

# Chapter 1

## INTRODUCTION

### 1.1 Background

Climate change is the most important present concern of the world. It is believed to be a function of concentration of green house gases particularly carbon dioxide (Rotter and Danish, 2002). Environmental degradation in terms of greenhouse gases, carbon dioxide emission, thinning of ozone layer, land degradation, water scarcity, deforestation and other calamities like flood and cyclone, etc. caused by anthropogenic and natural reasons have been a threat to the well being of people (Anon, 2001). Global climate is changing day by day as a result of natural variability and anthropogenic causes. This includes the change in the atmospheric composition, hydrological cycle, solar inputs and finally in the land surface (Negi *et al.*, 2003). Emissions of CO<sub>2</sub>, methane, nitrous oxide, chloroflourocarbons, hydroflouro carbons and perflourocarbons are identified as green house gases causing warming of earth globally. There was an increase of 0.75 °C in earth's mean temperature during the last century and the projected increase of 1 to 4 °C during the 21<sup>st</sup> century caused by an increase in the concentration of GHGs in the atmosphere (IPCC, 2001; 2007). Of these, CO<sub>2</sub> alone is accounted for 60% share, the contribution of other greenhouse gases is recorded as methane 20%, nitrous oxide 6% and chloroflourocarbons 14%. (Melkania, 2009). It is estimated that tropical deforestation, forest fires, and land use change contribute approximately 20% of global carbon dioxide emissions (USAID, 2010).

Increasing global temperatures will result in rising sea levels (Unnikrishanan *et al.*, 2006), disappearance of islands and (or) low lying coastal areas, increasing water stress, glaciers retreat, increased risk of extinction of some valuable species and health hazards ( Bhattacharya *et al.*, 2006). The effect of climate warming in mountain environments is the upward shift of species distribution (Parmesan and Yohe, 2003). If the increase of air temperature continues, by the end of the year 2030, sea level will rise by 20 cm, and at the end of this century it will rise by one meter. As a result, low lying countries of the world may go under water partly or wholly (Miah, 2002). The developing countries are faced with immediate concerns related to forest and land

degradation, fresh water shortage, food security and air and water pollution. (Melkania, 2009).

Increasing carbon emission is one of the major concerns (Ravindranath *et al.*, 1997) because it is the main causal factor for global warming (Lal *et al.*, 2001). The Kyoto protocol of the UN framework convention on climate change (UNFCCC) was the first step taken by the international community to address the problem of anthropogenic CO<sub>2</sub> accumulation in the atmosphere (Jina *et al.*, 2008). The Kyoto protocol 2005, rules industrialized countries to reduce their green house gases emissions by a weight average of 5.2 percent based on 1990 green house gases by the end of five year period (2008-2012) but does not require developing countries to reduce their green house gases (Sathaye *et al.*, 2006). The problem of anthropogenic CO<sub>2</sub> accumulation in the atmosphere can be addressed either by reducing CO<sub>2</sub> emission or by developing carbon sinks. If appropriately managed, forests and soils can become carbon storage pools, known as 'carbon sinks' under the Kyoto Protocol (IPCC, 2000). But Kyoto only addresses afforestation/reforestation and does not provide incentives to reduce deforestation and degradation.

Vegetation and soils are viable sinks of atmospheric carbon and may significantly contribute to mitigation of global climate change (Bajracharya *et al.*, 1998; Phillips *et al.*, 1998; Lal, 2004; Smith, 2004). The forests of Himalayan zones are recognized for their unique conservation value and richness of economically important biodiversity. Managing these forests may be useful technique to increase soil carbon status because the presence of trees affects carbon dynamics directly or indirectly. Forest vegetation and soils share almost 60% of the world's terrestrial carbon (Winjum *et al.*, 1992). The carbon stock in forest vegetation varies according to geographical location, plant species and age of the stand (Van Noordwijk *et al.*, 1997). Forests play an important role in the carbon cycle by absorbing carbon dioxide and releasing oxygen into the atmosphere. Carbon dioxide is converted to carbon and stored in the woody tissue of plant. Active absorption of CO<sub>2</sub> from the atmosphere through photosynthesis, and its subsequent storage in the biomass of growing trees or plants is the carbon storage (Baes *et al.*, 1977). Forest has the capacity to sequester carbon from the atmosphere and same to store in organic form. It was reported that a hectare of actively growing forest can sequesters 2–5 t of carbon per year (Brown, 1996), so forests play an important role in sequestration of carbon globally (Rawat *et al.*, 2003). Carbon

sequestration can be defined as the removal of carbon dioxide from atmosphere (source) into green plants (sink) where it can be stored indefinitely (Watson *et al.*, 2000). Kyoto Protocol recognizes that forest may be the best land used as a sink and sources of atmospheric carbon (Ross, 2000). Each year, as forests grow and their biomass increase, they absorb carbon from the atmosphere and store it in the plant tissue (Matthews *et al.*, 2000), so forests play multiple and significant roles in regulating atmospheric concentrations of carbon dioxide (Rotter *et al.*, 2002). Forest has three major roles in climate change as: a source of CO<sub>2</sub> when destroyed or degraded; react sensitively to changing climate; and sustainably managed forests to provide a unique environmental service by removing CO<sub>2</sub> from the atmosphere and by offering an alternative to fossil fuels (Schoene, 2002). Forests store more carbon dioxide (4500 Gt CO<sub>2</sub>) than the atmosphere (3000 Gt CO<sub>2</sub>) (Prentice *et al.*, 2001).

Soil carbon, on the other hand, depends on the aboveground input received from leaf litter and on the decomposition of fine roots below ground (Rasse *et al.*, 2006) and also from the residues of animals and microorganisms (Cowie *et al.*, 2006). Soil organic matter increases or decreases depending on numerous factors, including climate, vegetation type, nutrient availability, disturbance, and land use and management practice (Six and Jastrow, 2002; Baker, 2007). Soils are the largest carbon reservoirs of the terrestrial carbon cycle that contains about three times carbon than in the world's vegetation (IPCC, 2000; Smith, 2008; Sheikh *et al.*, 2009) and about two times of atmospheric carbon (Sheikh *et al.*, 2009). Soils play a key role in the global carbon budget and greenhouse effect (Jha *et al.*, 2003). Teller 1968 pointed out that the forest floor biomass plays a significant role in the structure and functioning of forest ecosystems by acting as a nutrient reservoir for the intra system cycling processes and improves the infiltration rate and water holding capacity of soils. The protection of organic soil carbon stocks in forest soils to increase carbon sequestration is crucial to maintenance of carbon balance (Ostle *et al.*, 2009). Worldwide the first 30 cm of soil holds 1500 Gt carbon (Batjes, 1996). The potential of soil C sequestration in central Asia is 10 to 22 Tg C yr<sup>-1</sup> (16±8 Tg C yr<sup>-1</sup>) for about 50 years, and it represents 20 percent of the CO<sub>2</sub> emissions by fossil fuel combustion (Lal, 2004b). About 40% of the total SOC stock of the global soils resides in forest ecosystem (Eswaran *et al.*, 1999). Litter fall is another important component of nutrient recycling in a forest and its input depends on a variety of factors such as

species, age groups, canopy cover, weather conditions and biotic factors (Lodhiyal and lodhiyal, 1997). The release of nutrients from litter decomposition is a fundamental process in the internal biogeochemical cycle of an ecosystem, and decomposers recycle a large amount of carbon that was bounded in the plant or tree to the atmosphere (Sevgi and Tecimen, 2008).

Biomass is defined as mass of live or dead organic matter. Biomass plays two major roles in the climate system:

- I. Photosynthesis withdraws carbon dioxide (CO<sub>2</sub>) from the atmosphere and stores it in plants as biomass, part of which is transferred to the soil when it decomposes or is stored in protected soil carbon pools.
- II. Biomass burnt by fire emits CO<sub>2</sub>, other trace gases and aerosols to the atmosphere (GTOS, 2009).

The importance of biomass as an Essential Climate Variable is due to both its role as a carbon sink during the process of photosynthesis, its role in governing ecosystem productivity and its growing use for generation of bioenergy. Sustainable management of biomass sources, in particular forests, which store most of the Earth's biomass, contributes to reduction of CO<sub>2</sub> in the atmosphere, mitigation of climate change and protection of other ecosystem services including biodiversity conservation and water resources. Estimates of biomass change (due to land use and management practices or natural processes) enable a direct measurement of carbon sequestration or loss (as long as associated changes in soil carbon are accounted for) that can help validate carbon-cycle models and to quantify the human induced impacts on global climate change (GTOS, 2009).

Vegetative carbon can be further categorized into carbon in aboveground (shoot) biomass, belowground (root) biomass, and necromass (Hamburg, 2000). Root biomass is an important carbon pool, which often represent 10 to 40% of total biomass (MacDicken, 1997). It is estimated that the underground biomass represents 26% of aboveground biomass (Cairns *et al.*, 1997).

Vegetation biomass is a crucial ecological variable for understanding the evolution and potential future changes of the climate system. Vegetation biomass is a larger global store of carbon than the atmosphere, and changes in the amount of vegetation

biomass already affect the global atmosphere by being a net source of carbon, and having the potential either to sequester carbon in the future or to become an even larger source. Depending on the quantity of biomass the vegetation cover can have a direct influence on local, regional and even global climate, particularly on air temperature and humidity (GTOS, 2009). Immature forests sequester carbon at high rates, while in mature forests carbon sequestration eventually equals decomposition; that is, the carbon balance of the ecosystem reaches a steady state (Streck and Scholz, 2006).

According to Leith and Whittaker (1975) if forest biomass is measured and analysed in its proper context as part of production, an overall picture of ecosystem functioning can be gained. However, the biomass and productivity of tree species varies from place to place due to variation in climate, soil, temperature and rainfall. Biomass and net primary productivity (NPP) have been studied in temperate and tropical forest vegetation types (Pal and Raturi, 1990; Sharma *et al.*, 1988; Bargali *et al.*, 1992). Lodhiyal *et al.*, 1995; and Lodhiyal and Lodhiyal, 1997 have made detailed studies of the biomass and productivity of exotic plantations in the central Himalayan Terai belt. But, little is known about the structure and function of Himalayan high-altitude forests. They have been under continual threat of deforestation and degradation for thousands of years posing a serious ecological crisis in these inherently fragile ecosystems (Ives and Messerli, 1989). They grow in an environment dissimilar to that of the subalpine and alpine communities of higher latitudes (Garkoti, 2008). At high altitudes, a larger amount of production is invested in biomass structure. Due to the low air temperature in the subalpine and alpine belt, plants with low stature are favoured as their leaves occupy the warmest microenvironment near to the ground (Wilson *et al.*, 1987).

A realistic estimate of the carbon stock at any given time is crucial for two reasons. First, it indicates the potentiality of vegetation to release or absorb carbon. Secondly, a time series of the carbon stock in vegetation can be used to strain methods such as inverse modeling in estimating the net carbon flux to or from the global soils (Goodale *et al.*, 2002). The aboveground tree biomass and belowground root biomass both need to be measured to enable better calculations of total forest carbon (Hamburg, 2000). Several methods have been devised to estimate biomass; the most frequently used being based on allometric relationships of biomass and plant

measurements, such as stem diameter, plant height, and wood specific gravity (WSG) (Ter- Mikaelian and Korzukhin, 1997; Zianis and Mencuccini, 2004; Chave *et al.*, 2005).

Carbon stock is typically derived from above-ground biomass by assuming that 50% of the biomass is made up by carbon. The most accurate method for the estimation of biomass is through cutting of trees and weighing of their parts. This destructive method is often used to validate others, less invasive and costly methods, such as the estimation of carbon stock using nondestructive *in-situ* measurements and remote sensing (Clark *et al.*, 2001; Wang *et al.*, 2003). The general lack of accurate spatial forest biomass data has been considered one of the most persistent uncertainties concerning global C budgets (Harrell *et al.*, 1995).

## **1.2 Rationale**

Climate change due to global warming is a burning issue. Carbon sequestering in the biomass and soil of forest has evolved as a good alternative to tackle global warming and climate change. Forest carbon estimates are of scientific importance to improve the understanding of the role of forest carbon sequestration in Earth's climate system. Various studies regarding the carbon sequestration in tropical and temperate regions have been done by various researchers (Pal and Raturi, 1990; Sharma *et al.*, 1988; Bargali *et al.*, 1992). Few studies have been done in high altitudes (Garkoti and Singh, 1995; Garkoti, 2008). In Nepal carbon stock estimation is done mostly in tropical and temperate regions. Carbon stock estimation in high altitude of Nepal is still lacking. Moreover, most of the studies have been done in Central and Eastern part of the country. Western part of the country is still an unexplored region. The present study tries to estimate the carbon stock in high altitude forest. The study also focuses on the effect of environmental parameters on the carbon stock of the area. At the same time, the study aims to explore the western part of the country to some respect.

## **1.3 Research Questions**

The research questions of the study were:

- Is there any variance in tree carbon stock in different forest types?
- Does altitude have any effect in the carbon stock?

- Does environmental parameters like moisture, pH, rock cover and canopy affect the carbon stock?

#### **1.4 Hypothesis**

The general hypotheses of the study were:

- The biomass carbon stock of trees in different forest types is different.
- Soil organic carbon content decrease with increase in altitude.

#### **1.5 Objectives**

The broad objective of the study was to estimate the biomass carbon stock of trees in different forest types of upper Humla. The specific objectives of the study were as follows:

- To show the relationship between biomass carbon stock of trees with respect to different forest types.
- To assess the biomass carbon stock of trees in each forest type along altitudinal gradient.

## CHAPTER 2

### STUDY AREA

#### 2.1 Geographical location

Humla district is a mountainous district that lies in Karnali zone of Mid Western Development Region of Nepal. Geographically, Humla district lies between 29° 35' to 30° 70' North latitude and 81° 18' to 82° 10' East longitude in global map. It covers an area of 6003.66 sq km (KSL-Nepal, 2010). Its elevation ranges from 1,220m to 7,336m above sea level (a.s.l.). It is surrounded by the Mugu district in the East; Bajhang district to the west; Bajura district to the south and Tibetan Autonomous Region of China to the north (DDC, 2004). Simikot is the district headquarters of Humla, which is situated at an elevation of 2945 m a.s.l. It is situated on a ridge high above the Humla Karnali river and is surrounded by high snow-covered peaks. According to District Irrigation Office in Humla, there are more than 50 rivers in the district. The major river is Humla Karnali. Other rivers of the district are Dojam, Kawadi, Lukya, Gothi, Takche, Tanke, Karanga, Miniman, Kumuchiya, etc. These rivers have potential to generate hydropower upto 10,300 MW however these resources have yet to be exploited.

Humla has been divided into three regions namely lower, middle and upper Humla. The division is based on the location from the district headquarter – *Simikot*. Lower Humla is situated in the south of *Simikot*, middle Humla lies in the north and north east of *Simikot* and upper Humla lies in the north-west of *Simikot*. Humla consists of 27 Village Development Committees (VDCs) and each VDC is further divided into nine wards.

Table 1: Geographical location of VDCs with reference to district headquarters

S.N.	Geographical location	No. of VDCs	Name of VDCs
1.	Lower Humla	13	Madanaa, Mailaa, Shreenagar, Kaalika, Jaira, Daarmaa, Mimi, Melchhaam, Saanyaa, Serkideu, Baraai, Gothi and Rodikot
2.	Middle Humla	8	Laali, Raayaa, Shreemastaa, Kharpoonaath, Chhipraa, Thehe, Bargaun and Simkot

3.	Upper Humla	6	Daandaafaya, Hepkaa, Syaandaa, Khagaalgaun, Muchu and Limi
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(Source: Roy, 2010)

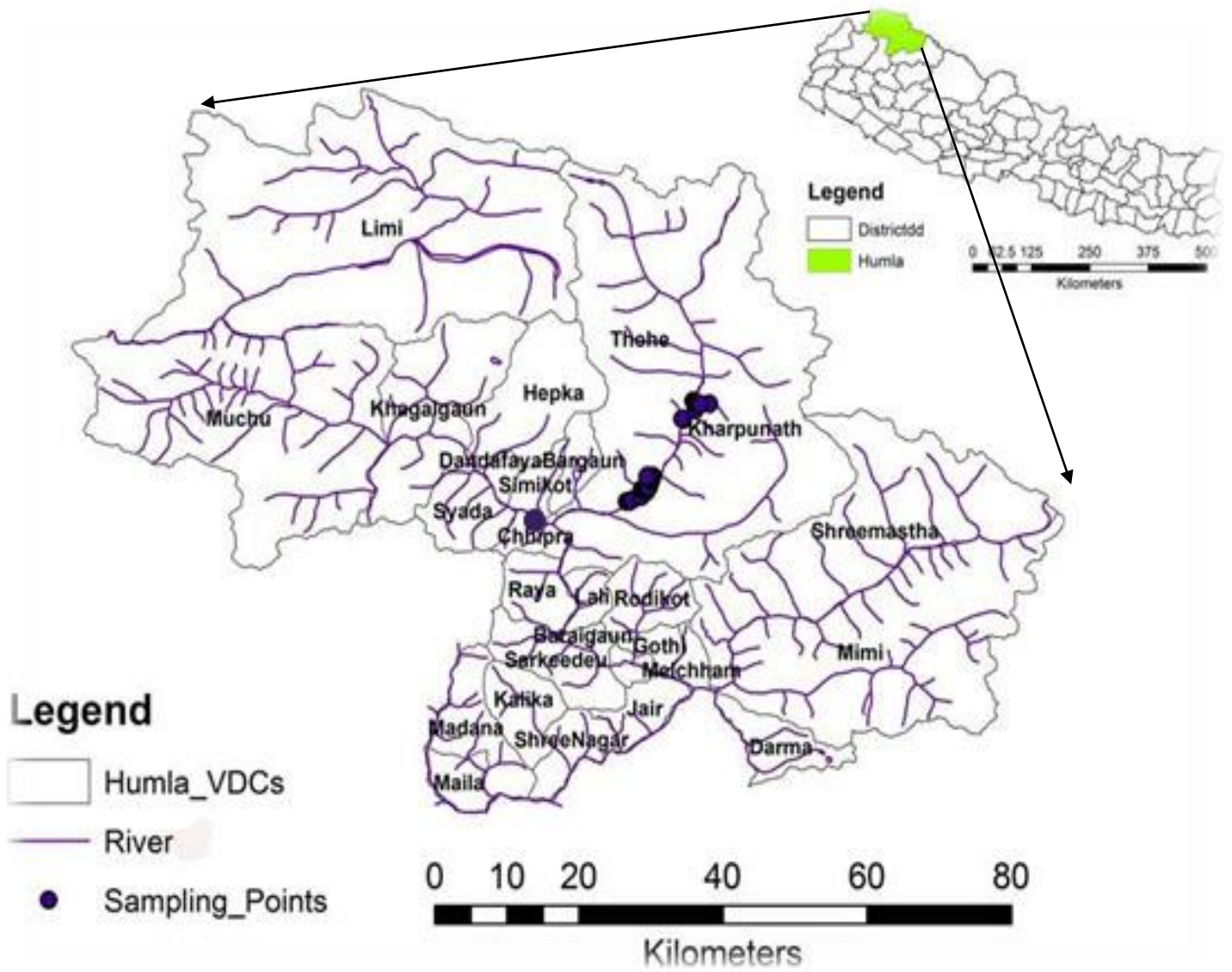


Fig 1. Location of the study area and sampling plots

## 2.2 Climate

The altitude of Humla ranges from 1220 m to 7336m a.s.l. Due to this variation, the climate of the region varies greatly from subtropical to alpine type. Climate of the area is generally characterized by high rainfall and humidity; whereas some part of district is drier ( KSLCI, 2011). In north, most part is covered with snow and the climate is alpine. In the southern part and valleys the climate is subtropical, and in middle hill region it is temperate type. The average maximum temperature is 25 °C and the minimum temperature is –12 °C at Simikot. Rainfall ranges from 14-148 mm per month, with nearly 80% of the total annual rainfall (783 mm) falling during the four months of monsoons from June to September. All areas experience very high rainfall intensities, while upper part of Humla is relatively much drier. Within its elevation range up to 2,000 m there are limited subtropical valleys in the southern margin although most of the area is physiographically temperate or highland. A cold, generally dry climate exists in the high alpine valleys just north of the southern arm of the Himalaya that cuts across the bottom of Humla. The climatic data was obtained from Department of Hydrology and Meterology, Babarmahal which was recorded at the station of district headquarters, *Simikot*.

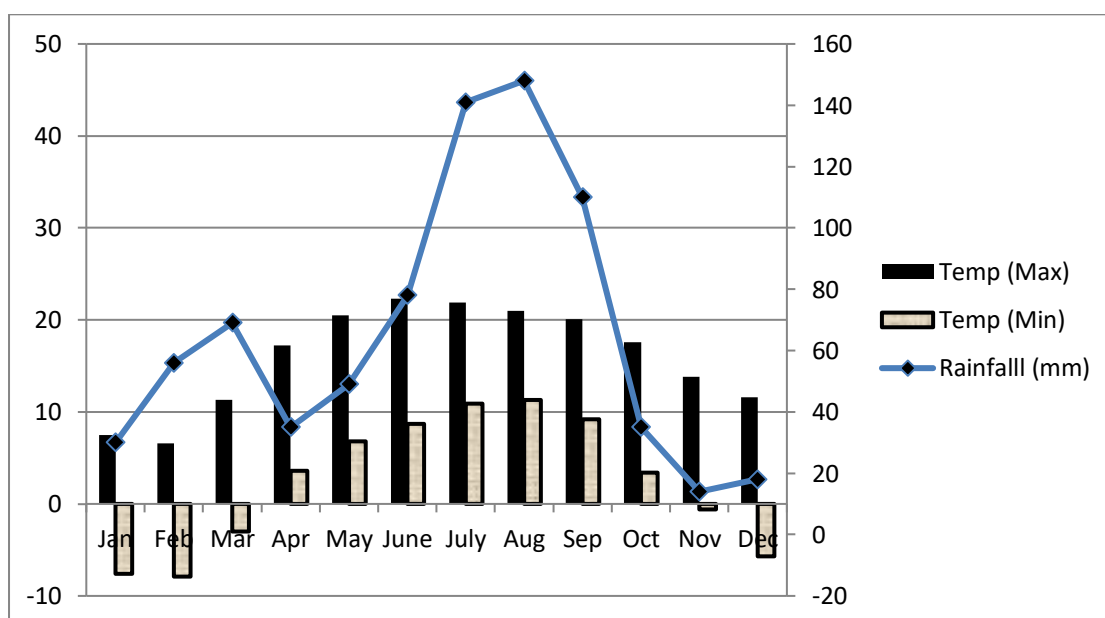


Fig 2. Average maximum and minimum temperature (°C) and average rainfall recorded at *Simikot* station (1989-2006). *Source:* Department of Hydrology and Meterology, Kathmandu, Nepal.

## 2.3 Soil

In the high himalayan region fine particles of stony soil exist in cracks of larger rock while in high mountains stony soil is found. In the middle mountain soil is moderately to high acidic, medium to light textured coarse grained sand and gravel. Soils of the lower region are predominantly fine to coarse loam; and alluvial and coarse textured in irrigated field. Soils in the middle mountains are moderately acidic, medium- to light- textured coarse grained sand and gravel (KSL-Nepal, 2010).

## 2.4 Vegetation

Vegetation of an area largely depends on the altitudinal and climatic variations. Of 35 forests types found in Nepal, 15 types of forests are found in Humla (Stainton, 1972: KSL-Nepal, 2010).

Table 2 : Forest types found in Humla

S.N.	Forest type	Altitude (m asl)	Forest sub type	Associated species
1.	Chir pine forest	1000-2700	<i>Pinus roxburghii</i> forest	<i>Olea cuspidate</i> , <i>Capparis spinosa</i> , <i>Woodfordia fruticosa</i> , <i>Indigofera heterantha</i>
2.	Alder forest	500-2700	<i>Alnus nepalensis</i> and <i>A. nitida</i> forest	<i>Juglans regia</i> , <i>Quercus floribunda</i> , <i>Populus ciliata</i>
3.	Oak Forest	2000-3100	Oak ( <i>Q. floribunda</i> ) forest (2100-2750m)  Oak ( <i>Quercus leucotrichophora</i> , <i>Q.lanata</i> )- chir pine ( <i>Pinus roxburghii</i> ) forest (2000-2450m)	<i>Alnus nepalensis</i> , <i>Q. leucotrichophora</i>

			Oak <i>semecarpifolia</i> - blue pine <i>wallichiana</i> ) forest (2450-3000m)	( <i>Q.</i> <i>Pinus</i> )	
			Oak forest ( <i>Quercus</i> <i>semecarpifolia</i> ) (2450-3100m)	<i>Abies spectabilis,</i> <i>utilis, Rosa sericea</i>	<i>Betula</i>
4.	Himalayan blue pine forest	2000- 3500	Pine <i>wallichiana</i> ) (2000-3200m)	( <i>Pinus</i> forest <i>Pinus wallichiana,</i> <i>Picea smithiana,</i> <i>pindrow,</i> <i>leuchotrichophora</i> )	<i>Abies</i> <i>Q.</i>
			<i>Pinus-Picea-Abies</i> forest (2800-3500m)	<i>Pinus wallichiana,</i> <i>smithiana,</i> <i>spectabilis,</i> <i>semecarpifolia,</i> <i>Juniperus wallichiana</i>	<i>Abies</i> <i>Q.</i> <i>Sorbus</i> <i>cuspidata, Juglans regia,</i>
5.	Upper temperate mixed broad-leaved forest	2000- 2900	<i>Aesculus-</i> <i>Acer</i> forest	<i>Juglans-</i> <i>Juglans</i> <i>regia, Acer caesium,</i> <i>Betula alnoides,</i> <i>nepalensis,</i> <i>floribunda,</i> <i>semecarpifolia,</i> <i>Prunus</i> <i>cornuta</i>	<i>Aesculus indica, Juglans</i> <i>regia, Acer caesium,</i> <i>Betula alnoides, Alnus</i> <i>nepalensis, Quercus</i> <i>floribunda, Q.</i> <i>semecarpifolia, Prunus</i> <i>cornuta</i>
6.	Hemlock forest	2100- 3200	<i>Tsuga dumosa</i> forest	<i>Pinus wallichiana, Abies</i> <i>spectabilis,</i> <i>Sorbus</i> <i>cuspidate, Ilex dipyrena)</i>	

7.	Himalayan Cypress forest	2100- 2900	<i>Cupressus torulosa</i> - <i>Abies pindrow</i> forest <i>Cupressus torulosa</i> forest	<i>Rosa macrophylla</i> , <i>Syringa</i> <i>emodi</i> Juniperus indica, Viburnum cotinifolium, Berberis species, Cotoneaster species
8.	Himalayan Spruce forest	2150- 3200	<i>Picea smithiana</i> forest	<i>Pinus wallichiana</i> , <i>Abies</i> <i>pindrow</i> , <i>Tsuga dumosa</i> , <i>Populus ciliate</i> , <i>Betula</i> <i>utilis</i>
9.	Fir forest	2150- 3500	<i>Abies pindrow</i> (2150- 2900m)  <i>Abies spectabilis</i> (3050-3950m)  <i>Abies spectabilis</i> - <i>Betula utilis</i> forest (3000-4000m)  <i>Abies spectabilis</i> - <i>Junipeus indicar</i> forest (3000-3500m)	<i>Sorbus foliolosa</i> , <i>Taxus</i> <i>wallichiana</i> , <i>Rosa sericea</i> , <i>Cotoneaster acuminata</i> , <i>Ribes graciale</i>
10.	Himalayan Cedar forest	2000- 2600	<i>Cedrus deodara</i> forest	<i>Pinus wallichiana</i> , <i>Rosa</i> <i>sericea</i> , <i>Berberis aristata</i> , <i>Cotoneaster frigidus</i> , <i>Spiraea canescens</i>
11.	Poplar forest	2150- 3200	<i>Populus ciliata</i>	<i>Picea smithiana</i> , <i>Pinus</i> <i>wallichiana</i> , <i>Hippophae</i>

				<i>salicifolia, Rosa sericea, Jasminus officinale</i>
12.	Birch forest	2900-4000	<i>Betula utilis</i> forest (2900-3800m)	<i>Prunus rufa, Acer caesium, Sorbus microphylla, Lonicera myrtillus</i>
			<i>Betula utilis- Rhododendron campanulatum</i> (3500-4000m)	<i>Abies spectabilis, Prunus cornuta, Ribes graciale, Lonicera myrtillus</i>
13.	Moist alpine shrub	3650-4400	Moist alpine shrub	<i>Juniperus wallichiana, Rhododendron lepidotum, R. anthopogon, Potentilla fruticosa, Lonicera obovata</i>
14.	Caragana Steppe	4000-4500	<i>Caragana</i> Steppe	<i>Caragana gerardiana, C. brevifolia, Myricaria rosea</i>
15.	Upper Alpine meadows	4500-5000	Upper alpine meadows	<i>Festuca ovina, Kobresia seliculmus, Agrostis munroana, Allium carolinianum, Arenaria polytrichoides, Saxifraga stenophylla</i>

(Source: Stainton 1972; KSL-Nepal, 2010)

Based on botanical collections made in Humla, the largest ten families comprises of Asteraceae (18 genera/29species), Poaceae (16/18), Fabaceae (12/17), Brassicaceae (11/13), Liliaceae (10/15), Lamiaceae (10/10), Scrophulariaceae (9/10), Ranunculaceae (8/29), and Polygonaceae (7/16). Similarly, Largest genera of angiosperms include *Anemone* and *Potentilla* (8 species each), *Lonicera* (7 species), *Berberis*, *Ficus*, *Rhododendron* and *Rubus* (6 species each), *Acer*, *Androsace*,

*Artemisia, Clematis, Prunus, Rosa, Salix* (5 species each), *Aconitum, Cotoneaster, Primula, Thalictrum* (4 species each). A recent cursory survey in some parts of Humla district and screening of the specimens in National Herbarium revealed the presence of nearly 700 species (KSL- Nepal, 2010).

## 2.5 Forest Resources

Humla is rich in natural resources especially in forest products, Non Timber Forests Products (NTFPs) and Medicinal and Aromatic Plants (MAPs). Non-timber forest products and timber are two main categories of forest products. With the increasing importance of forest resources, the forest products are further classified into major forest products and minor forest products. In this context, timber and firewood have been categorized into major forest products whereas other products of the tree are considered as the minor forest product (Khatri, 1993).

Humla is rich in different NTFPs species such as wild edible and medicinal plants. Hammett (1993) and De Beer and Mcdermott (1996) define NTFPs as ‘all biological material other than timber which are extracted from forests for human use’. It further broadens the definition by including the forest products such as foods, medicines, spices, essential oils, resins, gums, latexes, tannins, dyes, ornamental plants, wildlife products (bones and skins) fuelwood and raw material resources like bamboo, broom grass, rattan, small wood and fibers. Furthermore, Kanel (2000) puts more emphasis on the socio-economic aspect of the NTFPs, which include bamboo, canes, medicinal plants and their products under the NTFPs definition. Generally, NTFPs have been understood as the forest products other than timber.

“Jatamansi” (*Nardostachys grandiflora*), “Atis” (*Delphinium himalayai*), “Guchchi Chyau” (*Marchella conica*), “Kutki” (*Picrorhiza scrophulariiflora*), “Padamchal” (*Rheum austral*) and “Sugandhawal” (*Valeriana jatamansii*) are the major NTFP species found in Humla. Similarly, other NTFPs species are: “Nirmansi” (*Pamassia nubicola*), “Pakhanbed” (*Berginia ciliate*), “Dale Chuk” (*Hippophae salicifolia*) “Chiraito” (*Swertia chirayita*), “Panch Aule” (*Dactylorhiza hatagirea*), “Satuwa” (*Paris polyphylla*) and so on (DDC, 2004; NIDS, 2005). “Yarsagumba” (*Cordyceps sinensis*) is recently found in some high altitude area of Humla i.e. Raani Sainya. All these plants have both economic and medicinal values. According to District Forest

Office (DFO), Humla (2005), “Jatamansi” (*Nardostachys grandiflora*), “Kutki” (*Picrorhiza scrophulariiflora*) and “Atis” (*Delphinium himalayai*) were the most exported NTFPs species in the year 2005/06. This record of DFO is only for legally exported NTFPs species by paying royalty to the government. Due to high market demand of NTFPs, there is high possibility of illegal trade of NTFPs.

# CHAPTER 3

## MATERIALS AND METHODS

### 3.1 Forest Identification and Sampling Design

Different types of forests were identified on the basis of altitude, slope and aspect along the Humla Karnali River within 2450-4250 m. In each forest type ten plots each measuring 10x10m were randomly marked for sampling tree species. In each of the 10 plots, woody plant  $\geq 10$  cm in diameter at breast height (1.37 m above the ground level) were identified, counted and measured for diameter at breast height (dbh) and height. The dbh was measured using dbh tape whereas the tree height was determined by using clinometer and trigonometric ratios as below.

$$H = \tan\theta \times b + a$$

where, H= total height of the tree in meter

$\theta$ = angle of elevation to the top of the tree from observers eyes.

b = distance between the tree base and the observer in meter

a = eye-height of the observer in meter.

### 3.2 Soil sampling

Soil samples were collected in each sampling plot, 20 cm below the ground surface from the four corners using a soil digger. These sub samples were mixed thoroughly and about 200g was collected in zipper polythene bag. The soil samples were air dried in shade for a week and stored in air tight plastic bags until laboratory analysis.

### 3.3 Environmental Parameters

Longitude, latitude, and elevation of each sample plot were recorded by global positioning system (GPS, eTrex Garmin) and elevation was cross-checked with a standardized altimeter. Slope and aspect of each plot were recorded by a clinometer compass. Soil moisture and pH of each sub-plot were recorded by using a gauge (Soil

pH and moisture Tester; Model DM 15) with a default scale of 1 to 8 for both parameters. The rock cover and canopy were estimated by visual observation. The average of three people's estimation was used for analysis.

### 3.4 Specimens collection and identification

All the tree species were identified in the field at the time of data collection using the floristic literatures Polunin and Stantion (1984) and Stantion (1988) and with the help of experts in the Central Department of Botany.

### 3.5 Soil organic carbon content

Soil organic carbon content (SOC) was determined in Ecology laboratory in the Central Department of Botany, Tribhuvan University. SOC was calculated by Walkey and Black's rapid titration method (1934). Soil sample was sieved through fine sieve (0.5 mm). Then 0.10 g fine sieved soil sample was taken in a 500 ml conical flask and 5 ml of 1N  $K_2Cr_2O_7$  and 10 ml of conc.  $H_2SO_4$  were added successively with gentle swirling. The digestion reaction being exothermic, the flask was left for about 30 minutes to cool down to room temperature. To that mixture 100 ml distilled water, 5 ml orthophosphoric acid and 1 ml diphenylamine indicator solution were added successively and shaken. Ferrous ammonium sulphate solution (0.5 N) was run from burette, with constant stirring until the colour changed from violet to bright green through blue. The volume of ferrous ammonium sulphate solution used for titration was noted. Similarly, a blank titration (without soil) was carried out at every lot of 11 samples.

Volume of 0.5N ferrous ammonium sulphate solution used for blank titration: X

Volume of 0.5N ferrous ammonium sulphate consumed with soil: Y

Volume of 1N  $K_2Cr_2O_7$  used for oxidation of organic carbon in soil:  $\frac{X-Y}{2}$

Mass of soil sample taken in gram = s

Organic carbon in soil (%) =  $\frac{X-Y}{2} \times 0.003 \times \frac{100}{s}$

## 3.6 Calculation

### 3.6.1 Biomass estimation

Most of the research on biomass estimation has focused on the tree components of forest because it accounts for the greatest fraction of the total biomass, its response to clearing and regrowth is reasonable well understood for modeling purposes, and forest inventories generally give information for this components only.

In this study we consider only the total above ground biomass in trees of diameter 10 cm or larger, estimates of the biomass of the other living aboveground components of a forest were not included mainly because (1) the present data base for them is insufficient to make extrapolations to a larger scale, and (2) they represent a small fraction of the total biomass. For example the contribution of understory shrubs, vines and herbaceous plants to aboveground mass can be variable but generally very small (about 3% or less (Hegarty, 1989; Jordan and Uhl, 1978; Tanner, 1980), although it is likely to be a larger proportion in disturbed forests.

For aboveground biomass estimation allometric models developed by Chave *et al.*, (2005) was used for the tree with dbh  $\geq 10$ cm of which wood specific density was known. The calculated values of wood density of the tree species (ANNEX IV) were taken from HMGN/MPFS/FRISDP (1988) and Jackson (1987). For remaining species (with unknown wood density) empirical biomass equation developed by Zianis (2008) for global approach was used. The equations are as followings.

$$1) \text{ AGB} = \exp [-2.187 + 0.916 \times \ln \{ \rho(\text{dbh})^2 H \}] \text{ (Chave } et \text{ al., 2005)}$$
$$\equiv 0.112 \times \{ \rho(\text{dbh})^2 H \}^{0.916}$$

Where, D = diameter of tree at breast height

$$2) \text{ AGB} = a(\text{dbh})^b \text{ (Zianis, 2008)}$$

where, dbh= diameter of tree at breast height (1.37m above ground)

H= height of tree in m

$\rho$  = wood specific gravity (g cm<sup>-3</sup>)

$$a= 0.1424 \text{ and } b= 2.3679$$

The root biomass was calculated by multiplying the aboveground biomass by 0.26 as the root to shoot biomass ratio (R/S) is 0.26. (Cairns *et al.*, 1997). The total biomass was calculated by adding total aboveground biomass and root biomass.

$$\text{Total biomass} = \text{Aboveground biomass} + \text{Belowground biomass}$$

### **2.6.2 Carbon stock in biomass**

The amount of carbon in biomass was assumed to be 50% of the biomass. Total biomass was multiplied by biomass expansion factor i.e., 0.5 (Brown 1997; Macauley *et al.*, 2009) to get carbon content.

### **2.6.3 Basal area**

Basal area (BA) of a tree was obtained by following formula:

$$\text{Basal area (BA)} = \frac{\pi(\text{dbh})^2}{4}$$

Basal area of trees in each quadrat was obtained by the summation of BA of all trees in the quadrat.

### **2.6.4 Statistical analysis**

Mean values of basal area, canopy cover, soil pH, soil moisture and SOC of the soil layer was calculated. Regression was calculated among elevation, soil attributes and carbon stocks. Effect of soil pH, soil moisture, SOC, basal area, canopy cover, rock cover and altitude on biomass C stock were evaluated by regression analysis. In this analysis soil pH, soil moisture, SOC, basal area, canopy cover, rock cover and altitude were considered as explanatory variable and biomass C stock as response variables. Likewise, effect of soil pH, soil moisture, basal area, canopy cover, rock cover and altitude on soil organic carbon were evaluated by regression analysis. In this analysis soil pH, soil moisture, basal area, canopy cover, rock cover and altitude were considered as explanatory variable and soil organic carbon as response variables. A Linear Model (LM: McCullagh & Nelder, 1989; Dobson, 1990) was used for

regression. A log linear model with a Poisson error distribution was used for the analysis due to the count nature of the response variables. The Chi square-test statistics was used for analysis. A quasi- Poisson error distribution with F- test was used where the data showed the over dispersion to handle the over dispersion of the deviance (Crawley, 2007). The significance of each model was tested against the null model as well as with each other up to the third-order polynomials. Forward selection of model was done. The model with higher F-value and highly significance value of Chi square test was selected for the model fitting and graphical representation. R version 2.10.1 (R Development Core Team, 2010) was used for regression analyses and graphical representation. Carbon stock (biomass) between seven forest types were also compared using one way ANOVA. The statistical analyses were done on the spreadsheet of MS-Excel and the Statistical Package for Social Sciences (SPSS) version 16.0 was also used.

## CHAPTER 4

### RESULTS

The correlations among different parameters are shown in the following table 3. The highest correlation was observed between carbon stock and basal area.

Table 3. Correlation matrix

	forest types	Altitude	soil pH	soil moisture	canopy	rock cover	basal area	carbon stock
forest types	1							
Altitude	-0.95	1						
soil pH	0.13	-0.21	1					
soil moisture	-0.51	0.66	-0.5	1				
canopy	0.46	-0.48	0.07	-0.24	1			
rock cover	0.19	-0.06	-0.08	0.25	-0.15	1		
basal area	0.27	-0.28	-0.15	-0.01	0.46	-0.16	1	
carbon stock	0.19	-0.21	-0.09	-0.12	0.38	-0.18	0.88	1

#### 4.1 Biomass

The mean biomass of the study area was found 516.56 t/ha with the mean above ground tree biomass of 409.97 t/ha. The biomass of different forest types ranged from 140.18 t/ha to 670.3 t/ha. The maximum biomass was found in *Abies spectabilis* forest and minimum biomass was found in birch forest. The above ground biomass ranges between 111.25 t/ha to 531.99 t/ha.

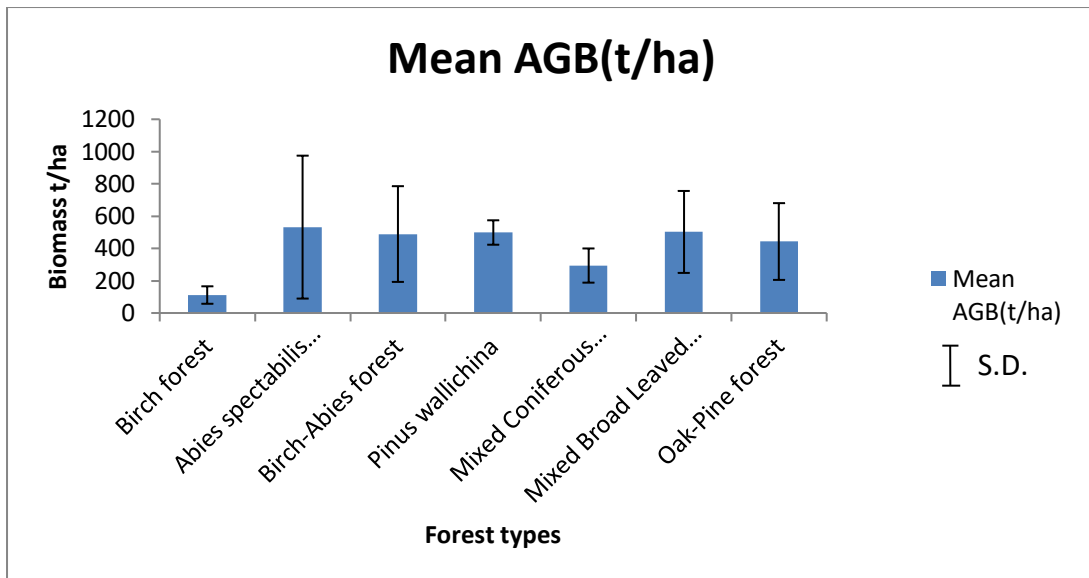


Fig. 3: Mean above ground biomass (t/ha) in different forest types

#### 4.2 Biomass Carbon Stock

The mean biomass carbon stock in the study area was found 258.28 t/ha (Table 4). Biomass carbon stock in seven forest types were found significantly different at  $p=0.002$ .

Table 4: Analysis of Variance table between forest types and carbon stock

Total Biomass Carbon stock

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	560712.499	6	93452.083	3.881	0.002
Within Groups	1517111.985	63	24081.143		
Total	2077824.483	69			

Mean biomass carbon stock (t/ha) were found 70.09, 335.15, 308.12, 314.15, 185.19, 316.36 and 278.91 in Birch forest, *Abies spectabilis* forest, Birch-Abies forest, *Pinus wallichiana* forest, Mixed Coniferous forest, Mixed Broad Leaved forest and Oak-Pine forest, respectively (ANNEX III).

A unimodal relationship was observed between biomass carbon stock when regressed against altitude (fig. 4). Statistically both 1<sup>st</sup> and 2<sup>nd</sup> order polynomial was found significant but second order polynomial was most appropriate model that fit the pattern (ANNEX V). In this regression, the biomass carbon stock was low at lower

and higher altitude whereas more biomass carbon stock was found in mid altitude. The maximum biomass carbon stock was found 335.15 (t/ha) in *Abies spectabilis* forest, at an altitude ranges from 3640m-3785m. The minimum biomass carbon stock was found 70.09 (t/ha) in Birch forest, at an altitude ranges from 4008m – 4220 m asl.

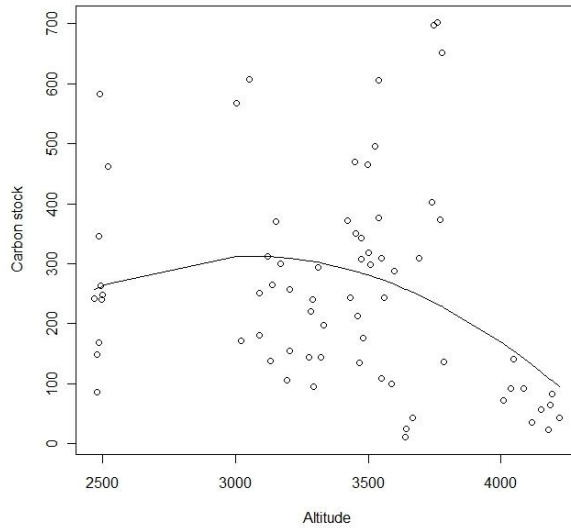


Fig.4 Relationship between biomass carbon stock (t/ha) with altitude (m), (lines are fitted with LM, 2<sup>nd</sup> order).

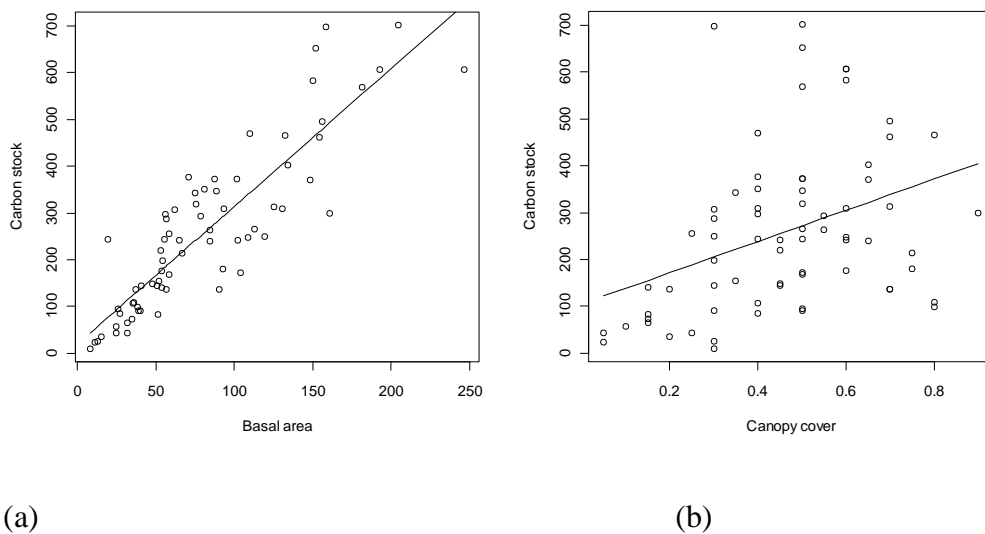


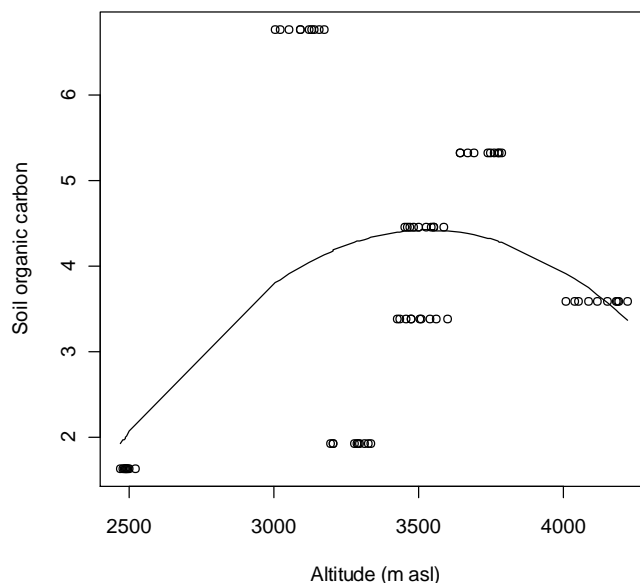
Fig. 5(a) Relationship between biomass carbon stock (t/ha) with basal area (m<sup>2</sup>) and (b) between biomass carbon stock (t/ha) with canopy cover, (lines are fitted with LM, 1<sup>st</sup> order).

A linear relationship was observed between biomass carbon stock when regressed against basal area and canopy cover (fig.5 a & b). Statistically 1<sup>st</sup> order polynomial was found significant with basal area whereas both 1<sup>st</sup> and 2<sup>nd</sup> order polynomial was found significant but first order polynomial was most appropriate model that fit the pattern (ANNEX V). In this regression, the biomass carbon stock was found low at both lower basal area and less coverage of canopy. While increasing the basal area and canopy, the biomass carbon stock also increases successively.

### 4.3 Soil Organic carbon

The average soil organic carbon was found 3.87% in the study area. The soil organic carbon was found maximum in Mixed Broad Leaved forest and minimum in Oak-Pine forest with the values 6.76% and 1.64% respectively (ANNEX III).

A unimodal relationship was observed between soil organic carbon when regressed against altitude (fig. 6). Statistically both 1<sup>st</sup> and 2<sup>nd</sup> order polynomial was found significant but second order polynomial was most appropriate model that fit the pattern (ANNEX V).



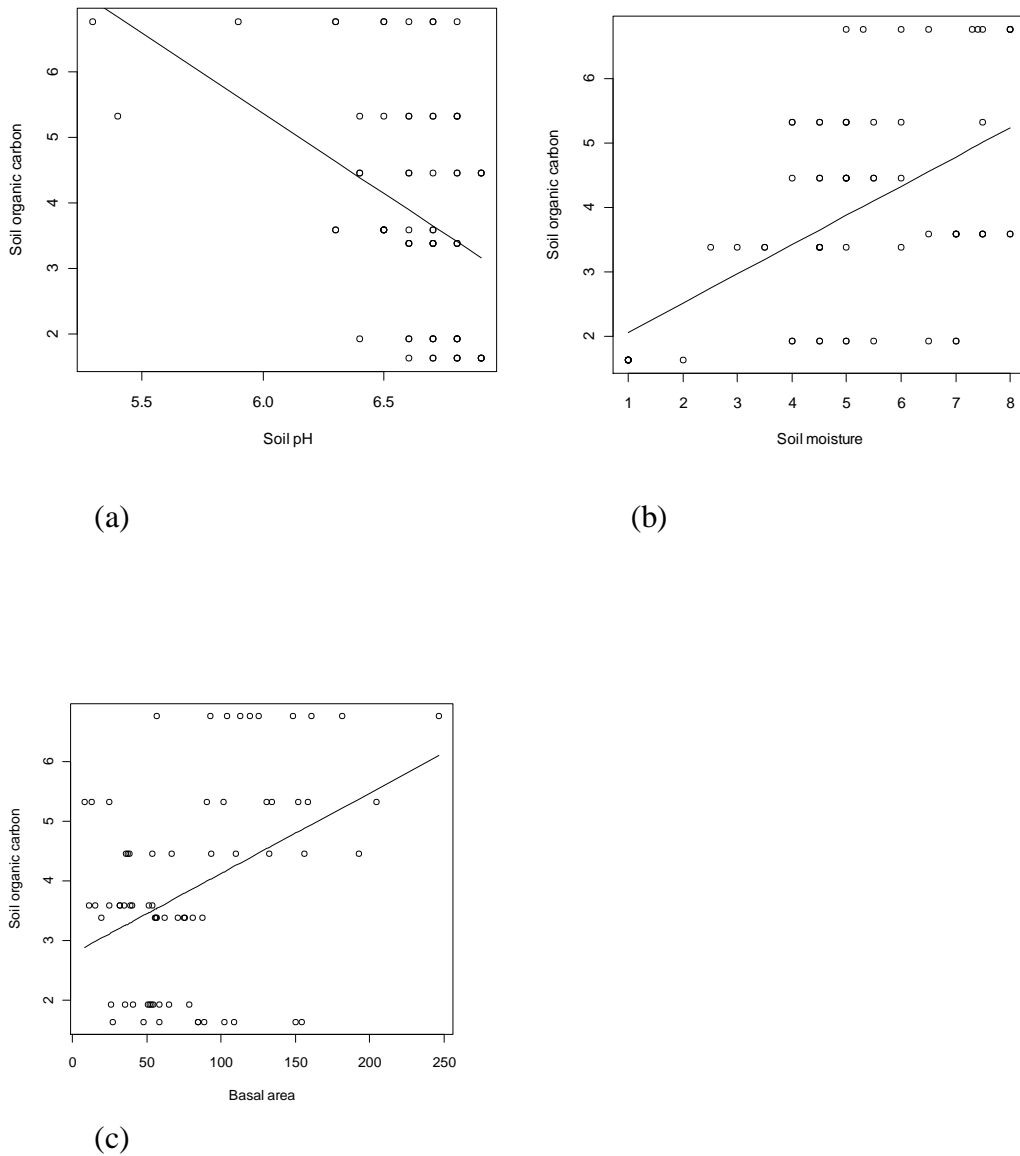


Fig. 7 (a) Relationship between soil organic carbon (%) with soil pH, (b) between soil organic carbon (%) with soil moisture and (c) between soil organic carbon (%) with basal area ( $m^2$ ), (lines are fitted with LM, 1<sup>st</sup> order).

A linear relationship was observed between soil organic carbon when regressed against soil pH, soil moisture and basal area (fig.7 a, b & c). Statistically 1<sup>st</sup> order polynomial was found significant that fit the pattern with all these parameters. (ANNEX V). In this regression, the soil organic carbon was found low at high soil pH and it goes on increasing as the pH goes on decreasing. But soil organic carbon was found low at both lower soil moisture and basal area. While increasing the soil moisture and basal area, the soil organic carbon also increases successively.

# CHAPTER 5

## DISCUSSION

### 5.1 Biomass

#### 5.1.1 Aboveground biomass

The mean above ground tree biomass of different forest types in the study area were different. The minimum above ground tree biomass was found in the Birch forest and the maximum in the *Abies spectabilis* forest. Other forest types have the value in between these two forest types. The difference in the above ground tree biomass in the study area is due to the difference in topography, edaphic and environmental factors. Mean aboveground tree biomass of the study area was found 409.97 t/ha. This value is near to the values for above ground biomass in Nepal Central Himalaya studied in mixed oak forest in eastern Nepal at altitude 2270m which was 454.8 and at altitude 2390m it was 475.1 t/ha (Yoda, 1968). Likewise in Kharsu oak, *Quercus semecarpifolia*, in Nepal Central Himalaya at 2650m it is 332.0 t/ha, at altitude 2600m 462.1 t/ha, at 2600m, it is 445.9 t/ha and at 3260m the above ground biomass was 338.6 t/ha (Subedi and Shakya, 1988). In Royal Bardia National Park, Nepal, the total living above ground biomass in evergreen riverine forest was 459.74 t/ha (Giri *et. al.*, 2001). The mean above ground biomass of the study area also lies in between the values of above ground biomass (182-584 t/ha) estimated in Churia forest in Ilam district, Nepal by Joshi (1999).

In the Indian central Himalaya, the maximum values for total forest biomass remained high, generally between 500 and 600 t/ha, from the foothills to 2600 m elevation. However, much lower biomass values, 200 t/ha, occurred in stands of early successional *Pinus roxburghii* between 1300 and 1750 m elevation. Above 2600 m, maximum biomass declined sharply to 170 t/ha in birch forest with Rhododendrons, at 3100-3200 m elevation. At 3300 m elevation in pure thickets of small statured Rhododendrons, the biomass was 40 t/ha. In two stands, one of *Shorea robusta* forest at 300 m and the other in *Q. floribunda* forest at 2200 m elevation, forest biomass exceeded 700 t/ha. Biomass values up to 400 t/ha occurred up to 3400 m elevation in the Nepal central Himalaya forests. In both Kumaun, India and Nepal, *Q.*

*semecarpifolia* forest attained similar maximal biomass, up to 550-600 t/ha near 2600 m elevation (Singh *et al.*, 1994).

In our study area, the minimum above ground tree biomass was found in *Betula* forest which was 111.25 t/ha. The present estimates for the *Betula* forest fall within the range estimated by Rodin and Bazilevich (1967). He found 59- 169 t/ha above-ground biomass for *Betula* forests in the former USSR. Similarly, the estimation of above ground biomass of *Betula* in a high mountains of Central Himalayas was 127.3 t/ha (Garkoti and Singh, 1995). At high altitudes, a larger amount of production is invested in biomass structure. Because of the low air temperature in the subalpine and alpine belt, plants with low stature are favoured as their leaves occupy the warmest microenvironment near to the ground (Wilson *et al.*, 1987), where wind action is limited. Due to the low stature, the biomass accumulation is low the high altitude forests.

The overall mean above ground biomass of the study area is higher than the values of above ground tree biomass in two *Shorea robusta* forests in Royal Bardiya National park, Nepal. The values were 348.02 t/ha in *Shorea-Terminalia* forest and 330.87 t/ha in Terai *Shorea* forest by Giri *et al.*, (1999). Likewise, in the same national park, the total living above ground biomass in deciduous riverine forest was 150.65 t/ha (Giri *et al.*, 2001). The above-ground tree biomass values of *Acer cappadocicum* forest was 237.7 t/ha (Garkoti, 2008) which was also below the present study. Present finding is also higher than the above ground biomass in different regions in Indian Central Himalaya. It is higher than the mixed banj oak-chir pine forest (325.7 t/ha) (Rana *et al.*, 1989); *Acer* forest (237.7 t/ha), *Betula* (127.3 t/ha) and *Rhododendron* (26.0 t/ha) by Garkoti and Singh (1995). Likewise, Oak forest India 301.5 t/ha (Rawat, 1983; Rawat *et al.*, 1988b); Oak forest, India, 263.2 t/ha (Negi *et al.*, 1983), *Pinus roxburghii*, India, 113.0-283.0t/ha (Chaturvedi, 1983); *Populus* forest, India, 134.3 t/ha (Lodhiyal *et al.*, 1995). It is also higher than in oak forest (323.1 t/ha) at 2300-2400m in Kumaon hill of Himalaya (Negi *et al.*, 1983); (63.72 t/ha) in teak plantation by Thapa and Gautam (2005); (61.09 t/ha) in tropical sal forest (Sujakhu *et al.*, 2009) and (217 t/ha) in subtropical sal forest Baral *et al.*, (2009). Similarly, higher than (397.7 t/ha) Nascimento and Laurance (2002); (355.8 t/ha) Laurance *et al.*, (1999) and (95.4 t/ha) in aspen-maple-birch forest USA (Crow, 1978); as well as higher than (247.89 t/ha) Gnanavelrajah *et al.*, (2008) in land-use under para rubber in

Thailand. The above ground biomass of natural semi evergreen forest and sal plantation forest in the humid tropical region of northeast India were 323.9 t/ha and 406.4 t/ha (Baishyal, 2009). The biomass value of sal plantation forest is nearly equal to the value of present study area. The difference in the values might be due to difference in region, forest type and management as well as the different regression equations used for estimation of the biomass.

Values for above ground biomass in the present study are comparable with those of mean aboveground biomass of the temperate forest of Shivapuri Nagarjun National Park, Kathmandu, Nepal by Ranjitkar, 2010. He estimated the mean above ground biomass 633.53 t/ha. This value is higher than the value from of study area. This may be due to the region that the Central Nepal is moister than the western Nepal. The soil as well as topography is favourable for the growth and development of plants. As well as the region he studied is protected area so that there is less destruction and human influence in the forest. Likewise the above ground biomass in natural forest of Siwalik region of Central Nepal was estimated 807 t/ha by Shrestha et al., 2000.

Sharma et al., 2008 recorded the highest above-ground mean tree biomass density of 1158 t/ha for the reserved forest and 728 t/ha for the protected forest in Solan district of Indian state of Himachal Pradesh. This high value on that study site might be due to earlier protection and maturity of the Indian forests. Similarly, lower than AGB reported by Keeling and Philips (2007) in temperate forests of *Sequoia sempervirens* forests in northern California and *Tsuga heterophylla* forest in Oregon. Where they recorded greatest range of AGB from 1492 to 3300 t/ha and assumed that exceptionally tall and massive trees, longevity, low disturbance levels and long growing season might have resulted very large biomass.

The contribution of above-ground biomass in the tree layer ranges between 71 and 84% of the total biomass (Garkoti, 2008).

#### **5.1.2 Total biomass**

Mean total tree biomass in the study area was found 516.56 t/ha. It was nearly equal to the total biomass of the tropical rainforest of Marelongue Reserve (Mascarene Archipelago, Indian Ocean), where it was estimated 535t/ha by Kirman *et al.*, (2007).

The present finding is greater than the mean biomass of pine forest (233.0 t/ha) of mid hills of Central Nepal (Dahal, 2007); Acer forest (304.3 t/ha), *Betula* forest (173.5 t/ha) and *Rhododendron* forest (38.7 t/ha) in Indian Central Himalaya (Garkoti and Singh, 1995); pine forest (301.5 t/ha) in central Himalaya (Chaturvedi and Singh, 1987); Eucalyptus forest (96 t/ha) in Northeast Australia (Zerihun *et al.*, 2006). Likewise, it is higher than the *Dalbergia sissoo* forests growing in central Himalaya, India, where total biomass of trees ranges from 50.3±2.46 (5 year old stand) to 122.7±3.14 t/ha (15 year old stand) (Lodhiyal, 2002). Garkoti, 2008, reported that the total biomass of the tree layer was 304.3 (t/ha) in a high altitude maple forest occurring at an altitude of 2750 m in the west central Himalayas. He also reported that a large proportion (70.4%) of the total biomass was contributed by the dominant species, *Acer cappadocicum*. The biomass of the forest (153–503 t/ha) for several temperate deciduous forests reported by Rodin and Bazilevich, (1967) was also below than the present study. But the mean total biomass of the temperate forest of Shivapuri was found 797.57 t/ha (Ranjitkar, 2010) which was higher than the present finding.

## **5.2 Biomass carbon stock**

### **5.2.1 Aboveground biomass carbon stock**

The mean aboveground biomass carbon stock in the present study area was found 204.98 t/ha. The present value was close to 203.18 t/ha which was estimated from the plantation forest of humid tropics in northeast India reported by Baishya *et al.*, (2009). The value of aboveground biomass carbon stock was higher than 97.86 t/ha of mid hill sal forest of Nepal (Baral *et al.*, 2009) and 161.97 t/ha in natural forest of humid tropics in northeast India reported by Baishya *et al.*, (2009). But it is lower than the above ground biomass carbon stock in the forest of the Eastern Panama which was 343.3 t/ha (Kirby and Potvin, 2007) and the aboveground biomass carbon stock of the temperate forest of Shivapuri Nagarjun National Park, which was 316.49 t/ha estimated by Ranjitkar (2010).

### **5.2.2 Total biomass carbon stock**

The mean total biomass carbon stock in the study area was estimated 258.28 t/ha which ranges in between the value in non-degraded oak site of Kumaun Central Himalaya which was 242.56-290.62 t/ha (Jina *et al.*, 2008).

The present finding was higher than the value estimated by Lodhiyal and Lodhiyal, (1997) in the Terai belt of Himalaya. They estimated the total biomass carbon stock to be 113.0 t/ha in 4year old poplar plantation. Kraenzel *et al.*, (2003) reported 126 t/ha of harvest-age (20-year old) teak plantations of Panama. Likewise in the same year Lodhiyal and Lodiya, (2003) reported 109.6 t/ha total biomass carbon stock in the 15 year old sisso forest in Shiwalik of Himalaya. Adhikaree (2005) reported 125.33 t/ha in mixed broadleaved midhills forest of Central Nepal; Dahal (2007) reported 116.5 t/ha in pine forest from midhills of Central Nepal; Khanal (2007) reported 24.72 t/ha in community forest in surrounding of Kathmandu; Navar (2009) reported 65 t/ha in Pine-oak temperate forests of Mexico. The total biomass carbon stock of the temperate forest of Shivapuri Nagarjun National Park, Nepal was reported 398.78 t/ha by Ranjitkar (2010) which was higher than that of the present study. These differences in value of total biomass carbon stock might be due to forest age, forest type (Guo *et al.*, 2010) and geographical as well as environmental regions.

### **5.3 Soil organic carbon**

The average soil organic carbon was found 3.87% in the study area. The soil organic carbon was found maximum in Mixed Broad Leaved forest and minimum in Oak-Pine forest with the values 6.76% and 1.64% respectively. The soil organic carbon was found to be 3.55% in the forest of Mt. Stara Planina which was close to our study area. But in the same mountain, the soil organic carbon in the pasture land was 5.22% (Belanovic, 2008). The soil organic carbon lies between 3.40%-7.46% in evergreen broadleaf forest, coniferous forest, sub-alpine dwarf forest, and alpine meadow along an altitude gradient in Wuyi Mountain National Nature Reserve in Fujian Province of China, which is higher than our study area Xu X (2008). The percentage of soil organic carbon decreases with the increase in altitude. In Langtang national park, the soil organic carbon at 1278 m was found to be 2.36% and at 4414 m it was 1.23%. But the highest soil organic carbon was found at 3048m with the value 2.43% in the same national park (Panhi, 2010). This value is lower than our study area. But the

soil organic carbon of Shivapuri was found 5.16% (Ranjitkar, 2010) which was higher than the present finding.

The differences of soil organic carbon in different forests which we have compared and within the study area may be due to different forest types, aspect and slope of the study area. Generally maximum soil organic carbon is found in deciduous forest than in evergreen forest because the decomposition rate of litter is higher in deciduous forest.

## CHAPTER 6

### CONCLUSIONS

Mean biomass carbon stock of forest types in upper Humla along the Humla Karnali river valley was found 258.28 t/ha with maximum and minimum values of 335.15 t/ha and 70.09 t/ha, respectively. Biomass C stock was found positively associated with altitude, basal area and canopy cover. Biomass carbon stock increases with the increase in altitude upto certain level than it starts decreasing. Whereas, biomass carbon stock increases along with the increase in basal area and canopy cover of the forest. But it was found negatively associated with soil organic carbon, soil pH, rock cover and soil moisture.

The average soil organic carbon was found 3.87% in the study area. The soil organic carbon was found maximum in Mixed Broad Leaved forest and minimum in Oak-Pine forest with the values 6.76% and 1.64%, respectively. Soil organic carbon was found positively associated with altitude, soil pH, soil moisture and basal area. The soil organic carbon was low at lower and higher altitude whereas more soil organic carbon was found in mid altitude. Whereas, soil organic carbon increases along with the increase in soil moisture and basal area but it decreases with increase in soil pH. The soil organic carbon was found negatively associated with canopy cover and rock cover. The local topographic as well as environmental factors affect the soil organic carbon of the area.

This study led to conclude that the forests in the upper Humla region are mature and they are sequestering considerable amount of carbon compared to different forests of Central Himalaya.

Finally, from this study the first hypothesis was accepted whereas, the second hypothesis was rejected. The biomass carbon stock and soil organic carbon are determined by various environmental parameters.

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## ANNEXES

### ANNEX I

Altitude, GPS locations, aspect, slope, soil pH, soil moisture, canopy and rock cover of different forest types.

#### Birch forest

Plot no.	Altitude (m)	Latitude	Longitude	Aspect	Slope	Soil pH	Soil Moisture	Canopy	Rock Cover
1	4220	30°04.704'	82°02.407'	NW 290	45°	6.5	6.5	5%	15%
2	4191	30°04.755'	82°02.414'	NW 280	30°	6.3	7.5	15%	5%
3	4186	30°04.779'	82°02.418'	NW 300	35°	6.5	7	15%	60%
4	4180	30°04.796'	82°02.408'	NW 300	35°	6.7	7.5	5%	5%
5	4150	30°04.785'	82°02.403'	NW 310	40°	6.5	7.5	10%	20%
6	4116	30°04.797'	82°02.379'	NW 290	40°	6.6	7	20%	10%
7	4084	30°04.820'	82°02.361'	NW 280	25°	6.5	7	50%	75%
8	4048	30°04.830'	82°02.315'	NW 310	30°	6.7	>8	15%	25%
9	4037	30°04.842'	82°02.303'	NW 320	30°	6.3	>8	30%	40%
10	4008	30°04.872'	82°02.291'	NW 290	25°	6.5	7	15%	85%

#### *Abies spectabilis* forest

Plot no.	Altitude (m)	Latitude	Longitude	Aspect	Slope	Soil pH	Soil Moisture	Canopy	Rock Cover
1	3640	30°03.719'	82°01.382'	E 90	30°	6.5	5	30%	5%
2	3667	30°03.735'	82°01.676'	SE 100	22°	6.8	4.5	25%	5%
3	3642	30°03.745'	82°01.363'	SE 108	29°	6.6	4	30%	15%
4	3690	30°03.761'	82°01.351'	E 90	24°	6.8	6	60%	5%
5	3738	30°03.759'	82°01.342'	NE 70	21°	6.7	5.5	65%	0%
6	3745	30°03.764'	82°01.307'	E 90	19°	6.6	5	30%	0%
7	3761	30°03.762'	82°01.295'	SE 120	38°	6.4	4.5	50%	0%
8	3772	30°03.766'	82°01.271'	SE 120	24°	6.8	5	50%	0%
9	3777	30°03.772'	82°01.265'	SE 98	23°	5.4	7.5	50%	25%
10	3785	30°03.781'	82°01.254'	E 90	24°	6.7	4	20%	5%

#### Birch-Abies forest

Plot no.	Altitude (m)	Latitude	Longitude	Aspect	Slope	Soil pH	Soil Moisture	Canopy	Rock Cover
1	3586	29°59.775'	81°58.649'	E 90	30°	6.9	5	80%	10%
2	3551	29°59.7764'	81°58.651'	E 90	30°	6.6	5.5	40%	10%
3	3548	29°59.777'	81°58.667'	NE 80	25°	6.8	5.5	80%	15%

4	3540	29°59.777'	81°58.680'	NE 65	30°	6.9	4	60%	5%
5	3526	29°59.781'	81°58.709'	NE 70	35°	6.9	4.5	70%	10%
6	3498	29°59.780'	81°58.729'	NE 70	30°	6.8	5	80%	5%
7	3480	29°59.782'	81°58.737'	NE 20	35°	6.7	6	60%	10%
8	3467	29°59.788'	81°58.757'	NE 80	40°	6.4	4.5	70%	10%
9	3460	29°59.766'	81°58.787'	NE 40	35°	6.6	5	75%	5%
10	3450	29°59.763'	81°58.828'	NE 50	30°	6.4	5	40%	5%

### *Pinus wallichiana* forest

Plot no.	Altitude (m)	Latitude	Longitude	Aspect	Slope	Soil pH	Soil Moisture	Canopy	Rock Cover
1	3433	30°00.383'	81°59.403'	SE 145	10°	6.6	4.5	50%	25%
2	3454	30°00.400'	81°59.407'	SE 132	18°	6.7	4.5	40%	20%
3	3472	30°00.415'	81°59.410'	SE 150	18°	6.8	3.5	30%	60%
4	3473	30°00.436'	81°59.416'	SE 98	20°	6.7	2.5	35%	15%
5	3597	30°00.449'	81°59.418'	SE 104	25°	6.6	6	30%	20%
6	3507	30°00.462'	81°59.411'	SE120	23°	6.8	3	40%	45%
7	3501	30°00.454'	81°59.390'	SE 150	15°	6.7	3.5	50%	40%
8	3538	30°00.490'	81°59.352'	SE 132	25°	6.8	4.5	40%	30%
9	3560	30°00.526'	81°59.317'	SE 140	22°	6.6	4.5	40%	60%
10	3423	30°00.316'	81°59.415'	SE 132	12°	6.7	5	50%	25%

### Mixed Coniferous forest

Plot no.	Altitude (m)	Latitude	Longitude	Aspect	Slope	Soil pH	Soil Moisture	Canopy	Rock Cover
1	3322	29°59.87'	81°59.235'	SE 172	10°	6.8	6.5	30%	35%
2	3331	29°59.893'	81°59.248'	SE135	20°	6.7	4	30%	25%
3	3275	29°59.840'	81°59.203'	SE 154	10°	6.7	7	45%	60%
4	3203	29°59.810'	81°59.193'	SE 138	20°	6.7	4	35%	35%
5	3193	29°59.722'	81°59.168'	SE 162	22°	6.8	4.5	40%	60%
6	3204	29°59.707'	81°59.122'	SE 176	25°	6.8	5.5	25%	70%
7	3285	29°59.825'	81°59.209'	SE 150	15°	6.6	7	45%	35%
8	3290	29°59.823'	81°59.213'	SE 170	15°	6.4	5	60%	35%
9	3294	29°59.820'	81°59.215'	SE 150	10°	6.6	5	50%	25%
10	3310	29°59.883'	81°59.241'	SE 160	20°	6.8	4.5	55%	35%

### Mixed Broad-leaved forest

Plot no.	Altitude (m)	Latitude	Longitude	Aspect	Slope	Soil pH	Soil Moisture	Canopy	Rock Cover
1	3170	29°58.936'	81°58.843'	NW 320	10°	6.7	5	90%	25%
2	3050	29°58.921'	81°58.754'	NW 340	20°	6.5	8	60%	25%
3	3090	29°59.028'	81°58.771'	SE 170	10°	5.9	>8	30%	40%
4	3002	29°58.962'	81°58.789'	NW 340	20°	6.8	7.5	50%	75%

5	3019	29°58.992'	81°58.808'	SE 170	10°	6.6	5.3	50%	20%
6	3090	29°59.018'	81°58.809'	SE 160	15°	6.3	6.5	75%	50%
7	3120	29°59.036'	81°58.856'	SE 170	20°	6.5	7.3	70%	40%
8	3130	29°59.055'	81°58.881'	SE 150	15°	6.7	6	70%	40%
9	3137	29°59.095'	81°58.897'	SW 250	10°	6.3	>8	50%	45%
10	3153	29°59.216'	81°58.960'	SW 210	15°	5.3	7.4	65%	30%

### Oak-Pine forest

Plot no.	Altitude (m)	Latitude	Longitude	Aspect	Slope	Soil pH	Soil Moisture	Canopy	Rock Cover
1	2469	29°56.265'	81°50.801'	NE 60	30°	6.8	2	45%	70%
2	2478	29°56.258'	81°50.810'	NE 25	35°	6.9	1	40%	40%
3	2483	29°56.238'	81°50.835'	NE 40	30°	6.8	1	50%	30%
4	2479	29°56.228'	81°50.846'	NE 35	25°	6.6	1	45%	5%
5	2484	29°56.223'	81°50.853'	NE 40	40°	6.7	1	50%	5%
6	2490	29°56.217'	81°50.863'	NE 30	35°	6.8	1	55%	5%
7	2488	29°56.205'	81°50.882'	NE 10	45°	6.9	1	60%	10%
8	2500	29°56.209'	81°50.892'	NE 30	45°	6.9	1	60%	10%
9	2495	29°56.179'	81°50.980'	NE 25	30°	6.9	1	65%	10%
10	2519	29°56.162'	81°50.927'	NE 22	40°	6.7	1	70%	15%

## ANNEX II

Basal area of a tree, soil organic carbon, aboveground biomass (AGB) total biomass and carbon stocks in different forest types.

### Birch forest

Plot no.	Tree BA (m <sup>2</sup> /ha)	SOC %	Biomass (t/ha)		
			AGB	Tot. biomass	Biomass C Stock
1	32.03	2.01	67.25	84.74	42.37
2	51.24		131.24	165.37	82.68
3	31.95	3.48	103.09	129.89	64.94
4	10.89		36.41	45.88	22.94
5	24.45	2.72	90.09	113.52	56.76
6	15.35		55.11	69.44	34.72
7	38.97	3.19	145.52	183.36	91.68
8	53.79		222.75	280.67	140.33
9	39.8	3.47	145.42	183.23	91.61
10	34.8		115.62	145.68	72.84

### *Abies spectabilis* forest

Plot no.	Tree BA (m <sup>2</sup> /ha)	SOC %	Biomass (t/ha)		
			AGB	Tot. biomass	Biomass C Stock
1	8.27		16.26	20.48	10.24
2	24.55	2.84	69.09	87.05	43.52
3	13.01		38.81	48.90	24.45
4	130.77	8.47	489.69	617.01	308.51
5	134.16		638.57	804.59	402.29
6	158.31	4.89	1108.13	1396.24	698.12
7	204.69		1113.9	1403.51	701.76
8	101.44	4.95	592.53	746.59	373.29
9	152.15		1035.72	1305.01	652.50
10	90.42	5.42	217.19	273.66	136.83

Birch-Abies forest

Plot no.	Tree BA (m <sup>2</sup> /ha)	SOC %	Biomass (t/ha)		
			AGB	Tot. biomass	Biomass C Stock
1	38.11	6.71	157.91	198.97	99.48
2	93.14		491.46	619.24	309.62
3	36.12	4.60	173.15	218.17	109.09
4	192.51		961.96	1212.07	606.04
5	155.85	3.31	786.77	991.33	495.66
6	132.22		739.46	931.71	465.86
7	53.57	5.77	280.67	353.65	176.82
8	36.88		215.18	271.13	135.56
9	66.95	1.90	338.47	426.47	213.24
10	110.09		745.70	939.58	469.79

*Pinus wallichiana* forest

Plot no.	Tree BA (m <sup>2</sup> /ha)	SOC %	Biomass (t/ha)		
			AGB	Tot. biomass	Biomass C Stock
1	19.59	4.25	386.97	487.59	243.79
2	80.63		556.51	701.20	350.60
3	61.88	3.78	487.98	614.85	307.43
4	75.12		544.33	685.85	342.92
5	56.41	2.37	456.54	575.24	287.62

6	56.07		472.68	595.58	297.79
7	75.26		506.40	638.06	319.03
8	71.07	3.95	598.02	753.50	376.75
9	55.63		386.37	486.82	243.41
10	87.37	2.60	590.64	744.21	372.10

Mixed Coniferous forest

Plot no.	Tree BA (m <sup>2</sup> /ha)	SOC %	Biomass (t/ha)		
			AGB	Tot. biomass	Biomass C Stock
1	50.4252	2.60205	227.7664	286.9857	143.4928
2	54.2634		313.3696	394.8457	197.4229
3	40.698	3.13069	228.0412	287.3319	143.6659
4	51.6529		246.3297	310.3755	155.1877
5	35.4259	0.66375	169.0261	212.9729	106.4864
6	58.2784		407.1688	513.0326	256.5163
7	53.1064	1.60352	349.376	440.2138	220.1069
8	64.9884		381.9853	481.3015	240.6508
9	26.0386	1.60352	150.1964	189.2475	94.62373
10	78.3514		466.235	587.4561	293.7281

Mixed Broad-leaved forest

Plot no.	Tree BA (m <sup>2</sup> /ha)	SOC %	Biomass (t/ha)		
			AGB	Tot. biomass	Biomass C Stock

1	160.99	6.01	475.55	599.20	299.60
2	246.67		964.52	1215.30	607.65
3	119.07	5.30	397.38	500.70	250.35
4	181.81		902.21	1136.78	568.39
5	103.91	6.42	273.08	344.08	172.04
6	92.84		285.71	360.00	180.00
7	125.25	6.13	496.29	625.32	312.66
8	56.89		218.02	274.71	137.35
9	112.72	9.94	420.01	529.21	264.60
10	148.35		588.81	741.90	370.95

Oak-Pine forest

Plot no.	Tree BA (m <sup>2</sup> /ha)	SOC %	Biomass (t/ha)		
			AGB	Tot. biomass	Biomass C Stock
1	102.13		383.85	483.66	241.83
2	27.20	2.015	135.60	170.86	85.43
3	58.27		266.91	336.31	168.15
4	47.99	2.60	236.20	297.62	148.81
5	88.32		550.19	693.24	346.62
6	84.14	1.19	418.73	527.60	263.80
7	150.37		926.55	1167.45	583.72
8	108.97	0.78	394.56	497.15	248.57

9	84.24		380.54	479.48	239.74
10	154.49	1.60	734.04	924.89	462.45

### ANNEX III

Mean values of AGB, total biomass, biomass carbon stocks, SOC, basal area and canopy cover of different forest types.

Forest type	AGB (t/ha)	Tot. biomass (t/ha)	Biomass carbon stock (t/ha)	SOC (%)	Basal area (m <sup>2</sup> /ha)	Canopy cover (%)
Birch forest	111.25	140.18	70.09	3.59	33.33	18
<i>Abies spectabilis</i> forest	531.99	670.30	335.15	5.32	101.78	41
Birch-Abies forest	489.1	616.23	308.12	4.46	91.54	66
<i>Pinus wallichiana</i> Forest	498.64	628.29	314.15	3.39	63.90	41
Mixed Coniferous forest	293.95	370.38	185.19	1.92	51.32	42
Mixed Broad Leaved forest	502.16	632.72	316.36	6.76	134.85	61
Oak-Pine forest	442.72	557.83	278.91	1.64	90.61	54

## ANNEX IV

### Forest types, representative species and wood density

SN	Forest type	Representative species	Relative weight	Density (kg/m <sup>3</sup> )	Wt. Avg. Density
1.	Sal forest	<i>Shorea robusta</i>	0.90	880	878
		<i>Terminalia tomentosa</i>	0.02	950	
		<i>Adina cordifolia</i>	0.01	670	
		<i>Anogeissus latifolia</i>	0.02	900	
		<i>Lagerstroemia parviflora</i>	0.05	850	
2.	Khair-Sissoo forest	<i>Acacia catechu</i>	0.50	960	870
		<i>Dalbergia sissoo</i>	0.50	780	
3.	Oak forest	<i>Quercus floribunda</i>	0.10	970	897
		<i>Q. lamellosa</i>	0.10	940	
		<i>Q. leucotrichoflora</i>	0.10	1020	
		<i>Q. lanata</i>	0.10	880	
		<i>Q. semecarpifolia</i>	0.60	860	
4.	Birch forest	<i>Betula utilis</i>	1.00	700	700
5.	Terai/Lower slopes mixed hardwood forest	<i>Schima wallichii</i>	0.45	690	720
		<i>Castanopsis</i> sp.	0.35	740	
		<i>Myrica esculanta</i>	0.05	750	
		<i>Daphniphyllum himalense</i>	0.05	640	
		<i>Eugenia/ Syzygium</i> sp.	0.05	770	
		<i>Diospyros</i> spp.	0.02	840	
		<i>Shorea robusta</i>	0.03	880	
6.	Upper slopes mixed hardwood forest	<i>Alnus nepalensis</i>	0.20	390	594
		<i>Schima wallichii</i>	0.20	690	
		<i>Acer</i> sp.	0.20	640	
		<i>Litsea</i> sp.	0.20	610	
		<i>Rhododendron arboreum</i>	0.20	640	
7.	Chir pine forest	<i>Pinus roxburghii</i>	1.00	650	650
8.	Blue pine forest	<i>Pinus wallichiana</i>	1.00	480	480
9.	Fir forest	<i>Abies pindrow</i>	0.50	480	480
		<i>A. spectabilis</i>	0.50	480	
10.	Mixed and other Conifer Forest	<i>Cedrus deodara</i>	0.15	560	506
		<i>Cupressus torulosa</i>	0.15	600	
		<i>Larix griffithiana</i>	0.15	510	
		<i>Juniperus indica</i>	0.15	500	
		<i>Tsuga dumosa</i>	0.40	450	
11.	Chir pine- Sal forest	<i>Pinus roxburghii</i>	0.45	650	758

		<i>Shorea robusta</i>	0.45	880	
		<i>Schima wallichii</i>	1.10	690	
12.	Birch-Fir Forest	<i>Betula utilis</i>	0.45	700	600
		<i>Abies spectabilis</i>	0.45	480	
		<i>Schima wallichii</i>	0.10	690	
13.	Other Mixed Hardwood- Conifer Forest	<i>Abies</i> sp.	0.20	480	563
		<i>Betula utilis</i>	0.10	700	
		<i>Castanopsis</i> sp.	0.10	740	
		<i>Q. semecarpifolia</i>	0.10	860	
		<i>Tsuga dumosa</i>	0.40	450	

Source: HMGN/MPFS/FRISDP 1988

## ANNEX V

a. Regression statistics for biomass carbon stock: LM model are significant over 1<sup>st</sup> and 2<sup>nd</sup> order (Carbon stock is response variable)

Predictor	Model	Polynomial order	Residual degree of freedom	Residual sum of square	D.F	Sum of square	F-Value	P(>F)
Altitude	Null	0	69	2077876	0	-	-	-
	LM	1 <sup>st</sup>	68	1985455	1	92421	3.6653	<0.05
	LM	2 <sup>nd</sup>	67	1839872	2	238004	4.3335	<0.05
Basal area	Null	0	69	2077876	0	-	-	-
	LM	1 <sup>st</sup>	68	470817	1	1607059	232.11	<0.001
	LM	2 <sup>nd</sup>	67	462924	2	7893	1.1424	NS
Canopy	Null	0	69	2077876	0	-	-	-
	LM	1 <sup>st</sup>	68	1784810	1	293066	11.166	<0.01
	LM	2 <sup>nd</sup>	67	1594886	2	482990	10.145	<0.01

b. Regression statistics for soil organic carbon: LM model are significant over 1<sup>st</sup> and 2<sup>nd</sup> order (Soil organic carbon is response variable)

Predictor	Model	Polynomial order	Residual degree of freedom	Residual sum of square	D.F	Sum of square	F-Value	P(>F)
Altitude	Null	0	69	198.80	0	-	-	-
	LM	1 <sup>st</sup>	68	181.02	1	17.780	6.6788	<0.05
	LM	2 <sup>nd</sup>	67	153.52	2	45.282	9.8812	<0.001
Soil pH	Null	0	69	198.80	0	-	-	-
	LM	1 <sup>st</sup>	68	165.01	1	33.794	13.926	<0.001
	LM	2 <sup>nd</sup>	67	162.28	2	2.732	1.128	NS

Soil	Null	0	69	198.80	0	-	-	-
moisture	LM	1 <sup>st</sup>	68	137.58	1	61.225	30.261	<0.001
	LM	2 <sup>nd</sup>	67	133.00	2	4.578	2.306	NS
Basal	Null	0	69	198.80	0	-	-	-
area	LM	1 <sup>st</sup>	68	165.10	1	33.704	13.882	<0.001
	LM	2 <sup>nd</sup>	67	161.38	2	3.7138	1.5418	NS

## ANNEX VI

### List of trees present in sampled plots

1. *Betula utilis*
2. *Abies spectabilis*
3. *Pinus wallichiana*
4. *Taxus sp.*
5. *Populus ciliate*
6. *Picea smithiana*
7. *Acer sp.*
8. *Aesculus indica*
9. *Juglans regia*
10. *Prunus cornuta*
11. *Quercus semecarpifolia*
12. *Lyonia ovalifolia*
13. *Rhododendron arboreum*
14. *Myrica esculanta*
15. *Pyrus malus*

## PHOTOGRAPHS



Photo 1: Vegetation in sampling site



Photo 2: Measurement taking at sampling site