LAND USE CHANGE EFFECT ON SOIL ORGANIC CARBON STOCK IN BALKHU KHOLA WATERSHED, SOUTHWESTERN PART OF KATHMANDU VALLEY, CENTRAL NEPAL

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Abstract

Soils of the world are potentially viable sinks for atmospheric carbon and may significantly contribute to mitigate the global climate change. Soil organic carbon (SOC) content exhibits considerable variability spatially both horizontally according to land use and vertically within the soil profile. Land use and management are among the most important determinants of SOC stock. Present study was focused on implication of land use changes for SOC sinking as its major objective was land use change effect on SOC stock. Land use change was analyzed using GIS tool and soil samples were collected by stratified random sampling technique within the Balkhu Khola watershed. Natural ecosystems were degraded notably within first analysis period (1978-1994) and in later 11 years (1994-2005) positive sign of natural ecosystem conservation was seen as Bushland were transfermed to forested land. Land use and soil depth both affect significantly on SOC stock. It was found that forest soil was good potential for sinking SOC having capacity of 8.12kgC/m^2. Upland cultivation (Bari) has sunk 6.12kgC/m^2 and lowland cultivation (Khet) has sunk 4.93kgC/m^2. The forest soil of 0-13 cm depth has contributed almost 50.6% of total SOC stock; Khet sunk 44.2% while Bari contributed only 31 % of total SOC. The estimated amount of SOC in Balkhu Khola watershed was found to be 257.71 MTC among which forest contain 107.61 MTC (41.76%) and cultivation 146.68 MTC (56.92%). Land use and soil depth also has significant effect on bulk density (BD) of soil. BD was found less in forest soil compared to Bari and Khet in all depth which showed negative correlation with SOC. Conversion of forest to cultivation and other land uses has resulted loss of SOC while reverse phenomenon enhanced the SOC stock. The Balkhu Khola watershed has gained net SOC by 10.36 MTC during 27 years period because of promotion of regrowth of forested land.

***Keywords:* Sink, Soil Organic Carbon, Land use Change, Bulk Density and Conversion.**

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ACRONYMS AND ABBREVIATIONS

BD	:	Bulk Density
C	:	Carbon
CDM	:	Clean Development Mechanism
CO_2	:	Carbon dioxide
COP	:	Conference of the Parties
DNA	:	Designated National Authority
FYM	:	Farm Yard Manure
G g	:	Giga Gram
GHG	:	Greenhouse Gas
GIS	:	Geographic Information System
GPS	:	Geographic Positioning System
G t	:	Giga Ton
HKH	:	Hindu Kush Himalaya
HMG/N	:	His Majesty of Government of Nepal
ICIMOD	:	International Center for Integrated Mountain Development
IPCC	:	International Panel for Climate Change
KMC	:	Kathmandu Metropolitan City
KVMP	:	Kathmandu Valley Mapping Program
LRMP	:	Land Resource Mapping Project
LUCF	:	Land Use Change and Forestry
LULUCF	:	Land Use, Land Use Change and Forestry
MOPE	:	Ministry of Population and Environment
MTC	:	Metric Ton of Carbon
NBS	:	Nepal Biodiversity Strategy
NIR	:	National Inventory Report
OC	:	Organic Carbon
OM	:	Organic Matter
P g	:	Peta Gram
PPM	:	Parts Per Million
SIC	:	Soil Inorganic Carbon
SOC	:	Soil Organic Carbon
SOM	:	Soil Organic Matter
UNEP	:	United Nations Environment Program
UNFCCC	:	United Nations Framework Convention on Climate Change
VDC	:	Village Development Committee

CHAPTER ONE

1. INTRODUCTION

1.1 Background

1.1.1. Land Use and Land Use Change Phenomenon

Marrian, Clawson and Steward (1965) defined the term land use specifically to man's activities on land which are directly related to the land. According to *Best (1981)* land use deals essentially on land and in the way in which the land surface is adopted or could be adopted to some human needs. *Vink (1983)* defined land use as the expression in order to produce some of his needs. In his study he viewed that man is not only the seeker of his benefit from the nature guided or enforced by his greed, but also he feels responsibility to protect and conserve the natural ecosystem through natural reserves for his sustained benefit. *Basnet (1995)* defined land use as development of land for any use. Competition for limited areas of land requires the establishment of priorities among claims, which is the object of land use planning.

The common view from the above mentioned definition is that land use is the result of human's activity on natural landscape. Even though the most important aspect of land use lies in relation to man and his livelihood, man has always played an important role in modifying the land use patterns. The study of land use should not only aim at describing the human impact of landscape where satisfaction of his needs from land resource are concerned but also elucidate the management of the land resources by which man tries to optimize the utilization, avoids the resource depletion from being overuse, misuse and abuse.

Land use is the expression of human management of ecosystem in order to produce some of his basic needs. "Land is used differently in different places or geographical regions according to the necessity of local people. In rural area, land is used for agriculture, pasture, settlement, forestlands etc where as in urban area it is mainly used for residential, industrial and business purposes" *(Kumar, 1986).*

The concept of land use pattern includes farming system; patterns of land cover technique of land practices and management of land. Basically changing pattern of

land use is an initial process for the understanding of its pattern, categories, sub division and the level of management. Generally two types of technique are known as key factors for the land use and its appropriate utilization, land practices of people, which relates with productivity, is one technique. It is actually the result of interrelationship between input utilization and the nature of land resources. Another technique is social phenomenon which is related with written systems, legal rights, inheritance and land tenure systems *(Vink, 1983)*. Land use refers to the management regime humans impose on a site (e.g., plantations or agro forestry), whereas land cover is a descriptor of the status of the vegetation at a site (e.g., forest or crop) *(Virginia, 1997)*.

Land use pattern are determined basically by ecological condition, altitude geological structure and slope. Apart from the above sectors technological and institutional factors are also expected to affect the land use change *(Akhouri, Rai and Sharma, 1994)*.

Land use pattern is a dynamic phenomenon because it changes with times as well as geographical unit. Generally the time and geographical unit is dominated by physical and infrastructural environment. In recent years the land use pattern has also been changed due to the government policy and technological development *(Chouhan, 1996)*. The major drivers of Land use changes are human population, affluence, technology, political economics, political structure, attitudes, and values *(Turner et al. 1993 cited by Virginia, 1997)*. The importance of these factors varies with the situation and the spatial scale of analysis. Human population growth can be considered an ultimate cause for most Land use changes; however, local demographics as well as consumption per capita and its variability can modify the effects of population. Economic incentives set by government policies are key cause of deforestation. Typical land-cover changes include forest harvesting, agricultural expansion, slash-and-burn agriculture, urbanization, and flooding (e.g., for rice cultivation). A number of common themes relate the drivers to particular land-cover patterns. For example, local population increase leads to urbanization and a decline in the natural land-cover types of the region. Elucidating these themes and exceptions to them would help us understand better the causes of specific Land use patterns.

There has been a general belief that forests and pasture/grazing lands in Nepal, a typical region in Hindu Kush Himalaya (HKH) had been more abundant relative to

the population size until the early 1950s *(DOF, 1976 cited by Upadhyay et. al., 2005).* Consequently, 'frontier' policy was adopted by the government during that time encouraging people to convert forestlands into agricultural lands with the objective of raising revenue through taxation on the converted lands. This policy aggravated forest degradation, necessitating rethinking on the part of government as reflected through comprehensive plans for the sustainable use of forestry *(HMG/ADB/ FINIDA, 1988).*

In Nepal out of the total area of 147181 Sq. Km 86% of land is occupied by hill and mountains *(NBS, 2002).* Naturally altitudinal variation and steepness of the slope determine the changing pattern of land use. But the speed and degree of changing land use pattern differ from place to place and from time to time *(Shrestha, 1975).* Land is divided into the following usage in Nepal: forest land (29%), shrub land (10.6%), grassland (11.8%), cultivated land (20.2%), and others (28.4 %). Due to high population pressure, these areas are subjected to drastic change *(Sharma 2000).* According to recent data by *UNEP (2001),* total land area of 14.7 x10^6 ha of Nepal is distributed among different land uses, of which cultivated land, non-cultivated land, forests, shrub land/degraded forests, grassland and other categories account for 20.2. 6.8, 29, 10.6, 11.8 and 21.6%, respectively. The decline in forest area from 37% during 1985–1986 to 29% in 1994 is reflected in increased shrub area from 5 to 10.6% during this period, indicating that forest is being degraded and gradually converted into shrub land over time. The problem of deforestation was more pronounced in the Siwalik (areas of low, hogback ridges with valleys and outwash plains adjacent to Terai region) and Terai (Southern plain) regions of Nepal as shown by the fact that forest and shrub lands in these regions were reduced by -1.1 and -1.8% per annum during the 1964–1978 period *(HMG/ADB/ FINIDA, 1988).*

Land use change has great significance on environment. According to *Rai and Sharma (1995)* land use changes are responsible for degradation of the environment and natural resource base. The impacts of land use changes are loss in soil productivity, accelerated soil erosion, climate change and more frequent natural calamities.

1.1. Soil as a Sink for Carbon.

Carbon is the building block of plant life and a major constituent of soil organic matter. Organic carbon is stored in the top layers of mineral soil as humus or above

the mineral soil as peat or litter. This organic material is by no means in equilibrium neither the carbon concentrations nor is the depth of the soil layers constant, although changes generally occur very slowly. Soil receive dead organic material i.e. litter mainly from the plant cover. This material is decomposed by the soil biota and partly mineralized and is subsequently released to the atmosphere in the form of carbon dioxide and methane or by leaching into groundwater.

Balance between input and output determines whether a soil is accumulating or losing carbon. Soil organic Carbon (SOC) consists of diverse compounds with different chemical and physical properties; for scientific purposes, SOC is divided into an active and a passive pool, the latter being more resilient to further degradation possibly existing in soil for hundreds to thousands of years. All factors that reduce biological activity and that stabilize SOC by physical protection or binding to clay silicates or metals will promote accumulation; factors that increase biological activity and destabilization encourage degradation.

The interplay of these factors is highly complicated. For example, in humid regions given an adequate supply of moisture global warming may increase microbial activity and accelerate SOC mobilization; in drier areas, the converse may apply. Changing patterns of land use can also have significant effects. Losses of SOC occur when natural ecosystems are cultivated because of degradation of soil fertility, intensified soil disturbance and reduced carbon input *(Environment Ministry, Helsinki, 2001, cited by E. D. schulze, Annette Freibauer, 2005).*

Perhaps the single most important factor or constituent of soil, which significantly impacts upon its biological, nutrient and structural status, is soil organic matter, or more specifically, the organic carbon component, SOC *(Tisdall & Oades 1982; Bajracharya et al. 1998).* On a global scale, soils play an important role in regulating the gaseous composition of the atmosphere and moderating greenhouse gases, thereby influencing global climate change. The carbon pool in world soils is estimated at about 1550 Gt (700-3000) for organic, and 780 to 1700 Gt for inorganic carbon, while terrestrial biomass carbon is estimated at 835 Gt, about half that in soils *(Lal 1994; Sombreck 1993).* Although it is well established that conventional cultivation practices generally tend to lead to a depletion of SOC, there is evidence to suggest that proper management and restoration of world's degraded soils offers significant

potential to sequester carbon and contribute to mitigation of global warming *(Lal 1994; Bajracharya 1998).*

1.1.3 Factors Effecting SOC Stock

A complex interaction of natural and human factors influences the SOC status, dynamics and carbon sequestration potential of soils. Organic carbon pool in soil is determined by different factors such as climate and elevation, soil types and geology, landscape position and aspect, land use and management, farming system and agricultural practices and erosion and deposition. But present study concern is only land use/ land cover change effect on soil organic carbon stock.

1.1.3.1. Land Use Effect on SOC Stock

Land use and management are among the most important determinants of SOC stock status, other factors being similar, as they govern the long-term patterns of vegetation, frequency of removal and the amount of organic matter (OM) returned to the soil system. Cultivation of annual crops generally has the effect of reducing inherent SOC amounts under natural vegetation due to extensive soil disturbance and manipulation, harvesting and removal of crop residues and periods of bare or fallow soil conditions. Retaining land under natural vegetation, particularly, climax forest communities; offer the best potential for enhancing SOC stock status. However, well-managed pastures may be equally suitable from the standpoint of carbon sequestration in soil due to the prolific nature and rapid turnover of root masses of improved pasture grasses and the associated soil organisms. Thus, changes in land use patterns clearly have major implications for carbon dynamics in the Middle Mountains, with deforestation and forest quality degradation having the worst impact in recent decades (*Shah and Schreir 1995, Schreier et. al. 1999* cited by *Bajracharya et. al. 2004).*

Terrestrial ecosystems contain large amounts of organic carbon, which is about three times the amount of carbon as found in the atmosphere *(Watson et al., 1990 cited by X. Chen, B. L. Li, 2003),* and they play a significant role in the uptake of carbon dioxide in overall budget *(Schimel et al., 1995; Fan et al., 1998, Houghton, 1999; Rayner et al., 1999 cited by X. Chen, B. L. Li, 2003).* The effects of land use change on soil carbon stocks are of concern in the context of international policy agreements on greenhouse gas emissions mitigation. For example, Kyoto Protocol stipulates that countries will be credited for planting new forests and docked for cutting down

existing ones; it also specifies that developed countries must account for changes in carbon stocks as a result of afforestation, reforestation and deforestation in meeting their green house gas emission mitigation targets *(IGBP, Terrestrial Carbon Working Group, 1998).* However how to manage current terrestrial ecosystems to conserve existing carbon stocks (especially the soil pool) is a new challenge. Human disturbance, such as for food or timber production, can cause a change in land use which, associates with carbon stocks. After human disturbance, the soil carbon level is disturbed before a new equilibrium reached in a new ecosystem.

Soil organic carbon (SOC) content exhibits considerable variability spatially, both horizontally according to land use and vertically within the soil profile. The SOC diminishes with depth regardless of vegetation, soil texture, and clay size fraction *(Trujilo et al., 1997).* Soils of the world are potentially viable sinks for atmospheric carbon (C) and may significantly contribute to mitigate the global climate change *(Lal et al., 1995; Bajracharya et al., 1998a; Lal et al., 1998; Singh and Lal, 2001).* However, the assessment of potential carbon sequestration in soil requires estimating carbon pools under existing land uses and its depth wise distribution in the soil profile. Minimizing soil disturbance generally leads to soil organic carbon accumulation, while high intensity/frequency of cultivation causes decline in SOC *(Bajracharya et al., 1998a).*

Soils are major players in the carbon cycle globally; they store the equivalent of about 300 times the amount of carbon now released annually through the burning of fossil fuels. It is generally assumed that most of the carbon locked up in soils is inert, and stays there. But *Bellamy et al., 2005 cited by Schulze 2005* had reported as soil carbon may be more vulnerable to changing climate and patterns of land use than expected.

The population growth and density of mountain and hilly region of Nepal is very high. The rapidly increasing population is moving towards the forestland and even to the marginal land in search of fulfilling their demands of food, fodder, fuel wood and timber etc. The activities of these people are disturbing the environmental balance. Estimating shifts of carbon due to land use change is a key process in determining impacts of disturbances on carbon storage in ecosystems. The carbon is stored in the living biomass of the trees and other vegetation by the process of photosynthesis. The carbon builds up in soils and the forest floor when dead and decaying biomass is detached from the parent plant. In general there is a favorable interplay between

carbon stock and various recommended land management practices: tillage, grazing, and forestry. Increase long-term sequestration of carbon in soils will benefit the environment and agriculture. Cropping, grazing and forestlands can be managed for both economic productivity and carbon stock.

1.2. Statement of the Problem

Balkhu Khola watershed lies within Kathmandu district. Its population is increasing at a higher rate. In 1981 and 1991 census the total population of Kathmandu district was 426281 and 675341, while in 2001 it was 1081845. The population growth rate of this district was +4.71 and population density was 2738/Sq. km (1981-2001) *(MoPE, 2004)*. Agricultural land at downstream is being rapidly converted into settlements within the study area while some positive signs can be seen at upstream where shrub lands are changing into forests. Local community are playing important role for such improvement by developing community forests. But these are regenerating slowly and are in pressure due to increase in population and settlements which demand more cultivated land at the cost of forestland. The high competition on limited resources has been rapidly changing the land use pattern. The landslide, soil erosion, flooding, human encroachment in the river valley etc are taking place frequently. Encroachment of agricultural land and replaced by urbanization and settlements are also arising as another set of problems. Therefore it is necessary to aware people as well as policy makers not to disturb natural ecosystem and expand settlements haphazardly which will increase carbon dioxide emission rate to the atmosphere from soil horizons. Present study explored the benefits of greenery to sink carbon in the soil layers answering the following questions.

- What is the changing scenario of land use pattern?
- What are the consequences of the land use change in the watershed especially on soil organic carbon stock?

1.3. Rationale of the Study

The growing evidence of climate change resulting from the continued increase of greenhouse gas concentrations in the atmosphere has made it a powerful political, social and trade issue.

In response to the problem of climate change, Kyoto protocol – protocol of regulating carbon emissions was adopted in December 1997 which focuses on commitments, including legally binding emissions targets and general commitments, implementation, including domestic steps and three novel implementation mechanism, minimizing impacts on developing countries, including use of an Adaptation Fund, accounting, reporting and review, including in-depth review of national reporting and compliance, including a Compliance Committee to assess and deal with problem cases *(UNFCCC, 2003).* The protocol has provisions of trading emissions so that countries sequestering carbon are eligible to charge its value to the CO_2 emitting countries through the Clean Development Mechanism (CDM). The CDM has twin goals of lowering the overall cost of reducing greenhouse gas (GHG) emissions released to the atmosphere, while also supporting sustainable development initiatives within developing countries.

Soil plays a strategic role in the global carbon balance. It is the biogeochemical interface between the atmosphere, biosphere and hydrosphere. It plays a key role in the global carbon balance because it supports all terrestrial ecosystems that cycle most of the atmospheric and terrestrial carbon. It contains more inorganic carbon than the atmosphere and more organic carbon than the biosphere. It is considered to be an active and significant component in global carbon emission and sequestration potential. Similarly, land use practices determine the sustainability of common resources. Natural ecosystems are converting to agriculture, settlements and other secondary ecosystems rapidly. Nowadays this is the most important issue whole over the world which also effect on carbon sinks and release to atmosphere.

In Nepal most of the research has focused on soil and water as the principle component of watershed management. The mis-utilization of these resources causes the watershed degradation. There is severing pressure on agriculture and forestland that need appropriate planning and management. The deforestation, overgrazing,

higher population pressure has caused landslide and mass movement phenomena in the area of weak geology, higher relief and maximum slope. Flooding is frequent in downstream. The linkages between appropriate research, demonstration, and extension and education are very weak. On the other hand conversion of forest and other natural lands to cultivation and settlements increase the carbon dioxide emission , depleting soil organic carbon that might have contribute local climate change phenomenon.

Balkhu Khola being one of the major tributaries of Bagmati River affects the volume of water and sediment load in Bagmati River System, which is destroying the fertile lands in Terai in every monsoon. Malpractices of land use enhance various types of disasters. Landslides, seasonal and annual soil erosion and deforestation in northern part of watershed are major problems at upstream while downstream part is affected by flooding. Peoples are developing community forest in Chandagiri range lying in this watershed. But there is no any research based on benefits of forest regrowth. Carbon issue is new for people living within the watershed. It is essential to develop a well-designed land use planning of the watershed which can address the scientific, technical and economic issues. For this effort detail study and adequate information are not available. It is in this ground the present study is based on.

1.4. Objective

The broad objective of this study is to identify the land use pattern and its effect on soil organic carbon stock.

The specific objectives are as follows.

- To study the existing land use practices
- To analyze land use change patterns in it
- To quantify the organic carbon content of soil in different land uses

1.5. Hypothesis

- Different land uses have different SOC stock
- Different land uses have different BD of soil

1.6. Limitation

- The research was conducted within a limited time interval from January 2005 to January 2006
- Soil microbial carbon estimation could not perform due to lack of well equipped laboratory
- Data consistency was not found while using secondary information, which has been affected during spatial analysis

CHAPTER TWO

2. LITERATURE REVIEW

Literatures relating to present study are reviewed under following headings.

2.1. Land Use and Land Use Change

Many literatures exist on land use change but relevant literatures pertaining to Nepal Himalaya relating to present study are reviewed.

Land use study is concerned with land utilization process in time series change. Land use survey of Great Britain, Michigan and land economic survey as well as land use survey of Tennessee Valley Authority (TVA) are pioneer studies of land use research.

In Nepal land use survey was started in 1950's. The Survey of India had conducted first topo mapping survey. It produced the topographical map at the scale 1:63,360. This survey for the first time provided the general land use inventory of the country. Later on 1978/79 Land Resource Mapping Project (LRMP) photographed at the scale 1:50,000. The land use map prepared by LRMP became the basis of study of land use change; with the reference to land use data provided by the Survey of India. Nowadays Survey Department of Nepal has the Aerial Photo based topographical map at scale 1:25,000.

Shrestha (1975) has studied the land use pattern of Nepal in 1964 and 1974 as well as its regional distribution. He has mentioned that there are two causes of land use change, natural factors (geological structure, relief, drainage, climate etc) and anthropogenic factors (population growth, migration and infrastructure development etc).

With regard to relationship between land use and ecological factors viz. altitude and slope gradient. *Shrestha (1976)* pointed out that the land use of the hilly area is more complex than plain areas. In the Himalayan Country, the changes of land use patterns are more striking features. Altitude and slope are the two major physical factors, which have directly controlled the land use pattern and other physical as well as social elements. He also argued that climate; vegetation, cropping pattern, land use practices

and population density has also varied with the changes in altitude and slope. Generally less steep slope and lower elevated areas have high land use changes whereas the steep slope and elevated areas have no such changes. So the land use planning and policy should be developed based on the altitude and slope which may help to set up a sound agricultural economy.

Bajracharya (1983) stated that during the 104 years (1845-1949) of Rana'a rule most of the commercial forests as well as cultivated land were converted into private property of the ruling families. Efforts to extend agricultural land had been shifted to terai from hill.

Manandhar (1987) has studied about land use/ land cover to asses his detail study of mass movement and landslide hazard in Kulekhani watershed. He has found that pastoral and agricultural lands are being increased from down slope to upslope. He identified two broad groups of natural and anthropogenic factors affecting the occurrence of landslide.

Gurung and Khanal (1988) have studied the landscape process in Chure Range of central Nepal. They found out that the forestland was being replaced by agricultural land even up to critical slope of the hills.

Shrestha (1988) studied about the resource use and its ecological implication of Tinau watershed area. He found that the northern part of watershed has been inclusively used due to the concentration of human and livestock population. Forestland has increasingly converted into agricultural land and without proper conservation; watershed management had resulted the loss of topsoil caused landslide.

A rapid transformation of land-use has led to environmental degradation and economic deterioration in the Himalaya, where majority of people are living just at or below the subsistence level *(Thapa & Weber 1990).*

Thapa and Weber (1990) studied in upper Pokhara Valley and found that the agricultural lands are expanding and the area under forest, shrub and grazing lands are shrinking gradually. The rate and extent of change were very high until 1978. Since 1978 it has declined sharply owing to lack of agriculturally suitable lands. Altogether 1634 ha of forest, shrub and grazing lands were changed into agricultural land over the past 31 years from 1957 to 1988. The largest stock of public resources was destroyed in the Kali Watershed followed by Mardi, Yamdi and Seti Watershed

between 1957 to 1988. The forest was converted into agriculture land into different ways. In some part initial forest was changed into shrub land owing to regular grazing, fodder collection and fuelwood gathering and then gradually converted to agriculture land.

Budhathoki (1991) studied on "Deforestation in Nepal causes and consequences". He found that the serious problem facing by country was deforestation. Despite an increase in agricultural land, overall crop productivity had been declining, loss of soil nutrients and declining in the supply of leaf litter and fodder were believed to be the cause of declining productivity in the country. This forced farmers to extend cultivated land at the cost of forests.

Shrestha and Brown (1995) stated population growth and rapid land use changes are affected for the sustainable use of biophysical resources. In hilly area the farming system are very intensive in arable land and a heavy dependence on livestock as well as forest. Study in Jhikhu Khola watershed by *Shrestha and Brown (1995)* shows there has been over all gain in agriculture, forest, plantation area but grazing and shrub land have been decreasing. Agriculture land has increased by 5.7 percent. The largest increase has been in plantation forest which increased by 6.7 percent and slight increment of 2.6 percent in forest land.

Shrestha (1997) pointed out that conversion of the forestland is significantly high. It means the forestland is decreased in 1996 than in the 1978/79. Major causes of decreasing of forest area in the Godhawari watershed are high population growth rate, high demand of forest product and scarcity of agricultural land.

Study on land use change in Lalitpur District indicates that agriculture land has decreased by 13.1 percent whereas forest has increased by 28 percent 1978 to 1994. Similarly built up area has been increased by 98.4 percent, bush/ shrub land has been decreased by 38 percent, grazing by 63.6 percent and waste land has been decreased by 67.7 percent. The main causes of such changes in land use are expansion of built up area, development of infrastructure, technological development *(Acharya, 1997).*

A study done at watershed level in the mid-hills of Nepal by *Balla et al. (2000)* using GIS technology found a significant reduction in forest areas during the period 1978–1999. The changes in agriculture, forest, shifting cultivation and shrub land areas were reported to be 17.3, -10.1, -4.5 and -2.8%, respectively of total area in Kali

Khola watershed. The corresponding figures for land-use change in Andheri-Khahare Khola watershed were 1.6, -18.5, 15.8 and 1.1%, respectively. Study conducted by *Awasthi et. al (2002)* in Fewa and Mardi watershed of western Nepal reported the annual change in different land uses as forest 0.16 and 0.24%, Pasture and shrub -0.22 and -0.54%, Agricultural land -0.051 and -0.265% respectively.

2.2. Carbon Dynamism

In the past two decades, C budget studies have become increasingly more important, particularly in the area of climate change, land use and sustainable forest management. The studies of carbon dynamism relevant to present study are reviewed under the heading of (1) Land use Effect on Global Carbon Cycle, (2) Land use Effect on Soil Organic Carbon Stock and (3) Land use Effect on Green House Gas (GHG) Emission and Climate Change.

2.2.1. Land Use Effect on Global Carbon Cycle

In nature, carbon cycles continuously among three main global reservoirs: the atmosphere, the terrestrial biosphere and the oceans. Carbon is also stored in carbonate form in rocks and sediments, but this carbon store cycles on a far longer time-scale if undisturbed. Natural carbon exchange between the atmosphere and the terrestrial biosphere total about 60 GtC (Giga ton carbon) annually (net primary productivity), while natural carbon exchanges between the atmosphere and the oceans total about 90 GtC. The oceans store by far the largest pool of carbon, about 38-40,000 GtC, predominantly in the form of dissolved inorganic carbon. The terrestrial biosphere stores the next largest pool, approximately 2,200GtC, in vegetation and surface soils to a depth at 100 cm *(Matthews et. al, 2000)*. The atmosphere stores a relatively small amount of carbon, about 760 GtC *(Schimel et. al., 1996 cited by Adhikaree 2005)*. In postglacial times, the carbon cycle is believed to have been in a state of dynamic equilibrium; despite the immense movements of carbon between atmosphere, oceans and the terrestrial biosphere, totals in each of the three reservoirs remained roughly constant over time *(Matthews et. al, 2000)*. Natural exchanges of carbon (C) between the atmosphere, the oceans and terrestrial ecosystems are currently modified by human activities. These changes are the result of fossil fuel burning in the northern hemisphere and the conversion of forests to agricultural land

in the tropics *(Paustian et al., 2000)*. Store of carbon in the atmosphere, measured as the atmospheric concentration of CO_2, has risen nearly 30 % over the past 200 years, from about 280 parts per million (ppm) to about 366 ppm. This increase is primarily as a result of land use change and combustion of fossil fuels *(Keeling and Whorf, 1999)*.

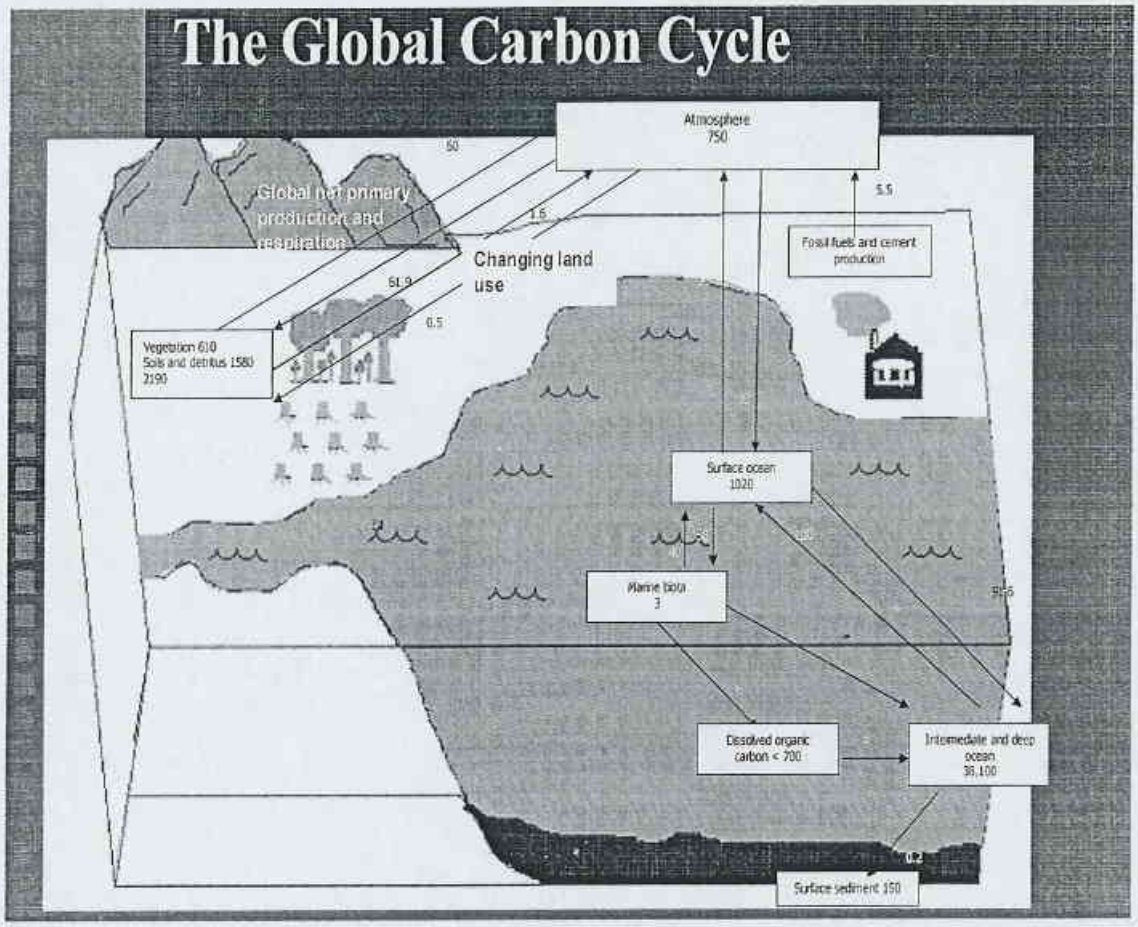


Fig 1: The Global Carbon Cycle (Puchin and Lasco, 2003)

The change of land use system especially from forestry to other land use system has major impacts on global carbon cycle. Such conversion can be expected to decrease carbon stored in above ground and below ground biomass and also in soil. Figure 1 shows the carbon mobilization and storing capacity of carbon of different reservoirs. All values shown in this figure are in Giga ton. Soil is the largest pool of terrestrial carbon in the biosphere, storing some 1500 Pg (1 Pg $=10^{15}$ g = 1 Gt) of carbon in the upper meter of mineral soils which is about 2.5 times more than is contained in terrestrial vegetation *(Houghton et al. 1985; Eswaran et al. 1993; Batjes 1996; Batjes & Sombroek 1997; Singh 2002)*. World soils constitute one of the five principal global carbon pools. The soil C pool comprises two components, the soil organic carbon

(SOC) pool with 1550 Pg of C in the top 1 m depth, and the soil inorganic carbon (SIC) pool containing 950 Pg C. The organic C pool in the soil affects plant production and thus plays a key role in soil fertility and agricultural production management more than a century *(Jenny 1941; Tiessen et al. 1994).*

Globally, it is estimated that changes in land use released 156 Pg C to the atmosphere over the period 1850–1990 *(Houghton, 2003 cited by Houghton and Goodale, 2004)*, about half as much as released from combustion of fossil fuels **(Figure 2)**.

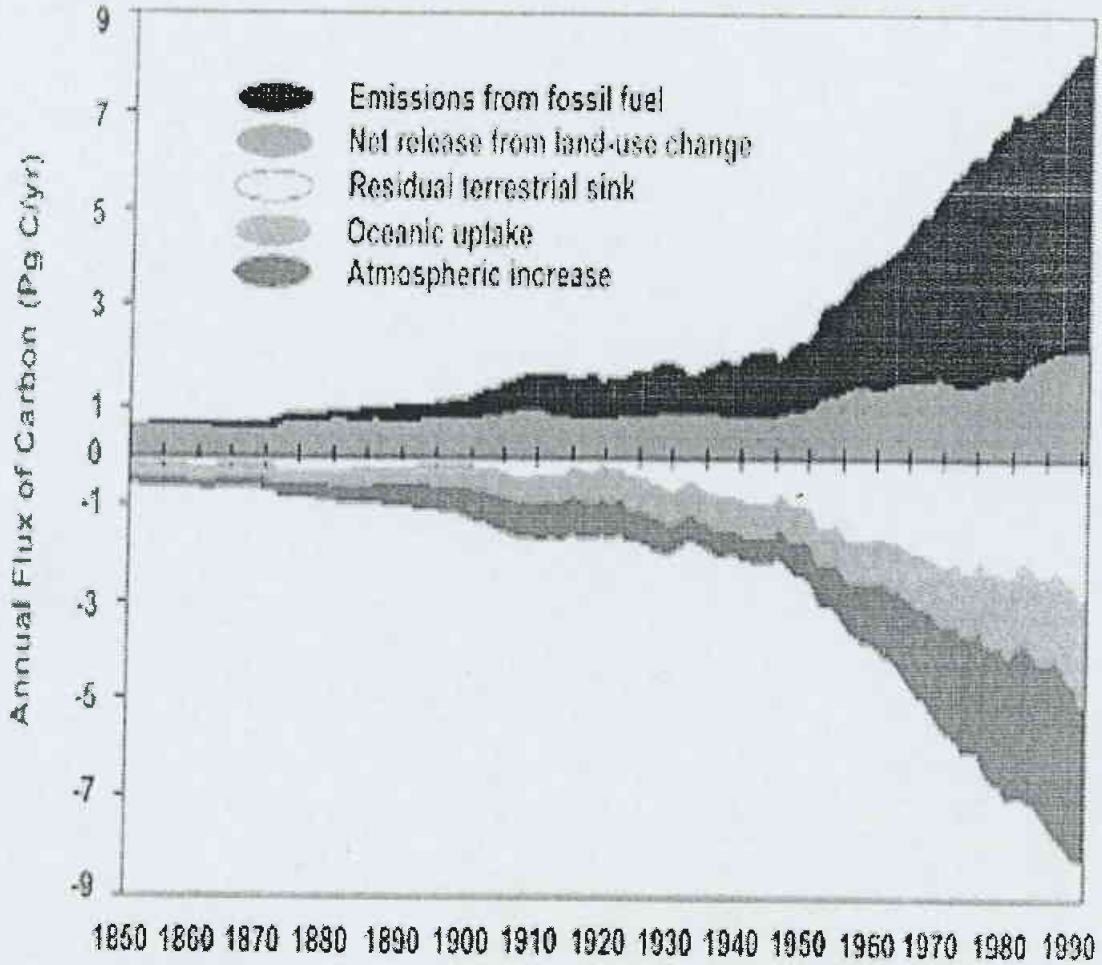


Fig 2: Annual emissions and accumulations of carbon in the major reservoirs of the global carbon cycle. The residual terrestrial flux is defined by the difference between total releases (fossil fuels and land-use change) and uptake (atmosphere and oceans).

Source: Houghton and Goodale, 2004.

Soils accounted for about a quarter of the long-term global release, although the fraction was higher in temperate-zone regions and lower in the tropics. During the 1990s the estimated annual flux averaged 2.2 Pg C yr^{-1}, almost entirely from the tropics. Outside the tropics, the average flux was a sink of 0.01 Pg C yr^{-1}. Errors for

the annual estimates are thought to be approximately +50% for tropical regions, where annual emissions are substantial. Outside the tropics, percentage errors are inappropriate because the fluxes are near zero. Deforestation dominates the tropical source of carbon. Outside the tropics, the losses of carbon from decay of wood products and slash (from logging) are largely offset by the accumulation of carbon in regrowing forests following harvest. This estimate of a release of carbon to the atmosphere from changes in land use (a source of 2.2 ± 0.8 Pg C yr^{-1} in the 1990s) is opposite in sign to the recent estimate obtained from inverse calculations based on atmospheric concentrations of O_2 and CO_2 (*Plattner et al.*, 2002). The difference (2.9 Pg C yr^{-1}) has been referred to as the "missing" carbon sink or the residual terrestrial sink (*Prentice et al.*, 2001 cited by *Houghton and Goodale, 2004*). The explanation for this residual sink is uncertain but was initially attributed to the effects of CO_2 fertilization, N deposition, climatic change, or forest regrowth (*Schimel et al.*, 1996 cited by *Houghton and Goodale, 2004)*. Recent analyses, however, have supported the importance of recovery processes (i.e., regrowth) in accounting for the sink *(Houghton and Goodale, 2004).*

2.2.2. Land Use Effect on Soil Organic Carbon Stock

Historically, between 32.5 and 34.7×10^6 km^2 have been converted from natural vegetation, approximately 10% of the total land surface *(DeFries et. al. cited by Canadell, 2002).* Since 1700 there has been a net loss of 11.4×10^6 km^2 of forests and woodlands to cropland, and 6.7×10^6 km^2 of savannas, grasslands, and steppes to cropland *(Ramankutty and Foley, 1999 cited by Canadell, 2002).* Recent deforestation estimates detected by satellite for the humid tropical regions show that (5.8 ±1.4) $\times 10^6$ ha have been deforested annually between 1990 and 1997, and additional (2.3 ±0.7) $\times 10^6$ ha of forest were annually degraded *(Achard et. al, 2002 cited by Canadell, 2002).* In this analysis, Southeast Asia had the highest deforestation rate followed by Latin America and Africa. However, given the large extension of tropical forest in Latin America, the annual loss of forest areas in Latin America and Southeast Asia were similar *(Canadell, 2002).*

Current land use change and the legacy of past practices (clearing followed by abandonment and regrowth) are now believed to contribute to a large extent to the current Northern Hemisphere terrestrial C sink of about 1.4 Pg C *(Schimel et. al, 2001).*

Natural sinks for CO_2 already play a significant role in determining the concentration of CO_2 in the atmosphere. They may be enhanced to take up carbon from the atmosphere. Examples of natural sinks that might be used for this purpose include forests and soils *(IPCC, 2000)*. Enhancing these sinks through agricultural and forestry practices could significantly improve their storage capacity but this may be limited by land use practice, and social or environmental factors. Carbon stored biologically already includes large quantities of emitted CO_2 but storage may not be permanent (*IPCC, 2005)*.

According to *Bajrachraya et al (1998b)* several global studies and models have been proposed to evaluate SOC storage and dynamics in an effort to provide better guidelines for soil management. Better knowledge of the soil management effects on distribution and forms of SOC in different soil aggregate size-fractions and at different depths within the soil profile could contribute to improved understanding and modeling of C dynamics and sequestration. The SOC in micro aggregates is believed to be protected from degradation and hence relevant for C sequestration.

Guo and Gifford (2002) revised research on soil carbon stocks and land use change and indicated that soil C stocks decline after land use changed from pasture to plantation, native forest to plantation, native forest to crop and pasture to crop; but soil C stocks increased if land use changed from native forest to pasture, crop to pasture, crop to plantation and crop to secondary forest.

X Chen and B. L. Li (2003) concluded in their study that wherever one of the land uses caused by human disturbances decreased soil carbon, the reverse process usually increased soil carbon. And also found that there was similar or slightly higher total soil C in shrubs with more soil C below the depth of 10 cm than the primary forest.

Bajracharya et. al (2004) have analyzed the existing data on SOC in Middle Mountains Region of Nepal and have concluded upland soils has the lowest SOC contents overall (Mostly between 1-2%), lowland areas were mainly in the range of 1.5-2.6 % SOC by weight. Shrub and forest soils had, on average, more SOC in the top 0-30 cm (2.0 and 2.3%, respectively) than cultivated soils. Land use and management significantly effects SOC status and dynamics. Forest soils tend to have low SOC pools and carbon stocks despite high surface SOC due to often shallow soil depths. Nonetheless, forest soils have good potential to sequester carbon because

more SOC is concentrated in micro-aggregates (<1mm) and thus, less readily decomposed. Shrub/grass land soils may also sequester carbon by allocation to substantial depths, i.e., 1 or more meters, where it is less accessible and hence more persistent. Modified agricultural practices, which minimize tillage and increase OM retention/additions, could lead to net carbon sequestration and sustainable production.

Sitaula et al. (2002) cited by *Bajracharya et. al (2004)* attempted to gather the available data on SOC status under various land uses in different watersheds of Nepal and to infer the total OC stocks and pools. Mean SOC contents in topsoil ranged from a low of 0.1% for severely degraded forests and grazing lands to a modest 4% under well managed forest. For agricultural soils the SOC contents fell mostly between 1 and 3% in topsoil. Median SOC pools in the upper 1 m soil profile was estimated to range from 2.6 kg C/m^2 for Arenosols, to a maximum of 17.8 kg C/m^2 for Humic Acrisols.

Shrestha et al. (2002) investigated SOC stocks and C sequestration in a mid-hill watershed in western Nepal and reported a significant influence of land use on SOC contents and distribution in various aggregate size classes. Among the cultivated land use types, upland soil had higher SOC, while natural forest had the highest overall OC stocks. A net loss of 29% of SOC stock in the upper 40 cm soil layer was calculated due to changes in land use over the period from 1978 to 1996.

2.2.3. Land Use Effect on Green House Gas (GHG) Emission and Climate Change

According to IPCC (2000) the major cause for the increase in carbon in the atmosphere (90% of the net release) is change in land use in the tropics. Agriculture through conversion of forests and grassland during the past 140 years, has led to a net release of about 121 GtC, of which about 60% has been emitted in the tropics and about 40% in middle and high latitudes.

Singh et al. (1991) concluded deforestation is still one of the most important sources of CO_2 emissions into the atmosphere. Deforestation accounts for substantial release of carbon, one third of which could be due to oxidation of soil carbon in tropics occasioned by changes in land-use pattern. Deforestation has occurred since the evolution of early settlements and the start of agriculture but over the last decades its rate has accelerated. The resulting net flux from such changes in land-use is difficult

to establish because most deforested plots are abandoned after a shorter or longer period of intensive use. This dynamics make the determination of carbon fluxes more complex because during forest re-growth carbon is sequestered again. Carbon dynamics also depend on the dynamics of abandonment, which are complex and depend on a multitude of socio-economic conditions and possibilities for land-use, including suitability for agriculture. The evaluation of carbon dynamics under such land-use change thus requires a detailed description of activities both in time and space. Historic and current land-cover and its land-use have to be portrayed and changes have to be adequately monitored.

The historical conversion of natural systems to agriculture and other human uses of the land have resulted in a net release of CO_2 to the atmosphere *(Houghton et al. 1985; Houghton et al. 1987; Houghton & Skole 1990).* The impact of human land-use on the global carbon cycle through changes in terrestrial vegetation, is a major research concern in understanding the control of global carbon cycle, and therefore, future climatic changes by land and ocean *(Houghton et al. 1983).* The global mobilization of carbon from soils and vegetation, estimated at 2-2.8 x 10^{15} g C in 1989 *(Houghton 1990),* mainly results from changes in land-use in the tropics and represents 25-35% of carbon mobilization from fossil fuels.

Land-use and land cover changes have been recognized to be responsible for a substantial part of anthropogenic greenhouse gases releases to the atmosphere. Input of CO_2 to the atmosphere due to deforestation and land use change during the period of 1961-1991 was estimated to be 4 x 10^7- 15 x 10^7 tons yr^{-1} *(Haughton et al. 1987; Devkota 1992).* The GHG emitted through utilization of petroleum products is 72 Gg (Giga gram = 10^9g) of carbon and 1.79 Gg of nitrogen *(Devkota 1992).* In 1992, CO_2 emission due to utilization of fossil fuel only was estimated 35.4 Gg *(Boden et al. 1994 cited by B. M. Shrestha, 2002).*

Land use/land cover change has emerged as a central issue within the scientific community concerned with global environmental change (1). Land-use patterns, driven by a variety of social processes, result in land-cover changes that affect biodiversity, water and radiation budgets, greenhouse gas (GHG) emissions, and other factors that, cumulatively, alter the global climate and the biosphere (2). The emission of CO_2 to the atmosphere by land use/ land cover change in low-latitude forests is estimated at 1.65 ± 0.4 Pg C yr^{-1}, due to the modification of high-biomass forest

ecosystems to systems of lower biomass such as secondary and degraded forests, cultivated land and pastures *(Dixon et. al, 1994 and FAO, 1993).*

The cumulative anthropogenic C emissions over the last two centuries are 180-200 Pg C from land use change *(DeFries et. al. cited by Canadell, 2002),* largely from deforestation. Between 1850 and 1890, 60% of the emissions from land use change came from tropical areas and 40% from temperate areas *(Houghton, 1999).* However. during the decade of the 1990s almost all land use change emissions came from tropical regions. Overall, changes in land use and land cover since 1850 are responsible for 33% of the increased in CO_2 concentrations observed in the atmosphere *(Houghton, 1998 cited by Canadell, 2002)*, 68% of which were due to permanent cropland establishment (Houghton, 1999). For the 1990s C budget, CO_2 emissions from land use change account for 10%-30% of the total anthropogenic C *(Prentice et. al, 2001 cited by Canadell, 2002).*

Land use/land cover type is an important control of C storage, and shifts from one type to another are responsible for large C fluxes in and out of the terrestrial biosphere. Historically, land use emissions have been responsible for a large portion of the cumulative human induced CO_2 emissions. Globally, land use C emissions are no longer dominating the human perturbation of the C cycle, but they are still dominant in many parts of the world particularly in the humid tropics *(Schimel et. al, 2001).*

Most changes in land use affect the vegetation and soil of an ecosystem and thus change the amount of carbon held on a hectare of land. Because of the growing political interest in carbon accounting (the Kyoto Protocol), the definition of land-use change might better be expanded to include all direct human effects on terrestrial carbon storage; that is, various forms of forest and agricultural management as well as harvests and land conversion. Such an expanded definition would be consistent with the Marrakech accord under the United Nations Framework Convention on Climate Change that distinguishes between direct and indirect effects of human activity on carbon stocks. However, subtle management activities, such as forest thinning, low-impact logging, fertilization, selection of species or varieties, and tilling practices, although they affect carbon stocks, have not always been explicitly considered in analysis calculating the sources and sinks of carbon from land-use change *(Houghton and Goodale, 2004).*

Given the complex political and economic history of the Asia Pacific region, land cover conversion and associated C emissions have varied spatially and temporally.

Based on the results obtained for Central Himalaya and assuming the same conditions, total net release of carbon in the entire Indian Himalayan forests has been assessed by *Singh et al. (1985).* It is cleared that, because of over exploitation, the Himalayan forests have become a net source of CO_2 to the atmosphere. Most of these forests when unexploited can constitute an effective net sink of CO_2 *(Singh et al. 1985).* According to *Rai and Sharma (2004)* the conversion of forest into agriculture had resulted substantial decline both in carbon budget and flux.

Initial national communication of Nepal to the conference of the parties of the UNFCCC *(HMG/N, 2004 cited by Adhikaree 2004)* has established the baseline of CO_2 emission as following: Net emissions of CO_2 in the country were estimated at 9,747Gg for the base year 1994/95. The total CO_2 emission from fossil fuel consumption in the base year was estimated at 1,465 Gg. The biggest contributor, e.g. Transport sector, shares 31%, Industrial sector 27%, Residential sector 22%, commercial sector 11% and the remaining 9% is shared by Agriculture sector. Total CO_2 emissions from land use change and forestry in the base year 1994/95 were 22,895 Gg, out of which 14,738 Gg of CO_2 were sequestered due to the biomass growth. Thus net emission of CO_2 from the land use change and forestry sectors were about 8,117 Gg in the base year 1994/95.

Land use effects on climate change include both implications of land use change on atmospheric flux of CO_2 and its subsequent impact on climate and the alteration of climate change impacts through land management.

There is wide spread concern that observed increase in the concentration of carbon dioxide and other green house gases in the earth atmosphere which ultimately lead to changes in the earth climate. *IPCC (2000)* reported an increase in mean surface temperature in the range of 0.3-0.8°C over the past 100 years in tropical Asian region including Nepal. Such a climate change leads to occurrence of natural hazards such as dry period increase, intensive rainfall, flood, landslides, forest fire, less snowfall in alpine regions, melting of glacial lakes etc. For example, prevalence of unusually high temperature during the middle of March resulted in massive forest fires destroying vast area of natural forest in eastern Nepal, and in Jumla district, there was no

snowfall at all in the winter, which used to be covered with snow at least twice a year *(Gajurel 1999)*. United Nations Environment Program *(UNEP 2002 cited by B. M. Shrestha, 2002)* recently reported that historic Everest glacier has retreated 3 miles up the mountains due to global warming and warned that more than 44 Himalayan lakes in Nepal and Bhutan are close to burst.

Land use change and forest management activities have historically been and are currently net sources of carbon to the atmosphere *(Schimel et. al. 1996 cited by Adhikaree 2005)*. On the other hand, there is potential for land use change and forestry (LUCF) activities to mitigate carbon emissions by (1) emission avoidance or conserving existing carbon pools on the land (e. g. slowing deforestation or improved forest harvesting practices), (2) Carbon sequestration or expanding the storage of C in forest ecosystems by increasing the area and/or carbon density of forests(e.g. plantations, agro forests. natural regeneration, soil management) and to increase storage in durable wood products, and (3) substitute sustainably grown wood for energy intensive and cement based products (e.g. biofuels, construction materials). The potential amount of carbon that could be conserved and sequestered through an aggressive program of such changes in LUCF practices over the next 50 yr or so is equivalent to about 12 – 15% of the " business- as usual" fossil- fuel emissions over the same time period *(Brown et. al. 1996)*.

Carbon dioxide is the gaseous form of carbon and is a greenhouse gas. Since the beginning of the industrial revolution, CO_2 levels have risen at a rate of approximately 1.5 percent per year. The continued rise of atmospheric yield increase CO_2 concentration could lead to global warming. In late 1980s CO_2 was the dominant source of global warming acting as a major GHG with 57% contribution (Masters, 2001). According to *Field (1997)* contribution of CO_2 to the global warming was 49% in late 1990s, the principal source of which is fossil fuel combustion, deforestation and cement production. Fixation of CO_2 by plants into soil organic carbon is one possible mechanism for reducing the rise of CO_2 concentration in the atmosphere. A long-term reduction in atmospheric CO_2 levels will require a reduction of fossil fuel use and development of alternative energy sources and well planned land management system.

2.2.3.1. Kyoto Protocol

The concern over rising levels of CO_2 and other greenhouse gases (GHGs) in the atmosphere was addressed at the third meeting of the United Nations Framework Convention on Climate Change (UNFCCC) in 1997, in Kyoto, Japan. The results of this convention led to an agreement, known as the Kyoto protocol, among participating countries to reduce the rising levels of CO_2, and other GHGs, in the atmosphere

Kyoto Protocol is an important international treaty that seeks to strengthen the international response to climate change by arresting and reversing the upward trend in greenhouse gas emissions. The Kyoto Protocol, signed by the Parties to (UNFCC) in December, 1997 in Kyoto, Japan, was intended to set quantified emission limitation and reduction commitments for different countries (mostly OECD (Organization for Economic Co- operation and Development), Annex I). Signatories to the UNFCCC are split into two groups as:

- Annex I countries (Industrialized countries)
- Annex II countries (Developing countries)

Annex I countries agree to reduce their emissions (particularly carbon dioxide to target levels below their 1990 emissions levels. If they cannot do so, they must buy emission credits or invest in conservation.

Although developing countries have no immediate restrictions under the UNFCCC it is one of the important issues for them. Some opponents of the convention argue that both developing countries and developed countries need to reduce their emissions. Some countries claim that their costs of following the convention requirements will stress their economy. America is the country stating this with loud voice.

This protocol has come into force in 16 February 2005.

The Kyoto Protocol broke new ground by defining three innovative "flexibility mechanisms" to lower the overall costs of achieving its emissions targets. These mechanisms (Clean Development Mechanism, Joint Implementation and emissions trading) enable parties to access cost-effective opportunities to reduce emissions or to remove carbon from the atmosphere in other countries. While the cost of limiting emissions varies considerably from region to region, the benefit for the atmosphere is

the same, wherever the action is taken. Much of the negotiations on the mechanisms have been concerned with ensuring their integrity. There was concern that the mechanisms do not confer a "right to emit" on Annex I Parties or lead to exchanges of fictitious credits which would undermine the Protocol's environmental goals. There are fifteen sectors in which CDM projects can takes place, sinks mainly carbon only by afforestation and reforestation is also included.

For a project to be classified as a CDM project must satisfy the following two criteria.

(1) **Additionality:** A CDM project must result in "reduction in emissions that are additional to any that would occur in the absence of the project activity". The CDM project must lead to real, measurable and long term benefits related to the mitigation of climate change. In other words a CDM project must not be one that can be classed as a "project as usual". The additional GHG reductions are calculated with reference to a defined baseline.

(2) **Sustainable Development:** A CDM project must benefit the non- Annex-I countries in the following areas:

Social Criteria: Improves the quality of life, alleviates poverty and improves equity.

Economic Criteria: Provides financial returns to local entities, results in positive impact in balance of payments, and transfers new technology.

Environmental Criteria: Reduces greenhouse gas emissions and the use of fossil fuel, conserves local resources, provides health and other environmental benefits and meets energy and environmental policies.

Austin et. al. (1999) have discussed and presented a comprehensive list of forestry based land use management and environmental conservation practices that can qualify as CDM projects under the Kyoto protocol. Though at the moment land use, land use change and forestry (LULUCF) is not endorsed as a climate change strategy under the Kyoto protocol, negotiations and several studies on its support are going on.

A study conducted on action on climate change post 2012 by *Joint Research Centre of the European Commission* has summarized that climate change impacts are still hard to understand and to predict. Information concerning LULUCF processes contributing to climate change such as deforestation or vegetation fires can be provided in a

systematic manner by a number of individual scientists or research institutes who are often trying to combine the efforts and results of a larger community of researchers. Unfortunately despite the fact that the tools and technologies to monitor the LULUCF process have been available for many years, nobody has ever been able to offer a complete and exhaustive monitoring system for LULUCF processes around the globe. Data gaps are one of the main reasons for this remaining uncertainty in climate change impacts. According to that study the Kyoto Protocol requires the compilation by each Annex 1 party of a *National Inventory Report* (NIR) with, following articles 3.3 and 3.4, a section for LULUCF activities. One of the main parts of this NIR sections is related to land area information. For these, the IPCC Good Practice Guidance for LULUCF proposed three different approaches. Among the three approaches, the so-called "geographically explicit land use data" allows land-use changes to be tracked on a spatial basis. The adoption of this approach, which is mainly based on geographical information system (GIS) and remote sensing techniques, would ensure advantages in the compilation of NIR's, and would also generate benefits for our understanding of climate change impacts. Indeed using this approach, the NIR system would generate a large amount of multi-temporal spatially explicit reference data describing LULUCF processes, which could be used by the scientific community to analyze and better predict climate change, but would also promote synergies with the other real environmental Conventions (e.g. Biodiversity, Desertification).

Activities in the LULUCF sector can provide a relatively cost-effective way of combating climate change, either by increasing removals by sinks of greenhouse gases from the atmosphere (e.g. by planting trees or managing forests), or by reducing emissions (e.g. by curbing deforestation). There are drawbacks, however, since it may be often difficult to calculate greenhouse gas removals and emissions from LULUCF. In addition, greenhouse gases may be unintentionally re-released if a sink is damaged or destroyed through a forest fire or disease. However negotiations and simplified models and procedures for LULUCF projects are developing to increase the GHGs sink.

The Conference of the Parties (COP) by its decision 19/CP.9 adopted modalities and procedures for afforestation and reforestation project activities under the clean development mechanism (CDM) in the first commitment period of the Kyoto

Protocol. Paragraph 1 (i) of the annex to this decision defines small-scale a forestation and reforestation project activities under the CDM as those that are expected to result in net anthropogenic greenhouse gas (GHG) removals by sinks of less than 8 kilotonnes (kt) of carbon dioxide per year and are developed or implemented by low-income communities and individuals as determined by the host Party. In accordance with paragraph 1 (d) of decision 19/CP.9, the actual net greenhouse gas removals by sinks are estimated on the basis of two variables: the sum of the verifiable changes in carbon stocks and the emissions of GHG that result from the implementation of the project. Management type and forest formation have a direct influence on the emissions and on the dynamics of the carbon pools (e.g., the changes in carbon stocks) of a given project. In addition, projects that are established on highly organic soils and/or in very humid conditions (e.g., the prior land use category "wetlands") might alter local conditions and cause emissions from the soil. Projects where the prior land use was wetland may require emissions to be monitored *(UNFCCC, 2004)*.

The discussion about LULUCF activities that can bring under CDM projects after 2012 is going on.

Carbon trading allows industries in developed countries to offset their C emissions by investing in reforestation and in clean energy projects in developing countries. Some such projects are active in this field. There are some agroforestry projects in Costa Rica and 3000 farmers have participated in Costa Rica's carbon credit system conserving 150,000 ha of forest. However *Oelbermann et. al., (2004)* concluded data on C sequestration and the role of C trading in agroforestry systems are still in its infancy. For example, no information is currently available to design agroforestry system as a C sink while at the same time maintaining crop productivity. It is a great challenge to the people working in the field of carbon trading.

With the signing of the treaty, Nepal has agreed to work with the international community to address the common challenge of global climate change and its adverse environmental consequences. Recently Nepal ratified the Kyoto Protocol and also developed Designated National Authority (DNA) to approve and monitor the CDM projects. Ministry of Environment, Science and Technology has organized "Nepal Carbon Fair" very recently. The buyers, Validaters, national technical exports and policy makers have interacted in that forum to uplift CDM within the country. It is

good news for us however very few CDM projects are going to be lunched in Nepal in first commitment period of Kyoto Protocol.

King Mahendra Trust for Nature Conservation is initiating a project " Kyoto: Think global, Act Local-Action Research to Bring Community Based Forest Management Projects under the UNFCCC and the Kyoto Protocol" is only one project targeting LULUCF activities bring under CDM project. This project is trying to develop a practical monitoring method of carbon sink within Community forest in Lalitpur and Illam districts. This project seeks to develop techniques that can partially be carried out by communities themselves at a much lower cost and to demonstrate that these are as reliable as 'expert' methods that might be the solution of carbon measurement in community based forest management.

Community forest management is supposed the most successful programme in Nepal which is able to transform unsustainable management of existing natural forests to sustainable management. That's why once LULUCF is endorsed under the CDM, the community forests of Nepal will have high chance of getting paid for their work of forest conservation.

CHAPTER THREE

3. DESCRIPTION OF STUDY AREA

3.1. Location

Balkhu Khola watershed is a sub-watershed (27°38'59" to 27°43'02" Lat. and 85°11'25.85" to 85°18'05.49" Long.) of the macro Bagmati watershed located at Northwestern part of Kathmandu Valley represents mid-hill watershed of Central Nepal. It has the area of about 4140.63Ha (District Soil Conservation Office, Kathmandu); 4420.8 ha computed from topographical map 2003. **Table 1** shows the extent points and **Figure 3** shows the location of Balkhu Khola watershed.

Table 1: Extent points of Balkhu Khola watershed

Extent Points	Latitude	Longitude	Easting	Northing
Lower	27°38'59.38"	85°11'25.85"	617454.12	3059639.50
Upper	27°43'01.97"	85°18'05.49"	628328.59	3067217.00

It includes 11 Village Development Committee (Thankot, Mahadevsthan, Matatirtha, Machhegaun, Satungal, Tinthana, Badbhanjyang, Dahachok, Balambu, Purano Naikap and Naya Naikap), some parts of Syuchatar V.D.C., Kirtipur Municipality, Kathmandu Metropolitan City (KMC) and very small part of Ramkot V.D.C. Makawanpur district lies in south western, Dhading in north western, KMC in north eastern and Kirtipur Municipality in south eastern part of the watershed. **Figure 4** shows the administrative map of the watershed.

3.2. Topography

The watershed area under study lies entirely in the middle mountainous zone. The area is characterized by varied lithology and folded structure. Altitude of the watershed ranges from approximately 1300m to 2561m. The topography progressively becomes undulated from Valley floor to Chandragiri range in the south and Dahachok in the north. Physiographically, the watershed has been divided into

two geomorphic divisions viz., (ii) Middle Hill Slope (1300-2000 m) and (iii) Upper Hill Slope (>2000 m) based on land use and natural vegetation cover. Some landslides and gullies are also observed. The vegetation changes remarkably with variation in micro-climate in a gradient of altitude. Most of the area lies under the Middle Hill slope. **Figure 5** shows the altitudinal zonation map of the watershed.

3.3. Slope

The slope of the watershed was divided into three categories as gentle (< 5°), moderate (5-30°) and steep (> 30°). The moderate slope covers the highest area of the watershed. **Figure 6** shows the zonation map by slope of the watershed.

3.4. Climate

There are two meteorological stations in the watershed, one at Thankot (1630 m) and other lies at Naikap (1520 m). Since these are rainfall stations the data of temperature and humidity are not available. So, annual temperature was taken from the nearest station at Panipokhari. Balkhu Khola watershed lies between sub-tropical to warm temperate humid climate. The climate of the area is typically monsoonal having the four main seasons: Pre-monsoon (March-May), Monsoon (June-September), Post monsoon (October-November) and winter (December to February).

Rainfall varies from area to area, and 80% of the total rain occurs through June to September. Annual rainfall ranges from 1400mm to 2200mm. Annual temperature ranges from 12°c to 22°c.

3.5. Drainage

Balkhu Khola originates from Chandragiri Range. It flows from North West to South East and meets to holistic river Bagmati at Balkhu. Major streams drain in it are Gkhcha Khola (South-West), Thosne Khola and Kalo Khola (North), Dhaksi Khola (South), Ghatte Khola and Thulo Khola (South-East). The drainage pattern of the watershed is dendritic type; **Figure 9** shows the drainage map of the watershed.

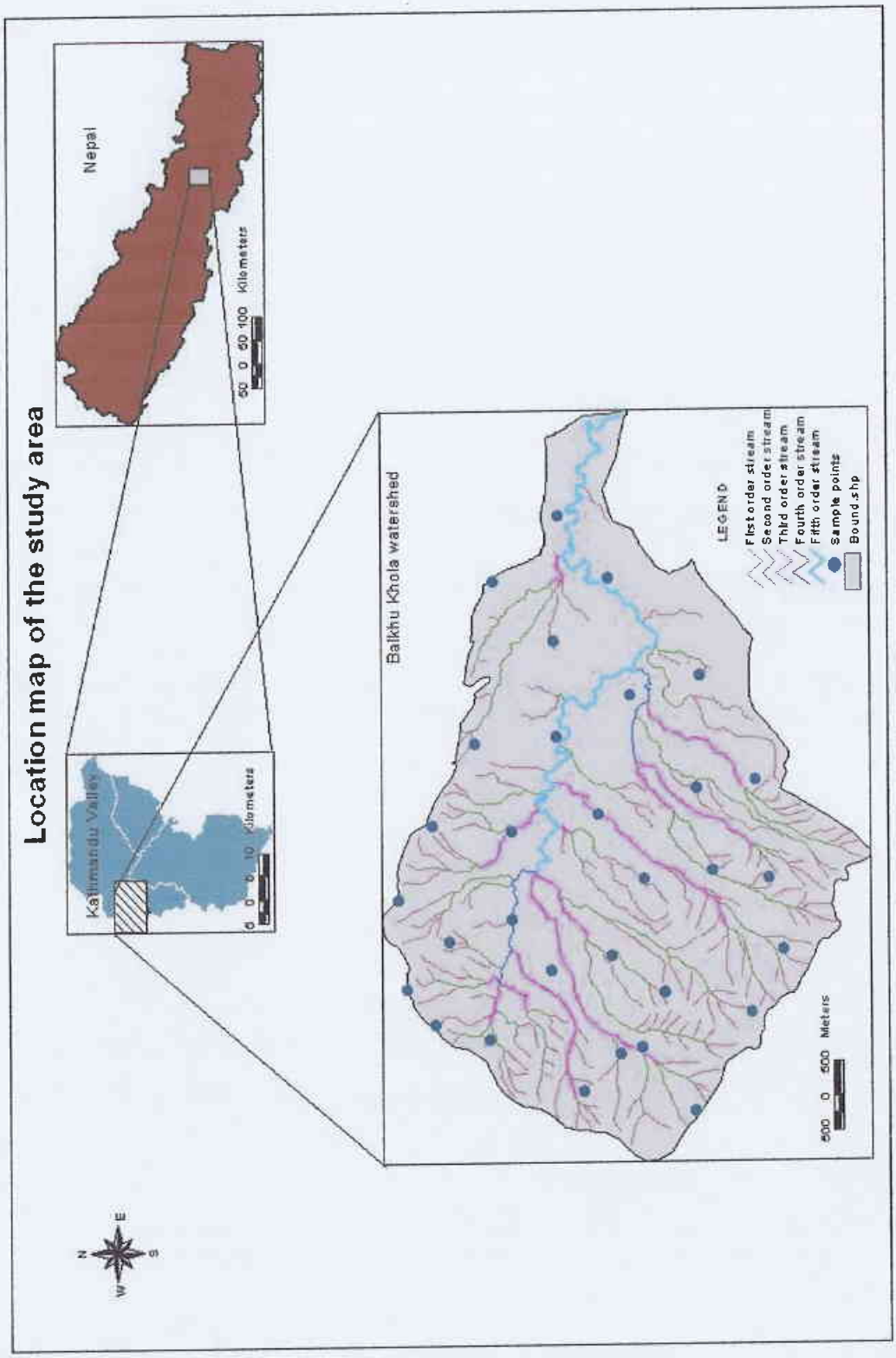


Fig 3: Location map of the study area

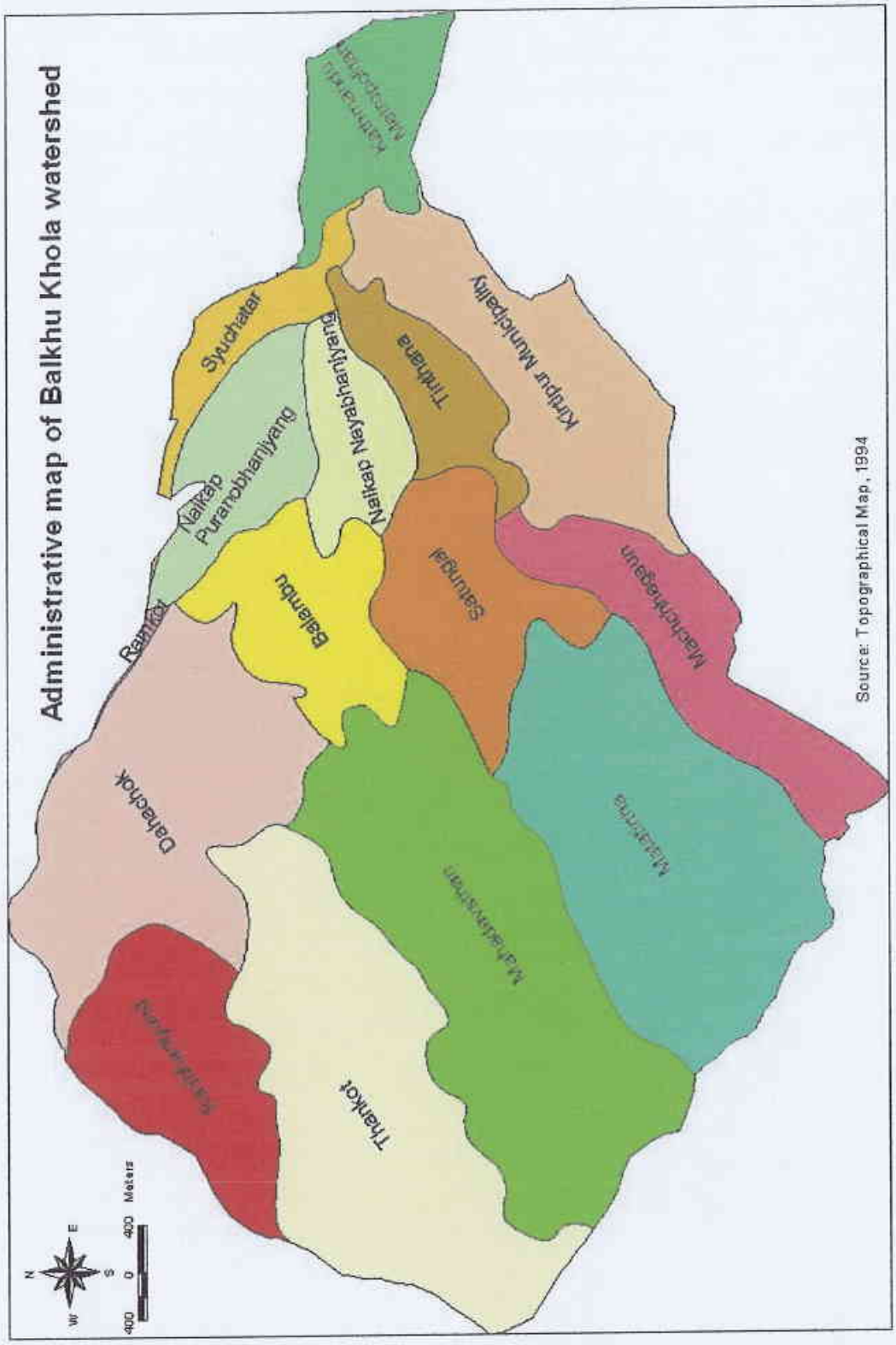


Fig 4: Administrative map of Balkhu Khola watershed

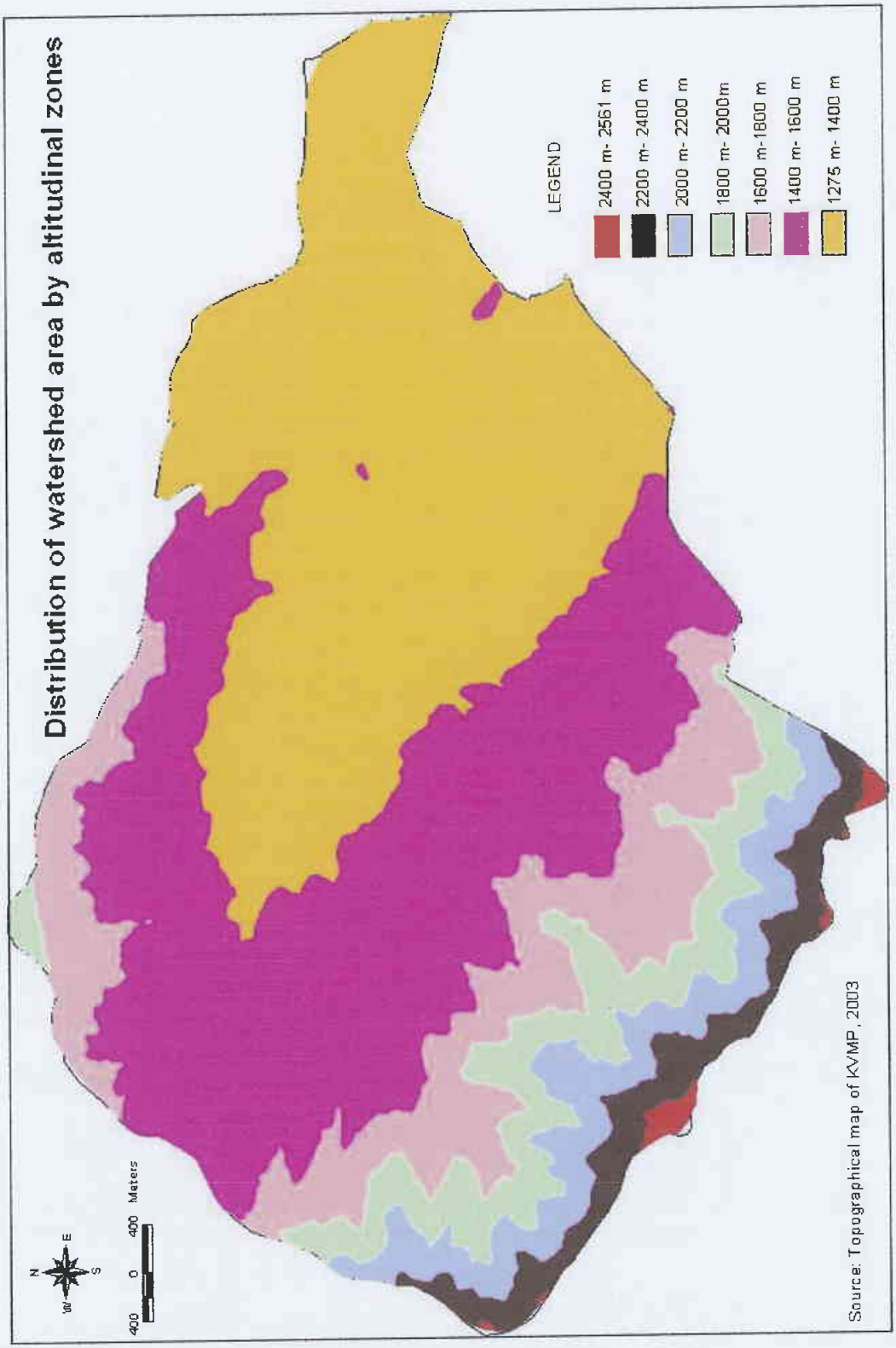


Fig 5: Distribution of the watershed area by altitudinal zones

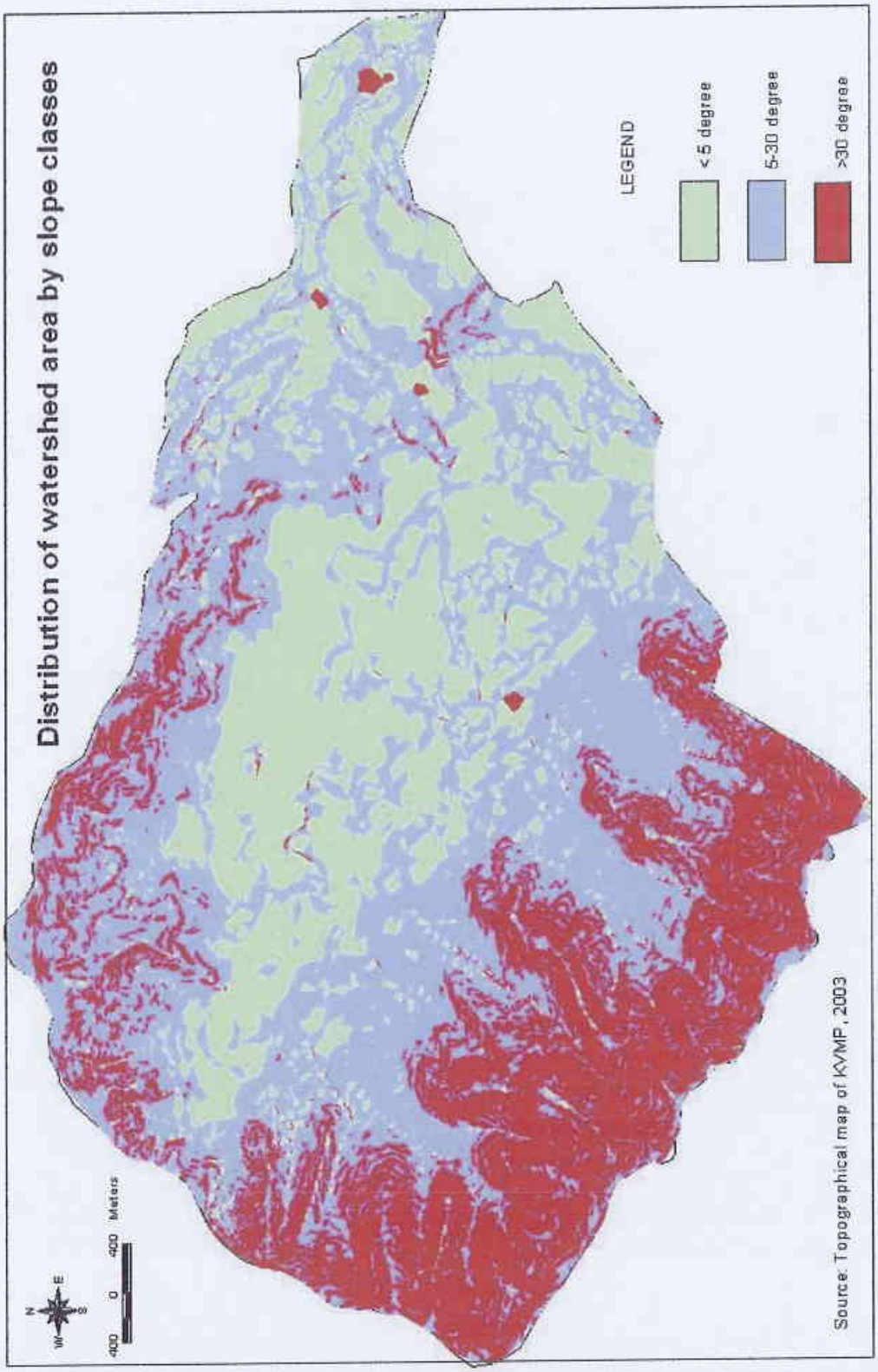


Fig 6: Distribution of the watershed area by slope class

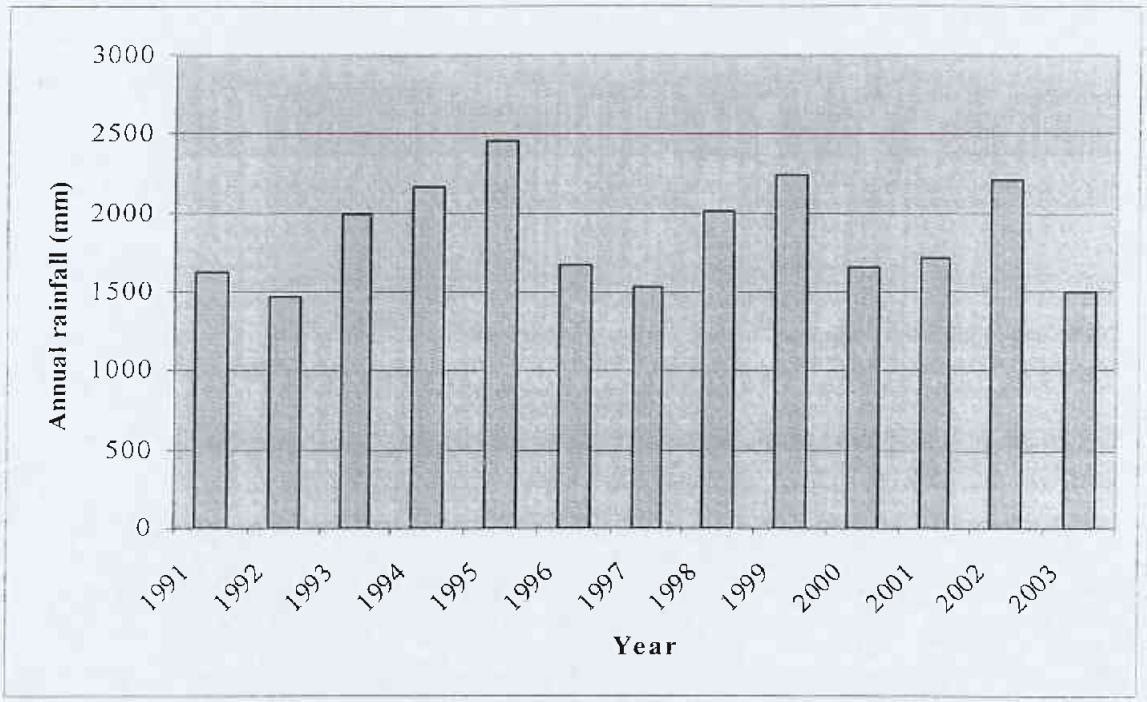


Fig 7: Annual Rainfall records at Thankot Station (Index1015, Elv: 1630, Lat: 27°41' and Long: 85°15')

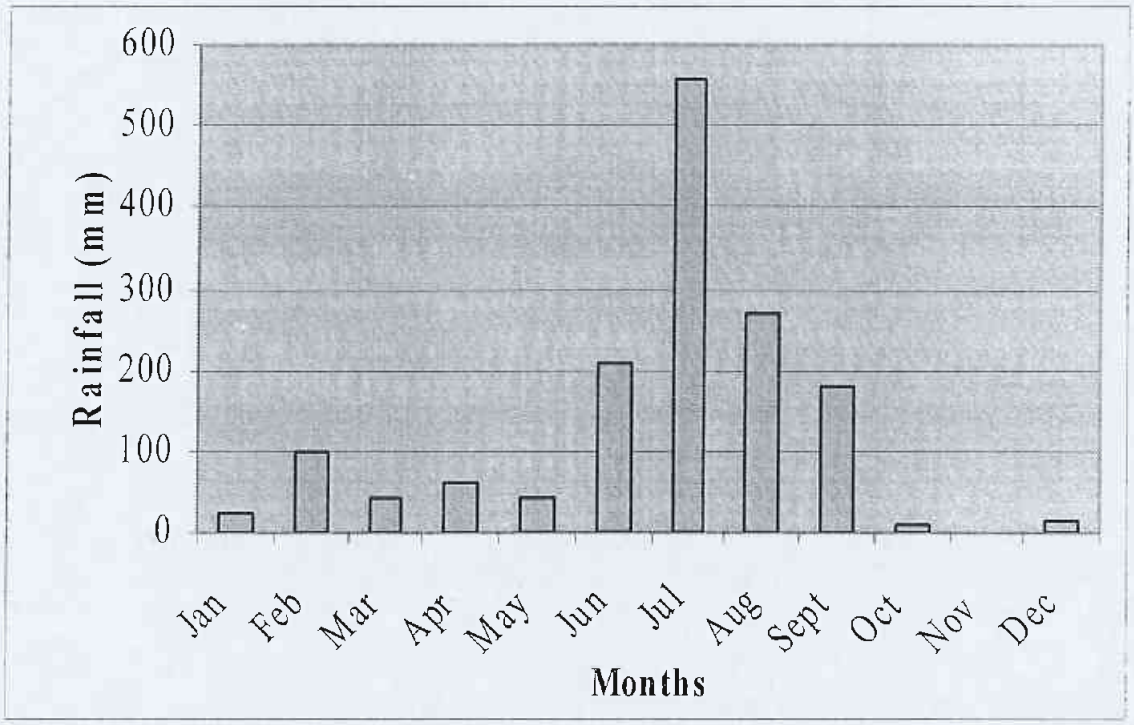


Fig 8: Monthly rainfall at Thankot station of the year 2003

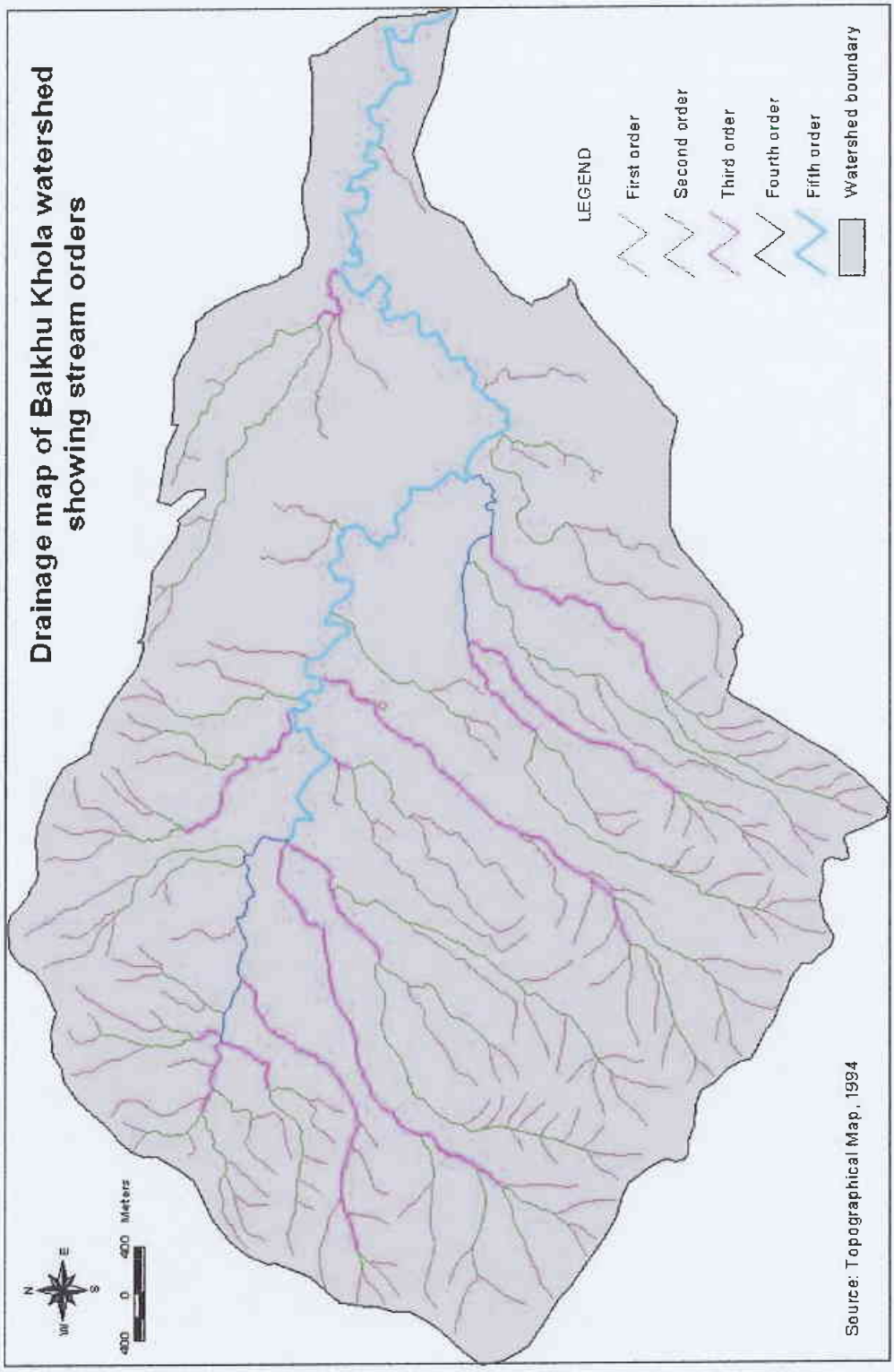


Fig 9: Drainage map of Balkhu Khola Watershed

The stream orders were considered on the basis of Strahler's stream order principle. There are 361 streams in the watershed among them 186 are first order, 110 second order, 38 third order, 12 fourth order drain into the main channel of fifth order. The total length of first order streams is 80.34, second order is 43.81, third orders 21.45, fourth order 3.97 and fifth orders 13.74 km. The total mean length of Balkhu Khola is 2.62. **Table 2** shows the number and length of the stream by order.

Table 2: Stream order and length

Stream Order	No. of Stream	Total Length, km	Mean Length, km
First Order	186	80.34	0.43
Second Order	110	43.81	0.39
Third Order	38	21.45	0.56
Fourth Order	12	3.97	0.33
Fifth order	15	13.74	0.91
Total	361	163.33	2.62

Source: Computed from topographical map of KVMP, 2003

3.6. Vegetation

Vegetation changes from valley floor to upper parts with the change in altitude. Three types of forest are recognizable in the watershed.

1. Schima Castonopsis Forest: Schima Castonopsis forest is abundant in lower altitudinal zone (1275-2000 m). The major tree species are chilaune (*Schima wallichii*-DC), Dhale katus (*Castonopsis indica*-Roxb), *Castonopsis tribuloides*- Sm, Okhar (*Juglans regia*-Linn), Kaphal (*Myrica esculenta*-Buch-Ham), Pipal (*Ficus religiosa*-Linn), Khanyu (*Ficus semicordata*-Buch-Ham), Mayal (*Pyrus pashia*-Buch-Ham), Timur(*Zanthoxyllum armatum*-DC), and Tanki (*Bauhinia semla*- Wounderlin) and shrubs are Chutro (*Berberis asiatica*-Roxb), Aaiselu (*Rubus ellipticus*-Smith), Aangeri (Lyonia ovalifolia-Wall) etc. Banmara (*Eupatorium adenophorum*) and *Lantana camera* have infested the ecosystem in abandoned slopes.

   Uttis (*Alnus nepalensis*- D. Don) form a separate dense forest (Alder forest) in moist places like river banks and fresh landslides areas. It is happening by natural regeneration as well as by plantation.

2. Chir Pine Broad Leaved forest: Chir pine broadleaved forest corresponds to subtropical pine forest (Champion and Sheth, 1968 cited by NARMSAP 2002). It is composed of Chir pine (*Pinus roxburghii*-Sarg), *Quercus leucotrichophora*-A.Camus, Lali gurans (*Rhododendron arborium*-Smith) and Chilaune (*Schima wallichii*-DC). Small Patches of *Pinus roxburghii* forest are developed by community by plantation in southern aspect of hills.
3. Lower Temperate Oak Forest: It is distinct in higher altitude at about 2500 m. Major tree species are *Quercus lanuginose* merge with Kharsu (*Q. semicarpifolia*-Sm), *R. arborium*-Smith and other broadleaved trees.

3.7. Geology and Soil

3.7.1. Geology

The basement geology of the Kathmandu Valley is composed of the upper part of the Kathmandu Nappe known as the Phulchauki Group, which unconformably rest on the Precambrian rocks of the Bhimphedi Group. The Phulchauki group consists of 5-6 km of Early-Middle Palaeozoic rocks that have been divided into five formations *(Stöcklin and Bhattarai, 1980).* Among them three lie within Balkhu Khola watershed as: Tistung Formation, Sopying Formation and Chandragiri Formation.

The Phulchauki Group begins with about three kilometres of unfossiliferous slates, siltstones, calc-phyllites and metasandstones known as the Tistung Formation. It is Late Precambrian to Early Cambrian in age (Kumar, 1985 cited by K.N. Paudel, 2002). The sandstone and metasandstone are cross-bedded with ripple marks, mud cracks and worm trails. The Tistung Formation is exposed in the southwestern part of the Kathmandu Valley.

The Tistung Formation is followed by the Sopyang Formation, which consists of dark argillaceous and marly slates with intercalations of limestone. The thickness of the Sopyang Formation is about 200 metres. Very small portion lie within the research area.

The Chandragiri Limestone consists of 2000 to 2500 metres of sometimes thinly interbedded limestone with occasional quartzite beds. Echinoderm fossils of Ordovician age are reported from the limestone of the Chandragiri Formation. This

formation is well exposed in the Chobhar and Kirtipur areas and partly forms the Chandragiri Hill.

Sediments of study area can be grouped as Talus Deposit, Recent River Deposit and Lower terrace Deposits

Talus deposits are loose rock fragments deposited at the bottom of a steep slope. The main agent of those deposits is gravity. These deposits are abundant on moderate slopes just below the higher slopes within the Balkhu Khola watershed.

Recent river deposit includes clay to gravel and other fragments within the channel and flood plain of the Stream. The Lower Terrace Deposit is found along the Balkhu Khola. It consists of unconsolidated micaceous sand, pebbles and gravel derived from the part of the Khola.

3.7.2. Soil

Soil of the watershed can be divided into **Valley Soils** and **Mountain Soils**. Haplaquepts, Ustifluvents and Fluvaquents are of valley soils, while Haplumbrepts, Dystrochrepts, Ustochrepts and Ustorthents are of mountainous soil (District Soil Conservation Office, Kathmandu, 2004).

Valley Soils

Haplaquepts: This type of soil is found in some part of valley floor of this watershed. In this soil some pedogenetic development can be seen in B horizon. They have aquic moisture regime. Some Haplaquepts are dry for 5 to 6 months. Texture of Haplaquepts range from loamy sand to heavy clay, with silty clay loam to loam predominating.

Ustrifluvents and Fluvaquents: these soils does not have significant pedogenic development. They can be calcareous in some place. Texture is loam to loamy sand with a risk to wind erosion. Fluvaquents are similar to Ustifluvents except permeability. Ustifluvents are high permeable than Fluvaquents. These soils are poorly drained soils.

Mountain Soil

1. Haplumberpts: Haplumberpts are characterized by well developed A and B horizon, low base status, found on steep slope and shallow soil depth.
2. Dystrochrepts: Dystrochrepts are commonly found in the hills. They are mainly found on siliceous formations. They are characterized by well developed B horizon; base saturation is less than 60% and occurs in an udic soil moisture regime.
3. Ustochrepts: Ustochrepts are one of the most commonly found soils in Nepal.They are characterized by well developed B horizon; pale colored surface horizon; high base saturation and occurs in an ustic moisture regime.
4. Ustorthents: Ustorthents are commonly found on steep slopes; no significant pedogenetic development is seen and has poor vegetation.

3.8. Land Uses

Land uses of the watershed consist of forest (29.98%), cultivation (62.01%), settlement (3.99%), Roads (1.17 %), Bush (1.0%), and grassland 0.65%) (**Table 3**).

Table 3: Area (ha) under different land uses 2005

Land use/land cover	Area in Ha	Percentage
Cultivation	2741.70	62.01
Forest	1325.27	29.98
Settlement	176.78	3.99
Roads	51.89	1.17
Bush	44.17	1.00
Grassland	28.78	0.65
Other	35.61	0.80
Unknown	16.62	0.37
Total	4420.82	99.97

Source: Updated topographical map of KVMP 2005

Vegetation type ranges from Schima-Castonopsis mixed forest to Lower Temperate Oak Forest along altitudinal gradient. Medium to Dense natural vegetation cover lies in the peaks of Mahadevsthan, Thankot and Dahachok V.D.Cs.

Dominant agricultural practices are irrigated rice cultivation with legumes (Khet) and upland dry maize-millet cultivation alternatively vegetable farming (Bari). Crop rotation is usually maize-millet–fallow in Bari and paddy- fallow in Khet (Land leased to Brick Factory). In some cases maize-millet-vegetables in Bari and Paddy-wheat-maize is major crop rotation in Khet.

Settlements are widespread in gentle to moderate slopes in valley floor to hills. In downstream part it is gradually increasing. There is no proper planning, no adequate water supply and drainage management.

CHAPTER FOUR

4. MATERIALS AND METHODS

4.1. General Study Approach

The main focus area of overall study is to analyze land use change and quantification of soil organic carbon within different land uses. For completion of research following activities were carried out.

4.1.1. Information Requirement Analysis

Various literatures, documents, some World Wide Web (www) pages, knowledge and discussion with supervisor and other personnel have been used as references for information requirement analysis. Various methods of mapping and assessing land use change have been also reviewed and a research proposal has been prepared with detail working methods.

4.1.2. Preliminary Field Observation

A short field observation was carried out during first week of January, 2005 to obtain basic information of watershed. The verification of watershed boundary, identification of existing drainage pattern and land use/ land cover condition and collection of some secondary information from local peoples was done during this field trip.

4.1.3. Field Observation and Sample Collection

Field observation was done firstly for the analysis of land use change. It was started from second week of May 2005. Completion of field verification for that analysis and soil samples collection was performed simultaneously afterwards. Soil samples were collected according to sampling design from different land uses by stratified random sampling during first week of June to second week of July 2005. Geographic Positioning System (GPS) observations of sampling sites and changed land uses coordinates were also collected in similar time.

4.1.4. Post Field Activities

This is the final phase of research which includes laboratory works, final map preparation, data verification, analysis, interpretation and research paper writing.

4.2. Acquisition of Secondary Information

Various government and non-government organizations identified during information requirement analysis and World Wide Web (www) were visited.

Table 4: List of web pages visited

S.N.	WWW address	Remarks
1	http:/www.ipcc.ch/	Official page of Intergovernmental Panel on Climate Change (IPCC)
2	http://www.unfccc.int/	Official page of United Nations Framework Convention on Climate Change (UNFCCC)
3	http:/www.sciencedirect.com/	World's largest electronic collection of science and technology full text papers.
4	http://www.google.com/	One of the most popular web search page. This page was used to search literatures by key words.

Both spatial and non spatial data were collected from respective sources as follows.

- Land Utilization map (Scale, 1:50,000) of sheet no 72 E/2 and 72 E/6 prepared by Land Resource Mapping Project in 1978
- Topographical map (Scale, 1:25,000) of sheet no 2785 06A and 2785 05B published by Survey Department, Nepal in 1994
- Topographical map (Scale, 1:10,000) prepared by Kathmandu Valley Mapping Program (KVMP) in 2003 (studies done in-house within the purpose of study)
- Digital version of satellite imagery (a part of the watershed) acquired in 2001(in-house observation)
- Aerial photograph (1:15,000) published by Survey Department, Nepal in 2003
- Digital set of rainfall and temperature data of study area of last 13 years from Department of Hydrology and Meteorology

4.3. Land use Change Analysis

4.3.1. Application of Geographic Information System (GIS)

GIS is not simply a computer system for making maps, it is an analytical tool. GIS store two types of data: spatial and non spatial. Spatial data are associated with the real world location of surface, features, where as non spatial data represent the characteristics of feature processes *(ICIMOD, 1991)*. GIS is a modern computer based information and decision support system concerning geographic and geo referenced data. It employs enhanced data storage techniques, offers powerful data analysis engine, provides efficient data maintenance and update facility, presents virtually unlimited ways of displaying data and secures tight integration, easy accessibility and fast distribution of data without compromising the privacy and safety requirements on data.

With all those outstanding features, GIS is arguably the most efficient and effective system conceived for management and use of geographic and geo referenced data. A GIS, however, is more than just a combination of computer hardware, software, data and people. It entails a whole array of data standards, rules, policies, customs and procedures.

4.3.2. Preparation and Acquisition of Data

Hardcopy Map Acquisition and Digitization: The map of topo sheet, 1994 and land utilization map, 1978 were acquired through Survey Department. These maps were scanned and database modeling was done in which data layers and code to be given were defined. On the basis of database modeling these maps were digitized using R2V a GIS based software. Data layers were prepared, based on survey department, Nepal, are shown in **Table 5.** The digital set of river, road, contour, spot height, building points and land use/ land cover was prepared.

Updating Field records: Information collected through GPS and mapped on topo sheet showing sample points, changed area in existing land uses, channel shifting were digitized and prepared spatial digital database. For this effort coordinates were recorded in GPS (Garmin); downloaded to the computer; changed the projection of the data; calculated the area in case of polygons. Finally, merged and edited to the existing topographical map. In case of sampling points, after projection, the data were directly plotted in the existing map.

Acquisition of Digital Data: Topographic map sheet 2003 prepared by KVMP and satellite imagery were acquired through Survey Department for in-house observation and analysis.

Table 5: Data layers prepared during digitization

Data layers	Sub layers	Type	Code
Hydro_ln	Central line of stream	line	30131
Trans_ln	Highway	line	10111
	Feeder		10121
	District road		10131
Land cover	Forest	polygon	25212
	Cultivation		25102
	Bush		25262
	Barren land		25352
	Pond		30131
	Bridge		60000
	Built up		15102
	Buildings		15202
Topog_pt		Point	Spot height value
Topog_ln		Point	Contour value
Build_pt		Point	

4.3.3. Digital Data Editing and Visualization

The data digitized in R2V environment were exported to ArcView GIS and checked accordingly. Since the data vectorised were not in topological model, it was then passed to PC Arc/Info for further processing. These digitized data were edited using PC Arc INFO software. Overshoot, undershoot were edited, code consistency were checked, topology constructed and polygon coverage were defined.

Digital visualization of edited data was done in ArcView GIS software and checked. After assigning symbols, map cosmetics were applied to enhance the appearance of the map.

4.3.4. Land Use Change Analysis

The land use / land cover types of 1978 were categorized into four groups i.e. Forest, Cultivation, Bush and Settlement as per research need. Similarly the land use / land cover types of 1994 were categorized into five groups i.e. Forest, Cultivation, Bush, Settlement and open/barren. These two coverages were overlaid in GIS to study the changing land use/ land cover pattern. The land use type of 1978 and its change were

observed in detail. Net and gross gain and loss within the period of 1978- 1994 were studied. The land use / land cover types of 2005 were categorized into eight groups i.e. Forest, Cultivation, Bush, Settlement, Grassland, Road, other and unknown. To make data consistent the area covered by road and river (grouped in other) were excluded from 1992 as well as 2005 and land use/ land cover change was studied following same procedure applied for land use change analysis (1978-1994). Finally map layout was prepared.

4.4. Soil Sampling

4.4.1. Sampling Sites and Soil Depth

Sampling sites were the strata which were determined on the basis of land uses. Cultivation and forest covered almost about 92% of the watershed area. Remaining 8% area consist various land cover such as bush, grassland, road, river and settlement etc. Thus three strata as cultivation, forest and remaining land were considered. Sampling points were determined by random sampling technique generating random numbers within the strata. During that process variation was seen in the condition of selected ecosystem. For example while two samples were randomly selected within strata covering 8% land one was selected from bush and the other was selected from grassland.

For soil organic carbon (SOC) analysis the incremental soil depth were taken up to 1 to 1.5 m in that lands which have more soil depth. But in middle mountains of Nepal there is thin soil depth, so for present study the depth from which soil samples were collected was taken up to 39 cm. The soil depths from where soil samples are to be collected were also determined on the basis of other literatures (Annex I: A, B, C and D).

4.4.2. Sample Collection and Laboratory Processing

Soil samples from each stratum were collected from a pit of 0.5x 0.5 m^2 for each incremental depth at every selected site. The depth increments were 0-13cm, 13-26cm and 26-39cm. About 1.5 -2.0 kg of fresh soil samples were collected from each depth and kept in polythene bag for soil organic carbon analysis. Simultaneously, soil samples for determining bulk density were also collected using core cutter of 10 cm

diameter and 12.73 cm height (volume 999.305cc). Finally soil samples were transported to laboratory for further processing.

4.4.2.1. Dry Bulk Density (BD)

Soil BD was determined using core sampling method (Baruah and Barthakur, 1999). Oven dry weight of soil samples was determined for moisture correction. The air dried soil was passed through a 2 mm sieve and weight and volume of fragments recorded for fragments correction. Volume correction was done by water displacement method.

4.4.2.2. Soil Organic Carbon (SOC)

Oven dried soil samples were passed through a 2 mm sieve to prepare sample for determining SOC in the bulk soil samples. The weight of fragments retaining in the 2 mm sieve was recorded. SOC in the soil samples was determined by titrimetric method (Walkley and Black, 1934) as:

- Firstly oven dried soil sample were taken
- A suitable quantity was weighed not exceeding 10 gm and transferred to a dried 500 ml conical flask
- 10 ml 1 N potassium dichromate solution and 20 ml conc. sulphuric acid was added and mixed by gentle swirling
- The flask was kept to react the mixture for about 30 minutes
- After the reaction was over, the content was diluted with 200 ml of distilled water and 10 ml phosphoric acid were added which was followed by 1 ml of diphenylamine indicator
- The sample was titrated with 0.4 N ferrous ammonium sulphate at the end point color was changed to brilliant green
- Blank was run with the same quantity of chemicals but without soil

4.4.3. Calculation

The SOC was calculated using the following equations

(Walkley and Black, 1934):

% of SOC in Soil=0.4x (B-S) x 1 x 0.003 x 1.3 x 100/W

Where,

B: volume of $Fe(NH_4)_2(SO_4)_2$ used for blank titration (ml)

S: volume of $Fe(NH_4)_2(SO_4)_2$ used for sample titration (ml)

W: weight of soil (g)

0.4: strength of $Fe(NH_4)_2(SO_4)_2$

1: Strength of $K_2Cr_2O_7$

1.3: Correction factor (100/77)

(De Wit and Kvindesland, 1999):

Carbon stock = d x BD x SOC-content x CFst

Where,

Carbon stock (kg/m^2)

d: depth of horizon (m)

BD: bulk density (kg/m^3)

SOC-content (g/g) and

CFst: Correction factor for gravel content;

$$CFst = 1-(\%gravel)/100$$

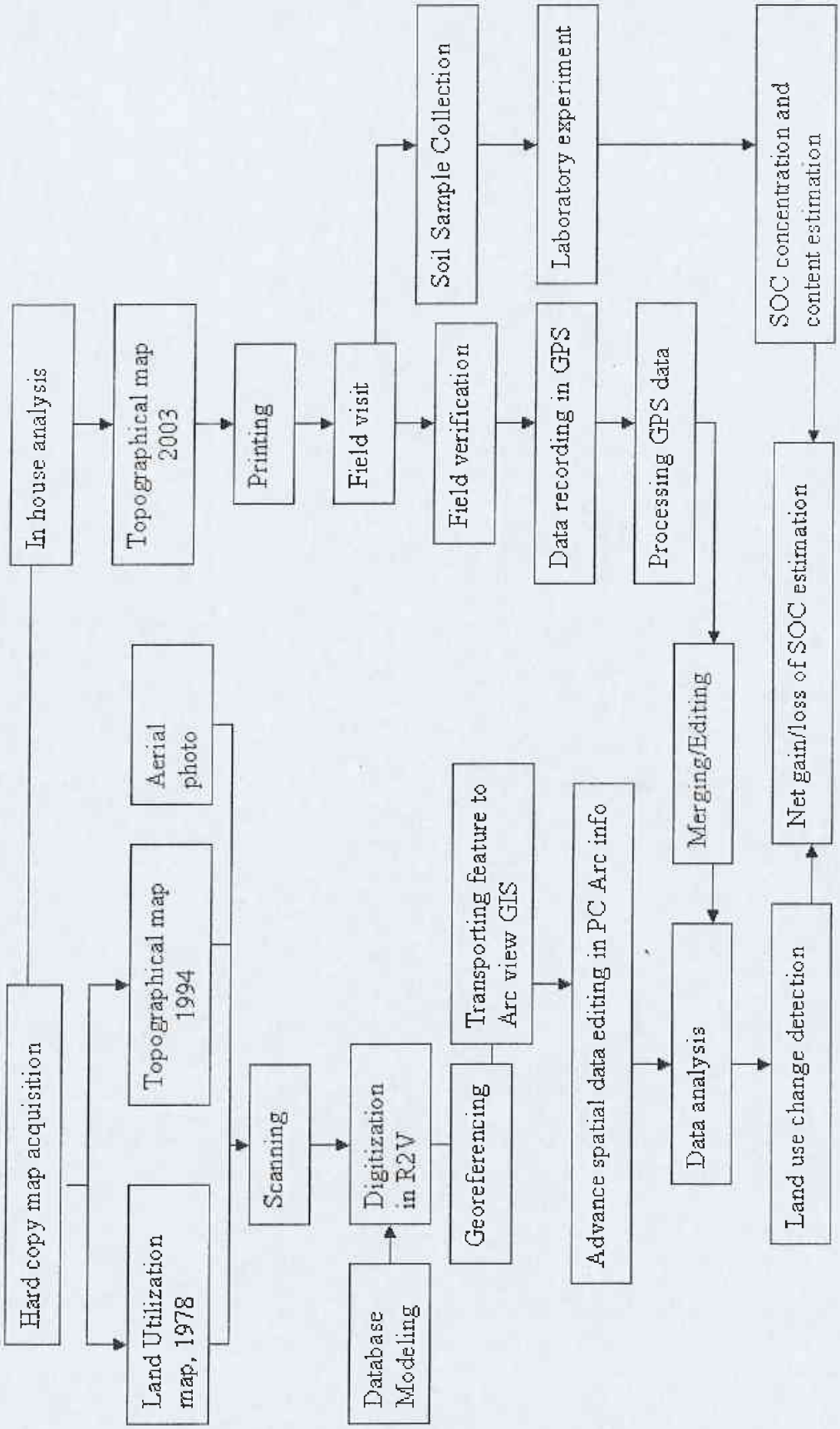
Carbon stock in each depth of dominant land use of the watershed was estimated multiplying the mean SOC stock in each unit area (Kg/m^2) by the total area covered by them. Summation of SOC stock in each depth gave SOC stock in each land use in the watershed.

Effect of land use change on SOC stock was estimated by taking account of net change in area under different land uses from 1978 to 2005.

4.4.4. Statistical Analysis

Data were analyzed using Microsoft Excel, SPSS software (SPSS 10.0 for windows) and SYSTAT version 6.0. Correlation between SOC and BD was determined as Pearson correlation. Effect of land use on SOC and BD was analyzed by comparison of mean. Multiple comparisons of means for each class variable (among land uses, depth, SOC, BD) were carried out using two ways ANOVA in SYSTAT.

Conceptual Flow Chart of Overall Method



CHAPTER FIVE

5. RESULT AND DISCUSSION

5.1. Result

5.1.1. Land Use/ Land Cover Change in the Watershed.

5.1.1.1. Land Use/ Land Cover in 1978

Land use/ land cover pattern in 1978 were categorized into four groups as Forest, Cultivation, Bush and Settlement. The largest area of watershed was covered by cultivation i.e. 3083.10 ha, that contributed 69.74 % of total watershed area. Bushland was found to be second largest land use which covered 779.75 ha i.e. 17.64 % of total watershed area. Forest had covered 506.86 ha i. e. 11.46 % of the total watershed area. Settlement had covered the least area of 51.13 ha i. e. 1.15% of the total watershed area **(Annex III: B).** The land use area has been shown in map **(Figure 10).**

5.1.1.2. Land Use/ Land Cover in 1994

Land use/ land cover pattern in 1994 were categorized into five groups i.e. Forest, Cultivation, Bush, Settlement and open/barren. The largest area of watershed was covered by cultivation i.e. 2903.73 ha which contributed 65.67% of total watershed area. Bush land covered 1076.60 ha i. e. 24.35% of total watershed area. Forest had covered 287.18 ha i. e. 6.49 % of total watershed area. Settlements covered 149.77 ha (included only cluster of settlements and large buildings) which contributed 3.38% of total watershed area. The least area is covered by barren land i.e. 1.0921 ha (0.024%) of total watershed area **(Annex III: C),** the land use area has been shown in map **(Figure 11).**

5.1.1.3. Land Use/ Land Cover in 2005

Land use/ land cover pattern in 2005 were categorized into eight groups i.e. Forest, Cultivation, Bush, Settlement, road, grassland, unknown and other. The largest contribution was by cultivation which covered 2741.70 ha (62.01%). Forest is regenerating which contributed 1325.27 ha of land i. e. 29.98% of total watershed.

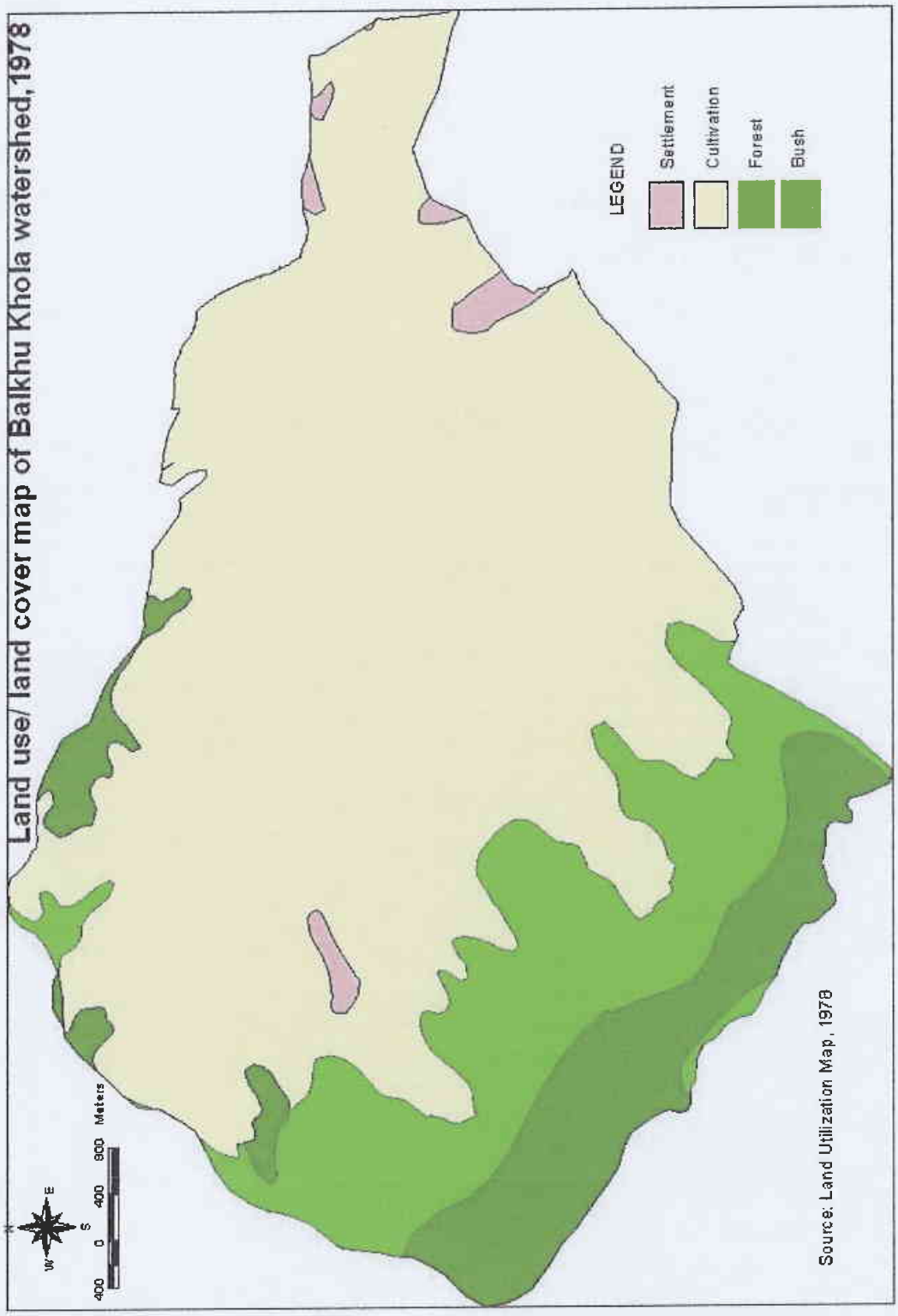


Fig 10: Land use/ land cover of Balkhu Khola watershed, 1978

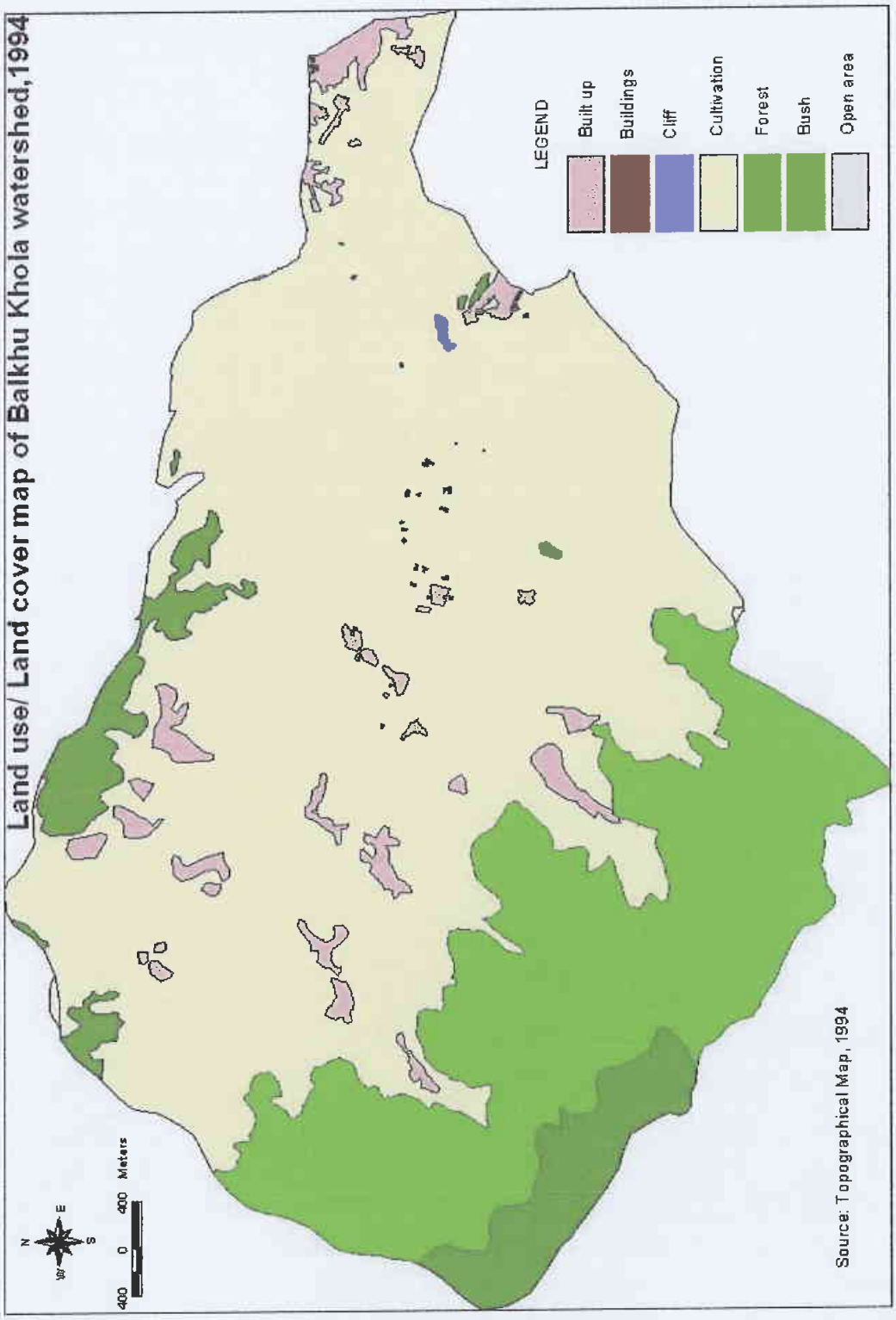


Fig 11: Land use/ land cover of Balkhu Khola watershed, 1994

Bush land was degraded (44.17 ha) and grass land was appeared (28.78 ha). Road networks had expanded (51.95). Settlement contributed the area of 176.78ha (3.99%). The unknown area covered 16.62 ha **(Table 3).** The land use area has been shown in map **(Fig: 12).**

5.1.1.4. Land Use/ Land Cover Change (1978-1994)

Cultivation land was remained as same during 16 years (1978-1994) by 2826.76 ha. Similarly forest, bush and settlement was remained same by 222.28 ha, 736.98 ha and 21.29 ha respectively. Forest area was degraded by 43.39% while bushes were increased by 38.12%. Cultivation land was decreased by 5.80%. Settlement was dramatically increased i. e. by 194%. **Table 6** shows the changed area within the period of 16 years.

Table 6: Land use/ land cover change 1978-1994

Land use/cover Type	Area in 1978 (km^2)	Area in 1994 (km^2)	Change area (km^2)	Rate of change (%)
Forest	5.07	2.87	-2.2	-43.39
Bush	7.79	10.76	2.97	38.12
Cultivation	30.83	29.04	-1.79	-5.80
Settlement	0.51	1.5	0.99	194
Other		0.03		
Total area	44.20	44.20		

The overall change in land use/ cover has been shown in **Figure 13** and the matrix of land use/ cover conversion have been shown in **Annex III: G.**

Forest and cultivation land were changed to bush and settlement remarkably which had covered the area of 272.59 ha and 128.48 ha respectively. To some extent cultivation land was changed to forest (58.07 ha) and bush (67.03 ha). Settlement was changed to cultivation contributing area of 26.97 ha.

5.1.1.5. Land Use/ Land Cover Change (1994-2005)

Land under cultivation was remained consistent during 11 years (1994-2005) by 2696.58ha. Similarly land under forest and settlement were remained same by 238.80 ha and 136.24 ha respectively. Bush land has no consistency during these 11 years.

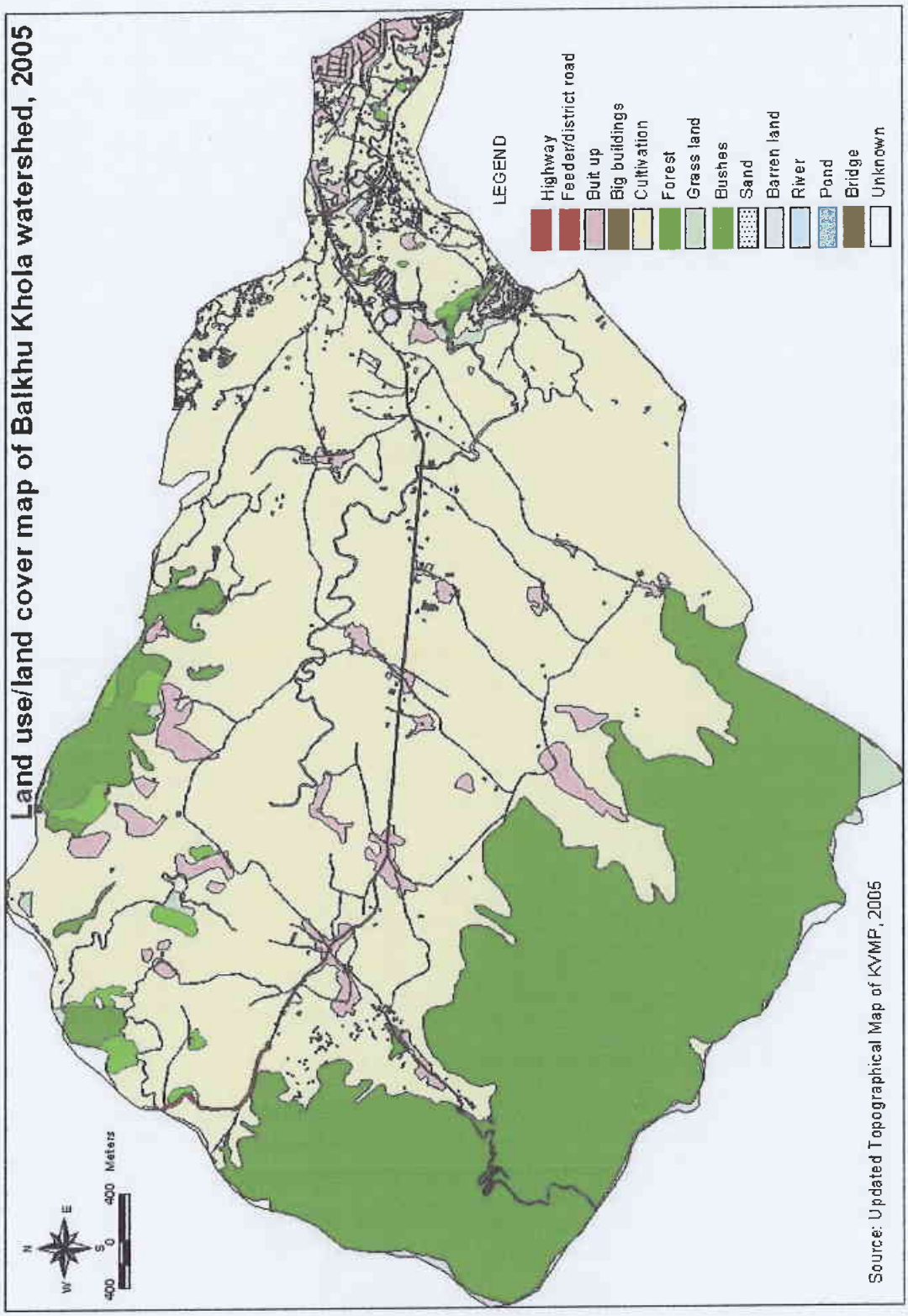


Fig 12: Land use/ land cover of Balkhu Khola Watershed, 2005

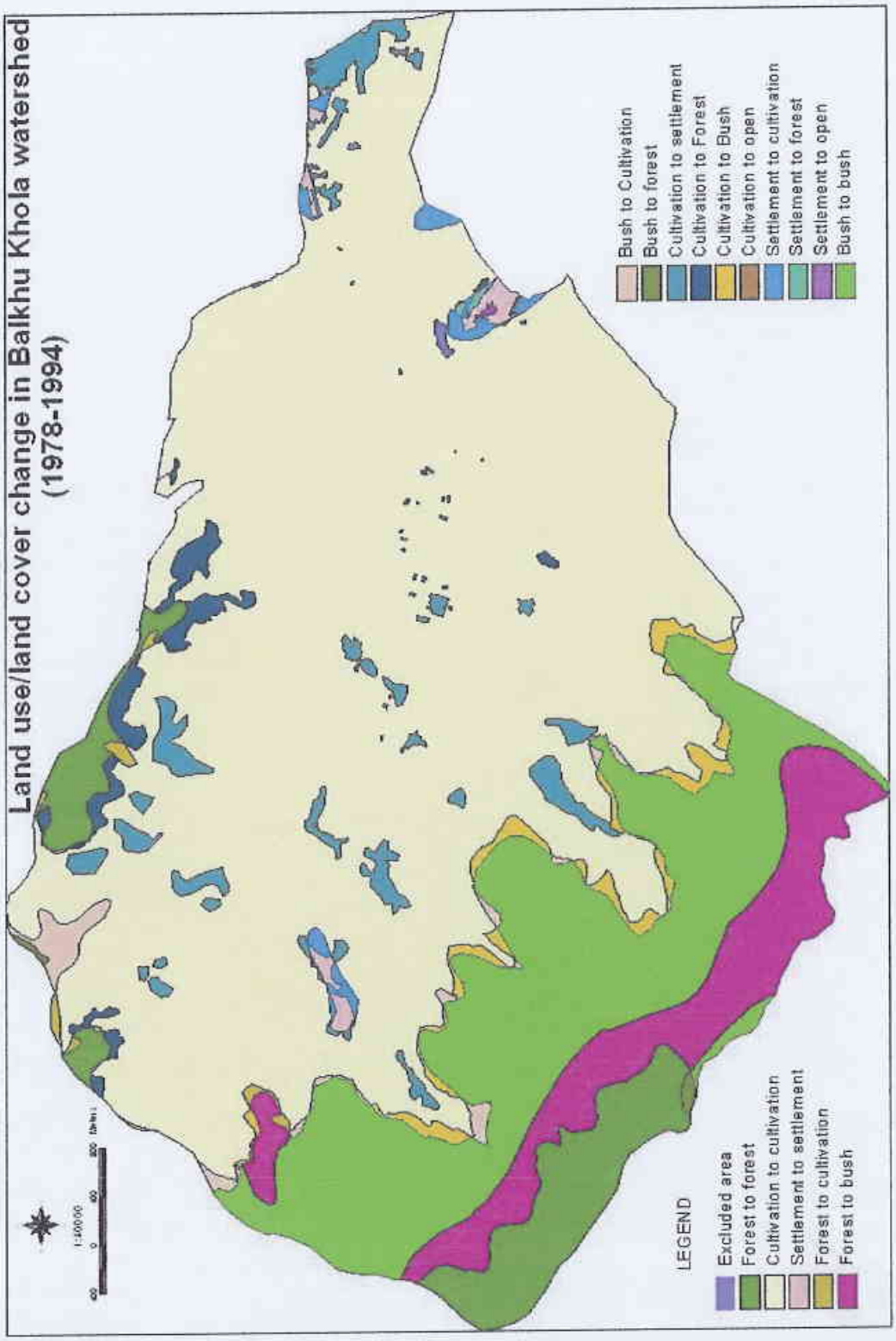


Fig 13: Land use/ land cover change in Balkhu Khola watershed, (1978-1994)

The overall change in land use land cover has been shown in **Figure 14** and the matrix of land use/ cover conversion have been shown in **Annex III: H.**

The remarkable change on bush land to forest was seen which contributed 1034.57 ha. Bush land was changed to cultivation (17.63 ha), open (1.79 ha) and grassland (13.87 ha), very small part of it also changed to settlement. Cultivation land also changed to forest (50.81 ha), settlements (39.85), bush (31.79 ha), grassland (13.40ha) and open (7.85 ha). Settlement land has changed to others which contribute small percentage. The remarkable change on bush land to forest was seen which contributed 1034.57 ha. Bush land was changed to cultivation (17.63 ha), open (1.79 ha) and grassland (13.87 ha), very small part of it also changed to settlement. Cultivation land also changed to forest (50.81 ha), settlements (39.85), bush (31.79 ha), grassland (13.40ha) and open (7.85 ha). Settlement land has changed to others which contribute small percentage.

Forest area was increased in good figure i.e. by 361% while bushes were decreased by more than 95%. Land under cultivation was decreased by 5.57%. Settlement was also found in rapid increasing trend i. e by 51.33%. **Table 7** shows the changed area within these two time period.

Table 7: Land use /land cover change area (km^2). 1994-2005

Land use/cover Type	Area in 1994 (km^2)	Area in 2005 (km^2)	Change area (km^2)	Rate of change (%)
Forest	2.87	13.25	10.38	361
Bush	10.76	0.44	-10.32	-95.91
Cultivation	29.04	27.42	-1.62	-5.57
Settlement	1.5	1.77	0.77	51.33
Other	0.03	1.32		
Total area	44.20	44.20		

5.1.2. Soil Organic Carbon Stock

The total SOC stock in the soil profile (39 cm depth) in the entire watershed was estimated to be 257.71 MTC (metric tons of carbon). The SOC stock was estimated to be 107.61 MTC (41.76%) in *forest land*, 146.68 MTC (56.92%) in *Cultivation and* 1.09 MTC (0.42%) in *grassland* and 2.33 MTC (0.90%) in *Bush land* **(Table 8)**.

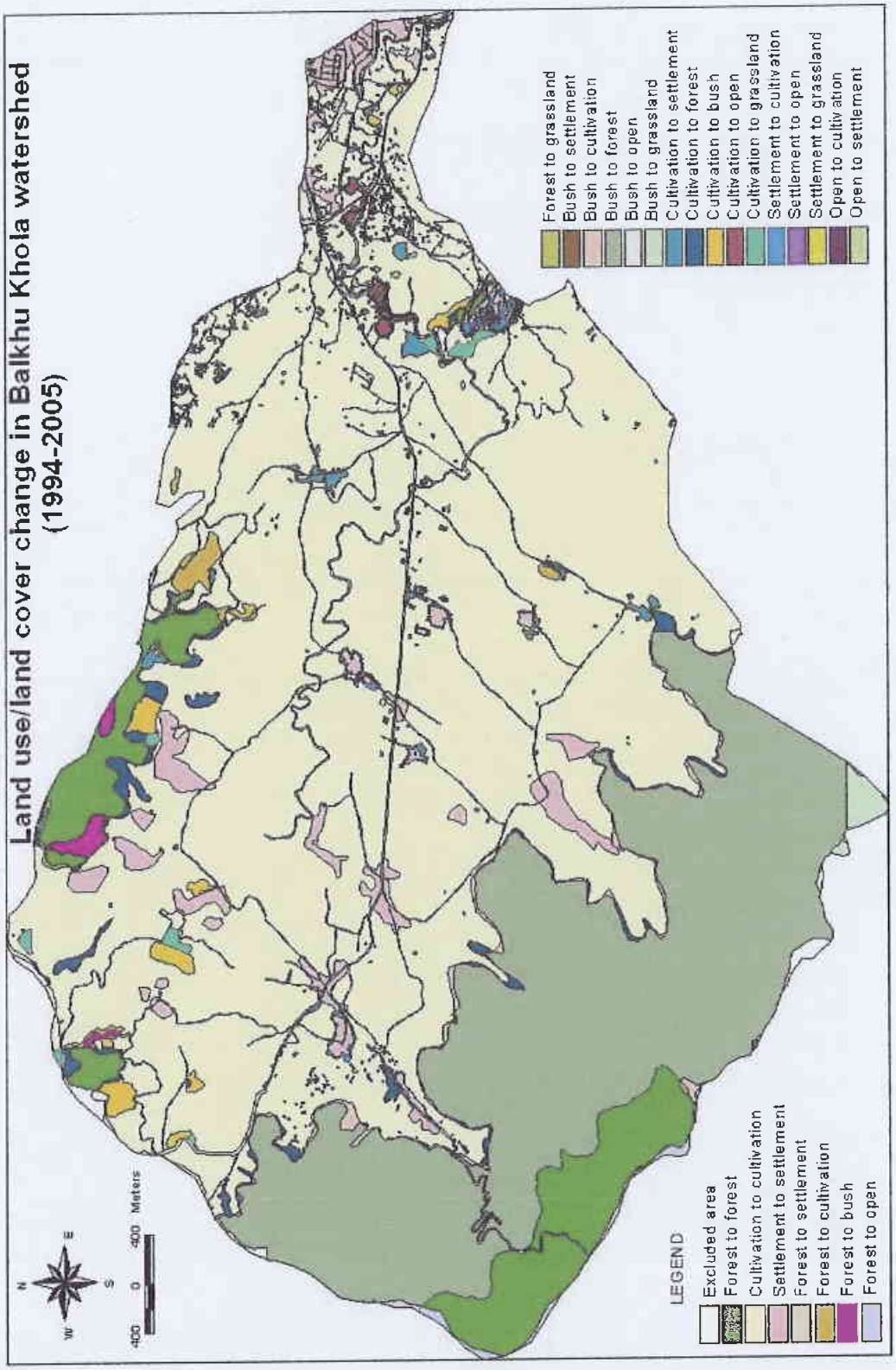


Fig 14: Land use/ land cover change in Balkhu Khola watershed, (1994-2005)

The data indicated that a considerable portion of land was occupied by secondary ecosystem i. e. cultivation with a total reserve of 56.92% of the SOC stock. This result is attributed to both the SOC content and the area covered by the respective land uses. The distribution of SOC in different land uses is shown in figure 15.

There was significant effect of land use $F_{(2, 78)}$ 6.582(P = 0.002) and soil depth $F_{(2, 78)}$ 12.390 (P = 0.000) on SOC stocks in the soil **(Table 9).** The forest soil has high SOC stock (8.13 kg/m^2) followed by Bari (6.11 kg/m^2) and Khet (4.93 kg/m^2) **(Figure 16a)**. The trend in case of grassland and bush land was not drawn due to less number of samples. Wide range of values was seen for forest soil i.e. from a low of 1.05%, degrading forest in high slope of Dahachok to 6.63%, natural dense forest at Chitlang. Bari and Khet soil have less variation which ranged from 0.93 to 2.90% in bari and 0.53 to 1.58% in Khet **(Table 11)**. In general, estimated SOC stock was observed to be higher in the topsoil (0-10 cm) compared to lower depths in various land use types **(Table 8)**.

Table 8: Mean SOC pools and total stock for different land uses

Land use	Depth (cm)	Area (Ha)	SOC%	BD Mg/m^3	Mean C pool (kgC/m^2)	Total C (MTC)
Forest	0-13		4.78	1.00	4.11	
	13-26	1325.27	2.42	1.11	2.37	107.76
	26-39		1.72	1.17	1.64	
Cultivation	0-13		1.61	1.22	2.31	
	13-26	2741.70	1.21	1.29	1.80	146.68
	26-39		0.84	1.36	1.24	
Bush*	0-13		2.18	1.22	3.30	
	13-26	44.17	0.74	1.33	1.15	2.33
	26-39		0.46	1.39	0.84	
Grassland*	0-13		2.49	0.91	2.35	
	13-26	28.78	0.93	1.16	0.96	1.09
	26-39		0.62	1.41	0.49	
Other		280.90				
Total		4420.82				257.71

*: These land uses do not consist mean value

Forest soil has 50.56% of its total SOC stock in the 0-10 cm depth, while it was 44.15% in Khet and 31% in Bari. The SOC (t/ha) in the topsoil (0-13 cm) varied between 14.10 to 81.31 in forest, 17.58 to 35.91 in bari and 7.37 to 31.16 in khet **(Table 12).**

The negative correlation between SOC and BD was found perfect in all incremental depth. It is stronger in Forest than Khet and Bari. Although it was found negative relationship in Bari statistically it is not significant which is showed in **Table 10.**

The result of present study showed conversion of forestland in to cultivation land may result in 34.11% losses of SOC compared to SOC level in the forest. The internal trading of land use area between the land uses during the 16 years period (1978-1994) indicated net loss of SOC stock by 6718.17 ton i.e 2.71% of the original stock in the Balkhu Khola watershed. Similarly, land use change during 11 years period between 1994-2005 shows net gain of SOC by 29358.41 ton i.e. 12.46% of the original stock.

The above estimation and calculation are based on the assumption that there is homogeneity within the same land use types in the watershed. There might be error involved in the estimation due to generalization of various factors prevailing in the watershed. It is a middle mountain watershed with varied altitude causing significant effect in microclimate. Variation in SOC content might be due to spatial variability in location of the site or due to land use, which is difficult to separate. Categorization of land use system is also very gross in this study as there might be several sub systems of land uses with in the same category, such as different cropping systems in cultivated land and different forest type in forest land.

5.1.3. Dry Bulk Density

There was significant effect of land use $F_{(2, 78)}$ 20.014 (P = 0.000) and soil depth $F_{(2, 78)}$ 7.822 (P = 0.001) on dry bulk density of soil **(Table 13).** Bulk density of forest was found to be least followed by Bari and khet for all incremental depths (Fig: 18a).

Estimated BD was observed to be higher in the topsoil (0-10 cm) compared to lower depths in various land use types. The BD (g/cm^3) in the top soil varied 0.77 to 1.29 in forest 1.09 to 1.25 in Bari and 1.10 to 1.41 in Khet **(Table 13).**

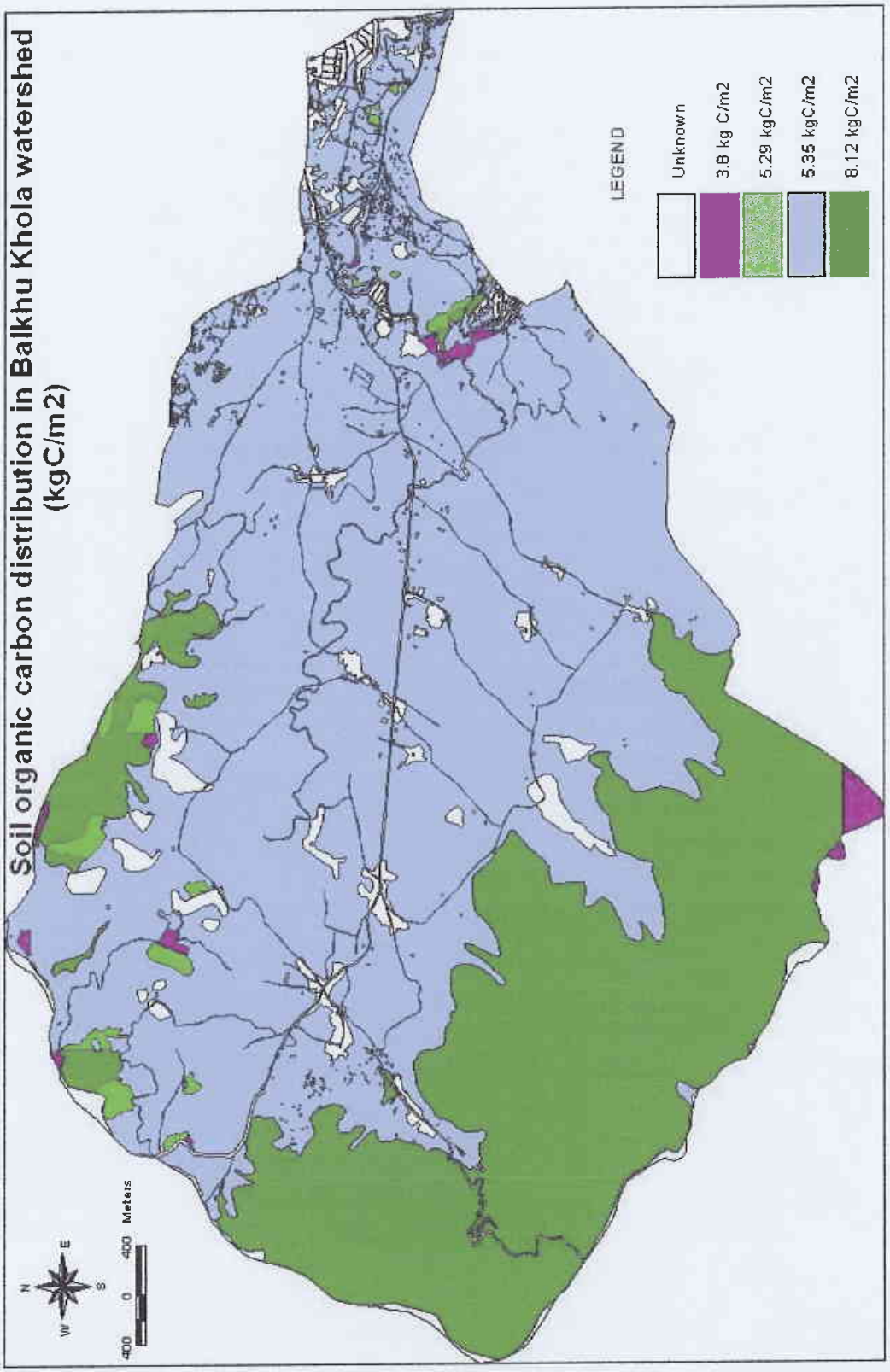


Fig 15: SOC distribution in Balkhu Khola Watershed

5.2. Discussion

5.2.1. Land Use/ Land Cover Change in the Watershed

There are several factors which contribute to change land use/ cover. According to *Shrestha (1975)* there are two major causes in land use change in Nepal. One is natural which include geological structure, relief feature, drainage, climate etc. Another is cultural factor which includes growth of population, migration of the people, infrastructural development etc. During the 16 years (1978-1994) period natural ecosystems were changed into secondary ecosystems i. e. cultivation and settlement from forest. The natural ecosystems were found to be degraded notably. This may be due to no conservation measure implemented and attraction of people to settle in Kathmandu valley from other parts of country. Similarly some settlements were changed to cultivation it may due to destruction by earthquake, 1990.

Bushes changed to forest significantly in 11 years (1994-2005) period because of community awareness towards conservation of Forest. Cultivation lands near regrowth of forest might have invaded by forest species or might have restored the encroached lands into the forest. Although it was contributed less area to develop grassland from forest and bush shows degradation of natural ecosystems. In other hands grassland was not considered during preparing topo sheet (in Badbhanjyang V.D.C. old grassland had mapped as cultivation in Topo sheet, 1994).

5.2.2. Soil Organic Carbon Stock

5.2.2.1. Soil Organic Carbon Stock: Effect of Land Use and Soil Depth

Differences in SOC stock in different land-use/covers support the hypothesis that different land uses have different SOC stock. Forest soil was richer in SOC than other land use types, due to organic input from litter fall and lower losses compared to cultivated soils. Since soil C is the largest C pool in all the land-use/covers, it is important to understand the effects of land-use/cover changes on C inputs and losses to the soil. Soil contains more carbon than vegetation. Soil organic matter (carbon) content is often related to soil fertility. Soil total and organic carbon level were highest in the dense forest. There was a decrease of total carbon and organic carbon content with consistent land-use/cover change. In conversion of forest to cropland, the

organic layer is depleted, and soil carbon content and cation exchange capacities can decrease *(Detwiler 1986; Man 1986; Schlesinger 1986; Davidson & Ackerman 1993 cited by Sharma 2003). Franzluebbers (2005)* also found land use change from natural to other disturbed patterns has negative impact on SOC while studied on SOC sequestration in southeastern USA and concluded as with soil disturbance of long-term native vegetation; loss of SOC can be rapid and extensive.

Table 9: Soil organic carbon stock (t/ha) in different depths of various land uses

Soil depth (cm)	Land use type	Soil Organic Carbon (t/ha)		
		Min	Max	Mean ± SE
0-13	Forest	14.10	81.31	41.16 ± 8.88
	Bari	17.58	35.91	25.93 ± 2.29
	Khet	7.37	31.16	21.78 ± 2.11
13-26	Forest	9.45	53.11	23.75 ± 4.49
	Bari	10.53	37.00	20.50 ± 3.15
	Khet	6.76	29.11	16.50 ±1.87
26-39	Forest	4.25	32.08	16.45 ± 3.20
	Bari	8.21	32.00	14.76 ± 2.65
	Khet	2.43	19.39	11.05 ± 1.65
Attribute	F-test			P value
Land use	6.582			0.002
Depth	12.390			0.000
Land use x depth	NS			

Comparison of SOC in natural vegetation and cultivated land gives some insight into the present management effect on SOC content. The *Bari* lands, having close proximity to the farm houses, are well managed by farmers in terms of Soil Organic Matter (SOM) supply. They collect all the above ground straw for animal feed from the *Khet* and hence organic matter turnover rate becomes lower. People rarely use organic manure in *Khet* compared to *Bari* land and usually leave khet fallow after harvesting of rice, the main crop of the area. The lower input of SOM to *Khet* by the farmers may be due to the fact that no crop residue is left behind after the harvest and the land is mostly located some what far from the source of farmyard manure (FYM) (farm houses).

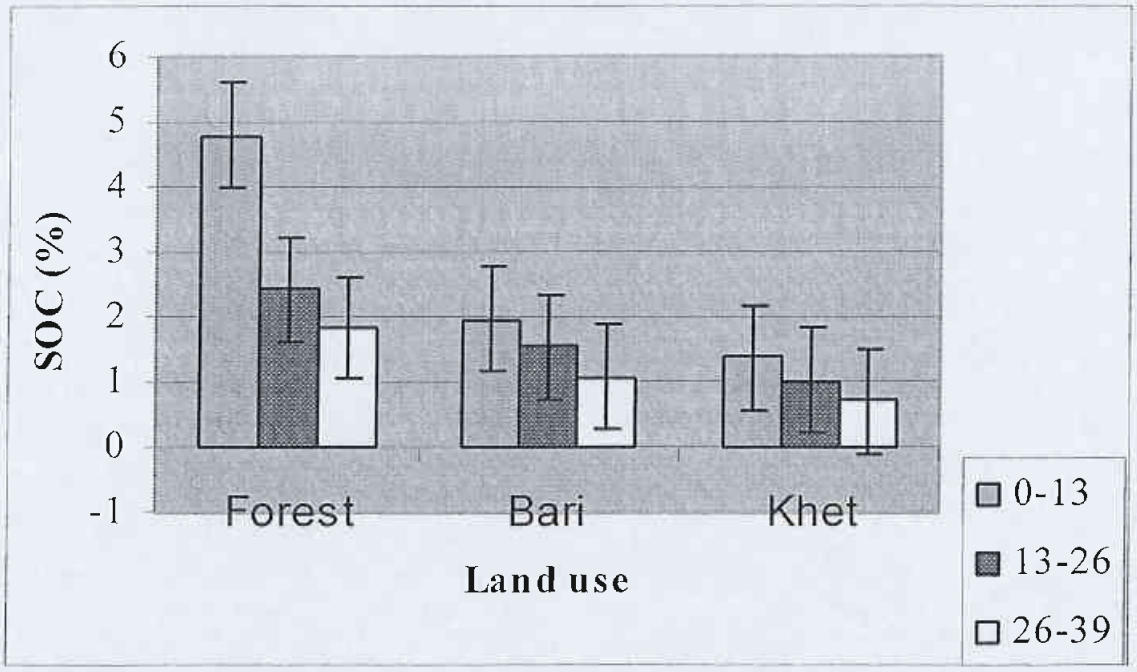


Fig 16 a: Soil organic carbon concentration in different land uses for all incremental depths, vertical bars show the standard errors

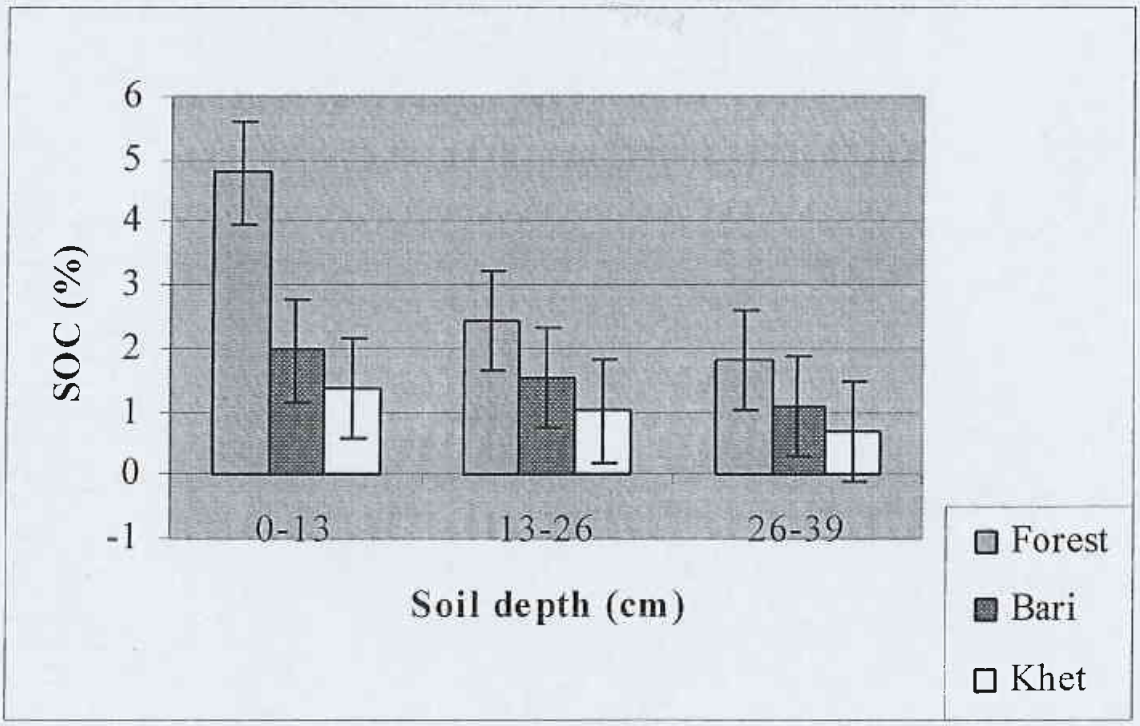


Fig 16, b: Soil organic carbon concentration in different soil depths of various lands uses, vertical bars show the standard errors

Beside, cropping pattern also has effect on SOC status in agriculture lands. That may be a cause which makes SOC higher in Bari than Khet. A study carried out in North Appalachian Experimental Watershed by *Hao et. al. (2002)* concluded that in comparison with the prevailing practice of moldboard tillage with corn–wheat–meadow–meadow rotation, use of the improved practice increased the SOC pool by 5 Mg/ha. The SOC content in cropland is strongly correlated to crop and soil management practices. These practices include crop species and rotation, tillage methods, fertilizer rate, manure application, pesticide use, irrigation and drainage, and soil and water conservation *(NRC, 1989; Paustian et al., 1997 cited by Hao et. al., 2002).*

They control SOC input from crop residue and addition of organic amendments, and SOC output through decomposition into gases and transportation into aquatic ecosystems via leaching, runoff, and erosion. Conversion of plow tillage to no tillage can increase SOC pool by up to 10Mg/ha during 5–20-years *(Paustian et al., 1997).* The SOC content also depends on landscape position due to soil erosion and leaching, which are predominant on sloping landscape. Increasing water content and soil deposition at lower slope position affects SOC decomposition and crop biomass production where the SOC content is often higher *(Pennock et al., 1994; Fahnestock et al., 1995; Gregorich et al., 1998 cited by Hao et. al., 2002).* The effects of cropland management practices and landscape position on SOC pool depend on climate, soil type, and landscape morphology, and are thus site-specific.

A gradual decrease in SOC content with soil depth was generally seen in all land uses. Similar result i.e. SOC decreased from top to deeper soil layers was reported by *Kyoto: Think Global, Act Local Project (2004)* in Indian forest of Dhaili and Toli Van Panchayat and *Corre M.D. (1999)* also concluded the average total SOC for all vegetation types decreased markedly with depth. Decrease in SOC content with soil depth was more pronounced in forest than Bari and Khet. SOC was found to be higher (0.96-4.22%) in surface layer (0-15 cm), decreased with depth first slightly (0.30-2.55%) up to 60 cm and then drastically (0.067-1.16%) at 90-100 cm *(Sharma, 2003).*

5.2.2.2. Soil Organic Carbon Stock: Effect of Dry Bulk Density

SOC was always negatively correlated with Bulk density. Present study also favors this concept i. e. this study found perfect negative correlation between SOC and BD. The trend of negative relationship between SOC and BD in different land uses was shown in **Figure 17**. The negative correlation between SOC and BD was found perfect in all incremental depth. It is stronger in Forest than Khet and Bari. Although it was found negative relationship in Bariland statistically it is not so significant which is showed in **Table 10.**

It may be due to turn over and manuring, which mix up the soils of top horizons. Dissolved organic carbon and deep rooting crops in *Bari* may have also contributed to higher SOC content in lower depths. *Shrestha (2002)* while studied on land use effect on soil carbon sequestration in Mardi watershed of Nepal reported the similar result of increasing trend of BD in deeper layer of the soil where SOC showed decreasing trend in such condition.

Table 10: Correlation between SOC and BD

Depth, cm	0-13	-0.484**
	13-26	-0.399*
	26-39	-0.496**
Land use	Forest	-0.540**
	Bari	-0.187
	Khet	-0.371*

*: Correlation is significant at 0.05 levels

**: Correlation is significant at 0.01 levels

5.2.2.3. Soil Organic Carbon Stock: Variability Study

The SOC stock of forest soil depends to a great extent upon condition of the forest. Erosion also control SOC reserves and distribution across the terrestrial landscapes and could therefore have major implications for terrestrial carbon cycling, atmospheric carbon dioxide and global warming. Climatic variations and geomorphological features are factors which could influence the fate of eroded carbon at the field and watershed scales. This may be the reason of low SOC in sloppy area of Dahachok although it has mature trees.

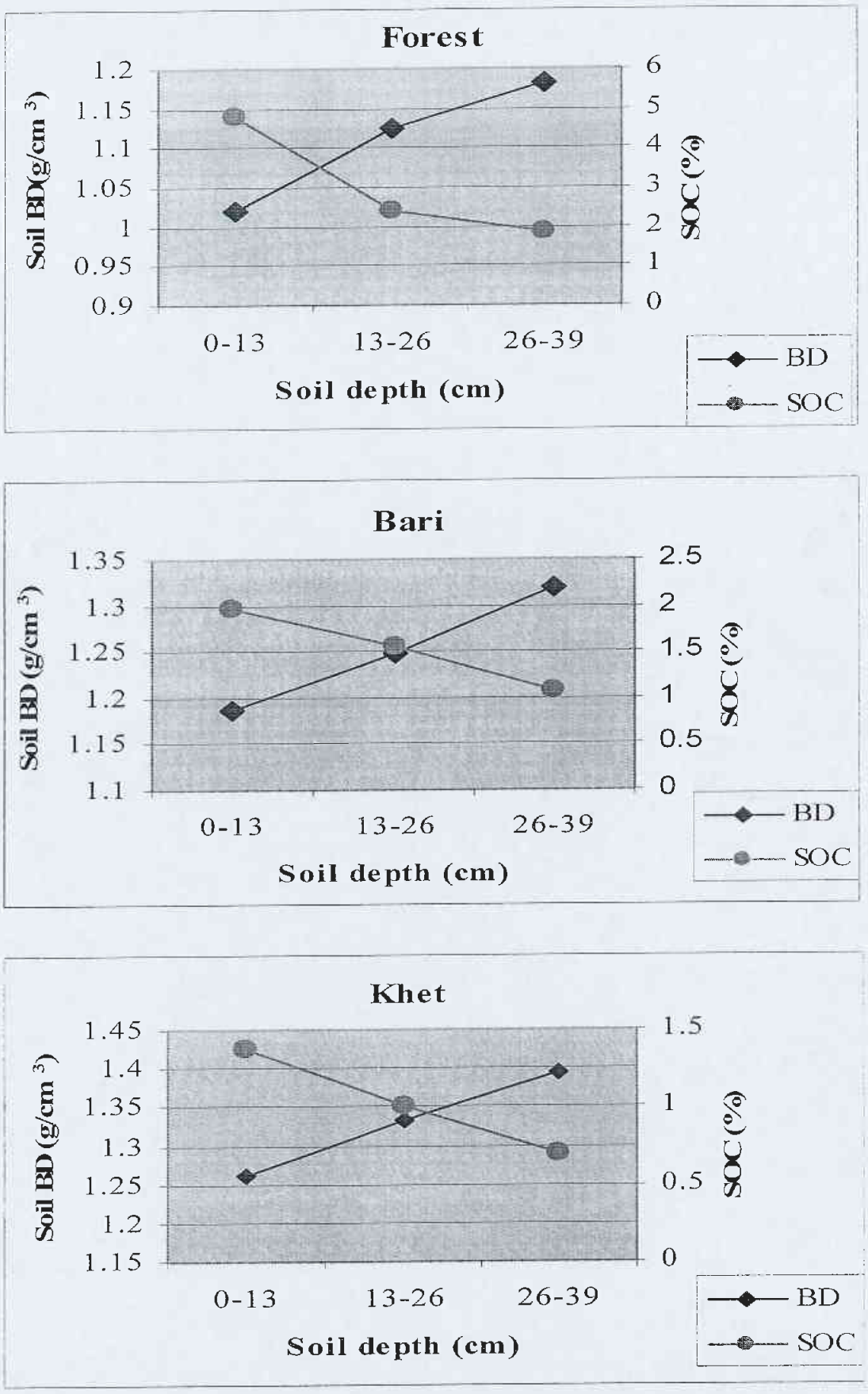


Figure 17: Soil organic carbon content and BD in different depths of various land uses

Table 11: Status of SOC (above 39 cm) in Balkhu Khola watershed

Location	Description	SOC %
Thankot Forest, F_1	Regenerating forest	1.44
Chitlang Forest, F_2	Dense-natural forest	6.63
Mahadevsthan, F_3	Dense plantation forest	4.28
Mahadevsthan, F_4	Dense-natural forest	4.67
Matatirtha Pine, F_5	Pine forest	1.84
Matatirtha, F_6	Well managed community forest	4.31
Machhagau, F_7	Plantation forest	1.17
Dahachok, F_8	Degrading forest	1.05
Mattikhel, F_9	Regenerating forest	1.16
Thankot, B_1	Maize-vegetable cropping	2.90
Naikap PuranoBhanjyang, B_2	Maize-millet cropping	0.93
Jogigufa, B_3	Maize-millet cropping	0.97
Bhusingkhel, B4	Maize-millet cropping	1.33
Bakhatigau B_5	Maize-legume cropping	1.73
Gumaune B6	Maize-legume cropping	1.02
Baligaun, B_7	Maize-legume cropping	1.68
Bambutar B8	Maize-vegetable cropping	1.65
Syuchatar, K_1	Rice-wheat cropping	1.49
Naikap Naya Bhanjyang, K_2	Rice- vegetable cropping	1.58
Badbhanjyang, K_3	Rice-fallow	1.02
Totipakha, K_4	Rice-fallow	1.14
Chaukitar, K_5	Rice-fallow	0.68
Balambu, K_6	Rice-fallow	0.61
Gurjhudhara, K_7	Rice-fallow	0.53
Satungal, K_8	Rice-wheat cropping	1.13
Kirtipur, K_9	Rice-fallow	0.62
Tyanglaphant, K_{10}	Rice-fallow	1.23
Thankot, K_{11}	Rice-fallow	0.63
Kalanki, K_{12}	Rice-maize-vegetable cropping	1.34
Bhurtelthok, Bh_1	Bushland	1.13
Jhanglejhiti, G_1	Grassland	1.35

F=forest, B=Bari, K=Khet, Bh=Bush land and G=Grassland

High values of SOC were seen for dense broad leaved forest than in pine forest, while very low SOC contents occurred under degraded conditions. The regenerating forest also has less SOC than dense forest. Similar result was found by *Baral et. al. 1999 cited by Bajracharya et. al., 2004.* (Annex I: C).

Findings of low SOC in degraded forest by *Schrier et. al. 1999* cited by Bajracharya et. al., 2004, low SOC in plantation forest reported by *Howell (1986)* and higher SOC in well managed forest than slightly degraded forest *(Awasthi et. al., 2002 cited by Bajracharya et. al., 2004),* also support the findings of present study (Annex I: C).

SOC variation within cultivated areas likely reflected location (i.e. reflecting landscape position, slope aspect, geology, parent material, moisture and temperature regimes, etc.), OM input and differences in soil type. *Bari* lands are sloping erosional upland areas while *Khet* depositional lowlands bordering streams and at foot slope positions in the valley.

Table 12: Soil organic carbon stock (t/ha) of different land uses in all depths

Soil depth (cm)	Land use type	Soil Organic Carbon (t/ha)		
		Min	Max	Mean ± SE
Forest	0-13	14.10	81.31	41.16 ± 8.88
	13-26	9.45	53.11	23.75 ± 4.49
	26-39	4.25	32.08	16.45 ± 3.2
Bari	0-13	17.58	35.91	25.93 ± 2.29
	13-26	10.53	37.00	20.50 ± 3.15
	26-39	8.21	32.00	14.76 ± 2.65
Khet	0-13	7.37	31.16	21.78 ± 2.11
	13-26	6.76	29.11	16.50 ±1.87
	26-39	2.43	19.39	11.05 ± 1.65

5.2.3. Dry Bulk Density: Effect of Land Use and Soil Depth

Bulk density of forest was found to be least followed by Bari and khet for all incremental depths **(Figure 18a).** The result generally agree with those of *Hajabbasi et al. (1997)* and *Sahani and Behera (2000)* who reported an increase in BD due to deforestation and continuous cultivation.

Land use/cover changes from forest to cultivation lead to surface compaction and significant decrease in SOC resulting in increased bulk density *(Islam and Weil, 2000).*

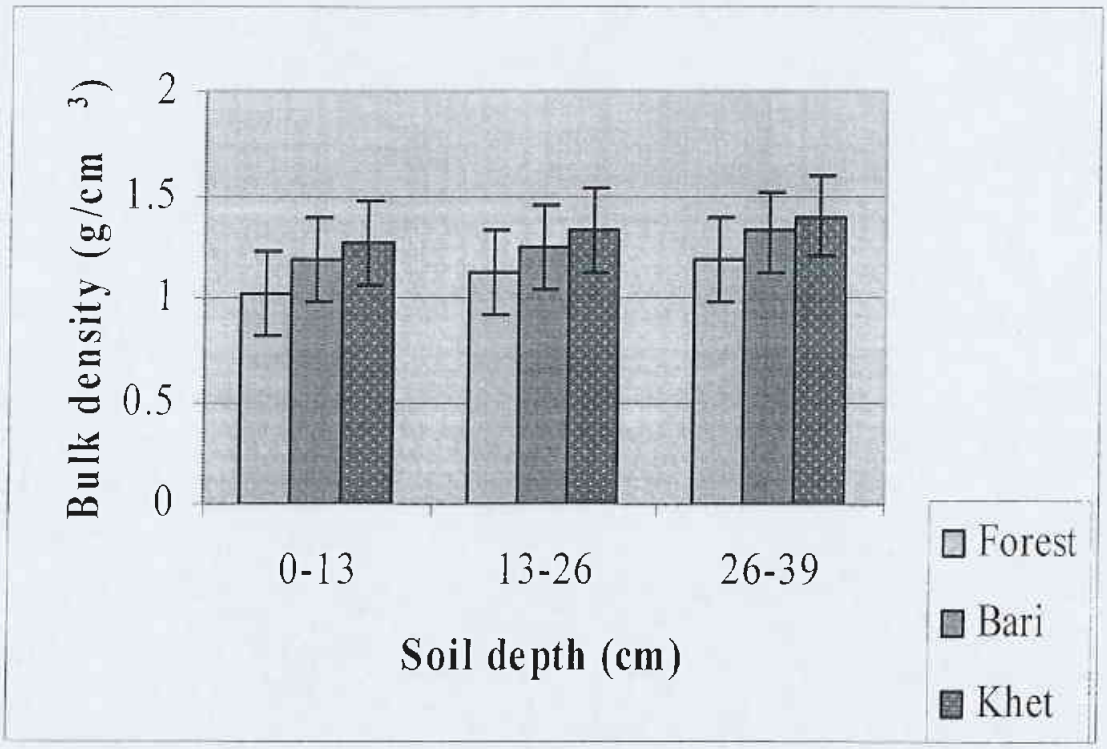


Fig 18 a: Bulk density of soil in different soil depths of various land uses, vertical bars show the standard errors

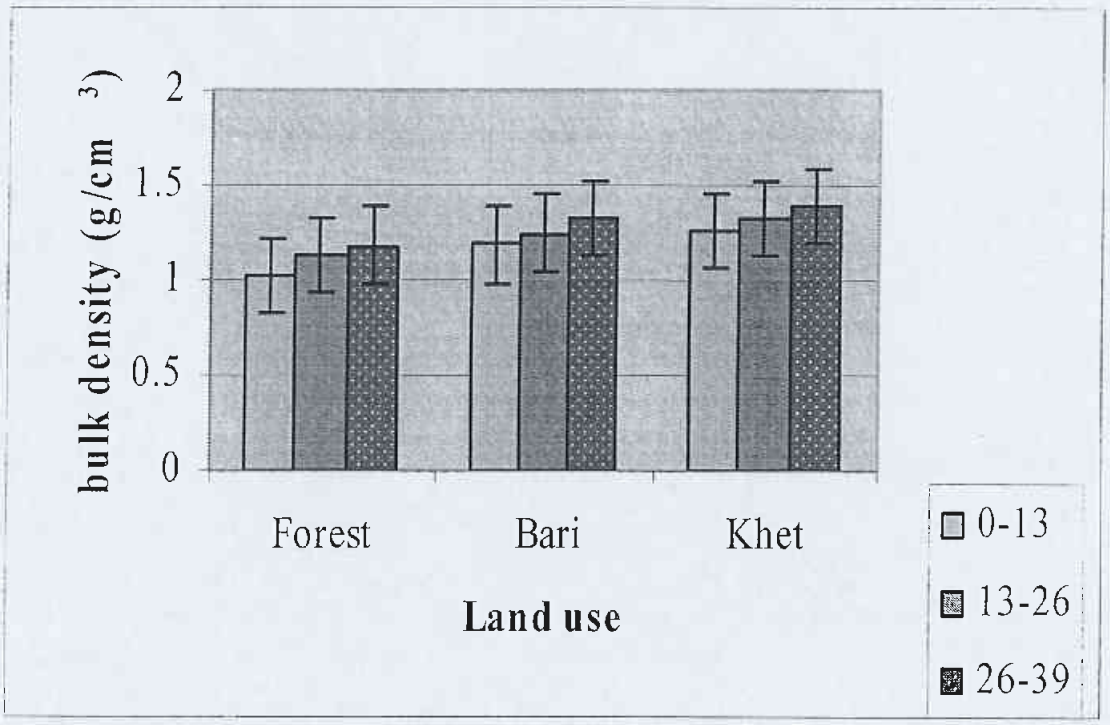


Fig 18 b: Bulk density of soil in different land uses for all incremental depth, vertical bars show the standard errors

In a twenty-year rice-wheat experiment, the soil BD ranged from 1.40 Mg/m^3 in treatments with FYM application to 1.65 Mg/m^3 in the control plots without FYM (*Gami et al., 2001).* General trend was a gradual increase in bulk density with depth. Similar result of increasing trend of bulk density from top to deeper layers was found in Indian forests of Dhaili and Toli Van Panchayat by *Kyoto: Think Global, Act Local Project (2004).* Forest soils expectedly showed significantly lower BD in all depths than other land uses due to high SOC content **(Figure 18b).** Likewise input to the soil during cultivation plays important role in soil BD.

Table13: Soil bulk density (g/cm^3) in different depths of various land use types

Soil depth (cm)	Land use type	Soil Bulk Density (g/cm^3)		
		Min	Max	Mean ± SE
0-13	Forest	0.77	1.29	1.01 ± 0.06
	Bari	1.09	1.25	1.18 ± 0.02
	Khet	1.10	1.41	1.25 ± 0.03
13-26	Forest	0.9	1.40	1.12 ± 0.06
	Bari	1.10	1.31	1.24 ± 0.02
	Khet	1.11	1.47	1.33 ± 0.03
26-39	Forest	0.93	1.42	1.18 ± 0.06
	Bari	1.16	1.48	1.32 ± 0.03
	Khet	1.16	1.59	1.39 ± 0.03
Attribute	F-test			P value
Land use	20.014			0.000
Depth	7.822			0.001
Land use x depth	NS			

5.2.4. Effects of Land Use Change on SOC Stock

The land transformation from forest to other usage leads to decline not only in plant biomass but also in SOC and other nutrients. The loss in the SOC on land use basis was 64% *(Sharma et. al. 2004).* Studies conducted in other parts of the tropics and sub-tropics approximated 20 to 50 % loss of the original carbon in topsoil after clearing of forest and their conversion into farmland *(Sombroek et al., 1993).* The result of present study showed conversion of forestland into cultivation land may result in 34.11% losses of SOC compared to SOC level in the forest. On the area basis, the SOC losses were at the rate of 2.77 kg C m^2 by converting forest to cultivation. The conversion of forest in to *Bush* and grassland may result in net loss of

2.83 and 4.32 kg C m^2 (assuming that all other factor remains the same). *Cleveland et. al. (2003) cited by Sharma et. al. (2004)* also found land transformation, a major cause of reduction in organic carbon, other nutrients and microbial biomass in soil. The estimated effects of other internal trading of land use changes are shown in **Table 14.**

The internal trading of land use area between the land uses during the 16 years period (1978-1994) indicated net loss of SOC stock by 6718.17 ton i.e 2.71% of the original stock in the Balkhu Khola watershed. Similarly, land use change during 11 years period between 1994-2005 shows net gain of SOC by 29358.41 ton i.e. 12.46% of the original stock.

Table14: Effect of land use changes in SOC stock

Land use change from-to	Change area		Change in SOC stock			
				TC		
	1978-1994	1994-2005	KgC/m^2	1978-1994	1994-2005	% change
Forest to cultivation	11.98	18.73	-2.77	-331.84	-518.82	-34.11
Forest to Bush	272.59	12.24	-2.83	-7714	-340	-34.85
Forest to grass		0.79	-4.32		-34	-53.20
Bush to cultivation	37.93	17.63	0.06	22.75	10.57	1.12
Bush to forest	4.83	1034.57	2.83	136.68	29270	34.85
Bush to grass		13.87	-1.49		-210	-28.16
Cultivation to forest	58.07	50.81	2.77	1608.53	1407.43	34.11
Cultivation to bush	67.03	31.79	-0.06	-440	-19.07	-1.12
Cultivation to Grass		13.40	-1.55		-207.70	-28.97
Total				-6718.17	29358.41	

TC= Carbon in Ton

This indication is based entirely on the conversion of land use areas and assuming similar SOC levels as found in this study for a given land use category in different time period for the entire watershed. The net change in SOC stock of the time interval is showed in **Table 15.**

Conversion of forest to grassland, bush land and cultivation and conversion of bush land to grassland, both processes may attribute to SOC losses from the watershed over a period of time. Due to the fact that several relevant factors and processes (topographic, climatic and socio economic limitation) are ignored in such estimates,

the implication of this on the effects of future land use changes should be interpreted with caution.

Table 15: Net change in SOC within 27 years from 1978-2005

Land use	1978		1994		2005	
	Area (ha)	SOC, MTC	Area (ha)	SOC, MTC	Area (ha)	SOC, MTC
Forest	506.87	41.16	287.18	23.32	1325.27	107.61
Cultivation	3083.10	164.94	2903.73	155.34	2741.7	146.68
Bush	779.75	41.25	1076.60	56.95	44.17	2.33
Grassland					28.78	1.09
settlement	51.13		149.77		176.78	
Other			3.56		104.12	
Total	4420.84	247.35	4420.84	235.61	4420.82	257.71

MTC=Metric Ton of Carbon

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The major conclusions drawn from present study are as follows.

- The result of this study indicated that land use has significant effect on SOC content in the soil depth
- Soils under natural vegetation have higher SOC content compared to cultivated soil, forest soil has higher SOC stock than in other land use systems
- In watershed level cultivation lands have high SOC which is attributed by large cover area and SOC stock
- Within the cultivated soils *Bari* soils has significantly higher SOC than *Khet*, which is attributed to the organic input by the farmers
- A decrease in SOC content with depth was observed regardless of land use type
- Land use has also significant effect on dry bulk density of soil
- Soil under natural ecosystem has low bulk density than cultivated soils; among cultivated soils Khet soil has higher bulk density than Bari
- Dry bulk density and SOC are negatively correlated
- Land use/ land cover has changed in positive direction in terms of natural ecosystem conservation, at upper parts of the watershed, while in valley floor settlement has been increasing haphazardly
- Changes in land use and land cover impart important effect on soil organic carbon sinking; SOC has lost from the watershed when forest changed to other ecosystems while reverse phenomenon has enhanced the SOC stock

6.2. Recommendation

Present study is initial step to explore the interaction of watershed components. There are lots of factors which effect on carbon sinking and dynamism within the watershed. Although research in this field is encouraging in global scale there are very few studies in Nepal concerning carbon sinking and dynamism. On the basis of knowledge gained through this study following recommendations are considered.

- Detail study on carbon dynamism and factors effecting in it (topography, geology, soil types and aggregates, climate and vegetation) should conduct especially in Nepalese mountain watershed
- Research on carbon content in soil components of representative forest types of Nepal and humus decomposition rates should be conducted
- Valuation of regenerating forest especially community forest in terms of biomass, soil and microbial carbon should conduct which make people aware about hidden significance of natural ecosystem conservation, without it we can not trade carbon as per Kyoto Protocol
- Forest as well as cultivation land management and product harvesting data should be carefully and precisely recorded
- Data consistency is an important component during spatial analysis, so consistent data should make easily available by concern body, therefore new researcher can use GIS technology easily as a major research tool

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ANNEXES

Annex I: SOC Status in Central Nepal

Annex I, A: Status of soil organic carbon (SOC) in upland agricultural soils of the Central Nepal Middle Mountains (top 20, 30 or 40 cm of soil)

Location VDC/Watershed	District (Dev. Region)	Description (Soil/cropping pattern)	SOC (%)	BD (Mg/m^3)	Source
Chhaimale Mahadevsthan Godavari Gotikhel Chitlang Phakhel Kalati Riyale Naubise	Kathmandu Central Lalitpur Central Makwanpur Central Kavre Central Dhading	Red/red-brown soils somewhat acidic Maize-millet, Maize-mustard, vegetables	1.44 1.48 1.31 2.01 1.56 1.67 1.74 1.76 1.18	N/A	Bajracharya (1999)
Dhulikhel	Kavre	Sandy-acidic; maize/ soybean-mustard	0.95	1.20	Atreya (2002)
Raigau	Dhading	Red-gravelly; maize-chillies	2.13	1.22	Pathak (2003)
Pokare water-shed	Dhading	Maize-millet, mustard, chillies	1.41	N/A	Scherchan et al. (2003)
Mardi W/S	Kaski Western	Red-brown; maize-millet-vegetables	2.50	1.00	Shresth et al. (2003)
Dordor gau Lumle	Tanahun Kaski	Moderately acidic soil maize-fingermillet Nine districts (mean)	0.82 3.20	N/A	Tripathi (2002) Tripathi (1999)
	Western	Red upland soil Managed bari Dryland bari	2.90 3.20 1.20	N/A	Vaidya et al. (1999)
Naldung, Chitte	Kavre Central	Danda khet, rice-wheat	2.00	N/A	Adhikari et al. (1999)
Jhikhu Khola watershed	Kavre Central	Degraded red soil Degraded brown soil	0.90 1.00	N/A	Shah et al. (1999)
Bela sub-water -shed	Kavre	Red soil Degraded soil	0.99 0.68	N/A	Brown et al. (1999)
All locations		Mean Std.Dev.	1.65 0.73		

BD = dry soil bulk density; N/S = data not available

Source: Bajracharya et. al. 2004

Annex I, B: Soil organic carbon (SOC) status of lowland agricultural soils of the Central Nepal Middle Himalaya (top 20, 30 or 40 cm soil depths)

Location VDC/Watershed	District (Dev. Region)	Description (Soil/cropping pattern)	SOC (%)	BD (Mg/m^3)	Source
Chhaimale Mahadevsthan Godavari Gotikhel Chitlang Phakhel Kalati Riyale Naubise	Kathmandu Central Lalitpur Central Makwanpur Central Kavre Central Dhading	Brown/black-brown soil alluvial or lacustrine Rice-wheat, rice-veg.- wheat, rice-potato-wheat rice-veg.-potato	1.11 1.54 1.69 1.62 2.22 1.63 1.89 1.98 0.98	N/A	Bajracharya (1999)
Pokare water-shed	Dhading	Rice-wheat, vegetables rice-potato, vegetables	1.38	N/A	Scherchan et al. (2003)
Mardi	Kaski Western	Sandy, alluvial deposits rice-wheat, rice-vegetable	0.50	1.26	Shresth et al. (2003)
Sipaghat, Mahadevsthan Singhe, Nayagau	Kavre Central	Alluvial, valley soils rice-wheat	1.50 2.10	N/A	Adhikari et al. (1999)
Dordor Tar Chambas Lumle	Tahahun Western Kaski Western	upland rice-black gram rice-wheat Managed khet, 9 districts rice-wheat	1.08 0.92 1.82 2.60	N/A	Tripathi (2002) Tripathi (1999) Tripathi (1997)
	Western hills	Black soil Managed khet	3.10 2.60	N/A	Vaidya et al. (1999)
All locations		Mean Std.Dev.	1.70 0.65		

BD = dry soil bulk density; N/S = data not available

Source: Bajracharya et. al. 2004

Annex I, C: Status of soil organic carbon (SOC) in forest soils of the Central Nepal Middle Himalaya (top 15 or 20 cm soil depth)

Location VDC/Watershed	District (Dev. Region)	Description	SOC (%)	BD (Mg/m^3)	Source
Chhaimale Mahadevsthan Godavari Gotikhel Chitlang Phakhel Kalati Riyale Naubise	Kathmandu Central Lalitpur Central Makwanpur Central Kavre Central Dhading	Moderately managed forest Dense community forest Moderately managed Well-managed CF Slightly degraded forest Degraded forest Moderately managed Slightly degraded forest	3.08 3.01 5.55 3.62 3.85 1.77 1.15 3.05 2.39	N/A	Bajracharya (1999)
Pokare water-shed	Dhading	Degraded to moderately managed forests	1.50	N/A	Scherchan et al. (2003)
Mardi watershed	Kaski Western	Well managed	2.90	0.70	Shresth et al. (2003)
Mardi watershed Fewa watershed	Kaski Western	Well managed Slightly degraded forest	5.00 2.00	N/A	Awasthi et al. (2002)
Panchkhal	Kavre Central	Plantation forest	0.55	N/A	Howell (1986)
Panchkhal	Kavre Central	Degraded forest Plantation fores Sal regeneration forest	0.10 0.40 1.20	1.40 1.50 1.23	Baral et al. (1999)
Jhikhu Khola	Kavre	Degraded forest	0.50	N/A	Schrier et al. (1999)
All locations			2.31 1.58		

BD = dry soil bulk density; N/S = data not available.

Source: Bajracharya et. al. 2004

Annex I, D: Soil organic carbon (SOC) status in shrub/grazing land soils of the Central Nepal Middle Himalaya (top 15 or 20 cm soil depth)

Location VDC/Watershed	District (Dev. Region)	Description	SOC (%)	BD (Mg/m^3)	Source
Chhaimale Mahadevsthan Godavari Gotikhel Chitlang Phakhel Kalati Riyale Naubise	Kathmandu Central Lalitpur Central Makwanpur Central Kavre Central Dhading	Grass/shrub grazing/pasture land	2.85 3.78 2.31 2.85 2.16 1.77 0.69 2.07 1.85	N/A	Bajracharya (1999)
Mardi watershed	Kaski Western	Grass/shrub	1.70	1.00	Shresth et al. (2003)
Jhikhu Khola	Kavre	Shrub/degraded forest	0.99 1.01	N/A	Shah et al. (1999) Brown et al. (1999)
All locations			2.00 0.89		

BD = dry soil bulk density; N/S = data not available

Source: Bajracharya et. al. 2004

Annex I, E: Mean SOC pools and total stocks for different land uses in the Nepal Middle Mountains Region

Land Use	**Area (m ha)**	**SOC (%)**	**BD (Mg/m^2)**	**Mean C pool (KgC/m^2)**	**Total stock (MtC)**
Forest (0-0.3m)	2.20	2.31	0.70	4.85	196.00
Forest (0.3-1m)		0.58	1.00	4.06	
Shrub (0-0.3m)	0.68	2.00	1.00	6.00	100.30
Shrub (0.3-1m)		1.00	1.25	8.75	
Agric. (0-0.3m)	1.22	1.68	1.25	6.30	127.1
Agric. (0.3-1m)		0.42	1.40	4.12	
Other	0.34				
Totals	4.44				372.4

Source: Bajracharya et. al. 2004

Annex II: Other Relevant Tabular Information

Annex II, A: Listing of feature codes

Feature Class	Feature Type	Feature Category	Feature Component	Feature Code
Transportation10	Roads 1	Highway 1	Centre line 1	10111
		Feeder Road 2	Centre line 1	10121
		District Road 3	Centre line 1	10131
		Other Road 4	Centre line 1	10141
	Trails and	Cart track 1	Centre line 1	10211
	tracks 2	Main Trail 2	Centre line 1	10221
		Foot path 3	Centre line 1	10231
	Railway 3	Trunk 1	Centre line 1	10311
		Other 2	Centre line 1	10321
	Ropeway 4	0	Centre line 1	10401
			Tower 2	10402
	Bridge 5	Road 1	Centre line 1	10511
		Trails & tracks 2	Centre line 1	10521
		Railway 3	Centre line 1	10531
	Other	Causeway1	Centre line 1	10611
	crossing 6	Ford 2	Centre line 1	10621
		Ferry 3	Centre line 1	10631
	Tunnel 7	Road Tunnel 1	Centre line 1	10711
		Railway Tunnel 2	Centre line 1	10721
		Canal Tunnel 3	Centre line 1	10731
	Airport 8	Runway 1	Centre line 1	10811
		Taxiway 2	Centre line 1	10821
		Tower 3	Location 0	10830
Building15	Built up	0	Edge 1	15101
	area 1		Area extent 2	15102
	Building 2	0	Edge 1	15201
			Area extent 2	15202
	Religious 3		Edge 1	15301
			Area extent 2	15302
	Other		Edge 1	15401
	structure 4		Arer extent 2	15402

Feature Class	Feature Type	Feature Category	Feature Component	Feature Code
Topography20	Contour 1	Index 1	0	20110
		Intermediate 2	0	20120
		Supplementary 3	0	20130
	Characteristic	Embankment,	Top edge 1	20211
	line 2	Cutting, cliff or		
		cutting 1	Extent (area) 2	20212
		Quarry, pit 2	Top edge 1	20221
			Extent (area) 2	20222
	Characteristic	Peak 1	0	20310
	point 3	Pit (Local) 2	0	20320
		Pass 3	0	20330
	Spot			
	elevation 4	0	0	20400
Landcover25	cultivation 1	0	Edge 1	25101
			Extent (Area) 2	25102
	Vegetation 2	Forest 1	Edge 1	25211
			Extent (Area) 2	25212
		Orchard 2	Edge 1	25221
			Extent (Area) 2	25222
		Plantation 3	Edge 1	25231
			Extent (Area) 2	25232
		Nursery 4	Edge 1	25241
			Extent (Area) 2	25242
		Grass 5	Edge 1	25251
			Extent (Area) 2	25252
		Bush 6	Edge 1	25261
			Extent (Area) 2	25262
		Bamboo 7	Edge 1	25271
			Extent (Area) 2	25272
		Scattered tree	Edge 1	25281
		area 7	Extent (Area) 2	25282
		Tree 9	Single tree 1	25290
			Center line of row	25291
			of trees 2	
	Other 3	Rock outcrop 1	Edge 1	25311
			Extent (Area) 2	25312
		Swamp 2	Edge 1	25321
			Extent (Area) 2	25322
		Sand 3	Edge 1	25331
			Extent (Area) 2	25332
		Snow 4	Edge 1	25341
			Extent (Area) 2	25342
		Barren Land 5	Edge 1	25351
			Extent (Area) 2	25352

Feature Class	Feature Type	Feature Category	Feature Component	Feature Code
Hydrography30	River/Streams 1	Bank 1	0	30110
		Flow line 2	0	30120
		Edge of water body 3	0	30130
			Extent (Area) 2	30131
	Glacier 2	0	Center line of glacier 1	30201
			Edge of moraine 2	30202
	Canal 3	0	Center line 1	30301
	Pond or lake 4	0	Edge 1	30401
			Extent (Area) 2	30402
	Structure	Dam 1	Center line (Dam axis) 1	30511
	Hydro 5	Weir 2	Center line (Axis) 1	30521
		Sluice gate 3	Center line 1	30531
		Spillway 4	Center line 1	30541
	Associated	Well 1	0	30610
	Hydro 6	Water Tower 2	0	30620
		Hydrant 3	0	30630
		Water Spout 4	0	30640
		Spring 5	Edge 1	30651
		Ooze away place 6	Edge 1	30671
Utility35	Electricity 1	High Tension line	Centre line 1	35111
		11 KV and above 1	Pylon 2	35112
		Distribution	Centre line 1	35121
		(Consumer) line 2		
	Telephone 2	0	Centre line 1	35201
	Telegraph 3	0	Centre line 1	35301
	Transmission	0	Location 0	35400
	tower 4			
	Pipe line	0	Centre line 1	35501
	(Water) 5			
	Sewerage	0	Centre line 1	35601
	line 6			

Feature Class	Feature Type	Feature Category	Feature Component	Feature Code
Control points40	Bench	0	0	40100
	Marks 1			
	Planimetric	0	0	40200
	control 2			
	Three			
	dimentional 3	0	0	40300
Administrativ e area45	Country 1	0	International Boundary 1	45101
		0	Extent (Area) 2	45102
		0	International Boundary	45103
			Pillar 3	
	Region 2	0	Boundary line 1	45201
		0	Extent (Area) 2	45202
	Zone 3	0	Boundary line 1	45301
		0	Extent (Area) 2	45302
	District 4	0	Boundary line 1	45401
			Extent (Area) 2	45402
	VDC,Muni-	0	Boundary line 1	45501
	cipality 5	0	Extent (Area) 2	45502
		Ward 6	Boundary line 1	45601
		0	Extent (Area) 2	45602
Designated area50	National	0	Boundary Line 1	50101
	Parks,			
	Wild Life			
	Reserves 1		Extent (Area) 2	50102
55				55
60				60
65				65
70				70
75				75
80				80
85				85
90				90
95				95

Source: Survey Department, Kathmandu, Nepal

Annex II, B: Rainfall records at Thankot station (Index: 1015, Elevation: 1630 m, Latitude: 27°41' and Longitude: 85°12').

Year\Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1991	25.2	21.3	71.1	133.7	87.8	215	224.5	548.9	255.8	0.0	0.0	33.4	1616.7
1992	10.4	23.5	1.0	4.0	113.5	5.1	363.2	530.3	264.8	135.2	14.5	5.1	1470.6
1993	29.3	49.5	59.8	124	166	194.6	593.2	597	184.4	0	0	DNA	1997.8
1994	44.3	36.3	36.6	14.2	150.7	490.8	382	549.3	438.5	0	16	0	2158.7
1995	3.5	44.5	37.4	8.3	104.8	864.1	638.1	359.1	225.1	21.4	136.4	17.5	2460.2
1996	70.5	20.1	3.1	33.8	100.6	400.1	420.3	454.7	157.1	10.5	0	0	1670.8
1997	29.2	7.2	21.5	95.8	93.3	238	547.9	265.9	122.4	26.3	10.4	69.6	1527.5
1998	0	24	97.9	81.2	232.2	209.8	677.5	538.2	103.3	38.4	11.3	0	2013.8
1999	4.3	0	0	7.1	153.7	467.8	709	438.8	256.6	197.6	0	0	2234.9
2000	1.6	3.3	28.8	31.0	172.5	363.9	342.8	552.6	126.1	28.1	0	0	1650.7
2001	7.7	34.7	9.9	56.6	209.8	283.8	447.6	355.9	224	42.3	38.5	0	1710.8
2002	48.8	48.7	67.6	42.9	340	215.4	849.2	439.5	145	14.3	5.2	0	2216.6
2003	21.3	101	42.1	60.1	43.6	209.9	558.8	267.7	180.2	7.8	0	13.4	1505.6
2004	8.0	0	17.5	98.2	229.5	145.5	517.9	DNA	180.8	32.0	2.5	0	1231.9

Source: Department of Hydrology and Meteorology, Babarmahal, Kathmandu, 2005

Annex III: Detail Tabular Output of Soil Samples and Land Use Change Analysis

Annex III, A: Soil organic carbon and bulk density of all sampling points with all depths

Sampling points	Depth, cm	Bulk density g/cm^3	SOC %	SOC kg/m^2
Thankot Forest, F_1	0-13	1.298	1.754	2.068
	13-26	1.294	1.500	1.793
	26-39	1.396	1.067	1.166
Chitlang Forest, F_2	0-13	0.830	10.389	5.974
	13-26	0.916	5.772	3.097
	26-39	0.935	3.75	2.324
Mahadevsthan Forest, F_3	0-13	0.923	10.389	7.692
	13-26	1.402	1.443	1.959
	26-39	1.421	1.010	0.848
Mahadevsthan Forest, F_4	0-13	0.965	7.012	8.131
	13-26	0.976	4.368	5.311
	26-39	1.036	2.652	3.208
Matatirtha Pine Forest, F_5	0-13	1.260	2.279	2.991
	13-26	1.263	1.606	2.103
	26-39	1.278	1.638	1.884
Matatirtha, F_6	0-13	0.770	6.240	5.146
	13-26	0.905	3.432	3.344
	26-39	1.022	3.276	2.836
Machhagau,F_7	0-13	1.258	1.404	1.856
	13-26	1.362	1.185	1.517
	26-39	1.333	0.936	1.260
Dahachok Forest, F_8	0-13	1.013	1.778	1.778
	13-26	1.113	0.936	0.945
	26-39	1.154	0.436	0.425
Mattikhel, F_9	0-13	0.858	1.419	1.410
	13-26	0.903	1.170	1.313
	26-39	1.050	0.920	0.935
Thankot, B_1	0-13	1.244	3.102	3.591
	13-26	1.318	3.030	3.700
	26-39	1.334	2.597	3.201
Naikap Purano Bhanjyang, B_2	0-13	1.097	1.404	1.758
	13-26	1.109	0.780	1.053
	26-39	1.239	0.624	0.955
Jogigufa, B_3	0-13	1.232	1.716	2.528
	13-26	1.246	0.780	1.222
	26-39	1.487	0.436	0.821
Bhusingkhel,B_4	0-13	1.113	1.560	2.098
	13-26	1.228	1.310	1.984
	26-39	1.288	1.123	1.697
Bakhatigau, B_5	0-13	1.165	2.324	3.436
	13-26	1.211	1.856	2.898
	26-39	1.166	1.014	1.511

Sampling points	Depth, cm	Bulk density g/cm^3	SOC %	SOC kg/m^2
Gumaune, B_6	0-13	1.181	1.466	2.073
	13-26	1.307	0.873	1.384
	26-39	1.383	0.748	1.262
Baligau, B_7	0-13	1.251	2.152	2.542
	13-26	1.280	1.872	2.076
	26-39	1.321	1.045	1.196
Bambutar, B_8	0-13	1.201	2.052	2.274
	13-26	1.283	1.873	2.083
	26-39	1.344	1.035	1.169
Syuchatar Khet, K_1	0-13	1.201	1.872	2.873
	13-26	1.282	1.747	2.911
	26-39	1.318	0.873	1.495
Naikap Naya Bhanjyang, K_2	0-13	1.133	1.872	2.757
	13-26	1.159	1.778	2.556
	26-39	1.167	1.092	1.449
Badbhanjyang, K_3	0-13	1.418	1.248	2.250
	13-26	1.415	0.998	1.798
	26-39	1.428	0.842	0.769
Totipakha, K_4	0-13	1.235	1.653	2.612
	13-26	1.400	0.936	1.595
	26-39	1.595	0.858	1.756
Chaukitar K_5	0-13	1.344	1.248	2.102
	13-26	1.408	0.499	0.892
	26-39	1.391	0.312	0.506
Balambu, K_6	0-13	1.307	0.811	1.359
	13-26	1.478	0.717	1.322
	26-39	1.526	0.327	0.624
Gurjhudhara, K_7	0-13	1.284	0.686	1.145
	13-26	1.444	0.624	1.167
	26-39	1.530	0.280	0.554
Satungal, K_8	0-13	1.367	1.404	2.441
	13-26	1.374	1.029	1.825
	26-39	1.330	0.967	1.660
Kirtipur, K_9	0-13	1.237	1.684	2.530
	13-26	1.364	0.717	1.243
	26-39	1.421	0.468	0.855
Tyanglaphant, K_{10}	0-13	1.100	1.560	2.218
	13-26	1.118	1.248	1.806
	26-39	1.210	0.904	1.421
Thankot, K_{11}	0-13	1.124	0.733	0.737
	13-26	1.218	0.686	0.676
	26-39	1.410	0.483	0.243

Sampling points	Depth, cm	Bulk density, g/cm^3	SOC %	SOC kg/m^2
Kalanki, K_{12}	0-13	1.369	1.775	3.116
	13-26	1.321	1.185	2.019
	26-39	1.413	1.060	1.939
Bhurtelthok, Bh_1	0-13	1.222	2.184	3.309
	13-26	1.338	0.748	1.158
	26-39	1.392	0.468	0.846
Jhanglejhiti, G_1	0-13	0.914	2.496	2.359
	13-26	1.161	0.936	0.966
	26-39	1.410	0.624	0.499

F=forest, B=Bari, K=Khet, Bh=Bush land and G=Grassland

Annex III, B: Area (Ha) under different land uses in 1978

Land use/ land cover	Area in Ha.	Percentage
Cultivation	3083.10	69.74
Forest	506.86	11.46
Bush	779.75	17.64
Settlement	51.13	1.15
Total	4420.84	99.99

Source: Land Utilization Map of LRMP, 1978

Annex III, C: Area (Ha) under different land uses in 1994

Land use/land cover	Area in Ha	Percentage
Cultivation	2903.73	65.68
Bush	1076.60	24.35
Forest	287.18	6.49
Settlement	149.77	3.38
Open/barren	1.09	0.02
Cliff	2.47	0.06
Total	4420.84	99.98

Source: Topographical Map of Survey Department, 1994

Annex III, D: SOC % in different sampling points with incremental depths

Sampling points	0-13 cm	13-26 cm	26-39 cm
Thankot Forest, F_1	1.754	1.500	1.067
Chitlang Forest, F_2	10.389	5.772	3.750
Mahadevsthan, F_3	10.389	1.443	1.010
Mahadevsthan, F_4	7.012	4.368	2.652
Matatirtha Pine, F_5	2.279	1.606	1.638
Matatirtha F_6	6.240	3.432	3.276
Machhagau, F_7	1.856	1.517	1.260
Dahachok, F_8	1.778	1.053	0.955
Mattikhel F_9	1.419	1.170	0.920
Thankot, B_1	3.102	3.030	2.597
Naikap Purano Bhanjyang, B_2	1.404	0.780	0.624
Jogigufa, B_3	1.716	0.780	0.436
Bhusingkhel, B_4	1.560	1.310	1.123
Bakhatigau B_5	2.324	1.856	1.014
Gumaune, B_6	1.466	0.873	0.748
Baligaun, B_7	2.152	1.872	1.045
Bambutar, B_8	2.052	1.873	1.035
Syuchatar, K_1	1.872	1.747	0.873
Naikap Naya Bhanjyang, K_2	1.872	1.778	1.092
Badbhanjyang, K_3	1.248	0.998	0.842
Totipakha, K_4	1.653	0.936	0.858
Chaukitar, K_5	1.248	0.499	0.312
Balambu, K_6	0.811	0.624	0.280
Gurjhudhara, K_7	0.686	0.624	0.280
Satungal, K_8	1.404	1.029	0.967
Kirtipur, K_9	1.684	0.717	0.468
Tyanglaphant, K_{10}	1.560	1.248	0.904
Thankot, K_{11}	0.733	0.686	0.483
Kalanki, K_{12}	1.775	1.185	1.060
Bhurtelthok, Bh_1	2.184	0.748	0.468
Jhanglejhiti, G_1	2.496	0.936	0.624

F=forest, B=Bari, K=Khet, Bh=Bush land and G=Grassland

Annex III, E: SOC stock (t/ha) in different sampling points for all depths

Sampling points	0-13 cm	13-26 cm	26-39 cm
Thankot Forest, F_1	20.68	17.93	11.66
Chitlang Forest, F_2	59.74	30.97	23.24
Mahadevsthan, F_3	76.92	19.59	8.48
Mahadevsthan, F_4	81.31	53.11	32.08
Matatirtha Pine, F_5	29.91	21.03	18.84
Matatirtha F_6	51.46	33.44	28.36
Machhagau, F_7	18.56	15.17	12.6
Dahachok, F_8	17.78	9.45	4.25
Mattikhel F_9	14.1	13.13	9.35
Thankot, B_1	35.91	37	32.01
Naikap Purano Bhanjyang, B_2	17.58	10.53	9.55
Jogigufa, B_3	25.28	12.22	8.21
Bhusingkhel, B_4	20.98	19.84	16.97
Bakhatigau, B_5	34.36	28.98	15.11
Gumaune, B_6	20.73	13.84	12.62
Baligau, B_7	25.42	20.76	11.96
Bambutar, B_8	22.74	20.83	11.69
Syuchatar, K_1	28.73	29.11	14.95
Naikap Naya Bhanjyang, K_2	27.57	25.56	14.95
Badbhanjyang, K_3	22.5	17.98	7.69
Totipakha, K_4	26.12	15.95	17.56
Chaukitar, K_5	21.02	8.92	5.06
Balambu, K_6	13.59	13.22	6.24
Gurjhudhara,K_7	11.45	11.67	5.54
Satungal, K_8	24.41	18.25	16.6
Kirtipur, K_9	25.3	12.43	8.55
Tyanglaphant, K_{10}	22.18	18.06	14.21
Thankot, K_{11}	7.37	6.76	2.43
Kalanki, K_{12}	31.16	20.19	19.39
Bhurtelthok, Bh_1	33.09	11.58	8.46
Jhanglejhiti, G_1	23.59	9.66	4.99

F=forest, B=Bari, K=Khet, Bh=Bush land and G=Grassland

Annex III, F: Soil BD (g/cm^3) in different sampling sites for all depths

Sampling points	0-13 cm	13-26 cm	26-39 cm
Thankot Forest, F_1	1.298	1.294	1.396
Chitlang Forest, F_2	0.830	0.916	0.935
Mahadevsthan, F_3	0.923	1.402	1.421
Mahadevsthan, F_4	0.965	0.976	1.036
Matatirtha Pine, F_5	1.260	1.263	1.278
Matatirtha, F_6	0.770	0.905	1.022
Machhagau, F_7	1.258	1.362	1.333
Dahachok, F_8	1.013	1.113	1.154
Mattikhel, F_9	0.858	0.903	1.050
Thankot, B_1	1.244	1.318	1.334
Naikap Purano Bhanjyang, B_2	1.097	1.109	1.239
Jogigufa, B_3	1.232	1.246	1.487
Bhusingkhel, B_4	1.113	1.228	1.288
Bakhatigau, B_5	1.165	1.211	1.166
Gumaune, B_6	1.181	1.307	1.383
Baligau, B_7	1.251	1.280	1.321
Bambutar, B_8	1.201	1.283	1.344
Syuchatar Khet, K_1	1.201	1.282	1.318
Naikap Naya Bhanjyang, K_2	1.133	1.159	1.167
Badbhanjyang, K_3	1.418	1.415	1.428
Totipakha, K_4	1.235	1.400	1.595
Chaukitar, K_5	1.344	1.408	1.391
Balambu, K_6	1.307	1.478	1.526
Gurjhudhara, K_7	1.284	1.444	1.530
Satungal, K_8	1.367	1.374	1.330
Kirtipur, K_9	1.237	1.364	1.421
Tyanglaphant, K_{10}	1.100	1.118	1.210
Thankot, K_{11}	1.124	1.218	1.410
Kalanki, K_{12}	1.369	1.321	1.413
Bhurtelthok, Bh_1	1.222	1.338	1.392
Jhanglejhiti, G_1	0.914	1.161	1.410

F=forest, B=Bari, K=Khet, Bh=Bush land and G=Grassland

Annex III, G: Matrix of land use/cover conversions from 1978 to 1994 (ha)

Land use/cover type	Forest	Bush	Cultivation	Settlement	Excluded	Total area in 1994
Forest	222.28	4.83	58.07	1.93	0	287.11
Bush	272.59	736.98	67.03	0	0	1076.60
Cultivation	11.98	37.93	2826.76	26.97	0	2903.65
Settlement	0	0	128.48	21.29	0	149.77
Open	0	0	0.16	0.93	0	1.09
Excluded	0	0	0	0	2.48	2.48
Total area in 1978	506.86	779.74	3080.50	51.13	2.48	4420.71

Annex III,H: Matrix of land use/cover conversions from 1994 to 2005 (ha)

Land use/ cover type	Forest	Bush	Cultivation	Settle-ment	Open	Excluded	Total area in 2005
Forest	238.8	1034.57	50.81	0	0	0	1324.18
Bush	12.24	0	31.79	0	0	0	44.03
Cultivation	18.73	17.63	2696.58	7.79	0.92	0	2741.65
Settlement	0.52	0.0003	39.85	136.24	0.13	0	176.740
Open	8.99	1.79	7.85	0.34	0	0	18.97
Grassland	0.79	13.87	13.40	0.05		0	28.11
Excluded	0	0	0	0	0	87.16	87.16
Total area in 1994	280.07	1067.86	2840.28	144.42	1.05	87.16	4420.84

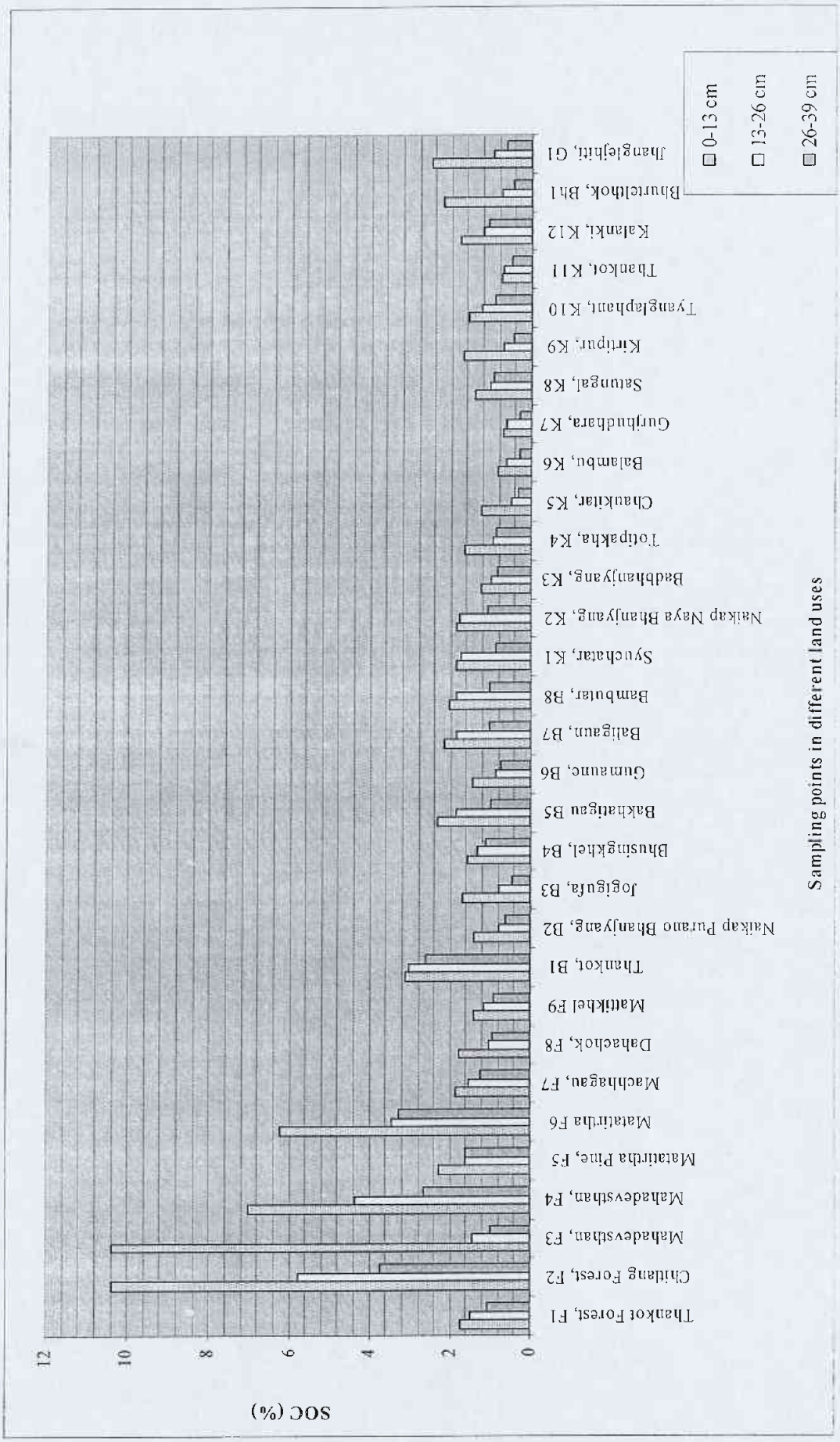
Annex III, I: Soil Organic Carbon: Analysis of Variance

Source	Sum of squares	DF	Mean Square	F Ratio	P
Land use	1779.225	2	889.613	6.582	0.002
Depth	3349.428	2	1674.714	12.390	0.000
Land use x Depth	720.810	4	180.202	1.333	0.2650
Error	10542.832	78	135.165		

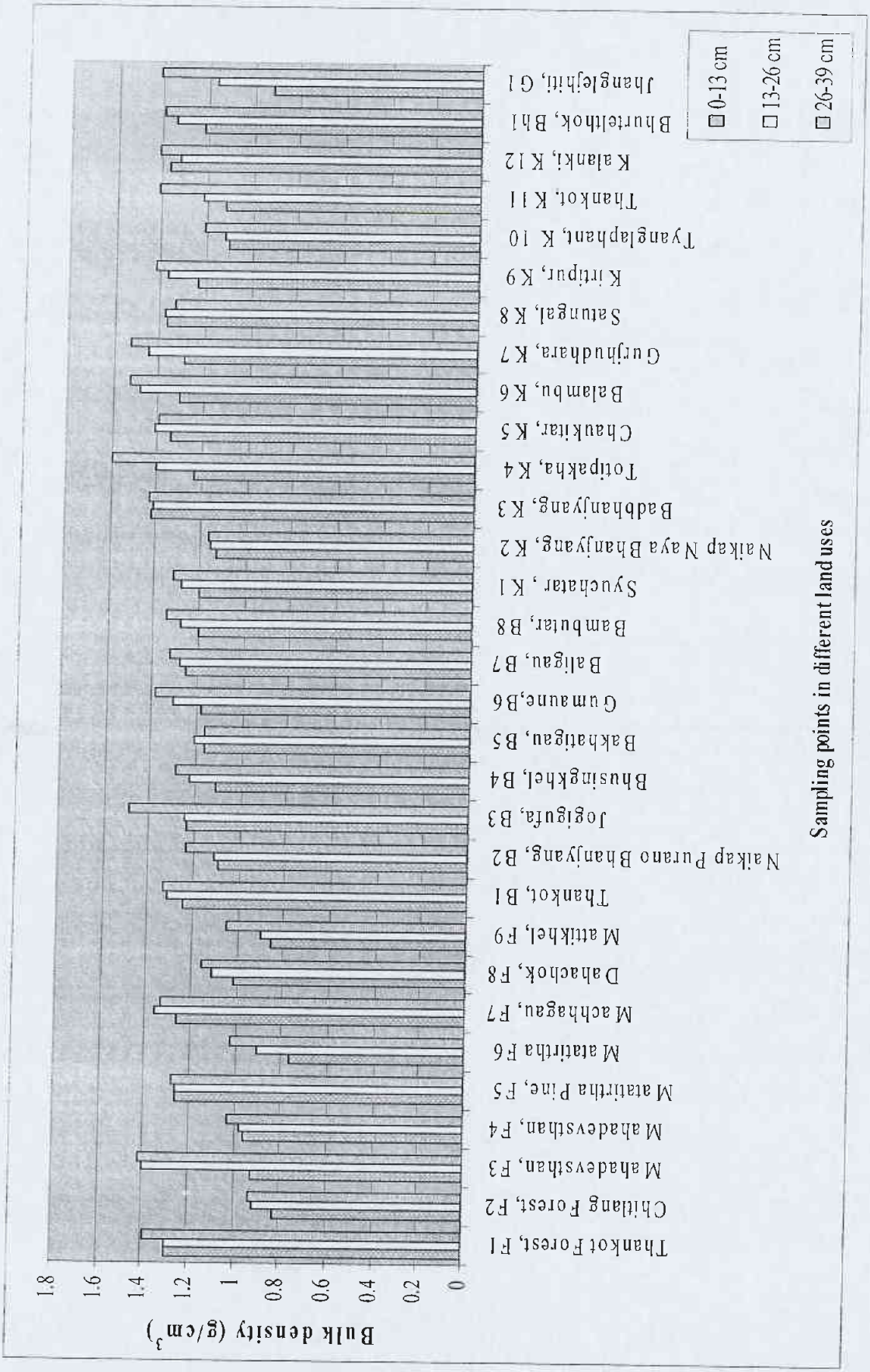
Annex III, J: Bulk Density: Analysis of Variance

Source	Sum of squares	DF	Mean Square	F Ratio	P
Land use	0.764	2	0.382	20.014	0.000
Depth	0.299	2	0.149	7.822	0.001
Land use x Depth	0.006	4	0.001	0.064	0.9920
Error	1.490	78	0.019		

ANNEX IV: GRAPHS



Annex IV, A: Soil Organic carbon concentration in different soil depths of various land uses



Annex IV, B: Bulk density of soil in different soil depth of various land uses

Annex V: Photographs

Plate 1: Mature trees in the natural forest

Plate 2: Mature community forest

Plate 3: *Castonopsis* flowering in the natural forest

Plate 4: Regenerating forest

Plate 5: Planted *Alnus* forest

Plate 6: Pine forest

Plate 7: Grassland

Plate 8: A typical land use pattern in the watershed

Plate 9: Lowland rice cropping

Plate 10: A typical type of upland land use/land cover

Plate 11: Upland maize and lowland rice cropping

Plate 12: Newly Grown built up area

Plate 13: River course encroaching at downstream part

Plate 14: Recording coordinates of changed land

Plate 15: Locating sampling points

Plate 16: Weighing core sampler containing soil sample

Plate 17: Researcher walking through the jungle with friends

Plate 18: Pit after the sample collected

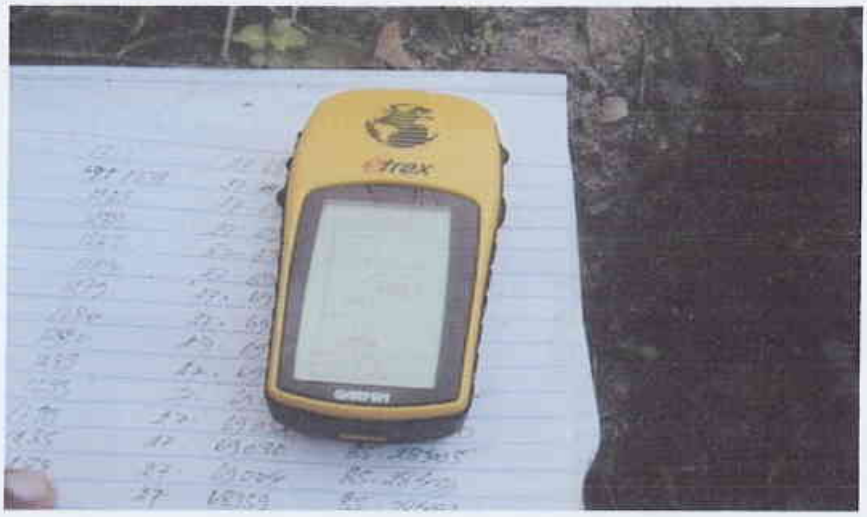


Plate 19: Taking location points by GPS

Plate 20: Soil samples kept for air drying

Plate 21: Researcher analyzing the soil samples in the laboratory