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Implications of changes in land use on soil and biomass carbon sequestration: a case study from the Owabi reservoir catchment in Ghana

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ABSTRACT
Land use changes affect soil and biomass carbon sequestration potential of the agroecosystems of most Sub-Sahara Africa facing rising temperatures due to global climate change. One such ecosystem is the Owabi reservoir catchment in Ghana, which has undergone extensive changes in land use through urbanization. Our study aimed to determine the impact of the spatial and temporal variability of the different land uses on soil and biomass carbon storage in the Owabi catchment. Land use/cover maps were elaborated using SPOT satellite images of 30×30-m resolution and Erdas Imagine and ArcGIS Pro softwares. Soil and vegetation were sampled along three transects in the Y plane in early 2014. Nested plot design and temporary sample plots of 50×50 m were demarcated within a 1 ha plot in each of the land uses. Trees, herbs and litter were sampled to assess aboveground carbon, and soil samples were taken at 0–15 cm and 15–30 cm depth. Belowground (root) biomass was calculated using the root:shoot ratio. Seven (7) land use types – dense forest, sparse forest, grassland, cropland, wetland, settlement, and excavated land – were identified and differences in carbon stocks were assessed. Soil carbon stock (0–30 cm) ranged from 51.80 Mg/ha in dense forest to 7.00 Mg/ha in excavated land. Our study showed that the conversion of forest lands to other land uses through excavation resulted in about 30-folds loss in carbon and also a major loss of carbon in the catchment from c. 1.4×10^6 Mg C in 1990 to 0.55×10^6 Mg C in 2014. Enhancing forests or growing trees to sequester carbon seems to be the optimum choice among the seven land uses if the introduction of payment for environmental services options is considered.

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Introduction

The storage of carbon in soils as soil organic matter through plant biomass has received global attention from both national governments and several world agencies as a means to mitigate carbon emissions and adapt to climate change threats. The average temperature of the world's atmosphere has increased by approximately 0.5 °C since 1975 [1], triggering changes in the global climate, and these constitute one of the greatest threats to the well-being of mankind in the twenty-first century [2]. A key reason for global warming is the increased release of anthropogenic greenhouse gases, especially atmospheric carbon dioxide [3].

Although most developing countries are considered small contributors to climate change, they are more vulnerable to such changes than developed countries, and the ongoing climatic alterations threaten sustainable growth and development [4]. Developing countries will face changes in precipitation patterns, creating shortage of water and major increases in temperatures, which will lead to changes in crop planting and harvesting seasons. Globally, soil stores up to 1576 Pg carbon [5], which exceeds the carbon storage potential of other terrestrial ecosystem compartments. According to Read et al. [6], the global estimated total carbon stock value of tropical forest is 428 Pg

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C, 240 Pg C in wetlands, 131 Pg C in croplands, 199 Pg C in deserts, and 304 Pg C in grasslands.

Soil and vegetation carbon stocks are highly influenced by anthropogenic activities (land use changes) and the overall long-term soil and vegetation carbon source/sink dynamics [7]. For instance, land use changes, particularly the loss of forest resources, have led to reduced carbon sink(s) and a net emission globally of 1.7 Gt C per year in the 1980s and 1.8 Gt C in the 1990s [8]. A global meta-analysis of land use change in the tropics showed that forest conversion into cropland resulted in a soil organic carbon loss of 25%, while forest conversion into grassland reduced soil organic stocks by 12% [9].

In the Owabi reservoir catchment in Ghana, considerable land use/land cover changes have taken place in the past three decades [10], mostly reflecting an increase in settlements. These changes have resulted in considerable food security threat and other livelihood related-issues in the catchment [11]. As an important reservoir acting as a principal supply of pipe-borne water to parts of the nearby city of Kumasi and its suburbs, several studies of the water-related consequences of these changes have been conducted [11–16]. However, information on the effects of the land use changes on the total carbon stocks storage (i.e. vegetation which is above and below carbon and soil carbon stocks) within the catchment is limited. Due to the extensive changes in land use with potential strong impact on carbon sequestration in the catchment (major loss of forest), better knowledge on changes in total carbon stocks of the catchment is needed to explore various avenues to incentivize reductions of carbon emissions resulting from land degradation due to changes in land uses around the catchment in Ghana and globally. This study aimed to provide an inventory of carbon stocks relative to the existing land use/cover and to estimate changes in the carbon sequestration in the Owabi catchment between 1990 and 2014, where substantial land-use changes occurred in the catchment. We hypothesize that the conversion of any forest vegetation to other land uses in the Owabi catchment area will result in loss of soil carbon stocks.

Materials and methods

Study area

The Owabi catchment includes the river basin of the Owabi River located in the Ashanti Region of Ghana and lies between latitudes –6°41′30″ - 6°47′300″N and longitudes 1°44′30″–1°37′30″W [11] (Figure 1). Parts of the catchment that form the Owabi Sanctuary were purposely acquired by the Government of Ghana to create a protected watershed to ensure a continuous and constant supply of water to the reservoir. The Wildlife Division of the Forestry Commission manages the protected lands and the reservoir is controlled and managed by the Ghana Water Company. The area is characterized by a bimodal rainfall pattern with an annual rainfall ranging between 1700 mm and 1850 mm per annum and annual temperatures of 27 °C in August to 31 °C in March [17]. The vegetation has been strongly disturbed by human activities, depriving it of valuable plant and animal species and other anthropogenic activities and forest products [17].

The vegetation distribution of the eight-land use/cover classes of the Owabi catchment area based on 1990, 2010, and 2014 satellite images are presented in Figures 2–4, respectively whereas and Figure 5 displays the corresponding changes in the key land uses over time. A cropland, which has not been farmed for over four years (fallowed) was selected for this study. The forest cover comprises; 'dense' forest where the majority of trees were tall (>30 m) and closely spaced ($\geq$50 trees ha^{-1}). The 'sparse' forest was also characterized by close shrubs and lower tree density (<20 trees ha^{-1}). The grassland was uplands dominated by tall grasses, mainly guinea grass (Panicum maximum), on emerging settlement sites and young fallows. Cropland, which has not been farmed for over five years were selected for the study. Wetland was restricted to poorly drained valley bottoms with tall elephant grasses (Pennisetum puparium) and patches of paddy rice fields. Excavated land comprised nearly bare lands and sand pits left after sand winning activities. The settlement included herbaceous vegetation within a residential area with no established housing.

Plot layout and sampling

The soil and biomass data were taken in early part of 2014. Each of the land-use categories was analyzed based on satellite images (SPOT images with 30 × 30 m resolution) processed in Erdas Imagine and ArcGIS softwares. Images from 1990, 2010 and 2014 were classified using supervised classification methods and validated through field ground truthing.

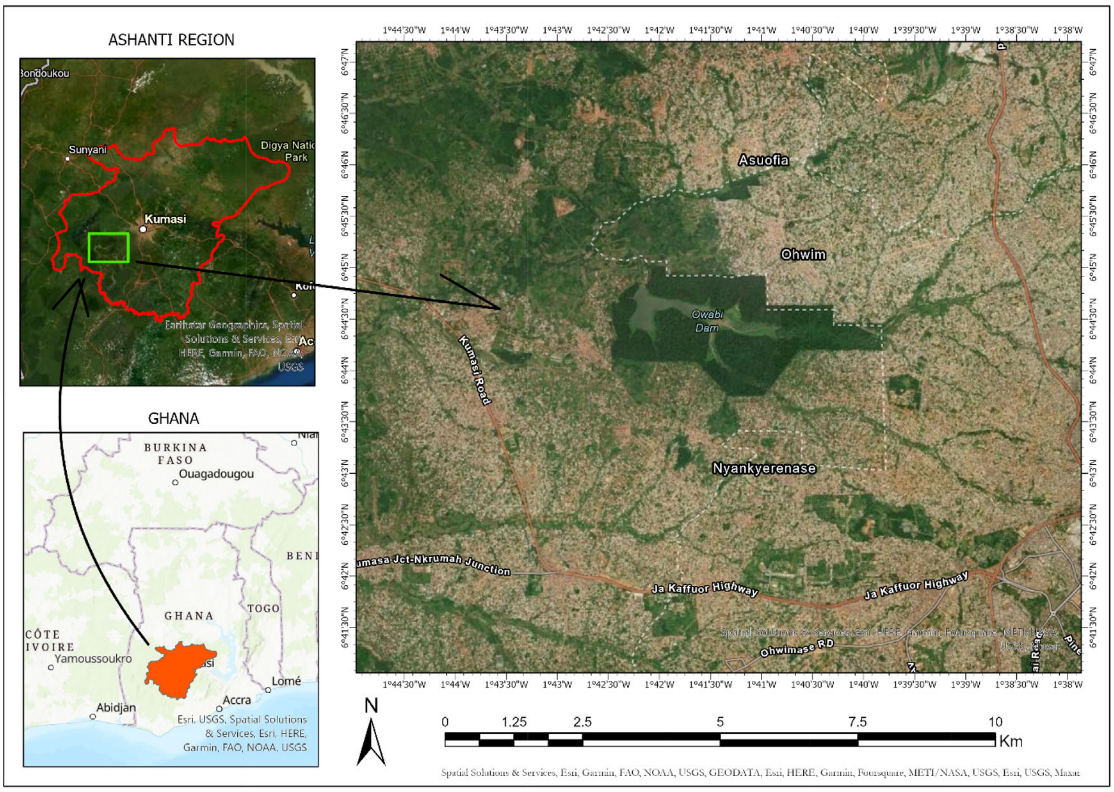

Figure 1. **Location map of the Owabi reservoir catchment area.**

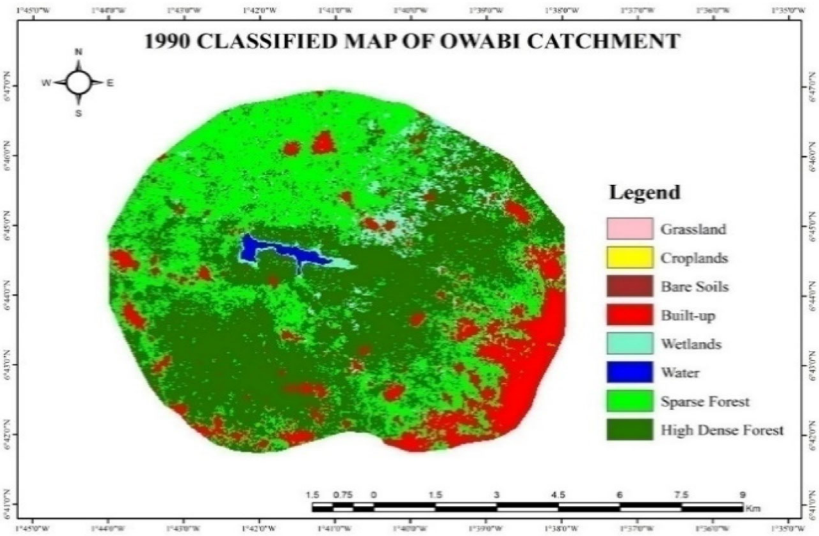

Figure 2. **Land use/cover classes in the Owabi catchment in 1990.**

Four subplots of a dimension 50 × 50 m were established within a 1 ha plot in each of the land use. In each of these subplots, all trees were measured at breast height using a diameter tape at 1.3 m above the ground divided into four size classes (0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm), The height of standing trees was measured indirectly using triangulation of a hypsometer, while the root to shoot ratio was calculated as in Deans [18]. Biomasses inside a 1 × 1 m quadrat of herbs, grasses, crops cut at the soil surface and leaf litter were determined based on randomly selected replicate samples from each plot. Fresh weight of each sample was measured using a scale balance before it was chopped using a machete, mixed in a plastic basin, subdivided into four portion and a portion collected as sub-sample. The field weight of subsamples was taken, before they were bagged in nylon bags and oven-dried in the laboratory at 60 °C in steel pans to constant weight.

Soil samples were taken along three transect in a Y plane within each of the four 50 × 50 m (replicate) at two different depths 0–15 and 15–30 cm. Thus, four sampling points were taken in each of the subplots. Samples were bulked, thoroughly

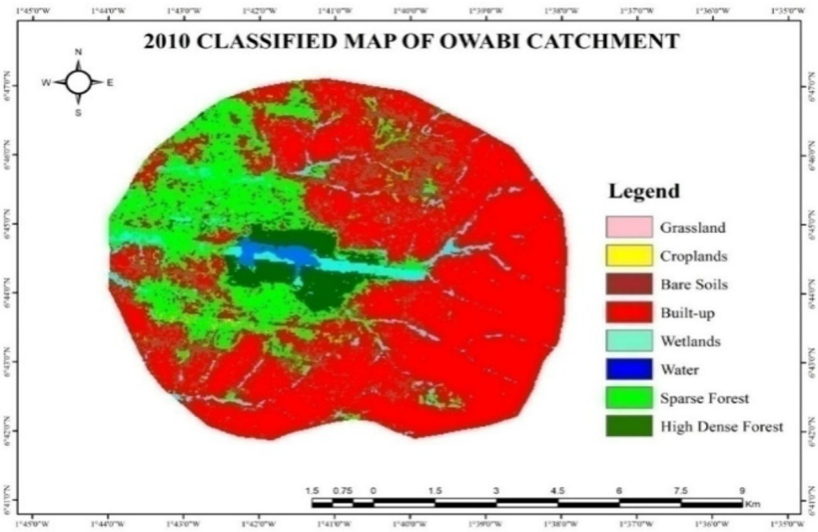

Figure 3. Land use/cover class in the Owabi catchment in 2010.

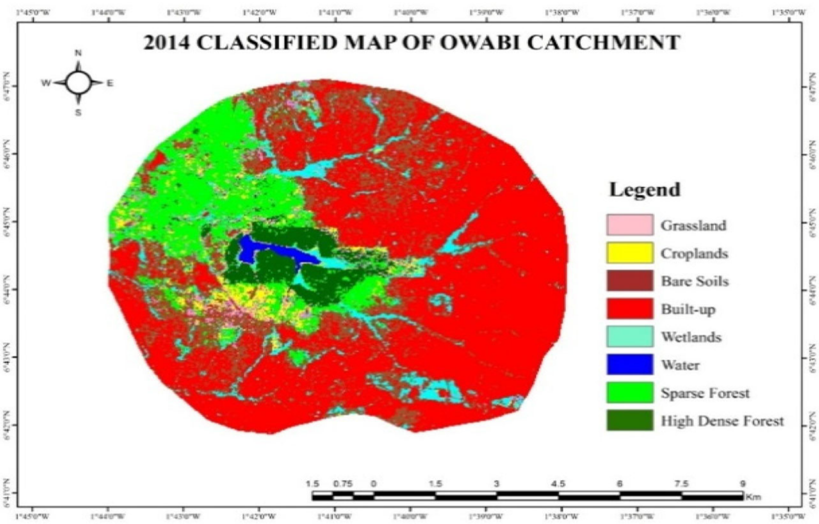

Figure 4. The state of the land cover types in Owabi catchment in 2014.

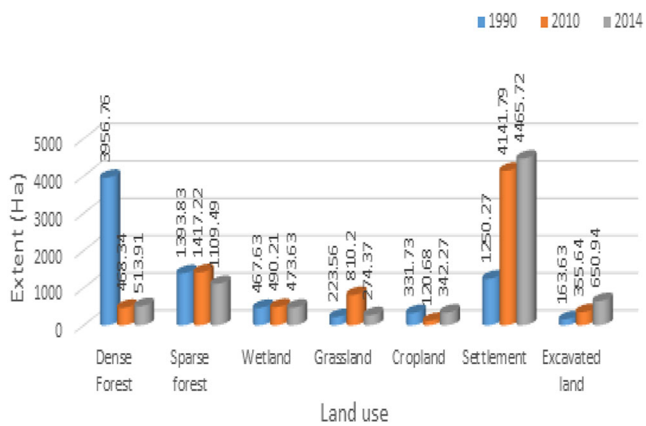

Figure 5. The extent of fluctuation in land cover types in Owabi catchment from 1990 to 2014.

mixed with sub-samples taken and bagged for laboratory analyses. For each land use system, four samples were taken at the 0–15 cm and 15–30 cm, respectively. A 1 kg of soil sample was taken for each subplot for each depth. In all 224 soil samples were taken for the seven land uses. Samples for determination of bulk density were taken in the center of the TSPs with a steel corer (diameter 7.5 cm, height 15 cm) for each key land use. Two samples were taken at each sampling point at 0–15 cm and 15–30 cm depth, and the samples were placed in sealed bags. The composite samples from the subplots were later air-dried for seven days. Each sample was sieved through a 2-mm mesh for determination of soil organic carbon content. Soil organic carbon was determined using the Walkley and Black [19] and bulk density determined by oven drying the samples at 105 °C for 24 hr [20].

Computation of soil, above and below ground carbon stocks

Soil carbon stocks of each of the land use types were calculated according the formula in Equation (1) below;

$$SOC\ stock\ (Mgha^{-1}) = \%\ SOC\ \times\ BD\ \left(Mg\ m^{-3}\right) \times\ soil\ depth\ (m)\ \times\ 10000\ m^2\ ha^{-1}. \quad (1)$$

where: SOC = Soil organic carbon, BD = Dry bulk density of soil.

Tree biomass and biomass carbon were determined using the allometric equation for tropical rainforests [21] in Equation (2).

$$Y = \exp(-2.977) + 1n(X * Z^2 * W) \quad (2)$$

where Y = biomass of forest, X = wood density, Z = diameter at breast height, W = height of tree.

Total dry mass of sub-samples per m^2 was calculated using the formula (see Equation (3)):

$$Total\ dry\ mass\ \left(kgm^{-2}\right) = \frac{Sample\ dry\ mass\ (kg)}{Subsample\ fresh\ mass\ (kg)} \times\ Total\ freshmass\ \left(kgm^{-2}\right). \quad (3)$$

Root biomass was calculated using the root:shoot ratio for tropical semi-deciduous forest as described by the Deans [18]:

$$AGC \times 0.37$$

where: BGC = Belowground carbon, AGC = Aboveground carbon, 0.37 = Ratio of BGC to AGC.

Total carbon stock per land use was the sum of above ground, root carbon and soil organic carbon stocks. For calculating the total carbon stock of the different land uses over time, it was assumed that the carbon stock per ha was constant for each land use for each year (1990, 2010 and 2014). Therefore, all carbon stocks per ha were multiplied by the area (ha) covered by the various land uses at each defined year (1990, 2010 and 2014).

$$TCST \neq TSOC\ stock\ *\ LS \quad (4)$$

where TCST = total carbon stocks per year; TSOC; total soil organic carbon stocks, LS; Land size

Data analysis

Data were analyzed using Analysis of Variance (ANOVA) in GenStat statistical package (12th edition). Comparisons of means to assess the significance differences in carbon stocks between land use using. Fisher's LSD at 5% probability level.

Results

Area covered by key land uses within the Owabi catchment (1990–2014)

The areas of land occupied by the various land uses in 1990 were in a decreasing order of; dense forest (3956.76 ha) >sparse forest (1393.83 ha) > settlement (1250.27) > wetland (467.63 ha) > cropland (331.73 ha)> grassland (223.56 ha)> excavated land (163.63 ha) >water (97.30 ha) (Figures 2 and 5).

Intriguingly in 2010, the dense forest declined about 8-fold to 468.34 ha with sparse forest covering 1417.22 ha, while settlement increased three times (4141.79 ha) more than in 1990. The grassland increased to 810.20 ha; while the cropland decreased about 3-folds to 120.68 ha (Figures 3 and 5). There was a slight increase in dense forest to 513.91 ha in 2014 while there was a reduction in sparse forest (1109.49 ha) (Figures 4 and 5). In this same year, settlement attained the highest of 4465.72 ha whereas grassland declined 274.37 ha in total coverage, respectively. Forest covers declined drastically between 1990 and 2010 but became fairly stable between 2010 and 2014, while settlement expanded widely from 1990 to 2010 and gradually between 2010 and 2014 (Table 1). The size of the wetland increased between 1990 and 2010, and with a sharp decrease between 2010 and 2014 (Table 1), while the remaining land use practices/covers showed minor declines or fluctuations.

Total carbon stocks of the key land use in the Owabi catchment

The aboveground carbon stock (trees, litter, herbs) of the different land uses ranged from

Table 1. Area and proportional changes in the key land use/cover classes in the Owabi catchment over time.

	Area (ha)		% Change		
	Year		Year		
Land use	1990–2010	2010–2014	1990–2010	2010–2014	1990–2014
Dense forest	−3488.40	45.50	−88	10	−87
Sparse forest	23.30	−307.70	2	−22	−20.50
Wetland	22.50	−16.50	5	−3	1.28
Grassland	586.60	−535.80	262	−66	22.70
Cropland	−211.00	221.50	−64	184	3.18
Settlement	2891.60	323.90	231	8	257.20
Excavated land	192.00	295.30	117	83	297.80

Table 2. Total carbon stocks for the various land uses.

	Total carbon stock (Mg C ha^{-1}) Means ± SEM					
Land use type	Aboveground	Root	Soil (0–15 cm)	Soil (15–30 cm)	Soil (0–30)	Total
Dense forest	153.6 ± 5.8^{a}	55.0 ± 2.6^{a}	30.2 ± 0.9^{a}	21.7 ± 1.0^{a}	51.8 ± 1.9^{a}	260.6 ± 10.3^{a}
Sparse forest	126.7 ± 2.1^{b}	45.0 ± 0.8^{b}	29.6 ± 1.1^{a}	19.9 ± 0.6^{a}	49.5 ± 1.7^{a}	221.4 ± 2.7^{b}
Cropland	2.7 ± 0.1^{c}	NA	28.0 ± 0.9^{a}	18.4 ± 0.6^{ab}	46.5 ± 1.6^{a}	49.3 ± 1.7^{c}
Wetland	1.7 ± 0.2^{c}	NA	29.3 ± 0.6^{a}	17.5 ± 1.1^{ab}	46.7 ± 0.9^{a}	48.6 ± 1.2^{c}
Grassland	2.5 ± 0.1^{c}	NA	8.8 ± 4.4^{a}	15.1 ± 1.5^{b}	43.9 ± 5.9^{a}	46.5 ± 5.9^{c}
Settlement	1.6 ± 1.0^{c}	NA	14.5 ± 5.8^{b}	10.2 ± 4.0^{c}	24.6 ± 9.8^{b}	26.3 ± 9.9^{d}
Excavated land	0.2 ± 0.0^{c}	-NA	4.0 ± 0.1^{c}	2.9 ± 0.1^{d}	7.0 ± 0.1^{c}	7.3 ± 0.1^{e}

SEM: Standard error of means. Numbers with no letters in common are significant different ($p < 0.05$). NA: not available.

0.20 Mg C ha^{-1} in the excavated land to 153.60 Mg C ha^{-1} in the dense forest and dense and sparse forest were significantly ($p < 0.05$) higher than the cropland, grassland, wetland, settlement and excavated land (Table 2). However, the belowground carbon (root carbon) was significantly higher in the dense forest than sparse forest and were significantly higher than all the land use systems. The estimated total soil carbon stock ranged from 7.00 Mg C ha^{-1} in the excavated to 51.80 Mg C ha^{-1} in the dense forest at the 0–30 cm depth. At this same layer, soil carbon stock in the excavated land was significantly ($p < 0.05$) lower than the Settlement and the stocks were all significantly lower than in the other land use types (Table 2). The total carbon stocks (soil C + root C + above ground C stocks) was significantly higher in the dense forest and sparse forest than in the other land use categories, showing $a > 80\%$ in all the stocks (Table 2).

Contribution of the different land uses to total carbon stocks with time

In 1990, dense forest held the largest proportion of the carbon stock of 1031 Mg C/ha/year which was 3-folds higher than the sparse forest. The aforementioned land use was consistently higher than the other land uses in 2010 and 2014 within the catchment (Table 3), respectively. Analysis showed that land use change from forest vegetation to other land use types in 2010 and 2014 reduced total carbon stocks drastically (Table 3).

Table 3. Total carbon stocks of the different land use Carbon stock (Mg C*10^{3}/ha).

Means ± SEM			
Land use type	1990	2010	2014
Dense forest	1031 ± 41^{a}	120.2 ± 3.6^{b}	133.9 ± 5.3^{b}
Sparse forest	309.0 ± 3.8^{b}	312.6 ± 3.1^{a}	245.6 ± 3.0^{a}
Grassland	10.4 ± 1.3^{c}	40.6 ± 5.5^{d}	12.8 ± 1.6^{c}
Wetland	22.7 ± 0.5^{c}	24.0 ± 0.7^{de}	23.0 ± 0.6^{c}
Cropland	16.3 ± 0.6^{c}	6.1 ± 0.02^{e}	16.9 ± 0.6^{b}
Settlement	32.9 ± 12.3^{c}	89.5 ± 27.3^{c}	117.6 ± 44.0^{c}
Excavated land	1.2 ± 0.02^{c}	2.6 ± 0.02^{e}	4.7 ± 0.07^{c}
Total	423.60	595.70	554.50

Values are mean + standard error of mean (SEM). Values with the same alphabet are significantly not different ($p > 0.05$).

Discussion

Land use/cover changes (1990–2014)

Results in Figures 2–5 and Table 1 indicated that, between 1990 and 2014, forest cover dwindled, while settlement expanded considerably, mainly horizontally, in the peri-urban catchment to meet the housing need of the people. Our findings corroborate with other studies of catchment land cover changes, which have shown extensive changes in the land cover [10]. Horizontal expansion is characteristic of the majority of expanding communities in Ghana [22]. As the cities expand, the value of land in the outskirts increases and is leased for housing. Forest lands are cleared for settlement and for cropland purposes where the latter is subsequently taken over by houses [11, 23, 24]. Studies in the same area by Agyen-Brefo [25], have reported that the limited cover of dense forest in the catchment is possible indication that most of the forest reserve around the Owabi reservoir and the stream is protected from high anthropogenic activities. The small increase in dense forest in 2014 compared with 2010 may be due to enforcement of restrictions against entry into the protected Owabi sanctuary [26].

Vegetation carbon stocks of the different land uses

The level of aboveground carbon varied significantly among the land use/land covers (Table 2). The higher aboveground carbon levels recorded in dense forest were expected as it mainly held older trees with large boles (DBH of 24–35 cm, etc.) and higher litter fall with thick leaf than the other land uses. This result confirms with Sundarapandian and Swamy [27], who reported higher litter fall with larger thickness in dense forest. Sparse forest was dominated by shrubs (<10 m high), widely spaced slender trees and thin leaf litter, rendering a low carbon stock per hectare compared with the dense forest. Köhl et al. [28] reached conclusions similar to ours in an investigation of the impact of tree age on biomass and carbon accumulation.

Cropland, grassland, wetland, settlement and excavated land contained few isolated trees and little or no leaf litter and consequently had low carbon stocks (Table 2). The differences in vegetation carbon stock, accounted for this observation. Other researchers such as Ngo et al. [29], have reported similar findings in carbon stocks of primary and secondary forest vegetation and other land uses in tropical ecosystems. The vegetation carbon stock which comprised the aboveground and root carbon (208.6 Mg C ha^{-1}) of dense forest is comparable with the value of 202.07 of moist evergreen forest in Ghana estimated by Adu-Bredu et al. [30]. Tree carbon is influenced by the size and density of the trees [21]. For example, ornamental trees and patches of forest trees located in residential areas contributed significantly to the carbon stock of the settlement areas.

Total soil carbon stock (0–30 cm)

The soil carbon stock decreased with increasing depth (Table 2). This is partly due to more prominent litter accumulation, microbial activity, and humus formation in the topsoil than in the subsoil [31–33]. The opposite may occur, mostly through intense bioturbation or mechanical cultivation of land [34]. The decreasing soil carbon stock with increasing depth is similar to that observed by Nasigri [35] for different land use systems.

The soil carbon stock at 0–30 cm depth did not vary markedly among the land use/cover classes, except for settlement and excavated land where it was significantly lower than all the other land use systems. The value of soil carbon stock in the dense forest is consistent with 49.1 Mg C ha^{-1} of values reported by Iqbal and Tiwari [36]. However, Gyabaah [37] reported lower values for natural forest (31.9 Mg C ha^{-1}) and cropland (19. 7 Mg C ha^{-1}). A popular explanation of this is that climate acts together with vegetation, soil depth, topography, time, and management in influencing soil organic carbon [38].

From the description of the various land use/land covers, cropland is recently cleared sparse forest, consequently, cropland soils have been disturbed for only 1–2 years without serious degradation. Therefore, soil organic carbon stocks of cropland and sparse forest were similar in the short term. However, accelerated erosion in the long-term may occur [39] due to the land rotation, cropping system and subsistence farming practiced in the Owabi catchment. Grassland was short fallows or abandoned cropland that were not expected to be much lower in soil organic carbon than cropland. This result resonates well with a previous study by Bernoux et al. [40], suggesting that low or no-tillage activities may increase carbon levels in the topsoil.

The significantly lower carbon stocks in settlement and excavated land can be attributed to poor land cover exposing the land to both wind and water erosion, creating trenches and deep holes on the surface of the soils and complete removal of vegetation and topsoil. While it is argued that sand mining is necessary to satisfy human demands, sand-mining activities have led to land degradation and ecological imbalances [41]. The lack of litter input in such systems contributes to pushing the balance between organic matter build up and degradation toward the latter.

The carbon content of wetland was expected to be considerable higher than the other landuse types because the moist nature of the soil encourages long-term storage of carbon due to the slow movement of oxygen into the wetland [42]. However, wetland had low carbon levels due to poor litter decomposition resulting from limited oxygen supply to soil microbes. This confirms the findings of other studies such as Wang et al. [43] suggesting that rate of litter decomposition influences soil carbon retention. Moreover, patches of the wetland were cultivated with rice and okra and the usual length of the dry season is about three months where oxygen availability is high and biological activities are enhanced. Moreover, changes in flooding can affect the litter decomposition process [44] and the release of carbon [45].

It is generally accepted that once conversion of forest areas to different land uses takes place through removal of vegetation, decarboxylation processes trigger a decrease in the stock of soil organic carbon with consequent additional CO_2 emissions [46]. However, significant changes do not occur until after considerable time.

Total carbon stock (aboveground and belowground)

The total carbon stock determined in our study was much higher for dense forest and sparse forest than for the other land uses. This concurs with the estimation that about half of the global terrestrial biomass carbon is tied up in tropical and subtropical forests [28]. The total carbon stock in the dense forest and sparse forest were higher compared with the contributions of the other land uses (Table 2). The high total carbon stock of forest provides clear evidence that forests are able to sequester larger amounts of CO_2 than most other land use types. Forests may thus help reduce greenhouse gas emissions into the atmosphere. As asserted by Bernstein et al. [47]: 'a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber fiber or energy from the forest, will generate the largest sustained mitigation benefit'. It should be noted that settlement carbon was influenced by trees and landscape grasses left in-between houses of new settlement areas, probably for aesthetic and beautification purposes. This suggests that promoting grassing and tree growing in settlements *via*, for instance, payment for ecosystem services could help increase the carbon storage capacity of the Owabi catchment.

Temporal variability of the carbon stock within the Owabi catchment

The carbon stock within the Owabi catchment decreased between 1990 and 2014 due to the conversion of land previously occupied by forests to other uses (Table 3), mainly due to a reduction of standing biomass. Furthermore, these conversions induce changes to the biological and physical conditions of the soil that lead to lower soil carbon content and thereby additional emissions of carbon dioxide. Our results are in line with Mande et al. [48] who suggested that vegetation covers are critical for managing soil CO_2 emissions in forest ecosystems at different stages, as these play a crucial role in soil respiration. From 1990 to 2014, the carbon stock within the Owabi catchment decreased from $1.03*10^3$ Mg C to $0.45*10^3$ Mg C, which is a very significant decline of the carbon stock within the catchment during a short time period.

Conclusions and recommendations

This study documents how changes in tropical forest coverage led to the decline of carbon stock, which is primarily present in biomass and soil. Considerable changes in land use occurred between 1990 and 2014 in the Owabi catchment, with dense forest and sparse forest declining about 87% and 20%, respectively. Settlement and excavated areas increased more than two-fold from 1250 to 4466 ha and from 163 to 651 ha, respectively, and grassland by 22%. Accordingly, the carbon stock within the catchment decreased with more than 60% between 1990 and 2014, mainly due to the loss of forest.

Investigations into community tree planting for aesthetic purposes is essential to establish the basis for landscape restoration. The laws governing the use of forest areas must be strictly enforced by city authorities, such as the Forestry Commission, to halt the encroachment of forest in the catchment area. Extensive education should be conducted by city authorities to inform relevant stakeholders in the Owabi catchment of their vital role in protecting and managing the land. Dissemination of information centered on the importance of forest is recommended.

Conflicts of interest

The authors declare no conflict of interest.

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References

1. Crutzen PJ. The "anthropocene". In: Ehlers E, Krafft T, editors. Earth system science in the anthropocene. Berlin (Germany): Springer; 2006. p. 13–18.
2. Anstey MH. Climate change and health – what is the problem? Global Health. 2013;9(1):4. doi:10.1186/1744-8603-9-4.
3. Hansen J, Sato M, Ruedy R, et al. Global warming in the twenty-first century: an alternative scenario. Proc Natl Acad Sci USA. 2000;97(18):9875–9880. doi:10.1073/pnas.170278997.
4. Asante FA, Amuakwa-Mensah F. Climate change and variability in Ghana: stocktaking. Climate. 2014;3(1):78–99. doi:10.3390/cli3010078.
5. Eswaran H, Van den Berg E, Reich P, et al. Global soil carbon resources. In: Lal R, Kimble J, Levineeditors E,

et al., editors. Soils and global change. Boca Raton, FL: CRC/Lewis Publishers; 1995. p. 27–43.
6. Read D, Beerling D, Cannell M, et al. The role of land carbon sinks in mitigating global climate change. Policy document, 10/01. London (UK): Royal Society; 2001. p. 27.
7. Kim DG, Kirschbaum MU. The effect of land-use change on the net exchange rates of greenhouse gases: a compilation of estimates. Agric Ecosyst Environ. 2015;208:114–126. doi:10.1016/j.agee.2015.04.026.
8. Sres I, Nakićenović N, Swart R. 2000. Special report on emissions scenarios: a special report of working group III of the Intergovernmental Panel on Climate Change. Cambridge (UK): Cambridge University Press.
9. Don A, Schumacher J, Freibauer A. Impact of tropical land-use change on soil organic carbon stocks – a meta-analysis. Global Change Biol. 2011;17(4):1658–1670. doi:10.1111/j.1365-2486.2010.02336.x.
10. Forkuo EK, Frimpong A. Analysis of forest cover change detection. IntJ Remote Sens Appl. 2012;2(4):82–92.
11. Antwi-Agyei P, Kpenekuu F, Hogarh JN, et al. Land use and land cover changes in the Owabi reservoir catchment, Ghana: implications for livelihoods and management. Geosciences. 2019;9(7):286. doi:10.3390/geosciences9070286.
12. Akoto O, Abankwa E. Heavy metals contamination and speciation in sediments of the Owabi reservoir. Environ Res J. 2014;8(1):10–16.
13. Akoto O, Bruce TN, Darko D. Heavy metals pollution profiles in streams serving the Owabi reservoir. Afr J Environ Sci Technol. 2008;2(11):354–359.
14. Armah FA, Obiri S, Yawson DO, et al. Mining and heavy metal pollution: assessment of aquatic environments in Tarkwa (Ghana) using multivariate statistical analysis. J Environ Statis. 2010;1(4):1–13.
15. Fosu-Mensah BY, Okoffo ED, Darko G, et al. Organophosphorus pesticide residues in soils and drinking water sources from cocoa producing areas in Ghana. Environ Syst Res. 2016;5(1):10. doi:10.1186/s40068-016-0063-4.
16. Maoulidi M. A water and sanitation need assessment for Kumasi, Ghana. Millennium Cities Initiative; 2010. MCI Social Working Paper Series No. 16/2010
17. Ghana Statistical Service. Update of Annual Progress Report for Atwima Nwabiagya District Assembly (2014), Accra; 2014.
18. Deans JD, Moran J, Grace J. Biomass relationships for tree species in regenerating semi-deciduous tropical moist forest in Cameroon. For Ecol Manag. 1996;88(3):215–225.
19. Nelson DW, Sommers LE. Total carbon, organic carbon, and organic matter. In: Methods of soil analysis part 3 – chemical methods. Madison, WI: Agron. Monogr. 9:1996. p. 961–1010.
20. Blake GR, Hartge KH. Bulk density. In: Klute A, editor. Methods of soil analysis. Part 1. Physical and mineralogical methods. Second edition. American Society of Agronomy and Soil Science Society of America. Wisconsin USA: Madison; 1986. p. 363–375.
21. Brown S, Gillespie AJ, Lugo AE. Biomass estimation methods for tropical forests with applications to Forest inventory data. Forest Sci. 1989;35(4):881–902.
22. Adarkwa KK. The changing face of Ghanaian towns. Afr Rev Econ Fin. 2012;4(1):1–29.
23. Appiah M, Blay D, Damnyag L, et al. Dependence on forest resources and tropical deforestation in Ghana. Environ Dev Sustain. 2009;11(3):471–487.
24. Tuffour-Mills D, Antwi-Agyei P, Addo-Fordjour P. Trends and drivers of land cover changes in a tropical urban Forest in Ghana. Trees For People. 2020;2:100040. doi:10.1016/j.tfp.2020.100040.
25. Agyen-Brefo R. 2012. The effects of encroachment on sustainable public land management: a case study of the Owabi catchment area in Kumasi, PhD Dissertation, Kwame Nkrumah University of Science and Technology, Kumasi.
26. Barima Y, Boateng-Kyei J. 2016. Four arrested for encroaching on Barekese catchment area. Graphic Online. Available from: https://www.graphic.com.gh
27. Sundarapandian SM, Swamy PS. Litter production and leaf-litter decomposition of selected tree species in tropical forests at Kodayar in the Western Ghats, India. For Ecol Manage. 1999;123(2-3):231–244. doi:10.1016/S0378-1127(99)00062-6.
28. Köhl M, Neupane PR, Lotfiomran N. The impact of tree age on biomass growth and carbon accumulation capacity: a retrospective analysis using tree ring data of three tropical tree species grown in natural forests of Suriname. PLoS One. 2017;12(8):e0181187. doi:10.1371/journal.pone.0181187.
29. Ngo KM, Turner BL, Muller-Landau HC, et al. Carbon stocks in primary and secondary tropical forests in Singapore. For Ecol Manage. 2013;296:81–89. doi:10.1016/j.foreco.2013.02.004.
30. Adu-Bredu S, Abekoe MK, Tachie-Obeng E, et al. 2008. Carbon stock under four land use systems in three varied ecological zones in Ghana. Africa and the carbon cycle: the CarboAfrica Project.
31. Luss I. FAO, 2006. World base reference for soil resources. Report on World Soil Resources. FAO. Rome, Italy; 2006.
32. Michalzik B, Kalbitz K, Park JH, et al. Fluxes and concentrations of dissolved organic carbon and nitrogen – a synthesis for temperate forests. Biogeochemistry. 2001;52(2):173–205. doi:10.1023/A:1006441620810.
33. Murty D, Kirschbaum MU, Mcmurtrie RE, et al. Does conversion of Forest to agricultural land change soil carbon and nitrogen? A review of the literature. Global Change Biol. 2002;8(2):105–123. doi:10.1046/j.1354-1013.2001.00459.x.
34. Mora JL, Guerra JA, Armas-Herrera CM, et al. Storage and depth distribution of organic carbon in volcanic soils as affected by environmental and pedological factors. Catena. 2014;123:163–175. doi:10.1016/j.catena.2014.08.004.
35. Nasigri M. 2015. Carbon stock under four different land-use systems in the savanna ecosystems, in Ghana, PhD Dissertation.
36. Iqbal S, Tiwari SC. Sequestration of soil organic carbon pool under different land uses in Bilaspur

District of Achanakmar, Chhattisgarh. Int J Sci Res. 2015;4(7):1920–1924.

37. Gyabaah G. 2012. Carbon sequestration in four land use systems in a moist semi deciduous ecological zone of Ghana, PhD Dissertation, Kwame Nkrumah University of Science and Technology, Kumasi.
38. Nacro HB, Struwe S, Abbadie L, et al. 2008. West Africa's savannahs under change: integrated view on positive and negative effects of agriculture and land cover changes on carbon cycling and trace gas emission. Africa and the Carbon Cycle: the CarboAfrica Project.
39. Breuning-Madsen H, Kristensen JÅ, Awadzi TW, et al. Early cultivation and bioturbation cause high long-term soil erosion rates in tropical forests: OSL based evidence from Ghana. Catena. 2017;151:130–136. doi:10.1016/j.catena.2016.12.002.
40. Bernoux M, Cerri CC, Cerri CEP, et al. Cropping systems, carbon sequestration and erosion in Brazil, a review. Agron Sustain Dev. 2006;26(1):1–8. doi:10.1051/agro:2005055.
41. Saviour MN, Stalin P. Soil and sand mining: causes, consequences and management. IOSR J Pharm. 2012;2(4):01–06. doi:10.9790/3013-242016.
42. Whiting GJ, Chanton JP. Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration. Tellus B. 2001;53(5):521–528.
43. Wang WQ, Wang C, Liu BG. Effect of salinity on carbon, nitrogen and phosphorus stoichiometry during the decomposition of wetland litter. China Environ Sci. 2012;32(9):1683–1687.
44. Ott D, Rall BC, Brose U. Climate change effects on macrofaunal litter decomposition: the interplay of temperature, body masses and stoichiometry. Phil Trans R Soc B. 2012;367(1605):3025–3032. doi:10.1098/rstb.2012.0240.
45. Tong C, Liu BG. Litter decomposition and nutrient dynamics in different tidal water submergence environments of estuarine tidal wetland. Geogr Res. 2009;1:013.
46. Bonsu M, Adukpo DC, Adjei-Gyapong T. 2008. Estimates of CO_2 emissions from soil organic carbon for different land uses. Africa and the carbon cycle: the Carbon Africa Project.
47. Bernstein L, Bosch P, Canziani O, et al. 2008. IPCC, 2007: climate change 2007: synthesis report. Intergovernmental Panel on Climate Change, Cambridge University, United Kingdom.
48. Mande HK, Abdullah AM, Aris AZ, et al. Factors responsible for spatial and temporal variation of soil CO_2 efflux in a 50 year recovering tropical Forest, Peninsular Malaysia. Environ Earth Sci. 2015;73(9):5559–5569. doi:10.1007/s12665-014-3810-8.