CARBON STOCK ESTIMATION IN LOWER TEMPERATE FOREST IN SHIVAPURI NAGARJUN NATIONAL PARK, NEPAL

A Dissertation Submitted for the Partial Fulfillment

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RECOMMENDATION

Tribhuvan University Central Department of Botany Kirtipur, Kathmandu

This is to certify that the dissertation work entitled **"Carbon Stock Estimation in Lower Temperate Forest in Shivapuri Nagarjun National Park, Nepal"** submitted by **Mr. Niranjan Bhakta Ranjitkar** has been carried out under my supervision. The entire work is primarily based on the results of his research work and has not been submitted for any other degree. I recommend this dissertation work to be accepted for the partial fulfillment of Master of Science in Botany.

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LETTER OF APPROVAL

The dissertation work entitled **"Carbon Stock Estimation in Lower Temperate Forest in Shivapuri Nagarjun National Park, Nepal"** submitted by **Mr. Niranjan Bhakta Ranjitkar** has been accepted as a partial fulfilment of the requirements for Masters of Science in Botany (Plant Ecology).

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ABSTRACT

Mitigating the climate change due to increase in CO_2 emissions is gaining increased importance. Forests play an important role in the global carbon cycle as forest vegetation and soil can sequester the atmospheric carbon in the form of biomass and soil organic carbons. Thus buffering the rate of climate change by reducing the atmospheric CO_2 which is one of the GHGs. Maintaining existing stocks of carbon in forests is also important as a cheap way to mitigate climate change. Shivapuri Nagarjun National Park (SNNP) having a luxuriant temperate forest is serving well in carbon sequestration.

Temperate region of Shivapuri forest of SNNP was sampled. Quadrats of size 20m×20m were laid randomly at different altitude zones. Four altitude zones (2100m, 2300m, 2500m and 2700m) were considered and sampling was done within 2050-2150m, 2250-2350m, 2450-2550m and 2650-2732m, respectively. In each altitude zone four South-East and four South-West facing quadrats were plotted. Using allometric equations and root shoot ratio the vegetation biomass of tree and shrub of each quadrat was estimated. The biomass was converted to carbon stock. Bulk density, pH, organic carbon content and nitrogen content of soil at different horizontal depths of 0-25cm and 25-50cm were analyzed. The soil carbon stock upto the depth of 50cm was estimated. Then biomass carbon and soil carbon were summed up to get total carbon stock.

Mean biomass, biomass carbon stock, soil carbon stock of the temperate forest of Shivapuri were found 797.57, 398.78 and 200.80 t/ha, respectively. Thus mean total carbon stock was 599.58 t/ha. Mean total carbon stock at four different altitude zones were significantly different, whereas at the SE and SW aspects were similar. The altitude zone 2500m was found with highest biomass carbon stock, soil carbon stock and total carbon stock with mean values 682.19, 238.09 and 920.28 t/ha, respectively. The organic carbon content and nitrogen content in the upper horizon (0-25cm) were found higher than that of lower horizon (25-50cm). Whereas the pH and bulk density in the upper horizon (0-25cm) were found lower than that of lower horizon (25-50cm).

Temperate forest of Shivapuri was found with more carbon stock in comparision to other forest types of Central Himalaya.

***Key words**: Carbon, biomass, carbon stock, climate change, Shivapuri.*

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ACRONYMS

°C	degree celsius
AGB	aboveground biomass
ANOVA	analysis of variance
asl	above sea level
BA	basal area
C	carbon
cm	centimeter
dbh	diameter at breast height
DNPWC	Department of National Park and Wildlife Conservation
et al.	and others
GHGs	green house gases
GoN	Government of Nepal
Gt	billion tonnes
ha	hectare
km	kilometer
m	meter
ml	milliliter
Mt	mountain
N	nitrogen
ppm	parts per million
REDD	Reducing Emissions from Deforestation and Degradation
S.D.	standard deviation
SE	south-east
S.E.	standard error
SNNP	Shivapuri Nagarjun National Park
SOC	soil organic carbon
sp.	species
sq km	square kilometer
SW	south-west
t	tonne
Tg	teragram, 10^{12} gram
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Atmospheric CO_2 concentration is increasing which is most likely affecting the climate (Luo *et al.* 2002). The term climate change, or global warming, refers to the acceleration of the natural greenhouse effect by anthropogenic activities leading to changes in the earth–atmosphere system. The climate change, 0.75 °C increase in earth's mean temperature during the last century and 1 to 4°C projected to increase during the 21st century, is caused by an increase in the concentration of GHGs in the atmosphere (IPCC 2001; IPCC 2007). Mean temperature rise in middle mountain and Himalayan regions of Nepal in 1977-1994 ranged from 0.06 ºC to 0.12 ºC yr^{-1} (Shrestha *et al*. 1999).

Anthropogenic perturbation of the global C cycle is responsible for the increase in atmospheric concentration of CO_2 and CH_4 (IPCC 2001). The atmospheric carbon (C) pool has steadily increased since 1850 and is currently increasing at the rate of 0.5% per year due to burning of fossil fuels and land use changes (Lal 2002). Continuous increase in burning of fossil fuel is releasing large amount of CO_2 in the atmosphere. Atmospheric C concentrations are now estimated to be at 1.3 times preindustrial levels (IPCC 2001, Houghton 2005). The CO_2 emission from land use change only was estimated to be 1.7 Gt C yr^{-1} in 1980-1989 and 1.6 Gt C yr^{-1} in 1989-1998 (IPCC 2000). Since atmospheric CO_2 concentrations have been increasing globally due to anthropogenic CO_2 emissions, the question of reducing these emissions is gaining increased importance. Concerns have been raised to mitigate the climate change due to increase in CO_2 emissions. So United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol came into existence as a legal basis to mitigate climate change by reducing the emission of greenhouse gases (GHGs), particularly CO_2. When 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. Reducing emissions from deforestation and degradation (REDD) was a prominent section of the Bali Road Map established in 2007 and continues as a leading topic in international climate negotiations (Macauley *et al.* 2009). Global greenhouse gas emissions from changes in land use, including tropical deforestation, are estimated to make up around 20% of annual global emissions from all sources (IPCC 2007).

Of the 8.6 Gt C yr^{-1} emitted into the atmosphere, only 3.5 Gt or 40% of the anthropogenically emitted CO_2 remains in the atmosphere primarily owing to unspecified terrestrial sinks which sequester atmospheric CO_2 and play an important role in the global C cycle (Lal 2008).

Vegetation and soils are viable sinks of atmospheric carbon (C) and may significantly contribute to mitigation of global climate change (Bajracharya *et al*. 1998, Phillips *et al*. 1998, Lal 2004a, Smith 2004). Vegetation by storing the carbon can become good sink of carbon. As forest act as carbon sink by accumulation of carbon in vegetation by the process of photosynthesis and in soil by decomposition of litter and woody debris, the process of climate change can also be moderated by removing CO_2 from the atmosphere by natural process. This can be achieved by sequestrating atmospheric carbon by forest in form of biomass and soil organic carbon.

A primary motive for including sinks in the accounting process is the prospect of avoiding expensive controls on the emission of carbon dioxide and other greenhouse gases. It has been anticipated that growing trees to remove CO_2 from the atmosphere would be cheaper than developing and implementing technologies to decrease the emissions of existing industries, such as switching to alternative fuels for energy production (Obersteiner *et al*. 2001; Chomitz 2000).

1.2 Forest as carbon sink

Transfer of atmospheric CO_2 into biotic and pedologic C pools is called terrestrial C sequestration. Terrestrial ecosystems constitute a major C sink owing to the photosynthesis and storage of CO_2 in live and dead organic matter (Lal 2008). Terrestrial ecosystems store almost three times as much carbon as is in the atmosphere (Trumper *et al*. 2009). Forest vegetation and soils constitute a major terrestrial carbon pool with the potential to absorb and store carbon dioxide (CO_2) from the atmosphere (Kaul *et al*. 2010). Forest ecosystems contain the majority (approximately 60 percent) of the carbon stored in terrestrial ecosystems (IPCC 2000). Thus the world’s forests sequester and conserve more carbon than all other terrestrial ecosystems and account for 90 percent of the annual carbon flux between the atmosphere and the earth’s land surface (Winjum *et al*. 1993).

Forests are an important and manageable carbon sink and play a critical role in reducing the carbon concentration in the atmosphere (Grace *et al.* 1995, Schimel *et al.* 2001, US Climate Change Science Program 2007). Forests are large reservoirs of carbon as well as potential carbon sinks of the atmosphere (Streck and Scholz 2006). Forest ecosystems contain an estimated 638 Gt C with 283 Gt C in biomass alone (FAO 2005). Consequently, changes in the forest carbon store have an impact on global climate change. Even potentially small increases in carbon sequestration in forest biomass and soil may help buffer the impact of anthropogenic carbon dioxide (CO_2) emissions, regulating the rate of climate change (Cao and Woodward 1998; Phillips *et al.* 1998; Jastrow *et al.* 2005). Forest biomass acts as a source of carbon when burned or when it decays. Also when soil is disturbed it releases CO_2 and other greenhouse gases into the atmosphere. The carbon is stored both in biomass and soil. Biomass comprises of both aboveground and underground parts. Root biomass is an important carbon pool, which often represent 10 to 40% of total biomass (MacDicken 1997). Cairns *et al.* (1997) estimated the underground biomass represents 26% of aboveground biomass. Globally, the soil carbon exceeds the carbon stocks in vegetation by a factor of about five, but this ratio varies among different ecosystems (Streck and Scholz 2006).

Over time forests accumulate carbon through the growth of trees and the increase of soil organic carbon unless major disturbances occur. 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). Leakage and permanence of carbon sequestration in forest is of problem. However the permanent storage can be achieved either by storing the felled trees in an area protected from rain or burring under soil for low decomposition rate. For example Zeng (2008) has suggested permanent sequestration of carbon via wood burial.

1.3 Carbon sink in soil

Soil organic carbon comprises residues of plants, animals and microorganisms in various stages of decomposition among these the major sources are turnover of leaves and fine roots (Cowie *et al.* 2006). Soils being the largest carbon reservoirs of the terrestrial carbon cycle 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).

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). However, the process of sequestering C in the soil pool is slow (Oelbermann and Voroney 2007). It is important to consider soil C in C sequestration calculations (Takimoto *et al.* 2008). 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^{-1} (16±8 Tg C yr^{-1}) for about 50 years, and it represents 20 percent of the CO_2 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). Forest soils are one of the major carbon sinks on earth, because of their higher organic matter content (Dey 2005). 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. 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). Trees improve soil productivity through ecological and physicochemical changes that depend upon the quantity and quality of litter reaching soil surface and rate of litter decomposition and nutrient release (Meentemeyer and Berg 1986).

Soil organic matter increase or decrease depending on numerous factors, including climate, vegetation type, nutrient availability, disturbance, and land use and management practice (Six and Jastrow 2002; Baker 2007).

1.4 Carbon sinks in protected area

Protected areas are primarily designated for the purpose of biodiversity conservation, but have a substantial additional value in maintaining ecosystem services; including climate regulation through carbon storage.

Nearly 20-25% of the annual atmospheric increase of about 8 billion ton of carbon is a consequence of deforestation, which results in the depletion of the carbon-sink. Forest sinks represent much cheaper and easier solution to the build-up of the atmospheric carbon. However, carbon sequestration by existing forests of protected areas are not eligible for carbon trade under the Kyoto Protocol. Under the Kyoto Protocol only afforestation (plantations on land where forests did not exist) and reforestation (plantation on land which was cleared before 1990) are eligible for carbon trade. However, avoidance of deforestation by conserving forests is more effective solution to the atmospheric rise of CO_2, as what matters is the carbon pool size in a forest, not the rate at which carbon cycles through it. Indeed, plantations would bind carbon rapidly, but they may take 40-50 years to accumulate amounts equal to that are stored in the existing forests (Singh 2007). So, keeping existing forests stay intact is a cheap way to mitigate climate change (Karky and Skutsch 2010).

It has been argued that land use changes acceptable under the Protocol should also include soil carbon sequestration, and changes in carbon emitted as a result of afforestation, reforestation and deforestation activities. Carbon loss from soil following deforestation can be very high, particularly in the Himalaya, where slopes are steep, immature and subject to three monsoon months of heavy rainfall (Singh 2007). At global scale, soil holds more carbon than the atmosphere and biomass combined (Jobbagy and Jackson 2000), and is therefore important for managing global carbon budget. Since deforestation often results in a rapid soil erosion and chemical breakdown of soil organic matter, the carbon cost of deforestation needs to take this into account as well as the carbon in trees. Indeed on monetary basis the total cost of lost carbon due to deforestation is far greater than that the cost of raising plantations (Korner 2001). Plantations, although, may contribute to the prevention of deforestation and long-term carbon fixation in biomass, they certainly cannot substitute for the forest, which provides many services which a plantation cannot (Singh 2007). The role of existing forests in carbon strategy was excluded Under the Kyoto Protocol because of reasons such as monitoring and measuring sequestration is difficult in natural mixed forests making verification problematic (Zahabu 2008).

Recent recognition of the importance of land use change in the carbon cycle, and the commitment to include reduced emissions from deforestation and degradation (REDD) in the post-2012 agreements of the UNFCCC, has raised the policy relevance of carbon storage in terrestrial ecosystems. Protected areas worldwide cover 12.2% of the land surface, and contain over 312 Gt C, or 15.2% of the global terrestrial carbon stock. If all of the carbon stored within ecosystems were to be valued according to current carbon market prices, it would have an estimated worth of €5,700 billion. Whilst the current protected area network undoubtedly plays a role in conserving the carbon stock, it is not clear whether existing protected stocks will be included in a REDD mechanism. (Campbell *et al.* 2008).

1.5 Rationale

It is evident that carbon sequestration is one of the major environmental services provided by forest besides other important services being watershed protection, biodiversity conservation, ecotourism, etc. Recent efforts to put a monetary value on such services (Costanza *et. al*. 1997) have also led to an increase in awareness on the need to protect forest resources, particularly as they can be traded in emerging markets (Powell *et al.* 2002). In this circumstance, estimation of biomass is becoming vital for selling carbon into national and international markets.

Carbon sequestering in the biomass and soil of forest has evolved into a good alternative to tackle global warming and climate change. Moreover, policy initiatives such as the Kyoto Protocol have introduced flexible mechanisms that encourage carbon trading and promote forestry activities. After the Kyoto Protocol entered into force, in 2005, the demand for 'carbon credits' has been escalating in the international market.

Forest carbon estimates are of scientific importance to improve understanding of the quantitative role of forest carbon sequestration in Earth's climate system and also of intense interest to policymakers in shaping climate policy like REDD (Macauley *et al.* 2009). Reduced emissions from deforestation and degradation (REDD) continues as a leading topic in international climate negotiations. Recent recognition of the importance of land use change in the carbon cycle, and the commitment to include REDD in the post-2012 agreements of the UNFCCC, has raised the policy relevance of carbon storage in terrestrial ecosystems (Campbell *et al.* 2008). In these circumstances the total carbon storage that can be credited to global forest by our national forest and forest of protected areas is needed to be estimated.

And nowadays carbon stock is being calculated and evaluated on the monetary basis all over the world. In our country too many forests have been measured for its carbon stock and carbon sequestrating rate. But all the works are concentrated in community forestry. Measurements of carbon stocks in National forest and Protected areas are few. While using forests as a means of mitigating climate change, maintaining existing stocks of carbon (C) in forests including forests of protected areas is also important. A cheap way to mitigate climate change is to make sure existing forests stay intact (Karky and Skutsch 2010).

Protected areas of Nepal covers 23.23 percentage of the country land (DNPWC 2010). If protected areas of Nepal is included in REDD and it comes into existence, it will regularly get certain income from this mechanism. Through REDD mechanism, Nepal has good opportunity for raising international fund. To have benefits from future implementation of REDD mechanism it's necessary to create base for negotiation.

Shivapuri Nagarjun National Park is a conserved area with sub-tropical and temperate forests. Pacala and Socolow (2004) estimated management of temperate and tropical forest is one of the 15 options to stabilize atmospheric CO_2 concentration at 550 ppm by 2050. Temperate forests are considered to act as a sink for carbon from the atmosphere because of reduced harvest levels (Schulze *et al.*1999; Myneni *et al.* 2001; Schimel *et al.* 2001; Goodale *et al.* 2002; Streck and Scholz 2006). Shivapuri Nagarjun National Park preserves a luxuriant temperate forest serving well in carbon sequestration.

Kathmandu city is undergoing catastrophic environmental degradation primarily from air pollution, which has caused significant number of respiratory related illness in the valley's resident population. The air pollution caused from burning of fossil fuel leaves a thick cloud of pollutants, mainly CO_2 suspended in the air for a long period until wind or rain disperse it. In this scenario, SNNP plays a vital role as sink by sequestering carbon from the source and reducing the time taken to clean the valley's environment. Therefore, SNNP is vital in mitigating adverse environmental impacts of emission from burning fossil fuel in Kathmandu Valley by sequestrating carbon in forest biomass from the valley's atmosphere. The valley's entire population shares sequestering CO_2 by SNNP as an ancillary benefit (KMTNC 2004).

1.6 Hypotheses

- Carbon stock (biomass and soil) of different altitudes are different.
- Carbon stock (biomass and soil) of south-east and south-west aspects are different.

1.7 Objectives

The main objective of the research is estimation of carbon stock of the temperate forest of Shivapuri Nagarjun National Park at different altitudes and aspects. To achieve the goal of main objective following objectives are determined.

- To estimate the biomass carbon stock of the trees and shrubs.
- To estimate the soil carbon stock.

1.8 Limitations

- Nothern aspect of Shivapuri forest was not included.
- Forest below 2050m asl was not included.
- Litter and understorey biomass was not considered.

CHAPTER TWO

2. LITERATURE REVIEW

Due to burning of fossil fuels and land use changes, the atmospheric carbon (C) pool is currently increasing at the rate of 0.5% per year (Lal 2002). The burning of fossil fuel is releasing large amount of CO_2 in the atmosphere. Atmospheric C concentrations are now estimated to be at 1.3 times preindustrial levels (IPCC 2001, Houghton 2005). The CO_2 emission from land use change only was estimated to be 1.7 Gt C yr^{-1} in 1980-1989 and 1.6 Gt C yr^{-1} in 1989-1998 (IPCC 2000). Svirejeva-Hopkins and Schellnhuber (2006) estimated the qualitative and quantitative contribution of urban territories and precisely of the process of urbanization to the Global Carbon Cycle (GCC).

Although natural terrestrial and oceanic sinks are presently absorbing approximately 60% emitted C, natural sink capacity and rate are not large enough to assimilate all the projected anthropogenic CO_2 emitted during the twenty-first century or until the C-neutral energy sources take effect (Lal 2008). The engineering techniques like direct injection of CO_2 in oceanic and geological strata and mineral carbonation of CO_2 into stable carbonates of Ca and Mg are being developed and may be available for routine use by 2025 and beyond (Lal 2008).

Forest management plays an important role in maximizing carbon storage for young or disturbed forests (Zhang *et al.* 2007). Total ecological services provided by the forest is estimated to be \$969 $ha^{-1}yr^{-1}$ and for climate regulation only it accounts for \$141 $ha^{-1}yr^{-1}$ (Costanza *et al.* 1997). For the entire biosphere, the economic value of ecosystem services was estimated worth US\$ 33 trillion per year and that of forest is US\$4.7 trillion per year (Costanza *et al.* 1997). The economic returns to carbon abatement through biological sequestration in community managed forest was estimated by Karky and Skutsch (2010) and found that a typical household derived products and services whose values ranging from \$ 85 to \$ 128, as a result of managing the forests.

The response of a forest ecosystem in pine (*Pinus taeda*) plantation to elevated atmospheric CO_2 concentrations over a 9-year period (1996–2005) was examined by Lichter *et al.* (2008). During the first 6 years of the experiment, forest-floor C and N pools increased linearly under both elevated and ambient CO_2 conditions, with significantly greater accumulations under the elevated CO_2 treatment. Between the sixth and ninth year, forest-floor organic matter accumulation stabilized and C and N pools appeared to reach their respective steady states. An additional C sink of 30 g Cm^{-2} yr^{-1} was sequestered in the forest floor of the elevated CO_2 treatment plots relative to the control plots maintained at ambient CO_2 owing to increased litterfall and root turnover during the first 9 years of the study.

The potential for gains and losses of soil carbon in the Australian rangelands as affected by grazing and climate was studied by Hill *et al.* (2006) and found that soil carbon stocks are lower with the removal of understorey and presented that there was at least 40% chance of significant carbon losses in a 5-year reporting period.

The two largest variations of the global carbon cycle (largest land carbon uptake by global cooling in 1992/93 after the Pinatubo volcanic eruption and largest land carbon release by the strong El Nino event of 1997/98) observed were predominantly controlled by soil processes rather than by vegetation activity (Erbrecht and Lucht 2006).

A carbon sequestration strategy was proposed by Zeng (2008) in which certain dead or live trees are harvested via collection or selective cutting, then buried in trenches or stowed away in above-ground shelters. A methodology was presented by Minnen *et al.* (2008) to evaluate the potential effectiveness of carbon plantations. Forestry project in China is mitigating CO_2 emissions (up to about 1.4 C t ha^{-1} yr^{-1}) and with a change in management, an almost two-fold increase in the reduction of net C emissions would occur (Brown 1996).

2.1 Biomass

Biomass is considered a useful indicator of structural and functional attributes of forest ecosystems across a wide range of environmental conditions (Brown 2002). It is therefore important to accurately estimate biomass to assess the role of forests in meeting the region's energy demand or in the global carbon (C) cycle, particularly when defining its contribution toward sequestering carbon (Ramchandra 2010).

2.1.1 Above ground biomass

Standing biomass of the natural oak forests of Nepal is not well known (Subedi and Shakya 1988). The aboveground biomass of *Quercus semecarpifolia* forest at Phulchowki and Shivapuri forest were 346.87 and 462.14 t/ha, respectively (Subedi and Shakya 1988). A study from Kumaun Himalaya India reported aboveground tree biomass for three relatively protected oak forests ranged from 197.2 to 322.8 t ha^{-1} (Negi *et al.* 1983). Temperate pine–oak forests of the Sierra Madre Occidental mountain range of Northern Mexico was reported with 130 t/ha of aboveground biomass (Navar 2009). The status of *Quercus* (oak) species in the three hill forests viz Nagarjun, Phulchowki and Shivapuri around the Kathmandu Valley was studied by Siluwal (1999) and estimated the average above ground biomass of *Quercus semecarpifolia* in the range of 704.35-1126.90 t/ha. In Shivapuri the maximum AGB of *Q. semecarpifolia* was at 2600m altitude with 1770.67 t/ha (Siluwal 1999).

Aboveground biomasses in the five major forest types of Nepal estimated by Baral *et al.* (2009) were: tropical riverine (178.83 t/ha), hill sal (217.47 t/ha), pine (86.02 t/ha), *Schima-Castanopsis* (76.24 t/ha) and *Alnus nepalensis* forests (76 t/ha). Similarly, Shrestha *et al.* (2000) estimated aboveground biomass of tree species in sal regenerating forest (698 t/ha), mixed regenerating forest (337 t/ha), natural forest (807 t/ha) and degraded forest (160 t/ha) in Chitrepani in Siwalik region of Central Nepal. In Kumroj Community Forest, Chitwan aboveground biomass of the tree species was estimated 61.09 t/ha (Sujakhu *et al.* 2009). The AGB in Churia range forest of Nepal was reported in range of 182-584 t/ha (Joshi 1999). Aboveground biomass in 7.5 year old *Tectona grandis* (teak) plantation at Shankarnagar, Rupendehi district Nepal was reported 63.72 t/ha by Thapa and Gautam (2005).

The above-ground biomass (AGB) in inland and coastal tropical dry evergreen forests of peninsular India were reported 99.83 and 104.65 t/ha, respectively by Mani and Parthasarathy (2007). In the Indian Himalayan state of Himachal Pradesh, Sharma *et al.* (2008) estimated above-ground mean tree biomass density of the reserved forest (1158 t/ha), protected forest (728 t/ha), fallow land (13 t/ha), cultivated-unirrigated land (11 t/ha), grassland (8 t/ha), orchard land (5 t/ha) and cultivated-irrigated land (3 t/ha). A study on different agricultural land-uses in a sub-watershed of Thailand by Gnanavelrajah *et al.* (2008) found that highest biomass stock was in land-use under para rubber with 247.89 t/ha. Aboveground biomass in 5, 10, 15 and 20 year old poplar plantation stands were reported 38.82, 151.01, 289.63 and 426.53 t/ha, respectively by Mao *et al.* (2010) in a semiarid region of Liaoning Province, Northeast China.

Average temperate forest biomass (AGB) of world was estimated 387.3±33.9 t/ha by Keeling and Philips (2007). However, in same study temperate forests of *Sequoia sempervirens* forests in Northern California and *Tsuga heterophylla* forest in Oregon were reported with greatest range of AGB from 1492 to 3300 t/ha. Aboveground biomass estimates of living tree including palms varied more than two-fold, from 231 to 492 t/ha, with a mean of 356±47 t/ha in study conducted by Laurance *et al.* (1999) in Central Amazonia. Similarly, aboveground biomass quantified by Nascimento and Laurance (2002) in undisturbed Central Amazonian rainforests was 397.7±30 t/ha. Foliage biomass in a natural deciduous broad-leaved forest area dominated by Siebold's beech (*Fagus crenata*) was estimated 3.8±1.6 t/ha (Tatsuhara and Kurashige 2001). In this study topographical factors were considered while using geographic information system (GIS).

2.1.2 Total biomass (Aboveground and belowground)

Biomass table of *Bambusa nutans* subspecies *cupulata* grown at Belbari, Morang district of Eastern Terai was prepared and regression model to estimate the biomass was developed by Oli and Kandel (2005). Biomass table of *Dendrocalamus hookeri* grown at Jhanjhatpur, Kailali district of Far-western Terai was prepared by Oli and Kandel (2006)

The biomass and productivity of maple (*Acer cappadocicum*) forest in the west central Himalayas was described by Garkoti (2008) and found total vegetation biomass was 308.3 t/ha, of which the tree layer contributed the most, followed by herbs and shrubs.

Total vegetation biomass of horse chestnut (*Aesculus indica*), silver fir (*Abies pindrow*) and kharsu oak (*Quercus semecarpifolia*) forests was 505, 566 and 593 t/ha, respectively (Adhikari *et al.* 1995). The total C stock in Indian forests was estimated to be 2156 Tg with the mean above-ground biomass density of 67.4 t/ha, which equals around carbon density of 34 C t/ha (Haripriya 2000). The total biomass in Indian forests ranged from 24.5 to 218 t/ha with an average biomass of 92 t/ha. Converting these estimates into unit of C, the total carbon stock in Indian forests is 2940 Tg with a carbon density of 45.8 C t/ha (Haripriya 2002). The mean biomass density in Indian forests was found to be 135.6 t/ha and amongst the states it varied from 27.4 t/ha in Punjab to 251.8 t/ha in Jammu and Kashmir, respectively. The aboveground and belowground biomass were estimated to be contributing 79 and 21 percent to the total biomass, respectively (Chhabra *et al.* 2002). Biomass in tropical rainforest of Marelongue Reserve (Mascarene Archipelago, Indian Ocean) was reported 535 t/ha by Kirman *et al.* (2007) and also examined the part played by the different species as well as the role of seasonality and cyclones.

The relationship between root biomass density (root mass per unit area) and aboveground biomass density (shoot mass per unit area) across biomes and the altitudinal trend in root biomass density along the Tibetan Alpine Vegetation Transects was analyzed by Luo *et al.* (2005). Belowground biomass, aboveground biomass and vertical root distribution patterns in Eucalyptus forest along a steep rainfall gradient in Northeast Australia was examined by Zerihun *et al.* (2006).

Increase in biomass from 84.0 in the 5-year old to 170.0 t/ha in the 8-year-old poplar plantation was reported by Lodhiyal *et al.* (1995). The total vegetation biomass increased from 12 in the 1-yr-old to 113 t/ha in the 4-yr-old plantation (Lodhiyal and Lodhiyal 1997). The biomass (dry weight) was described in four (1 to 4-yr-old) poplar (*Populus deltoides*) plantations growing after clear felling of natural sal (*Shorea robusta*) mixed-broad leaved forest in the Terai belt of Central Himalaya. Similar type of study was done by Lodhiyal and Lodhiyal (2003) in 5, 10 and 15 years old planted Shisham (*Dalbergia sissoo*) forests in Bhabar region of Kumaun in Central Himalaya and reported biomass 52.5, 83.9 and 118.1 t/ha, respectively.

2.2 Biomass carbon stock

2.2.1 Aboveground biomass carbon stock

Trees more than or equal to 10 cm dbh accounted for over 90% of above-ground carbon stocks in forest (Kirby and Potvin 2007). Aboveground biomass carbon stock in the five major forest types of Chitwan, Lalitpur, Kavre and Kaski of Nepal was estimated (tropical riverine (80.47 t/ha), hill sal (97.86 t/ha), pine (38.70 t/ha), *Schima-Castanopsis* (34.30 t/ha) and *Alnus nepalensis* (34.60 t/ha)) by Baral *et al.* (2009). Baishya *et al.* (2009) compared biomass carbon stock between natural semi-evergreen forest and sal plantation forest in the humid tropical region of Northeast India and found 161.97 and 203.18 t/ha, respectively. Shrestha (2007) conducted research in Pokhare Khola, a mid hill watershed in Nepal with objectives including estimating the existing C pools in soil and vegetation.

2.2.2 Total biomass carbon stock

Carbon stock in forest biomass in non-degraded Oak forest of Uttarakhand, India was reported 242.56-290.62 t/ha by Jina *et al.* (2008). Total biomass carbon content of harvest-age (20-year old) teak plantations in Panama was reported 126 t/ha by Kraenzel *et al.* (2003).

2.3 Soil carbon stock

Quercus and *Rhododendron* tree species are good sequesters of organic carbon in soils (Martin *et al.* 2010). The protection of organic soil carbon stocks and the management of forest soils to increase carbon sequestration is crucial to the maintenance of the carbon balance (Ostle *et al.* 2009). SOC is affected quantitatively and qualitatively by land use changes; however the SOC pool can be increased under better management of forest and cultivated soil (Shrestha 2007). Glaser *et al.* (2000) found that land use change from forest to pasture mainly affected the soil organic matter bound to the silt fraction. Organic C stock in forest floor generally increased with stand age. SOC was found decreasing with soil depth (Mishra 2010).

A study in the mid-hills of Nepal, Mardi watershed estimated the SOC contents in different land-use types by Shrestha (2002) and reported highest SOC in the topsoil (0–10 cm depth) of grazing land with 34 t/ha followed by the cultivated upland (Bari) (20 t/ha), forestland (14 t/ha) and level terraces (Khet) (12 t/ha). Sheikh *et al.* (2009) found that stocks of SOC decreased with altitude: from 185.6 to 160.8 C t ha^{-1} and from 141.6 to 124.8 C t ha^{-1} in temperate (*Quercus leucotrichophora*) and subtropical (*Pinus roxburghii*) forests of Garhwal Himalaya, respectively. Chhabra *et al.* (2003) estimated mean soil organic C density ranged from 70 t/ha in tropical dry deciduous forest to 162 t/ha in montane temperate forest for top 1 m soil depth. Yang *et al.* (2007) determined the major pools of SOC in four sites representing major forest types in China. Gnanavelrajah *et al.* (2008) estimated carbon stock of different agricultural land-uses in a sub-watershed of Thailand and assessed the land-use sustainability with respect to carbon management. In Panama most of the carbon in the system of teak plantation was reported in the soil, averaging 225 t/ha by Kraenzel *et al.* (2003).

The influence of woody plant expansion on soil carbon (C), soil nitrogen (N), and roots to a depth of 15 cm encompassing grassland, woodland, and transition zones in a northern Great Plains of North Dakota was determined by Springsteen *et al.* (2010).

2.4 Total carbon stock

Forest age could be used as an easily understood and scientifically sound measure of the progress in complying with national targets on the protection and enhancement of forest carbon sinks (Alexandrov 2007).

Total carbon stored in Pine forest and Broad-leaved forest was estimated 245.95 and 163.99 t/ha respectively by Adhikaree (2005). Total carbon stock of Pine Forest was 126.56 t/ha which was higher than that of Mixed Broad Leaf Forest i.e. 49.76 t/ ha (Dahal 2007). The total carbon content in a community managed forest of Champadevi Community Forest was estimated to be 24.72 t/ha. (Khanal 2007). The total carbon sequestration potential of *Alnus nepalensis* forest was estimated 186.05 t/ha by Ranabhat *et al.* (2008). Total carbon sequestration in *Schima-Castanopsis* forest in midhills of Western Nepal was estimated 178.52 t/ha by Shrestha (2009) and found that carbon sequestration was high in higher elevation concluding an important role of elevation on total carbon sequestration. Total carbon content in Chapako Community Forest, a sub-tropical forest in North-West Kathmandu was reported with 152.04 t/ha by Mishra (2010).

In four Panamanian plantations of 20-year-old teak (*Tectona grandis*) trees, Kraenzel *et al.* (2003) estimated 351 t C/ha carbon content. Carbon storage estimation of major temperate forests on Mt Changbai, Northeast China by Zhu *et al.* (2010) found total ecosystem C density (carbon stock per hectare) averaged 237 C t/ha (ranging from 112 to 338 C t/ha). The carbon accumulation over 14 years in four different types: three monospecific plantations of slash pine (*Pinus elliottii*), Chinese fir (*Cunninghamia lanceolata*), and tea-oil camellia (*Camellia oleifera*) and one natural secondary forest (*Pinus massoniana* and *Cyclobalanopsis glauca*) were 104.07, 102.95, 113.09 and 141.99 t/ha, respectively (Zheng *et al.* 2008).

CHAPTER THREE

3. STUDY AREA

3.1 Location

Shivapuri Nagarjun National Park (SNNP) is situated on the northern fringe of Kathmandu Valley and lies about 12 km away from the center of capital city. SNNP initially established as Shivapuri Watershed Reserve in 1976 and Shivapuri Watershed and Wildlife Reserve in 1984. The area was gazetted as the country's ninth national park in 2002 and was known thereafter as Shivapuri National Park (ShNP). After inclusion of Nagarjun Forest Area (15 sq km) in 2009, the park was renamed as Shivapuri Nagarjun National Park (SNNP). With increased area the park now covers an area of about 159 sq km (http://www.dnpwc.gov.np, DNPWC 2009).

Shivapuri forest region is located between 27^0 45' and 27^0 52' North latitude and 85^0 15' and 85^0 30' East longitude. It covers an area of 144 sq km. Situated in middle mountain region of the Central Development Region, it lies in Kathmandu, Nuwakot and Sindhupalchok districts of Bagmati zone (KMTNC 2004).

3.2 Geology, topography and elevation

Geologically, SNNP falls in the Inner Himalayan Region. The gneiss and migmatite with mica schist and pegmatic granite are the dominant rocks. 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 more than 30^0 at least half of the total area of the park (HMGN 1995, KNTNC 2004). Because of the steep topography and nature of soil, soil erosion and landslides are common all over the SNNP. The elevation ranges from 1366 m to 2732 m at Shivapuri peak (KMTNC 2004).

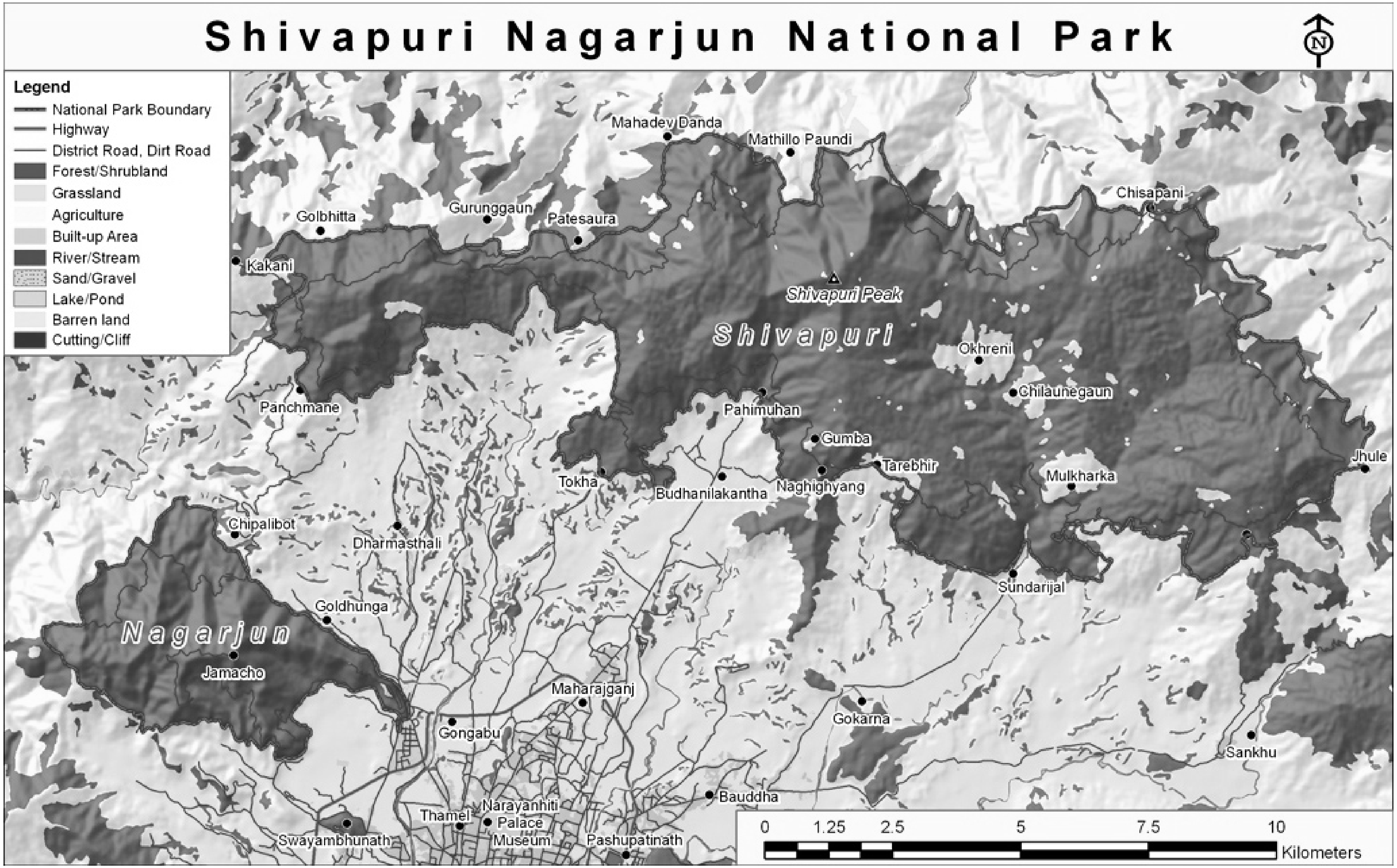

Figure 1: Map showing Shivapuri Nagarjun National Park. (Source: http://www.dnpwc.gov.np/maps/large_shivapuri.jpg)

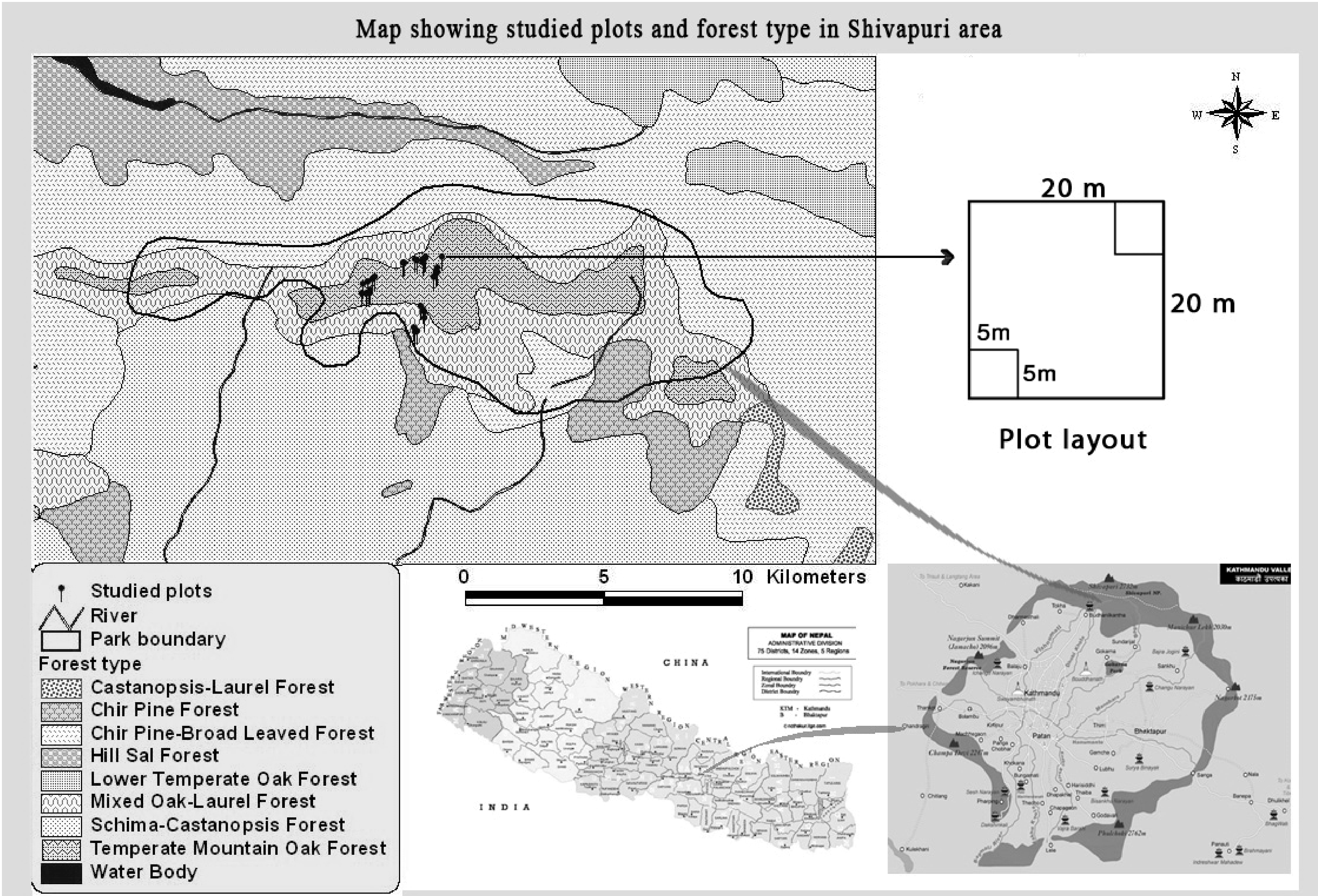

Figure 2: Map of Shivapuri region showing sampled quadrats. Prepared by: Ranjitkar, S.

3.3 Climate

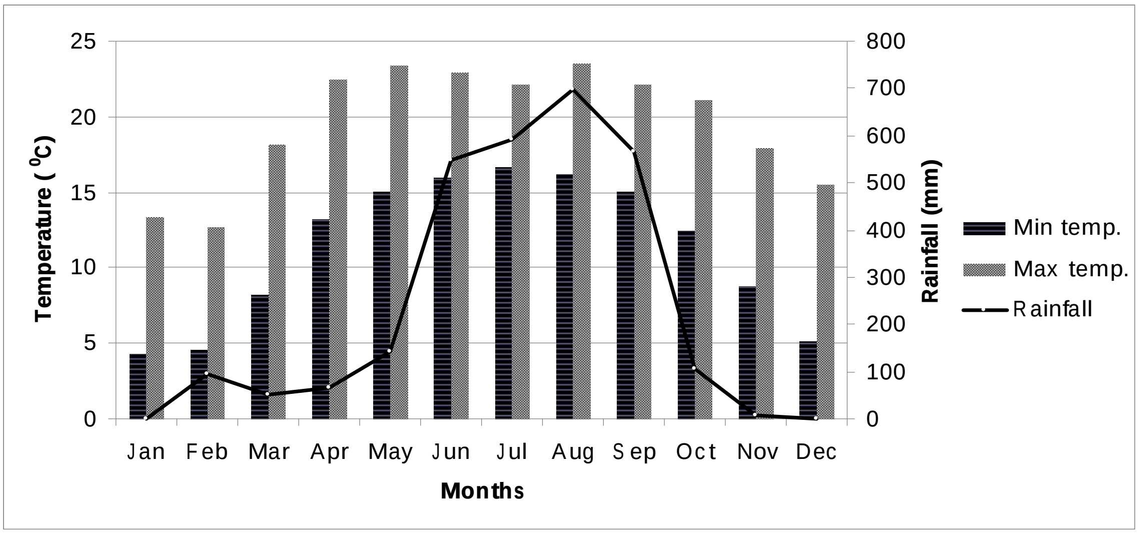

Figure 3: Five years (2004-2008) average minimum-maximum temperature and rainfall of Kakani station. (Source: Department of Hydrology and Meteorology)

Climatic zones ranges from subtropical to lower temperate (HMGN 1995). There is a high variation in the annual temperature and precipitation. For the period of 2004 – 2008, the highest maximum average temperature is 23.5°C and the minimum average temperature is 4.3°C. The average annual rainfall is 2872.2 mm for the period of 2004-2008 and more than 80% of annual precipitation (2404.4 mm) occurs during the rainy season (monsoon rainfall) i.e. from June to September (Figure 3).

3.4 Vegetation

SNNP has high floral diversity due to its location, altitudinal and climatic variations. SNNP has four types of forests, which are distributed along the altitudinal gradient (Amatya 1993, Kattel 1993, KMTNC 2004). These forest types are:

i) Lower mixed hardwood (*Schima-Castanopsis*) forest at 1000-1500m asl
ii) Chir pine forest at 1000-1600m asl
iii) Upper mixed hardwood forest at 1500-2300m asl and
iv) Oak forest at 2300-2700m asl

There are more than 2122 species of flora and 16 of them are endemic flowering plants. About 129 species of mushroom have been identified in SNNP (BPP 1995, KMTNC).

Table 1: Forest Habitats and Altitudinal Distribution of Flora in SNNP.

Forest type or Habitat	Lower mixed hardwood	Chir pine forest	Upper mixed hardwood forest	Oak forest
Altitude (m)	1000-1500	1000-1600	1500-2300	2300-2700
Dominant species	*Schima wallichi* *Castanopsis indica* *Alnus nepalensis* *Anthocephalus chinensis* *Prunus cerasoides*	*Pinus roxburghi* *Castanopsis indica* *Myrica esculenta* *Prunus pashia*	*Acer –Aesculus* *Juglans regia* *Betula* sp. *Fraxinus* sp. *Alnus nepalensis* *Salix* sp. *Quercus* sp. *Celtis* sp.	*Quercus semecarpifolia* *Eurya acuminata* *Ilex dipyrens* *Michelia champaca* *Rhododendron arboreum* *Symplocos* sp.

Source: KMTNC 2004.

CHAPTER FOUR

4. MATERIALS AND METHODS

4.1 Data collection and sources

The field data were collected from September to December 2009. The map of SNNP was obtained from http://www.dnpwc.gov.np/maps/large_shivapuri.jpg . Temperature and precipitation data of Kakani weather station (2004 to 2008) were obtained from the Department of Hydrology and Meteorology/GoN. The calculated values of wood density of the tree species were taken from HMGN/MPFS/FRISDP (1988) and Jackson (1987).

4.1.1 Quadrat layout and biomass sampling

Quadrats of size 20m×20m were laid randomly at different altitude zones. Four altitude zones (2100m, 2300m, 2500m and 2700m) were considered and sampling was done within 2050-2150m, 2250-2350m, 2450-2550m and 2650-2732m respectively. Eight quadrats in each altitude zone four facing South-East and four facing South-West were plotted. Altogether Thirty two quadrats were sampled.

In each quadrat, the number of trees (≥10cm diameter at breast height [dbh]) was noted. Diameter at breast height (dbh) of each tree at height of 1.37m from the base was measured using dbh tape. The tree height of each tree was determined by using clinometer and trigonometric ratios as below.

For estimation of tree height following relation was used:

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

where, H= total height of the tree in meter

θ= 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.

Two 5m×5m sub-quadrats were made diagonally at any two corners within each quadrat for sampling of saplings (dbh less than 10 cm and height more than 137 cm) and shrubs within each quadrat. The dbh of saplings lying within the quadrats were measured. And height of the saplings was also determined by using clinometer and trigonometric ratios as in the case of the trees. For shrub diameter was taken at 10 cm above ground. Shrub with diameter less than 2cm was not sampled. Seedlings (height<137cm) of the tree species and herbs were not sampled, since seedlings and other under storey vegetation are not used to estimate carbon stock (Payton *et al.* 2004)

4.1.2 Soil sampling

Soil samples were collected in each sampling plot, at different horizontal depths of 0-25 cm and 25-50cm 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.

Soil sample for the estimation of bulk density was collected separately from the centre of the plot at both horizontal depths of 0-25cm and 25-50cm using core sampler of volume 1000cm^3 (Metallic cylinder with diameter 10.4cm and height 11.78cm).

4.1.3 Plant collection, herbarium preparation and identification

Specimens of tree and shrub species encountered in sampling areas were collected, tagged and pressed in the field using a newspaper and herbarium presser. Colour of the flower (if available), fruit, fragrance or any special features of the plants collected were documented. When the plant specimens were completely dry, they were mounted on herbarium sheet of 16.5" × 11" using glue, and labeled in accordance to Press *et al.* (2000). The herbarium specimens were identified using references such as Polunin and Stainton (1984) and Stainton (1988). These were also compared with specimens at Tribhuvan University Central Herbarium (TUCH), National Herbarium and Plant Laboratories, Godawari (KATH) and some of them were identified by experts of taxonomy. The nomenclature adopted in this document is in accordance to Press *et al.* (2000). Herbarium specimens were deposited in Tribhuvan University Central Herbarium (TUCH) existed in Central Department of Botany, Tribhuvan University, Kathmandu.

4.2 Soil analysis

Soil samples were analyzed at the Ecology laboratory in the Central Department of Botany, Tribhuvan University. Soil pH, soil organic carbon (SOC), and total Nitrogen (N) were estimated in the soil samples using methods described by Gupta (2000) and Zobel *et al.* (1987).

4.2.1 Soil pH

Soil pH was determined using Digital pH meter in 1:2 ratio of soil-water mixture. Before measurement, the pH meter was calibrated using buffer solutions of known pH (pH 4 and pH 7). During the measurements, 40 ml of distilled water was poured into 20 g of soil sample. The mixture was stirred at least 30 minute using a magnetic stirrer and then allowed to settle down for five minutes. The electrode was dipped into the mixture and reading of pH was noted.

4.2.2 Organic carbon content

Organic carbon content in the soil 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 added 5 ml of 1N $K_2Cr_2O_7$ and 10 ml of conc. H_2SO_4 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. A blank titration (without soil) was carried out at every lot of 17 samples in a similar manner.

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

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

4.2.3 Total nitrogen

Micro-Kjeldahl method involves the conversion of organic Nitrogen into ammonia by boiling with conc. H_2SO_4; the ammonia was subsequently liberated from its sulphate by distillation in presence of an alkali, which is titrated against HCl.

Digestion: One gram air dry and sieved soil, 0.4 g Copper sulphate ($CuSO_4$) and 3.5 g potassium sulphate (K_2SO_4) were taken in a 300 ml clean and dry Kjeldahl digestion flask. Conc. H_2SO_4 (6 ml) was added to the soil mixture with gentle shaking. The mixture was heated on the preheated heating mantle at low heat until bubbles disappeared from the black mixture. When there was no frothing and then the heat was raised until the content of the flask would change to grey or greenish in colour for complete digestion. The digest was cooled to room temperature and about 50 ml distilled water was added to the mixture with gentle shaking.

***Distilation*:** The Kjeldahl distillation flask with digested materials was assembled on distillation chamber and warmed up for 15 minutes adjusting the heating mantle adjuster at 30. In the Kjeldahl distillation flask 30 ml sodium hydroxide (40% NaOH) was added through the funnel connected to tube of distillation flask and the cork was set. In clean and dry (100 ml) beaker 10 ml boric acid indicator was pipetted and placed below the nozzle of the condenser in such a way that the end of nozzle dip in to the indicator. The heating mantle's temperature adjuster was set at 70. When the distillate began to condense, the color of boric acid indicator changed from pink to green. Distillation was continued until the volume of distillate in beaker reached about 50 ml.

***Titration*:** Beaker containing about 50 ml distillate was removed and titrated it with hydrochloric acid (0.1 N) in burette. The volume of HCl consumed by distillate to change the green colour into pink was recorded. The same procedure was followed for other samples. For each batch of 17 samples, single blank (without soil) sample was included.

The following formula was used to calculate soil N.

$$\text{Soil N (\%)} = \frac{14 \times N \times (S - B) \times 100}{M}$$

where, N = normality of HCl

S = volume of HCl consumed with sample (ml)

B = volume of HCl consumed with blank (ml)

M = mass of soil taken (mg)

4.3 Bulk density

Soil bulk density at 0-25 and 25-50 cm horizons were determined using core sampling of known volume. For the purpose of core sampling a core sampler of volume 1000 cubic centimeter (Metallic cylinder with diameter 10.4cm and height 11.78cm) was used. The soil samples were collected without disturbing the natural structure. The samples were oven-dried at 65 ºC for 2-3 days. The weight of oven dried soil samples divided by its volume gave the bulk density.

$$\text{Bulk Density} = \frac{\text{Oven - dried weight of soil}}{\text{Volume of core sampler}}$$

4.4 Calculation

4.4.1 Biomass estimation

For aboveground biomass estimation allometric models developed by Chave *et al.* (2005) was used for the tree with dbh ≥10cm of which wood specific density was known. The calculated values of wood density of the tree species (ANNEX VI) 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) $AGB = \exp[-2.977 + \ln\{\rho(dbh)^2H\}]$ (Chave *et al.* 2005)
2) $AGB = a(dbh)^b$ (Zianis 2008)

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

H= height of tree in m

ρ = wood specific gravity (g cm^{-3})

a= 0.1424 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 for temperate region (Cairns *et al*. 1997). Total aboveground biomass and root biomass was summed up to get the total biomass

Total biomass = Aboveground biomass + Belowground biomass

For dead trees total biomass was assumed to be 90% of total biomass of live tree (Delaney *et al.* 1998).

The aboveground biomass of saplings (having dbh<10cm, height>137cm) and shrub were estimated using the global equation of Zianis (2008). And root biomass was again estimated using root to shoot biomass ratio given by Cairns *et al*. (1997) for temperate region.

For fallen logs diameter at the center along the length of the log was taken. Cross sectional area of the log at the center region was calculated. And finally volume of the log was calculated by multiplying the area with length of the log. And it was multiplied by the mean density of wood of *Quercus* forest i.e., 897 kg/m^3 (HMGN/MPFS/FRISDP 1988) for estimation of mass of the log.

$$\text{Cross sectional area (A)} = \frac{\pi d^2}{4}$$

$$\text{Volume} = A \times l$$

$$\text{Mass} = \text{Volume} \times \text{wood density}$$

where, d is diameter of log at the center.

l is length of the log.

4.4.2 Carbon stock in biomass

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.

4.4.3 Carbon stock in soil:

The soil carbon stock was calculated with the classical layer-based method whereby the soil carbon stock for the horizon 0–50cm was calculated using the following equation: (Mestdagh *et al.* 2005)

$$\text{Soil carbon stock (C t/ha)} = [\{(SOC/100) \times BD_{0\text{-}25} \times 25\} + \{(SOC/100) \times BD_{25\text{-}50} \times 25\}] \times 100$$

where, SOC is the percentage soil organic carbon,

BD is the bulk density (g dry soil cm^{-3}) and

25 is the depth (cm) of soil horizons 0–25 and 25–50cm.

4.4.4 Total carbon stock

Total carbon stock was calculated by summation of the carbon stocks in biomass and soil

Total Carbon stock = Carbon stock in biomass + Carbon stock in soil

4.4.5 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.

4.5 Statistical analysis

Mean values of soil pH, SOC, N, bulk density of the two soil horizons were calculated. Correlation and regression were calculated among elevation, soil attributes and carbon stocks. Effect of soil pH, SOC, N soil bulk density and altitude on biomass C stock, soil C stock and total C stock were evaluated by regression analysis. In this analysis soil pH, SOC, N, soil bulk density and altitude were considered as explanatary variable and biomass C stock, soil C stock and total C stock as response variables.

Carbon stock (soil and biomass) between two aspects and among four altitude zones were also compared using one way ANOVA. Soil pH, soil organic carbon (SOC), soil nitrogen content (N) and soil bulk density in two soil horizons were also compared using paired t-test. The statistical analyses were done on the spreadsheet of MS-Excel and the Statistical Package for Social Sciences (SPSS) version 12.0 and 16.0 were also used.

CHAPTER FIVE

5. RESULTS

5.1 Biomass

Mean biomass of the temperate forest of Shivapuri was found 797.57 t/ha with 633.53 t/ha in aboveground biomass. Maximum and minimum mean biomass were found in 2500 and 2100m altitude zones with values 1364.39 and 243.34 t/ha, respectively (ANNEX IV).

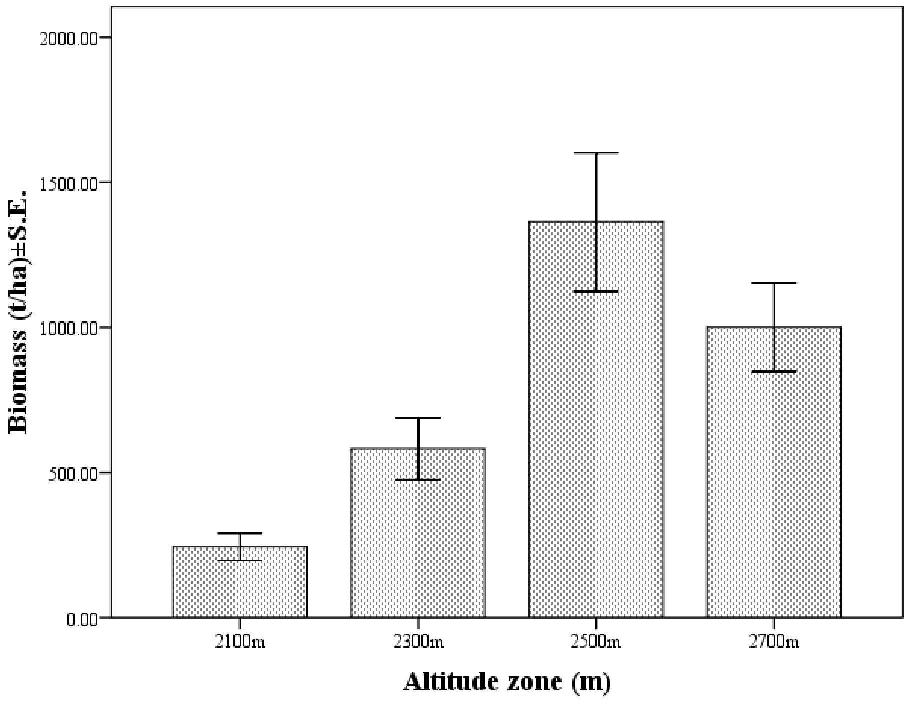

Figure 4: Mean bimass (t/ha) in different altitude zones.

5.2 Biomass carbon stock

Mean biomass C stock of the temperate forest of Shivapuri was found 398.78 t/ha (ANNEX IV). Biomass C stock was found positively associated (at p=0.01) with altitude, SOC and N (Figure 5, 6 and 7). Mean Biomass C stock of 2100m, 2300m, 2400m and 2700m altitude zones were found 121.67, 290.77, 682.19 and 500.50 C t/ha, respectively (ANNEX IV). Biomass C stock in four different altitude zones were found significantly different at p=0.01. Similar biomass C stock at SE and SW aspects were found with average values of 410.18 and 387.39 C t/ha, respectively (ANNEX IV).

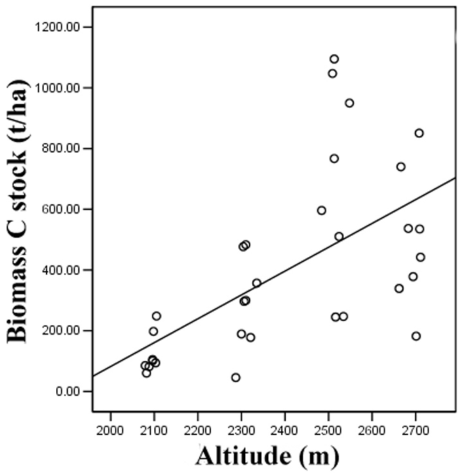

Figure 5: Relations between altitude and biomass C stock. The fitted line is based on linear regression model.

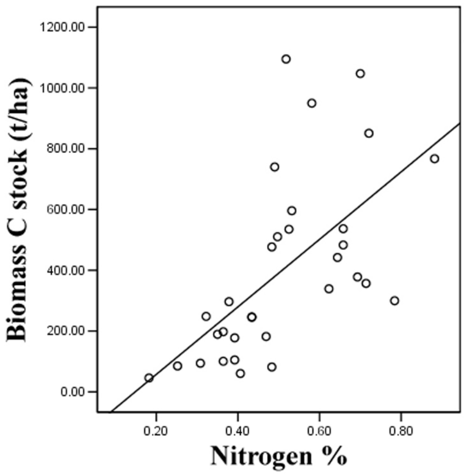

Figure 6: Relations between nitrogen % and biomass carbon stock. The fitted line is based on linear regression model.

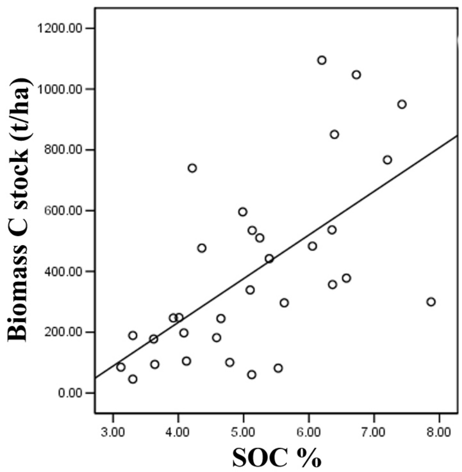

Figure 7: Relations between Soil organic carbon % and biomass carbon stock. The fitted line is based on linear regression model.

5.3 Soil carbon stock

Mean soil C stock of the temperate forest of Shivapuri was found 200.80 t/ha (ANNEX IV). Soil carbon content was found positively associated with N at p=0.01 (Figure 8) and negatively associated with pH at p=0.01 (Figure 9).

Mean Soil C stock of 2100m, 2300m, 2500m and 2700m altitude zones were found 179.49, 187.49, 238.09 and 198.12 C t/ha, respectively (ANNEX IV). Soil C stock in four different altitude zones were found significantly different at p=0.05.

Similar Soil C stock at SE and SW aspects were found with mean values of 193.46 and 208.13 C t/ha respectively (ANNEX IV).

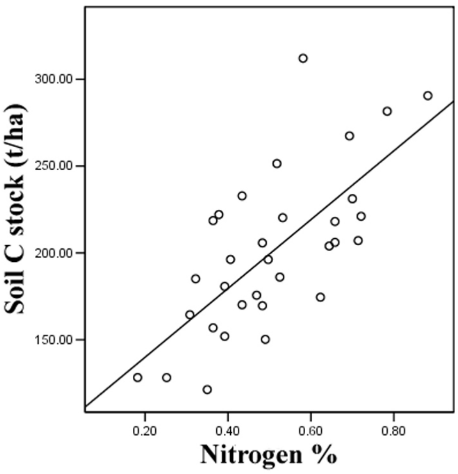

Figure 8: Relations between nitrogen % and soil carbon stock. The fitted line is based on linear regression model.

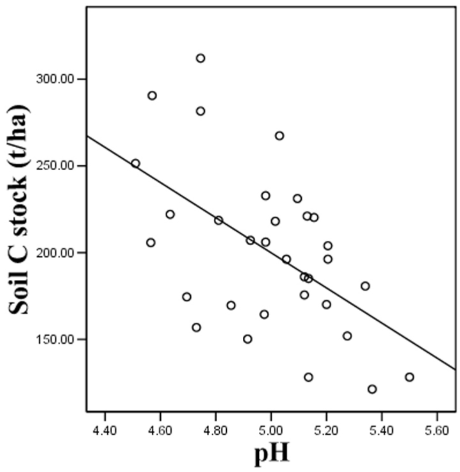

Figure 9: Relations between pH and soil carbon stock. The fitted line is based on linear regression model.

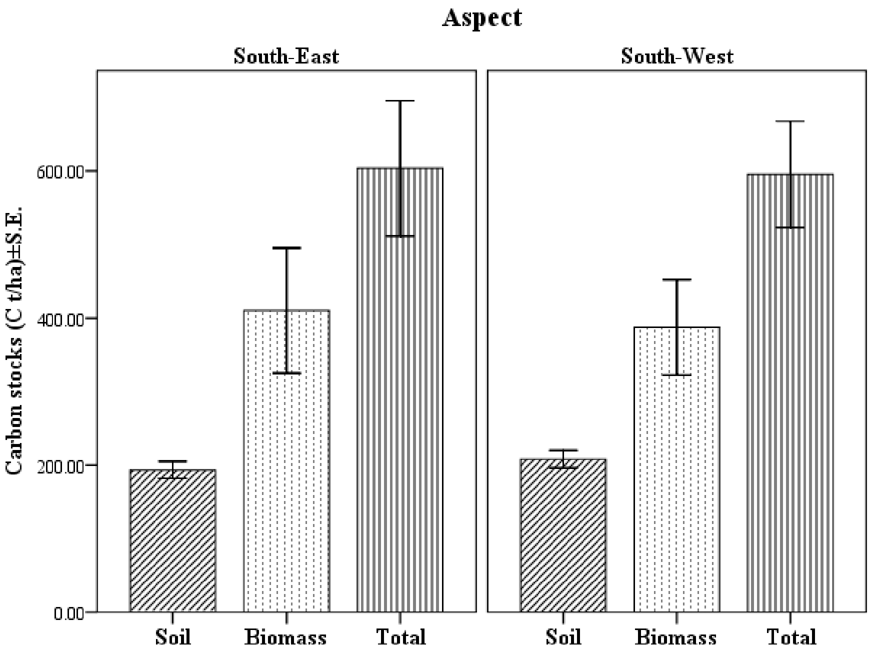

Figure 10: Mean carbon stocks in SE and SW aspects.

5.4 Total carbon stock

Mean total C stock (biomass C + soil C) of the temperate forest of Shivapuri was found 599.58 t/ha (ANNEX IV). Total carbon content was found positively associated with altitude, SOC and N at p=0.01 (Figure 11, 12 and 13). Mean total C stock of 2100m, 2300m, 2500m and 2700m altitude zones were found 301.16, 478.26, 920.28 and 698.62 C t/ha, respectively (ANNEX IV and Figure 14). Mean total C stock in four different altitudes were significantly different at p=0.01. Similar total C stock at SE and SW aspects were found with mean values of 603.64 and 595.52 C t/ha respectively (ANNEX IV).

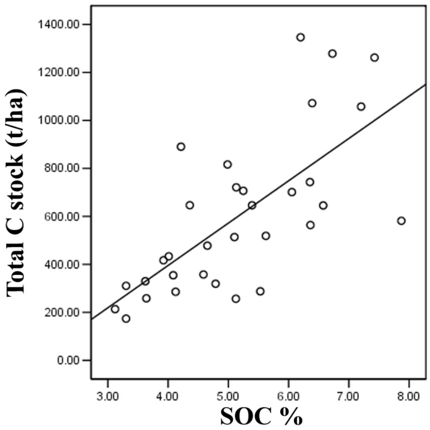

Figure 11: Relations between Soil organic carbon % and total carbon stock. The fitted line is based on linear regression model.

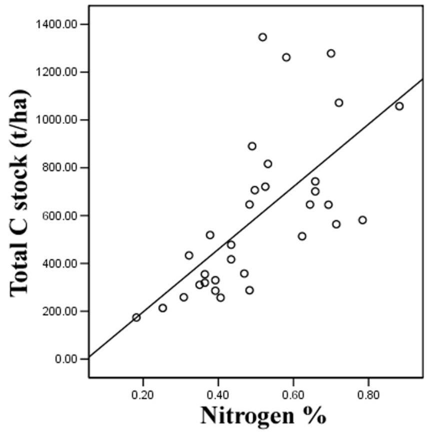

Figure 12: Relations between nitrogen % and total carbon stock. The fitted line is based on linear regression model.

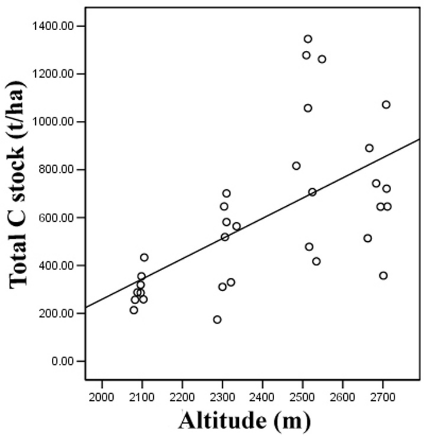

Figure 13: Relations between altitude and total carbon stock. The fitted line is based on linear regression model.

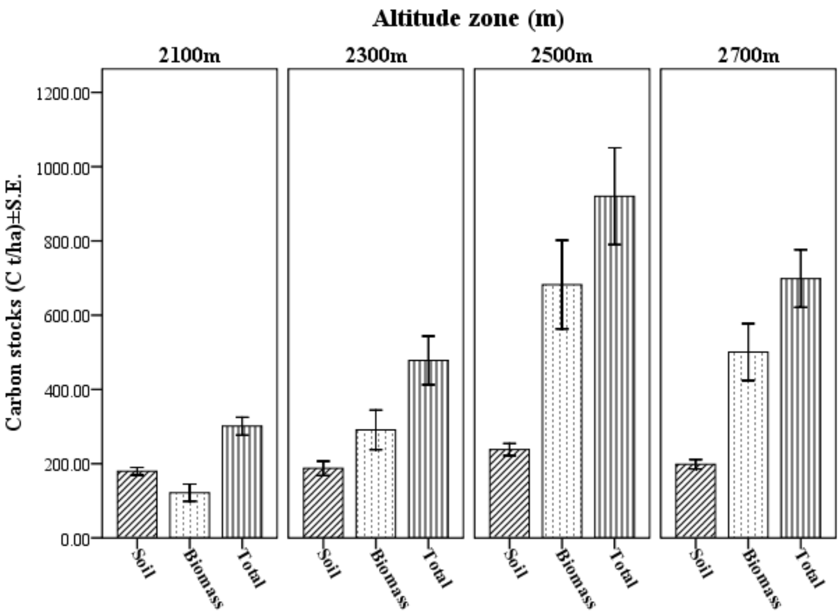

Figure 14: Mean carbon stocks in different altitude zones.

5.5 Soil attributes between different horizons

The organic carbon content and nitrogen content in the upper horizon (0-25cm) was found higher than that of lower horizon (25-50cm). Whereas the pH and bulk density in the upper horizon (0-25cm) was found lower than that of lower horizon (25-50cm). The SOC, N, pH and bulk density of two soil horizons were significantly different at p=0.01. Mean SOC, N, pH and bulk density were found 5.76 and 4.55%; 0.62 and 0.40%; 4.90 and 5.09; and 0.74 and 0.84 g/cm^3, respectively in the two respective horizons (Table 2).

Table 2: Soil attributes in different soil horizons.

Soil Attributes	Soil horizon	
	0-25cm (Mean ± SD)	25-50cm (Mean ± SD)
pH	4.90 ± 0.28	5.09 ± 0.25
SOC	5.76 ± 1.44	4.55 ± 1.55
N	0.62 ± 0.21	0.40 ± 0.14
Bulk Density (g/cm^3)	0.74 ± 0.08	0.84 ± 0.11

5.6 Basal area of tree

Basal area of tree was found in the range of 16.45-127.96 m^2/ha in temperate region of Shivapuri forest with mean value of 61.97 m^2/ha (ANNEX III).

CHAPTER SIX

6. DISCUSSION

6.1 Biomass

6.1.1 Aboveground biomass (AGB)

Mean aboveground biomass of the temperate forest of Shivapuri Nagarjun National Park was found 633.53 t/ha. Which is higher than the estimates (462.14 t/ha) of Subedi and Shakya (1988). This might be due to difference in forest age and different regression equations used for estimation of the biomass. Similarly their estimate of Phulchowki (346.87 t/ha) is lower than Shivapuri (462.14 t/ha) at the same time and present might be due to maturity and comparatively less disturbance. But the present estimation was lower than the estimation in natural forest of Siwalik region of Central Nepal (807 t/ha) of Shrestha *et al.* (2000) and three hill forests (Nagarjun, Phukchoki and Shivapuri around the Kathmandu Valley) of *Quercus semecarpifolia* (704.35-1126.90 t/ha) by Siluwal (1999).

The present finding is below the estimation of Western Himalaya by Sharma *et al.* (2008). Where they recorded aboveground mean tree biomass of 1158 and 728 t/ha for two protected Himalayan temperate forest in the Indian Himalayan 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 present finding is higher than in oak forest (323.1 t/ha) at 2300-2400m in Kumaon hill of Himalaya by Negi *et al.* (1983); (182-584 t/ha) in Churia forest by Joshi (1999); (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) and (355.8 t/ha) Laurance *et al.* (1999), mean total aboveground dry biomass values from Amazon forests, as well as higher than (247.89 t/ha) Gnanavelrajah *et al.* (2008) in land-use under para rubber in Thailand. The difference in the values might be due to difference in region, forest type and management.

6.1.2 Total biomass

Mean biomass of the temperate forest of Shivapuri was found 797.57 t/ha which is greater than the tropical rainforest (535 t/ha) of Marelongue Reserve (Mascarene Archipelago, Indian Ocean) by Kirman *et al.* (2007). Higher estimation in present study might be due to the higher BA (16.45-127.96 m^2/ha) of trees in the present study area (ANNEX III). Similarly, mean biomass of present study was higher than pine forest (233.0 t/ha) of mid hills of Central Nepal (Dahal 2007); Eucalyptus forest (96 t/ha) in Northeast Australia (Zerihun *et al.* 2006).

6.2 Biomass carbon stock

6.2.1 Aboveground biomass carbon stock

Considering only aboveground biomass carbon stock the present study value was found 316.49 t/ha. The present value was close to 343.3 C t/ha in the forests of the Eastern Panama (Kirby and Potvin 2007), but higher than 97.86 t/ha of mid hill sal forest of Nepal (Baral *et al.* 2009); 161.97 and 203.18 C t/ha in natural and plantation forests respectively of humid tropics in northeast India reported by Baishya *et al.* (2009).

6.2.2 Total biomass carbon stock

The mean total biomass carbon stock was estimated 398.78 t/ha. Which is close to the estimation (242.56-290.62 t/ha) of Jina *et al.* (2008) in non-degraded oak site of Kumaun Central Himalaya.

The present value was higher than value (125.33 t/ha) reported by Adhikaree (2005) in mixed broadleaved midhills forest of Central Nepal; (116.5 t/ha) reported by Dahal (2007) in pine forest from midhills of Central Nepal; (24.72 t/ha) reported by Khanal (2007) in community forest in surrounding of Kathmandu; (65 t/ha) reported by Navar (2009) in Pine-oak temperate forests of Mexico; (109.6 t/ha) of 15 year old sisso forest in Shiwalik of Himalaya reported by Lodhiyal and Lodhiyal (2003); (113.0 t/ha) of 4year old poplar plantation in Terai belt of Himalaya reported by Lodhiyal and Lodhiyal (1997); (126 t/ha) of harvest-age (20-year old) teak plantations of Panama reported by

Kraenzel *et al.* (2003). The difference in value might be due to forest age, forest type (Guo *et al.* 2010) and geographical regions.

6.3 Soil carbon stock

Soil carbon stock (200.80 t/ha) in the present study was higher than (183 t/ha) in Indian forest soil (Jha *et al.* 2003); (162 t/ha) in Indian montane temperate forest (Chhabra *et al.* 2003); (170 t/ha) in forest soil of Alay Range of Kyrgyzia (Glaser *et al.* 2000); (68.6 t/ha) in poplar stand in Northeast China (Mao *et al.* 2010); (63.7 t/ha) in woodland soil (0-15cm soil depth) of North Dakota (Springsteen *et al.* 2010). But soil carbon stock of present study was lower than (225 t/ha) in teak plantation of Panama (Kraenzel *et al.* 2003). Whereas Martin *et al.* (2010) found different soil carbon stock ranging 115-824 t/ha among different physiographic zone of Garhwal hills of Himalaya. These variations in the values might be due to difference in soil depths during sampling.

The present study found SOC and altitude were uncorrelated. While, Sheikh *et al*. (2009) found that stocks of SOC decreased with altitude from 185.6 to 160.8 C t/ha in temperate (*Quercus leucotrichophora*) forest.

6.4 Total carbon stock

Mean total carbon stock of the study area (599.58 t/ha) was higher than the findings of Adhikaree (2005) in Pine forest(245.95 t/ha) and Broad-leaved forest(163.99 t/ha) in midhills of Central Nepal; Dahal (2007) in Pine forest (126.56) and Broad-leaved forest (49.76 t/ha) of midhills of Central Nepal; Khanal (2007) in a Community Forest (24.72 t/ha) in Kathmandu; Ranabhat *et al.* (2008) in Alder forest (220.30 t/ha) of mid hill of Nepal; Mishra (2010) in a Community Forest (152.04 t/ha) in Kathmandu; Kraenzel *et al.* (2003) in Panamanian harvest-age teak plantations (351 t/ha); Shrestha (2009) in *Schima-Castanopsis* forest (178.52 t/ha) in midhills of Western Nepal; Zhu *et al.* (2010) in Broadleaf mixed forest (256.4 C t/ha) and *Picea-Abies* forest (247.7 C t/ha) of Northeast China. The higher value in present study might be due to strict protection of mature forest.

Total carbon stocks in SE and SW aspects were not different. Although the SE and SW aspects are not illuminated at the same time, however the time period of illumination might be same. Hence, the similarity in vegetation growth might be due to similar illumination time period in both aspects resulting in similar C stock.

Among the four altitude zones minimum total carbon stock was at 2100m and it increased and maximum was in 2500m and again it decreased at 2700m altitude. Prior to being conserved area the forest of the study area might have been under pressure. The low altitude forest near to settlements might have been under more pressure of deforestation. The upper altitude forest might have remained undisturbed due to remote accessibility. Where as the altitude zone 2700m is near the peak. So natural hazards (like wind, frost) might cause disturbance in growth, reproduction and accumulation of nutrient. However, Shrestha (2009) found that carbon sequestration is high at higher elevation.

6.5 Soil attributes between two soil horizons

The soil attributes SOC, N, pH and bulk density between two soil horizons were found significantly different. SOC and N in upper soil horizon (0-25cm) was found higher than lower soil horizon (25-50cm). This might be due to difference in time period of soil formation. The upper horizon being newly formed might have contained more carbon and nitrogen. In the upper horizon the nutrient might be continuously being replenished by the detritus decomposition. Whereas from the lower horizon the tree roots absorb more nutrients. Leaching of nutrients from upper horizon is source of accumulation in lower horizon. Hence, SOC and N accumulation is lesser in lower horizon compared to upper. Similar result was reported by Mishra (2010) in SOC of Chapako Community Forest, Kathmandu.

The pH and bulk density in upper soil horizon (0-25cm) was lower than lower soil horizon (25-50cm). This might be due to more amount of organic content in upper soil horizon. Soil pH and SOC were negatively correlated. The more accumulation of nutrient in upper horizon might have made the soil more porous resulting low bulk density. Also the clay particles might have leached out to lower horizon which increased compactness of soil making it more heavier.

CHAPTER SEVEN

7. CONCLUSION

Mean total C stock (biomass C + soil C) of the temperate forest of Shivapuri was found 599.58 t/ha with maximum and minimum values of 1346.45 and 173 t/ha, respectively. Total carbon content was found positively associated with altitude, SOC and N. The altitude zonal mean total C stock was found increasing from 2100m (301.16 t/ha) to 2500m (920.28 t/ha) and it again decreased at 2700m (698.62 t/ha). Similar total C stock at SE and SW aspects were found with mean values of 603.64 and 595.52 C t/ha, respectively.

Mean biomass C stock of the temperate forest of Shivapuri was found 398.78 t/ha with maximum and minimum values of 1095 and 45.66 t/ha, respectively. Biomass C stock was found positively associated with altitude, SOC and N. Mean soil C stock of the temperate forest of Shivapuri was found 200.80 t/ha with maximum and minimum soil C stock values of 312.07 and 121.29 t/ha, respectively. Soil carbon content was found positively associated with N and negatively associated with pH.

The organic carbon content and nitrogen content in the upper horizon (0-25cm) were found higher than that of lower horizon (25-50cm). Whereas the pH and bulk density in the upper horizon (0-25cm) were found lower than that of lower horizon (25-50cm). Mean SOC, N, pH and bulk density were found 5.76 and 4.55%; 0.62 and 0.40%; 4.90 and 5.09; and 0.74 and 0.84 g/cm^3, respectively in the two respective horizons (0-25cm and 25-50cm).

The first hypothesis of different carbon stocks at different altitudes was accepted whereas, the second hypothesis of different carbon stocks at south-east and south-west aspects was rejected.

Finally, it was found that temperate forest of Shivapuri is mature and it is sequestering more carbon compared to the different forests of Central Himalaya.

REFERENCES

Adhikaree, K. 2005. *Estimating Carbon Dynamics in a Nepalese Community Forest.* [M.Sc. Dissertation]. Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Adhikari, B.S., Rawat, Y.S. and Singh, S.P. 1995. Structure and function of high altitude forests of Central Himalaya I. dry matter dynamics. *Annals of Botany*, **75**:237–248.

Alexandrov, G. A. 2007. Carbon stock growth in a forest stand: the power of age. *Carbon Balance and Management*, **2:4**.

Amatya, D. 1993. *Study on Forest Vegetation Analysis.* Field Document No. 7, SIWDP HMG/FAO, Kathmandu, Nepal.

Baishya, R., Barik, S.K. and Upadhaya, K. 2009. Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in Northeast India. *Tropical Ecology,* **50**(2):295–304.

Bajracharya, R.M., Lal, R. and Kimble, J.M. 1998. Soil organic carbon distribution in aggregates and primary particle fractions as influenced by erosion phases and landscape position. In: Lal, R., Kimble, J.M., Follett, R.F. and Stewart, B.A. (Eds.) *Soil Processes and the Carbon Cycle.* CRC Press LLC, Boca Raton, FL, USA, pp353–367.

Baker, D.F. 2007. Reassessing carbon sinks. *Science,* **316:**1708–1709.

Baral, S.K., Malla, R. and Ranabhat, S. 2009. Above-ground carbon stock assessment in different forest types of Nepal. *Banko Janakari,* **19**(2):3–9.

Batjes, N.H. 1996. Total carbon and nitrogen in soils of the world. *European Journal of Soil Science,* **47**:151–163.

BPP 1995. *Biodiversity Profiles of the Midhills and High Mountains/High Himal Physiographic Zones,* Technical Publication Nos. 13-14. Department of National Parks and Wildlife Conservation, Kathmandu.

Brown, S. 1996. Mitigation potential of carbon dioxide emissions by management of forests in Asia. *Ambio,* **25**(4):273–278.

Brown, S. 1997. *Estimating Biomass and Biomass Change of Tropical Forests: A Primer*. FAO Forestry Paper 134, Rome, Food and Agriculture Organisation of the United Nations.

Brown, S. 2002. Measuring carbon in forests: current status and future challenges. *Environment Pollution*, **116**:363–372.

Cairns, M.A., Brown, S., Helmer, E.H. and Baumgardner, G.A. 1997. Root biomass allocation in the world' s upland forests. *Oecologia*, **111**(1):1–11.

Campbell, A., Miles, L., Lysenko, I., Hughes, A. and Gibbs, H. 2008. *Carbon Storage in Protected Areas-Technical Report*. UNEP World Conservation Monitoring Centre.

Cao, M.K. and Woodward, F.I. 1998. Net primary and ecosystem production and carbon stocks of terrestrial ecosystems and their responses to climate change. *Global Change Biology*, **4**:185–198.

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Leacure, J.-P., Nelson, B.W., Ogawa, H., Puig, H., Riera, B. and Yamakura, T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, **145**(1):87–99.

Chhabra, A., Palria, S and Dadhwal, V.K. 2002. Growing stock-based forest biomass estimate for India. *Biomass and Bioenergy*, **22**:187 – 194.

Chhabra, A., Palria, S and Dadhwal, V.K. 2003. Soil organic carbon pool in Indian forest. *Forest ecology and Management*, **173**:187–199.

Chomitz, K.M. 2000. *Evaluating Carbon Offsets from Forestry and Energy Projects: How do They Compare?* Working paper. World Bank, Development Research Group, Washington, DC.

Costanza, R., d'Arge, R., Groot, R., Faber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and Belt, M.V.D. 1997. The value of the world's ecosystem services and natural capital. *Nature*, **387**:253–260.

Cowie, A., Smith, P. and Johnson, D. 2006. Does Soil Carbon Loss in Biomass Production Systems Negate the Greenhouse Benefits of Bioenergy? *Mitigation and Adaptation Strategies for Global Change*, **11**:979–1002.

Dahal, P. 2007. *Carbon Sequestration Status at Sunaulo Ghyampe Danda Community Forest, Kathmandu.* [M.Sc. Dissertation]. Central Department of Environmental Science Tribhuvan University, Kirtipur, Kathmandu, Nepal.

Delaney, M., Brown, S., Lugo, A.E., Torres-Lezama, A. and Quintero, N.B. 1998. The quantity and turnover of dead wood in permanent forest plots in six life zones of Venezuela. *Biotropica*, **30**:2–11.

Dey, S.K. 2005. A preliminary estimation of carbon stock sequestrated through rubber (*Hevea brasiliensis*) plantation in north eastern regional of India. *Indian Forester*, **131**(11)**:**1429–1435.

DNPWC 2009. *Shivapuri Nagarjun National Park*. A brochure published by Department of National Parks and Wildlife, Babarmahal, Kathmandu.

DNPWC 2010. *Nepalka Samrakshit Chetraharu*. A booklet published by Department of National Parks and Wildlife Conservation (in Nepali), Babarmahal, Kathmandu.

Erbrecht, T. and Lucht, W. 2006. Impact of large scale climatic disturbances on the terrestrial carbon cycle. *Carbon Balance and Management,* **1:7.**

Eswaran, H., Reich, P.F., Kimble, J.M., Beinroth, F.H., Padmanabhan, E. and Moncharoen, P. 1999. Global carbon stocks. In: Lal, R., Kimble, J.M., Eswaran, H. and Stewart, B.A. (Eds.) *Global Climate Change and Pedogenic Carbonates.* Lewis Publishers, Florida, USA, pp15–25.

FAO 2005. *Global Forest Resource Assessment: Progress Towards Sustainable Forest Management.* FAO Forestry Paper 147. FAO, Rome.

Garkoti, S.C. 2008. Estimates of biomass and primary productivity in a high-altitude maple forest of the West Central Himalayas. *Ecological Research*, **23**:41–49.

Glaser, B, Turrion, M.B., Solomon, D., Ni, A. and Zech, D. 2000. Soil organic matter quantity and quality in mountain soils of the Alay Range, Kyrgyzia, affected by land use change. *Biology and Fertility of Soils*, **31**:407–413.

Gnanavelrajah, N., Shrestha, R.P., Schmidt-Vogt, D. and Samarakoon, L. 2008. Carbon stock assessment and soil carbon management in agricultural land-uses in Thailand. *Land Degradation & Development*, **19**: 242–256.

Goodale, C.L., Apps, M.J., Birdsey, R.A., Field, C.B., Heath, L.S., Houghton, R.A., Jenkins, J.C., Kohlmaier, G.H., Kurz, W., Liu, S.R., Nabuurs, G.J., Nilsson, S. and Shvidenko, A.Z. 2002. Forest carbon sinks in the northern hemisphere. *Ecological Applications*, **12:**891–899.

Grace, J., Lloyd, J., Mcintyre, J., Miranda, A.C. 1995. Carbon dioxide uptake by an undisturbed tropical rain forest in Southwest Amazonia, 1992 to 1993. *Science*, **270**:778–780.

Guo, Z., Fang, J., Pan, Y. and Birdsey, R. 2010. Inventory-based estimates of forest biomass carbon stocks in China: a comparison of three methods. *Forest Ecology and Management*, **259**:1225–1231.

Gupta, P.K. 2000. *Methods in Environmental Analysis: Water Soil and Air*. Agrobios, India.

Haripriya, G.S. 2000. Estimates of biomass in Indian forests. *Biomass and Bioenergy*, **19**:245–258.

Haripriya, G.S. 2002. Biomass carbon of truncated diameter classes in Indian forests. *Forest Ecology and Management*, **168**:1–13.

Hill, M.J., Roxburgh, S.H., McKeon, G.M., Carter, J.O. and Barrett, D.J. 2006. Analysis of soil carbon outcomes from interaction between climate and grazing pressure in Australian rangelands using Range-ASSESS. *Environmental Modelling and Software*, **21**: 779–801.

HMGN 1995. *Shivapuri Management Plan Part I: A Policy Framework for Participatory Management of Natural Resources, Protection and Development of the Shivapuri Area*. Shivapuri Integrated Watershed Development Project (GCP/NEP/048/NOR), HMGN/FAO, Kathmandu, Nepal

HMGN/MPFS/FRISDP 1988. *Master Plan for the Forestry Sector Nepal: Forest Resources Information Status and Development Plan*. HMFN/ADB/FINNIDA, Kathmandu.

Houghton, R.A. 2005. Aboveground forest biomass and the global carbon balance. *Global Change Biology*, **11**:945–958.

IPCC 2000. *Land Use, Land-Use Change and Forestry*. Cambridge University Press, New York.

IPCC 2001. *Climate Change 2001: The Scientific Basis.* Intergovernment panel on climate change, Cambridge University Press, Cambridge,UK.

IPCC 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jackson, J.K. 1987. *Manual of Afforestation in Nepal.* Nepal-United Kingdom Forestry Research Project, Forest Survey and Research Office, Department of Forests, Kathmandu, Nepal.

Jastrow, J.D., Michael Miller, R., Matamala, R., Norby, R.J., Boutton, T.W., Rice, C.W. and Owensby, C.E. 2005. Elevated atmospheric carbon dioxide increases soil carbon. *Global Change Biology,* **11**: 2057–2064.

Jha, M.N., Gupta, M.K., Saxena, A. and Kumar, R. 2003. Soil organic carbon store in different forests in India. *Indian Forester,* **129**(6)**:**714–724.

Jina, B.S., Sah, P., Bhatt, M.D. and Rawat, Y.S. 2008. Estimating carbon sequestration rates and total carbon stockpile in degraded and non-degraded sites of oak and pine forest of Kumaun Central Himalayan. *Ecoprint,* **15**:75–81.

Jobbagy, E.G. and Jackson, R.B. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, **10**:423–436.

Joshi, D.P. 1999. Status and biomass of Churia range forest in Ilam district, Nepal. In: *Proceedings of III National Conference on Science and Technology* (March 8-11, 1999). Royal Nepal Academy of Science and Technology, Kathmandu. pp1187–1193.

Karky, B.S. and Skutsch, M. 2010. The cost of carbon abatement through community forest management in Nepal Himalaya. *Ecological Economics,* **69**:666–672.

Kattel, B. 1993. Assessment of wildlife diversity and crop depradation in Shivapuri watershed and wild life reserve. FAO/HMG, SIWDP, Kathmandu, Nepal.

Kaul, M., Mohren, G. M. J. and Dadhwal, V. K. 2010. Carbon storage and sequestration potential of selected tree species in India. *Mitigation and Adaptation Strategies for Global Change,* **15**:489–510.

Keeling, H.C. and Phillips, O.L. 2007. The global relationship between forest productivity and biomass. *Global Ecology and Biogeography*, **16**:618–631.

Khanal, A. 2007. *Estimating the Potential of Community Carbon Forestry: A Case from Champadevi Community Forest.* **[**M.Sc. Dissertation]. Central Department of Environmental Science, Tribhuvan University, Kirtipur, Kathmandu, Nepal.

Kirby, K.R. and Potvin, C. 2007. Variation in carbon storage among tree species: implications for the management of a small-scale carbon sink project. *Forest Ecology and Management*, **246**:208–221.

Kirman, S., Strasberg, D., Grondin, V., Colin, F., Gilles, J. and Meunier, J.D. 2007. Biomass and litterfall in a native lowland rainforest: Marelongue Reserve, La Reunion Island, Indian Ocean. *Forest Ecology and Management,* **252**:257–266.

KMTNC 2004. *Shivapuri National Park: Management Plan.* King Mahendra Trust for Natural Conservation, Jawalakhel, Lalitpur, Nepal.

Korner, C. 2001. Experimental plant ecology: some lessons from global change research. In: Press, M.C., Huntly, N.J. and Levin, S. (Eds.) *Ecology: Achievement and Challenge*. Blackwell Science, Oxford, U.K. pp227–247.

Kraenzel, M.B., Moore, T., Castillo, A. and Potvin, C. 2003. Carbon storage of harvest-ageteak (*Tectona grandis*) plantations, Panama. *Forest Ecology and Management,* **173**:213–225.

Lal, R. 2002. Carbon sequestration in dryland ecosystems of West Asia and North Africa. *Land Degradation and Development,* **13**: 45–59.

Lal, R. 2004a. Soil carbon sequestration to mitigate climate change**.** *Geoderma,* **123:**1–22.

Lal, R. 2004b. Carbon sequestration in soils of Central Asia. *Land Degradation & Development*, **15**:563–572.

Lal, R. 2008. Carbon sequestration. *Philosophical Transactions of the Royal Society B,* **363**:815–830.

Laurance, W.F., Fearnside, P.M., Laurance, S.G., Delamonica, P., Lovejoy, T.E., Merona, J.M.R., Chambers, J.Q. and Gascon, C. 1999. Relationship between soils and Amazon forest biomass: a landscape-scale study. *Forest Ecology and Management,* **118**:127–138.

Lichter, J., Billings, S., Ziegler, S., Gaindh, D., Ryals, R., Finzi, A., Jackson, R.B., Stemmler, E.A. and Schlesinger, W.H. 2008. Soil carbon sequestration in a pine forest after 9 years of atmospheric CO_2 enrichment. *Global Change Biology*, **14**:1–13.

Lodhiyal, L.S. and Lodhiyal, N. 1997. Variation in biomass and net primary productivity in short rotation high density Central Himalayan poplar plantations. *Forest Ecology and Management,* **98**:167–179.

Lodhiyal, L.S., Singh, R.P. and Singh, S.P. 1995. Structure and function of an age series of poplar plantations in Central Himalaya: I dry matter dynamics. *Annals of Botany,* **76**:191–199.

Lodhiyal, N. and Lodhiyal, L.S. 2003. Biomass and net primary productivity of Bhabar shisham forests in Central Himalaya, India. *Forest Ecology and Management*, **176**:217–235.

Luo, T., Brown, S., Pan, Y., Shi, P., Ouyang, H., Yu, Z. and Zhu, H. 2005. Root biomass along subtropical to alpine gradients: global implication from Tibetan transect studies. *Forest Ecology and Management*, **206**:349–363.

Luo, T., Li, W. and Zhu, H. 2002. Estimated biomass and productivity of natural vegetation on the Tibetan plateau. *Ecological Applications*, **12**(4):980–997.

Macauley, M., Morris, D., Sedjo, R., Farley, K. and Sohngen, B. 2009. *Forest Measurement and Monitoring: Technical Capacity and "How Good Is Good Enough?"* REF report, Resources for the future.

MacDicken, K.G. 1997. *A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects.* Winrock International Institute for Agricultural Development.

Mani, S. and Parthasarathy, N. 2007. Above-ground biomass estimation in ten tropical dry evergreen forest sites of peninsular India. *Biomass and Bioenergy*, **31**:284–290.

Mao, R., Zeng, D.H., Hu, Y.L., Li, L.J. and Yang, D. 2010. Soil organic carbon and nitrogen stocks in an age-sequence of poplar stands planted on marginal agricultural land in northeast China. *Plant Soil*, (doi:10.1007/s11104-010-0292-7, accessed on 20th April 2010)

Martin, D., Lal, T., Sachdev, C.B. and Sharma, J.P. 2010. Soil organic carbon storage changes with climate change, landform and land use conditions in Garhwal hills of the Indian Himalayan mountains. *Agriculture, Ecosystems and Environment*, **138**:64–73.

Meentemeyer, V. and Berg, B. 1986. Regional variation in rate of mass loss of *Pinus sylvestris* needle litter in Swedish pine forest as influenced by climate and litter quality. *Scandinavian Journal of Forest Research*, **1:**167–180.

Mestdagh, I., Sleutel, S., Lootens P., Cleemput, O.V. and Carlier L. 2005. Soil organic carbon stocks in verges and urban areas of Flanders, Belgium. *Grass and Forage Science*, **60**:151–156.

Minnen, J.G., Strengers, B.J., Eickhout, B., Swart, R.J. and Leemans, R. 2008. Quantifying the effectiveness of climate change mitigation through forest plantations and carbon sequestration with an integrated land-use model. *Carbon Balance and Management*, **3:3.**

Mishra, N. 2010. *Estimation of Carbon Stock at Chapako Community Forest, Kathmandu.* [M.Sc. Dissertation]. Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal.

Myneni, R.B., Dong, J., Tucker, C.J., Kaufmann, R.K., Kauppi, P.E., Liski, J., Zhou, L., Alexeyev, V. and Hughes, M.K. 2001. A large carbon sink in the woody biomass of northern forests. *Proceedings of the National Academy of Sciences*, **98**:14784–14789.

Nascimento, H.E.M. and Laurance, W.F. 2002. Total aboveground biomass in Central Amazonian rainforests: A Landscape-scale Study. *Forest Ecology and Management*, **168:**311–321.

Navar, J. 2009. Allometric equations for tree species and carbon stocks for forests of Northwestern Mexico. *Forest Ecology and Management*, **257**:427–434.

Negi, K.S., Rawat, Y.S. and Singh, J.S. 1983. Estimation of biomass and nutrient storage in a Himalayan moist temperate forest. *Canadian Journal of Forest Research*, **13**:1185–1196.

Obersteiner, M., Rametsteiner, E. and Nilsson, S. 2001. *Cap Management for LULUCF Options*. IIASA Interim Report IR-01-011. International Institute for Applied Systems Analysis, Laxenburg, Austria.

Oelbermann, M. and Voroney, R.P. 2007. Carbon and nitrogen in a temperate agroforestry system: using stable isotopes as a tool to understand soil dynamics. *Ecological Engineering,* **29**: 342–349.

Oli, B.N. and Kandel, C.M. 2005. Biomass estimation of *Bambusa nutans* subspecies *cupulata* grown at eastern Terai, Nepal. *Banko Janakari,* **15**(2):34–37.

Oli, B.N. and Kandel, C.M. 2006. Biomass estimation of *Dendrocalamus hookeri* grown at far western Terai, Nepal. *Banko Janakari,* **16**(2):12–16.

Ostle, N.J., Levy, P.E., Evans C.D. and Smith, P. 2009. UK land use and soil carbon sequestration. *Land Use Policy,* **26S**:S274–S283.

Pacala, S. and Socolow, R. 2004. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science,* **305**:968–972.

Payton, I.J., Newell, C.L. and Beets, P.N. 2004. *New Zealand Carbon Monitoring System Indigenous Forest and Shrubland Data Collection Manual*. New Zealand, Climate Change Office, Ministry for the Environment, Wellington.

Phillips, O.L., Malhi, Y., Higuchi, N., Laurance, W.F., Nunez, P.V., Martinez, R.V., Laurance, S.G., Ferreira, L.V., Stern, M., Brown, S. and Grace, J. 1998. Changes in the carbon balance of tropical forests: evidence from long-term plots. *Science*, **282:**439–442.

Polunin, O. and Stainton, A. 1984. *Flowers of the Himalaya*. Oxford University Press, India.

Powell, I., White, A .and Landell-Mills, N. 2002. *Developing Markets for the Ecosystem Services of Forests*. Forest Trends, Washington D.C., USA.

Press, J.R., Shrestha K.K. and Sutton, D.A. 2000. *Annotated Checklist of Flowering Plants of Nepal*. The Natural History Museum, London.

Ramchandra, T.V. 2010. Mapping of fuelwood trees using geoinformatics. *Renewable and Sustainable Energy Reviews,* **14**:642–654.

Ranabhat, S., Awasthi, K.D. and Malla, R. 2008. Carbon sequestration potential of *Alnus nepalensis* in the Mid Hill of Nepal: A case study from Kaski district. *Banko Janakari*, **18**(2):3–9.

Schimel, D.S., House, J.I., Hibbard, K.A., Bousquet, P., Ciais, P., Peylin, P., Braswell, B.H., Apps, M.J., Baker, D., Bondeau, A., Canadell, J., Churkina, G., Cramer, W., Denning, A.S., Field, C.B., Friedlingstein, P., Goodale, C., Heimann, M., Houghton, R.A., Melillo, J.M., Moore, B., Murdiyarso, D., Noble, I., Pacala, S.W., Prentice, I.C., Raupach, M.R., Rayner, P.J., Scholes, R.J., Steffen, W.L. and Wirth, C. 2001. Recent patterns and mechanism of carbon exchange by terrestrial ecosystems. *Nature*, **414**:169–172.

Schulze, E. D. , Lloyd, J., Kelliher, F. M. , Wirth, C., Rebmann, C., Luhker, B., Mund, M., Knohl, A Milyukova, ., I. M., Schulze, W., Ziegler, W. , Varlagin, A. B. , Sogachev, A. F. , Valentini, R. , Dore, S., Grigoriev, S. , Kolle, O. , Panfyorov, M. I. , Tchebakova, N. and Vygodskaya, N. N. 1999. Productivity of forests in the Eurosiberian boreal region and their potential to act as a carbon sink: a synthesis. *Global Change Biology,* **5**(6):703–722.

Sevgi, O. and Tecimen, H.B. 2008. Changes in Austrian pine forest floor properties in relation with altitude in mountainous areas**.** *Journal of Forest Science,* **54:**306–313.

Sharma, R.K., Sankhayan, P.L. and Hofstad, O. 2008. Forest biomass density, utilization and production dynamics in a Western Himalayan watershed. *Journal of Forestry Research,* **19**(3):171–180.

Sheikh, M.A., Kumar, M. and Bussmann, R.W. 2009. Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. *Carbon Balance and Management*, **4:6.**

Shrestha, A.B., Wake, C.P., Mayewski, P.A. and Dibb, A.J.E. 1999. Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal from period 1971-94. *Journal of Climate*, **12**(9):2775–2786.

Shrestha, B.M. 2002. *Land Use Effect on Soil Carbon Sequestration and Greenhouse Gases Flux in a Mountainous Watershed of Nepal.* [M.Sc. Dissertation (Management of Natural Resources and Sustainable Agriculture)]. Noragic Agricultural University of Norway.

Shrestha, B.M. 2007. *Land Use and Land Use Changes Effects on Organic Carbon Pools, Soil Aggregate Associated Carbon and Soil Organic Matter Quality in a Watershed of Nepal.* [Ph.D. Dissertation]. Department of Plant and Environmental Sciences, Norwegian University of Life Sciences.

Shrestha, B.P. 2009. Carbon sequestration in *Schima-Castanopsis* forest: A Case Study from Palpa District. *The Greenery–a journal of Environment and Biodiversity*, **7**(1):34–40.

Shrestha, R., Karmacharya, S.B. and Jha, P.K. 2000. Vegetation Analysis of natural and degraded forests in Chitrepani in Siwalik region of Central Nepal. *Tropical Ecology*, **41**(1): 111–114.

Siluwal, H.R. 1999. *An Ecological Study of Quercus species in the Surrounding Hills of Kathmandu Valley, Nepal.* [M.Sc. Dissertation]. Central Department of Botany, Kirtipur, Kathmandu, Nepal.

Singh, S.P. 2007. *Himalayan Forest Ecosystem Services: Incorporating in National Accounting*. Central Himalayan Environment Association (CHEA), Nainital, Uttarakhand, India.

Six, J. and Jastrow, J.D. 2002. Organic matter turnover**.** In: Lal, R. (Ed.) *Encyclopedia of Soil Science*, Marcel Dekker, New York, pp936–942.

Smith, P. 2004. Carbon sequestration in croplands: the potential in Europe and the global context. *European Journal of Agronomy*, **20**(3):229–236

Smith, P. 2008. Land use change and soil organic carbon dynamics. *Nutrient Cycling in Agroecosystems*, (doi:10.1007/s10705-007-9138-y, accessed on 10th April 2010)

Springsteen, A., Loya, W., Liebig, M. and Hendrickson, J. 2010. Soil carbon and nitrogen across a chronosequence of woody plant expansion in North Dakota. *Plant Soil*, **328**:369–379.

Stainton, J.D.A. 1988. *Flowers of Himalaya*. Oxford University Press, India.

Streck, C. and Scholz S.M. 2006. The role of forests in global climate change: whence we come and where we go. *International Affairs*, **82**(5):861–879.

Subedi, M.N. and Shakya, P.R. 1988. Above-ground biomass and productivity studies of *Quercus semecarpifolia* Sm. forest at Phulchoki in Lalitpur district. In: *Proceedings of the First National Conference on Science and Technology*. Kathmandu: RONAST. pp381–385.

Sujakhu, N.M., Ranjitkar, S., Maharjan, D., Shakya, N., Suwal, A.L., Pandey, S. and Adhikari, M.K. 2009. The forest biomass estimation in the recently colonized forest at Kumroj community forest, Chitwan, Nepal: A preliminary study. *Bulletin of Department of Plant Resources*, **31**:64–69.

Svirejeva-Hopkins, A. and Schellnhuber, H.J. 2006. Modelling carbon dynamics from urban land conversion: fundamental model of city in relation to a local carbon cycle. *Carbon Balance and Management*, **1:8.**

Takimoto, A., Nair, P.K.R. and Nair, V.D. 2008. Carbon stock and sequestration potential of traditional and improved agroforestry systems in the West African Sahel. *Agriculture, Ecosystems and Environment*, **125**:159–166.

Tatsuhara, S. and Kurashige, H. 2001. Estimating foliage biomass in a natural deciduous broad-leaved forest area in a mountainous district. *Forest Ecology and Management*, **152**:141–148.

Thapa, H.B. and Gautam, S.K. 2005. Growth performance of *Tectona grandis* in the western Terai of Nepal. *Banko Janakari*, **15**(2):6–12.

Trumper, K., Bertzky, M., Dickson, B., van der Heijden, G., Jenkins, M. and Manning, P. 2009. *The Natural Fix? The Role of Ecosystems in Climate Mitigation*. A UNEP rapid response assessment. United Nations Environment Programme, UNEPWCMC, Cambridge, UK.

US Climate Change Science Program, 2007. *The North American Carbon Budget and Implications for the Global Carbon Cycle.* http://www.climatescience.gov/Library/sap/sap2-2/final-report/default.htm.

Winjum, J. K., Dixon, R. K. and Schroeder, P. E. 1993. Forest management and carbon storage: an analysis of 12 key forest nations. *Water, Air, and Soil Pollution*, **70**:239–257.

Yang, L., Pan, J., Shao, Y., Chen, J.M., Ju, W.M., Shi, X. and Yuan, S. 2007. Soil organic carbon decomposition and carbon pools intemperate and sub-tropical forests in China. *Journal of Environmental Management*, **85**:690–695.

Zahabu, E. 2008. *Sinks and Sources a Strategy to Involve Forest Communities in Tanzania in Global Climate Policy*. [Ph.D. Dissertation]. University of Twente, Netherlands.

Zeng, N. 2008. Carbon sequestration via wood burial. *Carbon Balance and Management,* **3:1.**

Zerihun, A., Montagu, K.D., Hoffmann, M.B. and Bray, S.G. 2006. Biomass in *Eucalyptus populnea* woodland communities of Northeast Australia along a rainfall gradient. *Ecosystems,* **9**:501–515.

Zhang, J., Ge, Y., Chang, J., Jiang, B., Jiang, H., Peng, C., Zhu, J., Yuan, W., Qi, L. and Yu, S. 2007. Carbon storage by ecological service forests in Zhejiang Province, subtropical China. *Forest Ecology and Management,* **245**:64–75.

Zheng, H., Ouyang, Z., Xu, W., Wang, X., Mial, H., Li, X. and Tian, Y. 2008. Variation of carbon storage by different reforestation types in the hilly red soil region of Southern China. *Forest Ecology and Management*, **255**:1113–1121.

Zhu, B., Wang, X. , Fang, J., Piao, S., Shen, H. , Zhao, S.and Peng, C. 2010. Altitudinal changes in carbon storage of temperate forests on Mt Changbai, Northeast China. *Journal of Plant Research*, (doi:10.1007/s10265-009-0301-1, accessed on 23th May 2010)

Zianis, D. 2008. Predicting mean aboveground forest biomass and its associated variance. *Forest Ecology and Management,* **256**:1400–1407.

Zobel, D.B., Jha, P.K., Behan, M.J. and Yadav, U.K.R. 1987. *A Practical Manual for Ecology*. Ratna Pustak Distributors, Kathmandu, Nepal.

ANNEXES

ANNEX I

GPS locations of the sampled quadrats with altitude, aspect and slope.

Quadrat No	Latitude	Longitude	Altitude (m)	Aspect		Slope
1	27º 48′ 41.88″	85º 23′ 08.46″	2711	225º	SW	29º
2	27º 48′ 40.38″	85º 23′ 09.24″	2701	220º	SW	28º
3	27º 48′ 43.08″	85º 23′ 02.28″	2708	215º	SW	30º
4	27º 48′ 43.86″	85º 22′ 59.04″	2694	196º	SW	32º
5	27º 48′ 44.82″	85º 23′ 12.3″	2683	140º	SE	26º
6	27º 48′ 44.94″	85º 23′ 10.32″	2709	128º	SE	26º
7	27º 48′ 46.32″	85º 23′ 12.3″	2666	122º	SE	28º
8	27º 48′ 43.62″	85º 23′ 08.4″	2662	122º	SE	46º
9	27º 48′ 46.56″	85º 23′ 30.48″	2548	235º	SW	34º
10	27º 48′ 40.56″	85º 22′ 47.28″	2534	234º	SW	28º
11	27º 48′ 28.74″	85º 23′ 25.26″	2484	229º	SW	30º
12	27º 48′ 29.76″	85º 23′ 24″	2524	227º	SW	24º
13	27º 48′ 40.5″	85º 22′ 45.48″	2516	200º	SE	27º
14	27º 48′ 22.92″	85º 23′ 21.48″	2513	152º	SE	22º
15	27º 48′ 35.1″	85º 23′ 25.86″	2509	152º	SE	25º
16	27º 48′ 27.84″	85º 23′ 24.12″	2513	126º	SE	20º
17	27º 47′ 35.88″	85º 23′ 10.62″	2310	248º	SW	26º
18	27º 47′ 49.5″	85º 23′ 06″	2310	240º	SW	24º
19	27º 47′ 42.54″	85º 23′ 09.78″	2335	239º	SW	20º
20	27º 47′ 45.3″	85º 23′ 09.12″	2304	234º	SW	24º
21	27º 48′ 20.88″	85º 22′ 10.26″	2306	150º	SE	33º
22	27º 48′ 24″	85º 22′ 13.14″	2321	134º	SE	35º
23	27º 48′ 17.34″	85º 22′ 04.5″	2300	120º	SE	27º
24	27º 48′ 14.94″	85º 21′ 58.98″	2287	120º	SE	35º
25	27º 47′ 20.52″	85º 23′ 01.62″	2079	238º	SW	29º
26	27º 47′ 24.36″	85º 22′ 58.5″	2098	230º	SW	30º
27	27º 47′ 23.82″	85º 22′ 59.76″	2088	230º	SW	29º
28	27º 47′ 18.96″	85º 22′ 59.64″	2082	210º	SW	34º
29	27º 48′ 08.64″	85º 22′ 07.92″	2105	156º	SE	37º
30	27º 48′ 04.02″	85º 21′ 58.14″	2096	144º	SE	27º
31	27º 48′ 03.66″	85º 22′ 03.18″	2103	140º	SE	26º
32	27º 48′ 04.56″	85º 22′ 06″	2096	124º	SE	38º

ANNEX II

Soil pH, SOC, N and bulk density in the sampled quadrats

Q. No.	pH			SOC (%)			N (%)			Bulk density(g/cm^3)		
	Horizon			Horizon			Horizon			Horizon		
	0-25	25-50	Mean	0-25	25-50	Mean	0-25	25-50	Mean	0-25	25-50	Mean
1	5.13	5.28	5.205	5.05	5.74	5.39	0.70	0.59	0.644	0.790	0.727	0.759
2	4.93	5.31	5.12	5.50	3.68	4.59	0.56	0.38	0.469	0.778	0.748	0.763
3	5.01	5.25	5.13	6.72	6.06	6.39	0.87	0.57	0.721	0.635	0.755	0.695
4	5.08	4.98	5.03	6.09	7.06	6.57	0.77	0.62	0.693	0.945	0.700	0.823
5	4.99	4.97	4.98	6.09	6.62	6.35	0.74	0.57	0.658	0.612	0.683	0.647
6	4.99	5.25	5.12	4.64	5.62	5.13	0.59	0.46	0.525	0.693	0.753	0.723
7	4.85	4.98	4.915	4.46	3.97	4.21	0.62	0.36	0.49	0.673	0.758	0.716
8	4.67	4.72	4.695	5.35	4.85	5.10	0.78	0.46	0.623	0.652	0.720	0.686
9	4.76	4.73	4.745	7.43	7.43	7.43	0.64	0.52	0.581	0.761	0.920	0.841
10	5.12	5.28	5.2	5.20	2.65	3.92	0.57	0.29	0.434	0.829	0.943	0.886
11	4.99	5.32	5.155	5.09	4.88	4.99	0.71	0.35	0.532	0.841	0.929	0.885
12	4.95	5.16	5.055	5.35	5.15	5.25	0.62	0.38	0.497	0.614	0.888	0.751
13	4.76	5.2	4.98	3.86	5.44	4.65	0.43	0.43	0.434	0.845	1.112	0.979
14	4.37	4.65	4.51	6.79	5.60	6.20	0.60	0.43	0.518	0.730	0.910	0.820
15	5	5.19	5.095	7.28	6.18	6.73	0.87	0.53	0.70	0.624	0.762	0.693
16	4.45	4.69	4.57	8.61	5.79	7.20	1.11	0.66	0.882	0.734	0.915	0.825
17	4.95	5.08	5.015	7.97	4.15	6.05	0.92	0.39	0.658	0.701	0.756	0.729
18	4.77	4.72	4.745	9.06	6.68	7.87	0.95	0.62	0.784	0.690	0.750	0.720
19	4.77	5.08	4.925	7.72	5.00	6.36	0.90	0.53	0.714	0.617	0.705	0.661
20	4.7	5.01	4.855	4.31	4.41	4.36	0.62	0.35	0.483	0.775	0.781	0.778
21	4.52	4.75	4.635	5.86	5.38	5.62	0.43	0.32	0.378	0.735	0.850	0.793
22	5.31	5.24	5.275	3.71	3.53	3.62	0.52	0.27	0.392	0.759	0.924	0.842
23	5.32	5.41	5.365	4.56	2.04	3.30	0.45	0.25	0.35	0.720	0.769	0.744
24	5.38	5.62	5.5	4.42	2.19	3.30	0.22	0.14	0.182	0.738	0.855	0.797
25	5.06	5.21	5.135	4.75	1.49	3.12	0.35	0.15	0.252	0.821	0.825	0.823
26	4.55	4.91	4.73	5.20	2.97	4.08	0.46	0.27	0.364	0.730	0.835	0.783
27	4.22	4.91	4.565	7.68	3.38	5.53	0.66	0.31	0.483	0.691	0.867	0.779
28	5.11	5.3	5.205	6.98	3.27	5.12	0.53	0.28	0.406	0.738	0.826	0.782
29	5.07	5.2	5.135	4.16	3.86	4.01	0.34	0.31	0.322	0.825	1.029	0.927
30	4.77	4.85	4.81	5.01	4.56	4.79	0.42	0.31	0.364	0.813	1.024	0.918
31	4.84	5.11	4.975	4.60	2.67	3.64	0.39	0.22	0.308	0.856	0.986	0.921
32	5.25	5.43	5.34	4.94	3.31	4.12	0.41	0.38	0.392	0.808	0.979	0.894

ANNEX III

Soil attributes, biomass and carbon stocks in sampled quadrats.

Q. No	Tree BA (m^2/ha)	pH	SOC (%)	N (%)	Bulk Density (g/cm^3)	t/ha				
						AGB	Biomass	Biomass C stock	Soil C stock	Total C stock
1	63.54	5.21	5.39	0.644	0.759	703.86	884.39	442.19	203.97	646.16
2	33.38	5.12	4.59	0.469	0.763	290.96	364.13	182.07	175.63	357.70
3	107.05	5.13	6.39	0.721	0.695	1350.43	1701.53	850.77	221.08	1071.85
4	65.25	5.03	6.57	0.693	0.823	598.02	756.08	378.04	267.38	645.43
5	64.49	4.98	6.35	0.658	0.647	854.31	1073.64	536.82	206.08	742.90
6	93.90	5.12	5.13	0.525	0.723	849.63	1069.96	534.98	186.07	721.05
7	101.44	4.92	4.21	0.49	0.716	1175.54	1480.08	740.04	150.21	890.24
8	54.15	4.7	5.10	0.623	0.686	544.83	678.26	339.13	174.50	513.63
9	127.96	4.75	7.43	0.581	0.841	1514.90	1899.60	949.80	312.07	1261.87
10	54.19	5.2	3.92	0.434	0.886	391.87	493.76	246.88	170.13	417.013
11	88.68	5.16	4.99	0.532	0.885	948.24	1192.03	596.01	220.27	816.28
12	78.11	5.06	5.25	0.497	0.751	810.18	1020.83	510.41	196.20	706.62
13	52.07	4.98	4.65	0.434	0.979	389.02	490.17	245.08	232.84	477.92
14	124.22	4.51	6.20	0.518	0.820	1738.10	2190.01	1095.00	251.45	1346.45
15	120.43	5.1	6.73	0.7	0.693	1663.68	2094.58	1047.29	231.19	1278.47
16	111.72	4.57	7.20	0.882	0.825	1217.98	1534.13	767.06	290.56	1057.62
17	68.51	5.02	6.05	0.658	0.729	767.02	966.45	483.22	218.09	701.32
18	46.12	4.75	7.87	0.784	0.720	475.95	599.70	299.85	281.58	581.43
19	51.74	4.93	6.36	0.714	0.661	566.40	713.67	356.83	207.09	563.92
20	74.25	4.86	4.36	0.483	0.778	756.96	953.76	476.89	169.59	646.47
21	43.16	4.64	5.62	0.378	0.793	472.41	593.31	296.66	222.08	518.73
22	44.28	5.28	3.62	0.392	0.842	284.95	355.49	177.75	151.98	329.73
23	57.69	5.37	3.30	0.35	0.744	300.44	378.56	189.28	121.29	310.57
24	19.55	5.5	3.30	0.182	0.797	72.48	91.33	45.66	128.24	173.91
25	22.12	5.14	3.12	0.252	0.823	135.16	170.30	85.15	128.18	213.33
26	35.88	4.73	4.08	0.364	0.783	314.04	395.70	197.85	156.87	354.72
27	16.45	4.57	5.53	0.483	0.779	129.84	163.60	81.80	205.77	287.57
28	18.52	5.21	5.12	0.406	0.782	95.93	120.87	60.44	196.25	256.69
29	58.92	5.14	4.01	0.322	0.927	384.08	496.70	248.35	185.10	433.45
30	26.87	4.81	4.79	0.364	0.918	159.73	201.25	100.63	218.62	319.24
31	24.71	4.98	3.64	0.308	0.921	149.28	188.09	94.05	164.42	258.47
32	33.71	5.34	4.12	0.392	0.894	166.84	210.22	105.11	180.74	285.85

ANNEX IV

Mean (±S.D.) values of AGB, biomass, carbon stocks, soil attributes of total sampled quadrats, different aspects and different altitude zones.

	All quadrats studied	SE aspect	SW aspect	2100m	2300m	2500m	2700m
AGB (t/ha)	633.53 ± 473.51	651.46 ± 540.79	615.61 ± 412.58	191.86 ± 101.14	462.08 ± 239.17	1084 ± 537.58	795.94 ± 343.00
Biomass (t/ha)	797.57 ± 595.77	820.36 ± 680.90	774.78 ± 518.47	243.34 ± 130.94	581.53 ± 301.72	1364.39 ± 676.13	1001.01 ± 433.20
Biomass C stock (C t/ha)	398.78 ± 297.88	410.18 ± 340.45	387.39 ± 259.23	121.67 ± 65.47	290.77 ± 150.86	682.19 ± 338.07	500.5 ± 216.60
Soil C stock (C t/ha)	200.80 ± 46.52	193.46 ± 46.13	208.13 ± 47.21	179.49 ± 29.05	187.49 ± 54.57	238.09 ± 46.55	198.12 ± 35.71
Total C stock (C t/ha)	599.58 ± 325.77	603.64 ± 368.36	595.52 ± 289.15	301.16 ± 68.28	478.26 ± 185.35	920.28 ± 368.57	698.62 ± 218.61
pH	4.99 ± 0.25	4.99 ± 0.30	4.99 ± 0.20	4.99 ± 0.27	5.04 ± 0.31	4.91 ± 0.27	5.02 ± 0.16
SOC (%)	5.16 ± 1.28	4.87 ± 1.25	5.44 ± 1.29	4.30 ± 0.80	5.06 ± 1.68	5.79 ± 1.28	5.47 ± 0.88
N (%)	0.51 ± 0.17	0.47 ± 0.18	0.54 ± 0.15	0.36 ± 0.07	0.49 ± 0.21	0.57 ± 0.15	0.60 ± 0.10
Bulk Density (g/cm^3)	0.793 ± 0.084	0.808 ± 0.100	0.778 ± 0.063	0.853 ± 0.068	0.758 ± 0.056	0.835 ± 0.087	0.726 ± 0.054

ANNEX V

Forest types, representative species and wood density

SN	Forest type	Representative species	Relative weight	Density (kg/m^3)	Wt. Avg. Density
1	Sal forest	*Shorea robusta*	0.90	880	878
		Terminalia tomemtosa	0.02	950	
		Adina cordifolia	0.01	670	
		Anogeissus latifolia	0.02	900	
		Lagerstroemia parviflora	0.05	850	
2	Khair-Sissoo forest	*Acacia catechu*	0.50	960	870
		Dalbergia sissoo	0.50	780	
3	Oak forest	*Quercus floribunda*	0.10	970	897
		Q. lamellosa	0.10	940	
		Q. leucotrichoflora	0.10	1020	
		Q. lanata	0.10	880	
		Q. semecarpifolia	0.60	860	
4	Birch forest	*Betula utilis*	1.00	700	700
5	Terai/Lower slopes mixed hardwood forest	*Schima wallichii*	0.45	690	720
		Castanopsis sp.	0.35	740	
		Myrica esculanta	0.05	750	
		Daphniphyllum himalense	0.05	640	
		Eugenia/ Syzygium sp.	0.05	770	
		Diospyros spp.	0.02	840	
		Shorea robusta	0.03	880	
6	Upper slopes mixed hardwood forest	*Alnus nepalensis*	0.20	390	594
		Schima wallichii	0.20	690	
		Acer sp.	0.20	640	
		Litsea sp.	0.20	610	
		Rhododendron arboreum	0.20	640	
7	Chir pine forest	*Pinus roxburghii*	1.00	650	650
8	Blue pine forest	*Pinus wallichiana*	1.00	480	480
9	Fir forest	*Abies pindrow*	0.50	480	480
		A. spectabilis	0.50	480	
10	Mixed and other Conifer forest	*Cedrus deodara*	0.15	560	506
		Cupressus torulosa	0.15	600	
		Larix griffithiana	0.15	510	
		Juniperus indica	0.15	500	
		Tsuga dumosa	0.40	450	
11	Chir pine- Sal forest	*Pinus roxburghii*	0.45	650	758
		Shorea robusta	0.45	880	
		Schima wallichii	1.10	690	
12	Birch-Fir Forest	*Betula utilis*	0.45	700	600
		Abies spectabilis	0.45	480	
		Schima wallichi	0.10	690	
13	Other Mixed Hardwood-Conifer Forest	*Abies* sp.	0.20	480	563
		Betula utilis	0.10	700	
		Castanopsis sp.	0.10	740	
		Q. semecarpifolia	0.10	860	
		Tsuga dumosa	0.40	450	

Source: HMGN/MPFS/FRISDP 1988

ANNEX VI

Tree species encountered within quadrat sampled with known wood density.

S.N.	Plant species	Wood density(g cm^{-3})
1	*Castanopsis indica* (Roxb.) Miq.	0.7
2	*C. tribuloides* (Sm.) A. DC.	0.6
3	*Cinnamomum* sp.	0.74
4	*Eurya acuminata* DC.	0.7
5	*Litsea* sp.	0.61
6	*Myrica esculenta* Buch-Ham. ex D. Don	0.75
7	*Quercus glauca* Thunb.	0.93
8	*Q. lamellosa*	0.94
9	*Q. lanata* Sm.	0.88
10	*Q. semecarpifolia* Sm.	0.86
11	*Rhododendron arboreum* Sm.	0.64
12	*Taxus wallichiana* Zucc.	0.7

Source: HMGN/MPFS/FRISDP 1988 and Jackson 1987

PHOTO PLATE


Photo 1: Soil sampling by core soil sampler.


Photo 2: Core soil sampler with sampled soil.


Photo 3: Measurement taking in sampling site.


Photo 4: Vegetation on sampling site.