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# Historical Changes in $CO_2$ Emissions and Removals from Land Use and Land Cover Changes in Sudan Savannah Ecological Zone of Ghana

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**Abstract**

Assessment of changes in carbon stock from land use and land cover change in necessary for carbon emissions/removals monitoring and enable countries to comply in line with the Good Practice Guidance of IPCC. This study aimed to estimate and map the historical changes in carbon emission and removal from land use and land cover change from 1986 to 2016 in Sudan savannah ecological zone of Ghana. Nested plot design was applied for field measurement, and Random forest algorithm was used to classify images. The zone was stratified into four Districts and each District further stratified into various land use and land cover (LULC) classes. Emission factors were determined for each LULC. Activity data were obtained from the spatial analysis. The overall carbon released from forest degradation and deforestation was found to be 554,684.96 Mg CO2 or 77.19% with 163,956.93 Mg or 31.84% removed. The inter-annual changes exhibited a decrease from 1986 to 1999, 1999 to 2006 and 2006 to 2016 with value being 642,342.79, 545,125.53 and 445,142.17 Mg $CO_2$, respectively. More $CO_2$ was released from forest degradation and in the area where cropland and forest have been converted to shrub/grassland; whereas carbon was removed in the area where shrub/grassland has been converted to cropland and/or forest land. However, more carbon was recorded in cropland compared to forest and shrub/grassland, which explains the difference in emission factor from carbon. Based on this finding reforestation and REDD+ implementation will be an efficient strategy for sustainable development in the Sudan Savannah ecological zone. In addition, farmers should be encouraged to maintain more trees on their farms to compensate for the forest loss.

**Keywords:** Carbon emission and removal, Land use and land, Sudan savannah ecological zone, Ghana

## 1. Introduction

Greenhouse gas (GHG) is the gas in the atmosphere which acts to trap the heat near the Earth's surface and enables human being to survive (Latake, 2015). The level of gases is increasing due to anthropogenic activities (IPCC, 2014; Zhao et al., 2012). Carbon dioxide is one of the most substantial gas (Guo et al., 2012), whose continual increase is changing the concentration of GHG in the atmosphere and ocean (Rajendran et al., 2014). Emissions from land use and land cover changes (LULCC) are one of the most important sources of GHG

(Rajendran et al., 2014), and contributes around 33% of the total emission to the anthropogenic carbon emissions over the last 150 years (Houghton et al., 2012). The net carbon flux from land use and land cover change represented 12.5% of anthropogenic $CO_2$ emissions from 1990 to 2010 (Houghton et al., 2012). Moreover, agriculture forestry and other land use (AFOLU) sectors represent the main source of $CO_2$ emission in Africa, because natural resources are used as food, medicinal plant, building material (FAO, 2014). The $CO_2$ equivalent from AFOLU sectors represented an average of 55% for West and Central Africa (FAO, 2014). Greenhouse gas (GHG) from AFOLU sectors in Ghana was estimated to be 45.1% of the total emissions in 2012. The estimated total of GHG emissions were 33.66 million tons of $CO_2$eq, which represents an increase of 10.7%, 106.7% and 136.7% over the period of 2000, 2010 and 2016, respectively (Republic of Ghana, 2015). Forest vegetation in the Upper East Region is being lost through charcoal production (Aabeyir et al., 2016), and vegetation burning for fresh grasses for animal and firewood (Adanu et al., 2013; Dimobe et al., 2018). Global warming is a worldwide concern (Deng et al., 2011). Therefore, stabilisation of the global temperature increase through reducing emission from deforestation and forest degradation, sustainable forest management, carbon stock, biodiversity conservation and carbon stock enhancement (REDD+) is one of the focus of the United Nation Framework Conservation on Climate Change (UNFCCC). Therefore, it is essential to provide accurate information to policymakers on the state of the spatiotemporal distribution of $CO_2$ emissions and removals (Deng et al., 2011). Mitigation, adaptation and sustainable management, and forest ecosystem protection constitute the main keys to reduce greenhouse gas emissions and avoid global warming (IPCC, 2014; Gizachew et al., 2016). Aboveground biomass is one of the most important parameters which is required for the assessment of carbon emissions due to deforestation and forest degradation (Houghton and Hackler, 2006; Urbazaev et al., 2016; Shao and Zhang, 2016). To fully understand the impact of land cover changes on $CO_2$ emissions/removals, it is important to have information on land use and land cover (LULC) classes, the spatial and temporal distribution of carbon stock and changes in LULC and from deforestation and forest degradation over time. However, studies that have evaluated the spatial distribution of carbon in Ghana (Tan et al., 2009; Bessah et al., 2016; Nero et al., 2016) did not consider the emission/removal from land use and land cover change. Savannah landscape represents more than 50% of the size of Ghana (Callo-cona et al., 2012) but deforestation and forest degradation contribution to its carbon dioxide emission and removal still remain underestimated. That is, carbon dioxide emissions and removals due to savannah vegetation degradation and deforestation is necessary in enhancing and contributing to the decisions of policy-makers. Therefore, this study seeks to estimate historical changes of $CO_2$ emission and removal from land use and land cover change and from deforestation and forest degradation in Sudan Savannah ecological zone of Ghana.

## 2. Material and Method

### *2.1 Study Area*

The study was carried out in the Sudan savannah ecological zone of Ghana notably Bawku Municipality, Binduri Garu and Pusiga Districts. The four areas were included in the traditional Bawku East (Ghana Statistical Service, 2012). The study site lies between latitudes

10º15 and 11º15 North and longitudes 0º03 East and -0º23 West. It shares boundaries with Burkina Faso to the north, the Republic of Togo to the east and Bawku West and East Mamprusi to the west and south, respectively (Figure 1).

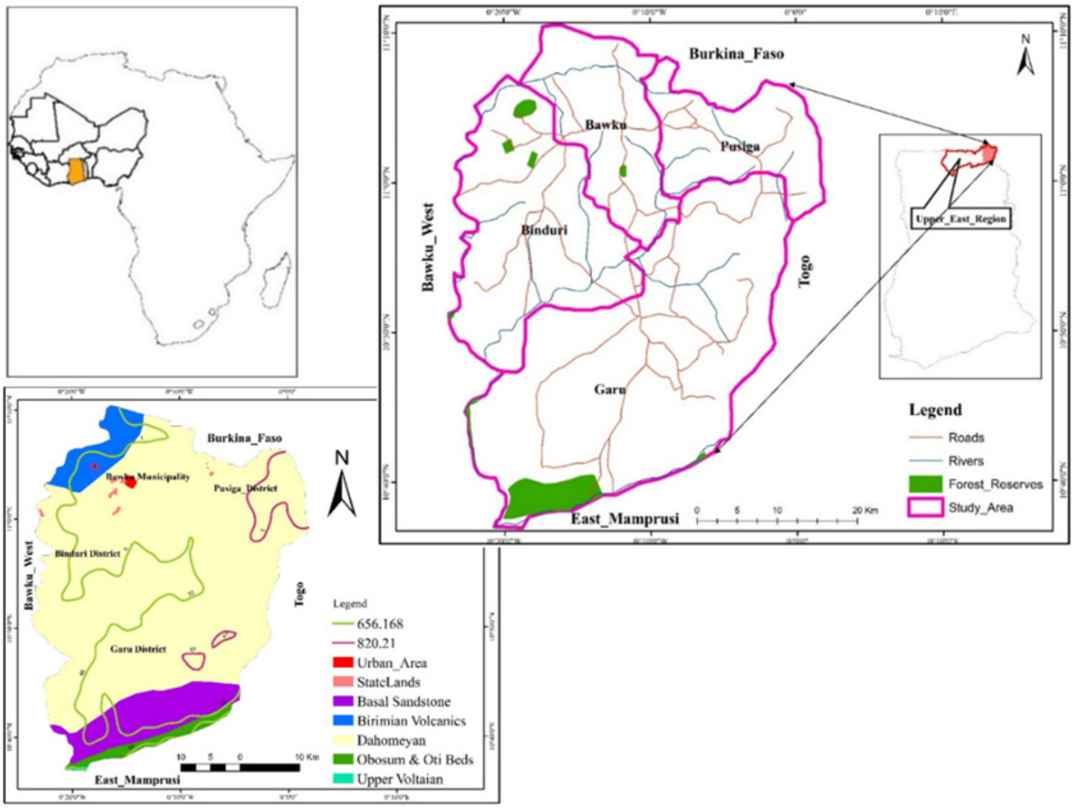



Figure 1. Map of Ghana (Africa) showing the location of the study site

Fire is an integral part of the vegetation management in our study area (Yiran, et al., 2012). The vegetation in Sudan savannah is characterised by grasses and scattered trees. The climate in the study area is characterised by a short rainy season from May/June to September/October and a long dry season from October/November to April/May (Kusimi & Yiran, 2011). The sum annual rainfall is between 800 to 1100 mm and the monthly mean temperature is 25°C as minimum and 40°C as maximum (Dickinson et al., 2017). The soil is mainly "upland soil" developed from granitic rock and soils are exposed to erosion, through rain and win (Aniah, Wedam, Pukunyiem, & Yinimi, 2013). Rolling land with isolated uplands and slopes ranging from 1 to 10%, characterised the topography of the study site. The soil is mainly "upland soil" developed from granite rocks. Bare soils are exposed to erosion through erosion agent such as rain and wing (Aniah et al.,2013). White Volta constitutes the main river. The total population is about 347,794 inhabitants (Ghana Statistical Service, 2012) where around 80% live in rural areas and, are engage in the agriculture for subsistence crop production (GSS, 2002). The study area is characterised by over-cultivation, overgrazing, settlement expansion and increase of firewood production and consumption (GSS, 2002).

*2.2 Emission Factor*

Each of the four areas (Bawku, Binduri, Garu and Pusiga) in the study area stratified into forest, cropland/farmland (near to settlement) and shrub/grassland LULC classes. Three sites were selected in each of the four areas and in each site, three sample plots were established in each of the three LULC classes. Nested design (Figure 1) adopted from RAINFOR protocol (Marthews et al., 2012) was employed for the field inventory.

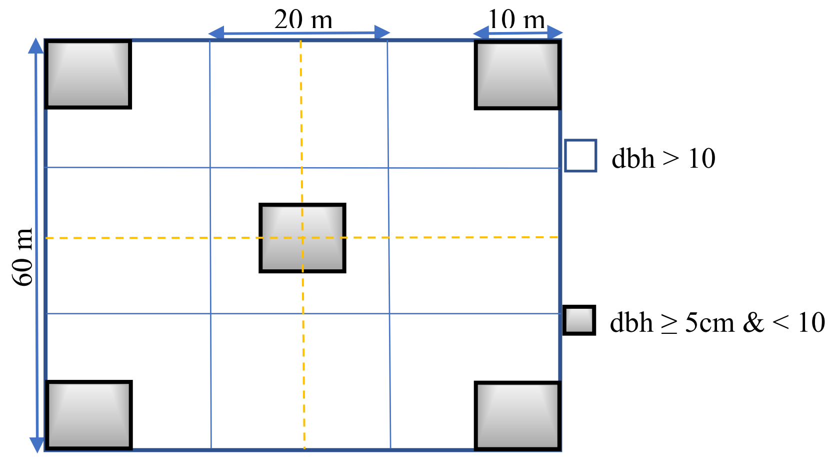



Figure 2. Plot demarcation of the field inventory (Source: Marthews et al., 2012)

The size of the main plot was 60 m × 60 m (0.36 ha) and this was divided into nine subplots with the size of 20 m × 20 m. Within the main plot, five smaller plots of size 10 m × 10 m were established in the four corners and the middle. Coordinates were taken at the four corners and the middle of the main plot using Global Positioning System (GPS). Trees with diameter at breast height (dbh) of 1.30 m greater than or equal to 10 cm were tagged in the main plot. While for 10 m × 10 m, tree with diameter between 5 cm and 10 cm (5 cm ≥ diameter < 10 cm) were considered. It the inventory, tree diameter at breast height (dbh), was measured with diameter tape, tree height measured with the Laser Ace (Height measuring instrument) and tree species identified, as a surrogate for wood density. The Allometric models developed by Aabeyir (2016) for savannah woodland was found to be the most appropriate existing allometric equation for this work due to its similarity in climatic, edaphic, geographic, taxonomic condition and trees species. The following equation is given as

$$AGB = 0.0580\ (\rho d_{bh}{}^{2} H)^{0.9991} \quad (1)$$

Here, AGB is aboveground biomass, dbh (cm) is the diameter at breast height, ρ ($gcm^{-3}$) is the density of a tree species and, H (m) is the total height of the individual tree.

Carbon content analysed in Ghana per Adu-Bredu et al. (2010), is used to estimate the carbon content (47.48%) of biomass.

The difference between the mean carbon stocks from different LULC classes (e.g. forest mean carbon stocks minus cropland mean carbon stocks) was used to calculate the emission factors. The forest and cropland of Bawku and the shrub/grassland of Garu were used as reference for emission factors determination. The emission factor is expressed in terms of $CO_2$ equivalent by converting the change in carbon to $CO_2$ equivalent as (IPCC, 2006).

$$EF = (\Delta C_G - \Delta C_L) \times \frac{44}{12} \quad (2)$$

Where, EF is the Emission Factor (tCO2-e-ha-1, $\Delta C_G$ and $\Delta C_L$ is the carbon stocks gains and lost, respectively

*2.3 Activity Data*

Tier 3 approach (IPCC, 2006) was used to estimate to estimate activity data. To classify land use and land cover, Random forest algorithm was applied using the open source R-software. At each node, the variables tried for splitting was set through the square root of the total number. Indicators such as overall accuracy, producer and user accuracy were calculated. Post classification comparison was applied to detect the change from one LULC class to another. Changes were estimated from 1986 to 1999, 1999 to 2006, 2006 to 2016 and 1986 to 2016.

The carbon dioxide emission is characterised by the combination of emission factor (EF) and activity data (AD). Carbon dioxide emission/removal is estimated as (IPCC, 2006)

$$\Delta C = EF \times AD \quad (3)$$

Carbon Dioxide Emission/Removal Uncertainty Assessment

The percentage of uncertainty was calculated for the 95% Confidence Interval through Equation adapted from IPCC, 2000 as:

$$U = \left(\frac{2 \times \sigma}{\mu}\right) \times 100 \quad (4)$$

Where, $U$ is the percentage uncertainty, $\sigma$ is the standard deviation $\mu$ is the mean of the distribution

**3. Results**

The results illustrated in Table 5 showed that the greatest emission factor under different LULC and for different District was the conversion of forest and/or cropland to shrub/grassland in Pusiga District. The second largest emission factor was recorded in the forest land remaining forest land in Pusiga District. Emission factor for deforestation was prominent for forest than the other LULC in all the Districts (Table 1). This was followed by cropland with the least being shrub/grassland. Emission factor uncertainty was estimated using the 95% Confidence interval through the overall mean and the standard deviation (Table 2).

Table 1. Emission factor estimated from different LULC classes and different Districts

| Area | LULC | Carbon stocks | Change from to | Emission factor (Mg $CO_2ha^{-1}$) |
|---|---|---|---|---|
| Bawku | Forest | 4.50 | Forest to cropland | 0.21 |
| | Cropland | 4.46 | Forest to shrub/grassland | 2.27 |
| | Shrub/grassland | 1.18 | Cropland to forest | -0.21 |
| | | | Cropland to shrub/grassland | 12.06 |
| | | | Shrub/grassland to forest | -12.27 |
| | | | Shrub/grassland to cropland | -12.06 |
| | | | Shrub/grassland to shrub/grassland | 1.23 |
| Binduri | Forest | 1.32 | Forest to cropland | 9.58 |
| | Cropland | 1.91 | Forest to shrub/grassland | 13.38 |
| | Shrub/grassland | 0.87 | Cropland to forest | -9.58 |
| | | | Cropland to shrub/grassland | 1.46 |
| | | | Shrub/grassland to forest | -13.38 |
| | | | Shrub/grassland to cropland | -1.46 |
| | | | Forest to forest | 1.73 |
| | | | Cropland to cropland | 9.37 |
| | | | Shrub/grassland to shrub/grassland | 2.34 |
| Garu | Forest | 1.72 | Forest to cropland | 7.30 |
| | Cropland | 2.53 | Forest to shrub/grassland | 0.82 |
| | Shrub/grassland | 2.51 | Cropland to forest | -7.30 |
| | | | Cropland to shrub/grassland | 10.83 |
| | | | Shrub/grassland to forest | -0.82 |
| | | | Shrub/grassland to cropland | -10.83 |
| | | | Forest to forest | 10.29 |
| | | | Cropland to cropland | 7.09 |
| | | | Shrub/grassland to shrub/grassland | 1.23 |
| Pusiga | Forest | 0.64 | Forest to cropland | 8.87 |
| | Cropland | 2.10 | Forest to shrub/grassland | 16.48 |
| | Shrub/grassland | 0.03 | Cropland to forest | -8.87 |

| | |
|---|---|
| Cropland to shrub/grassland | 16.27 |
| Shrub/grassland to forest | -16.48 |
| Shrub/grassland | -16.27 |
| Forest to forest | 14.22 |
| Cropland to cropland | 8.66 |
| Shrub/grassland to shrub/grassland | 5.44 |

Table 2. Uncertainty of mean emission factors

| LULC | Mean | StDev | 95% CI |
|---|---|---|---|
| Cropland to forest | 2.56 | 2.05 | (0.71, 4.41) |
| Cropland to shrub/grassland | 6.79 | 3.51 | (4.94, 8.64) |
| Forest to shrub/grassland | 4.23 | 4.81 | (2.37, 6.08) |
| Forest to cropland | -2.56 | 2.05 | (-4.41, 0.71) |
| Shrub/grassland to cropland | -6.79 | 3.51 | (-8.64, -4.94) |
| Shrub/grassland to forest | -4.23 | 4.81 | (-6.08, -2.37) |
| Forest to forest | 9.06 | 5.59 | (7.21, 10.91) |
| Cropland to cropland | 6.27 | 3.83 | (4.41, 8.12) |
| Shrub/grassland to shrub/grassland | 1.19 | 0.87 | (-0.06, 3.04) |

Note: StDev = Standard deviation, CI = Confidence interval

### *3.1 Activity Data*

The three-land use and land cover classes that were considered are forest, cropland and shrub/grassland. The outcome illustrated in Table 3 shows that the forest area which has undergone degradation was more than the area that has undergone deforestation. Activities data uncertainty was estimated using the 95% Confidence interval through the overall mean and the standard deviation (Table 4).

Table 3. Emission factors from land use and land cover change

| Years | LULC Change | Bawku | Binduri | Garu | Pusiga |
|---|---|---|---|---|---|
| 1986-1999 | Forest to cropland | 351.09 | 157.32 | 75.87 | 245.23 |
| | Forest to shrub/grassland | 2598.57 | 3111.10 | 9336.78 | 2805.21 |
| | Cropland to forest | 49.53 | 21.51 | 42.57 | 0.09 |
| | Cropland to shrub/grassland | 3141.45 | 250.06 | 1529.10 | 914.09 |

| | | | | | |
|---|---|---|---|---|---|
| | Shrub/grassland to forest | 338.49 | 904.95 | 6849.72 | 162.27 |
| | Shrub/grassland to cropland | 2199.69 | 1058.22 | 5068.80 | 1406.52 |
| | Forest to forest | 521.25 | 4120.00 | 14167.80 | 485.19 |
| | Cropland to cropland | 1853.17 | 3363.48 | 3295.99 | 1610.92 |
| | Shrub/grassland to shrub/grassland | 5031.00 | 10635.82 | 18546.21 | 16609.59 |
| 1999-2006 | Forest to cropland | 1405.00 | 42.75 | 8.64 | 71.02 |
| | Forest to shrub/grassland | 539.55 | 2772.72 | 7436.30 | 554.58 |
| | Cropland to forest | 3.69 | 6.48 | 9.72 | 0.09 |
| | Cropland to shrub/grassland | 2658.69 | 2057.31 | 4548.10 | 1760.94 |
| | Shrub/grassland to forest | 121.77 | 1510.55 | 5131.00 | 137.88 |
| | Shrub/grassland to cropland | 2772.36 | 897.48 | 1566.00 | 632.34 |
| | Forest to forest | 95.23 | 1206.78 | 13503.00 | 85.41 |
| | Cropland to cropland | 1954.27 | 1490.75 | 3849.60 | 1520.19 |
| | Shrub/grassland to shrub/grassland | 6188.13 | 9869.33 | 18956.45 | 19276.11 |
| 2006-2016 | Forest to cropland | 0.90 | 0.00 | 51.39 | 2.34 |
| | Forest to shrub/grassland | 132.00 | 21.56.31 | 9722.50 | 2.34 |
| | Cropland to forest | 0.27 | 0.18 | 0.00 | 0.00 |
| | Cropland to shrub/grassland | 631.62 | 988.83 | 302.67 | 138.15 |
| | Shrub/grassland to forest | 175.77 | 1833.84 | 2618.60 | 4.23 |
| | Shrub/grassland to cropland | 1348.23 | 2003.85 | 16295.00 | 9472.68 |
| | Forest to forest | 12.21 | 4556.25 | 8856.27 | 0.81 |
| | Cropland to cropland | 1553.28 | 2188.62 | 5119.47 | 1991.61 |
| | Shrub/grassland to shrub/grassland | 6679.44 | 35561.80 | 1156.68 | 12017.88 |
| 1986-2016 | Forest to cropland | 1642.95 | 213.21 | 794.89 | 1644.60 |
| | Forest to shrub/grassland | 1341.90 | 7175.50 | 15458.40 | 1644.60 |
| | Cropland to forest | 3.42 | 38.07 | 5.13 | 0.00 |
| | Cropland to shrub/grassland | 932.04 | 1319.70 | 1266.48 | 320.40 |
| | Shrub/grassland to forest | 149.49 | 2315.30 | 4071.87 | 0.00 |
| | Shrub/grassland to cropland | 4573.07 | 2929.60 | 17136.20 | 4648.65 |
| | Forest to forest | 7.24 | 4032.20 | 7395.57 | 5.04 |
| | Cropland to cropland | 2576.25 | 2668.70 | 3590.82 | 2194.38 |
| | Shrub/grassland to shrub/grassland | 8833.86 | 28627.00 | 0.00 | 10150.83 |

Table 4. Uncertainty of mean activity data

| LULC change | Mean | StDev | 95% CI |
|---|---|---|---|
| Cropland to forest | 10.74 | 17.18 | (-4428, 4249) |
| Cropland to shrub/grassland | 2190 | 1517 | (-2049, 6429) |
| Forest to shrub/grassland | 6187 | 7677 | (1948, 10426) |
| Forest to cropland | 438 | 578 | (-3801, 4677) |
| Shrub/grassland to cropland | 3667 | 4698 | (-572, 7906) |
| Shrub/grassland to forest | 1385 | 1988 | (-2854, 5624) |
| Forest to forest | 4131 | 4577 | (-108, 8370) |
| Cropland to cropland | 2796 | 1418 | (-1443, 7035) |
| Shrub/grassland to shrub/grassland | 13639 | 23474 | (9400, 17878) |

Note: StDev = Standard deviation; CI = Confidence Interval

### *3.2 Carbon Dioxide Emission and Removal from Land use and Land Changes*

The outcomes are presented in Table 5 and 6, and Figure 3A, 3B, 3C and 3D. The spatial distribution of $CO_2$ emissions and removals from land use and land cover changes exhibited important changes within LULC categories, Districts and within years. From 1986 to 2016, the overall $CO_2$ emitted and removed from deforestation in the Sudan savannah ecological zone of Ghana was 228,805.99 Mg $CO_2$ or 31.84% and -163,956.93 Mg $CO_2$ or 22.81%, respectively. The total $CO_2$ released from forest degradation was 325,878.96 Mg $CO_2$ or 45.35% of the total $CO_2$ emissions. Meanwhile, at District level, the highest $CO_2$ released was observed in Binduri (16.35%) and Pusiga (7.10%). The most important value of $CO_2$ released from forest degradation was found in Binduri (19.38%) and Garu (14.13%). However, Garu was the main sink of carbon with 9.36% as removal value, followed by Bawku 7.93%. In the years 1986 and 1999; the total $CO_2$ emission and removal from deforestation were as follows: 233,179.90 Mg $CO_2$ (33.71%) and -67,482.11 Mg $CO_2$ or 9.75%, respectively. The $CO_2$ emission from forest degradation was 391,162.11 Mg $CO_2$ or 56.54% of the total $CO_2$ released. The largest contribution of $CO_2$ emission from deforestation was found in Binduri and Bawku being 11.13% and 10.10%, respectively. While the most important rate of $CO_2$ released was observed in Garu and Pusiga with 24.45% and 16.06%, respectively. Focused on the removal values, Bawku and Garu were the major carbon sink with 4.44% and 3.49%, respectively. From 1999 to 2006, the total $CO_2$ emitted from deforestation was 198,050.86 Mg $CO_2$ or 33.22% and, the removal was 51,111.47 Mg $CO_2$ or 8.57% whereas the $CO_2$ emission from forest degradation was 347,074.67 Mg $CO_2$ or 58.21%. However, the most substantial rate of carbon emitted was observed in Binduri (11.02%) and Bawku (6.54%). The highest contribution for $CO_2$ emission from forest degradation was noticed in Garu and Pusiga being 28.37% and 19.98%. Meanwhile, Bawku and Garu were found to be the main sink of carbon with 5.86% and 1.63%, respectively.

During the past decade (2006-2016), the $CO_2$ released from deforestation in the entire District was 69,950.01 Mg $CO_2$ or 11.62% and the removal was 156,518.43 Mg $CO_2$ or 26.01%. The amount of $CO_2$ emitted from forest degradation was 375,292.16 Mg $CO_2$ or 62.37%. at the District level, the greatest emission from deforestation was found in Binduri (7.17%) and Garu (1.93%). In addition, the most important emission from forest degradation was recorded in Binduri and Garu being 26.11% and 21.17%, respectively. The largest rate of $CO_2$ removal was noticed in Pusiga and Garu with -11.99% and 10.48%, respectively. In general, more emissions were observed from forest degradation compared to deforestation.

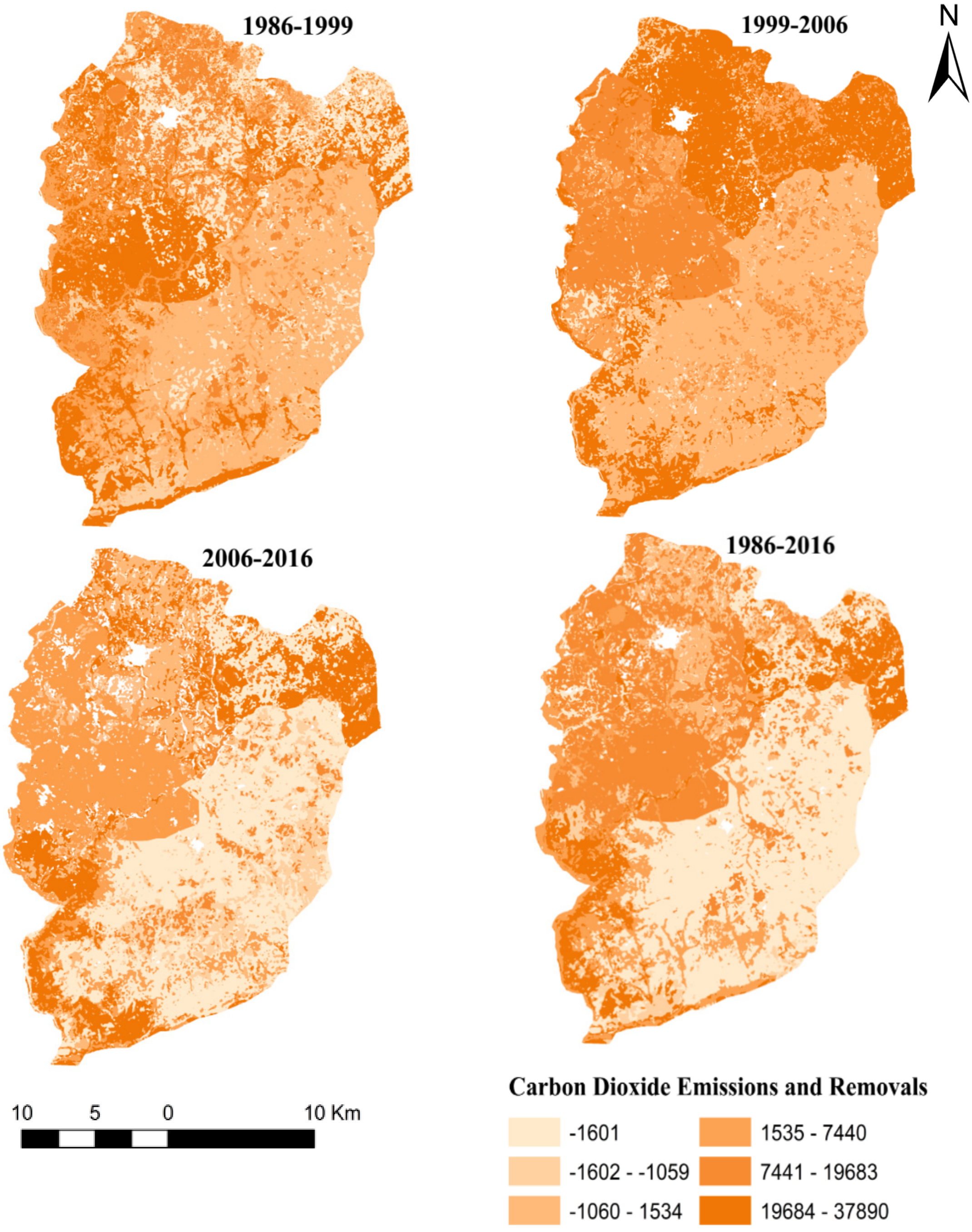
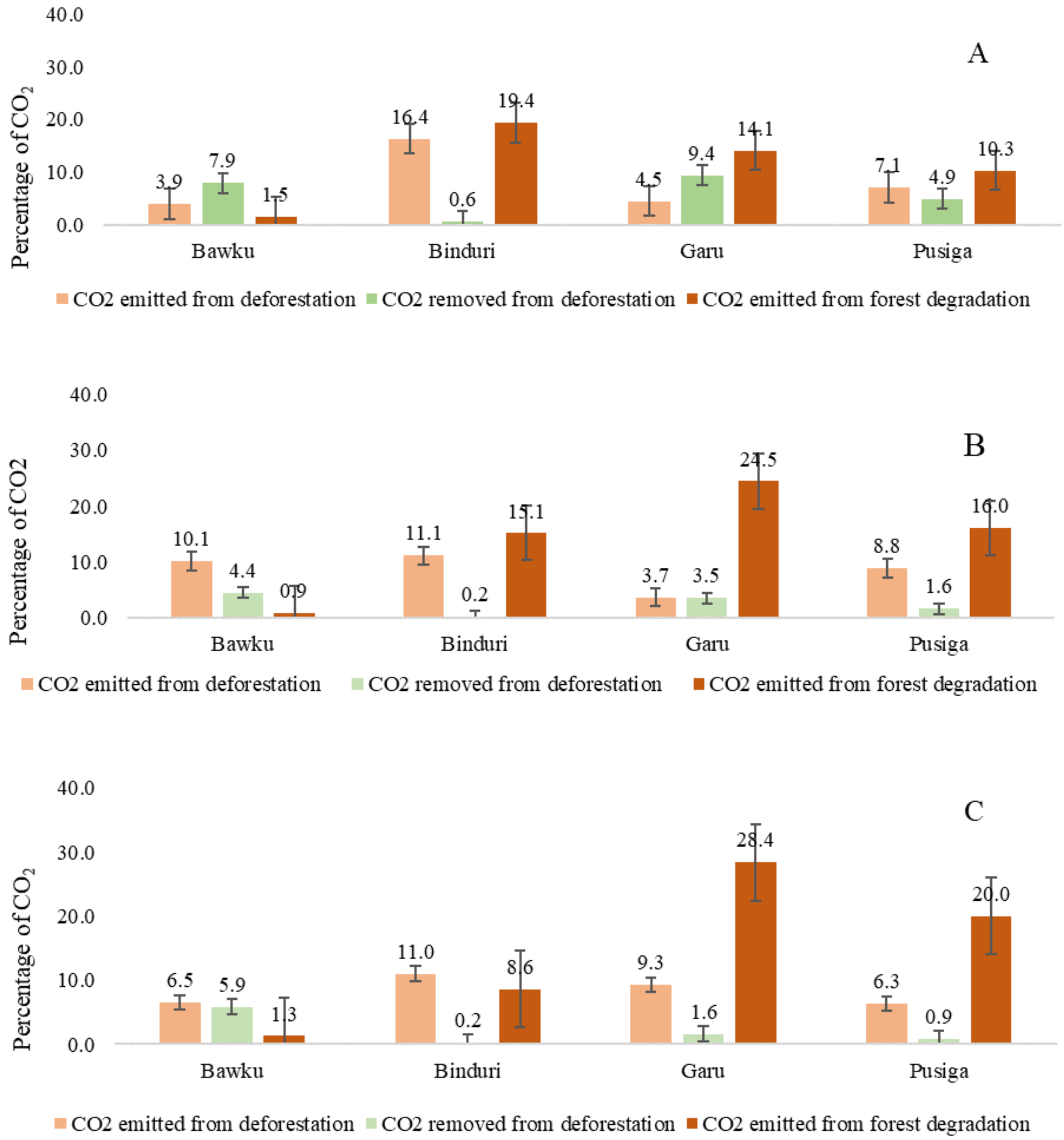



Figure 2. Maps showing the density of $CO_2$ emission/removal

Table 5. $CO_2$ emission and removal from land use and land cover change proportion

| Years | $CO_2$ emission from deforestation | | $CO_2$ removal from deforestation | | $CO_2$ emission from degradation | |
|---|---|---|---|---|---|---|
| | Mg $CO_2$ | % | Mg $CO_2$ | % | Mg $CO_2$ | % |
| 1986-1999 | 233,179.90 | 33.71 | 67,482.11 | 9.75 | 391,162.88 | 56.54 |
| 1999-2006 | 198,050.53 | 33.22 | 51,111.47 | 8.57 | 347,074.67 | 58.21 |
| 2006-2016 | 69,950.01 | 11.62 | 156,518.43 | 26.01 | 375,292.16 | 62.37 |
| Overall (1986-2016) | 228,805.99 | 31.84 | 163,956.93 | 22.81 | 325,878.96 | 45.35 |



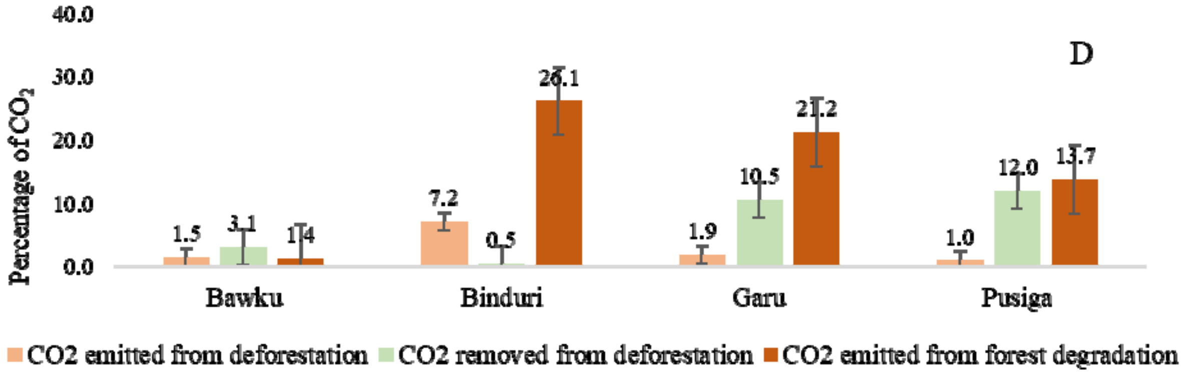



Figure 3. percentage of $CO_2$ emitted and removed at District level from 1986 to 2016 (A), 1986 to 1999 (B), 1999 to 2006 (C) and 2006 to 2016 (D)

Table 6. Uncertainty of mean $CO_2$ emission/removal

| | | Mean | StDev | 95% CI |
|---|---|---|---|---|
| Year | 1986-1999 | 7315 | 23719 | (-2766, 17396) |
| | 1999-2006 | 8373 | 25821 | (-1708, 18454) |
| | 2006-2016 | 10302 | 27249 | (221, 20382) |
| | 1986-2016 | 1187 | 424261 | (1797, 21958) |
| District | Bawku | 3830 | 13703 | (-6071, 13732) |
| | Binduri | 17884 | 40371 | 7983, 27285) |
| | Garu | 12216 | 41291 | (2314, 22117) |
| | Pusiga | 3937 | 9441 | (-5964, 13838) |

Note: StDev = Standard deviation; CI = Confidence Interval.

## 4. Discussion

During the past 30 years, the amount of carbon dioxide released to the atmosphere showed a decrease from 1986 to 2016. The overall carbon dioxide released from deforestation and forest degradation was 77.19% whereas, the removal was 22.81% with considerable uncertainties due to the spatial and temporal variability of the emission/removal. Regarding the inter-annual changes, similar decrease was observed in terms of amount from 1986 to 1999 and 1999 to 2006 being 642,342.79 and 545,125.53 Mg $CO_2$, respectively. These decreases observed in the Sudan Savannah ecological zone of Ghana could be related to the implementation of REDD+ in the area. On the contrary in terms of percentage, an increase was noticed being 90.25% and 91.00% from 1986 to 1999 and 1999 to 2006, respectively. During the past period (2006-2016), the amount of 445,142.17 Mg$CO_2$, as well as the rate of 71.00% of $CO_2$ emission have decreased compared to the previous years. Results obtained from $CO_2$ emissions are in agreement with the outcome of Friedlingstein et al (2010), who revised and updated the historical CO2 emissions at global level using new data on forest cover and land use (reported by each country and compiled by the Food and Agriculture Organisation (FAO). They found that $CO_2$ emission from land use change (LUC) has decreased from 1999s compared to 200-2009 with 1.5±0.7 Pg $Cyr^{-1}$ to 1.1±Pg $Cyr^{-1}$, respectively. For $CO_2$ removal, from 1986 to 1999 and 1999 to 2006, there was an increase from 67,482.11 to 51,111.47 Mg $CO_2$, but in terms of proportion, it has observed a reduction from 8.57% to 9.75%. however, during the past decade (2006-2016), the amount of $CO_2$ removed as well as the proportion were 156,518.43 Mg $CO_2$, with a contribution of 26.01%. This decrease observed in $CO_2$ emission and increase noticed in the removal could be attributed to the increase of cropland areas. Through the emission factors (EF) estimation, it was observed that there was removal when shrub/grassland are converted to cropland and/or forest land. Whereas focused on activities data the conversion rate of shrub/grassland to cropland increased from 1986 to 2016. Cropland contribution was found to be significant in $CO_2$ emission/removal in the Sudan Savannah zone of Ghana. This may be attributed to the importance of tree on farm for farmers and also cropland selected in the work was near to settlements. This results in in agreement with Sarkodie and Owusu (2017) and Kim et al. (2016). In the entire area and all years, the carbon released from forest degradation was greater than the one from deforestation. However, less studies have compared the emission from forest degradation and deforestation in Ghana. Nevertheless, in Venezuela, Pacheco-angulo et al. (2017) estimated the $CO_2$ emission from deforestation and forest degradation and found that the carbon emitted from deforestation was greater compared to the forest degradation in Caparo forest reserve. This difference could be explained by the type of vegetation. Their study was done in Caparo forest reserve of Venezuela whereas, the present study is carried out in the Sudan Savannah zone of Ghana in West Africa. Moreover, it was noticed that the highest positive value of emission factors was found in forest degraded areas, and extend of forest degraded areas was larger than that of deforested areas. This could explain the highest value observed fore forest degradation. In the country, the most important negative emission factor was found in the area where shrub/grassland were converted to cropland and/or forest land cover. This may be related to the difference of carbon mean in cropland, forest and shrub/grassland where the most important value was observed in cropland, followed by forest land and shrub/grassland.

## 5. Conclusion

The present study carried out in Sudan Savannah ecological zone of Ghana, estimated and mapped the historical change of the carbon dioxide emission from land use and land cover change. Based on the results, significant changes occurred in the study area from 1986 to 2016. The total carbon dioxide emitted from 1986 to 2016 in the entire area was 554,684.96 Mg $CO_2$ or 77.1 while the removal was 163,956.93 Mg $CO_2$ or 31.84%. The activity data generated from land use and land cover map indicated that areas degraded were greater than the areas that were deforested where the largest emission factor was found in forest degradation. Thus, the proportion of $CO_2$ emission from forest degradation (45.35%) was greater than the deforestation (31.84%). Based on the spatial distribution, Garu District (16.35%) was found to be the main sink of carbon because shrub/grassland emission factor of

Garu District has been used as reference to estimate the $CO_2$ of shrub/grassland in the other Districts. On the other hand, the highest amount of $CO_2$ emission was identified in Binduri (9.36%) because the most important value of $CO_2$ released from the forest degradation was found in Binduri. The historical mapping of $CO_2$ emission/removal from LULC and from deforestation and forest degradation is expected to improve the decision of policy makers on mitigation, and for sustainable development. However, future investigation needs to consider the five carbon pools and the six-land use and land cover classes provided by IPCC to quantify the current and future $CO_2$ emission and removal.

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## Reference

Aabeyir, R. (2016). Charcoal production and its implication for woodland degradation and climate change in the Forest-Savannah Transition Zone of Ghana: the case of Kintampo Municipality. *PhD. Climate Change and Land Use. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*, (May), 1–190.

Aabeyir, R., Adu-bredu, S., Agyei, W., & Weir, M. J. C. (2016). Energy for Sustainable Development Empirical evidence of the impact of commercial charcoal production on Woodland in the Forest-Savannah transition zone , Ghana. *Energy for Sustainable Development*, *33*, 84-95. https://doi.org/10.1016/j.esd.2016.03.005

Adu-Bredu S, Abekoe M. K, Tachie-Obeng E, T. P. (2010). Carbon Stock under Four Land-Use Systems in Three Varied Ecological Zones in Ghana. Africa and the Carbon Cycle: in Proceedings of the Open Science Conference on "Africa and Carbon Cycle: the CarboAfrica project". *WORLD SOIL RESOURCES REPORTS. FAO*, (November), 105-113.

Aniah, P., Wedam, E., Pukunyiem, M., & Yinimi, G. (2013). Erosion And Livelihood Change In North East Ghana : A Look Into The Bowl. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, *7 (1)*, 28–35.

Bessah, E., Bala, A., Agodzo, S. K., & Okhimamhe, A. A. (2016). Dynamics of soil organic carbon stocks in the Guinea savanna and transition agro-ecology under different land-use systems in Ghana. *Cogent Geoscience*, *2*(1), 1-11. https://doi.org/10.1080/23312041.2016.1140319

Callo-concha, C., Gaiser, T., & Ewert, F. (2012). Farming and cropping systems in the West African Sudanian Savanna. *Working Paper Series, 100*, (August), 1-32.

Deng, S., Shi, Y., Jin, Y., & Wang, L. (2011). A GIS-based approach for quantifying and mapping carbon sink and stock values of forest ecosystem : A case study. *Energy Procedia*, *5*, 1535-1545. https://doi.org/10.1016/j.egypro.2011.03.263

Dickinson, K. L., Monaghan, A. J., Rivera, I. J., Hu, L., Kanyomse, E., Alirigia, R., … Wiedinmyer, C. (2017). Changing weather and climate in Northern Ghana: comparison of local perceptions with meteorological and land cover data. *Regional Environmental Change*, *17*(3), 915-928. https://doi.org/10.1007/s10113-016-1082-4

FAO. (2014). Agriculture , Forestry and Other Land Use Emissions by Sources and Removals by Sinks 1990 – 2011 Analysis. In *ESS Working Paper No. 2, Mar 2014* (No. 2). Retrieved from http://www.fao.org/docrep/019/i3671e/i3671e.pdf

Friedlingstein, P., Houghton, R. A., Hole, W., & Conway, T. H. (2010). Update on CO2 emissions. *Nature Geoscience*, 4-6. https://doi.org/10.1038/ngeo1022

Ghana Statistical Service. (2012). *Population and Housing Census Final Results Ghana Statistical Service*. 1-11. Retrieved from http://www.statsghana.gov.gh/docfiles/2010phc/2010_POPULATION_AND_HOUSING_CENSUS_FINAL_RESULTS.pdf

Gizachew, B., Solberg, S., Næsset, E., Gobakken, T., Bollandsås, O. M., Breidenbach, J., … Mauya, E. W. (2016). Mapping and estimating the total living biomass and carbon in low - biomass woodlands using Landsat 8 CDR data. *Carbon Balance and Management*, *11*(13), 2-14. https://doi.org/10.1186/s13021-016-0055-8

Gómez, C., White, J.C., Wulder, M.A., A. (2014). Historical forest biomass dynamics modelled with Landsat spectral trajectories. *ISPRS Journal of Photogrammetry and Remote Sensing*, *93*, 14-28. https://doi.org/10.1016/j.isprsjprs.2014.03.008

Guo, M., Wang, X., Li, J., Yi, K., Zhong, G., & Tani, H. (2012). Assessment of Global Carbon Dioxide Concentration Using MODIS and GOSAT Data. *Open Access Sensors*, *12*, 16368-16389. https://doi.org/10.3390/s121216368

Houghton, R. A., & Hackler, J. L. (2006). Emissions of carbon from land use change in sub-Saharan Africa. *Journal of Geophysical Research*, *111*(January), 1-12. https://doi.org/10.1029/2005JG000076

Houghton, R. A., House, J. I., Pongratz, J., Van Der Werf, G. R., Defries, R. S., Hansen, M. C., … Ramankutty, N. (2012). Carbon emissions from land use and land-cover change. *Biogeosciences*, *9*, 5125-5142. https://doi.org/10.5194/bg-9-5125-2012

IPCC. (2006a). *IPCC Guidelines for National Greenhouse Gas Inventories: Agriculture Forestry and Other Land Use (Vol. 4)*. 1-21.

IPCC. (2014a). *Climate Change 2014: Mitigation of Climate Change. Summary for Policymakers and Technical Summary*. 1-161. https://doi.org/10.1017/CBO9781107415416.005

IPCC. (2014b). *Climate Change 2014 Synthesis Report Summary Chapter for Policymakers.* 1-31.

IPCC, 2006. (2006b). *Annexe 2: SUMMARY OF EQUATIONS*. Geneve.

Jian Zhao, c, Chunxiang Caob* and Peera Yomwana, c, D. (2012). Aboveground Shrub Biomass Estimation Based on Landsat Data in Mu Us Sandy Land, China. *Asian Conference on Remote Sensing*, 1-7.

Kim, D., Thomas, A. D., Pelster, D., Rosenstock, T. S., & Sanz-cobena, A. (2016). Greenhouse gas emissions from natural ecosystems and agricultural lands in sub-Saharan Africa : synthesis of available data and suggestions for further research. *Biogeosciences*, *13*, 4789-4809. https://doi.org/10.5194/bg-13-4789-2016

Kusimi, J. M., & Yiran, G. A. B. (2011). Application of Local Knowledge in Land Degradation Assessment in the Bawku East Municipality. *Ghana Journal of Geography*, *3*, 88-125.

Latake, P. T. (2015). The Greenhouse Effect and Its Impacts on Environment. *International Journal of Innovative Research and Creative Technology*, *1*(3), 333-337.

Mundava, C. (2015). *Estimating Above Ground Biomass using Remote Sensing in the Sub-Tropical Climate Zones of Australia Date :* Curtin University.

Nero, B., Callo-concha, D., Denich, M., & Borgemeister, C. (2016). *Urban green spaces and carbon sequestration in Kumasi, Ghana.* BOKU Vienna, Australia.

Nguyen, T. N. (2010). Estimation and mapping of above ground biomass for the assessment and mapping of carbon stocks in tropical forest using SAR data : a case study in Afram headwaters forest, Ghana. *PhD. Faculty of Geo-Information Science and Earth Observation*, 79. https://doi.org/Shelfmark 2010 THANH NGA

Pacheco-angulo, C., Vilanova, E., Aguado, I., Monjardin, S., & Martinez, S. (2017). Carbon Emissions from Deforestation and Degradation in a Forest Reserve in Venezuela between 1990 and 2015. *Forest*, *8*(291). https://doi.org/10.3390/f8080291

Rajendran, S., Nasir, S., & Kusky, T. M. (2014). Earth-Science Reviews Remote sensing based approach for mapping of CO 2 sequestered regions in Samail ophiolite massifs of the Sultanate of Oman. *Earth Science Reviews*, *135*, 122-140. https://doi.org/10.1016/j.earscirev.2014.04.004

Republic of Ghana. (2015). *National Greenhouse Gas Inventory Report Faculty of Geo-Information Science and Earth Observation*. 1-233.

Sarkodie, S. A., & Owusu, P. A. (2017). The relationship between carbon dioxide, crop and food production index in Ghana : By estimating the long-run elasticities and variance decomposition. *Environmental Engineers Resources*, *22*(2), 193-202. https://doi.org/10.4491/eer.2016.135

Shao, Z., & Zhang, L. (2016). Estimating forest aboveground biomass by combining optical and SAR data: A case study in genhe, inner Mongolia, China. *Sensors (Switzerland)*, *16*(6). https://doi.org/10.3390/s16060834

Tan, Z., Tieszen, L. L., Liu, S., Dieye, A. M., Falls, S., Observation, E. R., … Agency, P. (2009). Historical and simulated ecosystem carbon dynamics in Ghana : land use, management, and climate. *Biogeosciences*, *6*, 45-58. https://doi.org/10.5194/bg-6-45-2009

Toby R. Marthews, Daniel B. Metcalfe, Yadvinder Malhi, W. H. H. (2012). Measuring tropical forest carbon allocation and cycling. *Manual, Global Ecosystems*, *1*(2), 1-75.

Urbazaev, M., Thiel, C., Migliavacca, M., & Reichstein, M. (2016). Improved Multi-Sensor Satellite-Based Aboveground Biomass Estimation by Selecting Temporally Stable Forest Inventory Plots Using NDVI Time Series. *MDPI, Forest*, *7*(169), 2-16. https://doi.org/10.3390/f7080169

Yiran, G. A. B., Kusimi, J. M., & Kufogbe, S. K. (2012). A synthesis of remote sensing and local knowledge approaches in land degradation assessment in the Bawku East District, Ghana. *International Journal of Applied Earth Observation and Geoinformation*, *14*(1), 204-213.

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