MASTER THESIS

ON

Assessing the protection function of Natural and Community Managed Forest against Landslides in the Mid-Hills of Nepal

Submitted by

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In partial fulfillment of the requirements for the degree

Masters in Mountain Forestry

at the

Institute of Silviculture

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ABSTRACT

Forests are being valued for goods and services beyond timber, one of those being the protection function. In Nepal, people suffer from landslides and erosion more than from any of the other natural disasters. The current study is focussing on the stabilization of slopes through forest vegetation and its management. It addresses the research question whether the protection efficiency of the forests in the hill slopes of Nepal is strong enough to contribute to the landslide prevention. For the study three sites were selected (a) Shivapuri National Park, (b) Nilbarahi Community Forest, (c) Private Forest Badikhel. For the assessment, a forest inventory was conducted representing slopes affected and not affected by landslides. In addition semi structured interviews were made with local people and experts in order to have an idea about the existence of the knowledge on tree species and their characteristics in relation to landslide prevention in the natural and managed forest.

Analysing the responses of local people and experts, the knowledge on the use of the species based on the scientific characteristics was found to be insufficient for the selection of the appropriate species against landslide. Based on ANOVA tests there were no significant differences among the landslide and non landslide areas of the sample plots regarding the calculated vegetation indicators. Also the Kolmogorov-Smirnov test conducted to test the diameter distribution of slide and non slide areas of the forest types shows the similarity of the distribution. The regeneration of the tree species was found to be insufficient for the sustained stability of the slopes in all the assessed forest types. The NaiS guideline which is taken as a supportive tool for defining the ideal forest with regard to the protection function of the forest reflects for most plots that both the slide and non slide areas of the natural and managed forest fulfil the condition of ideal forest considering the parameters of the tree and regeneration but the key note is that it is very important to consider the species composition in the study area and NaiS does not consider this. Finally, it can be concluded that NaiS is not suitable to assess the landslide protection functionality in Nepal and secondly, beyond the efficiency of the forest there are several factors triggering the landslide conditions. There is a need of evaluation of protective functions to be fulfilled by forest against landslides by the concerned authorities in the context of the study sites in Nepal.

Key words: Nepal, Mid hills, natural and managed forest, protection efficiency, landslides, forest inventory, indicators

ZUSAMMENFASSUNG

In Nepal ist die Schutzfunktionalität von Waldvegetation in bezug auf Hangrutschungen und Erosion von besonderer Bedeutung. Die vorliegende Arbeit behandelt die Stabilisierung von Hängen durch Waldvegetation bzw. dessen Management, insbesondere die Frage, ob die Schutzwirkung von Wald in den Midhills von Nepal zur Verhinderung von Hangrutschungen signifikant ist. Drei Regionen wurden in den Analysen behandelt: (a) (a) Shivapuri National Park, (b) Nilbarahi Community Forest, (c) der Privatwald Badikhel. U.a. wurden in diesen Gebieten eine Waldinventur durchgeführt, in deren rahmen Rutschgebiete und vergleichbare nicht betroffene Hänge erfasst wurden. Zusätzlich wurden Interviews mit lokaler Bevölkerung sowie mit nepalesischen Experten zu geeigneten Baumarten für die Verhinderung von Rutschungen geführt.

Die Analyse der Interviews ergab, dass das vorhandene Wissen zur Schutzwirkung von Baumarten unzureichend für eine zielgerichtete Bewirtschaftung ist. Im Vergleich von Rutschgebieten mit nicht betroffenen Hängen konnten keine signifikanten Unterschiede für eine Reihe von Waldstrukturparametern gefunden werden (ANOVA, KS-Tests). Die vorhandene Verjüngung wurde als unzureichend für die dauernde Aufrechterhaltung von schutzgünstigen Waldstrukturen beurteilt. Desweiteren wurde die NaiS-Richtlinie auf die analysierten Waldflächen angewendet. In allen Fällen würden damit ideale Waldzustände diagnostiziert werden. Als ein wesentlicher Schwachpunkt des Ansatzes wurde die fehlende Sensitivität in bezug auf die Baumartenzusammensetzung beurteilt. Zusammenfassend wurde gefolgert, dass die NaiS-Richtlinie in der aktuellen Version in Nepal nicht sinnvoll anwendbar ist, um die Schutzfunktionalität von Waldvegetation in bezug auf Rutschungen und Erosion zu beurteilen. Neben dem Beitrag, den Vegetation leisten kann, müssten weitere Faktoren berücksichtigt werden. Weiterer Forschungsbedarf wurde diagnostiziert.

Schlüsselwörter: Nepal, Midhills, Naturwald, Gemeinschaftswald, Schutzwirkung, Hangrutschung, Erosion, Indikatoren

ACKNOWLWDGEMENT

I would like to thank all who supported me directly or contributed to this work indirectly.

First of all, I am very thankful to my supervisor, Ao.Univ.Prof. Dipl.-Ing. Dr. Manfred J. Lexer, who always supported me very patiently and motivated me with his great ability to cope with the difficult situations. I really admire his encouragement, guidance and motivation which helped me to understand the subject matter. Besides, I also learnt about the management of time from how he managed the time despite of his busy schedule. His guidance supported me a lot for the entire period of research and thesis writing.

I am very grateful to the Austrian Exchange Services, APPEAR program which enabled me by providing scholarship to undertake the MSc Mountain forestry at University of Natural Resources and Life sciences, Vienna. I would like to thank Katharina Engel, Elke Stinning and the entire office members for support during my stay in Vienna.

Thanks to the colleagues Nabin Dhungana and Uttam chapagain who supported me in the data collection period in Nepal. I really admire their flexibility and support.

The friendship of Adriana and Janine was inevitable to come up with the difficulties during my thesis writing. The time we spent together in Vienna is priceless.

I am thankful to my family, for being my back up and supporting me in every difficulty during my abroad studies. I heartly thank my friend Aakash Ghimire for his motivation and optimism. I also would admire the support of my cousin Dr. Madhusudan Acharya for the entire tasks and his encouragement to achieve the success.

Contents

Chapter 1: Introduction

1.1 An overview of forests in Nepal

Nepal, with area 147,181 sq km, occupies the central part of the Himalayas between latitudes 26°22’ and 30°27’ N and longitudes 80°40’ and 88°12’ E. The altitude varies from 67 m above sea level in the south-eastern Terai to 8848 m, the world’s highest peak in the north. The extreme altitudinal variation has resulted in the distinction of ecological belts such as Terai (67-300m), Hills (700-4000m) and the Mountains (above 4000m). The mid hills (average altitude 2000 m) occupy the central region of the country. Among the three major regions the mid hills cover about 57% of the total forest area of Nepal (JAFTA 2000). Below 1000m there are tropical forests dominated by *Shorea robusta* and replaced by *Acacia catechu* or *Dalbergia sisoo* along rivers. Sub tropical forests occur between 1,000-2,000m which include Pinus roxburghii, Alnus nepalensis, Schima wallichii and Castanopsis species whereas the lower temperate forests (2,000-2,700m) consist of Pinus wallichiana and several species of Quercus. Upper temperate forests (2,700-3,000m) include Quercus semicarpifolia forests along with Rhododendron arboretum, Acer species, Pinus wallichiana etc. Sub-alpine forests are found at around 3,000 m up to 4,200 m. *Abies spectabilis, Betula utilis* and *Rhododendron* forests and *Juniperus Indica* forest represent this category. The alpine zone has no trees, but shrubby *Rhododendron* and *Juniperus* are found up to 4,500 m. (FAO 1997).

Forests in general play a major role in sustaining society by supplementing income and providing a wide range of household use in developing countries like Nepal (Dhital et al. 1998). With the growing population and development activities, the condition of forests in Nepal is rapidly changing. Covering 37% of the total area, the forest is the most important natural ecosystem and extensive land use system in Nepal.

Forest has several functions such as wood and timber production, food resource or the maintenance of biodiversity. In mountain areas, forests have also an additional significant role: the protection against natural hazards. In order to prevent the natural hazards forest and its vegetation structure plays an important role. These forests, called protection forests, can partially or totally control some natural hazards such as erosion, floods, rock falls or avalanches (Renaud *et al.*, 1994). BRANG et. al (2001) stated that forest is a source of protection of people and resources from the hydro geomorphic hazards including landslides and erosion. Also, Sakals et al. (2006) conclude that natural and managed forests have been associated with reduced hazards like landslide, erosion, debris flows etc. Nepal being a mountainous country characterized by the rugged topography, variable climate and the complex geological structure which makes the country highly vulnerable to water induced hazards like landslide, erosion, debris flow etc. (Annual disaster review July 2007, series XIV; DWIDP; Nepal).

Being located in the central Hindu Kush region Nepal has a unique topography, geology, monsoon which plays a very important role in water induced disasters like landslide and erosion. Landslides and debris flows are the most common natural hazards in Nepal and cause disasters every year that bring hundreds of fatalities and loss of property worth hundreds of millions of rupees. In the last two decades, nearly one third of all deaths due to natural disasters came from landslides and floods. In the entire region of the hilly terrain of Nepal, landslides and debris flows are so pervasive that in one way or the other almost every individual is affected by these hazards. Many estimates of damage by these phenomena only take into account of the direct loss of life and property, but if the cost of labour spent by farmers is converted over the entire country on the maintenance of the damaged agriculture land every year and the loss of crops, the amount of loss is staggering. (Upreti, B.N. 2006). In 1979, more than 305 people were threatened for livelihood to leave the place as a big landslide occurred in Madi watershed area which was beyond the control of local people; in 1983 seven people were killed by a landslide and many were displaced in Madi watershed, western region on Nepal. This loss of life and properties from landslide and debris flow has been increasing and the livelihood options of mountain people have been threatened as they have to migrate in order to escape from the landslide (Khanal and Watanabe 2004). Due to landslide and floods alone the loss of lives are 303 persons per year. (Upreti B.N. 2006).

The sustainability of hazard control by forests depends on forest stability which in turn depends on stressors and disturbance agents. Usually, the protective efficiency decreases through time. Foresters have to adapt the silviculture to maintain or increase the protective function of these forests (Cloutet et.al 2008). Similarly, the forests of Nepal consist of the protected forests including national parks, wildlife reserves and the conservation areas which have been supportive for the resource protection as well as the hazard prevention especially in the hills of Nepal.

Forest land data of the past history show that the natural forest has been declining by 9% from 1964 to 1985. The quality of forest declined from high forest to shrub land areas which resulted into the reducing soil nutrient and increase in soil erosion (Pokhrel et.al 2005). Forest history and experiences in Nepal show that inappropriate and top down policies have led to forest degradation. Control and command approaches failed to bring positive outcomes in forest landscapes. Forest degradation was the major issue by 1980s in the mid hills areas leading to tremendous landslides which had a dramatic impact on the local communities. Then with the concept of the conservation and management involving the locals the concept of the landscape restoration has been implemented in the mid hills of Nepal. Recently, this system of forest management has been able to ensure the survival and strengthening of the forest areas (Jackson et.al. 2011).

1.2 Problem statement

In Nepal people suffer from landslides more than from any other type of natural disasters because of steep terrain, fragile geology and rainfall intensity characteristics. In case of Nepal, risk management of landslides in the hill slopes is not possible with higher technologies due to the fragile terrain and high cost. So the favorable medium is the establishment of suitable vegetation in the landslide prone areas (Dahal et al. 2008 and Devkota et.al 2006). As it is widely recognized that vegetation, particularly forest, can stabilize steep slopes, forest is the major source of protection of people from landslide and erosion especially in the hill slopes of Nepal (Devkota et.al 2006).

By 1980s it was clear that the forest degradation was a major problem in the mid hills of Nepal which led to an increase in landslides. As a consequence rural communities suffered, which clearly indicated that forest matters in Nepal especially in the hill slopes. The government of Nepal, Nepalese foresters and various agencies began the effort to involve the local communities in restoration of the forest in the mid hills. The communities were involved in the plantations and also in determining which species they planted and where they planted. This activity favored the restoration of the forest and somehow reduced the occurrence of landslides leading to the stabilization of the slopes on the community based forest land but still specific ideas about the most suitable tree and vegetation attributes is missing among the local people (Jackson et.al 2011). Therefore, there is still need for technical improvement for strengthening the effectiveness of vegetative measures with clear scientific research on identification of suitable species findings and the relationship between vegetation and the sliding to achieve the effective control measures (Devkota et al. 2006).

Plenty of literature is available about landslides and the protective effect of forest vegetation but still the study of protection efficiency of forest vegetation needs to be intensified in order to improve landslide prevention in the hill slopes of Nepal. It is essential to understand the importance of the protection function of forests at local, regional and national level in order to improve forest conditions efficiently and in a targeted way. As the current protection activities for landslides seem to be insufficient to prevent landslides and erosion, further studies are very important (Research report of IUCN 1999). Also, the importance of forests with protective function has increased in the last decades due to settlement pressure and high vulnerability of society. Therefore, the need of inventorying and monitoring protective functions of forests has increased subsequently (Bauerhansl et.al. 2010).

1.3 Objectives

The objective of the study is to assess the protection functionality of natural and managed forest in the mid hills of Nepal against landslides. The specific objectives include:

1. To review the available information on selected tree species regarding their effects on landslide prevention including expert interviews.
2. To assess and compare the structure and composition of forests in selected landslide and non-landslide areas in natural and managed forests.
3. To test an existing indicator based assessment scheme for the conditions in Nepal.
4. To synthesize and derive the preliminary conclusions regarding the forest management measures which positively affect the protection function of forest vegetation against landslides in the mid hills of Nepal.

Chapter 2: Literature review

2.1 The status of landslide in Nepal

The term landslide includes all varieties of mass movements of hill slopes and can be defined as the downward and outward movement of slope forming materials composed of rocks, soils, artificial fills or combination of these materials (Dey and Singh 2006).

Nepal being a mountainous country with difficult terrain and geology the problems of landslide hazards is being faced each year. The landslides are representing the constraints on development with high economic loss every year. Also there is a general consensus that the impacts of landslides in countries such as Nepal are increasing with time, but until now there has been little or no quantitative data to support this view, or to explain the causes of the increase. Petley *et al.* (2007) examined trends in fatal landslide activity in Nepal between 1978 and 2005.The dataset recorded for the period of 1978-2005 shows a total of 397 landslides in Nepal which caused 2179 fatalities, representing an average of 78 deaths per year. This database also suggests that there is a high level of variability in the occurrence of landslides from year to year, but that the overall trend is upward (see figure 1).

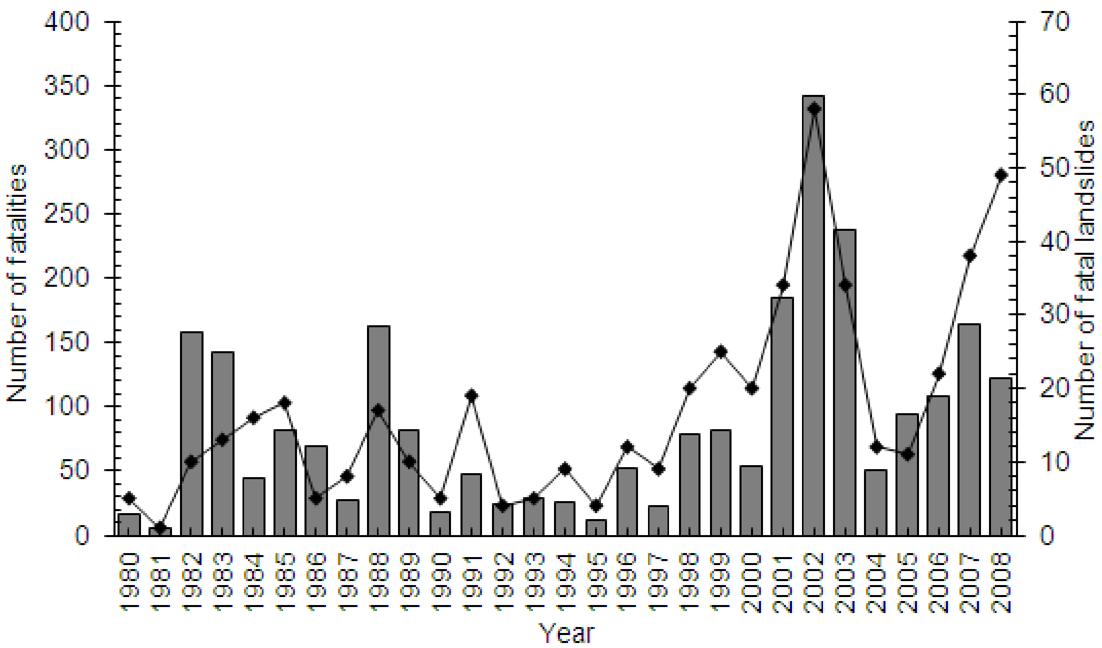


Figure 1: Number of landslide fatalities (bar graph, left hand scale) and number of fatal landslides (line graph, right hand scale) each year for the period 1978-2008 for Nepal. (Source: International Landslide Centre, 2009).

In general landslides concentrate in the hills of Nepal (Petley et al. 2007). Figure 2 shows the map of Nepal with the landslide prone hazardous areas mainly seen in the mid hills of Nepal.

Among the major causes of landslides, the loss of forest cover is thought to be important in reducing the rate of evapo-transpiration on slopes, leading to higher groundwater levels and water saturated soil horizons, to reduce cohesion through the loss of root strength and to increase overland flow, which enhances the rate of erosion and landslides (Crozier 2005).

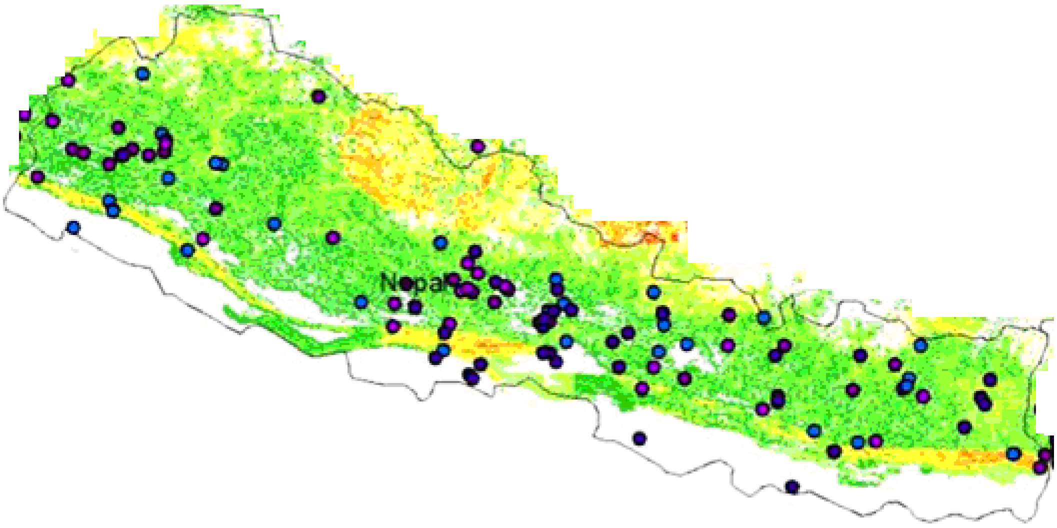


Figure 2: Map of Nepal showing the rainfall induced major landslide areas (mainly mid hills-green color). Source: Nepal Hazard Risk Assessment Study Project (2009)

2.2 Role of Forest for reducing landslide hazard

Forest is generally understood as an area dominated by trees along with plants and shrubs; having crown cover of more than 10 percent and a minimum contagious area of 0,5 hectares (FRA 2000). The forest is responsible for various functions like water resources, protection against various hazards, intercepting pollutants, etc. (Millennium Ecosystem Assessment 2005).

Forests offer protection from hydro geomorphic hazards in two broad ways (Motta and Haudemand 2000). Indirect protection refers to the general role of forests in reducing soil erosion or improving watershed condition and air quality. Direct protection forests specifically protect people, buildings, or utility corridors. Forest offers protection against hydro geomorphic hazards as the physical structure of the forest helps in material retention and roots increase slope stability with reinforcement (Sakals et.al 2006). Forest canopies intercept precipitation. Water intercepted in forest canopies is typically evaporated. This evaporation reduces water availability for other hydro- geomorphic processes, such as surface erosion or land sliding (Hewlett 1982). The stems of trees, both standing and down reduce the areas disturbed by snow avalanches, rock falls, floods, debris floods and debris flows. If the protection service is desired for the long-term, the management of the forest must be sensitive to the forest as it affects the rapidity of protective function recovery after disturbance (Sakals et al. 2006).

Forest canopy acts as the cover to control the heating and drying effects which generates the cracks in soils and also reduces the surface erosion due to vegetation cover. The roots of the trees provide stability to the slope providing reinforcement of the surface soil. As the leaves of the trees intercepts the rain reducing the evapo-transpiration and infiltration which supports slope stability (Acharya 2007).

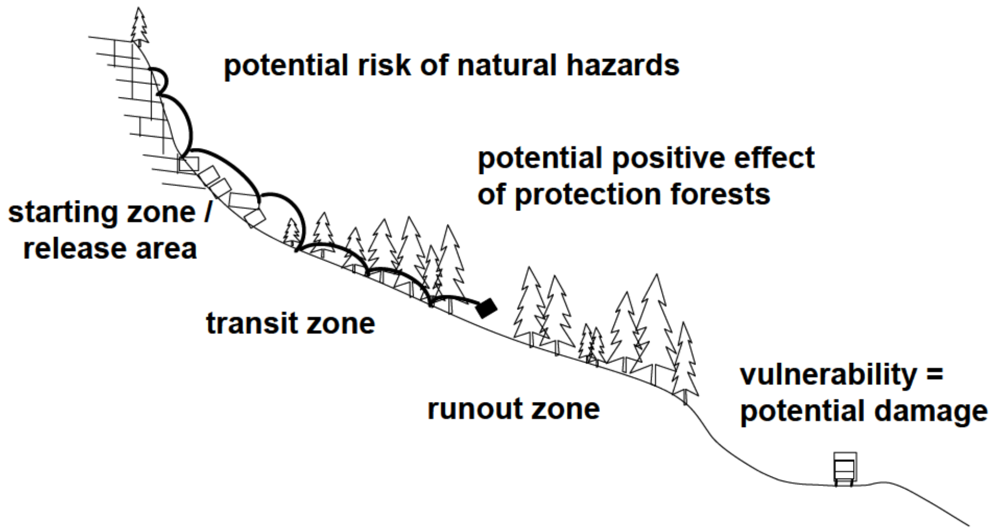


Figure 3: Illustration of forest with protective effect, protecting infrastructure against rock fall (source: European commission, Joint Research report 2010)

The protective effects of forest correspond to the current capability or suitability of the stand to prevent certain hazardous natural incidents before they occur, or in order to dampen their effects (Brändli et.al 2001). These protective forests have the primary function as the protection of people and assets against the natural hazards. The main product of these forest are the standing trees which act as an obstacle to down slope mass movements such as rock falls, avalanches, landslides, debris flows and floods. By increasing the roughness of the land surface, stabilizing the ground through widely ramified root systems and the snow cover through natural barriers formed by the stems, stumps and lying deadwood forest cover reduces the frequency and magnitude of natural hazards more than any other land cover or land use (Hamilton et al. 1997, Van et al. 1996). The protective effect of these forests is ensured only if the silvicultural system used and any natural disturbances that occur leave a sufficient amount of forest cover (Brang et. al 2006). It is however unsure whether all forests types can fulfill these protective functions continuously on a long run without management, or if the natural succession will lead to temporal stand wise breakdown or reduction of forest cover before the next forest generation can take over the protection (Dorren et al. 2004). For episodic hydro geomorphic hazards, protection forests of both varieties are an attractive measure due to their risk reduction services and relatively low costs (Schönenberger and Brang 2004). The appropriate designation and management of protection forests can make mountain regions safer for people and protect resources.

The maintenance of protection forest functions through active management appears to be a more recent idea. For centuries, the only action in some European protection forests was to ban woodcutting. This has resulted in a series of problems as the forests became over-mature from a lack of disturbance and under-utilization (Motta and Haudemand 2000). Some Japanese forests are also experiencing reduced protective capacity as a result of similar issues; recently depressed timber prices have led to the inadequate management of hinoki (*Chamaecyparis obtusa*) forests. Disease and wind throw become more common in many older forests and canopy gaps are created. These gaps are areas of reduced structure (Schönenberger et al. 2005) and root cohesion (Sakals and Sidle 2004) that may increase snow avalanche, rock fall and landslide hazards. Untended forests will continue to provide a level of protection regardless of their designation or management regime; however, as noted above, the capacity of the forest to mitigate effects may be reduced.

Although it is understood that the structure of a forest plays a vital role in determining its efficiency as protective barrier (Kräuchi *et al.* 2000; Dorren and Berger 2006), little information exists concerning the effectiveness of different tree species in ameliorating the impacts of different abiotic hazards. Broadleaved species are generally more mechanically resistant than conifers and heal more quickly after wounding (Stokes 2006).

Chapter 3: Materials and methodology

In this chapter, the methods and materials are explained. Field measurements and observation results are used as primary data in the analysis. In addition, the previous research of similar nature has been reviewed and the relevant data and results are used in the analysis and interpretation of this research work.

3.1 Site selection

Three areas (Two managed forests and one natural forest) have been selected ranging from 1000- 3000m in altitude representing the mid hills of Nepal. These sites are selected considering the possibility of occurrences of landslides in areas with different type and intensity of vegetation coverage. The selected areas include (refer to map-figure)

i) Shivapuri National Park (Unmanaged natural forest)
ii) Nilbarahi Community Forest, Bhaktapur (Managed secondary forest)
iii) Private Forest, Badikhel Lalitpur (Managed secondary forest)

3.1.1 Shivapuri National Park

National park covering the total area of 159 sq. km with an elevation ranging from 1,360m to 2,732m at Shivapuri peak. Geologically, the park falls in Inner Himalayan region with the dominant rocks gneiss and magnetite with mica and granite. The soils of the area range from loamy sand on the northern side to sandy loam on the southern slope. Topography is mostly mountainous with steep slopes of >30%, because of this the soil erosion is very high particularly in the northern part. Shivapuri national park has tropical to warm temperate climate. There is a variation in annual temperature and precipitation. The temperature at 2066m altitude is recorded as maximum of 22,7°C in May/June and the minimum of 0,30°C in December/January. The mean annual precipitation was 2727mm mostly occurring during the monsoon period. Covering more than 70% of the total area, forest is the major natural resource of the park. The park consists of four types of forest distributed along the altitudinal gradient: (i) Lower mixed hardwood (*Schima-castanopsis*), (ii) Chir pine forest, (iii) Upper mixed hardwood forest (*Alnus sp, Quercus sp, Betula sp*), (iv) Oak forest (Shivapuri management plan, 2004).

According to the 2001 census, there are 101,493 people living in the national park buffer zone area indicating high woman population. The dominant ethnic group is Tamang a group always marginalized socially and economically. The literacy rate is 51% in the area. Ownership of land is powerful economic significance governing the livelihood of the people. As the tourism has been gradually flourishing, local people are attracted towards tourism related occupations as forest based livelihood options such as timber, firewood have been substantially reduced after the national park declaration (Shivapuri management plan, 2004).

Figure 4: View of plot no. 5 with landslide in Shivapuri National Park

3.1.2 Nilbarahi Community Forest, Bhaktapur

Community forest area lies about 10km from Kathmandu with elevation ranging from 1300-1400m above sea level. The community forest encompasses the area of about 300 ropanies (15 hectares). Because of the low altitudinal variation, the climatic conditions of the district range from cold to sub-tropical with total 78.32 mm rainfall annually. The temperature from March to September remains very hot and humid reaching up to 35 degree Celsius, whereas, during winter months the temperature drops down to minus 2 degree Celsius (LRMP/GIS, 1999 cited in DDC Profile). The area is covered by coarse sandy soil with forest area mostly dominated by the species *Schima wallichii, Myrsina species*, and *Erythrina variegata*.

The literacy rate of the whole district is high due to the proximity to the capital. Agriculture is the predominant occupation in the area Tourism within the Bhaktapur district has emerged as an important economic activity also influencing the Nilbarahi region making a significant effect on the livelihood of the ethnic groups (Tourism development and management plan Bhaktapur 2010-2014).

Figure 5: Plot no. 12 in Nilbarahi Community Forest

3.1.3 Private Forest, Badikhel Lalitpur

Badikhel VDC is about 15km from the capital Kathmandu. Among the total area 35% of the land is agricultural land which is suitable for crop production whereas 44.04% is productive forest. The area has a subtropical to temperate climate. Most of the forest is owned by communities and private owners. The forest is dominated mostly by *Alnus nepalensis, Schima wallichii, Pinus roxburghii* and *castanopsis species* with the predominant soil type being of high clay content.

In Badikhel VDC, 40.78% of the people are illiterate, 47.81% are just literate or have minimal education whereas only 11.47% are well educated. Resin extraction from the pine forest is the major income source of CFUGs and timber selling to the community members at very low price is also an another source of income (VDC profile 2003).

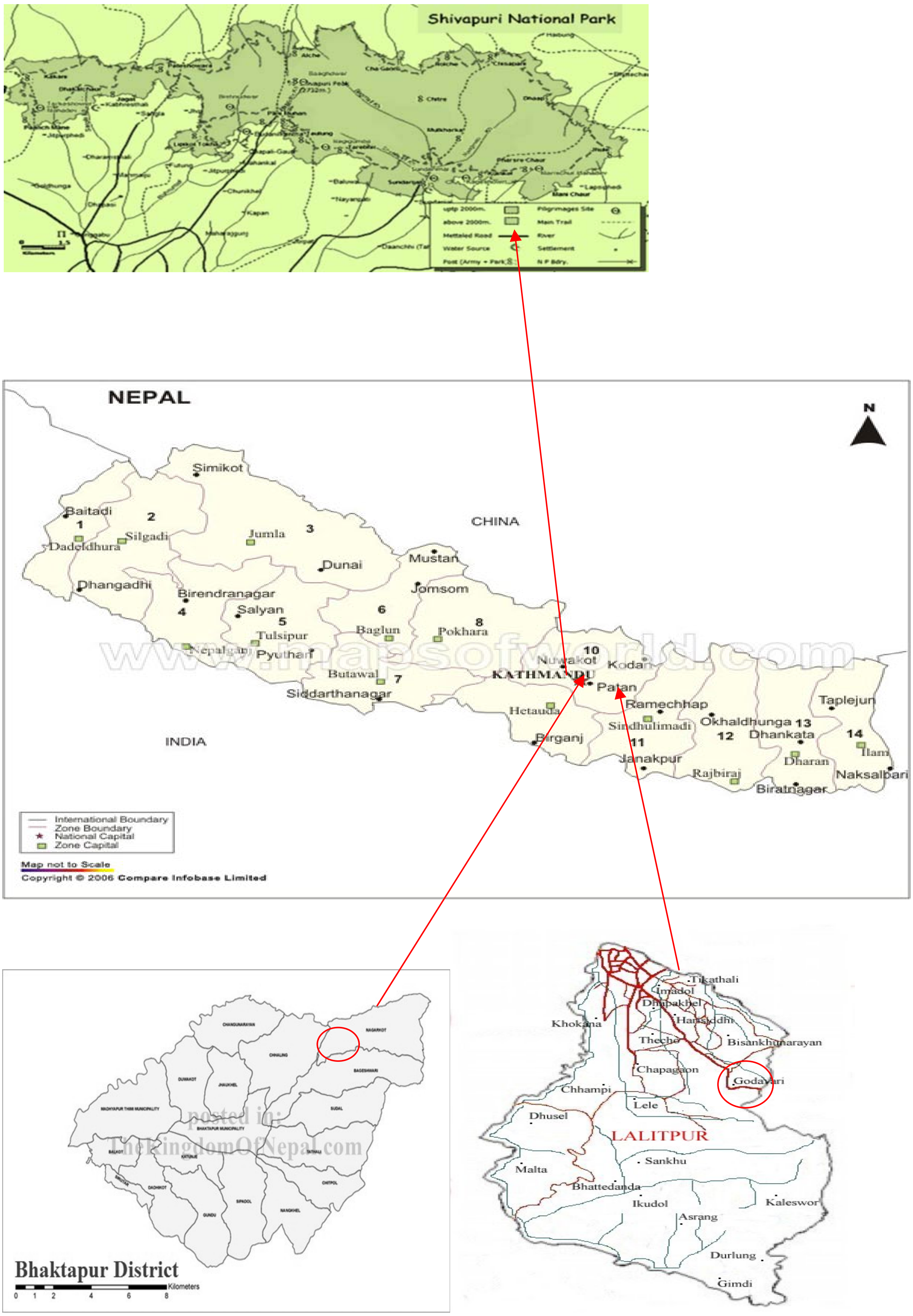


Figure 6: Map showing the study areas Shivapuri National park, Bhaktapur(circled Nilbarahi community forest) and Lalitpur (circled private forest)

3.2 Characterizing forest structure

3.2.1 Locating the sample plots

Considering the following procedure and criteria the sample plots were selected in the three sites:

1) The study area was screened for observed landslides

a) If landslide exists, the forest area was checked (the phase of stand development, age, structure, composition, etc) and the sample plot was placed so as to represent the slide area. The same conditions without a landslide were also represented by a separate plot.

b) If in a forest type no landslide occurred, this forest type without landslide was also eligible for locating a sample plot.

For the purpose of field observation and measurements, the selection of plots has been made as shown in Table 1.

Table 1 : Sample plots in the three study sites.

S.N.	Name of the Forest (ownership types)	Forest types	Number of plots	
			Land-slide Area	Non-Landslide Area
1	Shivapuri National Park	Unmanaged Natural forest	5	5
2	Nilbarahi Community Forest	Managed, secondary forest	3	3
3	Private Forest	Managed, secondary forest	2	2

20 sample plots (depending on the site) of approx. (15m-30m) × (15m-30m) depending on forest homogeneity and landslide size were selected. Among the 20 plots, 10 plots were selected in Shivapuri National park whereas 6 plots were selected in Nilbarahi community forest and 4 plots in the private forest in Lalitpur district.

3.2.2 Measurements in the sample plots

After the selection of the plot sites the forest inventories were made with the formation of rectangular sample plots. This sampling procedure is as follows. Within the sample plot the accurate position of each tree, tree diameter measured at 1,3m and 10cm above the ground; tree height, height to the live crown, crown size and damage were assessed for the trees with dbh >6cm. Within the sample plots circular sub sample plots with the radius of 1m were located where the tree regeneration (saplings/seedlings of height >15cm) were counted in species and size classes (height as 10-30cm, 31-50cm, 51-80cm, and 81-130cm, and in DBH classes of 0-3cm and 3-6cm). At each 5x5m grid node a sub sample plot was placed. From a number of seedlings and saplings the periodic height growth over the recent two complete vegetation periods was measured.

In addition the general site characteristics such as altitude, aspect, slope gradient, soil type, and ground cover, height of the ground cover, micro topography, and geology were assessed for each sample plot. Also the condition of the natural hazards (landslide/erosion) was observed according to their intensity of occurrence (light, heavy, small, shallow or deep) (Figure 7).

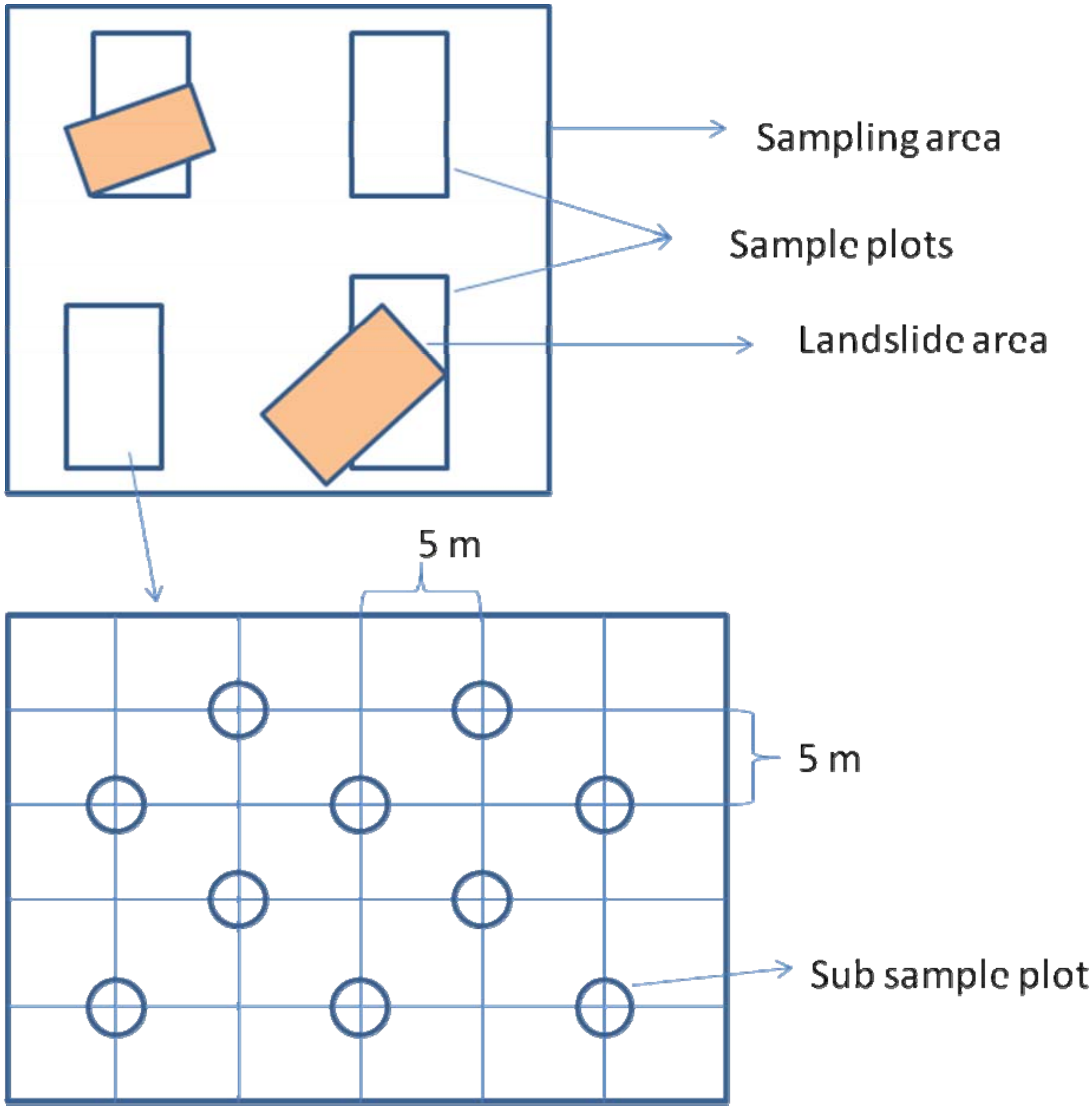


Figure 7: Layout of the rectangular sample plots with the circular sub plots.

This method is better to capture the forest stand structure and its features like crown diameter, gaps, etc. but it should also be considered that these plots are bigger and less in number so the variance may be high and it is difficult to generalize the characteristics with few plots so the selection has been made in order to generalize the features of the forest stand. Since the plots are larger the resources and time needed for the measurements per plot were also high.

3.3 Semi structured Interviews

This method was used in collecting the information on site. The interview was conducted with the local residents of the Dadagaun VDC in Shivapuri National park, the experts involved in managing the national park, the community forest users of Nilbarahi community forest, the local inhabitants around the community forest and the owners of the private forest in lalitpur district (Figure 8). The interview was made with the questionnaire (Annex I) which included the questions concerning the condition of forest and species composition before and after the landslide, the suitability for landslide protection and various problems with their management at the site regarding landslide conditions. Even though the species number was much higher the respondents described only limited number of species found in the field which might be due to the lack of knowledge regarding the specific attributes (scientifically) of the tree species that could contribute to the prevention of landslide in the hill slopes.

Figure 8: Community discussion at Dadagaun VDC in the buffer zone of Shivapuri National Park

3.4 Literature review

While searching through various websites and search engines, different research papers, journals, books online dissertations etc in order to find the attributes of the tree species using the key words “tree characteristics” , “trees” and “Nepal”, etc, various information has been collected. The collected papers were read and the main theme of the papers was noted. Then the tree attributes that were relevant for the current topic were collected from the respective paper and tabulated (Table 2).

Table 2: The key words and search engines used for literature search.

Key words	**Search engines**
Trees, characteristics Trees, Nepal Trees, landslide	www.scopus.com, www.sciencedirect.com, www.springerlink.com, www.google.com, www.wikipedia.org, www.forestrynepal.com, www.forestactionnepal.com, www.dwidp.gov.np, www.icimod.org, www.wwf.org

By examining trees which have and have not failed under mechanical loading, various authors have identified tree size and shape, wood strength, and root system characteristics as the most important factors governing tree stability (Stokes, 2006). Stokes (2006) report that root number and depth are the most important components of root system anchorage, and that species with shallow, plate-like root systems will be the least resistant to overturning. Therefore in a protection forest, highly branched and deep-rooted tree species should be encouraged in order to prevent the hazards like landslide. Each one of these factors is, in turn, influenced strongly by species type as the species type and composition will determine the ecosystem response to the disturbance. Fast-growing species, such as *Acer pseudoplatanus and Pinus sylvestris*, which colonize patches formed after a disturbance event (Schone and Schweingruber 2001; Wohlgemuth *et al.* 2002), might not confer the same potential protection against rock fall or mass movement activity as some slow growing broadleaved species.

For instance, Quercus species belong to the tree species with long roots (more than 6 m), deep-rooting (more than 1 m), which can penetrate through clay layers with a good capacity of reinforcing the banks of watercourses and soils against landslides. Also in deep soils the Pinus tree species forms a taproot with strong horizontal roots (also at two storeys), it is not afflicted by wind throws, and it reinforces well the soil against landslides. Alnus species are the trees species with short roots (max. 3 m), penetrating into medium depths which forms a heart shaped root system (the shape of a bell) when stronger but longer-reaching roots are missing (Čermák & Fér, 2007) Insufficient information is available concerning the complex relationship between species, tree age, and protection ability. Intuitively, older and larger trees should have the greatest resistance to mass movements. However, recent evidence suggests that young, healthy trees planted at a higher density than older, large trees (which often have internal decay) provide greater protection (Dorren *et al.* 2005).

Figure 9: Pinus roxburghii acting as an anchorage to prevent rock fall and landslides.

3.5 Analysis

The qualitative data (non-numerical) regarding the selected tree species has been incorporated into the analysis which supported the numerical findings to establish a clear link between qualitative and quantitative information in the final analysis. The information collected through interviews and literatures search (see table 2 and 3) and reviewed in order to describe their effects on landslide prevention. The result thus found has been analyzed in order to know the knowledge regarding specific tree species.

The quantitative data were analyzed using the Microsoft excel, descriptive statistics using SPSS. The basic measurements are used to calculate more variables which are important for stand characteristics. In the following a list of the calculated parameters is given:

Basal area

In central Europe, mainly the stand basal area per hectare is used to describe the stand density (Kramer 1988).

$$BA = (d^2 * \frac{\pi}{4}) \div 100 \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

BA is the basal area per tree and d the diameter in breast height.

Stem number

The number of trees in is calculated as

$$N = N_t * BF \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where N is the stem number, N_t is the number of trees per plot and BF is the blow up factor.

Arithmetic mean

The arithmetic mean in statistics is estimated from

$$\frac{\sum_{i=1}^{n} xi}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where n =sample size

Quadratic mean diameter

The quadratic mean diameter of the stand represents the tree with the mean basal area. The estimator is

$$QMD= \frac{\sqrt{\sum d^2}}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where d is the diameter at breast height and n is the number of trees.

Canopy Closure

The canopy closure of the sample plot is calculated as

Crown area of each tree (CA) = $\prod r^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (5)

Where r is the radius of the tree crown

Canopy closure (%) = $\sum CA/$ Area of the sample Plot *100%..................... (6)

Chapter 4: Results

4.1 State of knowledge regarding landslide protection by forest vegetation

The protective effects here correspond to the current capability or suitability of the stand to prevent certain hazardous natural incidents. Forest vegetation plays vital role in protection against landslide in the slopes is well known to people but the knowledge regarding the specific tree species and their characteristics like root system, anchorage, canopy coverage, colonization etc which contributes to landslide prevention is very limited among the local people. Tree growth and their importance are much more known but only with the superficial knowledge. Only the common species like *Alnus nepalensis, Schima wallichii, Prunus cerasoides, Pyrus pashia, Castanopsis indica, Rhododendron arboreum* etc are familiar to the people and they have known that these species are good for protection against landslide in hill slopes because of their high growth rate and root system. Ngai et al.(1998) says that on an exposed surface, the erosion rate would be much higher leading to massive landslides. Additionally the deep roots can penetrate through clay layers with a good capacity of reinforcing the banks of watercourses and soils against landslides.

Also the experts were quite familiar with the particular characteristic of the common species but all the species present in the forest stand were not known with their characteristics. Only certain number of species which were found to be very common in the forest area and which have been in the use for landslide and erosion prevention was well known with their attributes. These species include *Alnus nepalensis, Schima wallichii, Prunus cerasoides, Pyrus pashia, Castanopsis indica, Bombax ceiba, Ficus nemoralis, Quercus species, Prunus cerasoides and Pinus roxburghii.* But the species like *Myrsina capitellata, Sauraria nepalensis, Lyonia ovalifolia and Semicarpus anacardium* were not known clearly with their attributes by the local people as well as the experts.

Hence it can be stated that the knowledge was not so specific among the local people and also the experts concerning all the available species. But major attributes of the commonly available tree species and their protective effects on hill slopes sufficiently existed.

4.1.1 Literature review

In order to have a full overview whether the tree species in the area are contributors for the prevention of landslides due to their specific characteristics, the specific attributes of tree species were searched through various search engines like Scopus, science direct, Springer link etc. The characteristics that include the rooting system, the canopy closure, regeneration potential, colonization potential and the maximum size of the tree that it can grow as these tree characteristics are major contributors for the landslide prevention in the hill slopes (Table 3). These attributes were studied through various research papers, journals, books and the internet websites.

Table 3: The main contributing parameters to landslide prevention

S.N.	Parameters	Contribution to landslide prevention
1	Rooting system	is an individual tree, species and stand parameter; provides the stability to slope by reinforcing the surface soil; also important to secure tree and stand stability which in turn reduces risk of uprooting and subsequent erosion;
2	Canopy closure	Acts as a cover to control heating and drying effects on soil and reduces soil erosion by evapotranspiration from extensive tree canopies; reduces also direct impact of heavy rainfall on surface;
3	Regeneration	See canopy closure; stabilizes the eroded soil; important to sustain the protective effect of vegetation;
4	Colonization	Capacity of a species to move into new habitats; Acts as area of increased structure and higher root density that may reduce soil erosion and landslide; see attributes #1, #2 and #3;
5	Maximum tree size	Act as an obstacle to down slope mass movements such as rock falls, avalanches, landslides, debris flows and floods; indicates the growth potential of a tree species; may however also indicate the potential weight for an (instable) slope;

Based on these papers and journals the attributes of most of the species are collected. The root system of the species is the most important attribute for soil stability which is found among the species *Schima wallichii, Bombax ceiba, Pyrus pashia, Quercus species, Prunus cerasoides, Pinus roxburghii and Ficus nemoralis.* Also the regeneration potential of the species were checked which showed that almost all the species have the good ability to regenerate in the normal condition except *Ficus nemoralis and Celtis australis* which do not have high potential to regenerate. Similarly the colonization potential for each species is found to be well in the varieties of soil condition but some species like *Alnus nepalensis, Betula alnoides, Betula utilis, and Pinus roxburghii* are much more able to colonize in the harsh and eroded soil or just after a disturbance like landslide. Canopy closure being another important character, is also assessed (some from the literature and some on own observation). The formation of the canopy closure reduces the risk of erosion and landslides that occur due to effect of heavy rainfall or storms.

All the mentioned characters for some of the major species have been collected with detail description and were tabulated (see Table 4).

4.1.2 Expert Interviews

After having the discussion with the local people and the experts, they have expressed their views and knowledge regarding various tree species and their attributes that help in prevention of the landslide. Among the tree species found in the field, only very few of the species were known to the people in relation to their landslide preventive attributes. The species like *Alnus nepalensis* (the most common species among the people), *Schima wallichii, Castanopsis indica, Prunus cerasoides, Betula alnoides, Betula utilis, Quercus species, Rhododendron arboretum, Bombax ceiba* etc. were known to people as they were the common species available but the scientific characteristics that contributes for the landslide prevention were not really common in the knowledge of people. The specific information for the specific attributes for tree species was also not clearly present even among the experts.

The knowledge concerning the rooting system was found to be very rare as compared to canopy closure, colonizing potential and the regeneration was a bit higher (only for the common species) as these characteristics were much easier to notice.

The information that has revealed during the discussion with the local inhabitants and the local experts has been systematically arranged and tabulated below (Table 4).

Table 4a: Attributes of tree species from literature and interviews. Ni = no information available

SN	Species	Number of information sources	Attributes				
			Maximum size and growth characteristics	**Rooting system**	**Regeneration potential**	**Colonization potential**	**Canopy closure**
1	Alnus nepalensis Common Name: Alder Nepali name: Utis	Literature (5)	Growth rate is high on good sites upto 30m high and 60 cm (rarely upto2m) diameter	Shallow root system	High potential to regenerate with good ability to coppice.	Colonizes landslips and abandoned cultivation but steep slopes and shallow soil affects its growth	Has wide branches but the foliage cover is low
		Interviews (27)	Large tree upto 25m high	Shallow roots that do not go deep underneath the soil	High with whole year round sprouting	Colonizes well in landslide areas	branches with less foliage
2	Schima wallichii Common Name: Nepali name: chilaune	Literature (3)	Capable of growing up to 30m height with 1 m diameter	wide spread tap root system	Sprouts very well, seedlings can be found where light level is sufficient	Colonizes plantations of other species, grows on wide variety of soils	Forms large and spread branches with medium foliage cover
		Interviews (18)	Grows well up to 30-35 m high	Ni	Coppices very well	Colonizes on wide variety of soils	Have medium to dense foliage cover
3	Castanopsis indica Nepali name: Dhale katus	Literature (4)	Annual diameter increment of about 8-12 mm	Taproot or lateral root system	Good sprouting potential	Colonizes well in lots of soil types from shallow to deep soils.	Intermediate spread of branches with foliage(may be vigorous or decline if overtopped by other species)
		Interviews (11)	Grows up to height of 30-35 m	Ni	Sprouts well	Ni	Well developed with wide branches and averagely dense leaves
4	Prunus cerasoides Nepali name: Painyun	Literature (3)	Grows fast in juvenile stage and slows down later	Produces root suckers	Sprouts well	Colonize in poor soil conditions	Well spread branches but with less amount of leaves
		Interviews (20)	Grows fast in juvenile stage and slows down later	root system is well with anchorage	Sprouts well	Grows well even in nutrient poor soils	Branches are spread

Table 4b: Attributes of tree species from literature and interviews. Ni = no information available

SN	Species	Source of information	Attributes				
			Maximum size and growth characteristics	**Rooting system**	**Regeneration potential**	**Colonization potential**	**Canopy closure**
5	Pinus roxburghii Nepali name: Khote salla	Literature (5)	Grows well up to 50m high and 1m diameter as early growth is slow but grows well after 4-5 years	taproot with strong horizontal roots, it is not afflicted by wind throws, and it reinforces well the soil against landslides	Germinates well in bare ground with good light availability	Colonizes in dry sites, hard eroded soils and bare ground	Broad crown in older trees with wide branches and dense foliage
		Interviews (16)	Grows well up to 40m high	it reinforces well against landslides	Germinates even in dry places	Grows in dry conditions	Narrow canopy with short branches
6	Betula utilis	Literature (2)	Growth is slow with about 3mm mean annual diameter	Shallow root system	Germination is quite low in fresh seeds	Rapidly colonize after disturbance(in secondary succession)	Crown of arched branches with dense foliage
		Interviews (7)	Growth is slow	Ni	Germination is high	Ni	Ni
7	Betula alnoides Nepali name: saur	Literature (2)	Slow growth until 3 years but grows faster thereafter	Shallow root system	Germinates well in open space as it demands light	Grows on landslips and newly exposed soils	Canopy is well spread with dense leaves
		Interviews (10)	Slow growing	Ni	Germinates well in clay soils	Grows on slide areas	Wide Spread branches
8	Myrsina capitellata	Literature (1)	Grows slowly up to 9m high	Not deep or often superficial	Ni	Ni	Ni
		Interviews	Ni	Ni	Ni	Ni	Ni
9	Eurya cerasifolia Nepali: Jhingaine	Literature (1)	Not well developed tree (average of 6m height and 10 cm diameter)	Ni	Ni	Ni	Ni
		Interviews (5)	Grows in average about 5 m high	Ni	Ni	Ni	Ni
10	Rhodedendron arboretum Nepali: lali gurans	Literature (3)	Trees grow up to 15m high	Surfacial rooting systems	Regeneration is well but the small seedlings are very sensitive to drought. Coppices well.	Colonize in acidic soil, can withstand shade.	Small and narrow canopy coverage with short branches and less leaves
		Interviews (6)	Small tree	Ni	Regeneration is average (not really high)	Grows well in many areas	Narrow with less leaves

Table 4c: Attributes of tree species from literature and interviews. Ni = no information available

SN	Species	Source of information	Attributes				
			Maximum size and growth characteristics	**Rooting system**	**Regeneration potential**	**Colonization potential**	**Canopy closure**
11	Lyonia ovalifolia	Literature (2)	Small to medium tree growing upto 10m height	Ni	Sprouts well and regenerates frequently in normal condition.	Grows well in sandy, loamy or clay soils.	Ni
		Interviews	Ni	Ni	Ni	Ni	Ni
12	Pyrus pashia Nepali: Mayal	Literature (3)	Small to medium tree	Useful in preventing landslips as it produces abundant root suckers and spreading superficial roots	Regeneration is high(75percent germination from large fresh seed)	Colonizes well in dry soils as it is tolerant to drought	Oval shaped crown with fine leaves
		Interviews (9)	Small to medium tree	root system is well anchoring	Regeneration is high in normal condition	Can grow and colonize well in water deficit areas	Averagely dense leaves and medium sized branches
13	Ficus nemoralis(nerifolia) Nepali: Dudhilo	Literature (2)	Small deciduous tree upto 15 m	Adventitious and buttress roots	Regeneration is high with about 90 percent survival	Grows in gullies and tolerate	Wide canopy cover with spread leaves
		Interviews(11)	Average sized tree upto 10-12m high	Ni	Average regeneration in normal condition	Ni	Ni
14	Semecarpus anacardium	Literature(1)	Medium sized tree upto 10-15 m high	Ni	Ni	Ni	Low spreading crown with short branches
		Interviews	Ni	Ni	Ni	Ni	Ni
15	Bombax ceiba Nepali: simal	Literature (3)	Large tree upto 40m high and 2m diameter	produces abundant root suckers	Coppices well in early stage but not later	Grows well in deep sandy alluvial soils and colonize under abundant cultivation	Forms closed canopy with dense leaves
		Interviews (13)	Large tree upto 30m high	Ni	Coppices well	Ni	Broad canopies with high leaf density

Table 4d: Attributes of tree species from literature and interviews. Ni = no information available

SN	Species	Source of information	Attributes				
			Maximum size and growth characteristics	**Rooting system**	**Regeneration potential**	**Colonization potential**	**Canopy closure**
16	Quercus species Common: oak	Literature (6)	Large tree upto 30 m high	long roots (more than 6 m), deep-rooting (more than 1 m), which can penetrate through clay layers with a good capacity of reinforcing the banks of watercourses and soils against landslides	Coppices freely	Colonizes well in moist situations	large rounded crown with dense foliage and large branches
		Interviews (8)	Large trees up to 25-30 m high	long roots present that goes deep into the soil	Coppices well	Mostly seen in non dry places	Broad crown cover with dense foliage
17	Saurauia nepaulensis Nepali: Gogan	Literature (1)	Early growth was slow but Fast growing after the age of 5	Ni	Regenerates well but should be protected against shade and heavy rain for survival	Grows well in soil of low fertility and shady areas	Ni
		Interviews	Ni	Ni	Ni	Ni	Ni
18	Erythrina variegate Nepali: Phaledo	Literature (2)	Slow growth in early stage but fastens after the establishment	Superficial root system with main roots in 30cm soil but deeper for old trees.	Germination is high and rapid (up to 90 percent)	Grows well in much varieties of soil	Large Spreading crown with long branches and high leaf density
		Interviews (2)	Ni	Roots have good anchorage	Ni	Grows normally in all kinds of soil and slopes upto 2000m	Ni
19	Celtis australis Nepali: Khari	Literature (2)	Medium sized deciduous tree whose early growth is slow but fastens in later stage	Surfacial root system with laterally spread roots	Coppices well but germination is very low	Grows on varieties of soil	Round and spreading crown with average size of branches but high foliage
		Interviews (6)	Average growing up to 20 m	Ni	Less germination in normal conditions	Grows well in most of the areas ignoring the site conditions	Good foliage cover

4.1.3 Synthesis

Among the experts interviewed concerning the specific attributes of the tree species only a few species were known to them but only with the superficial characteristics (which can be observed) like canopy, tree growth and regeneration of these common species was existing in knowledge. Most of the people were aware that landslides is occurring and there is a need of identification of the suitable species for plantation or natural regeneration to prevent the landslide but the information for suitable tree species and their characteristics that helps in prevention was found to be very low. The common species like *Alnus nepalensis, Schima wallichii, Castanopsis indica, Pinus roxburghii, Pyrus pashia* etc were familiar to them but not with every aspect of preventive purpose.

The existing knowledge regarding tree species among the experts and the local people were similar to what was found with the literature search. The literature search has resulted in the specific characteristics of tree species whereas the information from the local people and experts were not found to be specific and was much more general (see Table 4). For example, experts and local people said that *Pinus roxburghii* has a kind of specific root system which makes this species able to reinforce against landslides which is similar to what can be found in the literature but it is more specific that the species have tap root system with strong horizontal structures that protects against the wind throws or landslides.

Although the species *Schima wallichii, Castanopsis indica, Betula utilis, Betula alnoides, Bombax ceiba* and *Rhododendron arboreum* found as commonly available species and are much more known to the local people but the knowledge about specific root system and the colonizing potential of the species were not available among the people. Additionally the idea about canopy closure of the species *Ficus nerifolia* and *Eurya cerasifolia* was not known to the people.

During the consultation with the stakeholders of the Nilbarahi community forest, it was observed that the terminology such as colonization potential, rooting density, maximum tree size and their interrelation with the landslide prevention is unfamiliar to the local communities. Thus the selection of the species might have been on the basis of the economic importance or the interest of the stakeholders. Therefore, species preference, selection of single species, and removal of other species from a mixed species forest stand in the community forest can eventually lead to monoculture in the forest and this has detrimental effect on not only species richness but also forest stability and health. The knowledge gap acts as one of the major constraints for achieving the goal of the forest ecosystem including the protection function of the forest (Shrestha et al. 2010).

The interviews with the local people and the experts reflects the present situation of the passive forest management associated with several underlying social and technical issues including the limited practical knowledge of tree species and forest management. A process of active forest management by adopting a joint learning among the local forest user groups, forest officials and the responsible non-government service providers is necessary in the present situation. Such an integration of local knowledge with the systematic management (focusing the landslide problem) could address the success in the forestry approach with the prevention of the landslide (Lawrence et.al 2000).

Additionally, the number of sources that describes about the characteristics of tree species (literature search) and the number of respondents who expressed their knowledge has been illustrated comparatively (see Figure 10).

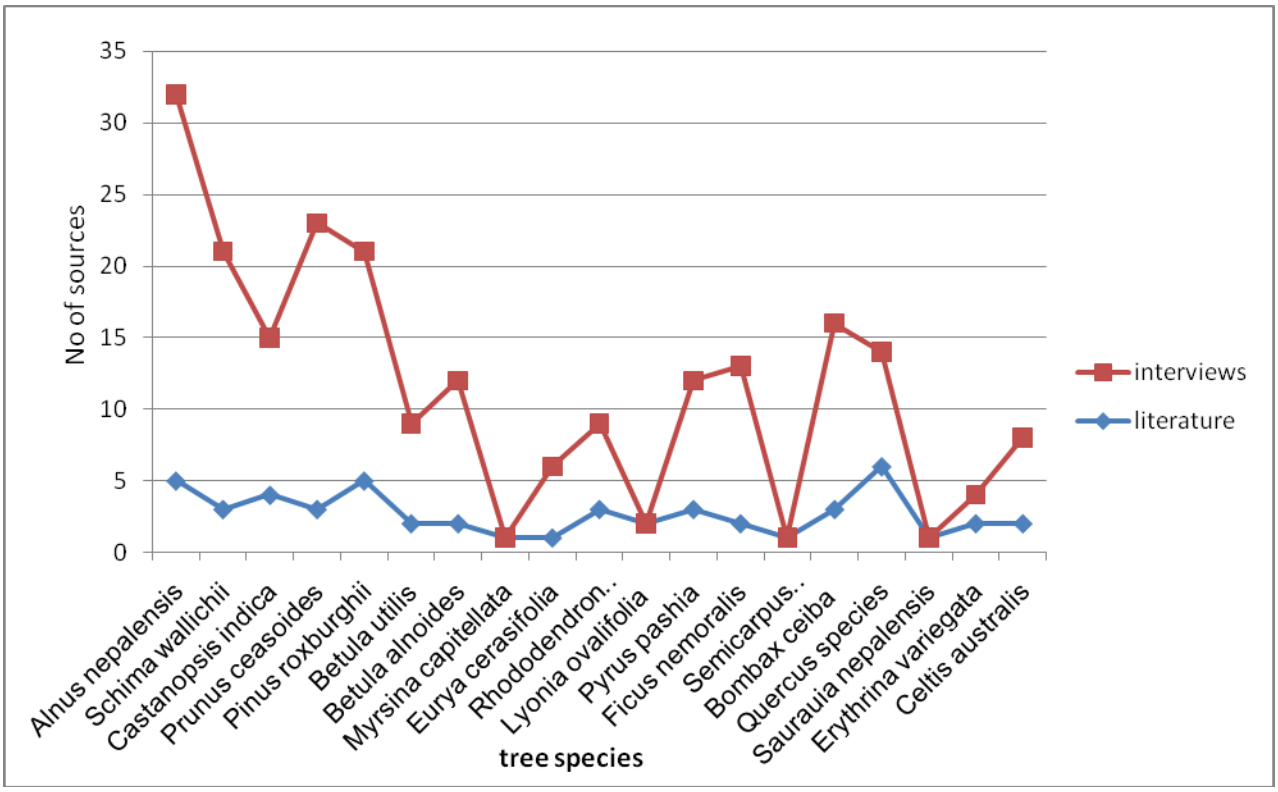


Figure 10: Number of sources (literature and interview) that describes the tree species.

4 .2 Comparative analysis of slide and non-slide areas

4.2.1 Forest structure at the sample plots

The mean basal area for the Shivapuri National Park (unmanaged natural forest) slide areas and non slide areas was calculated with 19,46 ± 59,85 m²/ha and 18,87 ± 42,70 m²/ha (mean ± standard deviation) respectively. The average stem number was found to be 589,58 ± 928,05 trees per hectare in the slide areas and in the non slide areas of national park 731,42 ± 872,79 trees/ha was determined on average (Table 5). The quadratic mean diameter and the mean height was also calculated in average for unmanaged natural forest slide areas as 21,9 ±21,7 cm and 9,5±9,7 m whereas for non slide it was calculated as 19,6 ±22,2 cm and 7,9 ±10,0 m (mean ± standard deviation respectively (Table 5).

Also within the community forest of Nilbarahi and the private forest of Lalitpur the following indicators has been calculated in slide and non-slide areas respectively: basal area (m²/ha), stem number, quadratic mean diameter and the mean height. Refer to table 5 for the summary values per sample plot.

Table 5: Mean values of the indicators for different forest types (BA =Basal area, N= stem number, QMD = Quadratic mean diameter and MH = mean height).

Forest types	Indicators (mean ± standard deviation)			
	BA [m²/ha]	N/ha	QMD [cm]	MH [m]
Unmanaged natural forest (slide areas)	16,87±59,85	589,58±928,05	21,9±21,7	9,5±9,7
Unmanaged natural forest (Non-slide areas)	18,87±42,70	731,42±872,79	19,6±22,2	7,9±10,0
Community managed secondary forest (slide areas)	16,19±16,60	515,48±300,81	14,5±18,3	6,7±10,1
Community managed secondary forest (Non-slide areas)	24,81±20,96	526,58±258,49	16,7±21,0	7,6±11,4
Private managed secondary forest (slide areas)	8,44±5,46	356,62±268,64	16,9±15,2	9,5±9,1
Private managed secondary forest (Non-slide areas)	11,96±10,69	623,27±466,60	15,7±13,6	8,7±9,7

Table 6: Information on the sample plots.

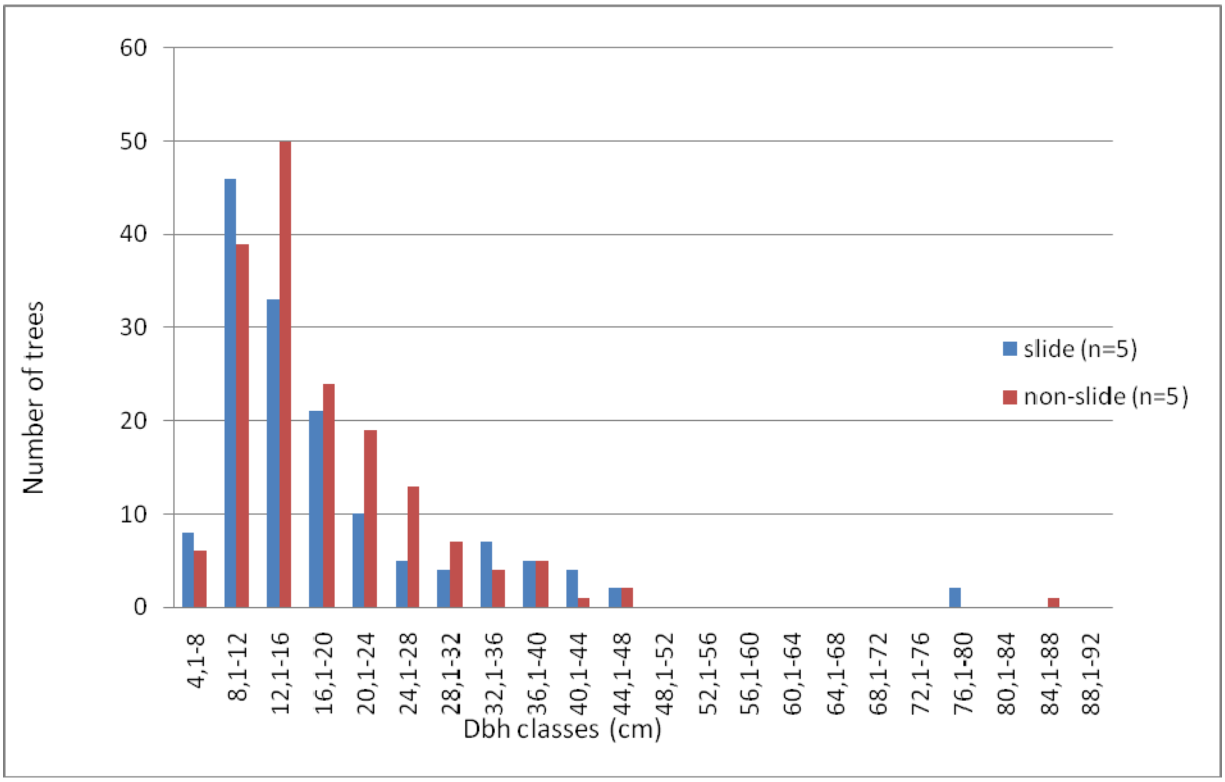
Plot ID	Slide (S) or Non-slide plots(NS)	Forest community	Altitude (m.a.s.l.)	Slope (degree)	Canopy Closure (%)	Basal_area(m²) Per hectare	stem_number per hectare	No. of saplings per hectare	Slide area(m²) per plot
1	S	Shivapuri NP	1718	40	37,5	18,0	768,0	480	3200
2	NS	Shivapuri NP	1695	28	92,2	15,4	784,0	400	0
3	S	Shivapuri NP	1811	42	30,8	17,1	1099,9	1700	3333,33
4	NS	Shivapuri NP	1825	35	114,3	17,5	1666,5	1233	0
5	S	Shivapuri NP	1785	33	92,7	20,7	239,9	373	2800
6	NS	Shivapuri NP	1790	26	82,7	19,3	279,9	333	0
7	S	Shivapuri NP	1645	40	127,1	10,3	360,0	496	2400
8	NS	Shivapuri NP	1644	39	166,5	15,9	620,0	416	0
9	S	Shivapuri NP	1599	30	153,8	31,4	480,0	192	1232
10	NS	Shivapuri NP	1604	32	135,2	26,3	320,0	736	0
11	S	Nilbarahi CF	1305	35	57,4	11,3	479,9	280	1666,67
12	NS	Nilbarahi CF	1335	33	70,7	16,9	439,9	147	0
13	S	Nilbarahi CF	1310	37	54,1	18,1	426,6	267	2493,33
14	NS	Nilbarahi CF	1330	35	111,1	35,9	599,9	147	0
15	S	Nilbarahi CF	1335	34	130,4	19,2	640,0	240	2400
16	NS	Private forest	1330	28	104,7	21,6	540,0	240	0
17	S	Private forest	1410	39	104,8	11,5	413,2	67	1533,33
18	NS	Private forest	1418	28	58,7	13,9	546,5	187	0
19	S	Private forest	1400	33	62,1	5,4	300,0	100	700
20	NS	Private forest	1440	35	123,9	10,0	700,0	120	0

The diameter distribution of the trees in the sample plots has been calculated. The distribution in the Shivapuri National Park shows a clear peak for the trees with DBH > 8cm. In the slide areas of the park the number of trees with lower diameter are higher and decreasing to the trees with higher diameter. This pattern is somewhat similar also for the non slide areas of the national park leading to an approximated reverse-J distribution. Therefore, from Figure 11a it can be concluded that the forest in Shivapuri National Park is unevenaged and vertically structured.

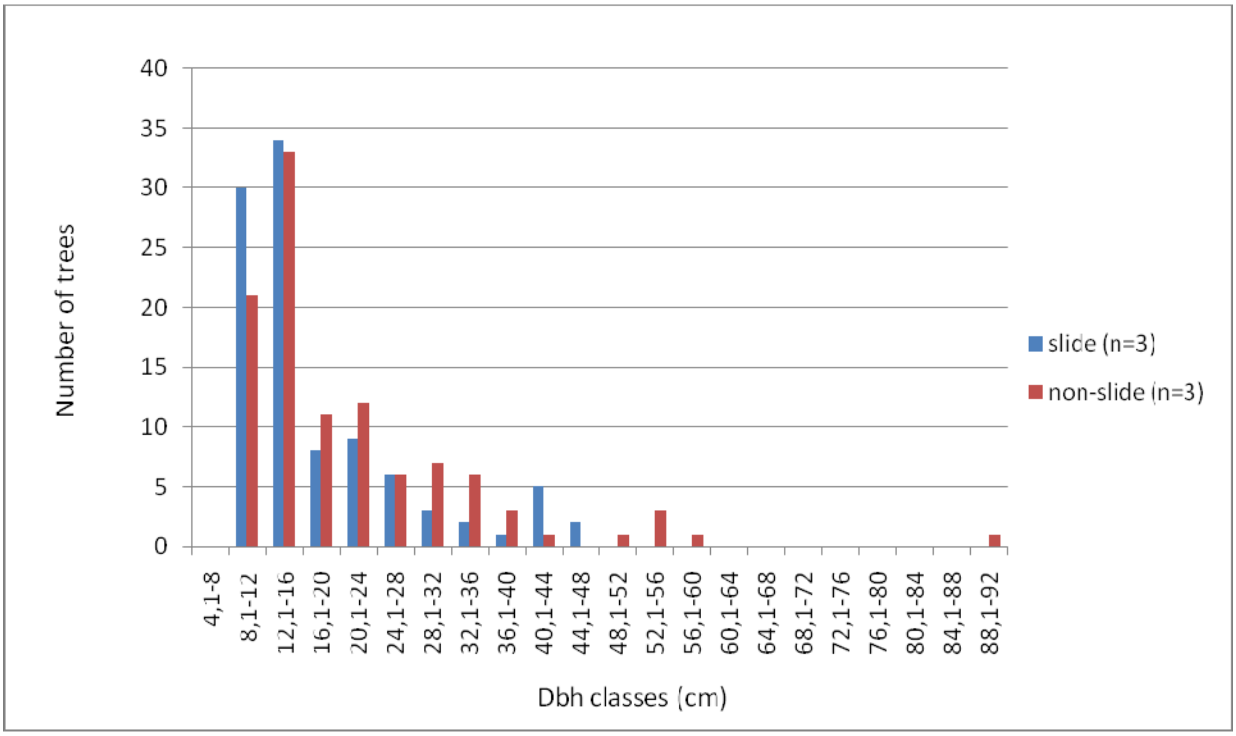
The diameter distribution of Nilbarahi Community Forest also shows that the number of trees with the DBH <16cm is higher than the trees with DBH> 16cm (Figure 11b). The slide and non slide areas both indicate the same pattern of DBH distribution with negligible trees with DBH ranging from 4- 8cm. Like the Shivapuri National Park, the community forest also shows an approximate reverse-J distribution showing the unevenaged managed and vertically structured forest.

In case of the private forest in Badikhel, the diameter distribution shows a completely different pattern. The non slide areas show the trend with higher trees with low DBH somewhat similar to community forest and the national park but the slide areas show a completely different pattern with somewhat equal number of trees for DBH classes of 8-12cm and 12-16 cm. From Figure 11c it can be concluded that the diameter distribution is close to normal distribution.

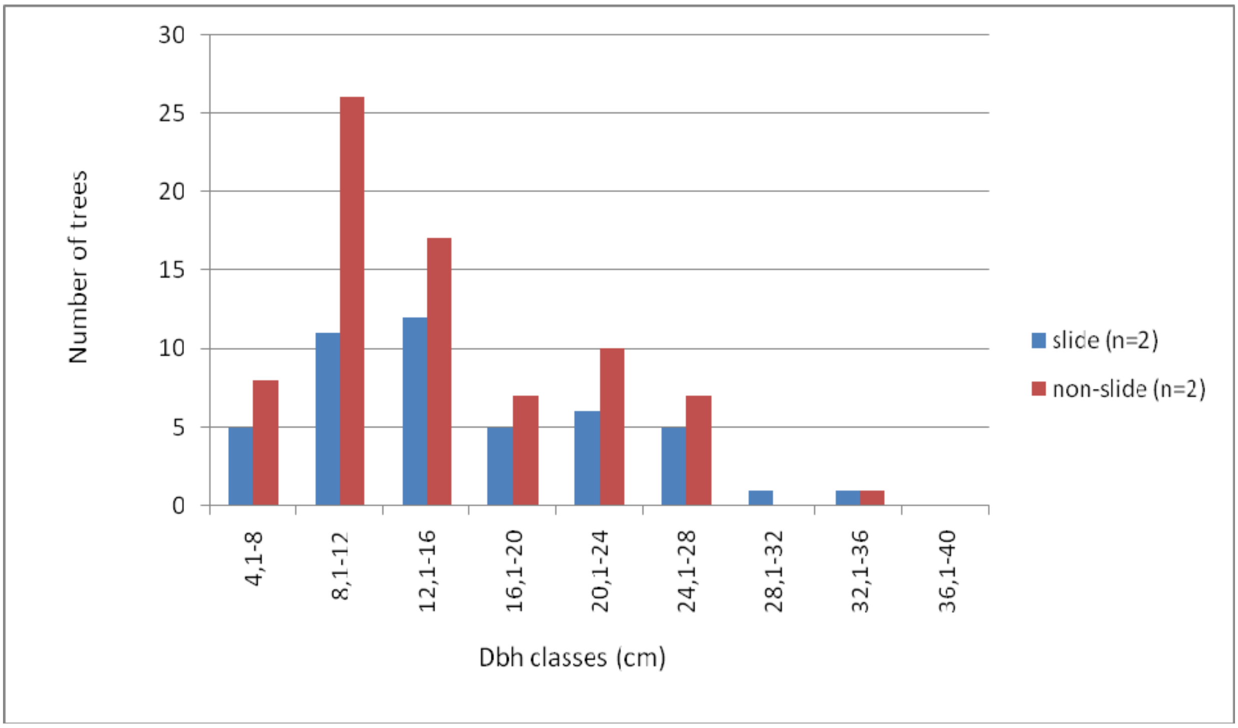
Also the frequency of regeneration in each plot has been counted (see Figure 12). The figure shows that the frequency of regeneration is higher in the natural forest compared to the community managed and private forests. However, even in the Natural forest at Shivapuri National park the frequency is highest with 1700 per hectare. But the community managed and the private forests have much lower regeneration which might be one of the possibilities for the occurrence of landslides. Regarding the species almost in all the sample plots the seedlings of Schima wallichii and Myrsina species are present whereas other species are present in very low numbers. For instance plot number 10 in Shivapuri national park show a high number of Myrsina species and Castanopsis species but none of the others. Similarly, plot number 18 in the private forest contains only Schima wallichii. Thus, the high variation can be seen in the regeneration number in all the sample plots.



11a: DBH distribution of sample plots at Shivapuri national park



11b: DBH distribution of sample plots at Nilbarahi Community forest



11c: DBH distribution of sample plots at Private forest Badikhel.

Figure 11a, b, c: DBH distribution of the forest types

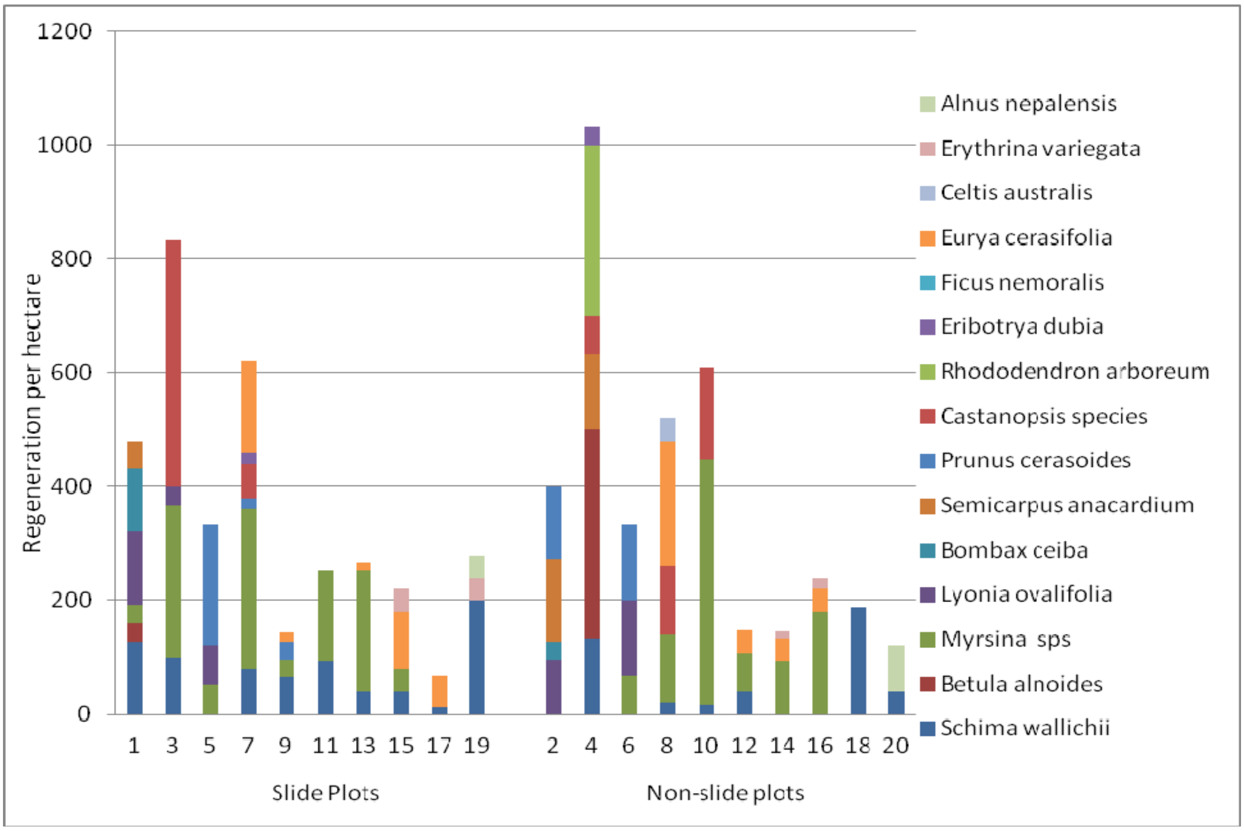


Figure 12: Frequency of regeneration in the slide and non slide areas of various forest types.

4.2.2 NaiS landslide protection indicators at the sample plots

Forested hill slopes offer significantly more protection than the non vegetated slopes (Brauner et. al 2005, Dorren et. al. 2005). But not all forests fulfill the requirement of protection to the same degree. In order to check the protective functions of forest the guidelines of the Swiss Federal Office of the Environment (FOEN) ”Sustainability and efficiency control in protection forests" (NaiS, in German: Nachhaltigkeit und Erfolgskontolle im Schutzwald) (Frehner et al. 2005) is used. This Nais guideline gives the overview of the protective structure of forest against natural hazards like landslide, soil erosion, rock fall, mud flows and snow avalanches. It checks the minimum and the ideal profile of the indicators in the respective area.

The indicators mentioned in the guideline are taken as a tool for determining the protective effect of forest against landslide in the mid hills of Nepal as well. The indicators focus on the horizontal structure i.e. gaps area, canopy closure and the sustainable regeneration rates. The same indicators have been assessed for the sample plots in all three areas and listed as per the requirement of Nais guideline (see Table 7).

Table 7: Nais guidelines for forest structure in landslide area (Frehner et al. 2005).

Natural hazard: Landslide, mud flow and soil erosion		
Areas	**Horizontal structure**	
	Minimum profile	**Ideal profile**
Landslide area	≤600 m² gap area	≤400 m² gap area
	≥40% canopy closure	≥60% canopy closure
Infiltration area	≥30% canopy closure	≥50% canopy closure
	Sustainable Regeneration	Sustainable Regeneration

As per the requirements of the indicators mentioned in the Nais guideline (Frehner et al. 2005), various parameters have been assessed which include gap area, canopy closure and the number of plants in regeneration per hectare according to the height classes for each plot. The comparison of the calculated indicator values and the standard profile shows that the presence of gap area is minimal in almost all plots, i.e. only two plots out of 20 sample plots contain gaps that also is relatively small at a size of 31m^2 and 6 m² in the plots 6 and 7 respectively.

Similarly the canopy closure has also been calculated for all the sample plots in the study area which shows that the canopy is very dense in almost all of the plots (excluding plot 1and 3). The canopy percentage is at most with 166% in plot 8 whereas plots 1 and 3 were with really very low in canopy percentage (plot 3 with

30,8%). From this observation, it can be noted that only sample plot number 1 and 3 do not fulfill the requirement for the minimal as well as ideal profile and plot number 13 do not meet the requirement only for ideal profile according to Nais.

Further the stem number per hectare for regeneration has been calculated according to different height classes. This showed that the values of stem number for height class 10-30 m in some plots are zero which means that there was no regeneration of this class in the sample plot. Similarly some plots have higher regeneration numbers of up to 5090,9 stems per hectare (Table 8).

Table 8: Indicators calculated for sample plots as Nais requirements.

Plot ID	Slide(S) or Non slide (NS) plots	Gap area [m²]	Canopy closure [%]	Regeneration [n/ha] in height classes [m]			
				10-30	31-50	51-80	81-130
1	S	0	37,5	397,7	0	795,4	3977,2
2	NS	0	92,2	2386,3	0	1590,9	795,4
3	S	0	30,8	0	0	1060,6	4242,4
4	NS	0	114,3	530,3	530,3	3181,8	1060,6
5	S	0	92,7	0	0	0	1988,6
6	NS	31	82,7	0	0	0	1988,6
7	S	6	127,1	0	0	1272,7	5090,9
8	NS	0	166,5	0	2651,5	530,3	2121,2
9	S	0	153,8	0	0	0	909,0
10	NS	0	135,2	0	5303,0	3712,1	1590,9
11	S	0	57,4	0	0	0	1988,6
12	NS	0	70,7	0	0	0	795,4
13	S	0	54,1	0	0	397,7	1988,6
14	NS	0	111,1	0	0	0	1193,1
15	S	0	130,4	0	0	0	795,4
16	NS	0	104,7	0	0	0	2121,2
17	S	0	104,8	0	795,4	0	0
18	NS	0	58,7	0	0	795,4	1193,1
19	S	0	62,1	0	0	0	1060,6
20	NS	0	123,9	0	0	0	1590,9

Table 9: Comparison of the Nais standards with the data from the sample plots.

Plot ID	Horizontal structure 1 Gap area		Horizontal structure 2 Canopy closure		Regeneration
	Minimal profile	Ideal profile	Minimal profile	Ideal profile	Required
1	√	√	×	×	√
2	√	√	√	√	√
3	√	√	×	×	√
4	√	√	√	√	√
5	√	√	√	√	√
6	√	√	√	√	√
7	√	√	√	√	√
8	√	√	√	√	√
9	√	√	√	√	x
10	√	√	√	√	√
11	√	√	√	√	√
12	√	√	√	√	x
13	√	√	√	×	√
14	√	√	√	√	√
15	√	√	√	√	x
16	√	√	√	√	√
17	√	√	√	√	x
18	√	√	√	√	√
19	√	√	√	√	√
20	√	√	√	√	√

The comparison of the result for the indicators calculated on the sample plots in relation to the requirement of the Nais guidelines is shown in Table 8. It shows whether the indicator values satisfy the Nais guideline´s (Frehner et.al. 2005) minimal and the ideal profile to be a protective forest against landslide. In the study, twenty out of 20 sample plots fulfill the requirement of minimal and ideal profile in relation to the gap area. In the context of canopy closure plot number one (37,5 %) and plot number three (30,8 %) do not fulfill the requirements for both minimal and ideal profile whereas plot number thirteen (54,1 %) fulfils the condition of minimal profile but not the condition for ideal profile. Regarding the regeneration on the sample plots, the qualitative regeneration status has been illustrated on the basis of the presence of the seedling per sample plot. If the seedling number is low then the regeneration is required and vice versa. No information exists currently on the regeneration dynamics in the species on the analyzed plots. However, it was concluded that stem numbers of less than 1000 seedlings per ha are not satisfactorily. Please note, that this is a judgment which requires scrutinization in the future. Accordingly, all the sample plots have a certain number of seedlings but there is no balance in the seedlings of various species. Thus the need of seedlings of some species is essential in all the plots in order to maintain the species balance for the protection against landslide.

4.2.3 ANOVA

Based on the hypothesis that the forest characteristics make some differences in the landslide occurrence the data from slide and non-slide areas are statistically compared. In order to test the hypothesis regarding the calculated indicators the normality test is not conducted due to the fact that the data set is very small and random (Johnson and Hixon 1952, Freese 1960).

The one way ANOVA test is carried out to analyze the variance between the slide and non slide areas of different forest types based on the indicator values in order to test the hypothesis “there is no significant difference between the slide and non-slide areas as represented by the sample plots regarding the calculated indicators with $p< 0.05$”. The result shows that all the values for significance are greater than 0.05. So the null hypothesis cannot be rejected (Table 10).

However, please note that the variance within the forest types was huge. Slope angle, characteristics not accounted for in the assessment such as top slope water issues (e.g., road construction) or combination of various site factors like soil type, geology etc. might have triggered a landslide.

Table 10: One way ANOVA for analyzing the differences among slide and non slide areas.

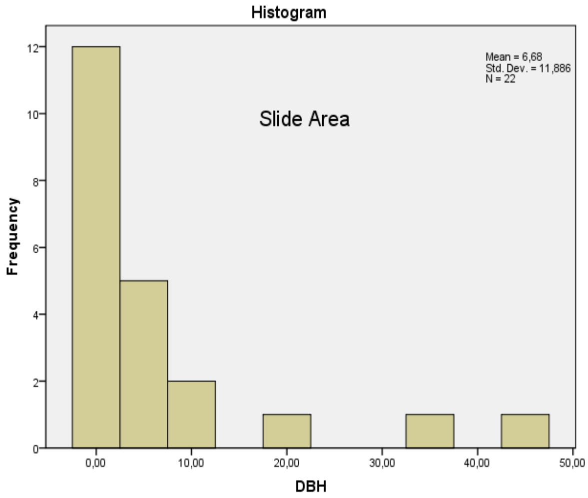
Indicators		df	Mean Square	F	Sig.	df	Mean Square	F	Sig.	df	Mean Square	F	Sig.
		Natural forest				Community forest				Private forest			
BA_m2ha	Between Groups	1	0,912	0,023	0,883	1	111,543	1,916	0,239	1	12,426	0,960	0,431
	Within Groups	8	39,230			4	58,224			2	12,947		
	Total	9				5				3			
stems_nha	Between Groups	1	52215,076	0,240	0,637	1	184,815	,020	0,895	1	71102,222	7,819	0,108
	Within Groups	8	217730,081			4	9435,776			2	9093,518		
	Total	9				5				3			
QMD_cm	Between Groups	1	0,121	0,002	0,968	1	21,282	1,923	0,238	1	1,563	0,189	0,706
	Within Groups	8	71,903			4	11,067			2	8,263		
	Total	9				5				3			
MH_m	Between Groups	1	1,089	0,207	0,661	1	,540	0,401	0,561	1	0,723	0,601	0,519
	Within Groups	8	5,263			4	1,345			2	1,202		
	Total	9				5				3			
canopy_closure	Between Groups	1	2220,100	1,091	0,327	1	331,527	0,284	0,622	1	61,623	0,041	0,859
	Within Groups	8	2034,407			4	1165,892			2	1518,583		
	Total	9				5				3			
Regeneration_N	Between Groups	1	57974,519	013	,912	1	187478,727	,327	,598	1	742595,828	13,00	,069
	Within Groups	8	4474852,004			4	574160,892			2	57123,419		
	Total	9				5				3			

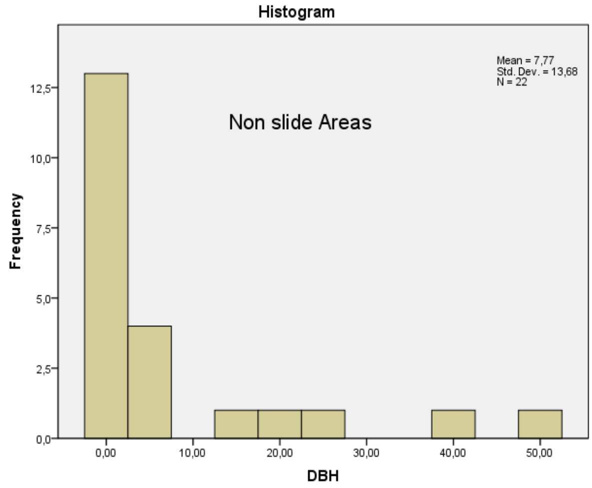
4.2.4 Kolmogorov –Smirnov test

The diameter distribution of the trees in the sample plots showed high variation as well. Therefore, in order to check if the diameter distribution varies significantly among the slide and non slide areas, Kolmogorov-Smirnov (KS) tests have been carried out. The diameter distribution displays almost the reverse-J shape in the national park and the community forest (see Figures 13a, 13b) whereas the distribution in the private forest shows that the distribution is reflecting a normal distribution (see Figure 13c). The significance values for National Park and the community forest are lower than 0,05 which states that the data is not normally distributed. But the private forest has the significance value greater than 0,05 meaning that the data are normally distributed (Refer Table 11). The value of significance in the national park and the Community forest shows that there is no significant difference between the slide and the non slide areas of the forest types. They show the similar trend of the distribution in the reverse –J shape. But in case of the private forest the values show that there is significant difference between the slide and the non slide areas.

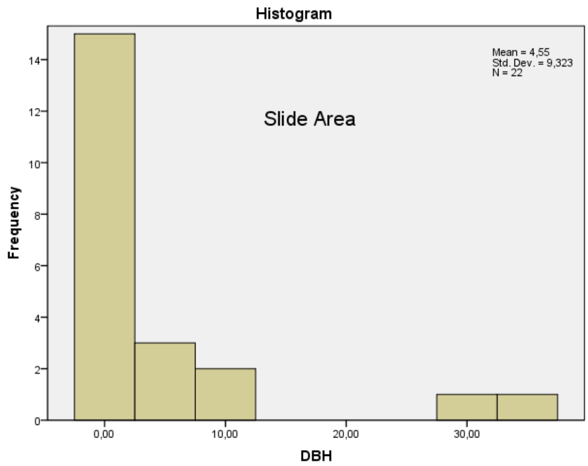
Table 11: Variation in dbh in different forest types with Kolmogorov Smirnov (where Slide refers to the sample plot with landslide and non slide refers to sample plot without the landslide)

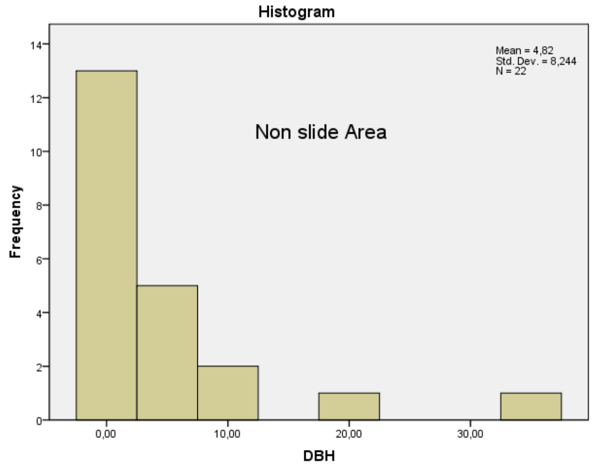
Forest type	Mean DBH	SD	Skewness	Kurtosis	df	Significance
National park (slide)	6,68	11,886	2,457	5,836	22	0,000
National park (non-slide)	7,77	13,68	2,169	4,229	22	0,000
Community forest (slide)	4,54	9,32	2,64	6,40	22	0,000
Community forest (non-slide)	4,81	8,24	2,43	6,25	22	0,000
Private forest (slide)	5,75	4,02	0,505	-0,590	9	0,215
Private forest (non-slide)	9,5	8,5	1,13	1,09	9	0,117



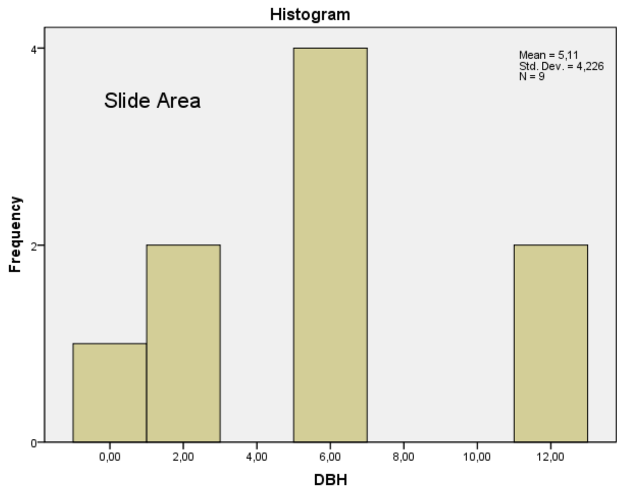


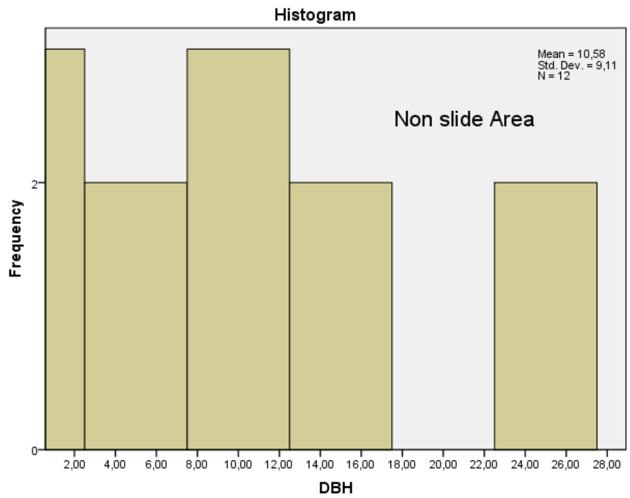
13a: DBH distribution of Shivapuri national park slide and non slide areas





13b: DBH distribution of Nilbarahi Community forest slide and non slide areas





13c: DBH distribution of Private forest Lalitpur slide and non slide areas

Figure 13 a,b &c: DBH distribution of slide and non slide areas in different forest types

Chapter 5: Synthesis and discussion

5.1 Reviewing the state of knowledge

The tree species are the major contributors of the protective functions of the forest against natural hazards. The specific tree species have their own characteristics to provide various effects to prevent the disturbance. For addressing the existing knowledge on this fact the interviews were made among various groups. The interviews clearly indicate that there is limited information available and the local users lack the sufficient knowledge in relation to the specific tree species and their attributes. Mostly the forest user groups believe that the availability of trees is sufficient for forest protection (Nagendra et.al. 2005). The protective effects of forest is based on the different indicators like rooting system, canopy closure and regeneration potential is a topic existing in the knowledge of people but only on the basis of observation. However, it is more important to focus that the existing local knowledge on species and their attributes is insufficient for the management of forest against landslide (Lawrence et.al. 2000).

When it comes to the knowledge about processes involving tree species it is associated with people´s experience with the different species. For instance, the knowledge of the specific broadleaved tree attributes affecting *tapkan (water flow over the leaves*) is common across all of the areas in local form but in varied manner (Sinclair et al. 2000). Much of the research has stressed the sophistication of local understanding of ecological processes, but it is also clear that there is a lot that local people do not know and this often constrains their practices. Limits to what resource users can observe often determine limits to their knowledge (Lawrence et.al. 2000). Even though the trees are regularly lopped for fodder, the species differences in root characteristics and the effects of different strategies on root development and competitiveness is found to be existing among the local people at least for the common species. Even though the local people including the community forest user groups were unable to address themselves scientifically with specific tree attribute but as noted above the general information was available about the common species which can be accounted important for protection against landslide.

On the other hand, the experts involved in the management of the forest have much more understanding about the attributes of the commonly existing tree species in the national park. Even though the state of knowledge was higher comparative to the local people, rarely available species or uncommon species attribute´s understanding was still low. The species *like Myrsina capitellata, Lyonia ovalifolia, Eurya cerasifolia, semicarpus anacardium and saurauia nepalensis* are not much familiar and the characteristics of these species were still limited. Furthermore, the existing knowledge among the experts is often limited in order to describe the protective function of the existing forest that could contribute for the prevention of landslide in the study areas.

However, the information related to the tree species and their attributes gathered from the local people and the experts did not show much significant difference for few very common species, instead only the way of expressing them was different (locally by the people and more scientifically by the experts). Moreover, it can be concluded that the existing knowledge is still insufficient among the local people as well as the concerned authorities in order to establish a sustainable forest to maintain the protective effect against landslide. The authorities still need to focus on the expansion of the specific knowledge for the specific tree species and also to spread this knowledge on the local people by involving them in the management activities so that the knowledge gap about the forest management can be improved.

5.2 Comparative analysis of slide and non-slide areas

Highly structured continuous cover forests show characteristic diameter distributions, with high numbers of thin stems and decreasing frequencies with increasing diameter, in equilibrium over time (Schütz 2001) which shows that there will be sufficient trees in all the diameter classes in order to replace the dying trees. A similar kind of trend is seen in the sample plots where DBH values are in different pattern (see Figures 11a, b & c) in all three types of forests. This diameter distribution shows the reverse-J shaped curve in natural managed and community forest stating the condition of the uneven managed forest whereas the completely different pattern in the private forest (see Figure 13). The KS test also concludes that the diameter distribution varies significantly in the National Park and the Community forest but the Private forest shows normal distribution only in case of the slide area which might be because of the availability of few samples. Dorren et al. (2005) stated that for effective protection instead of presence of thick trees in stand, presence of large number of trees covering the range between small and large stem diameters is preferable. Similar forest is also present on our study site (since the stand has varying diameter trees between different diameter classes) which can be considered as a effective forest structure for the fulfillment of the protective function against landslide but this kind of forest structure cannot be sustained in long run. This clearly gives an idea that the management system of the forest has to be focused by the concerned authorities in order to maintain the protective function of the forest against landslide in a sustainable manner.

Figure 14: Plot no 7 in Shivapuri National park with Castanopsis species.

Regeneration varies in natural and planted forests due to the variation in the microclimate and edaphic characteristics (Chauhan et.al. 2008). Beyond these factors the management plans of the respective forest is another main reason. In the sample plots, the frequency of regeneration is highest at 1700 saplings per hectare in natural forest and decreasing pattern in community managed and private forest (see Figure 12). This low number of regeneration might have been triggered by various factors like climate, soil type, slope, aspect, light, nutrient availability and the management systems. In case of the natural forest, the low frequency of the regeneration might be the result of the high shading conditions and the low availability of the nutrients due to the presence of dense and artificially unmanaged forest. Similarly the community and private managed forest might have this condition due to the unavailability of favorable conditions of regeneration and lacking the proper management techniques. Besides the various interests and the objectives of the management system influences the regeneration of the forest. The interest for the timber production by private owners, protection of the tree species by the National Park management team, focus on the fodder trees by the community highly influences the amount of regeneration in the forest types.

Figure 15: Sprouting in Castanopsis species in plot no 6 in Shivapuri National Park

Similarly, Nais guidelines has been taken as the supportive tool to define the ideal forest with regard to the protective function of forest against landslide which clearly showed that the slide and non-slide areas of both natural and managed forest fulfill the conditions to be the ideal forest while considering the parameters canopy closure, gap areas and the requirement of the regeneration for the sustainable forest (Refer Table 8). Also it should be noted on the other hand that in the context of study area along with the above mentioned parameters to be an ideal forest there is very important factor that determines the protective function of forest i.e. species composition. But the Nais guidelines do not consider any aspects about the species composition. Thus it can be misleading to conclude the assessed forests of Nepal are ideal forest with regard to protective functions against landslide without considering the species composition as tree species play major role in the protection of soil. However it can be concluded that Nais guidelines may not be a perfect tool to evaluate the protective functions of the forest against landslide (or hazard) in the context of Nepal. On the other hand, there are two possible conclusions: (a) NaiS is not suitable as it is now to assess landslide protective functionality in Nepal. (b) the forest contribution to landslide prevention is limited. And even when the NaiS profile is met there is severe landslide risk.

5.3 Knowledge gaps and challenges in forest management for landslide protection

Protection forests are instrumental in maintaining the quality of life and productivity of people and the environment in many mountain regions. It must be realized that science is only beginning to identify the stand characteristics that will optimize the protective functions of forests for specific hazards (BEBI *et al.* 2001;DORREN *et al.* 2004; PERRET *et al.* 2004). Among developing countries, Nepal was an early leader in initiating innovative programs of forest management aimed at involving local communities (Agrawal et al. 1999, Agrawal and Ostrom 2001).

On the basis of the study, it can be observed that in case of the natural (government managed) forest the management strategies are implemented according to the government policies. The forest user groups are only allowed to use certain proportion of the forest resources in the national park which shows that there is very less involvement of the local people in the management activities. While getting to know about the existing state of the knowledge among the local people in that area, as stated in chapter 5.2 the presence of the scientific knowledge for the tree species was found to be very low which may not be sufficient for the management of the forest in order to prevent or minimize landslide risk in that area. This gap of knowledge might be one of the major reasons for the management committee to involve less local people in the forest management. Lack of knowledge among the forest user groups (FUGs) coupled with ambiguity and knowledge gap among government and NGO staffs on understanding the forest and its consequences make the operation plan of forestry more complicated (Shrestha et al. 2010). So, the management of the forest with the sound knowledge about tree species and their attributes that supports for the prevention of landslide must be considered.

The active management of community forests enhances the development of forest user groups including the hazard prevention. Indigenous knowledge on forest management systems are of diverse nature and community specific. Forest resources have been protected over years through people's traditional technical knowledge which are believed to be many generations old knowledge (Sharma et.al. 2009). The community forest of the study area was also found to be managed in a non scientific manner which might have been the result of various underlying problems like management strategy, involvement of FUGs etc. The present situation of passive management is associated with several underlying technical and social issues including underutilization of forest, protection oriented forest management, overstocked forest (dense) with little regeneration, shortage of forest products, poorly designed silvicultural practices due to conservative provisions in forest management guidelines, and limited practical knowledge of forest management (Yadav et al. 2011). The private owners were also realizing the importance of management of the forest and were found to be much aware about the landslide as well but only in the context commonly available species like *Alnus nepalensis* as it grow automatically in the areas after the landslide.

The operational management plans in government-managed forests focus basically on timber production, and not on products of importance to local people who live near the forests. In community-managed forests, there is more emphasis on subsistence products, but the forests face problems of limited regeneration and growth. There is a need for further ecological information to sustainably manage these forests for multiple objectives or for specific focus interests other than timber. However, there is very limited ecological knowledge available for the management (Kanel et al. 2001). Therefore, it can be clearly understood that the involvement of the local people in the forest management is an important factor which on the other hand contributes for the prevention of landslide with sustainable management**.**

Figure 16: Landslide roots out Myrsina capitellata tree in plot no. 3 in Shivapuri National Park

The natural hazards like landslide and soil erosion are pronounced in some parts of Nepal. Although the control measures are in place and have been institutionalized by empowering the community users, the restoration of degraded lands is far behind in comparison to its expansion (FAO 2009). So the impact of landslide is necessary to be reduced with the strong involvement of the local people in the forest management. As protection forests represent a balance between protection and production. Protection forests may not prevent hydro geomorphic events from occurring, but may decrease their effects even for very large events (Sidle *et al.* 1985; Motta and Haudemand 2000; Cheng *et al.* 2002; Weir 2002). This concept must be known to the land managers responsible for protection forests so that they may realize substantial requirement of targeted forest management (BRANG *et al.* 2001). Lacking such knowledge among the technical staff might be one of the challenges that need to be built up by the management committee. Along with these, there are various challenges that hinders the forest management particularly for landslide which includes low level of public awareness, weak institutional management capacity, excessive use of resources (in case of community and private forest), lack of research and development, lack of integrated planning for resource use (water and land) and so on.

In a country like Nepal, where local biophysical, social, economic, and cultural conditions vary so markedly from one region to the next, allowing communities the flexibility to adapt management policies to local conditions is a crucial factor that impacts their success (Varughese and Ostrom 2001). Similarly, the site characteristics like geology and topography are the topmost hindering factor in the context of Nepal. However, managing institutional change from the top down is not an easy task, and management communities require the flexibility to incorporate context-specific learning into their management activities (Poffenberger and McGean 1996, Sundar 2000, Prasad and Kant 2003).

5.4 Conclusions

The study provides the insight of the current situation of the landslide conditions in the protected forest of Shivapuri National Park and the community managed forest of Nilbarahi in the mid hills of Nepal. As the study has also focused on the existing local understanding of tree species and their effect on landslide prevention, the existing knowledge status can be observed through it. This study also provides an insight that the proportion of the management program with local people's participation in comparison to the landslide occurrence is relatively low. Therefore, it can be summarized that the local people and the local knowledge should be actively involved with the participatory approach along with the knowledge strengthening as per the requirement.

The one way analysis of variance (ANOVA) test shows that in the collected data set there is no any significant difference between the slide and the non slide areas based on the calculated indicators. Therefore, it can be concluded that the occurrence of the landslide might have been triggered by various site factors like aspect, slope, soil type, geology, etc or also could have been the result of the heavy rainfall, constructive activities in the specific areas without specific concern to slides.

The comparison of the result with the Nais guidelines proofs that conditions the slide and non slide areas of both the natural and managed forest fulfill the requirement to be an ideal forest with regard to the protective effect against landslide excluding the species composition. So, the forest of the natural forest of Shivapuri National Park as well as Nilbarahi community forest and the private forest should effectively contribute to the protection function against landslide in most of the cases. But still the occurrence of the landslide is common and this should be evaluated by the responsible authorities or the forest owners that whether the protective functions can still be fulfilled by forest in order to stabilize the slopes or further artificial management or protection activities are necessary. Therefore Nais guidelines may not be a perfect tool to evaluate the protective functions of the forest against landslide (or hazard) in the context of Nepal since it does not consider the species composition.

Site characteristics as geology, topography and climate determine frequency and intensity of damaging events (Brang 2001). For the assessment of the protective functions of the natural forest of Shivapuri national park and the community managed forest this study gives a thorough outlook and helps to analyze the alterations in the future with the change in environmental and climatic conditions.

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Annex- I: Comparative table showing the indicators for slide and non slide areas in natural managed forest

Tree species	Indicators for Unmanaged natural forest (Slide areas) (n=5)								Indicators for Unmanaged natural forest (Non-Slide areas) (n=5)							
	BA/ha(m²/ha)		N/ha		Q M D (m)		Q .M H (m)		BA/ha (m²/ha)		N/ha		Q M D (m)		Q M H (m)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Castanopsis sps	4,10	4,11	157,86	213,80	0,16	0,15	8,46	5,62	3,50	24,14	321,05	361,73	0,15	0,05	9,17	2,62
Myrica species	1,78	3,29	45,86	64,17	0,07	0,11	2,64	3,62	0,28	0,56	9,87	14,83	0,06	0,09	3,00	4,24
Schima wallichii	1,09	3,67	67,47	93,45	0,08	0,07	4,49	4,38	4,62	2,86	150,93	137,20	0,15	0,10	8,57	4,88
Betula alnoides	2,00	8,16	48,00	107,33	0,04	0,09	3,33	7,44	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Myrsina capitellata	2,42	9,50	53,07	70,47	0,11	0,09	5,79	3,34	1,47	1,51	76,26	69,62	0,15	0,11	5,50	3,67
Madhuca indica	0,04	0,24	9,87	14,83	0,03	0,04	2,30	3,15	0,30	0,42	16,00	28,90	0,07	0,11	3,10	4,34
Eribotrya species	0,07	0,24	7,20	9,96	0,04	0,05	2,70	3,73	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Rhododendron sps	0,29	1,09	33,86	56,34	0,06	0,06	3,24	3,13	0,38	0,86	3,20	7,16	0,07	0,15	1,80	4,02
Eurya cerasifolia	0,12	0,44	14,40	19,92	0,04	0,05	3,80	5,20	0,33	0,26	36,80	29,78	0,08	0,05	6,63	4,23
Rhus javanica	0,08	0,30	6,67	14,91	0,02	0,05	0,90	2,01	0,25	0,56	20,00	44,72	0,02	0,05	1,42	3,17
Lyonia ovalifolia	0,70	2,63	19,73	29,67	0,08	0,13	2,38	3,54	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
malo(unknown)	0,20	0,71	20,00	44,72	0,02	0,04	0,97	2,38	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Alnus nepalensis	4,49	17,57	51,72	98,74	0,11	0,15	5,59	7,73	5,91	8,36	49,59	86,59	0,16	0,23	6,89	9,47
Prunuscerasoides	0,03	0,10	2,67	5,96	0,02	0,04	1,14	2,56	1,09	1,55	19,73	29,67	0,12	0,16	4,46	6,31
Ficus nemoralis	0,20	0,80	4,00	8,94	0,04	0,10	3,00	6,71	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Quercus species	1,08	3,94	28,80	39,84	0,08	0,11	4,04	5,58	0,13	0,30	8,00	17,89	0,03	0,06	1,27	2,85
Persea species	0,23	0,93	4,00	8,94	0,05	0,11	2,60	5,81	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Sauraruianepalensis	0,12	0,48	4,00	8,94	0,03	0,08	1,10	2,46	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Celtis australis	0,38	1,49	7,20	9,96	0,08	0,13	9,20	16,93	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
hadibel (unknown)	0,04	0,16	3,20	7,16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Bombax ceiba	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,09	0,20	6,67	14,91	0,02	0,05	1,40	3,13
Pyrus pashia	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,27	0,59	6,67	14,91	0,04	0,09	1,80	4,02
Semicarpus anac.	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,24	0,54	6,67	14,91	0,04	0,09	2,30	5,14
Total	19,46	59,85	589,58	928,05	1,16	1,65	67,66	95,32	18,87	42,70	731,42	872,79	1,14	1,37	57,31	62,11

Annex- II: Comparative table showing the indicators for slide and non-slide areas in community managed secondary forest

Tree species	Indicators for community managed secondary forest (Slide areas)(n=3)								Indicators for community managed secondary forest (Non-Slide areas)(n=3)							
	BA/ha (m^2/ha)		N/ha		Q mean Diameter (m)		Q mean Height (m)		BA/ha(m^2/ha)		N/ha		Q mean Diameter (m)		Q mean Height (m)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Schima wallichii	5,11	1,83	164,42	61,58	0,18	0,00	11,50	0,49	8,85	3,88	135,53	31,48	0,25	0,03	12,24	0,93
Myrsina capitelleta	3,15	2,80	248,86	101,85	0,10	0,03	7,98	0,57	3,49	1,57	213,30	23,12	0,13	0,04	8,70	1,66
Madhuca indica	0,12	0,11	8,89	7,70	0,08	0,07	4,67	4,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Erythrina variegata	5,35	7,59	62,21	75,80	0,18	0,16	9,30	8,06	8,52	9,54	99,98	99,98	0,19	0,17	8,65	7,51
Eurya cerasifolia	0,14	0,24	4,44	7,70	0,06	0,10	3,67	6,35	0,81	0,74	26,66	23,09	0,12	0,10	7,10	6,30
Pinus wallichiana	0,11	0,19	6,67	11,55	0,04	0,07	4,00	6,93	1,18	1,83	8,89	7,70	0,21	0,26	9,83	8,52
Hadibel (unknown)	2,22	3,84	20,00	34,64	0,11	0,08	4,75	8,23	0,36	0,62	4,44	7,70	0,09	0,16	4,17	7,22
Lyonia ovalifolia	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,14	0,25	13,33	23,09	0,03	0,06	2,30	3,98
prunus cerasoides	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,42	4,44	7,70	0,08	0,14	4,33	7,51
Pinus roxburghii	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,21	2,10	20,00	34,64	0,08	0,14	4,96	8,59
Total	16,19	16,60	515,48	300,81	0,75	0,51	45,86	34,67	24,81	20,96	526,58	258,49	1,18	1,09	62,28	52,22

Annex- III: Comparative table showing the indicators for slide and non slide areas in private managed secondary forest

Tree species	**Indicators for managed secondary (Slide areas) Private forest(n=2)**								**Indicators for managed secondary (Slide areas) Private forest(n=2)**							
	BA/ha (m²/ha)		**N/ha**		**Q mean Diameter(m)**		**Q mean Height (m)**		**BA/ha (m²/ha)**		**N/ha**		**Q mean Diameter (m)**		**Q mean Height (m)**	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Schima wallichii	4,55	4,86	223,29	174,35	0,13	0,03	9,06	0,98	6,86	6,71	366,61	179,04	0,22	0,18	7,97	0,25
Alnus nepalensis	3,48	0,02	103,33	51,87	0,19	0,05	12,13	2,38	4,39	2,98	206,66	216,85	0,17	0,05	11,19	0,02
Hadibel (unknown)	0,41	0,58	30,00	42,43	0,06	0,08	4,40	6,22	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Madhuca indica	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,28	0,39	20,00	28,28	0,06	0,08	4,38	6,19
Castanopsis indica		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,11	0,16	10,00	14,14	0,05	0,08	5,75	8,13
Erithrina variegata	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,32	0,45	20,00	28,28	0,06	0,09	6,13	8,66
Total	8,44	5,46	356,62	268,64	0,38	0,17	25,58	9,59	11,96	10,69	623,27	466,60	0,57	0,48	35,41	23,26

Annex IV: Guideline for interviews

Site:

Location:

Date:

Interviewee:

Fotos:

1) Who is using the forest?

2) Did any landslide occur in the past? If yes, when? And how many?

3) Do you know why the landslide occurred?

4) What was the species composition and forest structure in the area of the when the landslide occurred?

5) How did vegetation develop after landslide and which restoration measures have been taken?

6) Who is managing this forest?

7) Are there any management problems regarding this forest (specific to species)? If yes specify.

8) In your opinion which species are effective for landslide prevention? Why?