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Remaining resolute in harsh environments in Ghana: Wildfire control doing the magic in Zorbogu community

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Abstract

The paper examines the impact of anthropogenic activities on the bulk densities and levels of carbon stocks in Zorbogu, northern Ghana. The study focused on four areas; a natural forest (FR), a plantation forest (TP), a non-burnt (UBF) and a burnt farm (BF). Simple random sampling was used to establish five 20x20m quadrats. Nested 1x1m quadrats were established within these for soil sample collection. Soil samples were analysed for their bulk densities and percentage carbon. Data on the diameter at breast height (cm), total tree height (m), wood- specific gravity (g/cm^3) were used to estimate the carbon stocks of the community forests. Mean bulk density values increased from 1.17g/cm3 in the farmlands where burning is practiced to 1.53g/cm^3 in the community's natural forest. The teak plantation recorded a bulk density value of 1.36g/cm^3 which is lower than the value recorded in the non-burnt farm (1.50g/cm^3). BF recorded the least soil carbon stock (198.72 Mg C ha^{-1}) whiles FR recorded the highest (351.95 Mg C ha^{-1}). There were also significant differences in the carbon stocks of the community forest for the above ground tree biomass with FR recording higher carbon stocks (71.7t/ha) than TP (29.7t/ha).

Keywords: Bulk density; Soil carbon; Forests; Farmlands; Non-burning; Wildfires

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1. Introduction

Land ecosystems of the earth contain about 2.2 × 10^{18} g C, an estimated 0.6 × 10^{18} g C in vegetation and 1.6 × 10^{18} g C in soils; the soils of the world contain about three times more organic carbon than is contained in vegetation. However, tropical forests contain more carbon in their vegetation than in their soil (Houghton, 1991). These land carbon stocks are changing in response to changes in area of agricultural land, age structure of forests, climate, and chemistry of the atmosphere and precipitation (Melillo et al., 1996). The range of carbon found in Ghana by Greenland and Nye (1959) was 1680 g C m^{-2} for the drier savanna zones to 5600 g C m^{-2} for the humid savanna zone.

The relatively high content of root matter in grasslands decomposes more slowly and contributes more efficiently to soil humus formation than does forest leaf litter. The organic carbon content also decreases less abruptly with depth in grasslands than in forested ones, because of fibrous roots that extend deep into the profile. Since most organic residues are incorporated in, or deposited on the surface, organic matter tends to accumulate in the upper layers. Organic carbon contents are therefore generally much lower in subsurface horizons than those of the surface soil (Brady & Weil, 1996).

In general, soils in cultivated lands contain much lower levels of organic matter than do comparable soils under natural vegetation (Brady & Weil, 1996).

As in native systems, soil carbon pools and fluxes in agro-ecosystems are influenced by carbon inputs (e.g. amount and type of plant residue), climate (e.g. temperature and precipitation), and factors like soil texture, pH, drainage etc. In addition, land use and management strongly influence carbon content in agricultural soils (Cole et al., 1993). The balance of carbon in agro-ecosystems depends on plant residues, applied organic materials, respiration, plant removal, and erosion (Brady & Weil, 1996).

Within plant associations, biotic factors, topographic factors, and soil properties regulate the carbon accumulation. In successional ecosystems, there are additional factors that regulate the SOC pool. These include previous land use, elapsed time since abandonment (age), type of vegetation, and rates of organic matter production, both above- and belowground (Lugo & Brown, 1992).

Under natural conditions, when the soil is not disturbed by tillage, most of the organic matter produced by the vegetation is returned to the soil. In contrast, in cultivated areas much of the plant material is removed for human or animal food and relatively less returns to the land. The tillage aerates the soil and breaks up organic material, making it more accessible to microbial decomposition (Brady & Weil, 1996). Losses from many soils are typically 20 to 30% within the first decades of cultivation. The loss is greatest during the first few years of cultivation. Some of the SOM is lost in erosion, but most is probably oxidised to carbon dioxide and released to the atmosphere (Schlesinger, 1997).

With about 10% of the world's soils under cultivation, loss of organic matter from agricultural soils has been a major component in the past increase in atmospheric carbon dioxide. The current rate of release from soils, as much as 0.8 × 10^{15} g C yr-1 is largely dependent upon the current rate at which natural ecosystems, especially in the tropics, are being converted to agriculture (Schlesinger, 1997).

Taking cognisance of the dynamics of carbon between the atmosphere and biological systems (living biomass, forests and soils), there are global efforts through the Kyoto Protocol and others to improve carbon sequestration. Admittedly, soils have the capacity to hold more carbon than the atmosphere and vegetation combined, and can hold it longer, consequently the focus on carbon stocks has increasingly shifted to soil carbon as an opportunity to both mitigate and adapt to climate change and improve the provision of ecosystem functionality (Sheikh et al., 2009).

Various authors attest to the promotion of tree based systems, agroforestry, cover crops, residue retention, manure application, no/less tillage and other agrarian practices as options that may greatly reduce carbon loss and enhance soil organic carbon levels (Batjes & Dijkshoorn, 1999; Marland et al., 2004; Paustian et al., 1997). Enhanced soil organic carbon (SOC) has concomitant favourable effects on physical, chemical and biological activities of the soil for good crop yields (Ardo & Olsson, 2003). Soil Organic Carbon can consequently be used as an index of sustainable land management that provides options for improving soil fertility and ensuring food security (Marks et al., 2009; Nandwa, 2001).

It has been observed that quality of agricultural soils in tropical regions including Ghana continues to decline due to poor land use and soil management practices (Marks et al., 2009). This trend affects soil organic carbon which plays the dual role of promoting soil fertility/yield and provision of ecosystem service. Therefore adoptions of appropriate land use management practices are required to reverse this trend. Agricultural land use management activities that increase soil organic carbon promote sustainable land management (West & Post, 2002).

Nketia et al. (2009) have observed that currently in Ghana, the Reduced Emissions from Deforestation and forest Degradation (REDD) initiatives considers carbon conversion in farming systems as one of two thematic areas for emission reduction, which is gratifying. However in Africa and more specifically in Ghana very little have been done with respect to soil organic carbon dynamics in various land use systems (Yao et al., 2010).

1.1. Background

Ghana with a population of twenty-four (24) million people has a total area of 238,500 km^2. Twenty-eight (28) percent of the country is covered by forests. These are located in southern Ghana. In northern Ghana the vegetation is mainly of the Guinea savanna type.

The mean estimated annual cost of environmental degradation is nearly US $850 million or 10.0% of GDP. The degradation of natural assets (agricultural soils, forests and savanna woodlands, coastal fisheries, wildlife resources, and Lake Volta's environment) costs at least US$520 million annually (6.0% of Ghana's annual GDP) and health effects account for nearly US $330 million or 3.8% of GDP. Among the natural assets, the large majority of the estimated costs of environmental degradation come from in- and off-reserve forests (63%), and to a lesser extent, from soil nutrient depletion (20%) (AFSD, 2006).

Thirty to forty (30 to 40 per) cent of the total land area of Ghana experiences some form of land degradation (GOG, 2002). Land degradation is mainly attributed to deforestation, overgrazing and wildfire occurrence. Most of the wildfires are concentrated in the northern drier part of the country and certain coastal zones. In these areas there is a lot of dry combustible material (mainly grasses) in the dry season.

The Stimulating Community Initiatives in Sustainable land Management Project (SCI-SLM Ghana) selected four community innovations that have some sustainable land management qualities (Figure 1). A baseline carbon stocks assessment of some above and below ground carbon levels in the intervention (innovation areas) was therefore undertaking using first degree students of the University for Development studies. This presentation is focused on one of the selected sites, Zorbogu Community.

2. Materials and methods

2.1. Study area

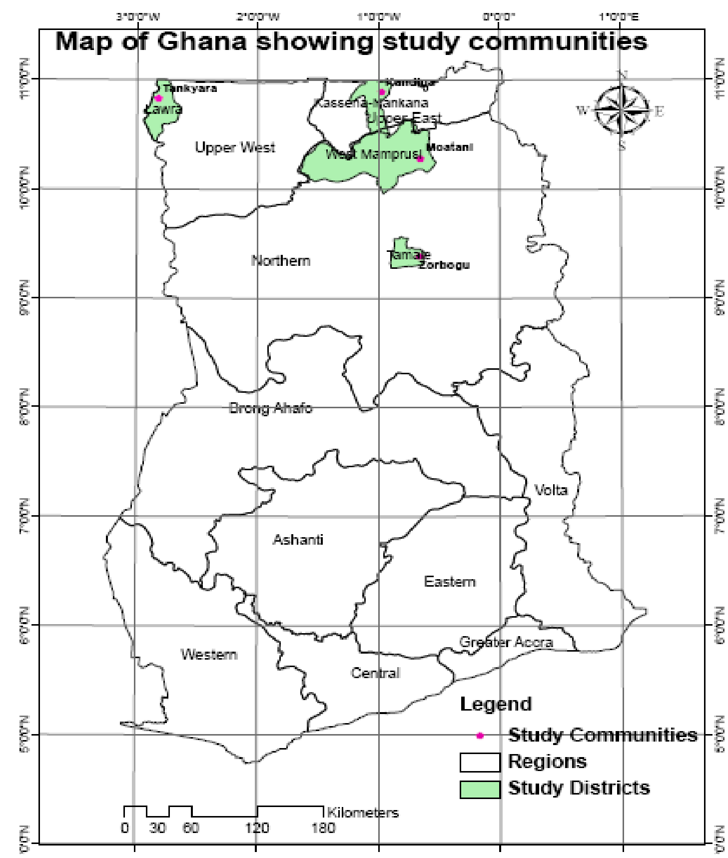

Figure.1. Map of Ghana Showing SCI-SLM Communities (Zorbogu arrowed)

The study was carried out at Zoborgu and its environs, which is about fifteen kilometers (15km) from Tamale, the Northern Regional Capital in Ghana. Zorbogu is a small community of about 152 inhabitants. Geographically, the area lies between latitude 9˚ 05' N to 9˚ 36' W and longitude 0˚ 10' W to 0˚ 90' W. The area experiences a unimodal rainfall pattern occurring between May and October with peaks in August and September. Average annual rainfall is 1,110mm and the mean annual temperature is 28.5˚C (Meteorological Station, Tamale). The soils at the study sites are savanna ochrosols found on the Voltian sandstone. Topsoils are generally thin (<20 cm), greyish-brown sandy loam, and weakly granular and friable.

2.2. Methods

There were four areas of focus; two different forest types [a natural savanna woodland stand (FR) and a teak plantation (TP)] and farmlands [non-burnt (UBF) and burnt (BF)]. Simple random sampling was used to establish five 20x20m quadrats in FR and TP. These quadrats were nested and soil samples collected from 1x1m quadrats established within them. Soil samples were also taken from three randomly established 1X1m quadrats on three non- burnt and three burnt farmlands each.

2.2.1. Soil organic carbon

Soil samples were taken at the various depths of 0-10cm, 10-20cm and 20-30cm. 100cm^3 of each sample was taken with the aid of a core sampler and transferred to pre-weighed polythene bags.

Wet weights of soil samples were determined with 0.1g precision. Soil samples were taken to the laboratory and oven dried until constant weight to determine the bulk density. Oven dried samples were next kept into a muffle furnace and burnt at 600^{0}C to determine percentage carbon.

Schollenberger method was adopted in determining carbon stocks.

The difference [(Oven dry weight (g)] – [(Furnace weight (g)] was calculated to obtain carbon weights in (g) in each case. Percentage carbon was subsequently derived for each sample plot by dividing the obtained carbon weights (g) by the initial wet weights (g), multiplied by 100%. The figures obtained per sampling plot were averaged and the representative values factored into the mother equation below for soil organic carbon estimation as calculated by (Pearson et al., 2007):

$$SOC = \rho \times d \times \%C$$

where,

SOC = Soil Organic Carbon Stock per unit Area (t ha^{-1})

ρ = Soil bulk density (g/cm^3)

d = Total depth at which the sample was taken (cm)

% C = Carbon concentration (%)

2.2.2. Above ground tree carbon stocks

Trees were identified and their diameter (cm) and heights (m) measured. Data obtained on the trunk diameter at breast height (in cm), total tree height, H (in m), wood-specific gravity ρ (in g/cm^3) were used to estimate the carbon stocks of the community forests.

Data on the trunk diameter at breast height, DBH (in cm), total tree height, H (in m) and wood- specific gravity ρ (in g/cm^3) was used in the allometric equation developed by Chave et al. (2005) to estimate above ground tree biomass:

$$AGTB = 0.112 \text{ X } (\rho D^2 H)^{0.916}$$

where,

AGTB = Above Ground Tree Biomass (kg)

ρ = wood specific gravity

D = Tree Diameter at Breast Height (cm) and

H = Tree Height (m)

The sum of the individual weights (in kg) of a sampling plot was then calculated and the value divided by the area of a sampling plot (thus 20m x 20m= 400m^2) to attain the biomass stock density in kg/m^2 and converted to t ha^{-1}. The biomass stock density of a sampling plot was then multiplied by the IPCC (2006) default carbon fraction of 0.47 to obtain the carbon stock density.

3. Results and discussion

3.1. Bulk density

Mean bulk density values increased from 1.17g/cm^3 in the farmlands where burning is practiced to 1.53g/cm^3 in the community's natural forest stand. The teak plantation recorded a bulk density value of 1.36g/cm^3 which is lower than the value recorded in the non-burnt farm (1.50g/cm^3). Values obtained in the burnt farms where significantly lower than those of the natural forest stand and non-burnt farm (Table 1).

Table 1. Bulk Densities of soils under different land uses

Landuse	Mean	Std Deviation	Sig.
BF	1.17	0.236	*
UBF	1.50	0.051	**
FR	1.53	0.029	**
TP	1.36	0.124	*

** P< 0.005; ** P<0.005; * and ** have P>0.005*

The mean bulk density values recorded in this study compare to values recorded in the Tene protected forest (0.6g/cm^3) and cultivated areas (0.9g/cm^3) in Ivory Coast by other scientist. They also compare to 1.51g/cm^3 in forest use type, 1.29g/cm3 in mixed fields and 1.36g/cm^3 in tree plantations in Bechem, Ghana (Agboadoh, 2011). The mean bulk density value in the natural forest stand, an arid woodland, at Zorbogu (1.53 g/cm^3) is similar to that at the forest lands at Bechem (1.51g/cm^3), a humid forest (Agboadoh, 2011) but lower than those (1.650 g cm^{-3}) found at Bawku (an arid area) by Dawidson & Nilsson (2000). This would confer on the soils of Zorbogu better physical properties such as infiltration, aeration, etc compared to the neighbouring area.

The teak plantation had bulk density values (1.36 g cm^{-3}) which were significantly lower than the adjoining natural forest stand at Zorbogu. These values are lower than those of teak plantations (0.82 g cm^{-3}) in Oumé, mid-West Côte d'Ivoire, in the subequatorial regions of Cote d' Ivoire (Yao et al., 2010). They also compare to 1.32 g cm^{-3} in Trichur, India (Balagopalan et al., 1991).

The non-burnt farmland had bulk density of 1.51 g cm^{-3} which is lower than values in manured cultivated farms (1.682 g cm^{-3}) in Bawku recorded by Dawidson & Nilsson (2000). Manure increases the bulk density of soils, hence the higher value. The soils on the non-burnt farms in Zorbogu do not have regular organized manuring, however the crop residue is allowed to decompose *in sito*. Animal droppings during feeding, on-farm, is also incorporated into the soil. Hence the bulk density vales are higher for the non-burnt farm compared to the burnt farmlands.

3.2. Soil organic carbon

SOC levels ranged from 198.72 t/ha in the burnt farmlands to a high value of 351.95 t/ha in the community's natural forest stand. Mean SOC levels differed significantly between the burnt farms, where land preparation includes the use of fire to burn farm residue, and the non-burnt farms and between the burnt farms and the community's natural forest stand; levels between the burnt farms and the teak plantation however did not differ significantly. Mean SOC levels did not differ significantly between the non-burnt farms, the natural forest stand and the teak plantation (Table 1).

Table 2(a). Carbon stocks under different land use types

Landuse Type	Minimum	Maximum	Mean	Std Deviation
Burnt Farm	188.93	209.58	198.72	1.036
Non-Burnt Farm	294.13	326.49	307.63	1.683
Natural Forest	322.17	371.58	351.95	2.621
Teak Plantation	213.68	264.15	238.62	2.524

Table 2(b). Carbon stocks under different land use types

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	BF - UBF	-1.089E2	2.67633775E1	1.54518432E1	-1.7539060E2	-4.2422771E1	-7.048	2	.020
Pair 2	BF - FR	-1.532E2	3.63463504E1	2.09845752E1	-2.4351666E2	-6.2937987E1	-7.302	2	.018
Pair 3	BF - TP	-3.989E1	3.12124540E1	1.80205187E1	-1.1743248E2	3.76395812E1	-2.214	2	.157
Pair 4	UBF - FR	-4.432E1	1.59106888E1	9.18604047E0	-8.3844982E1	-4.7962978E0	-4.825	2	.040
Pair 5	UBF - TP	6.9010E1	1.72287318E1	9.94701297E0	2.62116919E1	1.11808777E2	6.938	2	.020
Pair 6	FR - TP	1.1333E2	3.25332367E1	1.87830730E1	3.25138340E1	1.94147914E2	6.034	2	.026

The study area for this research is relatively small hence it can be assumed that land cover and land use change and management patterns will largely contribute to the spatial variability in soil organic carbon content since climate, soil type and terrain as variables could be overlooked as the study was conducted in a homogenous area.

The SOC values obtained compared with other finding were high. This may be attributable to high readings from the muffle furnace used in this research. However, since the focus of the study is to focus on the impacts of the different land uses on soil properties, the comparison is valid since the same instrument was used for the different land uses. For instance, carbon stocks in the forest of this study compare to 103.11 Mg C ha^{-1} in teak plantations in Lansak, Thailand (Tangsinmankong et al., 2007); 34.95 Mg C ha^{-1} in tree plantations and 43.38 Mg C ha^{-1} in forest in Bechem, Ghana (Agboadoh, 2011). Similarly farmland carbon stocks from this study compare to 28.09 Mg C ha^{-1} in continuously cropped farms and Mg C ha^{-1} in farms where some fallows were observed in Bawku, Ghana (Dawidson & Nilsson, 2000).

Agboadoh (2011) found that more than half (49-56%) of the SOC resides in the top layer (0-20cm). Consequently land uses that impact on this layer would affect SOC levels. This makes this layer most prone to land use change as indicated by various authors (Batjes & Dijkshoorn, 1999).

The high levels of SOC in the non-burnt farm (UBF), teak plantation (TP) and the natural forest stand (FR) can be attributed to the land use practice of non-burning that is practiced by the Zorbogu Community. The absence of the fire allows litter to be incorporated into the soil. The teak plantation is grown as a single species stand. Hence the undergrowth is not rich, with a lot of spaces. Consequently the underground growth of fibrous roots in this savanna ecozone is limiting. This explains the relatively low stocks of SOC in the teak plantation. In addition, although the community tries to prevent it, wildfires occasional burn the teak plantation which is prone to them due to its deciduous character. This is supported by Suwanaratana (2001), who found that forest fire was another factor that accounted for low level of soil organic carbon which probably caused low soil organic carbon in teak plantation.

Land preparation for agricultural (farming) purposes in this area typically includes the use of fire. Stocks, storms and litter are often gathered on-farm and burnt. The Zorbogu Community is however acting differently by allowing the previous year's growth to remain on-farm without burning. Cattle, sheep goats and other farm animals are allowed to graze in the plantation and on the farms. This makes available a larger quantity of decomposable material that is incorporated into the soil; hence the higher value of SOC in the non-burnt farmlands compared to the burnt farmlands. Indeed, crop yield in Zorbogu is three times higher than that of neighbouring Zakariyile (on-farm burning is practiced) village.

The lower losses reported in this study present an opportunity for cultivated areas practicing non-burning to serve as carbon sinks as the parent soil material is intrinsically fertile and the adoption of sustainable management practices is vital (Obeng, 2000; Yao et al., 2010). Indeed, from the Zorbogu experience, it can be suggested that management practices played a key role influencing the SOC content and therefore responsible for the high or low SOC levels.

3.3. Above ground tree carbon stock density

The carbon stock density of the teak plantation ranged from 26.34 to 34.80 Mg C ha^{-1} whilst that for the natural forest stand (savanna woodland) ranged from 35.34 to 94.18 Mg C ha^{-1}. Mean above ground carbon stock density of trees of the natural forest stand differed significantly from the teak plantation (Table 2).

Table 2(a). Above ground tree carbon stock density

Landuse Type	Minimum	Maximum	Mean	Std Deviation
Natural Forest Mg C ha^{-1}	35.34	94.18	71.72	23.540
Teak Plantation Mg C ha^{-1}	26.34	34.80	29.72	3.292

Table 2(b). Above ground tree carbon stock density

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Pair 1	forest_natural CSD (t/ha) - Teak Plantation CSD (t/ha)	4.1997E1	2.60144790E1	1.16340287E1	9.69634846E0	7.42988325E1	3.610	4	.023

4. Conclusions

This study shows that soil bulk densities as well as carbon stocks are significantly affected by land use type and land management (non-burning). Soil bulk density is highest in the natural forest stand, followed by the non-burnt farm and then the teak plantation. The burnt farmlands recorded the lowest. The large difference between the bulk densities of the burnt farmlands and the non-burnt farmlands shows clearly that the fire has considerable impacts on bulk densities in Zorbogu. Bulk densities in the natural forest stand which has rich undergrowth are higher than those of the single species teak plantation.

SOC levels were highest in the natural forest stand followed by the non-burnt farm and the teak plantation. The burnt farm recorded the least levels of SOC. Non-burning on-farm is a good farming practice that improves SOC and hence soil fertility thereby improving crop yields even on continuously cropped lands.

Figure 2. Zorbogu community sacred grove and Chief

Figure 3. Sheep grazing on the maize stocks during the dry season. Maize during the wet season.

Although teak is a fast grower and is used in most afforestation programmes in Ghana, it recorded a lower above ground carbon stock density compared to the natural woodland forest stand in Zorbogu. This is attributable mainly to age differences and a lower number of tree stems per unit area in the teak plantation compared to the natural forest stand.

When the stock levels are compared to those obtained from the National data base on carbon stocks it would be observed that the levels in the innovation areas are higher than the national estimates for the selected region (Figure 4).

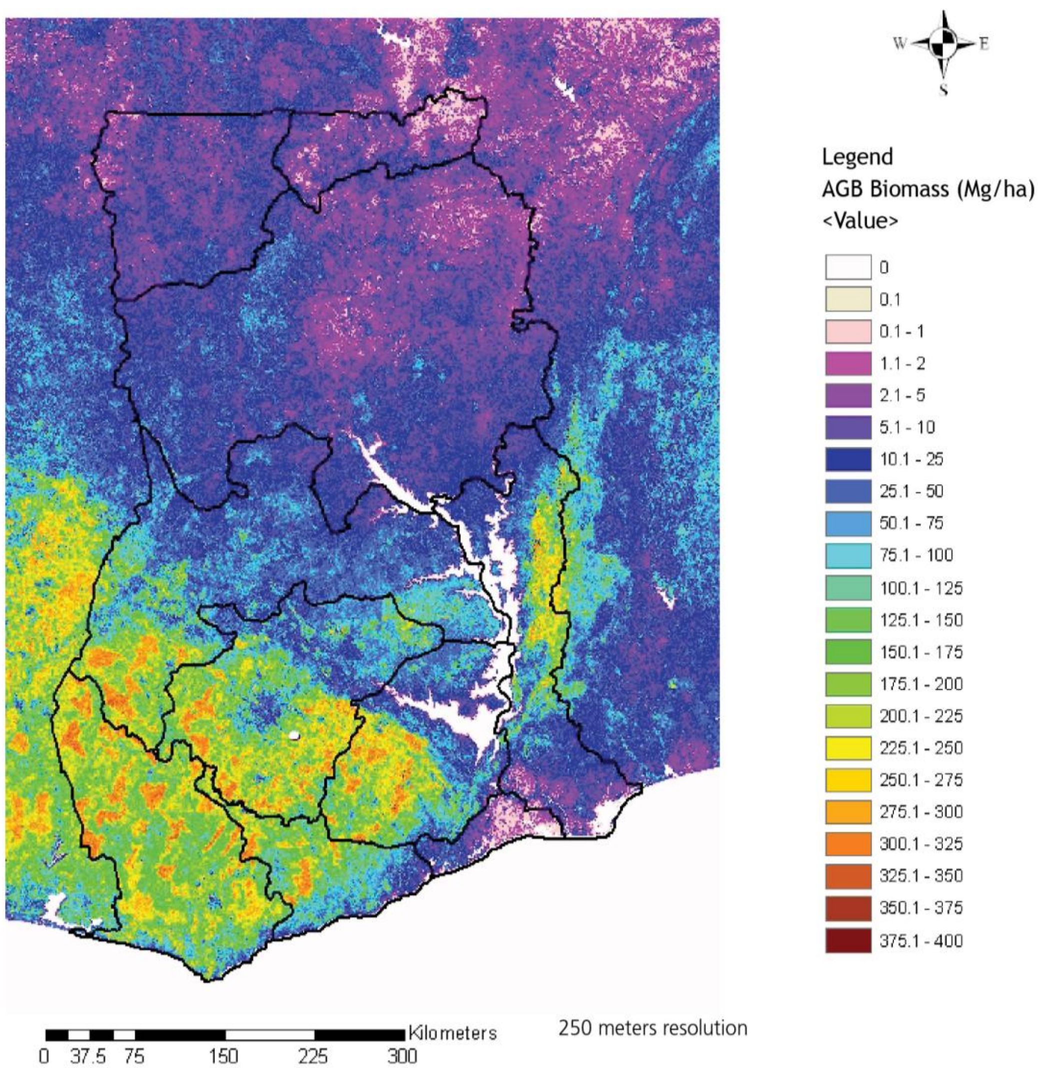

Figure 4. Carbon Stock Map of Ghana

Figure 5. Zorbogu community sacred grove and pond

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