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Land use and land cover change influence on soil organic carbon content for a pastoral area: use of geographical information system

[1]*NJAGI S M., [1]LEJJU J., [1]NKURUNUNGI J B

[1]Mbarara University of Science and Technology, Faculty of Science, Department of Biology, P.O. Box 1410, Mbarara, Uganda

*Corresponding author: murithishadra@gmail.com

Abstract

Data on land use and cover change and soil organic carbon (SOC) in rangelands are essential. This is because rangelands ecosystems are fragile, and poor land-use practices can significantly threaten their sustainability by depleting SOC and increasing atmospheric carbon dioxide. This study investigated soil organic carbon variations as influenced by land use/land cover changes in the unprotected area of the Sanga agropastoral ecosystem, southwestern Uganda. Landsat images provided data for land use and cover for 1987 and 2020. Soil organic carbon contents were investigated in farmland (FL), grassland (GL), woodland (WL), and bare land (BL) as control at 0-15 cm and 15-30 cm depths. Soil samples were analyzed for organic carbon and bulk density using the colorimetric and core ring methods, respectively. Total soil organic carbon content was significantly high in grassland (31.55 Mg C ha-1), p=0.005, and woodland (27.89 Mg C ha-1), p=0.028 compared to bare land (16.17 Mg C ha-1). Additionally, total soil organic carbon concentration in grassland (2.10%) was higher than SOC concentration in farmland (1.39%) p=0.001 and bare land (1.00%), p<0.001, respectively. Similarly, woodlands soil organic carbon concentration (1.98%) was higher than soil organic concentrations in bare lands, p=0.003 and farmlands, p=0.028. Bulk density was significantly different at lower horizons, with farmland having a higher bulk density than other land use types, p=0.013. Roots and litter inputs in woodlands and grasslands contributed to higher organic carbon than farmland and eroded/bare lands. Cultivation also increased the soil bulk density. This study concludes that land use and the land cover change affected soil organic carbon sequestration and bulk density. Therefore, farmers need to increase farm management practices to avoid an increase in bulk density. Further study to compare the effects of grazing intensity on SOC and modeling future SOC content in the study area is recommended.

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Keywords: *Susceptibility; Carbon Sequestration; Land cover; geographical information system*

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Introduction

Fragile ecosystems characterize rangelands, and that SOC is significantly susceptible to changes in the environment, primarily due to changes in vegetation cover (Wang *et al.,* 2011). Due to government policies on agricultural diversification, population pressure, sedentarization policies (Wurzinger *et al.,* 2009), and frequent animal diseases, land tilling, crop cultivation practices have been intensified in Sanga rangeland. This practice could have increased the net loss of carbon in the soil to the atmosphere since converting grassland into farmland can elevate atmospheric carbon dioxide (Shiferaw *et al.,* 2019). These practices threaten the rangeland ecosystems that support pastoralists' livelihoods (Shiferaw *et al.,* 2019). Agricultural practices affect SOC content, particularly on topsoil, by directly altering the carbon inputs and environmental modification for microbes (Zhao *et al.,* 2017). Particularly for Sanga, the natural pastoral system, which formerly involved free grazing practices, has been infringed by farmlands. Human activities such as charcoal burning have increased, whereby they could have altered carbon inputs. This alteration of carbon inputs and ecological change can adversely affect environmental sustainability, regional climate, and land productivity.

Human activities' impact on SOC and carbon sequestration is not well documented in Uganda recently, and thus more SOC data are needed (Gibbs *et al.,* 2007; Twongyirwe *et al.,* 2013). Researches on land use and land cover change (LULCC) in Uganda were conducted to assess the impact of LULCC on water quality, water management (Luwa *et al.,* 2020), carbon stock, and climate change in the Mt Elgon region (Mugagga, 2015) and the ecosystem (Mbaziira, 2019). This study assessed the variations in SOC content, SOC concentration, and soil bulk density across different land-use types to understand how conversing LULC affects these soil physical-chemical properties and carbon sequestration in Sanga rangelands, southwestern Uganda.

Materials and Methods

The description of the area of the study

This study was carried out in Sanga sub-county located in Kiruhura district, South Western Uganda, located at 0°22′22.50″ S to 0º42″39.59″ S and 30°47′06.04″ E to 31°02′01.25″ E as Figure 1 shows. This sub-county covers approximately an area of 55,700 hectares. Its altitude is 1200 m above sea level on average (Averbeck *et al.,* 2012). Temperature ranges in this area are from 17 ºC to 30 ºC and receive an average of 900 mm rainfall per year. Double maximum is the pattern of rain in this region, and it falls from March to May and August to October (Tibezinda *et al.,* 2016). The area has different types of soils. In lowlands, hard clay loams, black-gray, and reddish-brown sandy structures are typical. The savannah woodlands are the vegetation types found in Sanga (Basamba *et al.,* 2016).70% of the residents are pastoralists (Basamba *et al.,* 2016) who extensively graze cattle and goats in ranches (Nabasumba *et al.,* 2016). Besides livestock keeping, they also cultivate bananas, potatoes, maize, groundnuts, cassava, and other crops.

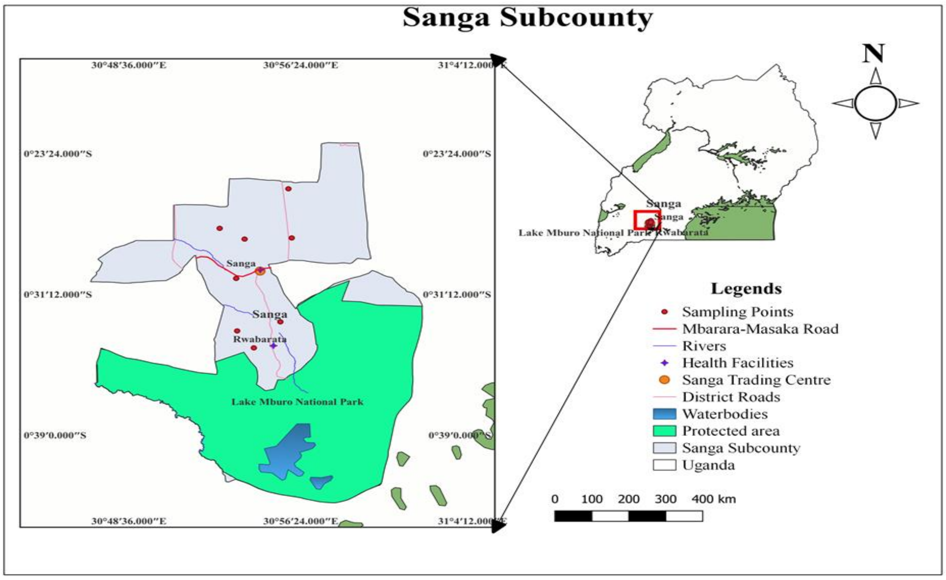

Figure 1: Study site: Sanga sub-county is shown in the inset map of Uganda

Land use/land cover change detection

Landsat 5 Thematic Mapper (5 TM) for the year 1987 and Landsat 8 Operational Land Imager and Thermal Infrared Sensors (OLI/TIRS) for 2020 were downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov). The images were processed in QGIS version 3.20.1 by loading bands to semi-automatic classification plugin (SCP) version 7.9.5 (Congedo, 2021). The classification of the images was by supervised methods, employing the maximum likelihood function. LULC classes identified were farmland, grassland, woodland, bare/eroded land, wetlands, water body, and built-up areas.

Soil sampling and organic carbon determination

Soil sampling was conducted in sampling plots of 20 by 20 meters of each land-use type (farmland, grassland, woodland and eroded/bare lands) at a depth of 0-15 cm and 15-30 cm. For organic carbon content assessment, composite soil samples were pooled from 5 positions within the subsampling plots of 25 m^2 located in four corners and one at the center of the sampling plot. One core sample was obtained from the center of each plot and soil depth for determining soil bulk density. Core sampling was done using the core method, where a core of 110cm^3 was used. A total of 64 composite soil samples and 64 core samples (2 sampling depths x 8 blocks x 4 land-use types =64) were collected to be analyzed in the laboratory. Soil samples were air-dried for over 48 hours before transporting them to the Mountains of the Moon University Soil Laboratory. The Walkley-Black (colorimetric) method using a spectrophotometer and following FAO (2019) and Tola et al. (2018) procedures was used. Soil organic carbon content was calculated according to the Equation 1 (Haile *et al.,* 2021);

SOC= $\%.OC \times \rho b \times d$……………….... (Equation 1)

Where; % OC is the soil organic carbon concentration, ρb is soil bulk density (gcm^{-3}), and d is the soil depth of the sample (cm).

Total soil organic carbon content and concentration for each LULC type were calculated by adding the SOC for 0-30 cm.

Bulk density determination

Samples were oven-dried to constant weight at 105 °C for two days. The bulk density was calculated as (Kurgat, 2011);

$\rho b=\frac{ODW}{CV}$…………. (Equation 2)

Where;

ρb is bulk density (gcm^{-3}), ODW is the mass of oven-dried soil (g), and CV is the volume of the core (cm^3).

Statistical analysis

We preferred nonparametric tests since the data were not very large and not meeting all the requirements for parametric tests. An SPSS software was used to analyze data using Kruskal-Wallis H tests to determine the differences in medians for SOC contents, SOC concentration, and bulk density in different land-use types at the statistical significance of $p \leq 0.05$. Dunn's pairwise comparison and Bonferroni correction were used for post hoc tests.

Results

Land use/cover in the unprotected area (1987 to 2020)

The main LULC were wetland, built-ups, farmlands, grasslands, woodlands, and eroded/bare lands, as shown in Figure 2 and Figure 3 below.

Wetland cover decreased significantly by 88.34%, while built-up areas increased tremendously by 1348.15%. Woodland declined by 22.81%. Moreover, farmland cover increased by a large margin of 405.03%, from 2.17% in 1987 to 10.96% in 2020. Similarly, there was a considerable increase by 25.07% in eroded/bare lands cover.

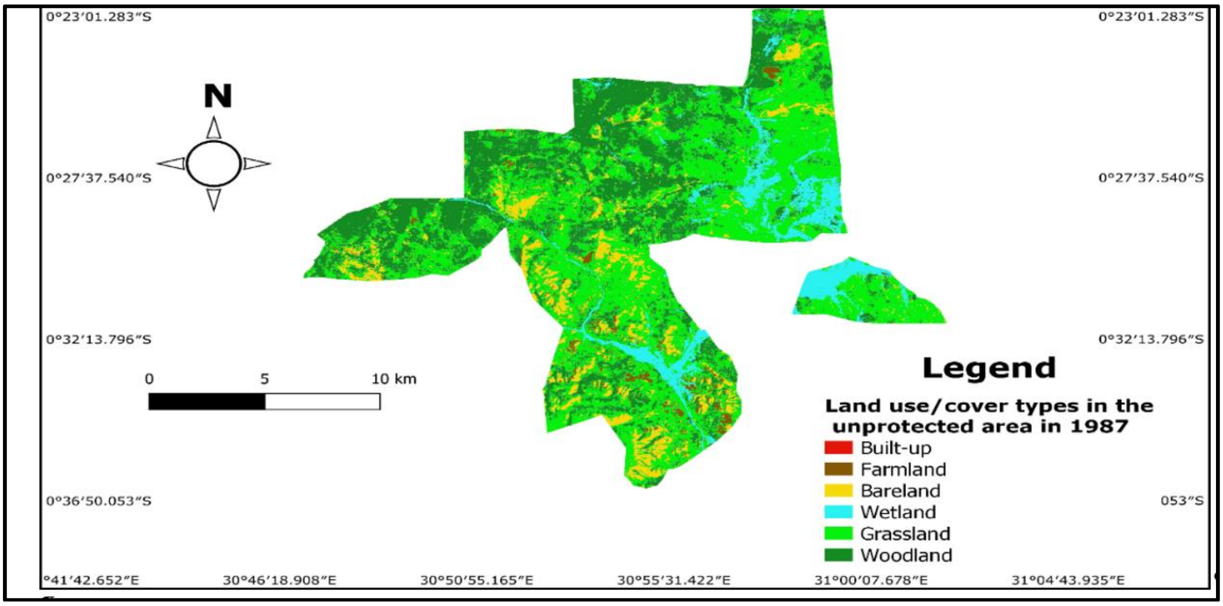

Figure 2: Land use/land cover types in the unprotected area of Sanga sub-county in 2020

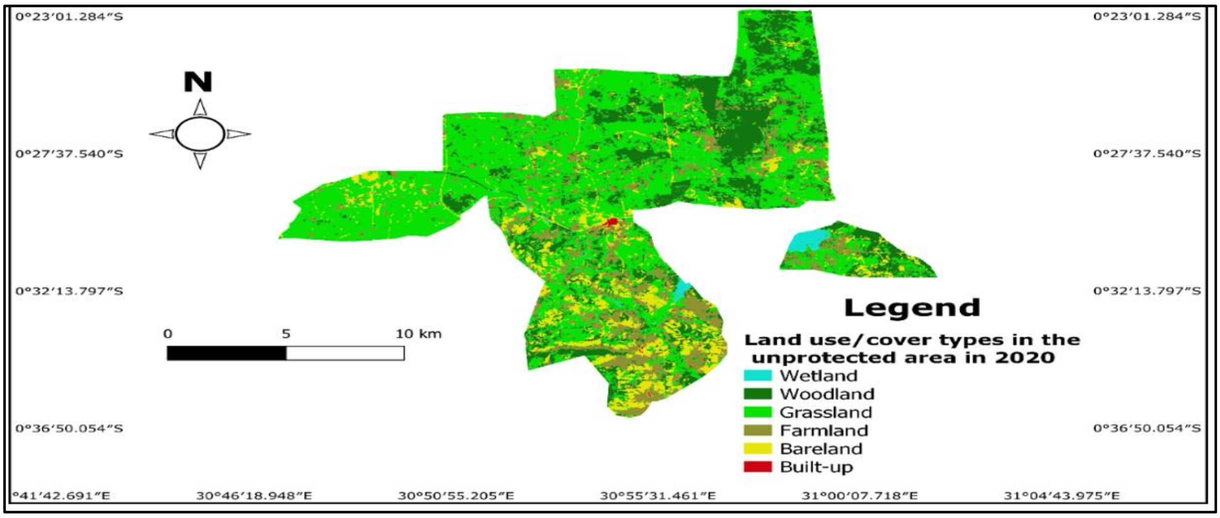

Figure 3: Land use/land cover types in the unprotected area of Sanga sub-county in 1987

Table 2: Land use/land cover and change from 1987 to 2020 in the unprotected area of Sanga

	1987		**2020**			
Land use/cover type	Area (Ha)	%Land cover	Area (Ha)	% Landcover	1987-2020 land cover change	1987-2020 % Land cover change
Wetland	2035.08	8.05	237.33	0.94	-1797.75	-88.34
Woodland	7910.91	31.30	6106.23	24.18	-1804.68	-22.81
Grassland	12660.84	50.09	13458. 96	53.30	798.12	6.30
Farmland	547.83	2.17	2766.69	10.96	2218.86	405.03
Bareland	2117.07	8.38	2647.8	10.49	530.73	25.07
Built-up	2.43	0.01	35.19	0.14	32.76	1348.15
Total	**25274.16**		**25252.20**			

The effects of land use/cover type on total SOC content and SOC concentrations

Total SOC content was significantly different $p=0.030$ (Table 3). The bare lands total content was lower than woodlands total SOC content, $p=0.028$, and grasslands total SOC content, $p=0.005$. However, total SOC contents did not significantly differ from other LULCs.

There was a substantial variation in total SOC concentrations $p<0.001$ (Table 3). Total SOC concentrations in grasslands were significantly higher than SOC concentrations in bare lands $p<0.001$. Additionally, total SOC in grasslands was also substantially higher than total SOC in farmlands, $p=0.001$. Furthermore, the SOC concentrations in woodlands differed significantly from SOC concentrations in bare lands, $p=0.003$. Additionally, there was a substantial difference between the SOC in woods and SOC in farmlands, $p=0.028$. However, woodlands and grasslands, and farmlands and bare lands did not show significant differences in SOC concentrations.

Table 3: Total SOC contents, SOC concentrations under different land-use types, medians at significant p≤0.05, and ranges

LUTs n=32	SOC content (Mg C ha^{-1}) medians + range	Organic carbon content (%) medians+ range
.FL	26.29 (11.94-35.06)	1.39ab (0.75-1.89)
GL	31.55a (20.12-36.34)	2.10b (1.54-2.32)
WL	27.29b (20.80-42.36)	1.96ac (1.23-3.24)
BL	16.17ab (12.67-23.12)	1.00bc (0.74-1.60)
p-value	0.030	<0.001

LUTs-Land use types; FL-farmlands; GL-Grasslands; WL-woodlands; BL-bare lands; Note: similar

letters in the same column indicate significant differences ($p\leq0.05$) in medians. The figures in the brackets represent the data range.

The effects of LULC on bulk density at 0-15 cm and 15-30 cm depths

There was no statistical difference in soil bulk density across the LUTs at 0-15 cm soil layer, p=0.126 (Table 4). Across LUTs at a soil depth of 15-30 cm, there was a significant difference in soil bulk density, p=0.013 (Table 5). Soil bulk density (1.28 gcm^{-3}) in farmlands was significantly higher than soil bulk density in grasslands (1.00 gcm^{-3}), p=0.005, woodlands (1.07 gcm^{-3}), p=0.050, and bare lands (1.04 gcm^{-3}) p=0.010, respectively.

Table 4: The medians of soil bulk density for different LUTs, and p values at ≤0.05 at 0-15 cm and 15-30 cm

Soil parameter	Depth (cm)	LUTS				*p*-value
		Farmland	Grassland	Woodland	Bare land	
	0-15	1.13	0.89	0.90	1.13	0.126
Bulk density (gcm^{-3})	15-30	1.28abc	1.00a	1.07c	1.04b	0.013

LUTs-Land use types Note: similar letters in the same column indicate significant differences (p≤0.05) in medians.

Discussion

The effects of LULC on SOC contents and SOC concentrations

This study revealed that land use types had a significant effect on SOC contents. Bare lands' SOC content differed only with grasslands and woodlands' SOC content, but grassland and woodlands' SOC content did not differ. This phenomenon can be attributed to the fact that SOC contents and storage depend on plant species growth characterizations, management practices, soil biological and physical characteristics (Yazdanshenas *et al.,* 2018).

Furthermore, these differences can be linked to the fact that land-use types tend to influence the SOC content in terms of the organic residue placements, amount, and types of organic residues (Ren *et al.,* 2009). Thus, due to litter input in farmlands, woodlands and grasslands, there was no significant difference in SOC content.

On the other hand, grasslands and woodlands had a higher SOC content than the bare lands because they had fine roots and above groundmass (Zhao *et al.,* 2017), which are scarce in bare lands. Grass vegetation such as *Chloris gayana, Panicum spp, Pennisetum spp, Cynodon spp*, and woody vegetation such as *Acacia spp*, *Lantana camara*, cypress, *Eucalyptus spp*, *Grewia spp*, *Carissa edulis*, *Albizia coriaria* (Nabasumba *et al.,* 2016; UWA, 2015) provided large roots base and litter. Thus, grassroots distribution in the surface layer is responsible for increased SOC content in grasslands than in bare lands. Haile *et al.,* (2021) also mentioned that high vegetation in undisturbed ecosystems contributes to high production and increased decomposition, contributing to high SOC in such ecosystems.

Low moisture content in bare land could be why the SOC content was also low (Bernice et al. 2018). Additionally, according to Wang *et al.,* (2018), root biomass contributes to carbon inputs and storage, and bare lands large lack roots mass. Also, bare soil lacks surface protection; SOC is easily lost from rain, erosion, and scouring (Qin *et al.,* 2017). The exposed land increase temperature and consequently microbial activity that decomposes organic matter (Xiangmin *et al.,* 2014), contributing to low SOC concentration and content in bare lands.

Munoz-Rojas *et al.,* (2012) state that deforestation leads to substantial loss of SOC stock by reducing SOC sequestration. Introducing agriculture in this study area could lead to a 33.81% loss of SOC sequestration. This loss of concentration of SOC is very close to what was found by Wang *et al.,* (2011) in their experiment, which indicated that cultivation reduced SOC concentration by 36%. This study, therefore, agrees that transforming grassland to cropland may significantly affect the SOC sequestration. However, the high level of SOC concentration in woodland and grassland than other LULC implies that woodlands and grasslands in this study can be suitable land use/cover for ecological restoration and carbon sequestration. The reason for homogeneous SOC concentrations in grasslands and woodlands is that litter input, lower herbaceous plants (grass), and woody canopy enhance the SOC concentration by creating a moist environment (Xue and An, 2018). Farmlands having no statistical difference in SOC concentration with that of bare lands implies that there is a high decomposition of SOC in the former. The high decomposition rate in farmlands (Zandi *et al.*, n.d.) could have contributed to this non-difference in SOC concentration in bare lands and farmlands, which indicates that with poor land management, degradation can be accelerated.

The impact of land use and depth on soil bulk density

The soil bulk density homogeneity in topsoil could be attributed to human activities in farms and animal grazing. Barelands, woodlands, and grasslands were mainly grazing land. (Rotich *et al.*, 2018) found that animal trampling can increase soil bulk density due to compaction. Continuous grazing of animals in rangelands was to have compacted soils. Additionally, land use for agriculture usually desegregates soil and increasing soil bulk density (Yao *et al.*, 2010). Thus, animal trampling and cultivation (Selassie *et al.*, 2015) could have caused the homogeneity in bulk density on the surface soil layer.

At the subsurface layer, the bulk density was significantly higher in farmlands than in other land-use types. Cultivation may have increased compaction at lower depths in this study. In the area under investigation, bananas, potatoes, beans, maize were mainly cultivated. Farmers frequently tilled to weed and enable water retention around the bananas. This tilling could remove the protective residues from the soil, which makes it prone to anthropogenic and natural forces (Gebresamuel et al. 2020). Low soil disturbance (Shiferaw et al. 2019) in lower horizons in grasslands, woodlands, and bare land could have contributed to their homogeneity in bulk density. Lower bulk densities in other land uses at the lower horizon than farmlands could be due to no-tillage and improved microporosity (Kurgat, 2011) due to microclimate in woodland and grasslands and aeration by termites in bare lands.

Conclusion

This study shows that LULC change influenced the SOC content in Sanga rangeland ecosystem despite these LULC being in the same climate conditions. SOC was highest in woodlands and grasslands compared to bare lands and farmlands, and carbon sequestration was high in woodlands and grasslands. Converting grassland and woodland to bare lands land and farmland caused a substantial loss of carbon sequestration. However, the SOC concentration does not meet the recommended threshold for East African soils since all LULC types had SOC concentrations more petite concentration less than the recommended 3%. Thus, carbon stock in unprotected areas is not very high, and therefore, it needs to be improved through increased sustainable land use. Human activities were also found to impact the soil bulk density, whereby cultivation increased the bulk density. Therefore, farmers need to improve their farm management and grazing practices in their farms and ranches to avoid an increase in bulk density and loss of soil carbon sequestration. Further study to compare the effects of grazing intensity on SOC and modeling future SOC content in the study area is recommended.

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