CARBON STOCKS AND SOIL NUTRIENT DYNAMICS IN THE PEAT SWAMP FORESTS OF THE AMANZULE WETLANDS & ANKOBRA RIVER BASIN

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Citation: Asante, W. and Jengre, N. (2012) Carbon Stocks and Soil Nutrient Dynamics in the Peat Swamp Forests of the Amanzule Wetlands and Ankobra River Basin. USAID Integrated Coastal and Fisheries Governance Program for the Western Region of Ghana. Accra: Nature Conservation and Research Centre. 45 pp.

Cover Photo: *Two men among mangroves.*

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The long-term instability of the large amount of carbon stored in tropical peat lands is of major concern within the context of contemporary climate change as result of rapid deforestation and degradation. In Ghana, however, most land use change studies have concentrated on terrestrial vegetation, with very few research activities on the peat swamp forest. Of those studies that have been conducted, the majority have focused on faunal surveys and plant species identification. As a result, there is no available data on the role of peat swamp forests in carbon sequestration and the associated impacts of anthropogenic activities in these unique ecosystems. This research was commissioned as a first effort to understand the carbon stock and nutrient dynamics of the peat swamp forest in the greater Amanzule Wetlands, including the role of anthropogenic activities in the loss of accumulated carbon stores.

Data was collected on tree species, above ground biomass, soil carbon stocks, and soil nutrients from twenty-one sample plots (100 m x 100m) that were stratified according to hydrology (permanently flooded, seasonally flooded) and site condition (intact forest, degraded areas and deforested areas).

Results indicated that mean aboveground carbon stocks in intact peat swamp forest areas was 114.29 ± 15.92 MgC/ha, with degraded areas recording 71.27 ± 10.26 MgC/ha, and deforested areas having 20.46 ± 12.12 MgC/ha.

Hydrology (permanent or seasonal inundation) had a clear impact on tree and soil biomass in the landscape. The seasonally flooded areas had the highest total carbon stocks, with aboveground carbon being the dominant pool. However, permanently flooded areas had higher soil carbon content than the seasonally flooded plots.

In terms of site condition and anthropogenic activities, overall, intact forest plots had the highest total carbon stocks, followed by the deforested sites and then the degraded plots. When broken down according to the carbon pools, the intact sites recorded the highest above and below ground biomass levels, followed by the degraded sites. As a result of anthropogenic activities, the deforested sites recorded the lowest above and below ground biomass carbon stocks because most of the sites were converted to agricultural crops (maize and cassava).

Unlike the biomass trends in the above and below ground pools, however, the highest carbon stocks in the soil component were recorded in the deforested sites. The reasons for these differences appears to be that deforestation activities, while removing aboveground biomass, leave large amounts of litter and woody debris to decompose into the soil. Therefore, following deforestation the soil receives a significant input of soil organic carbon. These differences can be further explained by the fact that degradation (small-scale logging and firewood harvesting) reduces the amount of biomass in the aboveground pool, but do not significantly impact the soil pool as only minimal amounts of debris are left to decompose.

Analysis of the major nutrients (N,P,K) and carbon content in the soil showed that all were significantly higher in the upper soil depth class (0-30 cm) than the lower soil depth class (30-100 cm), but that hydrology had a significant impact on nutrient distribution.

In terms of biodiversity, though the seasonally flooded sites recorded the highest number of individual species, as compared to permanently flooded sites, the latter was the most diverse (H) and had species which were more evenly distributed. In addition, two potentially new species were identified which are currently being confirmed.

This peat swamp forest of the Amanzule Wetlands and Ankobra River basin is a truly unique landscape. Threats to the peat swamp forest, while still minimal, may be mounting, particularly in the form of small-scale artisanal logging, firewood harvesting, and conversion to food crops like maize and cassava. As demonstrated by this study, these anthropogenic activities have a detrimental impact on the ecosystem's ability to store and sequester carbon, as well as on biodiversity and nutrient dynamics. Therefore, conservation of this intriguing and rare landscape is crucial. While more research is required, it is possible that carbon finance, in the form of REDD+, soil carbon, or climate smart agriculture could form part of a dynamic conservation and livelihood strategy.

1.0 INTRODUCTION

Globally, tropical peats cover approximately 11% of global peat lands (Page et al., 2010). Despite the relatively smaller area of tropical peats, compared to boreal and temperate peats, tropical peat lands are among the largest carbon stores (Jauhiainen et al., 2005; Rydin and Jeglum, 2006).

Like all tropical forests, peat swamp forest stores large amounts of carbon in plant biomass, with typical values in the range of 100-250 t C/ ha (Murdiyarso, Hergoualc'h & Verchot, 2010; Page et al., 2011). The incomplete decomposition of dead tree material, especially roots, has led to the slow but progressive accumulation of partially decomposed organic material (peat) over millennia and has given this ecosystem a very high carbon density.

Peat (and carbon) accumulates as a result of a positive net imbalance between the high primary production in tropical ecosystems and incomplete organic matter decomposition in permanently saturated soil conditions (Hooijer et al., 2010; Wösten et al., 2008).
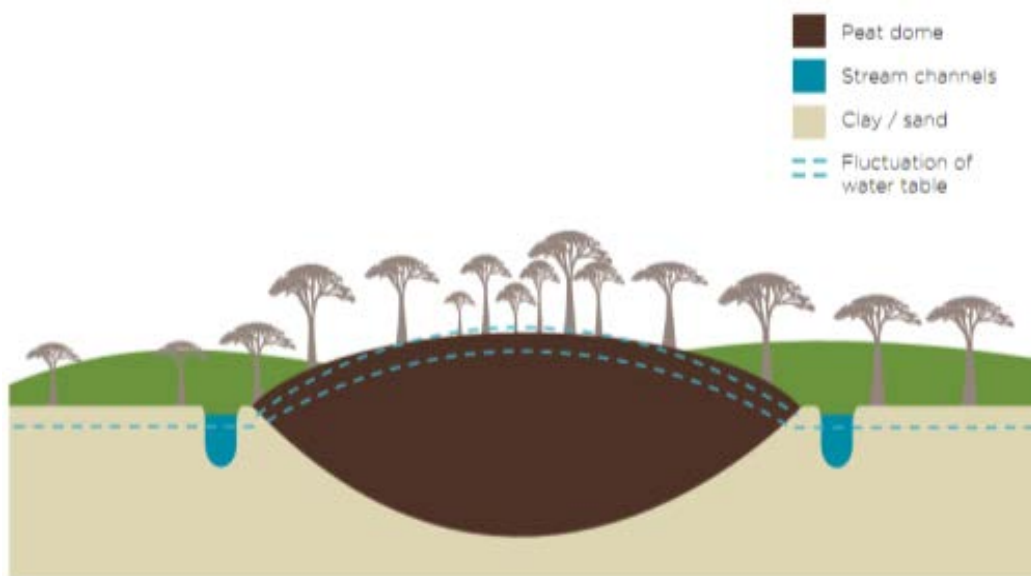
Figure 1 Schematic diagram of a tropical peat dome. The water table will be at or above the peat surface for much of the year, with limited drawdown during the dry season (typical range 30-40 cm) (Source: Verwer and van der Meer, 2010).

In a natural state, peat swamp forests are characterized by dense forest vegetation, thick (up to 20 m) peat deposits, and a groundwater table that is at or close to the peat surface throughout the year (Hirano, Jauhiainen, Inoue, & Takahashi, 2009; Page et al., 2004; Takahashi et al., 2002; Wösten et al., 2008). Surface peat is aerobic (unsaturated) only during relatively dry periods when the water table falls below the surface (Hirano et al., 2007, 2009; Jauhiainen et al., 2005; Jauhiainen et al., 2010).

However, the long-term maintenance of peat (and carbon) depends on both continuous inputs of organic matter and incomplete decomposition, a consequence of anaerobic conditions within the peat deposit. For peat accumulation to occur, the average rate of carbon

sequestration must exceed that in decomposition losses (Jauhiainen et al., 2008; Jauhiainen et al., 2005, 2010).

Therefore the existence of extensive peat deposits demonstrates that the associated ecosystems have functioned as a large net sink for atmospheric carbon at a millennial time scale (Page et al., 2010, 2004). Currently, however, the vast majority of the peat lands are to some extent degraded as a result of anthropogenic land use change and are emitting accumulated carbon faster than it is being sequestered (Hooijer et al., 2010, 2011; Jauhiainen et al., 2010; Page et al., 2011). Deforestation, drainage, large-scale conversion to plantation agriculture, and regular fires has all resulted in increased carbon transfer to the environment and loss of carbon sequestration function. Invariably, optimum carbon storage in tropical peat requires a combination of high vegetation biomass (carbon sequestration potential), a water table that is near to or above the peat surface for most of the year, and a much-reduced rate of organic matter decomposition. Drainage and other disturbances lead to increased surface peat aeration and decomposition as well as carbon losses (Page et al., 2011).

The long-term instability of the large amount of carbon stored in tropical peat lands is of major concern within the context of contemporary climate change (Raupach & Canadell, 2010) due to the chance of rapid deforestation and degradation (Mc Morrow and Talip, 2001).

However in Ghana, most land-use dynamics studies have concentrated on terrestrial vegetation, with little attention to these vital peat ecosystems and their ecosystem services. Only a few research activities have been carried-out in peat swamp forests, and the focus was primarily to conduct faunal surveys and plant species identification. There is no data on the role of peat swamp forests in carbon sequestration and the associated impacts from anthropogenic activities.

In light of this gap in understanding, this research was commissioned to provide an initial understanding of the carbon stocks and carbon stock dynamics of the peat swamp forest in the Amanzule Wetlands, including the role of anthropogenic activities in the loss of accumulated carbon stores.

2.0 METHODOLOGY

2.1 STUDY AREA

The sampling sites (see Figure 2) are located within the Amanzule River/Wetlands basin and the Ankobra River basin. The Amanzule Wetland (latitudes 4° 53' and 4° 46' North and longitude 2° 00' and 2° 05' west) is a community protected area in the Western Nzema Traditional Area of the Western Region. The catchment of both the Amanzule Wetland and the Ankobra River are contiguous and lie within the Wet Evergreen Forest Zone of Ghana. The Amanzule Wetland covers an area of approximately 100 sq. km. and is situated approximately 360 km west of Accra. The Ankobra River rises north-east of Wiawso, and flows about 190 km south to the Gulf of Guinea.
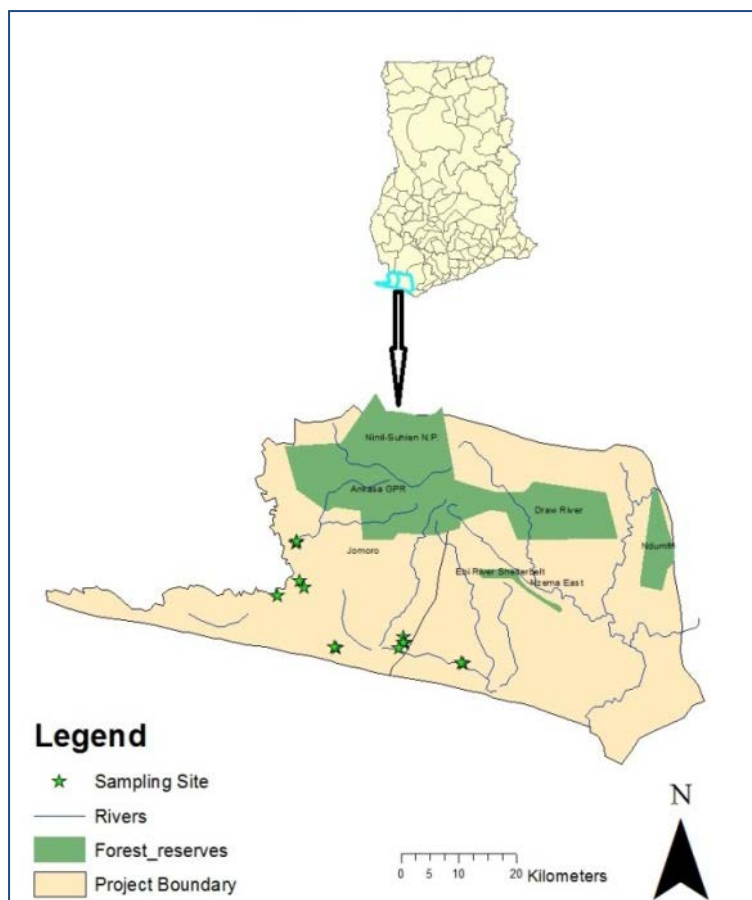
Figure 2 Map of the study area.

The soils in the study area are predominantly Forest Oxysols (Brammer, 1962). The hydrology is driven by six streams, one lake, and one outlet to the sea. It includes the freshwater Amanzule lagoon, the coastal Amanzule lagoon and estuary, and the sandy beach between the Amanzule and Ankobra River, an area that is subject to seasonal flooding. It is a relatively pristine complex consisting of a freshwater lagoon, forest, grasslands and rivers. It has the most extensive remaining stand of intact peat and swamp forest in Ghana. The area falls within Ghana's High Forest Zone, and is within the equatorial climate zone, which is characterized by moderate temperatures, high rainfall and relative humidity. Specifically, it experiences a double-maxima pattern of rainfall with peaks in May-June and October-November each year. The average annual rainfall is 1,600 mm with the relative humidity being 87.5%. A mean annual temperature of 26° C has been recorded. However, there is a short dry season (Dec-Mar) during which period a northwesterly directional wind is experienced which brings slight harmattan conditions.

2.2 METHODS

Initially, the team conducted a reconnaissance survey in order to generate a better understanding of the coverage of the swamp forest and to engage in community protocol in order to ensure easy access to the sample areas.

A total of twenty-one sample spots were selected (n=21) based on a two predominant landscape variables; site condition (e.g. anthropogenic disturbance) and hydrology in order to capture an understanding of soil nutrient and carbon stock dynamics within the peat swamp forest area. Table 1 shows all sample plots, their location, plot size and design, forest condition and hydrology. Sample locations were initially stratified visually according to three categories; intact forest (n=17), degraded forest (n=2), and deforested (n=2). Intact forest was quite common, whereas degraded and deforested patches were comparatively difficult to locate, hence the comparatively small sample sizes. Intact areas were judged to be relatively undisturbed. Degraded areas were judge to be areas which had been disturbed but had not been converted to other land use types. Deforested areas were patches which have been converted to other land use types. While in the field, the team realized that within the intact forest, extensive patches of *Raphia hookeri* were common. Therefore, of the intact forest sample plots, three were patches dominated by the palm species (n=3).

Samples plots were further stratified according to hydrology—permanently flooded and seasonally flooded. Four intact forest plots were permanently flooded (n=4) and 13 were seasonally flooded (n=13). The degraded sites were split between being permanently flooded (n=1) and seasonally flooded (n=1). The deforested sites were both seasonally flooded (n=2).

A 100 by 100 m nested approach in plot design was used to capture the different diameter classes in the sample areas. The number of nests for each plot was based on the variation in the diameter classes. In order to achieve statistical robustness, each nest was replicated twice.

Soil samples were taken at the four corners of each 100 x 100 m plot, and in the center to mimic the letter "z". Soil samples were taken from seventeen plots (n=17) for the determination of soil nutrients as an indication of fertility, including carbon stocks, as well as the determination of soil bulk density. Due to the flooded nature of the soil in four plots, it was impossible to collect accurate samples. A galvanized pipe (length = 100 cm; diameter = 5 cm) was driven into the soil up to the 100 cm mark to allow soil to fill it up. Soil samples were then taken at various depth intervals for laboratory analysis in the following order:

1-15 cm
15-30 cm
30-50 cm
50 -100 cm.

At each soil depth interval, due to the wet nature of the soil, samples were removed from the middle portion up to 5 cm, to give a representation of the particular soil depth and transported to Soil Science Laboratory of the Faculty of Agriculture, KNUST, for analysis.

The samples were air-dried, crushed and sieved through a 2 mm mesh. Soil pH was determined in distilled water using a Glass electrode- Calomel electrode (McLean, 1982) MV Pracitronic pH meter. Soil pH was measured at a soil: solution ratio of 1: 2. Organic carbon was determined using the wet combustion method of Walkley and Black (1934). Total N was determined using the method of Bremmer (1965). Available phosphorus was determined using the method of Bray and Kurtz (1945). Exchangeable bases were extracted with 1.0 M NH_4OAc (pH 7.0), exchangeable K, Al and H in the extract were determined by flame photometry (Chapman and Pratt, 1961). Soil particle size was determined using the hydrometer method (Bouyoucos, 1962). The soil analysis presents results from 0-30 cm depth and then 30-100 cm depth.

2.3 DATA COLLECTION

In each sampled nest, data was collected on the following parametres:

- tree diameter ($\geq$ 2 cm)
- tree height
- tree species

Soil samples were collected to generate data on the following parametres:

- soil nutrients
- bulk density
- soil texture

Table 1 Nested plot design at each site and site condition.

Site name	Latitude	Longitude	Plot size	Nest size sampled	Replicate	Hydrology	Condition
Ebonloa 1	543.04028	-2.72351	100x100	50x50	50x50	Permanent flooding	Intact
Ebonloa 2	5.04028	-2.72351	100x100	50x50	50x50	Permanent flooding	Degraded
Ebonloa 3	879.04028	-2.72351	100x100	50x50 plus 20x20	50x50 plus 20x20	Seasonal flooding	Intact
Ebonloa 4	1213.04028	-2.72351	100x100	50x50	50x50	Seasonal flooding	Intact-Raphia?
Kofi Jaman 1	5.16676	2.70642	100x100	100x100, 50x50, 20x20	100x100, 50x50, 20x20	Seasonal flooding	Intact
Kofi Jaman 2	5.16676	2.70642	100x100	50x50	50x50	Seasonal flooding	Degraded
Kofi Jaman 3	5.16676	2.70642	100x100	100x50	0	Seasonal flooding	Deforested
Kofi Jaman 4	5.16676	2.70642	100x100	100x100, 50x50, 20x20	100x100, 50x50, 20x20	Seasonal flooding	Intact
Kofi Jaman 5	5.16676	2.70642	100x100	50x50	50x50	Seasonal flooding	Intact (Raphia)
Alanda Wharf 1	5.09768	-2.72351	100x100	50x50, 20x20	50x50, 20x20	Seasonal flooding	Intact
Alanda Wharf 2	5.09768	-2.72351	100x100	50x50, 20x20	50x50, 20x20	Seasonal flooding	Intact
Alanda Wharf 3	5.09768	-2.72351	100x100	50x50, 20x20	50x50, 20x20	Permanent flooding	Intact

Site name	Latitude	Longitude	Plot size	Nest size sampled	Replicate	Hydrology	Condition
Alanda 1	5.11601	-2.72351	100x100	50x50, 20x20	50x50, 20x20	Seasonal flooding	Intact
Alanda 2	5.11601	-2.72351	100x100	100x100, 50x50, 20x20	100x100, 50x50, 20x20	Seasonal flooding	Intact
Alanda 3	5.11601	-2.72351	100x100	100x50, 50x50, 20x20	100x50, 50x50, 20x20	Seasonal flooding	Intact
Alanda 4	5.11601	-2.72351	100x100	50x50	50x50	Seasonal flooding	Intact (Raphia)
Aloapeke 1	4.99767	-2.72351	100x100	100x100, 50x50	100x100, 50x50	Seasonal flooding	Intact
Aloapeke 2	4.99767	-2.72351	100x100	100x100, 50x50, 20x20	100x100, 50x50, 20x20	Seasonal flooding	Intact
Aloapeke 3	4.99767	-2.72351	100x100	100x100	100x100, 50x50, 20x20	Seasonal flooding	Deforested
Twenen 1	5.02434	-2.72351	100x100	100x100, 50x50, 20x20	100x100, 50x50, 20x20	Permanent flooding	Intact
Twenen 2	5.02434	-2.72351	100x100	50x50, 20x20	50x50, 20x20	Permanent flooding	Intact

2.4 DATA ANALYSIS

Data on tree parameters were analyzed to generate data on biomass and carbon stocks at intact, degraded and deforested sites, as well as seasonally and permanently flooded areas. Chave and colleagues' (2005) allometric equation was used to generate aboveground biomass results, while belowground biomass was computed to be 20% of aboveground (IPCC GPG, 2003).

Soil bulk density was calculated using the equation;

$$Soil\ bulk\ density\ (g/cm^3) = \frac{mass\ of\ oven-dried\ weight\ of\ soil}{volume\ of\ soil}$$

$$soil\ organic\ carbon\ stocks\ (\frac{Mg}{ha}) = soil\ bulk\ density\ \times soil\ depth\ \times carbon\ content$$

Data were analyzed using excel for the computation of basal area, volume and carbon stocks per hectare. Two-way Anova was used to test the significance of soil parameters at the different depths using Genstat software. LSD was used to separate means at a statistical significance of 5%.

3.0 RESULTS

3.1 BIOMASS CARBON STOCKS

Results indicated that mean aboveground carbon stocks in intact areas was 114.29 ± 15.92 MgC/ha, with degraded areas recording 71.27 ± 10.26 MgC/ha, while that of deforested areas was 20.46 ± 12.12 MgC/ha. However, belowground carbon stocks for intact areas was 22.86 ± 3.18 MgC/ha, with degraded areas having 14.25 ± 2.05 MgC/ha, and that of deforested areas recording 4.09 ± 2.43. Figure 3 shows above and belowground carbon stocks under the different site conditions.
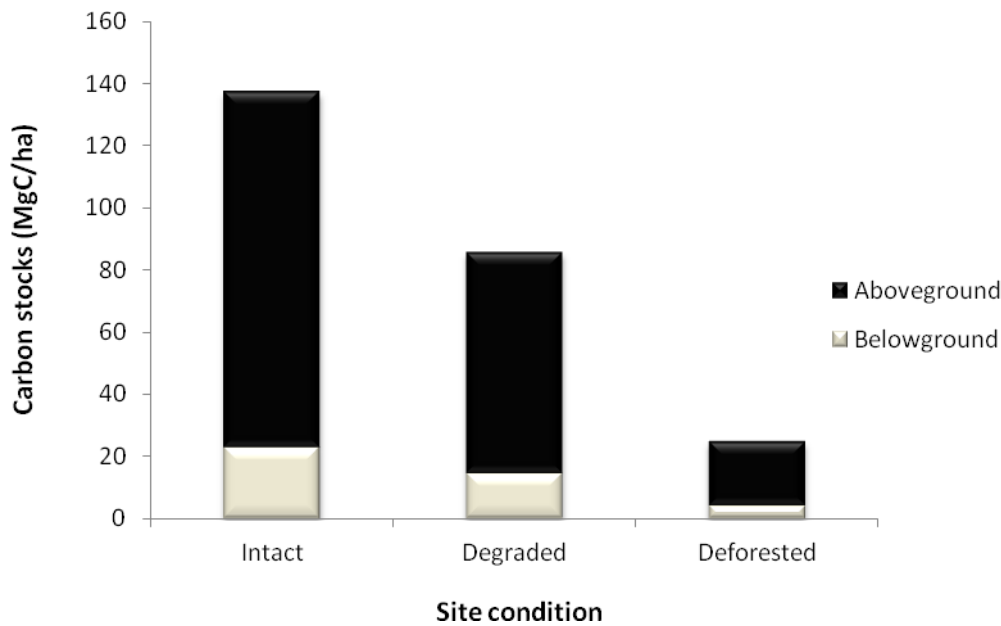
Figure 3 Above and belowground carbon stocks at different site conditions.

The mean difference between intact and degraded plots was 51.63 MgC/ha, while the mean difference between intact and deforested plots was 112.6 MgC/ha. Raphia palm constituted a major vegetation type in the site. The mean aboveground carbon stock of Raphia dominated patches was 49.31 ± 10.01, while the belowground carbon stock was 9.86 ± 0.84.

The influence of seasonality of the hydrological conditions at the site, in terms of duration of inundation showed that the permanently flooded areas had aboveground and belowground carbon stocks of 65.24 ± 11.83 and 13.05 ± 2.37 respectively, while that of seasonally flooded areas had aboveground and belowground carbon stocks of 133.92 ± 18.44 and 26.78 ± 3.69 respectively. Figure 4 shows the influence of hydrology on aboveground and belowground carbon stocks.
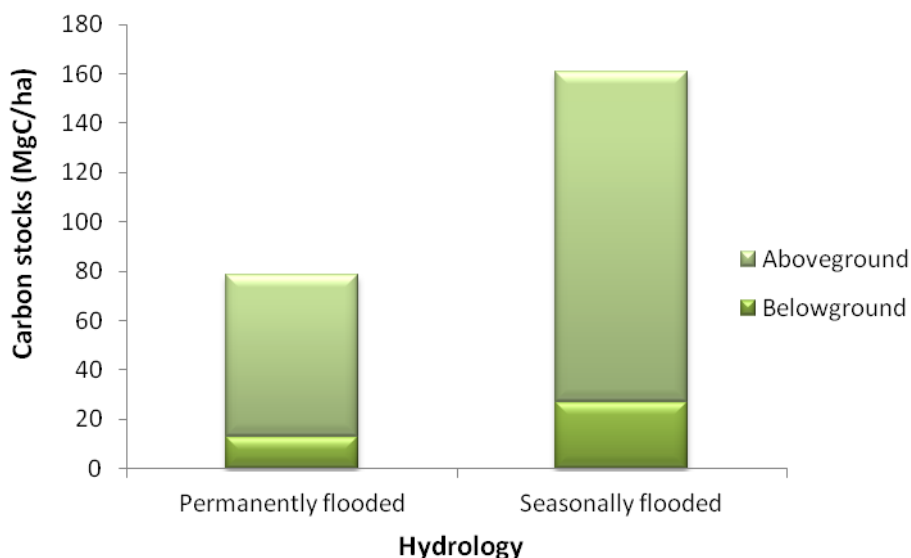
Figure 4 Influence of hydrological condition on above and belowground carbon stocks

Table 2 Aboveground and belowground carbon stocks in all the study areas.

SITE	HYDROLOGY	FOREST CONDITION	CARBON STOCKS (MgC/ha) ABG	CARBON STOCKS (MgC/ha) BG	TOTAL C STOCKS (MgC/ha)
Ebonloa 1	Permanent flooding	Intact	62.01	12.402	74.412
Alanda Wharf 3	Permanent flooding	Intact	103.44	20.688	124.128
Twenen 1	Permanent flooding	Intact	56.58	11.316	67.896
Twenen 1	Permanent flooding	Intact	38.91	7.782	46.692
Ebonloa 3	Seasonal flooding	Intact	85.56	17.112	102.672
Kofi Jaman 1	Seasonal flooding	Intact	111.99	22.398	134.388
Kofi Jaman 4	Seasonal flooding	Intact	88.91	17.782	106.692
Alanda Wharf 1	Seasonal flooding	Intact	126.19	25.238	151.428
Alanda Wharf 2	Seasonal flooding	Intact	89.95	17.99	107.94
Alanda 1	Seasonal flooding	Intact	98.06	19.612	117.672
Alanda 2	Seasonal flooding	Intact	244.27	48.854	293.124
Alanda 3	Seasonal flooding	Intact	86	17.2	103.2
Aloapoke 1	Seasonal flooding	Intact	231.78	46.356	278.136
Aloapoke 2	Seasonal flooding	Intact	176.47	35.294	211.764
Kofi Jaman 2	Seasonal flooding	Degraded	56.76	11.352	68.112
Ebonloa 2	Permanent flooding	Degraded	85.78	17.156	102.936
Kofi Jaman 3	Seasonal flooding	Deforested	3.31	0.662	3.972
Aloapoke 3	Seasonal flooding	Deforested	37.61	7.522	45.132
Ebonloa 4	Seasonal flooding	Intact (Raphia)	25.84	5.168	31.008

			CARBON STOCKS (MgC/ha)		TOTAL C STOCKS
SITE	HYDROLOGY	FOREST CONDITION	ABG	BG	(MgC/ha)
Kofi Jaman 5	Seasonal flooding	Intact (Raphia)	67.15	13.43	80.58
Alanda 4	Seasonal flooding	Intact (Raphia)	54.95	10.99	65.94

3.1.1 EFFECTS OF HYDROLOGY ON SPECIES DIVERSITY INDICES

There were a total of 52 species recorded in all the sites (seasonally and permanently flooded). Forty-one species were found in the seasonally flooded sites, while 31 species were identified in the permanently flooded sites. Twenty-one species only occurred in seasonally flooded areas, and 11 species were only identified in permanently flooded areas. *Raphia hookeri* was the dominant species in the seasonally flooded sample areas, while *Uapaca paludosa* was the dominant species in the permanently flooded area. Two species were unknown and according to the botanist are yet to be identified. This is currently being validated. Table 4 shows the species identified and their frequency.

Shannon-Weiner diversity index (Shannon H') showed that the permanently flooded area was more diverse, and had a more even distribution (Shannon J') than the seasonally flooded area. Kulczynski's species similarity index showed a similarity of 56.65% for the two site types.

Table 3 Species diversity indices at seasonally and permanently flooded sites.

Index	Seasonal	Permanent
Shannon H'	0.87	1.094
Shannon Hmax	1.613	1.491
Shannon J'	0.54	0.734

Table 4 Species identified and their frequency of occurrence at the seasonally and permanently flooded sites.

SPECIES	Frequency Seasonally Flooded	Frequency Permanently Flooded	SPECIES	Frequency Seasonally Flooded	Frequency Permanently Flooded
Amanoa bracteosa	1549	35	*Hannoa klaineana*	5	
Anthocleista vogelii	1	7	*Hexalobus crispifolia*	9	
Anthostema aubryanum	27	91	*Leptoderris faciculata*	1	
Baphia pubescens	1	5	*Lijndenia barteri*	27	
Bertiera racemosa		2	*Lonchocarpus santalinoides*	81	
Boerhaevia smeanthmania		1	*Mammea Africana*	1	
Bridelia grandis	3		*Manilkara sylvestris*	401	
Canthormion altissimum	1		*Millettia spp*	57	
Chrysophyllum africanum	13		*Myrianthus lebericus*	2	
Coffea humilis	1	62	*Macaranga heudelotii*		1
Cuviera subuliflora	25		*Parkia bicolor*	1	12
Carapa procera		7	*Pavetta quasidigita*	4	
Cissus producta		1	*Raphia hookeri*	1101	

SPECIES	Frequency Seasonally Flooded	Frequency Permanently Flooded	SPECIES	Frequency Seasonally Flooded	Frequency Permanently Flooded
Cleistopholis patens		6	*Sarcocephalus pobeguinii*	35	1
Coelocaryon oxycarpum		9	*Spondianthus preussi*	78	8
Cynometra ananta	4		*Symphonia globulifera*	81	79
Diospyros chevalieri	25	9	*Synsepalum brevipes*	8	
Euginea calophylloides		13	*Syzygium rowlandii*	140	136
Euginea afzelii	5	16	*Tetracera offinis*	1	12
Ficus tricopoda	9	13	*Treculia Africana*	23	
Ficus vogeliana	1		*Tricalysia coriacea*	21	
Garcinia smeathmannii	32		*Tetrorchidium didymostemon*		1
Gardenia imperialis	72	8	*Tabernaemontana africana*		8
Hallea ledermannii	54	90	*Uapaca heudelotii*	2	5
Hereteiria utilis		19	*Uapaca paludosa*	65	260
			Vitex grandifolia	2	1
			Xylopia rubescens	47	95

3.2 SOIL CHEMICAL AND PHYSICAL PROPERTIES DYNAMICS

Soil chemical properties presented in this section include pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, exchangeable aluminium and exchangeable hydrogen. The results demonstrate soil nutrients distribution in the different sites and at different depth classes.

Though the soil samples were taken at different intervals up to a depth of 100 cm, the results are presented in two depth classes (0-30 and 30-100 cm). This is because the IPCC recommends carbon accounting to the top 30 cm; however, the team also wanted to show what is happening at deeper depths.

3.2.1 SOIL CHEMICAL PROPERTIES

Soil pH

Results of the study indicated that there was neither a significant difference in pH from the 0 – 30 cm and 30 – 100 cm depths (F = 0.12, df = 1, P = 0.727), nor in the interaction between the two soil depth classes and the different sites in the study area (F = 7.19, df = 16, P = 0.476). Figure 5 shows soil pH variation at two depths at the sampled sites.
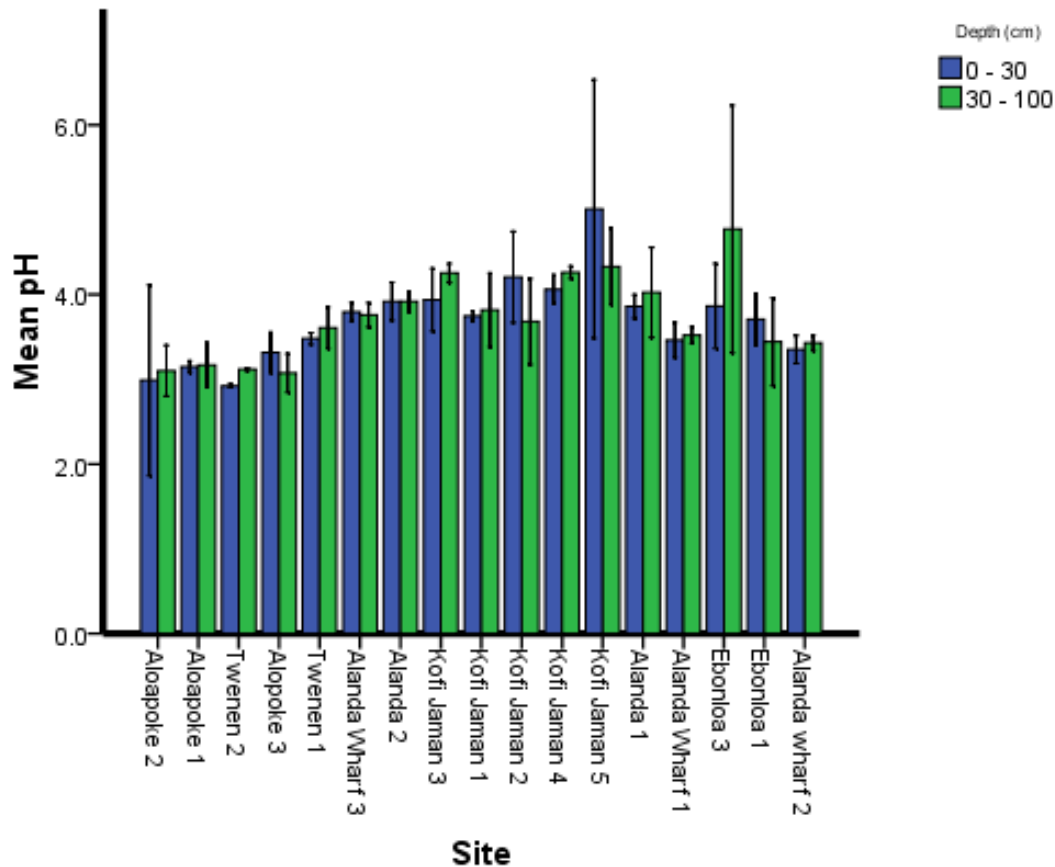
Figure 5 Soil pH variation at two depth classes at different sites

Soil Carbon Content

Soil organic carbon content showed significant difference between the two depth classes (0 – 30 cm and 30 – 100 cm) and the interaction between depth (F = 70.1, df = 1, P = <0.001) and site (F = 6.59, df = 16, P = <0.001).

Overall, the upper soil class had significantly higher carbon content than the lower depth class. With regard to depth and site interaction, the lower depth had significantly higher organic carbon content than the upper depth class at Kofi Jaman 3, Twenen 1 and at Alanda 1. However, at the rest of the sites the difference in carbon content between the two depth classes was not significant. Figure 6 shows soil organic carbon variation at two depths at different sites.

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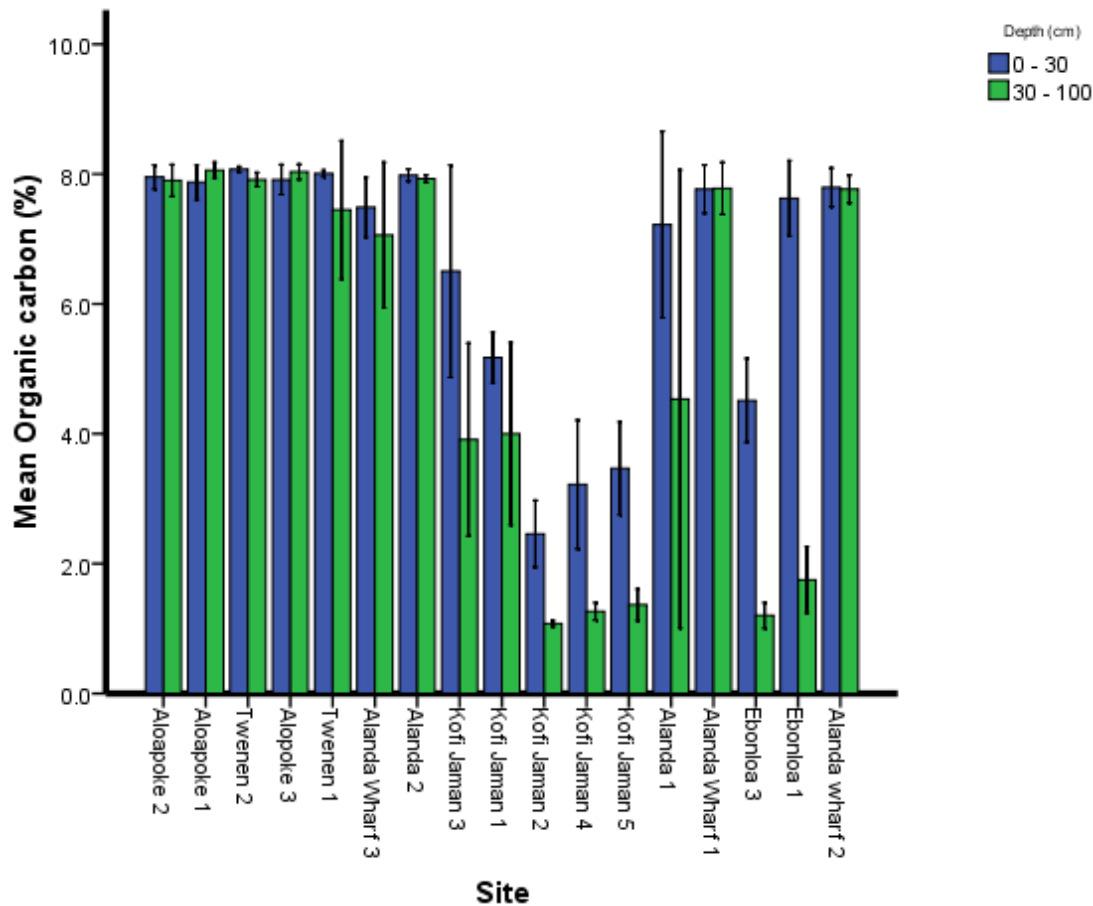
Figure 6 Soil carbon content variation at two depth classes at different sites

Total Nitrogen (N)

There was a significant difference in mean total N between the two depth classes ($F = 173.29$, $df = 1$, $P = < 0.001$) and in the interaction between depth and site ($F = 2.94$, $df = 16$, $P = 0.001$).

The upper soil class had a significantly higher percent N (1.06) than lower depth class (0.65). In terms of sites, Kofi Jaman 3, Kofi Jaman 1, Alanda 1, Aloapoke 2, Aloapoke 1, Twenen 2, Aloapoke 3, Twenen 1, Alanda Wharf 3 and Ebonloa 3 had significantly higher total N at the upper depth class compared the lower depth class. Figure 7 shows Total N variation at two depths at each sites.
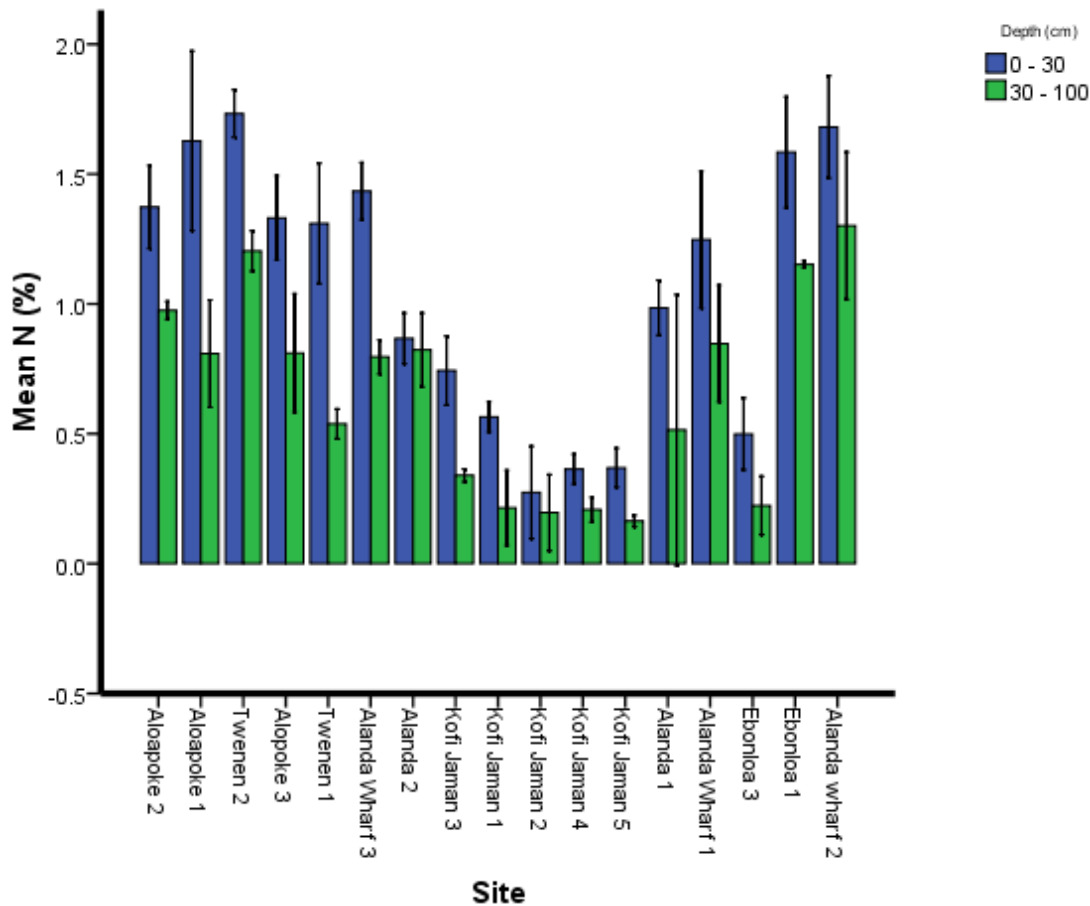
Figure 7 Total Nitrogen variation at two depth classes at different sites

Potassium (K)

There was a significant difference in K content between the two depth classes (F = 55.74, df 1, P = <0.001), as well as in the interaction between depth and site (F = 1.92, df 16, P = 0.034).

The upper depth class had a significantly higher K content than the lower depth class. With regard to the interaction between the different sites and depth, Aloapoke 2, Aloapoke 1, Alanda Wharf 3, Alanda Wharf 1, Ebonloa 1, Alanda and Wharf 2 had a significantly high K content at the upper depth class. Figure 8 shows potassium variation at two depths at different sites.
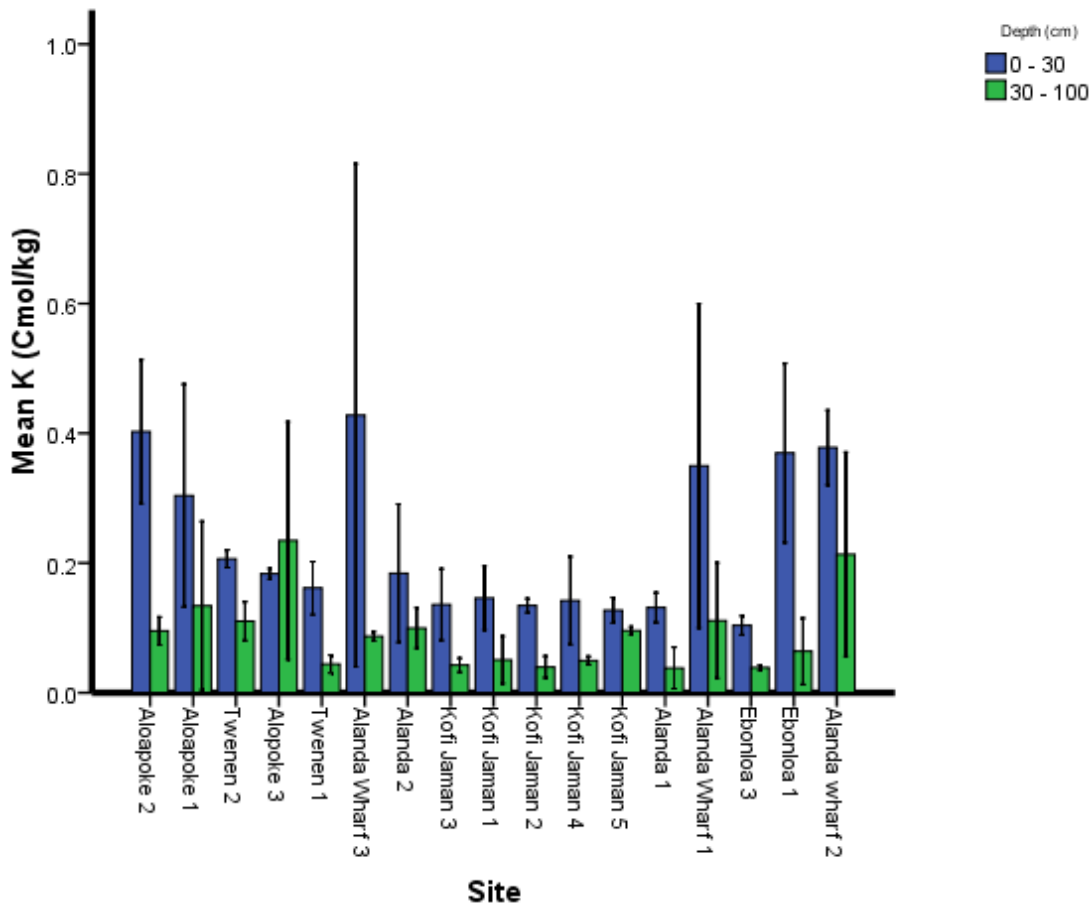
Figure 8 Potassium content variation at two depth classes at different sites

Phosphurus (P)

There was a significant difference in P content between the two depth classes (F = 42.18, df=1, P = <0.001), as well as the interaction between depth and site (F = 2.44, df 16, P = 0.006).

The upper soil class had a significantly higher P content than the lower soil class. However, only sites at Twenen 1, Alanda 2, Kofi Jaman 1, Kofi Jaman 4, Kofi Jaman 5, Alanda 1, Ebonloa 3 did not record significantly higher P content in the upper soil class than the lower soil class. Figure 9 shows soil phosphorus variation at two depths at different sites.
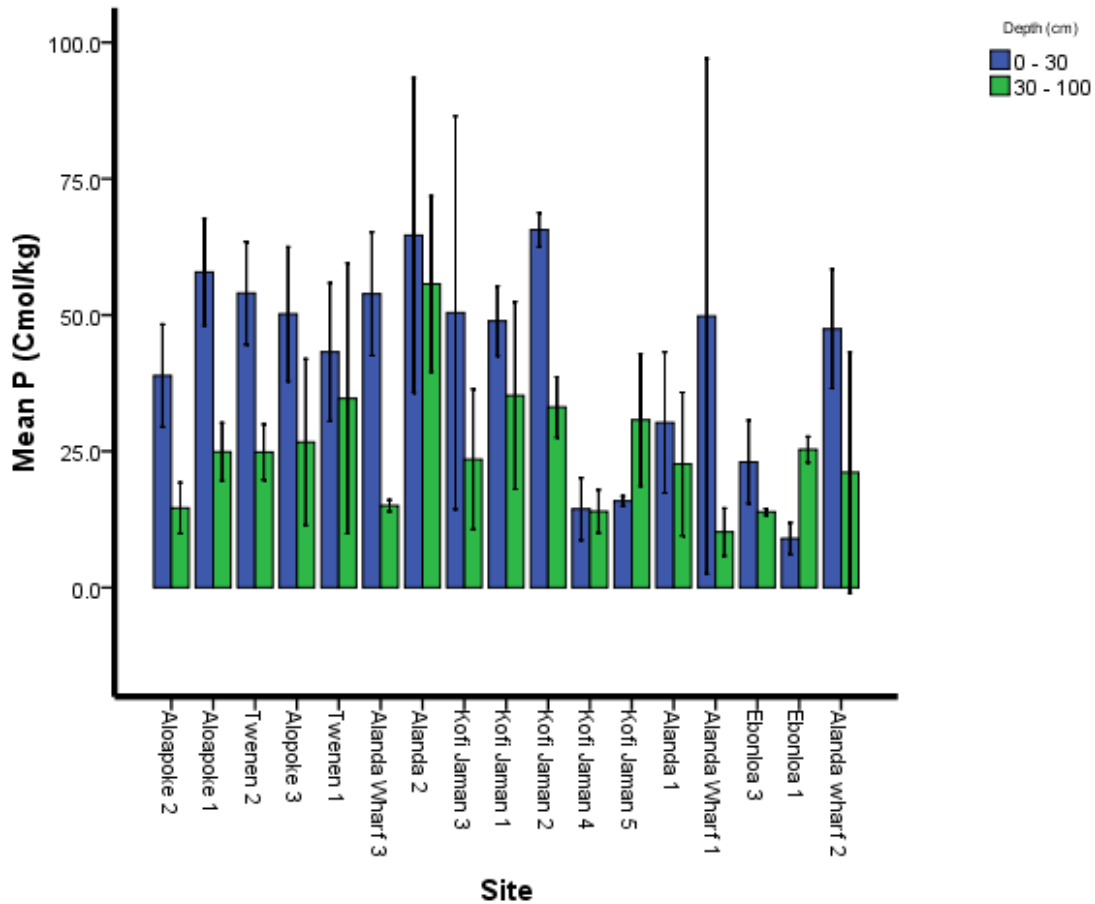
Figure 9 Phosphorus variation at two depth classes at different sites

Hydrogen concentration (H)

Results of the study indicated that there was neither a significant difference in pH from the 0 – 30 cm and 30 – 100 cm depths (F = 2.88, df = 1, P = 0.094), nor in the interaction between the two soil depth classes and the different sites in the study area (F = 1.1.3, df = 16, P = 0.350). Figure 10 shows soil Hydrogen variation at two depths at different sites.
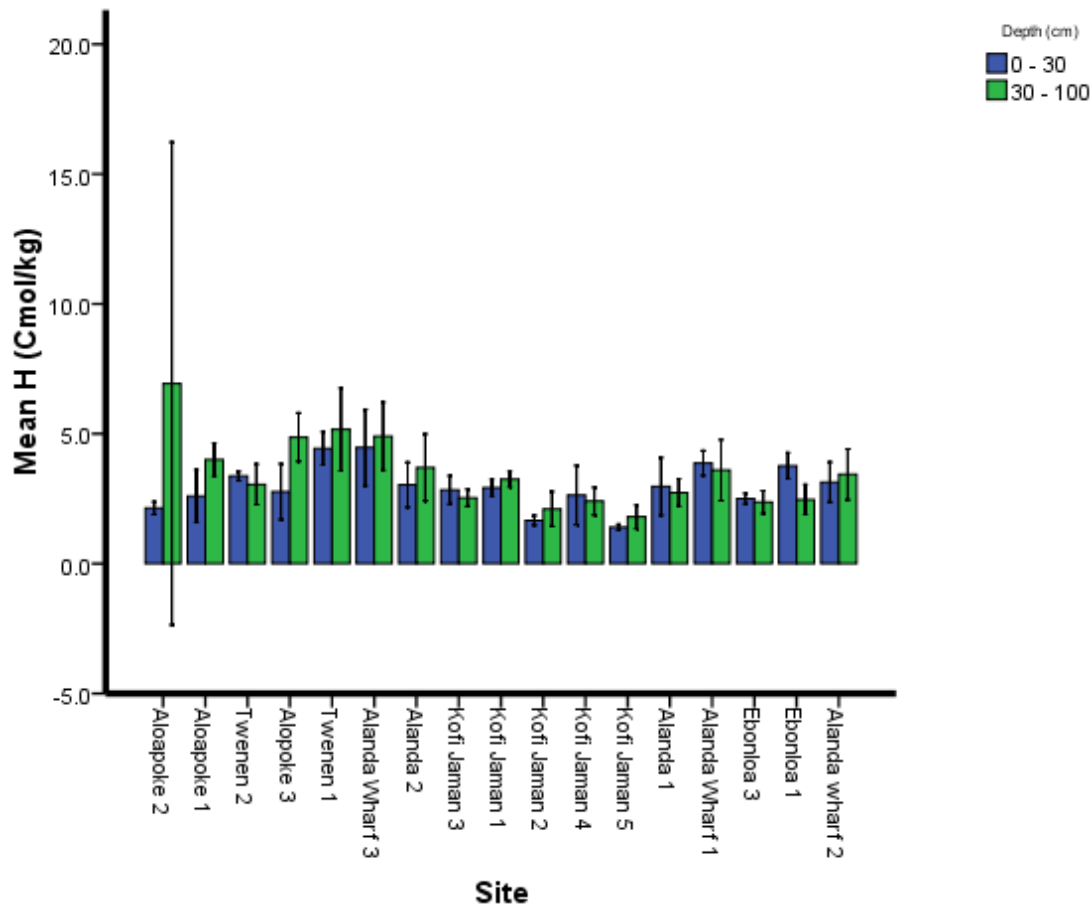
Figure 10 Hydrogen content variation at two depth classes at different sites

Aluminium concentration (Al)

There was a significant difference in Al content between the two depth classes (F = 6.08, df=1, P = 0.016). The difference was also significant in the interaction between depth and site (F = 7.42, df = 16, P = <0.001).

The lower soil class had a significantly higher Al content than the upper soil class. However, only the Aloapoke 1 and Aloapoke 3 sites recorded significantly higher Al content in the lower soil class than the upper soil class. Figure 11 shows Aluminium variation at the two depths at the different sites.

Figure 11 Aluminium variation at two depth classes at different sites

Table 5 Distribution of pH, N, P, and K at two depth classes at different sites

Site	Depth / cm	pH	SE	N (%)	SE	P (cmol/kg)	SE	K (cmol/kg)	SE
ALOAPOKE 2	0-30	2.9 9	0.3 3	1.37	0.0 7	38.88	5.61	0.40	0.1 1
	30-100	3.1 0	0.3 0	0.98	0.0 7	14.60	2.91	0.10	0.0 1
ALOAPOKE 1	0-30	3.1 5	0.0 4	1.63	0.1 2	57.88	4.52	0.30	0.0 6
	30-100	3.1 7	0.1 1	0.81	0.0 9	24.91	1.98	0.13	0.0 5
TWENEN 2	0-30	2.9 2	0.0 3	1.73	0.0 4	54.01	3.47	0.21	0.0 1
	30-100	3.1 2	0.0 8	1.20	0.1 4	24.86	3.09	0.11	0.0 3
TWENEN 1	0-30	3.4 8	0.0 5	1.31	0.1 2	43.21	4.15	0.16	0.0 3
	30-100	3.6 1	0.1 0	0.54	0.0 4	34.70	7.87	0.04	0.0 1
ALANDA WHARF 3	0-30	3.8 0	0.0 4	1.43	0.0 6	53.88	5.40	0.43	0.1 8
	30-100	3.7 6	0.0 5	0.80	0.0 5	15.04	2.07	0.09	0.0 1
ALANDA 2	0-30	3.9 2	0.0 8	0.87	0.1 0	64.62	10.8 6	0.18	0.0 3

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Site	Depth / cm	pH	SE	N (%)	SE	P (cmol/kg)	SE	K (cmol/kg)	SE
	30-100	3.92	0.06	0.82	0.05	55.68	5.57	0.10	0.01
KOFI JAMAN 3	0-30	3.94	0.11	0.74	0.06	50.43	12.75	0.14	0.03
	30-100	4.25	0.05	0.34	0.06	23.53	4.05	0.04	0.00
KOFI JAMAN 1	0-30	3.75	0.13	0.57	0.07	48.90	6.97	0.15	0.04
	30-100	3.82	0.14	0.21	0.05	35.24	5.05	0.05	0.01
KOFI JAMAN 4	0-30	4.06	0.07	0.36	0.04	14.41	3.44	0.14	0.04
	30-100	4.26	0.02	0.21	0.03	13.98	1.86	0.05	0.01
ALANDA 1	0-30	3.86	0.09	0.98	0.17	30.26	5.34	0.13	0.02
	30-100	4.03	0.16	0.51	0.15	22.67	3.82	0.04	0.01
ALANDA WHARF 1	0-30	3.46	0.08	1.25	0.15	49.77	19.73	0.35	0.12
	30-100	3.52	0.07	0.85	0.10	10.19	1.84	0.11	0.03
EBONLOA 3	0-30	3.87	0.17	0.50	0.06	23.05	3.14	0.10	0.02
	30-100	4.77	0.43	0.22	0.04	13.90	1.50	0.04	0.00
EBONLOA 1	0-30	3.71	0.25	1.58	0.12	9.00	1.19	0.37	0.11
	30-100	3.44	0.20	1.15	0.18	25.32	4.00	0.06	0.02
ALANDA WHARF 2	0-30	3.35	0.08	1.68	0.10	47.45	4.58	0.38	0.03
	30-100	3.43	0.08	1.30	0.11	21.11	6.58	0.21	0.05
ALOAPOKE 3	0-30	3.32	0.07	1.33	0.14	50.17	10.38	0.18	0.02
	30-100	3.07	0.08	0.81	0.07	26.67	4.60	0.23	0.08
KOFI JAMAN 3	0-30	3.94	0.11	0.74	0.06	50.43	12.75	0.14	0.03
	30-100	4.25	0.05	0.34	0.06	23.53	4.05	0.04	0.00
KOFI JAMAN 2	0-30	4.21	0.17	0.27	0.09	65.62	6.40	0.13	0.01
	30-100	3.68	0.18	0.20	0.05	33.12	4.97	0.04	0.01

Table 6 Distribution of H, C, and Al at two depth classes at different sites

Site	Depth / cm	H (cmol/kg)	SE	C (%)	SE	Al (cmol/kg)	SE
ALOAPOKE 2	0-30	2.13	0.25	7.95	0.08	3.80	0.15
	30-100	6.93	4.40	7.90	0.14	5.23	1.06
ALOAPOKE 1	0-30	2.60	0.40	7.87	0.11	4.17	0.28
	30-100	4.00	0.30	8.06	0.04	10.97	2.32
TWENEN 2	0-30	3.37	0.09	8.07	0.02	5.75	0.31
	30-100	3.05	0.33	7.91	0.05	6.25	0.53
TWENEN 1	0-30	4.43	0.35	8.01	0.02	6.83	0.61
	30-100	5.17	0.49	7.45	0.49	5.47	1.03
ALANDA WHARF 3	0-30	4.47	0.68	7.49	0.23	6.27	0.78
	30-100	4.90	0.40	7.06	0.36	4.85	0.55
ALANDA 2	0-30	3.03	0.51	7.98	0.03	4.43	0.23
	30-100	3.70	0.41	7.93	0.04	4.83	0.31
KOFI JAMAN 3	0-30	2.83	0.40	6.50	0.85	3.20	0.27
	30-100	2.53	0.13	3.91	0.90	2.50	0.15
KOFI JAMAN 1	0-30	2.92	0.31	5.17	0.89	4.00	0.13
	30-100	3.25	0.11	4.00	0.76	3.73	0.36
KOFI JAMAN 4	0-30	2.63	0.35	3.22	0.75	2.90	0.17
	30-100	2.40	0.23	1.26	0.08	3.17	0.30
ALANDA 1	0-30	2.97	0.33	7.22	0.54	3.00	0.46
	30-1000	2.73	0.24	4.54	1.04	4.43	0.50
ALANDA WHARF 1	0-30	3.87	0.42	7.77	0.15	5.70	0.32
	30-100	3.60	0.39	7.78	0.20	5.37	0.58
EBONLOA 3	0-30	2.50	0.08	4.51	1.07	2.88	0.60
	30-100	2.37	0.19	1.20	0.16	1.90	0.22
EBONLOA 1	0-30	3.77	0.25	7.63	0.57	2.97	0.36
	30-100	2.47	0.28	1.75	0.25	1.60	0.17
ALANDA WHARF 2	0-30	3.13	0.24	7.79	0.16	5.10	0.24
	30-100	3.43	0.33	7.77	0.14	5.03	0.37
ALOAPOKE 3	0-30	2.77	0.33	7.91	0.09	5.23	0.53
	30-100	4.87	0.40	8.03	0.04	8.80	1.16
KOFI JAMAN 3	0-30	2.83	0.40	6.50	0.85	3.20	0.27
	30-100	2.53	0.13	3.91	0.90	2.50	0.15
KOFI JAMAN 2	0-30	1.66	0.39	2.46	0.37	3.27	0.52
	30-100	2.10	0.37	1.07	0.03	3.10	0.29

3.2.2 SOIL PHYSICAL PROPERTIES

Soil Bulk Density

There was a significant difference in soil bulk density between the two depth classes ($F = 44.39$, df = 1, $P = <0.001$). The difference was also significant between depth and site ($F = 4.55$, df = 16, $P = <0.001$).

Overall, the lower soil class had a significantly higher bulk density than the upper soil class. However, only sites at Alanda Wharf 3, Kofi Jaman 3, Kofi Jaman 2, Alanda 1 and Ebonloa 1 recorded significantly higher bulk density in the lower soil class than the upper soil class. The other sites generally showed a similar bulk density between the depth classes. Figure 12 shows soil bulk density variation at two depths at different sites.
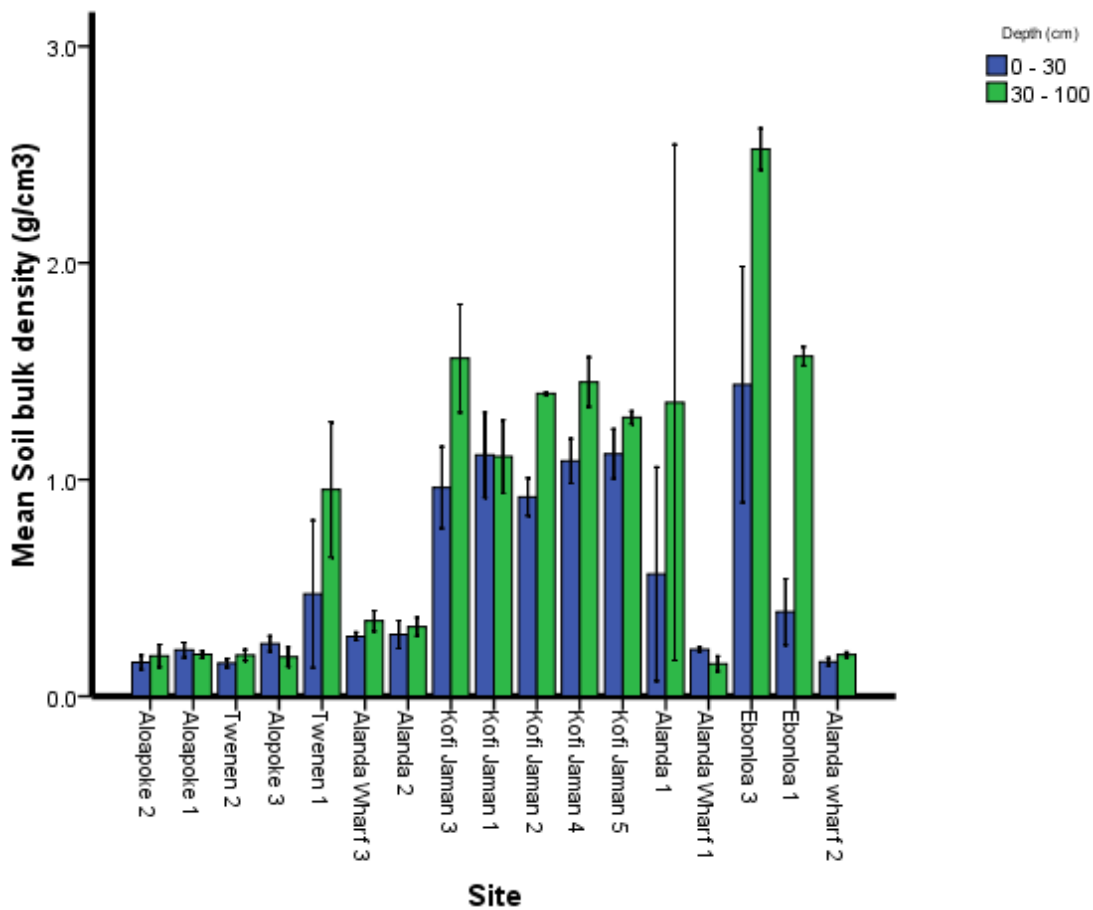

Figure 12 Soil bulk density variation at two depth classes at different sites

Table 7 Soil bulk density distribution at two depth classes at different sites

Site	Depth / cm	BD	SE	Site	Depth / cm	BD	SE
ALOAPOKE 2	0-30	0.16	0.02	ALENDA 1	0-15	0.56	0.21
	30-100	0.19	0.02		30-50	1.36	0.35
ALOAPOKE 1	0-30	0.21	0.02	E.WHARF 1	0-15	0.22	0.01
	30-100	0.19	0.01		30-50	0.15	0.01
TWENEN 2	0-30	0.15	0.01	EBANLOA 3	0-15	1.44	0.23
	30-100	0.19	0.04		30-50	2.52	0.08
TWENEN 1	0-30	0.47	0.15	EBANLOA 1	0-15	0.39	0.05
	30-100	0.95	0.21		30-50	1.57	0.13
ALANDA WHARF 3	0-30	0.28	0.02	E.WHARF 2	0-15	0.16	0.01
	30-100	0.35	0.02		30-50	0.19	0.01
ALANDA 2	0-30	0.28	0.02	ALOA POKE 3	0-15	0.24	0.02
	30-100	0.32	0.04		30-50	0.18	0.02
KOFI JAMAN 3	0-30	0.96	0.12	KOFI JAMAN 3	0-15	0.96	0.12
	30-100	1.56	0.08		30-50	1.56	0.08
KOFI JAMAN 1	0-30	1.11	0.10	KOFI JAMAN 2	0-15	0.92	0.12
	30-100	1.11	0.13		30-50	1.40	0.05
				KOFI JAMAN 4	0-15	1.09	0.10
					30-50	1.45	0.04

Soil texture

Generally, the majority of sites had a sandy or sandy-loam texture, but clay was also evident at some of the sites. The Ebonloa sites were found to be of a sandy loam texture, and the Aloapoke, Twenen and Alanda Wharf sites were sand. Table 8 shows the soil texture distribution across the study area.

Table 8 Soil textural classes at different sites in the study area

SITE	SAND	SILT	CLAY	TEXTURE CLASS
	%	%	%	%
ALOAPEKE 2	94.12	3.92	1.96	SAND
ALOAPEKE 1	92.16	3.92	3.92	SAND
TWENEN 2	92.16	5.88	1.96	SAND
ALOAPEKE 3	80.39	7.85	11.76	SANDY LOAM
TWENEN 1	86.27	3.93	9.80	LOAMY SAND
ALANDA 2	76.47	3.92	19.61	SANDY LOAM
KOFI JAMAN 3	58.82	9.81	31.37	SANDY CLAY LOAM
KOFI JAMAN 2	27.45	14.18	31.37	CLAY LOAM
KOFI JAMAN 4	47.06	7.84	45.10	SANDY CLAY
KOFI JAMAN 5	31.37	13.73	54.90	CLAY
ALANDA 1	86.27	3.92	9.80	LOAMY SAND
ALANDA WHARF 1	92.16	1.96	5.88	SAND
EBONLOA 3	76.47	7.84	15.69	SANDY LOAM

SITE	SAND	SILT	CLAY	TEXTURE CLASS
	%	%	%	%
EBONLOA 1	76.47	13.73	9.80	SANDY LOAM
ALANDA WHARF 2	94.12	1.96	3.92	SAND
ALANDA WHARF 3	80.39	9.80	9.80	LOAMY SAND
ALANDA 3	56.86	7.84	35.29	SANDY CLAY
ALANDA 4	76.47	7.84	15.69	SANDY LOAM
EBONLOA 2	76.47	9.80	13.73	SANDY LOAM
EBONLOA 4	76.47	11.76	11.76	SANDY LOAM

3.2.3 SOIL ORGANIC CARBON STOCKS

There was a significant difference in soil organic carbon stocks between the two depth classes (F = 26.97, df = 1, P = <0.001), as well as the interaction between depth and site (F = 1.86, df = 16, P = <0.041).

Overall, the lower soil depth class (30-100 cm) had a significantly higher soil carbon stock than the upper soil class (0-30 cm). At specific sites, however, the difference was only significant for Twenen 1, Kofi Jaman 3 and Alanda 1, where the soil organic carbon stocks were significantly higher at the lower depth class compared to the upper depth class. All other sites were generally found to have similar soil carbon stocks between the depth classes. Figure 13 shows soil organic carbon variation at two depths at different sites.
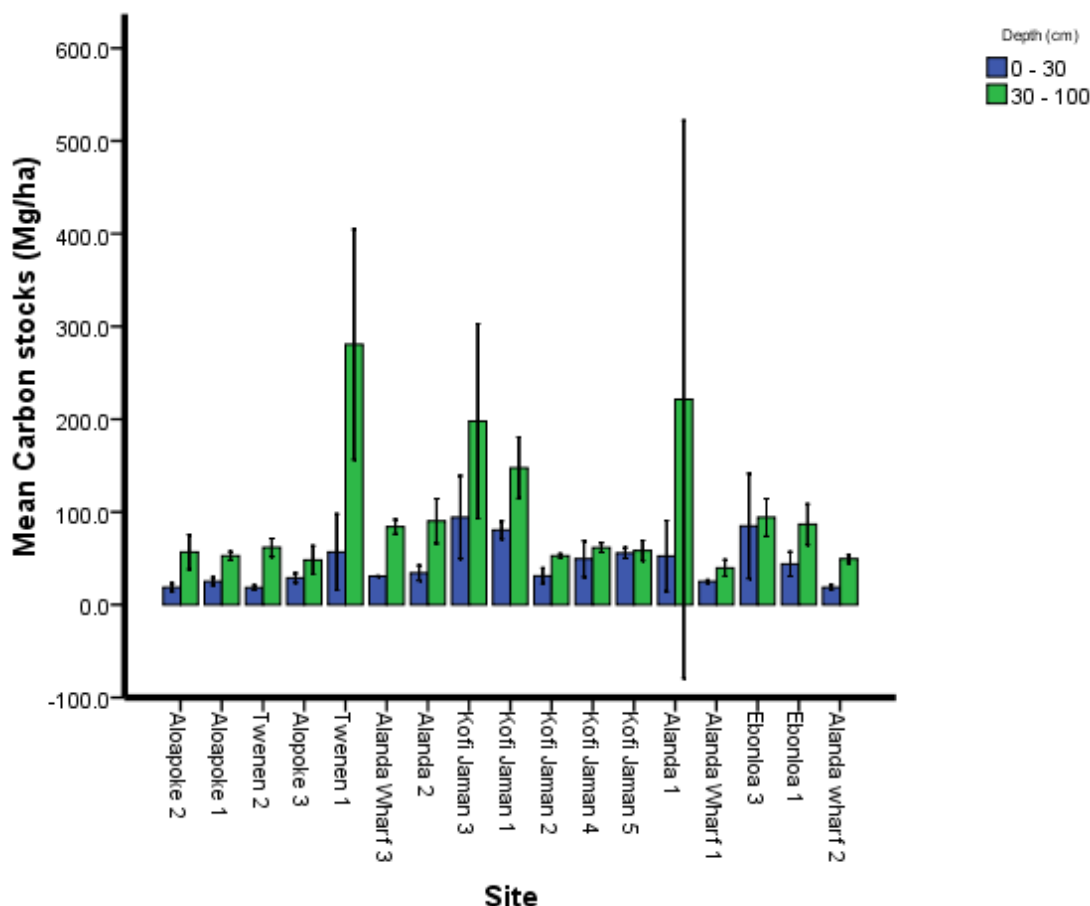

**Figure 13 Soil organic carbon stock variation at two depth classes at different sites**

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Table 9 Soil organic carbon stock distribution at two depth classes at different sites

| Site	Depth / cm	SOC stocks (Mg/ha)	SE	Site	Depth / cm	SOC stocks (Mg/ha)	SE
ALOAPOKE 2	0-30	18.72	2.58	KOFI JAMAN 4	0-30	49.40	10.97
	30-100	56.78	15.43		30-100	61.53	9.20
ALOAPOKE 1	0-30	25.18	2.29	ALANDA 1	0-30	52.36	15.20
	30-100	52.77	8.21		30-100	221.42	93.82
TWENEN 2	0-30	18.45	1.48	ALANDA WHARF 1	0-30	25.12	1.63
	30-100	61.77	18.65		30-100	39.56	6.68
TWENEN 1	0-30	56.80	18.18	EBONLOA 3	0-30	84.81	23.42
	30-100	280.62	93.91		30-100	94.08	10.60
ALANDA WHARF 3	0-30	30.66	1.35	EBONLOA 1	0-30	43.85	5.49
	30-100	83.98	14.45		30-100	86.63	11.83
ALANDA 2	0-30	34.16	3.08	ALANDA WHARF 2	0-30	18.63	1.53
	30-100	90.18	21.15		30-100	49.40	6.77
KOFI JAMAN 3	0-30	94.26	18.50	ALOAPOKE 3	0-30	28.82	2.29
	30-100	197.81	60.88		30-100	48.21	8.19
KOFI JAMAN 1	0-30	80.59	10.31	KOFI JAMAN 2	0-30	31.11	3.07
	30-100	147.57	32.63		30-100	52.68	9.59

3.2.4. EFFECTS OF HYDROLOGY ON DISTRIBUTION OF SOIL NUTRIENTS

At the 0 – 30 depth class, pH, P and K remained generally unchanged between the seasonally flooded and permanently flooded areas. However, N, H, C and Al were higher at the permanently flooded areas, while soil bulk density and carbon stocks were observed to be generally higher at the seasonally flooded areas.

With regard to the 30 – 100 cm depth class, pH, K, Al and bulk density remained fairly unchanged between the seasonally flooded and permanently flooded areas. But N, H, C and carbon stocks were higher at the permanently flooded areas, with P being marginally higher at the seasonally flooded areas. Figures 14 and 15 show the effects of hydrology on the distribution of soil nutrient between two soil depth classes
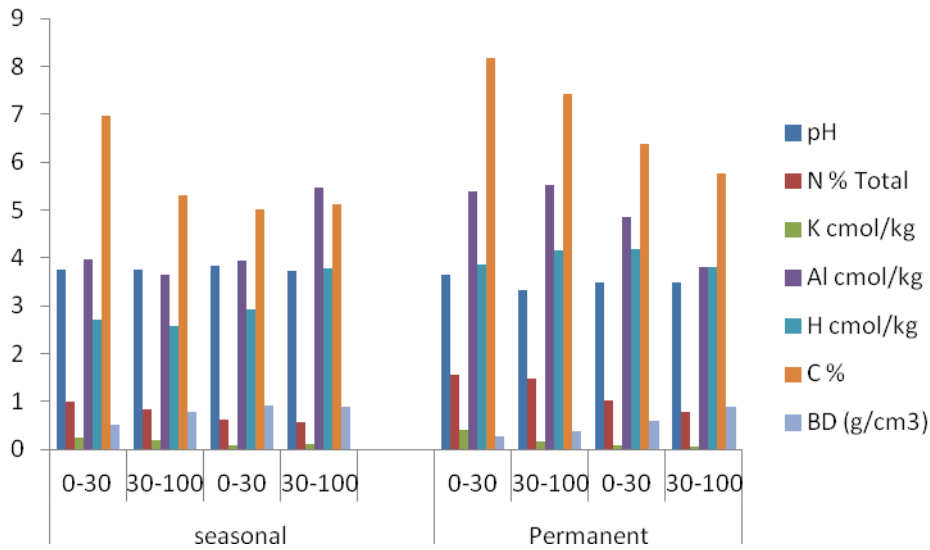
Figure 14 Effects of hydrology on the variation of pH, N, K, Al, H, C content, and bulk density at two depth classes in seasonally and permanently flooded sites
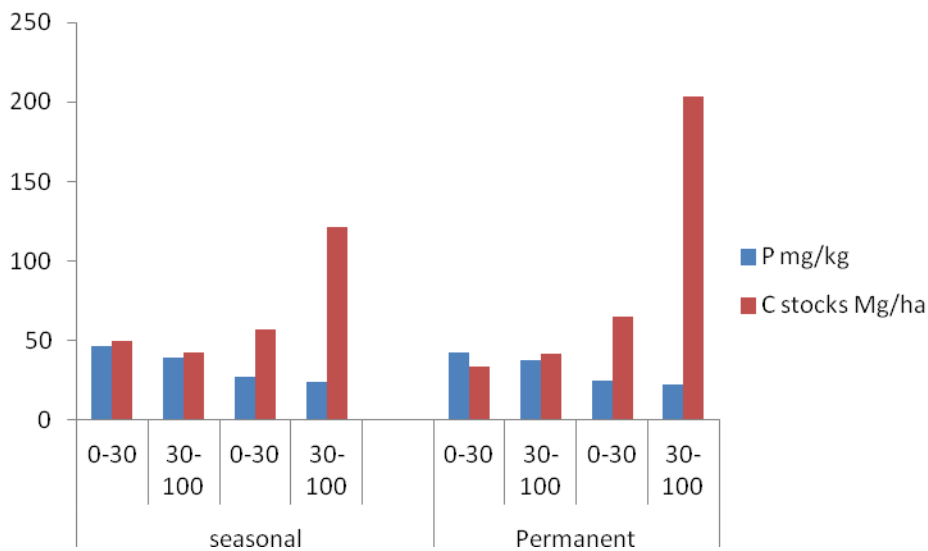

Figure 15 Effects of hydrology on the variation of P and C stocks at two depth classes in seasonally and permanently flooded sites

3.2.5. EFFECTS OF DEGRADATION AND DEFORESTATION ON DISTRIBUTION OF SOIL NUTRIENTS

At the 0 – 30 cm depth class, pH and bulk density were marginally higher at the degraded sites, but remained fairly unchanged at the intact and deforested areas. N, C and Al remained similar at the intact and deforested areas, but showed a sharp decrease at the degraded areas. P concentration was lower at the intact areas, but increased at the degraded and deforested sites. Carbon stock was also higher at the deforested sites, followed by the intact and the degraded sites.

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With regard to the 30 – 100 cm depth class, pH was generally constant for all the areas; however, N was highest at the intact area and lowest at the degraded area, with K being marginally higher at the deforested site. Al was highest at the deforested site, followed by the intact area, with the degraded area having the least Al concentration. But C content and carbon stocks were highest at the deforested site followed by the intact area, with the degraded site recording the lowest concentration. Figures 16 and 17 show effects of site condition on distribution of soil nutrients.
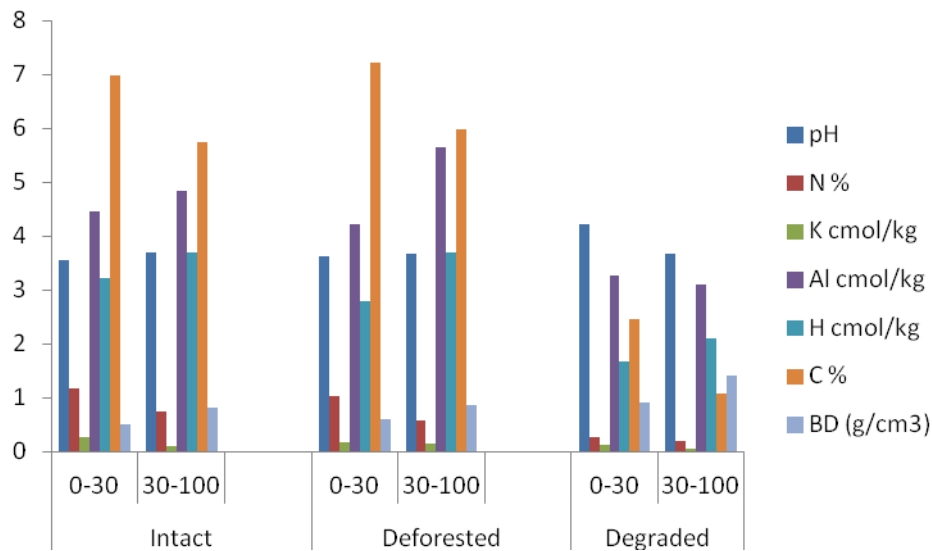
Figure 16 Effect of site condition on distribution of pH, N content, K, Al, H, C content and bulk density.
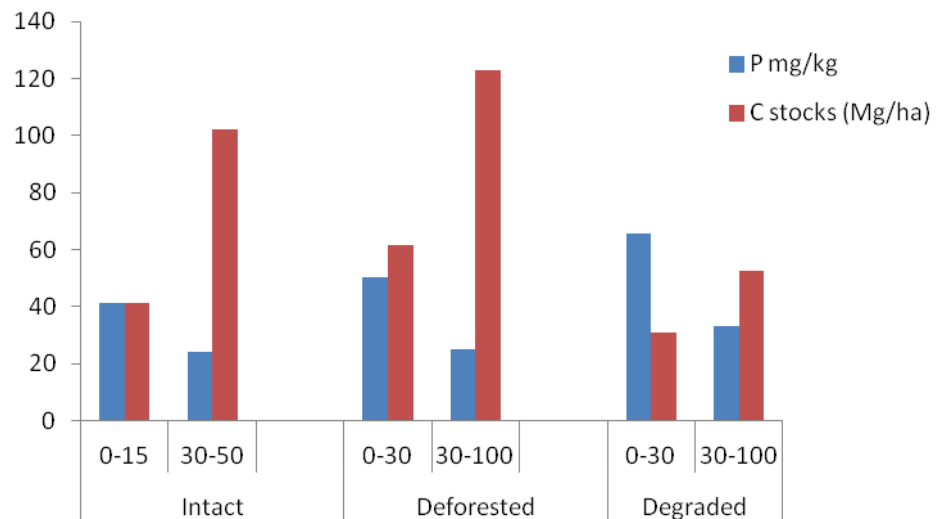
Figure 17 Effect of site condition on distribution of P and C stocks

4.0 DISCUSSION

4.1 BIOMASS CARBON STOCKS

Contrary to most other tropical forests, peat swamp forests are generally characterized by the fact that aboveground carbon does not form the bulk of the total ecosystem carbon pool, since an important portion of the carbon is stored in the peat soil (Joosten, 2009). The results of this study suggest that the peats in Ghana exhibits similar characteristics and functions in terms of carbon storage and sequestration as globally known peat forests in South East Asia.

Though logging in the study sites is not as intensive as commercial selective logging, its impact in reducing carbon stocks provides a useful indicators that these small scale illegal logging activities could be detrimental to carbon sequestration and other ecosystem functions that the peat swamp forests play in Ghana. For instance, degradation reduced soil carbon more than even deforestation. In terms of above and below ground stocks, the conversion of peat swamp forests to maize farms resulted in a decline of aboveground carbon stocks from 114.29 ± 15.92 to 20.26 ± 12.12 MgC/ha, and that of belowground from 22.86 ± 3.18 to 4.09 ± 2.42 MgC/ha, which translates into a loss of 112.6 MgC/ha, while degradation caused the loss of 51.63 MgC/ha. However, it also appears that soil carbon

Though degradation and deforestation of these peat swamp forests was not taking place on a large scale, it is instructive to understand that most upland and less swampy areas in proximity to the peat swamp forests have already been converted to other land use types, such as food crop farms, fallows, and tree-crop plantations (oil palm, coconut, rubber), leaving the swamp forests as the only remaining intact forest. The inhabitants of these areas appear to be less inclined to convert the wetlands to other land use types, perhaps because of the labor required. However, discussions with some farmers indicated that there were attempts to convert some swamp forests to rice farms in the 1980s, but that these efforts were unsuccessful due to difficulties with birds and other animals which fed on the budding grains and flowers.

Illegal, small scale logging is a major cause of degradation in the area. If unchecked, this could lead to a steady decline in the tree density of the swamp forests with a resultant effect on biomass and soil organic carbon. Importantly, most of these wetlands are community owned, thus outside of government control. There is evidence to suggest that most of the local governance systems that have kept these areas intact are increasingly losing their relevance; thus, exploitation is likely to increase, which could serve as a major threat to the peat swamp forest and its functional role.

Aboveground biomass also differs between natural peat swamp forest types, depending on their floristic composition and forest structure (Anderson, 1961). The occurrence of different forest types depends on the hydrology, chemistry and organic matter content of the peat, but these factors are in turn determined by the vegetation.

Figure 4 showed that the aboveground and belowground carbon stocks of the seasonally flooded areas are higher than that of the permanently flooded areas. This suggests the role of the hydrological condition and changing seasons on biomass. It is possible that the seasonally flooded areas have floristic composition and forest structure which is very much different from the permanently flooded areas. Indeed, the tree density at the seasonally flooded areas was higher than that of the permanently flooded areas. The higher tree density in the seasonally flooded areas could be due to the exposure of soil during the dry season, which could result in the germination and establishment of seedlings before inundation during the

rainy season; hence, recruitment could be higher, which could have an impact on the basal area.

Figure 18 Exploitation of swamp forest species for lumber and fuelwood.

4.2 SPECIES DIVERSITY INDICES

This swamp forest is a unique land cover type which is characterized by species specially adapted to swampy areas as evidenced by special adaptations in their root systems and physiology which enable the species to cope with the anaerobic conditions of the swamp. However, the hydrology of the landscape is such that some areas are seasonally flooded with water, while other areas are permanently inundated. The seasonally flooded areas are only fully covered with water during the rainy season (June to November), and during the dry season it assumes the nature of a terrestrial forest, with litter and twigs on the forest floor.

One of the indicators for assessing plant species diversity is the use of index of diversity, namely Shannon-Weaver diversity (H')(Shannon and Weaver, 1949; Ludwig and Reynolds,1988)[1].

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[1] Index H' denotes the number of species, number of individuals, and distribution of individuals for each plant species. The value of H' would be high if the number of species and the number of individuals of each species were also high, and the distribution of individuals for each species was almost even. Several forest ecologist categorized H' values into 3 levels, namely : > 3 was categorized as high; 2-3 moderate; and < 2 low (Istimo et al., 2009).

Though the seasonally flooded site recorded the highest number of individual species, with the permanently flooded recording the least, the latter was the most diverse (H) because it had species which were relatively evenly distributed. This could be due to the fact that the seasonally flooded areas have many individuals of a particular species, with only a few individuals of other species. For instance, *Raphia hookeri* was only found in the seasonally flooded area and had the highest frequency (1101 individual count) of all species encountered. Hence, the dominance of this species likely affected the diversity index, resulting in the lower index value of the seasonally flooded, despite it being the most species rich. The diversity index values recorded can be classified as low, based on the classification of Istimo et al (2009), because only specialized species can survive in this unique type of landscape, which is only found in a few areas of the country.

As already noted, two species could not be identified and were sent to the University of Ghana herbarium for confirmation of their status and identity. It is possible that this unique habitat type harbours species which are endemic to such sites and therefore cannot be found in other parts of the country. Personal communication with the botanist engaged for the species identification showed that many of the species identified cannot be found in other ecological zones in the country.

Figure 19 Branch samples of the two unidentified species showing their leaf structure

Figure 20 Boles of the two unidentified species showing bark slashes

4.3 SOIL CHEMICAL AND PHYSICAL PROPERTY DYNAMICS

4.3.1 SOIL CHEMICAL PROPERTIES

It was evident that the pH and H of the soil was fairly constant from the upper depth class to the lower depth class, whereas Al was higher at the lower depth compared to the upper depth. These H and Al parameters are strongly associated with acidic conditions. Studies have shown that high concentrations of hydrogen ions (caused by the low pH of these peat soils at levels of pH 3.0-4.0) means that toxic components damaging the plant growth become more soluble. Toxic levels of manganese, iron, aluminium, phenols and tannins are common in the acid peat soils. Soil pH, therefore, is probably the single most important management factor controlling the amount of Al in the soil solution (Ismawi et al., 2012). Though these parameters could have inhibitory effects on plant growth, it is possible that plant species which are found in the Amanzule Wetlands are well adapted to these site conditions.

As one might predict, the major nutrients (N,P,K) and carbon content were higher in the upper soil depth class than the lower soil depth class. This indicates that these soil nutrients are within the reach of the roots. Satrio et. al. (2009) reported that total P was higher in peat soil because peat is an organic soil which contains large amount of decomposed organic matter. This could therefore account for the high levels of P recorded in the study area. However, Golchin et. al. (1995) stated that as the peat land is tempered with, decrease in organic matter leads to decrease in P.

Results of the study also indicated that soil nutrients are not uniformly distributed across the entire Amanzule Wetlands, but that there is significant variability which could be due to differences in biodiversity, which contribute different organic materials to the soil, as well as anthropogenic activities.

4.3.2 SOIL PHYSICAL PROPERTIES (BULK DENSITY AND TEXTURE) DYNAMICS

Bulk density reflects the soil's ability to provide structural support, water and solute movement, as well as soil aeration. It is dependent on soil texture and the density of soil minerals (sand, silt, and clay) and organic matter particles, as well as their packing arrangement. Generally, loose, porous soils and those rich in organic matter have lower bulk density. Sandy soils have relatively high bulk density since total pore space in sands is less than that of silt or clay soils. Fine-textured soils, such as silt and clay loams, that have good

structure have higher pore space and lower bulk density compared to sandy soils (USDA, 2008).

Soil bulk density was significantly higher at the lower depth class than the upper depth class. According a USDA (2008) report, soil bulk density typically increases with soil depth since subsurface layers have reduced organic matter, aggregation, and root penetration compared to surface layers and therefore contain less pore space. Subsurface layers are also subject to the compacting weight of the soil above them.

Additionally, soils are made up of sand, silt and clay. The difference between them is in the size of the soil particle (sand particles are larger than silt and silt particles are larger than clay), in their ability to hold nutrients and in their ability to hold water. Generally clay and silt hold nutrients and water better than sand. Soil can also contain organic matter, such as decomposed leaves or peat moss. Since sand does not hold water and nutrients very well, it should be noted that with most of the sites having either sand or sandy-loam texture, fertility could be low.

Soil type also bears an influence on the flooding condition of an area (Leonor and Pablo, 1998). Sandy loams are permeable, but have a low porosity as the grains are of many different sizes and therefore s ubjected to rhombic packing, in which the grains fill spaces. Clay loams tend not to be permeable and have a higher porosity as the grains are of similar shape and subject to cubic packing allowing water to move between the grains (Venugopal et al., 2008).

4.3.3 SOIL ORGANIC CARBON STOCKS DYNAMICS

Soil organic carbon stocks were significantly higher at the lower soil depth than the upper soil depth, following the bulk density trend. It is also possible that the dimension of the depth classes could have contributed to the disparity in the figures. The upper soil depth was 30 cm, while that of the lower depth class was 70 cm.

4.4 EFFECTS OF HYDROLOGY ON DISTRIBUTION OF SOIL NUTRIENTS

Many biogeochemical processes are unique in wetlands due to waterlogging and extensive accumulation of soil organic matter (Bridgham and Richardson, 1993). Hydrology is the dominant variable controlling ecosystem dynamics, influencing such diverse factors as redox potential, soil oxygen content, pH, nutrient and carbon cycling, community composition and wetland development (Day et al., 1988; Bridgham et al., 1991). Important attributes of the hydro-period are the frequency, timing, depth and duration of flooding or waterlogging (Bridgham and Richardson, 1993). Differences in hydrology among wetlands and ultimately their position on the landscape are often the underlying cause of differences in soil chemistry (Bridgham and Richardson, 1993).

Similarly as reported by Nye and Greenland (1960) and Cunningham (1963), soil organic matter declines rapidly after soil is exposed due to clearing activities. Soil organic matter begins to decline as soil temperature increases when exposed to sunlight due to loss of canopy cover and shifts the equilibrium between accumulation and decomposition. When this condition occurs, decomposition rate will increase because of rapid activities of soil microorganism as the environment was favorable to them. Rapid decomposition makes the

carbon most utilized by microorganism and consequently change the value of total carbon in the peat soil.

Contrary to existing literature, this study found nutrients to be higher at the permanently flooded areas, with the seasonally flooded areas having the least, while in some instances soil nutrients remained generally unchanged between the permanently and seasonally flooded areas. One possible explanation is that samples were taken at the end of the dry season, when soil nutrients might have been at their lowest, but that these values should increase with flooding during the rainy season. According to Bridgham and Richardson (1993), differences in hydrology among wetlands and ultimately their position on the landscape are often the underlying cause of differences in soil chemistry. While this study did stratify site selection based on hydrology, landscape position was not considered.

4.5 EFFECTS OF DEGRADATION AND DEFORESTATION ON DISTRIBUTION OF SOIL NUTRIENTS

Generally forest disturbances result in a high residue load which will decompose and contribute organic materials to the soil. This causes an increase in specific soil nutrients through decomposition.

This study found that soil nutrients were variably distributed within the Amanzule Wetlands. Though anthropogenic activities such as deforestation or conversion of some parts of the swamp forests to agriculture, as well as degradation through small-scale logging contributed to changes in the distribution of soil nutrients in the landscape, variability of soil nutrients was also evident within the intact areas that were sampled. For instance, at the 0 – 30 cm depth class, pH and bulk density were marginally higher at the degraded sites, but remained fairly unchanged at the intact and deforested areas. Given that the intact areas were stratified according to seasonal and permanent flooding, it is possible that hydrology could have confounded the results, given that hydrology had an impact on the distribution of soil nutrients.

The degraded sites generally recorded the lowest distribution of soil nutrients, as compared to the intact and deforested areas. This could be because degradation reduces above ground biomass, which therefore has an impact on soil nutrients, but degradation does not result in a large load to the humus layer from debris (branches, stumps, leaves, twigs, etc) left behind in the clearing process.

Figure 21 Hydrological condition of the landscape. 1 is permanently flooded, and 2 is seasonally flooded.

4.6. EFFECTS OF HYDROLOGY ON TOTAL BIOMASS CARBON STOCKS

Figure 16 clearly demonstrates that the hydrology of the landscape (permanent and seasonal inundation) had an impact on tree biomass in the landscape. The seasonally flooded area had higher total carbon stocks, with aboveground being the dominant pool. However, the soil pool in the permanently flooded was higher than that of the seasonally flooded.

From the species diversity analysis, it was observed that the seasonally flooded had more species and a higher number of individuals than the permanently flooded areas, factors which could account for the high carbon stocks in the seasonally flooded area.

The permanently flooded plots, on the other hand, had higher soil carbon stocks than the seasonally flooded areas. This could be due to the fact that the anaerobic conditions in the permanently flooded area created a condition for carbon to accumulate, while at the seasonally flooded area, decomposition through microbial processes, high temperatures and other factors could have resulted in the loss of carbon stocks.
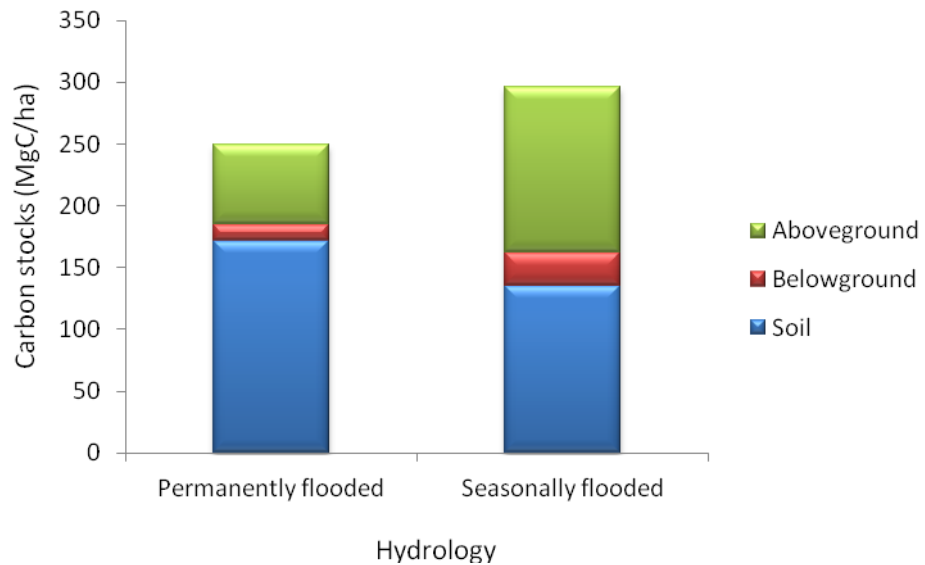
Figure 22 Effects of hydrology on total carbon stocks

4.7. EFFECTS OF DEGRADATION AND DEFORESTATION ON DISTRIBUTION OF TOTAL BIOMASS CARBON STOCKS

Overall, intact forest plots had the highest total carbon stocks, followed by the deforested area, and then the degraded plots. When broken down according to the different carbon pools, the intact sites recorded the highest above and below ground biomass levels, followed by the degraded sites. As a result of anthropogenic activities, the deforested sites recorded the lowest above and below ground biomass carbon stocks because most of the sites were converted to agricultural crops (maize and cassava).

Unlike the biomass trends in the above and below ground pools, however, the highest carbon stocks in the soil component were recorded in the deforested sites. Of particular interesting to ask why deforested plots have higher total biomass than degraded areas, and why the deforested plots have the highest amount of soil organic carbon. The answer appears to be that deforestation activities, while removing aboveground biomass, leave large amounts of litter and woody debris to decompose into the soil. Therefore, following deforestation the soil receives a significant input of soil organic carbon. These differences can be further explained by the fact that degradation (small-scale logging and firewood harvesting) reduces the amount of biomass in the aboveground pool, but it does not significantly impact the soil pool as only minimal amounts of debris are left to decompose.
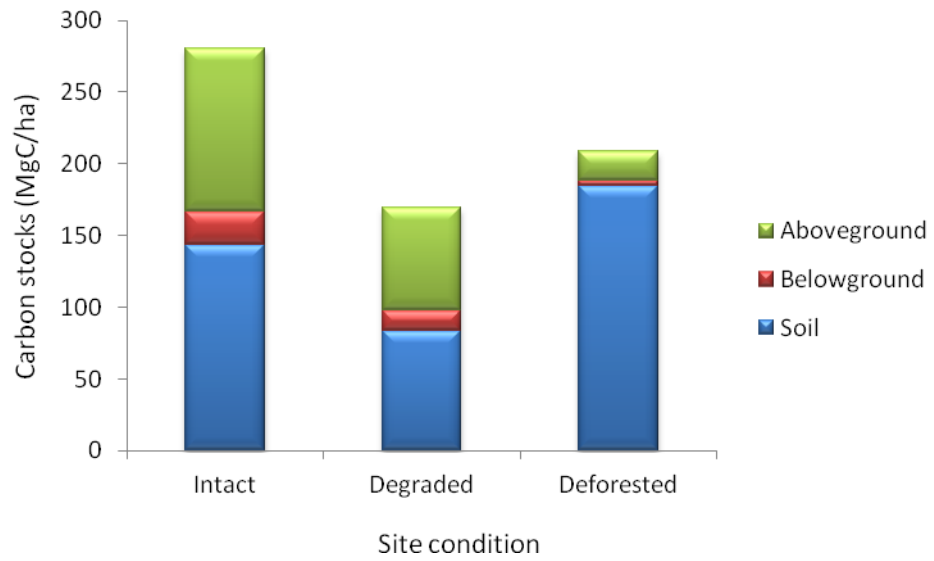
Figure 23 Effects of site condition on total carbon stocks

Figure 24 Site conditions in the landscape. 1 is an intact area, 2 is a degraded area and 3 is a deforested area.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

The data generated shows that the peat swamp forest in the Amanzule Wetlands is a unique and complex landscape that is affected by varying hydrological regimes and a diversity of potentially endemic or niche-specific tree species. It is also a place that appears to be increasingly coming under threat, and subsequently impacted by anthropogenic activities; specifically, conversion to food crop farms or degradation as a result of firewood harvesting or small-scale logging. While the biodiversity value of the Amanzule Wetlands has been widely recognized by numerous national and international NGOs and research institutions over the years, this study is the first effort to quantify its value from a climate change mitigation perspective.

As with peat forest swamps globally, the Amanzule Wetlands and Ankobra River basin contain high carbon stocks, primarily in the above ground and soil carbon pools. Biomass carbon stocks were highest in the intact peat swamp forest areas, followed by the degraded plots. The deforested areas recorded the lowest biomass carbon stocks in the landscape. This underlines the importance of protecting this forest type and its carbon stock. However, it is also interesting to confirm that significant carbon stores are located within the soil. While deforestation might lead to short term gains in soil carbon stocks, one can also assume that over time, if converted plots are put under agriculture or exposed to a change in conditions that these carbon stocks could rapidly be lost. Therefore, the value of conserving the peat swamp forest from a climate perspective applies to both the above ground carbon as well as the soil carbon stocks.

The biodiversity benefits of protecting the wetlands are further highlighted by this study, suggesting that conservation of both permanently flooded and seasonally flooded areas is critical due to significant differences in diversity (Shannon-Weiner index) and species richness. In addition, the species that were identified are clearly adapted to the waterlogged conditions, and therefore are relatively rare in Ghana and across the sub-region; two of the species may even be new species which are endemic to this type of terrain.

One interesting aspect coming out of the soil nutrient analysis is that while most nutrients are located in the top 30 cm of the soil (making them available for root uptake) the actual carbon stocks and bulk density of the soil increased with depth. Therefore, it is possible that if threats increase or portions of the landscape will inevitably be converted to agricultural land-uses, then a climate smart agriculture play / soil carbon option could be pursued in which appropriate crops and low-till activities would enable the conservation of these significant soil carbon stocks in the lower soil depths (30-100 cm).

5.2. RECOMMENDATIONS

1. Further stratification of the landscape: Results of the study clearly show that hydrology and site condition (intact forest, degraded, deforested) significantly impact nutrient and biomass dynamics. Therefore, any future research efforts should use a stratification strategy that prioritizes site selection across permanently flooded and seasonally flooded lands, followed by other land-use variables of interest.

2. Establishing deforestation / degradation rates for the peat swamp forest: Clearly, there is the need to better understand rate at which the peat forests are being exploited and

converted to other land use types. Such data will aid in future decision making about potential conservation and/or management strategies, including the potential for a carbon finance project (establishing REDD+ project baseline, soil carbon options, climate-smart agriculture options).

3. <u>Establishment of permanent monitoring plots:</u> There is need for the establishment of Permanent Sample Plots (PSPs) in different hydrological and disturbance regimes. This would provide long term information on total swamp forest carbon sequestration as well as nutrient and biomass dynamics (rates of recruitment, growth and mortality); such information is crucial for judging sustainable exploitation rates of a fragile ecosystem or assessing other management and use options.

4. <u>Measurement of fuelwood going out of the system:</u> There is the need to account for the actual amount of biomass that is being lost through fuelwood extraction / logging in order to clarify the amount of residue that is decomposing into the soil. This would provide a better understanding of carbon cycling within the system as a result of anthropogenic activities. It would also help to inform potential management strategies, including REDD+ feasibility.

5. <u>Assess the stability of soil carbon in the system</u>: There is the need to determine how labile soil carbon stocks are, so as to establish the stability of carbon stocks in the system.

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