

Effect of Land Use Change on Soil Organic Carbon Stock in Balkhu Khola Watershed Southwestern Part of Kathmandu Valley, Central Nepal

Susmita Dhakal, Madan Koirala, Eklabya Sharma and Nab Raj Subedi

Abstract—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 software and soil samples were collected by stratified random sampling technique within the Balkhu Khola watershed. Land use and soil depth both affected significantly on SOC stock. Forest soil was good potential to sink SOC having capacity of 8.12kgC/m^2 . Rainfed upland cultivation (Bari) has sunk 6.12kgC/m^2 and irrigated 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. 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 shown 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.

Keywords— Conversion, Land use Change, Sink, Soil Organic Carbon

I. INTRODUCTION

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 [1]. 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 [2]"). 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 [3].

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. 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 [4].

Land use/land cover change has emerged as a central issue within the scientific community concerned with global environmental change. 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. The emission of CO_2 to the atmosphere by land use/ land cover change in low-latitude forests is estimated at $1.65 \pm 0.4 \text{ Pg C yr}^{-1}$, due to the modification of high-biomass forest ecosystems to systems of lower biomass such as secondary and degraded forests, cultivated land and pastures [5], [6].

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

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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 [7]-[9].

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 [10]-[13].

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 [14]. Soils of the world are potentially viable sinks for atmospheric carbon (C) and may significantly contribute to mitigate the global climate change [15]-[18]. 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 [16].

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. There is severing pressure on forests and agriculture that needs appropriate planning and management. Conversion of forest and other natural lands to cultivation and settlements increase the carbon dioxide emission depleting soil organic carbon. Not only people in Balkhu Khola watershed but also policy makers of Nepal are not aware the benefits of forest in terms of carbon sink. In this ground the study was designed to measure the SOC stock in different land uses.

II. OBJECTIVE

The broad objective of this study is to identify the land use pattern and its effect on Soil Organic Carbon Sock.

The specific objectives are as follows:

- To study the existing land use patterns
- To analyze land use/ cover change

- To quantify the organic carbon stock of soil at different land uses

III. METHODOLOGY

A. Study Area

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 (Fig 1). It has the area of 4420.8 ha (computed from topographical map 2003).

The watershed lies entirely in the middle mountainous zone and 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. Balkhu Khola originates from Chandragiri Range. It flows from North West to South East and meets to holistic river Bagmati. 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.

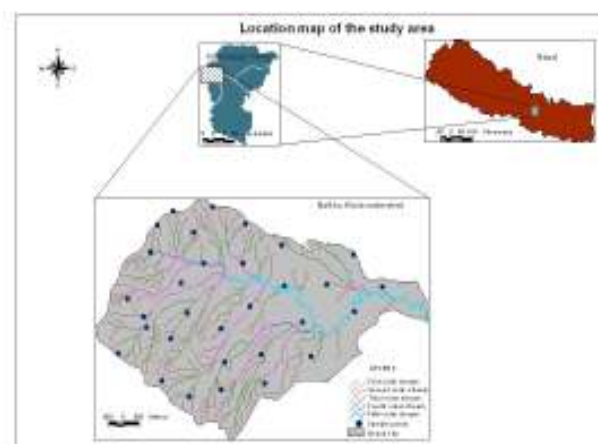


Fig. 1 Location map of the study area

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%). Although vegetation changes remarkably with variation in microclimate in a gradient of altitude the major forest types of the area are Schima Castonopsis Forest, Chir Pine Broad Leaved Forest and Lower Temperate Oak Forest. Most of the area lies under the Middle Hill slope. 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). 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

B. Study Design

The main focus area of overall study is to analyze land use change and quantification of soil organic carbon within different land uses. The designed study approach can be explained by following sub headings.

1. Information Requirement Analysis

Various literatures, documents, some World Wide Web (www) pages, knowledge and discussion with key stakeholders have been used as references for information requirement analysis. Various methods of mapping and land use change assessment have been also reviewed.

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.

3. Sampling sites 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. Sampling sites for soil samples 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. 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.

Soil samples were collected during first week of June to second week of July 2005. Geographic Positioning System (GPS) was used to record coordinates of sampling sites and changed land uses at the same time.

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.

C. Land Use Change Analysis

1. Hardcopy Map Acquisition and Digitization

Topographic map 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. The digital set of river, road, contour, spot height, building points and land use/ land cover was prepared.

2. 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.

3. Acquisition of Digital Data

Topographic map sheet 2003 prepared by KVMP and satellite imagery was acquired through Survey Department for in-house observation and analysis.

4. 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.

5. 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 1994 as well as 2005 and land use/ land cover change was studied. Finally map layout was prepared.

D. Soil Sample collection

Soil samples from each stratum were collected using Core Sampler of 10 cm diameter and 12.73 cm height (volume 999.305cc) up to 39 cm for each incremental depth at every selected site. The depth increments were 0-13cm, 13-26cm and 26-39cm. Fresh soil samples were collected from each depth. A portion of bulk soil of core cutter was cut using knife and transferred to plastic can for estimation of moisture; remaining soil was transferred to labeled polythene bag. Finally soil samples were transported to laboratory for further processing.

1. Laboratory analysis

Moisture correction for bulk density calculation was determined by taking soil in plastic can, sampled from core cutter [19]. Samples were prepared for SOC measurement passing an oven-dried portion of soil through 2 mm sieve. SOC was determined by titrimetric method [20]. For fragment correction soil samples in plastics bags were dried in room temperature. Air-dried such soil samples were passed through a 2 mm sieve. The weight of fragments retaining in the 2 mm sieve was recorded. Volume correction was done by water displacement method.

2. Data Analysis

Bulk density was calculated using the formula

$$BD = \frac{\text{Weight of dry soil}}{\text{Volume of Core}}$$

Volume of Core

The SOC concentration was calculated using the following equations

$$\% \text{ of SOC in Soil} = 0.4 \times (B-S) \times 1 \times 0.003 \times 1.3 \times 100/W$$

Where,

B: volume of $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2$ used for blank titration (ml)

S: volume of $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2$ used for sample titration (ml)

W: weight of soil (g)

0.4: strength of $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2$

1: Strength of $\text{K}_2\text{Cr}_2\text{O}_7$

1.3: Correction factor (100/77)

SOC stock (content) was calculated by formula [21]:

$$\text{Carbon stock} = d \times BD \times \text{SOC-content} \times \text{CFst}$$

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;

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

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.

Finally, 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.

IV. RESULT

A. Land Use/Cover Change in the Watershed

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 %, Bush was found to be second largest land cover which covered 779.75 ha i.e. 17.64 %, Forest had covered 506.86 ha i. e. 11.46 %, Settlement had covered the least area of 51.13 ha i. e. 1.15% of the total watershed area. The land use pattern has been shown in map (Fig 2).

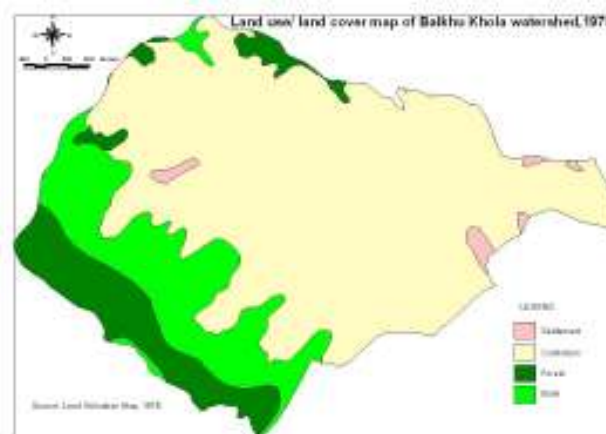


Fig. 2 Existing Land use/cover of the watershed in 1978

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 (Builtup, Buildings) and open/barren (Open area, Cliff). The largest area of watershed was covered by cultivation i.e. 2903.73 ha which contributed 65.67%, Bush land covered 1076.60 ha i. e. 24.35%, Forest had covered 287.18 ha i. e. 6.49 %, and Settlements covered 149.77 ha (included only cluster of settlements and large buildings) i.e. 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; the land use area has been shown in map (Fig 3).

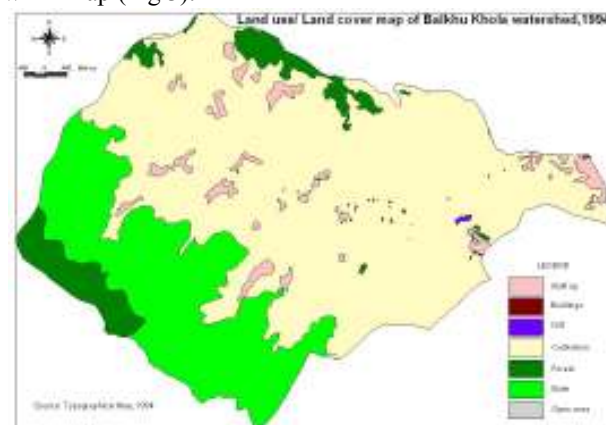


Fig. 3 Existing Land use/cover of the watershed in 1994

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 (Builtup, Big Buildings), road (Highway, Feeder/district Road, Bridge), grassland, unknown and other (River, Pond, Sand, and Barren land). 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. Bush land was degraded (44.17 ha) and grassland 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.

The land use area has been shown in map (Fig 4).

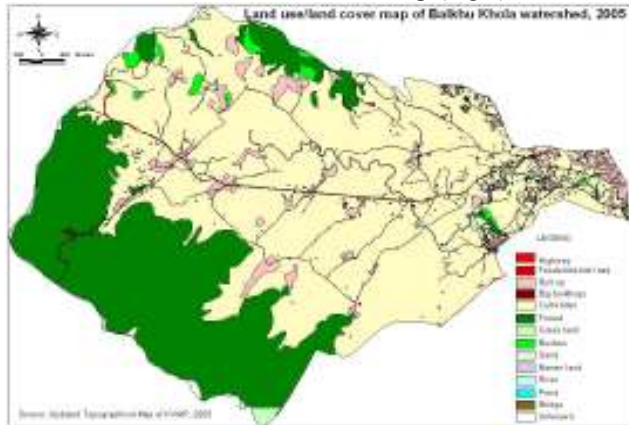


Fig. 4 Existing Land use/cover of the watershed in 2005

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

Cultivation land was remained 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 and cultivation land were changed to bush and settlement remarkably which had covered the area of 272.59 ha and 128.48 ha respectively. The matrix of land use/cover conversion has been shown in Table I. 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. The overall change in land use/ cover has been shown in Fig 5.

Forest area was degraded by 43.39% while bushes were increased by 38.13%. Cultivation land was decreased by 5.71%. Settlement was dramatically increased i. e. by 194.12% (Table II)

TABLE I
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

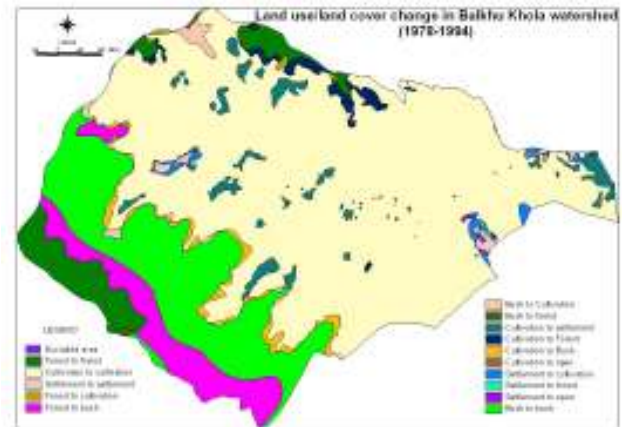


Fig. 5 Land use/land cover change in Balkhu Khola Watershed (1978-1994)

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. The overall change in land use/land cover has been shown in Fig 6.

TABLE II
LAND USE/ LAND COVER CHANGE (HA) 1978-1994

Land use/cover Type	Area in 1978 (ha)	Area in 1994 (ha)	Change area (ha)	Rate of change (%)
Forest	507	287	-220	-43.39
Bush	779	1076	297	38.13
Cultivation	3080	2904	-176	-5.71
Settlement	51	150	99	194.12
Other	2.5	3.5		
Total area	4420	4420		

The matrix of land use/cover conversion has been shown in Table III.

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.

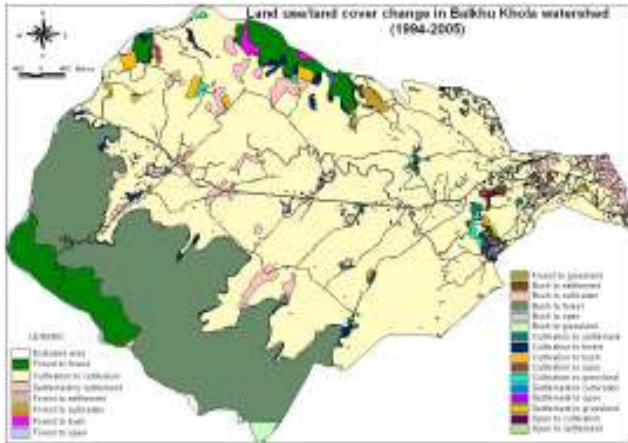


Fig. 6 Land use/land cover change in Balkhu Khola Watershed (1994-2005)

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 372.85% while bushes were decreased by more than 95.88%. Land under cultivation was decreased by 3.48%. Settlement was also found rapidly increasing trend – 22.91%. Table IV shows the changed area within these two-times period.

B. Soil Organic Carbon Stock

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

TABLE III
MATRIX OF LAND USE/COVER CONVERSIONS FROM 1994 TO 2005 (HA)

Land use/ cover	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

in the soil (Table V). The forest soil has high SOC stock (8.12 kg/m²) followed by rainfed upland (Bari) - 6.11 kg/m² and irrigated lowland, (Khet) - 4.93 kg/m² (Fig 7, Fig 8a).

TABLE IV
LAND USE /LAND COVER CHANGE (HA) 1994-2005

Land use/cover	Area in 1994 (ha)	Area in 2005 (ha)	Change area (ha)	Rate of change (%)
Forest	280	1324	1044	372.85
Bush	1068	44	-1024	-95.88
Cultivation	2840	2741	-99	-3.48
Settlement	144	177	33	22.91
Other	88	134		
Total area	4420	4420		

The trend in case of grassland and bush land was not drawn due to less number of samples.

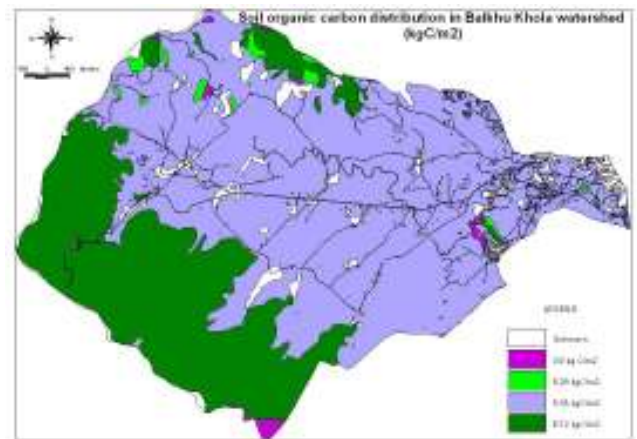


Fig. 7 SOC distribution in Balkhu Khola Watershed

In general, estimated SOC stock was observed to be higher in the topsoil (0-13 cm) compared to lower depths in various land use types (Fig 8b). Forest soil has 50.56% of its total SOC stock in the 0-13 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 V).

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, 146.68 MTC (56.92%) in Cultivation and 1.09 MTC (0.42%) in grassland and 2.33 MTC (0.90%) in Bush (Table VI).

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 VII.

TABLE V
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 $\pm$ SE
0-13	Forest	14.10	81.31	41.16 $\pm$ 8.88
	Rainfed upland	17.58	35.91	25.93 $\pm$ 2.29
	Irrigated lowland	7.37	31.16	21.78 $\pm$ 2.11
13-26	Forest	9.45	53.11	23.75 $\pm$ 4.49
	Rainfed upland	10.53	37.00	20.50 $\pm$ 3.15
	Irrigated lowland	6.76	29.11	16.50 $\pm$ 1.87
26-39	Forest	4.25	32.08	16.45 $\pm$ 3.20
	Rainfed upland	8.21	32.00	14.76 $\pm$ 2.65
	Irrigated lowland	2.43	19.39	11.05 $\pm$ 1.65
Attribute				
Land use	F-test			P value
Depth	6.582			0.002
Land use x	12.390			0.000
depth	NS			

This study showed conversion of forestland in to cultivation land might 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 (Table VIII).

V. DISCUSSION

A. Land Use/Cover Change in the Watershed

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, infrastructure development etc [22]. During the 16 years (1978-1994) period forests were changed into cultivation and settlement. The forests were degraded notably. This may be due to no conservation measure implementation and attraction of people to settle in Kathmandu valley from other parts of country.

Bushes changed to forest significantly in 11 years (1994-2005) period because of community awareness towards conservation of Forest. Cultivation lands nearer to the forest might have invaded by forest species or might have restored the encroached lands into the forest. Although development of grassland from forest and bush is very slow it shows degradation of natural ecosystems is also going on.

B. Soil Organic Carbon Stock

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

Forest soil was richer in SOC than other land use types. It may 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, organic layer is depleted, and soil carbon content can decrease [23], [24], [25]. Reference [26] also shows 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.

Comparison of SOC in natural vegetation and cultivated land gives some insight into the present management

TABLE VI
SOC POOLS AND TOTAL STOCK FOR DIFFERENT LAND USES (2005)

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

*: These land uses do not consist mean value

effect on SOC content. The *Bari* lands, having close proximity to the farmhouses, 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.

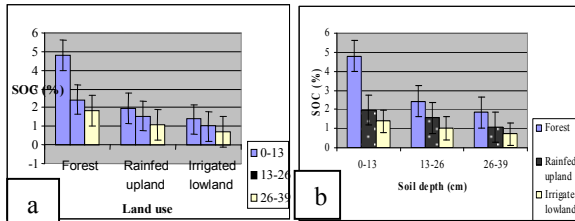


Fig. 8 Soil organic carbon concentration (a) in different land uses for all incremental depths and (b) in different soil depths of various lands uses. Vertical bars show the standard errors

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 somewhat far from the source of farmyard manure (FYM) (farm houses).

TABLE VII
CORRELATION BETWEEN SOC AND BD

Depth, cm	0-13	-0.484**
	13-26	-0.399*
	26-39	-0.496**
Land use	Forest	-0.540**
	Rainfed upland	-0.187
	Irrigated lowland	-0.371*

*, **: Correlation is significant at 0.05 and 0.01 levels respectively

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. Reference [27] 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 in North Appalachian Experimental Watershed. 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 [28].

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 [28]. 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 [29]-[31].

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 in Indian forest of Dhaili and Toli Van Panchayat [32] and [33] 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 [34].

2. Soil Organic Carbon Stock: Effect of Soil 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 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 VII. It may be due to turns over and manuring, which mix up the soils of top

TABLE VIII
EFFECT OF LAND USE CHANGES IN SOC STOCK

Land use change	Change area (ha)		Change in SOC stock			% change
	1978-1994	1994-2005	KgC/m ²	Ton of Carbon		
				1978-1994	1994-2005	
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	

horizons. Dissolved organic carbon and deep rooting crops in *Bari* may have also contributed to higher SOC content in lower depths. Reference [35] while studied on land use effect on soil carbon sequestration in Mardi watershed of Nepal reported the

ignored in such estimates, the implication of this on the effects of future land use changes should be interpreted with caution.

VI. CONCLUSION

The major conclusions drawn from present study are as follows.

- Land use has significant effect on SOC content in the soil depth
- Soils under forest 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 *rainfed upland* soils has significantly higher SOC than *irrigated lowland*, 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 forest has low bulk density than cultivated soils; among cultivated soils irrigated lowland soil has higher bulk density than rainfed upland
- Bulk density and SOC are negatively correlated
- Land use/ land cover has changed in positive direction in terms of forest 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

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TABLE IX
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

similar result of increasing trend of BD in deeper layer of the soil where SOC showed decreasing trend in such condition.

3. Soil Organic Carbon Stock: Effect of Land Use Changes

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% [36]. 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 [37]. The result of present study shown 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 m² 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 m² (assuming that all other factor remains the same). The estimated effects of other internal trading of land use changes are shown in Table VIII.

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 shown net gain of SOC by 29358.41 ton i.e. 12.46% of the original stock. 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 IX.

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

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