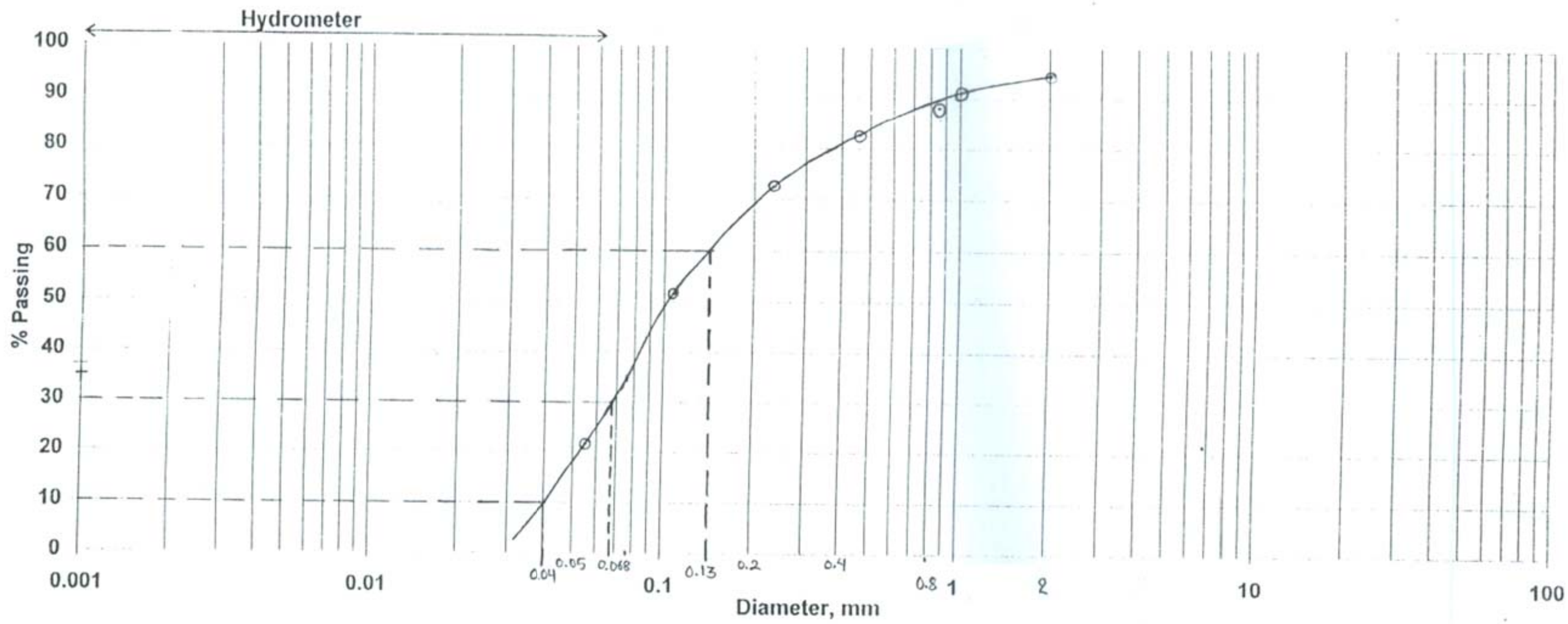
Tested by:

Checked by:

Date:

Project: Location: Hole No: Soil Sample No. and Depth: S_1

Grain Size Distribution Curve



Clay	Silt	Sand		Gravel			AASHTO
		Fine	Coarse	Fine	Medium	Coarse	

Description of Soil:

Tested by

Checked by:

Date:

TRIBHUVAN UNIVERSITY
Central Department of Environmental Science
Kirtipur, Kathmandu, Nepal

Grain Size Analysis
Mechanical Method

Project: Soil Analysis

Location of the Project: Nagarkot Phedi Landslide area, Site A at middle

Bore Hole No:

Description of Soil:

Date of Testing: 2062-08-11

Depth of Sample: 15cm

Type of Analysis: Wet Dry √

Soil Sample No: S_2

Mass of Total Soil Sample taken for analysis (gm) = 200 gm

Sieve No.	Sieve Opening (mm)	Mass of Sieve (gm)	Mass of Sieve+Soil (gm)	Mass of Soil Retained (gm)	Cumulative Mass of Soil Retained (gm)	Cumulative % of Soil Retained	% Passing
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	2			7.23	7.23	3.65	96.35
	1			15.07	22.30	11.25	88.75
	0.85			6.01	28.31	14.28	85.72
	0.45			17.13	45.44	22.92	77.08
	0.212			19.73	65.17	32.87	67.13
	0.106			35.20	100.37	50.62	49.38
	0.053			50.41	150.78	76.04	23.96
	Pan			47.50	198.28	100	0
			Total	198.28			

Remarks: % error = $\frac{200-198.28}{200}$ x 100 = 0.86 %

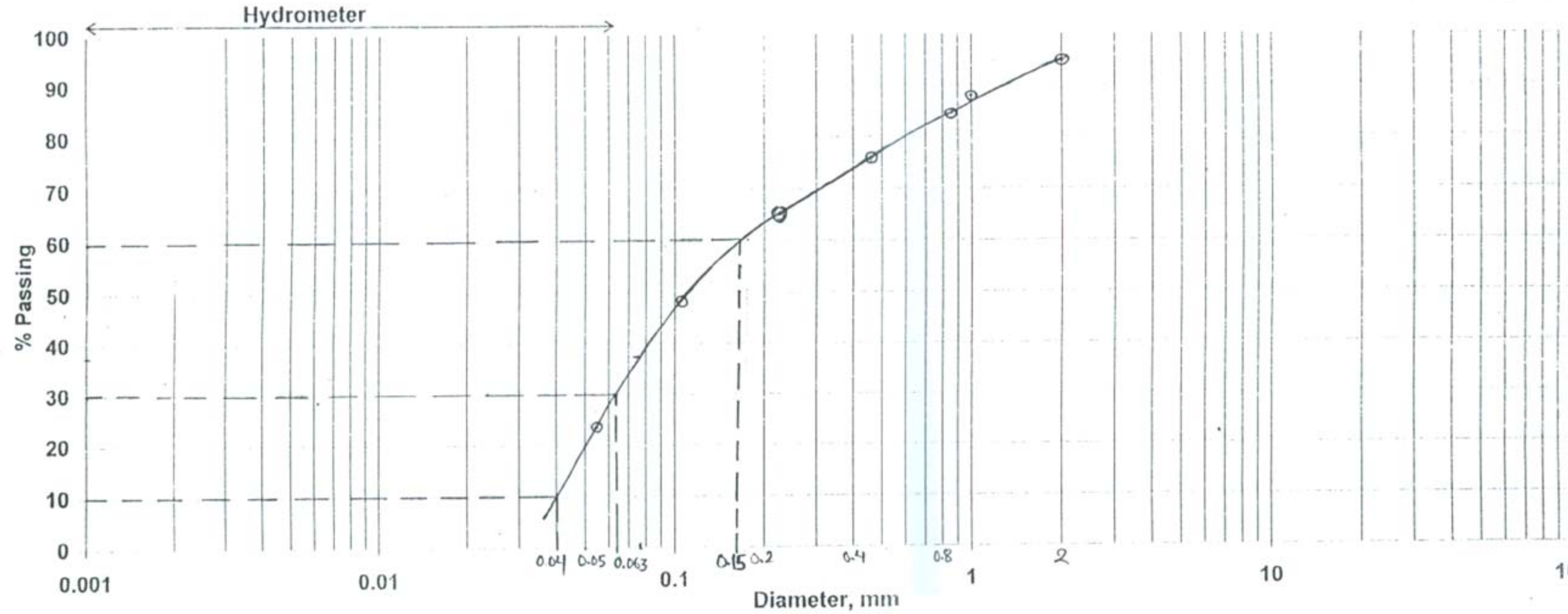
Tested by:

Checked by:

Date:

Project: Location: Hole No: Soil Sample No. and Depth: S2

Grain Size Distribution Curve



Clay	Silt	Sand		Gravel			AASHTO
		Fine	Coarse	Fine	Medium	Coarse	

Description of Soil:

Tested by Checked by: Date:

TRIBHUVAN UNIVERSITY
Central Department of Environmental Science
Kirtipur, Kathmandu, Nepal

Grain Size Analysis
Mechanical Method

Project: Soil Analysis

Location of the Project: Nagarkot Phedi Landslide area, Site A at base

Bore Hole No:

Description of Soil:

Date of Testing: 2062-08-11

Depth of Sample: 15cm

Type of Analysis: Wet Dry √

Soil Sample No: S_3

Mass of Total Soil Sample taken for analysis (gm) = 250 gm

Sieve No.	Sieve Opening (mm)	Mass of Sieve (gm)	Mass of Sieve+Soil (gm)	Mass of Soil Retained (gm)	Cumulative Mass of Soil Retained (gm)	Cumulative % of Soil Retained	% Passing
1	2	3	4	5	6	7	8
	2			6.12	6.12	2.45	97.55
	1			10.02	16.14	6.46	93.54
	0.85			5.83	21.97	8.79	91.21
	0.45			20.10	42.07	16.83	83.17
	0.212			25.26	67.33	26.94	73.06
	0.106			49.93	117.26	46.91	53..09
	0.053			78.24	195.5	78.22	21.78
	Pan			54.45	249.95	100	0
			Total	249.95			

Remarks: % error = $\frac{250 - 249.95}{250}$ x 100 = 0.02 %

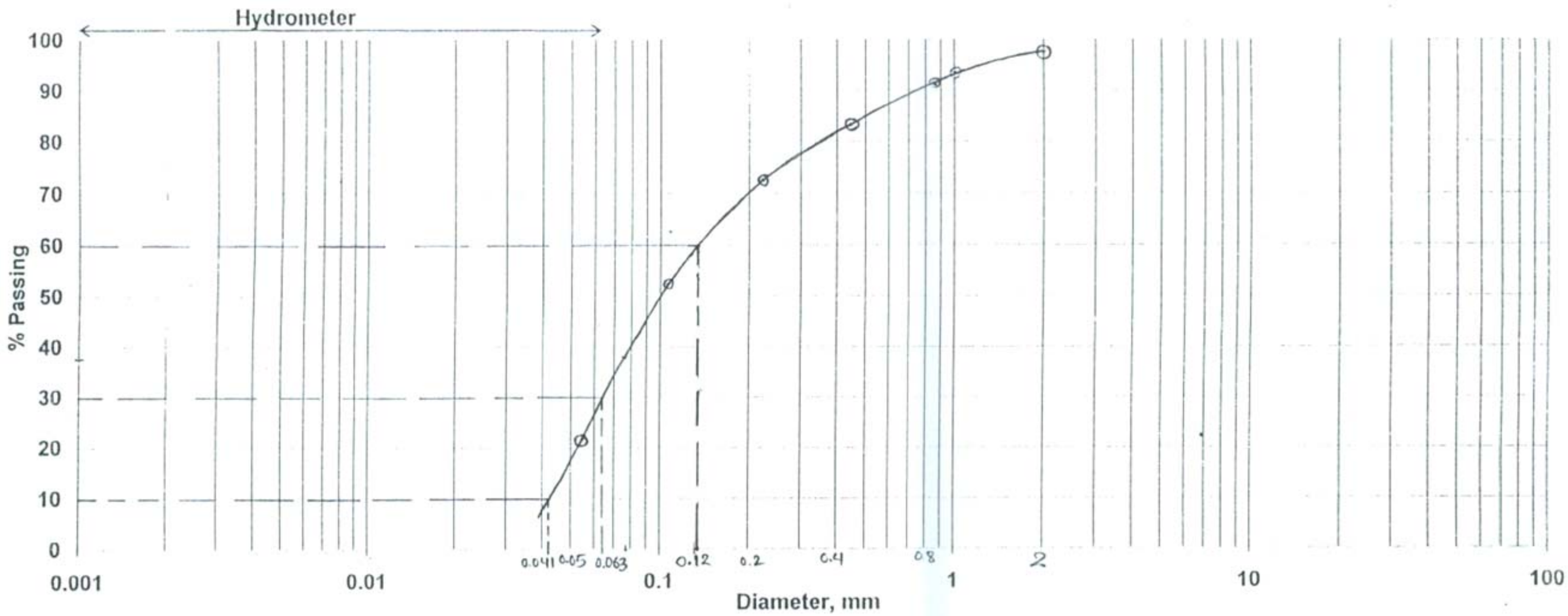
Tested by:

Checked by:

Date:

Project: Location: Hole No: Soil Sample No. and Depth: S3

Grain Size Distribution Curve



Clay	Silt	Sand		Gravel			AASHTO
		Fine	Coarse	Fine	Medium	Coarse	

Descripti n of Soil:

Tested by Checked by: Date:

TRIBHUVAN UNIVERSITY

Central Department of Environmental Science
Kirtipur, Kathmandu, Nepal

Grain Size Analysis

Mechanical Method

Project: Soil Analysis

Location of the Project: Nagarkot Phedi Road area, Site B

Bore Hole No:

Description of Soil:

Date of Testing: 2062-08-11

Depth of Sample: 15cm

Type of Analysis: Wet Dry √

Soil Sample No: S_4

Mass of Total Soil Sample taken for analysis (gm) = 300 gm

Sieve No.	Sieve Opening (mm)	Mass of Sieve (gm)	Mass of Sieve+Soil (gm)	Mass of Soil Retained (gm)	Cumulative Mass of Soil Retained (gm)	Cumulative % of Soil Retained	% Passing
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	2			2.65	2.65	0.89	99.11
	1			7.82	10.47	3.52	96.48
	0.85			4.06	14.53	4.88	95.12
	0.45			16.37	30.90	10.38	89.62
	0.212			26.87	57.77	19.41	80.59
	0.106			76.61	134.38	45.14	54.86
	0.053			101.74	236.12	79.32	20.68
	Pan			61.56	297.68	100	0
			Total	297.68			

Remarks: % error = $\frac{300 - 297.68}{300}$ x 100 = 0.77 %

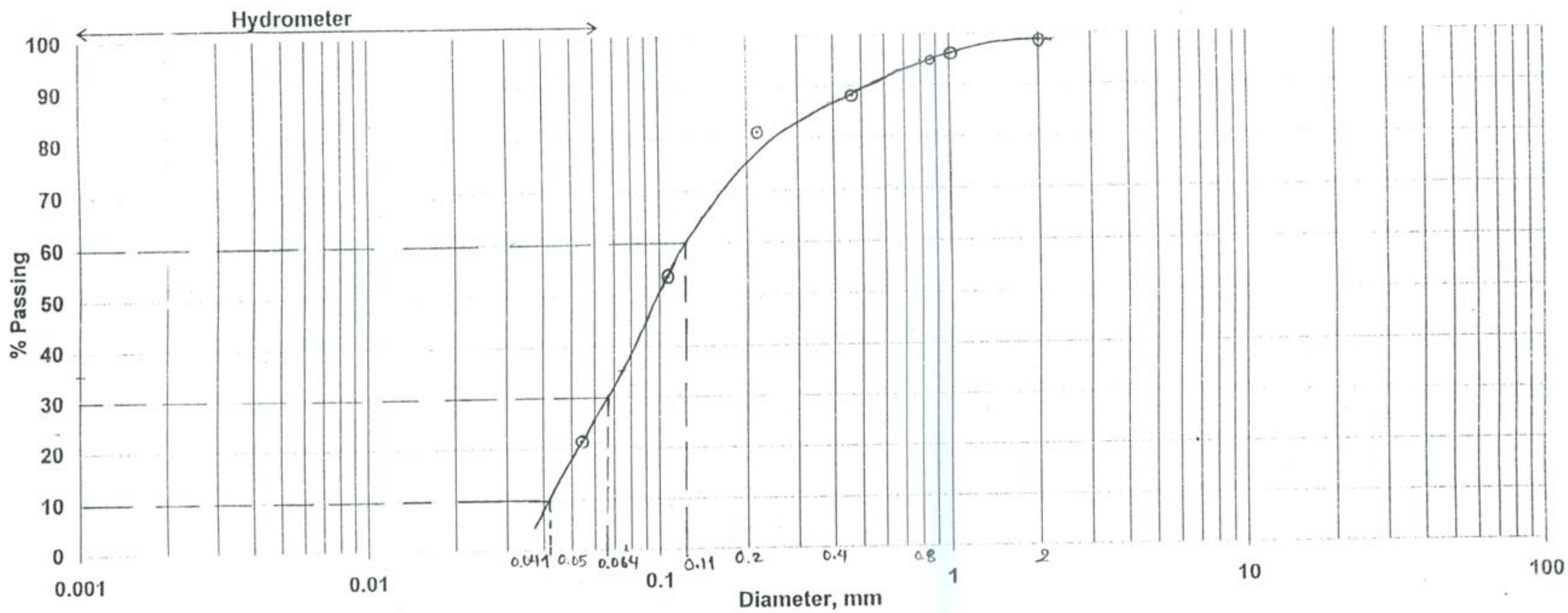
Tested by:

Checked by:

Date:

Project: Location: Hole No: Soil Sample No. and Depth: S4

Grain Size Distribution Curve



Clay	Silt	Sand		Gravel			AASHTO
		Fine	Coarse	Fine	Medium	Coarse	

Description of Soil:

Tested by: Checked by: Date:

TRIBHUVAN UNIVERSITY
Central Department of Environmental Science
Kirtipur, Kathmandu, Nepal

Grain Size Analysis
Mechanical Method

Project: Soil Analysis
Location of the Project: Tathali Phaidhoka Landslide site, Site C
Bore Hole No:
Description of Soil:
Date of Testing: 2062-08-11
Depth of Sample: 15cm
Type of Analysis: Wet Dry √
Soil Sample No: S_5
Mass of Total Soil Sample taken for analysis (gm) = 100 gm

Sieve No.	Sieve Opening (mm)	Mass of Sieve (gm)	Mass of Sieve+Soil (gm)	Mass of Soil Retained (gm)	Cumulative Mass of Soil Retained (gm)	Cumulative % of Soil Retained	% Passing
1	2	3	4	5	6	7	8
	2			0.76	0.76	0.78	99.22
	1			2.19	2.95	3.02	96.98
	0.85			1.35	4.30	4.40	95.60
	0.45			11.48	15.78	16.15	83.85
	0.212			18.72	34.50	35.32	64.68
	0.106			27.21	61.71	63.18	36.82
	0.053			26.84	88.55	90.65	9.35
	Pan			9.13	97.68	100	0
			Total	97.68			

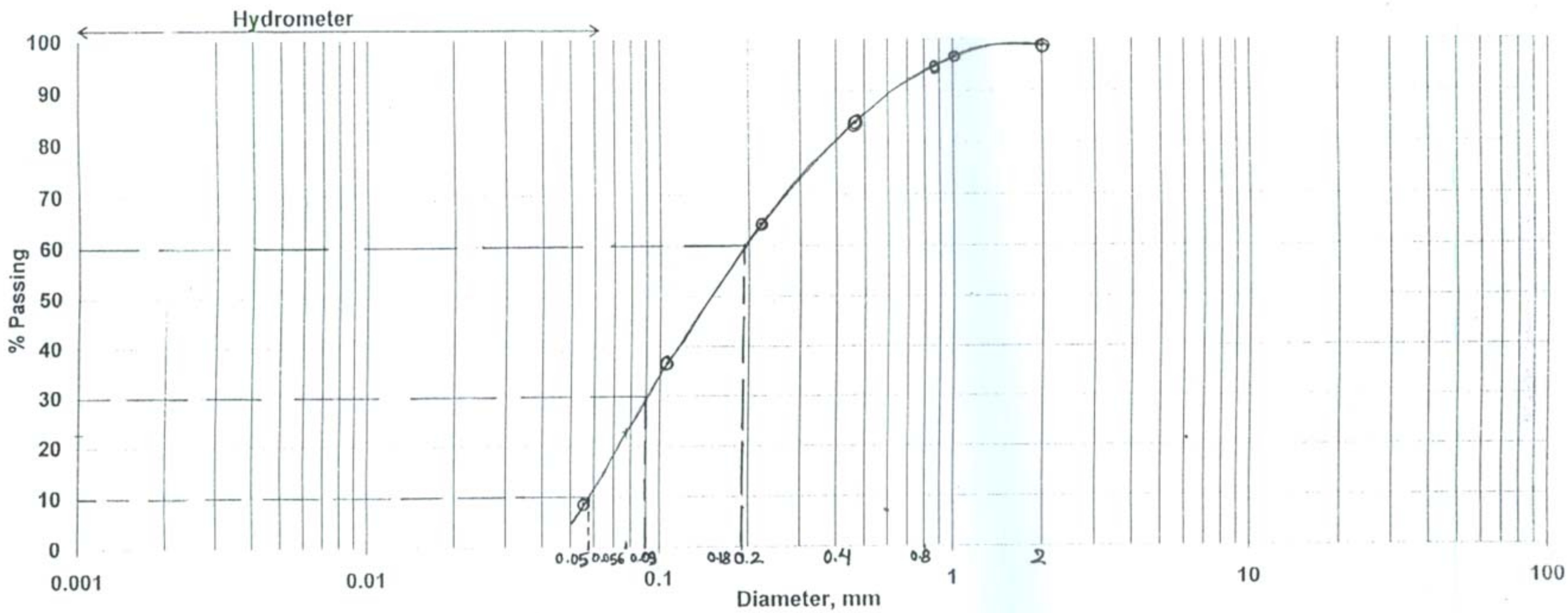
Remarks: % error = $\frac{100 - 97.68}{100}$ x 100 = 2.32 %

Tested by: **Checked by:**

Date:

Project: Location: Hole No: Soil Sample No. and Depth: S5

Grain Size Distribution Curve



Clay	Silt	Sand		Gravel			AASHTO
		Fine	Coarse	Fine	Medium	Coarse	

Description of Soil:

Tested by: Checked by: Date: