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Research Article

Impact of Land Use Types on Soil Organic Carbon and Nitrogen Stocks: A Study from the Lal Bakaiya Watershed in Central Nepal

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Understanding the role of soil carbon (C) dynamics and quantitative changes as affected by various land use patterns is very critical given the significance of carbon sequestration. In this context, the current study was conducted in the Lal Bakaiya watershed in Makawanpur District, Nepal, to assess the variation of soil organic carbon (SOC) and nitrogen (N) stocks in three different land use types, namely, natural forest, grassland, and cultivated land. Incremental soil depths method (i.e., 0–15 cm, 16–30 cm, and 31–45 cm) was applied to collect soil samples in bulk from each of the land use under the study to estimate SOC and N stocks in laboratory. A total of 90 soil samples were collected from three soil layers down the soil profile up to 45 cm for each land uses. The results show that both SOC and N contents decreased with soil depths; however, substantial amount of SOC and N stocks were reported in lower soil depths under land use with natural forest. Both SOC and N contents were found relatively higher at 0–15 cm depth in natural forest soil (1.40 ± 0.20% and 0.26 ± 0.04%) than those in grassland and cultivated land, respectively. The mean total SOC stock and N stock ranged from 46.3 ± 4.24 t ha^{-1} and 7.11 ± 1.86 t ha^{-1} in cultivated land to 62.05 ± 9.17 t ha^{-1} and 11.40 ± 1.92 t ha^{-1} in the land use with natural forest, respectively. Furthermore, the mean total carbon and nitrogen ratio (C/N ratio) of the soil was found to be higher in cultivated land (7.07 ± 1.93) than that in natural forest (5.75 ± 1.47) and grassland (5.62 ± 1.49), respectively. Two-way analysis of variance results showed that both land use type and soil depth have significantly ($p < 0.05$) affected the SOC and N stocks in the study. From the results, it is suggested that well-managed land use can contribute significantly in offsetting global carbon emission.

1. Introduction

Soil comprises the largest active terrestrial carbon (C) pool globally [1, 2]. About 1200–1800 gigatons of C are estimated to be stored in soil worldwide. Soil C pool stores more than three times C than the amount stored in atmosphere and 3.8 times more than in biotic pool [1, 3]. Therefore, estimating the amount of C in soils can provide a significant opportunity to mitigate global warming [4, 5]. Thus, improving the capture and storage of atmospheric C through improved land use systems can be a good strategy to lower its concentration while also improving the quality of soil.

Soil plays a crucial role in the ecosystem functioning and provisioning of its services [6, 7]. The function and viability of soil depends on the dynamic symmetry among its biophysical and chemical properties [8]. Soil organic carbon (SOC) and nitrogen (N) are fundamental for soil health, sustainable biological productivity, and environmental quality. In addition, the SOC and N contents in soil reveal the long-term equilibrium between additions and losses of organic C from various processes and pathways [9]. Different land use practices often influence the fluxes of SOC and N stocks and have been reported to differ with the change in land use types due to the combined effect of biophysical and chemical processes over time [10, 11]. SOC and N stocks can either increase or decrease depending on a number of factors including climate, soil type, topography, and soil management techniques. Therefore, the land use system is one of the most significant factors that control SOC and N stocks build up because of the presence of SOC and N in the soil. Studies have shown that changes in land use, particularly from natural vegetation to others, can cause SOC losses of 20–50% [12–14]. The SOC stock reduced in significant amount after using fire for land preparation and conversion from natural forest to maize field and change from maize field to other crops or grassland in northern Thailand [15, 16]. Similarly, converting natural vegetation cover to large-scale farmland resulted in significant loss of soil organic carbon and total nitrogen in Western Ethiopia [17]. Other studies also reported that a strong decrease of SOC and N after conversion of forest land to other land [18, 19], and this has provided a way to raise concern about the long-term sustainability of those land use types in the tropics [20].

C sequestration is the long-term process of capturing and storing of CO_2 from the atmosphere to reverse atmospheric CO_2 pollution and to reduce global climate change [21, 22]. With ever-increasing global warming issues, the topic of soil C sequestration is something that we cannot afford to pass over [1, 22]. Globally, soils are viable sinks for atmospheric C and they are an important part of terrestrial C pool [1, 23, 24]. About 1500 pentagrams of C is reserved in soils in the form of organic matter that accounts approximately twice the terrestrial C pool [25], and Nepalese soil holds 308.78 million tons [26]. Conversion of land use particularly of a natural into a managed system can change soil C pools and can exert critical impact on balance between soil properties and the atmosphere [27]. In tropics, about 12 to 20% anthropogenic greenhouse gases (GHGs) is due to land use changes which is reported as the second largest source of GHGs [19, 21]. Also, this scenario is likely to remain also for the future if we do not address the situation in time. In Nepal, total greenhouse gas emissions in 2014 were 44.06 million metric tons of CO_2, and the figure has increased to 51.24 million metric tons in 2017 [28]. Estimating SOC and N stock in various land uses has become very important because it will assist policy makers to work out approaches for managing land use systems sustainably as well as preventing loss of SOC and N stocks. In this backdrop, the objective of this study was to evaluate the variability in the SOC and N stocks with respect to various land use types in the northern part of Lal Bakaiya watershed in Bagmati Province, Nepal. Specifically, this study intended to address two concerns: (i) variation of SOC and N contents within different soil layers and (ii) impact of different land use types on SOC and N stocks.

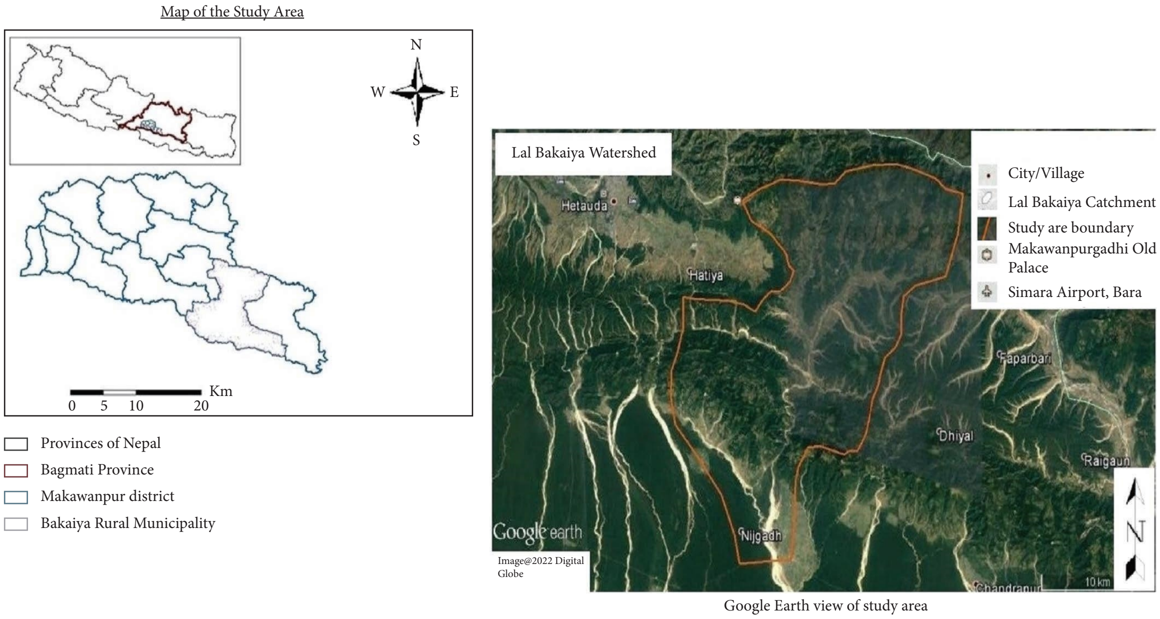
2. Materials and Methods

2.1. Study Site. This study was carried out in three major land use types such as natural forest, grassland, and cultivated land in the northern part of the Lal Bakaiya watershed located between 27°30′00″ N and 85°20′00″ E in Makawanpur District, Nepal. It is located in the central southern part of the country and covers about 868 km^2 of the total basin area (Figure 1). Out of the total watershed area, 42% lies in Makawanpur District, 20% in Bara, and 38% in Rautahat District [29]. The study focuses only on Makawanpur District which covers the geography from Terai to Mahabharata ranges. Furthermore, the watershed area can be partitioned into three major geological units: the Terai and Bhabar in the south, Chure/Siwalik in the middle, and the Mahabharata range in the north. The length of the river is 134 km and flows through elevations ranging from 2,000 to 71 m above MSL. The elevation of the study site ranges from 435 to 2000 m above MSL. The mean annual precipitation of the area is 1,434 mm (at Rautahat) to 2,306 mm (at Makawanpur) [29]. The soil texture in this area is sandy loam, and the area is environmentally vulnerable due to frequent landslide, soil erosion, forest encroachment, and deforestation.

For land use land cover classification, Landsat images were extracted for free from Earth Explorer of USGS, and object-based image analysis (OBIA) technique was employed to classify Landsat images to acquire land use map for the particular site [30, 31]. After that, on-field observation was carried out to validate the basic information topography of the study site, following that the boundary of the watershed was identified by using ArcGIS 10.2. Accordingly, three major land use types as natural forest, grassland, and cultivated land were defined for allocation of various samples.

(1) Natural forest: It includes land having at least 0.5 ha area and a minimum width/length of 20 m with trees higher than 5 m at maturity and a crown cover of more than 10%, not being utilized principally other than forestry purposes (Figure 2) [32].
(2) Grassland: It includes land in which the vegetation is dominated by a nearly continuous cover of grasses. They are commonly used for open grazing, maintained by grazing animals and sometimes for cut and carry system (Figure 3) [32].
(3) Cultivated land: It includes land primarily used for agricultural purposes such as production of crops and raring of livestock (Figure 4) [33].

2.2. Sampling Techniques. The field visit and soil sampling carried out starting from 13 March to 11 May 2018 for two months. Stratified random sampling technique was adopted for the study, and land use types were identified as the strata for soil sample collections. Upstream and downstream approach was followed for sampling. Two transect lines were delineated along the slopes; one in the downstream (at 500 m elevation) and the other in the upstream (at 1500 m) part of the watershed crossing natural forest, grassland, and cultivated land. The possible sampling points through transect lines were pointed out in Google earth, and when all likely points were being defined, a random selection was done. A total of 15 pairs of sample sites were identified (15 in each transect line); total 30 sample sites with 90 soil samples were collected for the study. At every sampling site, a pit of 30 cm by 50 cm was dug, and undisturbed soil core samples were collected by using a cylindrical core sampler (5.5 cm diameter and 5 cm height) from the 0–15 cm, 16–30 cm, and 31–45 cm soil depths for the determination of bulk density


Map of the Study Area

Google Earth view of study area

Figure 1: Map of the study site.

Figure 2: Map of the study site. Photo credit: Uchita Lamichhane, 2018.

Figure 3: Map of the study site. Photo credit: Uchita Lamichhane.

(BD), SOC content, and N content. The soil samples collected were analyzed at the Provincial Soil Laboratory, Hetauda, Nepal.

Figure 4: Map of the study site. Photo credit: Uchita Lamichhane,

2.3. Data Analysis. Soil BD was estimated using the core sampling method [29]. BD was room dried for 7 days, and then it was oven dried at constant temperature of 105°C for 24 h. Oven-dried weight was taken and soil was processed through 2 mm sieve to differentiate stones. Volume of the stone was taken for stone correction by putting it in a cylindrical jar with water. BD was then determined by the following formula:

$$\rho = \frac{Md}{Vt}, \tag{1}$$

where ρ = bulk density in g cm^{-3}, Md = oven dry weight of soil in g, Vt = volume of the soil in cm^3, and volume of the soil = volume of the core – volume of the stone.

The SOC content in the soil samples was estimated by using the Walkley–Black wet oxidation method [34]. Accordingly, soil N content was determined by the Kjeldahl method [31]. Finally, SOC and N stocks for each depth of land uses were determined by the following equation suggested by Pearson et al. [32].

$$\mathrm{SOC} = \rho * d * \%C, \tag{2}$$

where SOC = soil organic carbon stock per unit area in t ha^{-1}, ρ = soil bulk density in g cm^{-3}, D = depth of soil horizon at which the sample was taken in cm, and % C = organic carbon concentration in %.

$$\mathrm{NS} = \rho * d * \%N, \tag{3}$$

where NS = soil nitrogen stock per unit area in t ha^{-1}, ρ = soil bulk density in g cm^{-3}, D = depth of soil horizon at which the sample was taken in cm, and %C = nitrogen concentration in %.

The collected data were then categorized and summarized by land use types and soil depths. The two-way ANOVA model was applied to test the effect of land use types and soil depth on SOC and soil N. Furthermore, the correlation analysis was applied to determine relationship between the studied variables. Final data were analyzed by using Statistical Package for the Social Sciences (SPSS) software (version 20.0).

3. Results

3.1. Bulk Density. The study found that there was a significant variation in the BD with reference to soil depths in all three land uses. Higher variation was recorded in 0–15 cm depth, whereas BD values in 31–45 cm depths were clustered. The BD value was ranged from 0.96 g cm^{-3} to 1.54 g cm^{-3}. Significantly, lower BD values were observed in soil under natural forest while higher values were found in land under cultivation over three studied soil depths (Table 1), whereas in the grassland, the BD values were found intermediate between forest and cultivated land. BD values were found to increase with incremental soil depths in all three land use types. Furthermore, the result from two-way ANOVA showed that there are significant ($p < 0.05$) differences in BD by land use types and soil depths (Table 2). Even so, the interaction effect of land use types and soil depths on BD was not found significant ($p \geq 0.05$).

3.2. Organic C, Total Nitrogen Content, and C/N. In this study, higher variation of the SOC content was found in 0–15 cm depth than in 16–30 cm and 31–45 cm depths in all land uses. SOC contents were found from 0.57% to 1.70%. Significantly, higher SOC contents were found in natural forest than grassland and cultivated land over the three soil depths (Table 3). In all three land uses, SOC contents were significantly decreased with increase in depths; however, it did not show any consistent trend in the case of grassland (Table 3). In the case of grassland, organic carbon contents reported higher in 16–30 cm depth than in 0–15 cm depth. Accordingly, higher variations of the total nitrogen content were observed in 0–15 cm and 16–30 cm depth than in 31–45 cm in all three land uses. N content values were reported from 0.05% to 0.33%. Significantly, a higher N content was reported in natural forest followed by grassland and cultivated land, respectively. Furthermore, the N content is also decreased with increase in soil depths except the grassland in which it did not indicate any consistent trend down the soil profile (Table 3).

In this study, the C/N ratio did not follow likely trend of SOC and N contents with soil depths in all three land use types except in the case of cultivated land that showed the increasing trend with increasing soil depths (Table 3). In comparison, higher values of the C/N ratio were observed in cultivated land compared to forest and grasslands. The two-way ANOVA showed that both SOC content and N content were significantly ($p < 0.05$) affected by land use types and soil depths (Table 4). Furthermore, both soil properties were significantly ($p < 0.05$) affected by the interaction effect of land use and soil depth (Table 4). In addition, the C/N ratio was also affected by land use and soil depths but not affected by interaction of land use and soil depths (Table 4).

3.3. SOC and Nitrogen Stocks. From the study, significantly higher amount of SOC stock was found in all three depths of natural forest (Table 5). Furthermore, a declining trend in the SOC stock was reported in all three land uses with incremental soil depths. However, the contrasting trend was found in grassland as higher SOC stock was found in 16–30 cm than in 0–15 cm. Similarly, the same kind of pattern was found in the N stock within all three land uses (Table 5). Furthermore, the two-way ANOVA result shows that both SOC and N stocks were significantly ($p < 0.05$) affected by land use types and soil depth and further by the interaction effect of land use types and soil depths (Table 6).

4. Discussion

4.1. Variation in BD. In this study, significantly lower BD values were observed in natural forest compared to other two land uses. Higher organic inputs and lower losses might be reasons for lower BD values in the natural forest. Other similar studies have also highlighted significantly lower BD values in the natural forest soil compared to cultivated land, barren land, and grassland in central midland of Nepal [33, 35, 36]. Accordingly, BD values were found to be increased with the increasing soil depth for all three land uses. The increase in BD with incremental soil depth could be related with the decrease in OM source, root penetration, and the compaction pressure of the overlying soil mass. The findings are in line with those in [37, 38] who reported lower OM due to fewer root networks and less aggregation, and also the compaction caused by overlying soil layers increases the BD of soil. Many researchers in Nepal and around the world also reported a general increase in BD values with increasing soil depths [33, 36, 39–41]. The result is further supported by highly significant ($p < 0.001$) and negative correlation ($r = -0.59$) between BD and soil C contents.

4.2. Variation in SOC, N Contents, and C/N within Different Land Uses. This study found that soil under natural forest had higher organic C and N contents' level than grassland and cultivated land. Higher amount of organic C content in forest soil could be associated to improved accumulation of higher OM and decomposition of fine roots and also to

Table 1: Bulk density with respect to different land use types and soil depths.

Variable	Soil depths (cm)	Land uses		
		Natural forest (mean ± SD)	Grassland (mean ± SD)	Cultivated land (mean ± SD)
Bulk density (g cm^{-3})	0–15	1.14 ± 0.11	1.20 ± 0.08	1.21 ± 0.09
	16–30	1.22 ± 0.10	1.28 ± 0.05	1.33 ± 0.08
	31–45	1.30 ± 0.60	1.35 ± 0.06	1.42 ± 0.07

Table 2: Two-way ANOVA result for BD (g cm^{-3}) under different land uses and soil depths.

Sources of variation	Df	BD	
		MS	Sig
Soil depth	2	0.225	0.00100*
Land use	2	0.068	0.001*
Soil depth* land use	4	0.002	0.887

* $p < 0.05$ is considered as statistically significant.

Table 3: SOC content, N content, and C/N ratio with reference to different land uses and soil depths.

Variable	Soil depths (cm)	Land uses		
		Natural forest (mean ± SD)	Grassland (mean ± SD)	Cultivated land (mean ± SD)
SOC content (%)	0–15	1.40 ± 0.20	0.93 ± 0.07	0.96 ± 0.08
	16–30	1.09 ± 0.11	0.95 ± 0.08	0.77 ± 0.04
	31–45	0.91 ± 0.10	0.67 ± 0.06	0.63 ± 0.05
N content (%)	0–15	0.26 ± 0.04	0.18 ± 0.04	0.16 ± 0.04
	16–30	0.22 ± 0.03	0.21 ± 0.03	0.12 ± 0.03
	31–45	0.14 ± 0.03	0.13 ± 0.03	0.08 ± 0.02
C/N	0–15	5.40 ± 1.61	5.42 ± 1.48	6.38 ± 1.66
	16–30	5.14 ± 1.07	4.71 ± 1.07	6.58 ± 1.53
	31–45	6.72 ± 1.73	5.65 ± 1.92	8.24 ± 2.61

Table 4: Two-way ANOVA result for SOC content, N content, and C/N ratio under different land uses and soil depth.

Source of variation	Df	SOC content (%)		N content (%)		C/N ratio	
		MS	Sig	MS	Sig	MS	Sig
Soil depth	2	0.999	0.001*	0.061	0.001*	16.58	0.004
Land use	2	1.024	0.001*	0.059	0.001*	26.39	0.001
Soil depth* land use	4	0.770	0.001*	0.006	0.002*	1.74	0.658

* $p < 0.05$ is considered as statistically significant.

Table 5: SOC and N stocks with reference to different land use types and soil depths.

Variables	Soil depths (cm)	Land uses		
		Natural forest (mean ± SD)	Grassland (mean ± SD)	Cultivated land (mean ± SD)
SOC stock (t ha^{-1})	0–15	24.13 ± 4.58	16.76 ± 1.80	17.64 ± 2.01
	16–30	20.15 ± 2.77	18.30 ± 1.75	15.32 ± 0.83
	31–45	17.77 ± 1.82	13.58 ± 1.42	13.43 ± 1.40
N stock (t ha^{-1})	0–15	4.60 ± 0.61	3.30 ± 0.80	2.91 ± 0.74
	16–30	4.02 ± 0.67	4.01 ± 0.71	2.45 ± 0.62
	31–45	2.78 ± 0.64	2.61 ± 0.74	1.75 ± 0.50

Table 6: Two-way ANOVA result for SOC and N stocks under different land uses types and soil depth.

Source of variation	Df	SOC stock (t ha^{-1})		N stock (t ha^{-1})	
		MS	Sig	MS	Sig
Soil depth	2	162.75	0.001*	13.30	0.001*
Land use	2	238.98	0.001*	15.47	0.001*
Soil depth* land use	4	21.45	0.004*	1.65	0.009*

* $p < 0.05$ is considered as statistically significant.

frequent tillage in cultivated soil. As reported in [33, 36, 42], a higher level of organic C content is observed in forest soil than in agricultural and pastures land in central and western Nepal. Similarly, the authors in [41–44] reported that the organic C content in the cultivated soils is less protected than in undisturbed soils due to removal of large quantities of the biomass during clearing and land preparation. Accordingly, the higher N content in the natural forest could be associated with its higher organic C concentration, which is the prime source of soil N [45, 46]. This finding is further assisted by significant ($p < 0.001$) and positive correlation ($r = 0.69$) between organic C content and N content. Many similar studies carried out in Nepal and elsewhere also reported a higher level of organic C content and N content in forested land than in agricultural and other land uses [38, 47, 48].

The average C/N ratio of soils in forest, grassland, and cultivated land were found to be 5.57 ± 1.33, 5.26 ± 1.49, and 7.06 ± 1.93, respectively. However, the observed values of C/N ratios were out of the normal range of international soil which is about 10 to 12 [49]. As reported in [50], the OM matter with lesser C/N ratio (<10) opens up the N content leading to rapid release of N into the soil and increasing availability of N for the crop. The two-way ANOVA showed that both SOC content and N content were significantly ($p < 0.05$) affected by land use types and soil depths (Table 4). Kafle [51] also reported a significant difference of C/N with incremental soil depths in a community forest of Chitwan District, Nepal, within 1 m soil profile.

4.3. Variation in SOC and N Stocks within Soil Depths of Different Land Uses. Environmental factors such as vegetation cover, climate, and management practices have a significant impact on the soil's capacity to hold or release C [52]. The result found that both SOC stock and N stock were significantly higher in natural forest in comparison to grassland and cultivated land (Table 5). The result is further supported by a highly significant ($p < 0.001$) and positive correlation ($r = 0.60$) between SOC stock and N stock. The results show that natural forest land has a higher stock of SOC and soil N than grassland and cultivated land. Higher amount of SOC and N stocks in the natural forest could be associated with a higher organic C content due to the accumulation of aboveground leaves, ground litter, and underground root litter [53]. The findings are in line with those reported in [36, 54–57] which reported higher SOC stock than other land use types in Nepal and around the world.

Compared with natural forest, lower SOC and N stock in grassland land is associated with low organic inputs due to removal of aboveground biomass for livestock feed (i.e., cut carry system) in grassland and cultivated land in the watershed area which is further assisted by grazing pressure particularly in grassland [36, 41, 46, 58]. Furthermore, soil disturbance during land preparation and tillage activities exposes OM to decomposition and causes rapid losses in SOC and N stocks in cultivated land due to loss of root biomass and removal of crop residues [42, 59–61]. Due to the low input of organic matter from harvested farm residues, cultivated lands often have lower SOC stocks. In addition, the study also observed that farming systems (i.e., agriculture-based livelihood) practiced by local farmers in the study site are exploitative in nature. In this regard, a land use type that can improve SOC and soil N accumulation and protect against the loss of cations through leaching and biological processes should be promoted for better land management and to fight against the undesirable impacts of climate change as well [62, 63]. Thus, appropriate management intervention such as controlled or rotational grazing, optimizing livestock number, and addition of organic inputs should be applied to enhance C stock and N stock in grassland [41, 64]. Similarly, suitable practices such as conservation tillage, zero tillage, terrace farming, and agroforestry practices should be practiced to improve the carbon storage capacity of cultivated land [36, 59, 65, 66]. These findings are in line with the research of Leul et al. [17] on effects of land use dynamics on soil organic carbon and total nitrogen stock.

Depth-wise average SOC stock and N stock results are presented in Table 5. Significantly, a higher amount of SOC stock and N stock was reported in the top soil layer than in subsoil layers within the profile of the same land use. The highest SOC in the 0–15 cm depth was observed in the natural forest land followed by cultivated land and grassland (Table 5). Furthermore, the highest soil N stock in the topsoil was measured in the natural forest land followed by cultivated land and grassland (Table 5). The result demonstrates that both SOC and N stocks decrease with the increasing depths down the soil profile and it is attributed to the less accumulation of OM content at lower depths down the soil profile [41, 54]. Higher amount of SOC and N stocks in the 16–30 cm layer of grassland is attributed to the rapid leaching and greater accumulation of organic inputs from the top soil layer to the subsoil layer. Findings from other studies [33, 36, 67–69] also suggest that relatively higher amounts of SOC and N stocks are present in the top soil layer than those of the deeper layers. High OM content, greater root biomass, and higher accumulation of vegetative residues are the major reasons for higher amount of SOC and N stocks in the upper soil layer. The losses from decomposition, leaching, and soil erosion are major reasons for the low SOC stock. Low SOC storage levels in the topsoil may also be a result of poor land management and postharvest grazing [70]. The findings of this study are consistent with those reported in [41,71] which reported that land use types had a significant impact on the SOC and N contents, and soils under natural vegetation had a higher amount of SOC stock compared to shrub land and cultivated soil in the middle mountain region of Nepal. Studies around the world highlights that land use and land use changes are important determinants of landscape C stocks and that careful management of existing natural and managed ecosystem is critical to global C stock [72]. Therefore, this study recommends protection of soil C sequestration through improved land use system is a better strategy to reduce increasing concentration of atmospheric CO_2.

5. Conclusions

In order to identify and understand the influence of various land use and land cover on soil carbon storage, as well as how various land use and land management practices influence soil

C storage in soils, a better understanding of the impact of various land use on soil carbon storage is necessary. This study highlights the first reporting of variations in SOC and N stocks from three distinct land use types in the Lal Bakaiya watershed, Makawanpur District, Nepal. The study found that both land use types and soil depth significantly affected the amount of SOC and N stocks in the soil. The mean total SOC stock observed in the order as natural forest > grassland > cultivated land. Accordingly, the mean total N stock followed the order as natural forest > grassland > cultivated land. Land uses with forest cover have higher SOC and N stocks than those with less vegetation. As the study found that land use types do have significant impact on SOC and N storage capacity of soil, we recommend that soil C sequestration through an improved land use system is a better strategy to reduce increasing concentration of atmospheric C. Though there is lack of proper knowledge about C trading in Nepal, the present study also indicates the significance of watershed-level SOC valuation for better and C-friendly land use decision making in the future.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

Pramod Ghimire and Uchita Lamichhane conceptualized the study, performed data curation, and investigated the data; Pramod Ghimire, Uchita Lamichhane, and Sandesh Bolakhe performed formal analysis, contributed to methodology, and prepared the original draft; Pramod Ghimire validated the data; Pramod Ghimire, Uchita Lamichhane, Sandesh Bolakhe, and Chun-Hung Jeb Lee reviewed and edited the manuscript.

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References

[1] R. Lal, "Soil carbon sequestration to mitigate climate change," *Geoderma*, vol. 123, no. 1-2, pp. 1–22, 2004.

[2] Y. Chan, "Increasing soil organic carbon of agricultural land," *PRIMEFACT*, vol. 735, 2008.

[3] Fao, *Soil Carbon Sequestration For Improved Land Management*, Food and Agriculture Organization, Rome, Italy, 2001.

[4] S. K. Singh, C. V. Pandey, G. S. Sidhu, D. Sarkar, and R. Sagar, "Concentration and stock of carbon in the soils affected by land uses and climates in the western Himalaya, India," *Catena*, vol. 87, no. 1, pp. 78–89, 2011.

[5] N. Dahal and R. M. Bajracharya, "Prospects of soil organic carbon sequestration: implications for Nepal's mountain agriculture," *Journal of Forest and Livelihood*, vol. 9, no. 1, pp. 45–56, 2013.

[6] K. Adhikari and A. E. Hartemink, "Linking soils to ecosystem services: a global review," *Geoderma*, vol. 262, pp. 101–111, 2016.

[7] R. M. Bajracharya, B. K. Sitaula, S. Sharma, and A. Jeng, "Soil quality in the Nepalese context: an analytical review," *International Journal of Ecology & Environmental Sciences*, vol. 33, no. 2-3, pp. 143–158, 2007.

[8] J. Somasundaram, R. K. Singh, A. K. Parandiyal, S. Ali, and R. R. Simaiya, "Soil properties under different land use systems in parts of chambal region of Rajasthan," *Journal of Agricultural Physics*, vol. 13, no. 2, pp. 139–147, 2014.

[9] B. Majumder, B. Mandal, P. K. Bandyopadhyay et al., "Organic amendments influence soil organic carbon pools and rice–wheat productivity," *Soil Science Society of America Journal*, vol. 72, no. 3, pp. 775–785, 2008.

[10] P. Santra, U. K. Chopra, and D. Chakraborty, "Spatial variability of soil properties and its application in predicting surface map of hydraulic parameters in an agricultural farm," *Current Science*, vol. 95, no. 7, pp. 937–945, 2008.

[11] W. M. Post and K. C. Kwon, "Soil carbon sequestration and land-use change: processes and potential," *Global Change Biology*, vol. 6, no. 3, pp. 317–327, 2000.

[12] Z. Shi, X. Li, L. Zhang, and Y. Wang, "Impacts of farmland conversion to apple (Malus domestica) orchard on soil organic carbon stocks and enzyme activities in a semiarid loess region," *Journal of Plant Nutrition and Soil Science*, vol. 178, no. 3, pp. 440–451, 2015.

[13] E. A. Davidson and I. L. Ackerman, "Changes in soil carbon inventories following cultivation of previously untilled soils," *Biogeochemistry*, vol. 20, no. 3, pp. 161–193, 1993.

[14] A. Don, J. Schumacher, and A. Freibauer, "Impact of tropical land-use change on soil organic carbon stocks–a meta-analysis," *Global Change Biology*, vol. 17, no. 4, pp. 1658–1670, 2011.

[15] N. Arunrat, S. Sereenonchai, P. Kongsurakan, and R. Hatano, "Soil organic carbon and soil erodibility response to various land-use changes in northern Thailand," *Catena*, vol. 219, Article ID 106595, 2022.

[16] N. Arunrat, S. Sereenonchai, P. Kongsurakan, C. B. Iwai, M. Yuttitham, and R. Hatano, "Post-fire recovery of soil organic carbon, soil total nitrogen, soil nutrients, and soil erodibility in rotational shifting cultivation in Northern Thailand," *Frontiers in Environmental Science*, vol. 11, 2023.

[17] Y. Leul, M. Assen, S. Damene, and A. Legass, "Effects of land-use dynamics on soil organic carbon and total nitrogen stock, western Ethiopia," *Applied and Environmental Soil Science*, vol. 2023, Article ID 5080313, 12 pages, 2023.

[18] T. Guillaume, M. Damris, and Y. Kuzyakov, "Losses of soil carbon by converting tropical forest to plantations: erosion and decomposition estimated by δ^{13}C," *Global Change Biology*, vol. 21, no. 9, pp. 3548–3560, 2015.

[19] G. R. Van der Werf, D. Morton, R. Defries et al., "CO_2 emissions from forests," *Nature Geoscience*, vol. 2, no. 11, pp. 737-738, 2009.

[20] R. Lal, "Managing soils and ecosystems for mitigating anthropogenic carbon emissions and advancing global food security," *BioScience*, vol. 60, no. 9, pp. 708–721, 2010.

[21] Ipcc, "Climate change impacts adaptation and vulnerability," in *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*,

M. L. Parry, O. F. anziani, J. P. Palutikof, P. J. vander Linden, and C. E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 2007.

[22] R. Sedjo and B. Sohngen, "Carbon sequestration in forests and soils," *Annual Review of Resource Economics*, vol. 4, no. 1, pp. 127–144, 2012.

[23] P. Srivastava, A. Kumar, S. K. Behera, Y. K. Sharma, and N. Singh, "Soil carbon sequestration: an innovative strategy for reducing atmospheric Carbon Dioxide concentration," *Biodiversity & Conservation*, vol. 21, no. 5, pp. 1343–1358, 2012.

[24] R. Nair, C. R. Mehta, and S. Sharma, "Carbon sequestration in soils-A Review," *Agricultural Reviews*, vol. 36, no. 2, pp. 81–99, 2015.

[25] P. Smith, "Carbon sequestration in croplands: the potential in Europe and the global context," *European Journal of Agronomy*, vol. 20, no. 3, pp. 229–236, 2004.

[26] Dfrs, *State of Nepal's Forests Forest Resource Assessment (FRA) Nepal*, Department of Forest Research and Survey (DFRS), Kathmandu, Nepal, 2015.

[27] G. S. Yihenew and A. Getachew, "Efects of diferent land use systems on selected physicochemical properties of soils in North western Ethiopia," *The Journal of Agricultural Sciences*, vol. 5, no. 4, pp. 112–120, 2013.

[28] Usaid, *Greenhouse Gas Emissions Factsheet: Nepal*, United States Agency for International Development (USAID), Nepal, 2019.

[29] G. R. Blake and K. H. Hartge, "Bulk density," *Methods of Soil Analysis, Part 1, Physical and Mineral Method*, vol. 9, pp. 363–382, 1968.

[30] A. Walkley and I. A. Black, "An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method," *Soil Science*, vol. 37, no. 1, pp. 29–38, 1934.

[31] J. M. Bremner and C. S. Mulvaney, "Nitrogen total," in *Methods of Soil Analysis Part 2, 2nd ed. Chemical and Microbiological Properties*, A. L. Page, Ed., pp. 595–624, ASA. Madison. WI, Hoboken, NJ, USA, 1982.

[32] T. R. Pearson, S. L. Brown, and R. A. Birdsey, *Measurement Guidelines For The Sequestration Of Forest Carbon*, U.S. Department of Agriculture, Forest service, Northern research Stanton, Newton Square, PA, USA, 2007.

[33] S. Bhandari and S. Bam, "Comparatives study of soil organic carbon (SOC) under forest, cultivated and barren land: a case of chovar village, kathmandu," *Nepal Journal of Science and Technology*, vol. 14, no. 2, pp. 103–108, 2014.

[34] H. Gilani, H. L. Shrestha, M. S. R. Murthy et al., "Decadal land cover change dynamics in Bhutan," *Journal of Environmental Management*, vol. 148, pp. 91–100, 2015.

[35] D. Susmita, M. Koirala, E. Sharma, and N. R. Subedi, "Effect of land use change on soil organic carbon stock in balkhu khola watershed southwestern part of kathmandu valley, Central Nepal," *International Conference on Energy, Environment, Sustainable Development*, vol. 66, 2013.

[36] P. Ghimire, B. Bhatta, B. Pokhrel, G. Kafle, and P. Paudel, "Soil organic carbon stocks under different land uses in Chure region of Makawanpur district, Nepal," *SAARC Journal of Agriculture*, vol. 16, no. 2, pp. 13–23, 2019.

[37] N. C. Brady and R. R. Weil, *The Nature and Properties of Soil*, Macmillan Publishing Company, New York, NY, USA, 2017.

[38] T. Toru and K. Kibret, "Carbon stock under major land use/land cover types of Hades sub-watershed, eastern Ethiopia," *Carbon Balance and Management*, vol. 14, no. 1, 2019.

[39] A. Nahusenay, K. Kibebew, G. Heluf, and E. Abayneh, "Characterization and classification of soils along the toposequence at the wadla delanta massif, north central highlands of Ethiopia," *Journal of Ecology and the Natural Environment*, vol. 6, no. 9, pp. 304–320, 2014.

[40] K. Morisada, K. Ono, and H. Kanomata, "Organic carbon stock in forest soils in Japan," *Geoderma*, vol. 119, no. 1-2, pp. 21–32, 2004.

[41] B. Shrestha, B. Sitaula, B. R. Singh, and R. M. Bajracharya, "Soil organic carbon stocks in soil aggregates under different land use systems in Nepal," *Nutrient Cycling in Agroecosystems*, vol. 70, no. 2, pp. 201–213, 2004.

[42] S. Kalu, M. Koirala, and U. R. Khadka, "Soil quality assessment for different land use in the panchase area of western Nepal," *International Journal of Environmental Protection*, vol. 5, no. 1, pp. 38–43, 2015.

[43] B. J. Fu, S. L. Liu, L. D. Chen, Y. H. Lu, and J. Qiu, "Soil quality regime in relation to land cover and slope position across a highly modified slope landscape," *Ecological Research*, vol. 19, no. 1, pp. 111–118, 2004.

[44] J. Liefeld, S. Bassin, and J. Fuhrer, "Carbon stock in Swiss agriculture soils predicted by land use soil characteristics and altitude," *Agriculture, Ecosystems & Environment*, vol. 105, pp. 225–266, 2005.

[45] J. R. Landon, *Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics*, Routledge, Oxfordshire, England, UK, 2014.

[46] P. Ghimire, B. Bhatta, B. Pokhrel, I. Shrestha, and I. Shrestha, "Assessment of soil quality for different land uses in the Chure region of Central Nepal," *Journal of Agriculture and Natural Resources*, vol. 1, no. 1, pp. 32–42, 2018.

[47] G. Zhu, Z. Shangguan, X. Hu, and L. Deng, "Effects of land use changes on soil organic carbon, nitrogen and their losses in a typical watershed of the Loess Plateau, China," *Ecological Indicators*, vol. 133, Article ID 108443, 2021.

[48] W. Amanuel, F. Yimer, and E. Karltun, "Soil organic carbon variation in relation to land use changes: the case of Birr watershed, upper Blue Nile River Basin, Ethiopia," *Journal of Ecology and Environment*, vol. 42, no. 1, 2018.

[49] A. Ostrowska and G. Porebska, "Assessment of the C/N ratio as an indicator of the decomposability of organic matter in forest soils," *Ecological Indicators*, vol. 49, pp. 104–109, 2015.

[50] W. M. Strong and M. G. Mason, "Nitrogen," in *Soil Analysis, an Interpretation Manual*, K. I. Peverill, L. A. Sparrow, and D. J. Reuter, Eds., pp. 171–185, CSIRO Publishing, Australia, 1999.

[51] G. Kafle, "Vertical distribution of soil organic carbon and nitrogen in a tropical community forest of Nepal," *International Journal of Financial Research*, vol. 2019, Article ID 3087570, 6 pages, 2019.

[52] A. Demessie, B. R. Singh, and R. Lal, "Soil carbon and nitrogen stocks under chronosequence of farm and traditional agroforestry land uses in Gambo District, Southern Ethiopia," *Nutrient Cycling in Agroecosystems*, vol. 95, no. 3, pp. 365–375, 2013.

[53] G. Abebe, A. Tsunekawa, N. Haregeweyn et al., "Effects of land use and topographic position on soil organic carbon and total nitrogen stocks in different agro-ecosystems of the upper blue nile basin," *Sustainability*, vol. 12, no. 6, p. 2425, 2020.

[54] B. M. Shrestha and B. R. Singh, "Soil and vegetation carbon pools in a mountainous watershed of Nepal," *Nutrient Cycling in Agroecosystems*, vol. 81, no. 2, pp. 179–191, 2008.

[55] M. Schmitt-Harsh, T. P. Evans, E. Castellanos, and J. C. Randolph, "Carbon stocks in coffee agroforests and

mixed dry tropical forests in the western highlands of Guatemala," *Agroforestry Systems*, vol. 86, no. 2, pp. 141–157, 2012.

[56] W. Bewket and L. Stroosnijder, "Effects of agroecological land use succession on soil properties in Chemoga watershed, Blue Nile basin, Ethiopia," *Geoderma*, vol. 111, no. 1-2, pp. 85–98, 2003.

[57] S. Melero, R. J. López-Bellido, L. López-Bellido, V. Muñoz-Romero, F. Moreno, and J. M. Murillo, "Long-term effect of tillage, rotation and nitrogen fertiliser on soil quality in a Mediterranean Vertisol," *Soil and Tillage Research*, vol. 114, no. 2, pp. 97–107, 2011.

[58] T. Rudel, "Deforestation by land grabbers," *Nature Geoscience*, vol. 8, no. 10, pp. 752-753, 2015.

[59] G. Pan, P. Smith, and W. Pan, "The role of soil organic matter in maintaining the productivity and yield stability of cereals in China," *Agriculture, Ecosystems & Environment*, vol. 129, no. 1-3, pp. 344–348, 2009.

[60] World Bank, "Sustainable Land Management Project, Project Appraisal Document (PAD)," Ethiopia/Report No. 42927-ET, Project I.D P107139, 2008.

[61] M. de Blécourt, R. Brumme, J. Xu, M. D. Corre, and E. Veldkamp, "Soil carbon stocks decrease following conversion of secondary forests to rubber (Hevea brasiliensis) plantations," *PLoS One*, vol. 8, no. 7, Article ID 69357, 2013.

[62] S. A. Beza and M. A. Assen, "Soil carbon and nitrogen changes under a long period of sugarcane monoculture in the semiarid East African Rift Valley, Ethiopia," *Journal of Arid Environments*, vol. 132, pp. 34–41, 2016.

[63] S. Damene, A. Bahir, and G. B. Villamor, "The role of Chomo grass (Brachiaria humidicola) and exclosures in restoring soil organic matter, total nitrogen, and associated functions in degraded lands in Ethiopia," *Regional Environmental Change*, vol. 20, no. 3, pp. 92–13, 2020.

[64] L. B. Guo and R. M. Gifford, "Soil carbon stocks and land use change: a meta-analysis," *Global Change Biology*, vol. 8, no. 4, pp. 345–360, 2002.

[65] R. Lal, J. M. Kimble, and R. Follet, "Land use and soil carbon pools in terrestrial ecosystems," in *Management of Carbon Sequestration in Soils*, R. Lal, J. M. Kimble, and R. Follet, Eds., CRC Press, New York, NY, USA, 1997.

[66] P. R. Nair, V. D. Nair, B. M. Kumar, and S. G. Haile, "Soil carbon sequestration in tropical agroforestry systems: a feasibility appraisal," *Environmental Science & Policy*, vol. 12, no. 8, pp. 1099–1111, 2009.

[67] E. Gruneberg, I. Schöning, E. K. Kalko, and W. W. Weisser, "Regional organic carbon stock variability: a comparison between depth increments and soil horizons," *Geoderma*, vol. 155, no. 3-4, pp. 426–433, 2010.

[68] V. Sharma, S. Hussain, K. R. Sharma, and V. M. Arya, "Labile carbon pools and soil organic carbon stocks in the foothill Himalayas under different land use systems," *Geoderma*, vol. 232, no. 7, pp. 81–87, 2014.

[69] S. Ali, F. Begum, R. Hayat, and B. J. M. Bohannan, "Variation in soil organic carbon stock in different land uses and altitudes in Bagrot Valley, Northern Karakoram," *Acta Agriculturae Scandinavica Section B Soil and Plant Science*, vol. 67, no. 6, pp. 551–561, 2017.

[70] A. Abegaz, L. A. Winowiecki, T. G. Vågen, S. Langan, and J. U. Smith, "Spatial and temporal dynamics of soil organic carbon in landscapes of the upper Blue Nile Basin of the Ethiopian Highlands," *Agriculture, Ecosystems & Environment*, vol. 218, pp. 190–208, 2016.

[71] R. M. Bajracharya, B. K. Sitaula, B. M. Shrestha, K. D. Awasthi, M. K. Balla, and B. R. Singh, "Soil organic carbon status and dynamics in the central Nepal Middle Mountains," *Journal of the Institute of Fuel*, vol. 12, pp. 28–44, 2004.

[72] N. J. Ostle, P. E. Levy, C. D. Evans, P. Smith, and Smith, "UK land use and soil carbon sequestration," *Land Use Policy*, vol. 26, no. 1, pp. S274–S283, 2009.