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Livelihood, carbon and spatiotemporal land-use land-cover change in the Yenku forest reserve of Ghana, 2000–2020

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ABSTRACT

Tropical forests are important sources of securing basic human needs (livelihoods) for both the deprived and well-endowed but are also critical for reducing metric tonnes of carbon (tC) emitted from deforestation and land degradation. However, inequalities of human population and land-use land-cover change (LULCC) are existential threats to sustainable tropical forest reserve management and their aboveground biomass carbon stock (AGBCS) in Africa. This study examines the extent of LULCC, AGBCS and perception of livelihood effects on the Yenku Forest Reserve (YFR) in the Central Region of Ghana. Google Earth Engine remotely sensed Landsat data analysis using supervised classification, change detection, mixed with qualitative data from individual in-depth interviews and focus group discussions with inhabitants were used. The overall classification accuracy was 89.1%, 90.8% and 89.8% for the LULC in 2000, 2010 and 2020 respectively. Farming, charcoal production, hunting and harvesting non-timber forest products were the main livelihood activities impacting LULCC and AGBCS in the reserve. Open degraded forest was estimated at 1627ha, 1764ha, 1784ha out of 2293ha, corresponding to 36,349.6tC, 39,395.70tC, 39,840.0tC respectively in 2000, 2010 and 2020. Dense degraded forest cover yielded the least carbon stock of 938.6tC compared to 39,840.0tC from less dense degraded forest cover. These findings would aid policy decisions toward achieving United Nations land degradation neutrality and sustainable development goals (SDGs) one, ten and fifteen while ensuring YFR sustainability. Deprived forest-fringe communities, traditional authorities and other relevant stakeholders need to actively adopt gendered livelihood objectives to achieve SDGs, carbon and land degradation neutralities within YFR.

1. Introduction

Carbon neutrality and deforestation are major challenges of climate change mitigation and the United Nations (UN) Sustainable Development Goals (SDGs). About 1.2% of the world's tropical forest lands representing 21 million hectares, are destroyed annually through human livelihood development activities (FAO 2016). These anthropogenic activities release sequestered carbon (C) from the forest, which increases atmospheric carbon (CO_2), thereby exacerbating carbon emissions (CO_2e), global warming and climate change (CC) (Baccini et al. 2012; Rittenhouse and Rissman 2012). Rittenhouse and Rissman (2012) contend clearing forests correlates negatively with forest carbon stocks and positively with CO_2e. Africa accounts for 17% of the global forest lands (Hou Jones and Franks 2015). The anthropogenic land use land cover change (LULCC) constitutes 12.5% of the forest CO_2e (Friedlingstein et al. 2010; Houghton et al. 2012). Exploiting forest resources to secure livelihood objectives is well-known for causing deforestation and land degradation leading to land cover change (Baccini et al. 2012; Sobeng et al. 2018). Legal/illegal logging and agricultural activities caused 15.6 million hectares (ha) of Africa's forest land cover loss between 2010 and 2015 (Hou Jones and Franks 2015; FAO 2019).

Forest lands support more than 1.6 billion people's livelihoods (World Bank 2004; Sobeng et al. 2018). Some protected forest reserves appear crucial to the livelihoods of forest-fringe community dwellers, (Langat et al., 2016; Sobeng et al., 2018). While close to 90% of these forests support terrestrial biodiversity, about 90% of 1.2 billion

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residents in forest-fringe communities, live in extreme poverty less than one US$ per day (World Bank 2004). Therefore, sustainable management of forest reserves and livelihood activities in forest-fringe communities is essential in averting indiscriminate perturbation and deforestation CO_2e. Notably, for achieving the UN SDGs 1 (reduce poverty), 10 (gender equality) and 15 (life on land) as well as the carbon neutrality and land degradation neutrality (LDN) declarations toward climate change mitigation (Lal 2019).

In Ghana, one of the forest reserves in the Southern savanna dry forest zone under anthropogenic threat is the Yenku Forest Reserve (YFR). Dottey (2005), suggests human activities in the reserve have depleted essential forest resources and its sustainability is at risk with increasing population and urbanization. Some of the livelihood activities undertaken in the YFR are fetching fuelwood, illegal hunting, unstainable agricultural practices and charcoal production.

Managing the effects of livelihood activities on the YFR has become a Sisyphean task. Despite several restrictions governing the utilization of the forest resources, residents continue to exploit the resources due to limited alternative livelihoods (Amoah and Wiafe 2012; Cobbinah et al. 2015a). Although fringe community dwellers appreciate the need for conserving forest reserves, they cannot protect the forest when socio-economically constrained and have to rely on Non-timber Forest Products (NTFPs) for survival (Amoah and Wiafe 2012; Cobbinah et al. 2015a; Shackleton et al. 2015). Indigenes may be aware of illegal forest reserve activities but less concerned about the danger of such activities on YFR CO_2e and sustainability.

Reducing Emissions from Deforestation and Degradation (REDD+) necessitates local communities' participation (Forestry Commission 2015; Appiah et al. 2016). REDD+ is a financing mechanism of the United Nations Framework Convention on Climate Change UNFCCC) which is also linked to SDGs 13 and 15. The concept illustrates how forested African countries and donors traditionally engaged in forestry and agroforestry development finance by requiring proponents and stakeholders to demonstrate emissions reduction impacts for payments.

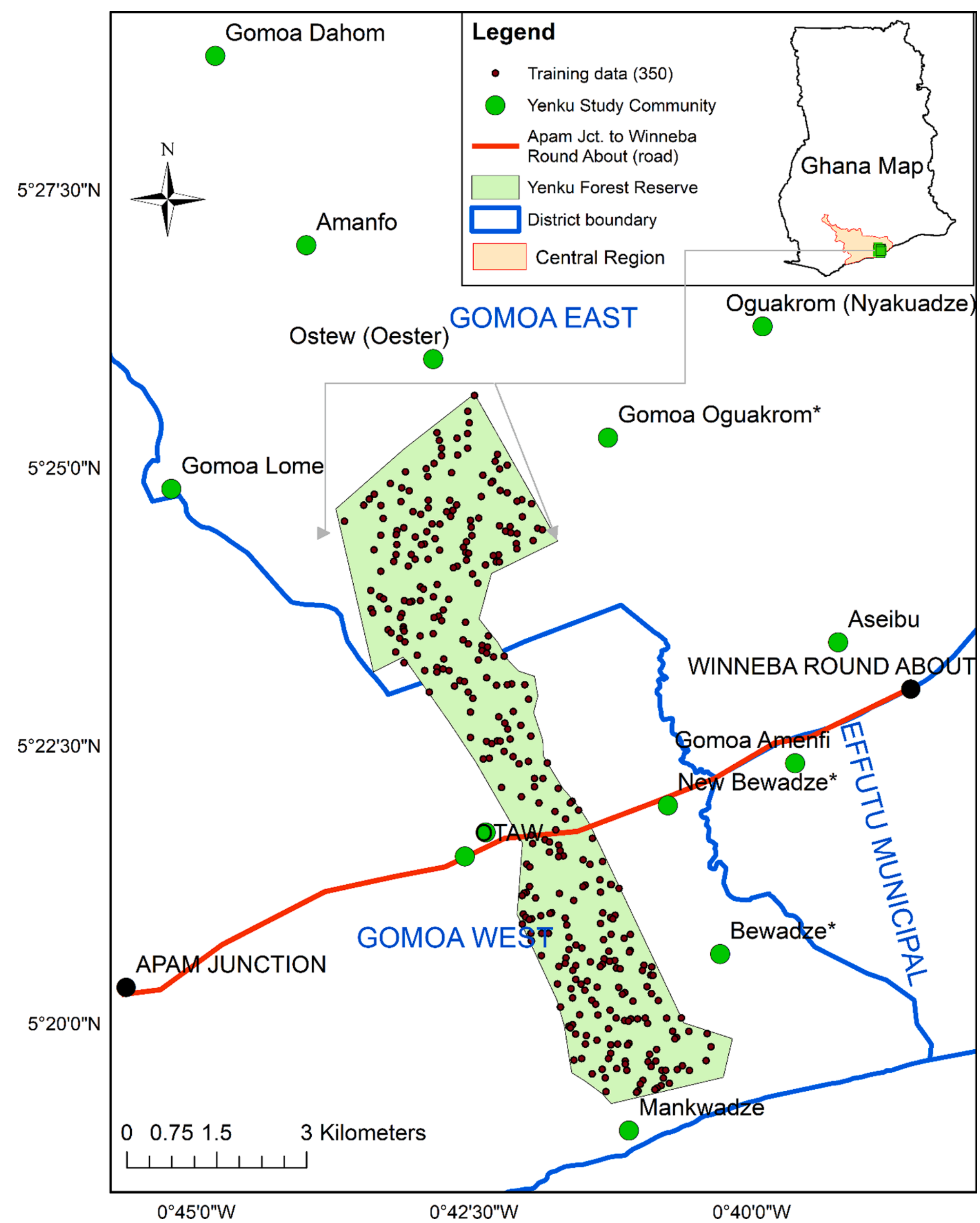


Fig. 1. Study area map showing the YFR in the Central Region (insert) of Ghana. Source: Authors' construct based on extracts from forest reserves and towns in Ghana.

Thus, it aims at reducing greenhouse gas (GHG) emissions from deforestation and forest degradation (Forestry Commission 2015; Appiah et al. 2016). Unlike REDD, REDD+ includes conservation, sustainable forest management (SFM) and forest carbon stocks enrichment. Ghana started to engage in REDD+ in 2008, as a multi-sectoral program promoting SFM for improved livelihoods and opportunities to increase forest cover (Forestry Commission 2015).

However, there is a little knowledge of indigenes' perception of the impact of their livelihood activities on the sustainability of the YFR. Furthermore, little is known about LULCC from 2000 to 2020 in the YFR. The present research, therefore, sought to examine the perception of the inhabitants of YFR fringe communities concerning threats posed by their activities on the reserve and carbon stock. Specifically, the study assessed the (1) magnitude, trends and rate of LULCC in the YFR; (2) effect of LULCC on carbon stock; (3) socio-economic characterization of the endowment of the inhabitants; (4) reasons for their continued livelihood activities in the reserve and (5) roles in YFR management in Ghana.

2. Methods

2.1. Study area

Fig. 1 shows the study area. The YFR is located within longitudes'$0^0$45′W and'$0^0$41′W and latitudes'$5^0$19′N and'$5^0$28′N. The area of the reserve is about 29.31km^2. It falls within the Effutu Municipality, Gomoa East and Gomoa West District Assemblies. It is managed by Winneba Forestry Service Division (FSD) of the Forestry Commission of Ghana as part of Forest Management Unit 29 under the SFM systems of Ghana. It was Gazetted as a forest reserve on 6th April 1940 under Forests Ordinance Cap 122 (WFD 2004; Dottey 2005).

The YFR has two primary vegetation types, the coastal savannah and semi-deciduous forest. The former consists mainly of grassland and short trees, patches of shrubs, while the latter is characterized by tall trees interspersed with grasses, shrubs, and soft woody species. There are two rainfall seasons, the major (April-July) and minor (September-November) rainy seasons (WFD 2004; Dottey 2005). The mean annual rainfall ranges between 70cm and 90cm in the southern coastal belt and 90cm to110cm in the northern and north-western semi-deciduous forest areas. The annual maximum and minimum temperatures of 29°C and 26°C occur in February-March and August, respectively. The forest livelihood activities are agroforestry (taungya), firewood cutting, charcoal production, hunting and farming (WFD 2004; Dottey 2005).

2.2. Theoretical framework: Land use and livelihood sustainability

This study is underpinned by land use and livelihood sustainability theories. In most rural settings, land is the primary means of livelihood (Scoones 1998). These theories elicit biophysical and perceived understandings of people's livelihood dynamics and effects on LULCC. The sustainable livelihood theory explains how people use their assets, capabilities (entitlements) to develop strategies for their survival amidst state policies, institutional framework and environmental occurrences (Chambers and Conway 1992).

Land use describes the management or activity to which people put a land cover (Doe et al. 2018) or the management within each land cover type (class) (Houghton et al. 2012). LULCC is the conversion from one land cover type to another. It is a biophysical process that alters forest land resources and ecosystem services, such as the magnitude of vegetative area and its carbon emission or sequestration potentials. Forested land size is directly proportional to the total metric tonnes of carbon emission (tCe) or otherwise sequestration. Nature and people define the rate of LULCC and its consequential effect on carbon sequestration or emissions, hydrological cycles, waste and pollution abatement, biodiversity, soil conservation and climate change (Verburg et al. 2019; Lal 2020).

Perception is "how something is regarded, understood and interpreted by people". The perception of fringe community dwellers is used to examine the effects of their livelihood activities on the YFR LULCC and the sustainability of the reserve. Sustainability is the use or management of resources to meet current needs without compromising the ability of future generations.

The sustainable livelihood framework (SLF) developed by the Institute of Sustainable Development (IDS) was adopted for this study because it captures the diverse components of sustainable rural livelihoods (Scoones 1998, Natarajan et al., 2022). The SLF shows how in different contexts, household livelihoods are achieved through access to a range of resources such as natural, economic, human and social capital in pursuit of different livelihood strategies and activities (Scoones 1998). The use of these resources is directly influenced by a structural process such as the laws and policies governing the management and use of land resources. SLF is defined by Scoones (1998) as human activities based on their assets, capabilities and entitlement required to achieve a basic standard of living; including their ability to cope with and recover from external stresses (policies) and shocks (climate, disaster) to their livelihood activities, without undermining the natural resource base and structures (Chambers and Conway 1992). The theory allows for a diverse aspect of livelihood activities to be inculcated into the examination and understanding of rural life and development out of poverty.

2.3. Study design

The study used exploratory mixed methods involving quantitative and qualitative data. Primary quantitative data, enabled socioeconomic description of the participants (N = 90, Female = 45, Male = 45). These participants came from nine (9) YFR fringe communities, namely Onyadze, Ostew-Jukwa, Mankoadze, Bewadze, Aseibu, Oguakrom, Gomoa Dahom, Amenfi and Gomoa Lome. As summarized in Fig. 2, preprocessed secondary quantitative data from remotely sensed Landsat data was applied for the spatiotemporal classification of land use-land cover (LULC) change and magnitude of carbon emission. These secondary data include Enhanced Thematic Mapper Plus (ETM+) Landsat 7 of 2000 and 2010 and Operational Land Imager (OLI) Landsat 8 of 2020 at 30 m × 30 m (pixel) resolution from Google Earth Engine (GEE). The imageries were acquired in February of each year, screened for less than 10–12 % cloud cover and haze.

The LULC classification was achieved using an automated supervised random forest classification algorithm, using GEE JavaScripts (Breiman 2001; Liaw and Wiener 2002; Gorelick et al. 2017). The GEE JavaScripts are available in supplementary material 1 in the online version of this paper. GEE offers widely accepted reproducible and effective means of large-scale spatial data analysis in the 21st century (Banerjee et al. 2021). Surface reflectance (level 2) of the LandSat image pixels (Chen et al. 2021) depicting five classes of the land cover types, aided quantification of each LULC type in hectares, using the random forest classifier. These LULC types are close (dense) degraded forest (close-df) and open (less dense) degraded forest (open-df). The rest are close (dense) grasses/herbaceous vegetation (close-ghv), open (less dense) grasses/herbaceous vegetation (open-ghv) and bare land surface.

Three Landsat datasets representing February of 2020, 2010 and 200 were used. Unlike temperature data which varies rapidly over short periods, rigidity of land cover data to short-term change allows LULCC trend analysis to use a few data points over long intervals. In China for example, Wu et al. (2021) classified urban LULCC in Wuhan using three Landsat data sets. Gao and Liu (2010) used only two Landsat images to detect trends of LULCC at 10-year intervals caused by soil salinization and waterlogging.

As demonstrated by Olofsson et al. (2014), Crowson et al. (2019) and Wu et al. (2021), training datasets (351 sites) for the supervised classifications were validated using key informants and visual assessment of unchanged pixel reflectance of the respective LULC types. In addition, the key informants confirmed the training data as semi-permanent like

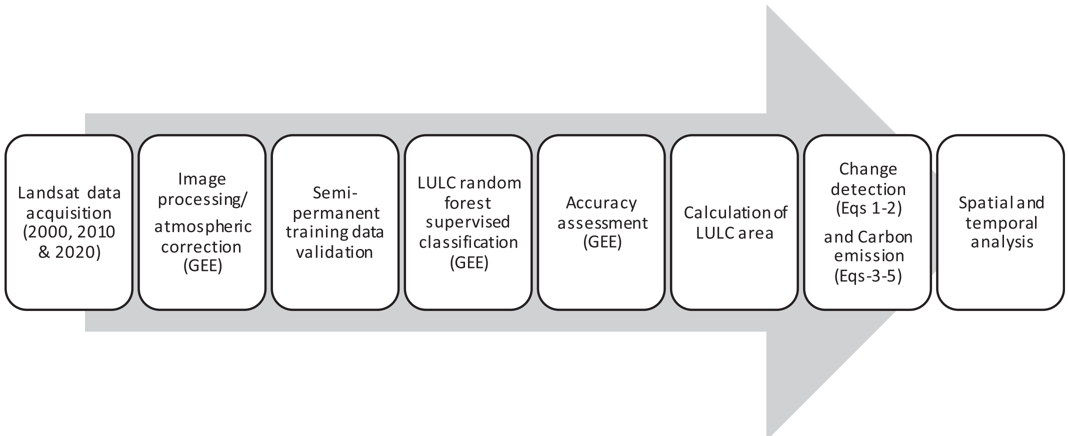


Fig. 2. Workflow of YFR LULC spatial and temporal changes and carbon emission.

rocky hills, sacred groves and bare lands that hardly changed during the study period, making them suitable for training the 2000, 2010 and 2020 LULC classifications. The use of these semi-permanent training data ensured parity in the classification process to permit comparisons of the classified images. For cross-validation purposes, ground-truthing of the sites was done where possible.

The classification accuracy of the 351 training data from different LULC types was examined using a confusion matrix following Olofsson et al., (2014). Please, refer to the confusion matrix results and training data available in the supplementary file online. For each LULC type, 40% of the training data were used as test samples and 60% as training samples to validate the accuracy of the classification. The accuracy of the classified LULC was tested using the confusion matrix to compare the predicted LULC types and the actual samples. The accuracy was also examined using expert knowledge and visual assessment.

Post-classification change detection was also conducted (Hassan et al. 2021). The magnitude and rate of change of each LULC type ($LULCC_{class\_i}$) were estimated following Doe et al., (2018) as expressed in equation (Eq.) one (1):

$$LULCC_{class\_i}(ha) = \frac{LULC_{class\_icurrentyear} - LULC_{class\_ipastyear}}{LULC_{class\_ipastyear}} \quad (1)$$

$$LULCC_{class\_i}(\%) = \frac{LULC_{class\_icurrentyear} - LULC_{class\_ipastyear}}{LULC_{class\_ipastyear}} * 100 \quad (2)$$

The computation was repeated for years 2000 to 2010, 2010 to 2020 and 2000 to 2020. Dividing each estimate by the observed time interval yields the annual rate of LULCC per land cover type (Doe et al. 2018).

In this study, a local carbon emission factor (EF) for the different categories of savanna forest vegetation (Forestry Commission 2017) enabled estimates of the vegetative carbon stock for each land cover type (Houghton et al. 2012; Goslee et al. 2014). The EF was obtained from the Ghana Forestry Commission provided in the refined 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines of 2019. The EF covers carbon stored in live and dead biomass such as trees, wood and litter, excluding soil carbon (Forestry Commission 2017). The default EF for LULCC of class "i" ($LULCC_{class\_i}$) such as the close savanna forest LULC type is 18.79tC ha^{-1} (EF_{class_i}) per year (Forestry Commission 2017). It is 22.34tC ha^{-1} for open savanna forest LULC type, 15.82tC ha^{-1} for grassland LULC type and 0.0tC ha^{-1} for bare land LULC type. Based on these EF values, the total carbon stock (TCS) for each LULC type was estimated (in tC) using equations (3)–(5).

$$TCS\ of\ LULC_{class_i} = Hectarage\ of\ LULC_{class_i} * EF_{class_i} \quad (3)$$

$$Change\ in\ TCS\ of\ LULC_{class_i} = LULCC_{class_i} * EF_{class_i} \quad (4)$$

$$Rate\ of\ change\ in\ TCS\ (tC/year) = \frac{LULCC_{class_i} * EF_{class_i}}{time\ interval} * 100 \quad (5)$$

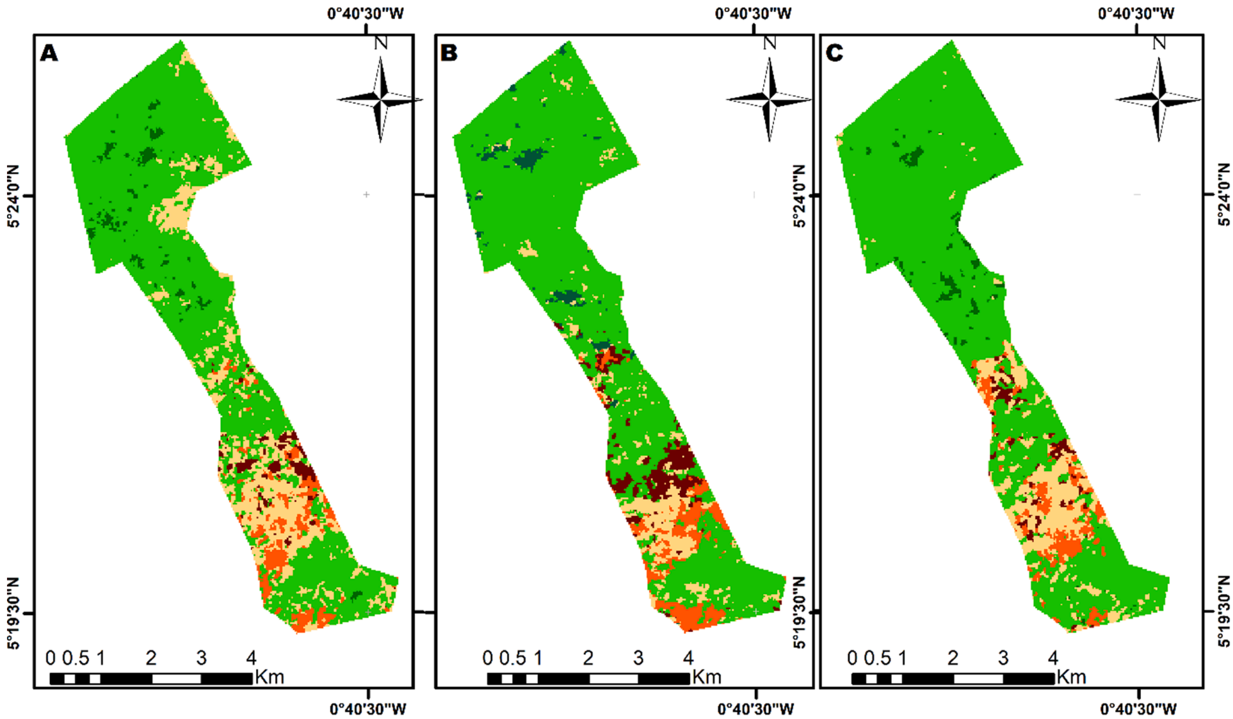
The primary qualitative data was necessary for exploring the experiences and perceptions of participants concerning their livelihood activities and implications in the management of the YFR. This was achieved using in-depth interviews (IDIs) and Focus Group Discussions (FGDs), following Ardayfio-Schandorf et al., (2007) and Kamwi et al. (2015). These authors used sustainable livelihood framework (SLF) and interview guides to assess socioeconomic drivers of LULCC in forest regions. The focus was on commons such as farmers, firewood cutters (FC), hunters and charcoal producers (CP) from nine YFR fringe communities. Purposive sampling was employed to select these participants based on their in-depth knowledge and lived experiences. Selection of these participants is essential for narrowing the inequality (SDG-10) between less-endowed and well-endowed (SDG-1) commons in the area while enhancing the involvement in sustainable management of the YFR lands (SDG-15) through carbon and degradation neutralities. The samples consisted of eight farmers and two hunters, making ten people drawn from each of the nine communities. Four of the farmers were firewood cutters and charcoal producers.

The interview guides cover questions like the type of livelihood activities undertaken at the reserve, the implication of these human activities on the reserve and the level of knowledge about climate change. They also include questions on community perception of sustainable management of YFR. Informed consent was sought before the interviews. We ensured participant anonymity and confidentiality of information provided using "farmer", "hunter", "firewood cutters (fetching)" and "charcoal producers" for purposes of anonymity. Field notes of observations were also taken. The IDIs and FDGs were recorded using a digital audio-type recorder. The recordings were later transcribed for thematic content analysis. Thematic analysis based on the steps proposed by Braun and Clarke (2006) was followed to enable systematic coding and generation of the themes.

3. Results and discussion

3.1. The magnitude and rate of land use land cover change within the YFR

Fig. 3 presents the spatiotemporal classification of the YFR LULC types as of 2000, 2010 and 2020. The confusion matrix estimated an overall classification accuracy of 89.1%, 90.8% and 89.8% respectively. The estimated producer accuracy (PA) and user accuracy (UA) are in the supplementary file. Fig. 3 shows evidence that the common LULC types are the close-df (49.95ha), open-df (1783.35ha), close-ghv (287.37ha), open-ghv (120.60ha) and Bare surface (51.66ha). As of the year 2020, the open-df dominates (77.8% of 2293.00 ha). This is followed by the



Legend	Year / Land Area (ha)		
	2000 (A)	2010 (B)	2020 (C)
a = Less dense (open) grass/herbaceous vegetation	131.04	138.78	120.60
b = Less dense (open) degraded forest vegetation	1627.11	1763.46	1783.35
c = Dense (close) grass/herbaceous vegetation	423.90	209.79	287.37
d = Dense (close) degraded forest vegetation	56.79	60.75	49.95
e = Bare land surface	54.09	120.15	51.66

Fig. 3. Spatiotemporal land use land cover (ha) within YFR in 2000 (A), 2010 (B) and 2020 (C). Source: Authors' construct based on Landsat data.

close-ghv (12.5%) and open-ghv types (5.3%). The bare land surface (2.3%) and the close-df were the least in area coverage as of 2020.

Concerning the trends (please, see in supplementary Fig. 1 or Table A2.2) of the LULCC, the open-df which depicts open savanna woodland vegetation increased in size (land area) steadily from 71.0% (1627.11ha) in 2000 to 77.8% (1783.35ha) in 2020. According to the interviewees, new plantations were established between 2002 and 2009. Concurrently, the size of close-df depicting close savanna woodland vegetation decreased from 2.5% (56.79ha) to 2.2% (49.95ha).

The two grass/herbaceous vegetation (ghv) types dwindled in size. The close-ghv reduced from 18.5% (423.90ha) in 2000 to 12.5% (287.37ha) in 2020 while the open-ghv dropped from 5.7% (131.04 ha) to 5.3 % (120.60ha), respectively. Although, the bare land surface showed an increase from 2.4% (54.09ha) to 5.2% (120.15ha) between 2000 and 2010 and it decreased to 2.3% (51.66ha) by 2020.

These estimates portray that the YFR is losing relatively high vegetation quality (dense cover) for low-quality vegetation cover which associates with biodiversity loss and reduced carbon sequestration capacity. These forest and land quality degradation patterns are consistent with Rittenhouse and Rissman (2012) and Dymond et al. (2012). The observations are buttressed by the magnitude of loss in the close-df by 12.0% (6.84ha) and an increase in the less degraded forest by 9.6% (156.24ha) over the 30 years observed. The close-ghv type experienced the largest decline of 32.2% (136.53ha) at an annual rate of 1.1%.

3.2. *Change in aboveground biomass carbon stocks of the YFR*

The YFR carbon stock (tC) appears to have increased at the expense of dense forest biomass aboveground. The total amount of carbon decreased from 46,196.8tC in 2000 to 46,052.6tC in 2010 and then increased to 47,233.7tC in 2020 (Fig. 4). A majority of the increase came from expansion in the open-df instead of the close-df (Fig. 4). The close-df decreased in carbon stock alongside decreases in the close-ghv and open-ghv types. This implies the close-df carbon stock of 1,067.1tC in 2000 and 938.6tC in 2020 was traded for open-df carbon which increased from 36,349.6tC to 39,840.0tC. Suggesting that the YFR is losing aboveground biomass carbon stock (128.5tC) from its close-df at an annual rate of 6.5%. The close-ghv also reduced in carbon from 6,706.1tC to 4,546.2tC at the rate 1.6% per year. The decreasing pattern of endemic vegetation was reported by Massetti and Gil (2020) at 2.0% elsewhere.

Although the rate of forest cover loss is lower than the national rate of 2 % (Forestry Commission 2015; FAO 2016), the forest vegetation cover loss in the YFR corresponds to overexploitation of resources in the reserve. The concept of sustainability recommends that the rate of resource exploitation should match the regenerative capacity of the resource to avoid overexploitation and degradation of the resource quality. Due to legal or illegal harvesting, encroachment, farming and wildfires, the degradation rate outweighs the rate of restoration of the YFR. This finding can be likened to the report of Doe et al., (2018), who concurred that human livelihood activities and population growth

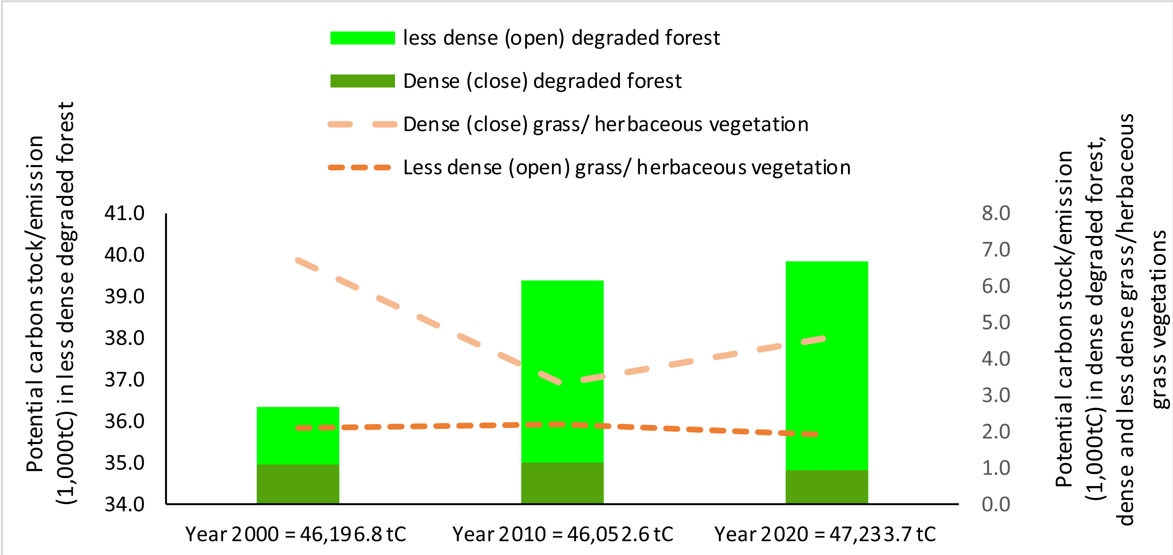


Fig. 4. Estimates of carbon stock of vegetation cover types in the YFR, tC = EF * hectarage of LULC type.

resulted in the loss of the natural forest vegetation cover within the Kakum Conservation Area in the Central Region of Ghana. Despite, the Modified Tuangya System (MTS), and its management challenges (Acheampong et al. 2016), the failure of the plantations could be attributed to livelihood activities that cause wildfire outbreaks and other forms of forest land degradation like charcoal production (Global Fire Monitoring Center (GFMC) 2007). It could also be due to climate change, drought, inadequate rainfall, poor supervision and maintenance contrary to the recommendations proposed by Ayivor et al. (2011).

3.3. Socioeconomic characteristics of respondents around the YFR

An equal number of women (50.0 %) and men (50 %) participated in the study. Most (77.0 %) of whom were above 40 years, married (72.2 %) with no formal education (48.9 %) and at least primary school education (51.1 %). The respondents (participants) were mainly indigenes (77.8 %) and a few migrants (22.2 %) making less than US$34.5 (Ghc200) of income a month from their livelihood activities, covering charcoal producers (26.7 %), farmers (26.7 %), firewood cutters (26.7 %) and hunters (20.0 %). This socioeconomic characterisation is consistent with Ayivor et al. (2011) but poorer than the description of Sobeng et al. (2018). Sobeng et al., (2018) indicate an income of US$1.9 per day for fringe community dwellers near the Tano forest reserve in the Atwima Mponua District of the Ashanti Region in Ghana. This finding confirms that poor households depend on protected forest reserve resources (Langat et al. 2016).

3.4. Reasons for continued human livelihood activities in the YFR

Table 1 reveals the fringe community dwellers' reasons for continued dependence on the YFR for their livelihoods.

Contrary to perceptions that YFR is a sacred grove where all forms of human activities are strictly forbidden except for the local "Aboakyir" festival, the current study corroborates Dottey, (2006) on the occurrence of human activities in the reserve. The participants revealed various motives for visiting the YFR. *"I go there for farming, hunting and to collect NTFPs"* **(IDI with Hunter, Community 8).** A farmer said *"I usually visit the forest to collect medicinal plant parts, but others enter the forest to produce charcoal, hunt grass cutters and antelopes. These animals feed on our food crops anyway"* **(IDI with Farmer, Community 9).** Another participant indicated that "*land scarcity is a major threat to our livelihoods. We are food crop farmers doing subsistence farming for our household income to survive*" **(IDI with a FC, Community 3).** Others said, *"We carry tree stems, branches and stumps from the reserve to burn charcoal outside the forest reserve"* **(IDI with a CP, Community 5).** Another explained that *"We collect medicinal plant parts and use them to treat ailments and other diseases like stomach aches, broken limbs and malaria"* **(IDI with FC, Community 7).** "*Such traditional healing methods are fading away making young ones ignorant about the most effective medicinal plants in the forest*" **(FGD, community 7)**.

Table 1
Reasons for continued livelihood activities in the YFR.

Community		Reasons for livelihood activities in the YFR
2	**FC**	for "*mushrooms, medicines, chewing sticks, tree trunk for preparing pestles, bushmeat, snails, firewood, and building posts, among others*" ***(IDI)***
3	**FC**	"*land scarcity is a major threat to our livelihoods. We are food crop farmers doing subsistence farming for our household income to survive*" ***(IDI)*** The dependence on NTFPs is because "*what they want cannot be obtained outside the forest reserve*" To enhance YFR sustainability, "*tree planting on farmlands (agroforestry) was initiated by the FSD to recover lost vegetation, improve soil fertility and NTFPs production*" ***(FGD)***
5	**CP**	*We carry tree stems, branches and stumps from the reserve to burn charcoal outside the forest reserve"* ***(IDI)***
	F	*"NTFPs are harvested for personal use and sold by those who do not farm in the forest"* ***(IDI)***
7	**FC**	*We collect medicinal plant parts and use them to treat ailments and other diseases like stomach aches, broken limbs and malaria"* ***(IDI)*** *Such traditional healing methods are fading away making young ones ignorant about the most effective medicinal plants in the forest"* ***(FGD)***
8	**H**	*"I go there for farming, hunting and to collect NTFPs*
9	**F**	*"I usually visit the forest to collect medicinal plant parts, but others enter the forest to produce charcoal, hunt grass cutters and antelopes. These animals feed on our food crops anyway"* ***(IDI)***

F = Farmer; **FC** = Fuelwood cutter; **CP** = Charcoal producer; **H** = Hunter; **IDI** = In-depth interview; FGD = Focus group discussion.

Most participants specified that NTFPs were harvested in different proportions and for several purposes. The *"NTFPs are harvested for personal use and sold by those who do not farm in the forest"* **(IDI with Farmer, Community 5).** These NTFPs include "*mushrooms, medicines, chewing sticks, tree trunk for preparing pestles, bushmeat (game), snails, firewood, and building posts, among others"* **(IDI with a FC, Community 2).** However, the daily collection in recent times has been much lower compared to the past 30 years. The dependence on NTFPs is because "*what they want cannot be obtained outside the forest reserve*". To enhance YFR sustainability, "*tree planting on farmlands (agroforestry) was initiated by the FSD to recover lost vegetation, improve soil fertility and NTFPs production*" (**FGDs in Community 3**). These findings are consistent with Daur et al., (2016) and Cobbinah et al., (2015a) that conservation approaches must be localized within the socio-cultural, economic and political context of the people without compromising on biodiversity. The findings also confirm Trædal and Vedeld, (2018) and Kyere-Boateng and Marek, (2021) that there are complexities in using forest resources. These complexities call for including livelihood objectives of forest fringe community dwellers in the YFR management more effectively.

3.5. Local perception about the role of YFR management

The results in Table 2 showed that the participants knew some of the mandates of the FSD concerning the YFR management.

They acknowledged that the "*FSD release degraded portions of the reserve for agroforestry purposes*" (**FGD, Community 9)**. This is known as the Modified Taungya System (MTS). The "*MTS module permits forest fringe community farmers to plant food crops within tree plantations until the tree canopy closes, usually within three (3) years*" **(IDI with a Farmer, Community 2)** or more, which corroborates Acheampong et al. (2016)**.** The "*farmers provide labour for land clearing, tending, and protection of the plantations to its rotation period*" **(IDI with a FC, Community 4).** The practice is consistent with the reports of Cobbinah et al. (2015a) and Mbanze et al. (2020), who demonstrate the potential of agroforestry systems in advancing forest frontiers.

However, YFR "*MTS project expired in 2009 and the farmers now have difficulties in forest farming*' **(IDI with a CP, Community 1).** When the participants were asked about the Benefit-Sharing Agreement (BSA) of the MTS, it was confirmed that the MTS gave farmers legitimate right to enter the reserve to farm as reported by Acheampong et al. (2016). The "*farmers, stool landowners and communities take 40 %, 15 % and 5 % of the share respectively from the proceeds, while the FSD takes 40 %*" **(IDI with a Hunter, Community 3).** The BSA enhanced forest protection and planting of *Cedrela odorata* (Cedrela), *Cassia spp*, (Cassia), *Tectona grandis* (teak), Ceiba *pentandra* (ceiba) and *Khaya spp* (mahogany) in the reserve. As a result**,** "*illegal farming stopped entirely between 2002 and 2009… because it became difficult for people who were not involved in the plantation to sneak into the forest illegally*" **(IDI with a Farmer, Community 9).** These findings imply that in the absence of resources and favourable forest management systems, people are likely to take the law into their hands, as shown in previous literature (Cobbinah et al. 2015a; Mbanze et al. 2020; Kyere-Boateng and Marek 2021).

Table 2
Local perceptions about the role of YFR management.

Community		Perceptions about YFR management
1	**CP**	The "*MTS project expired in 2009 and the farmers now have difficulties in forest farming*' **(IDI)**
2	F	The "*MTS module permits forest fringe community farmers to plant food crops within tree plantations until the tree canopy closes, usually within three (3) years*" **(IDI)**
3	H	The "*farmers, stool landowners and communities take 40 %, 15 % and 5 % of the share respectively from the proceeds, while the FSD takes 40 %*" **(IDI)**
4	FC	"*farmers provide labour for land clearing, tending, and protection of the plantations to its rotation period*" **(IDI)**
9	F	The BSA enhanced forest protection and planting of *Cedrela odorata* (Cedrela), *Cassia spp*, (Cassia), *Tectona grandis* (teak), *Ceiba pentandra* (ceiba) and *Khaya spp* (mahogany) in the reserve. As a result, "*illegal farming stopped entirely between 2002 and 2009… because it became difficult for people who were not involved in the plantation to sneak into the forest illegally*" **(IDI)** "*FSD release degraded portions of the reserve for agroforestry purposes*" **(FGD)**

F = Farmer; **FC** = Fuelwood cutter; **CP** = Charcoal producers; **H** = Hunter;; **IDI** = In-depth interview; FGD = Focus group discussion.

3.6. *Perceived effects of human activities in the YFR*

As shown in Table 3, the participants believe that YFR has dwindled in its status in terms of hectarage of trees, the greenness of the close-df and soil fertility compared to the past 30 years. This finding corroborates Kyere-Boateng and Marek (2021) and Doe et al., (2018) that access to forests, illegal timber harvesting and human pressure account for reserve vegetation loss in the long term. Participants in the current study believe that the YFR LULCC is caused by "*human pressure, overexploitation of NTFPs and unsustainable farming activities. These have resulted in deforestation and degradation of the forest resulting in inadequate rainfall, erratic rainfall and adverse temperature variability*" **(IDI with Hunter, Community 6).** "*There is a little rain, which comes with heavy storms and wildfires due to prolonged drought*" **(IDI with CP, Community 8).** These views confirm the observations and estimates of the LULCC in Fig. 3 as demonstrated in Appiah et al. (2016).

3.7. Local knowledge about climate change and climate variability effects of LULCC

Concerning climate change (CC) in the study area, the participants affirm a Community Education was conducted by the FSD Office at Winneba. According to the participants (Table 4), "*Climate Change is about the excessive heat from sunlight, drought, variability in rainfall patterns, sea-level rise and the effect of sea waves along the Winneba coast, which has resulted in corrosion of metallic roofs of buildings in the area*" **(IDI with Farmer, Community 7).** "*Salt from the sea waves can cause crop disease and death of forest plants… a 16.0 ha teak plantation was destroyed by bushfires in 2011 at the Bewadze portion of the reserve*" **(IDI with Hunter, Community 1).** Other participants attributed CC to God; "*The "making of God" who has promised that drastic changes can occur toward the end of man's existence on the earth*" **(IDI with FC, Community 3).** These findings corroborate previous literature on local CC knowledge (Derbile et al. 2016). support the global call for CC mitigation and adaptation (IPCC 2019).

3.8. *Perceived challenges of sustainable management of the YFR*

Table 5 presents some of the perceived challenges of the YFR. The study participants admitted they are partly responsible for the sustainable management of the YFR.

However, as earlier reported by Shackleton et al., (2015), unemployment and poverty that lead to desperation are forcing the people to overexploit or degrade the forest resources reluctantly. Hence the hesitance of the people to collaborate effectively with the FSD. For instance, an IDI revealed that "*lack of employment leads to inadequate household incomes, hunger, inability to pay for education and health facilities. This situation is worsened by low crop yields from off-reserve farmlands*" **(IDI with Farmer/CP, Community 6).** Another major hindrance is the "*failure of farmers to maintain their MTS plantations due to high maintenance cost, even though some operational costs such as weeding, climber cutting, protection and patrols were borne by the FSD*" **(IDI with a Farmer in Community 4).** Some participants reiterated *that "there used to be a Community Forest Committees between 2003 and 2007. It collapsed because of lack of local incentives to protect the forest"* **(IDI with FC, Community**

Table 3
Perceived effects of human activities in the YFR.

Community		Perceived effects of human activities on YFR
6	H	The YFR LULCC is caused by "*human pressure, overexploitation of NTFPs and unsustainable farming activities. These have resulted in deforestation and degradation of the forest resulting in inadequate rainfall, erratic rainfall and adverse temperature variability*" **(IDI).**
8	CP	"*There is a little rain, which comes with heavy storms and wildfires due to prolonged drought*" **(IDI).**

CP = Charcoal producers; **H** = Hunter; **IDI** = In-depth interview.

Table 4
Local knowledge about climate change and climate variability effects.

Community		Knowledge about climate change and variability effects
1	**H**	*"Salt from the sea waves can cause crop disease and death of forest plants… a 16.0 ha teak plantation was destroyed by bushfires in 2011 at the Bewadze portion of the reserve"* **(IDI)**
3	**FC**	*"The "making of God" who has promised that drastic changes may occur towards the end of man's existence on the earth"* **(IDI).**
7	**F**	*"Climate Change is about the excessive heat from sunlight, drought, variability in rainfall patterns, sea-level rise and the effect of sea waves along the Winneba coast, which has resulted in corrosion of metallic roofs of buildings in the area"* **(IDI).**

F = Farmer; **FC** = Fuelwood cutter; **H** = Hunter;; **IDI** = In-depth interview.

Table 5
Perceived challenges of sustainable management of the YFR.

Community		Challenges of managing YFR
4	**F**	*"failure of farmers to maintain their MTS plantations due to high maintenance cost, even though some operational costs such as weeding, climber cutting, protection and patrols were borne by the FSD"* **(IDI).**
5		*"Poor farming practices and illegal harvesting of timber and NTFPs lead to land degradation, including soil erosion leading to loss of vegetation, biodiversity and drying-up of water bodies* **(FGD).**
6	**F, CP**	"*lack of employment leads to inadequate household incomes, hunger, inability to pay for education and health facilities. This situation is worsened by low crop yields from off-reserve farmlands"* **(IDI).**
	FC	*"there used to be a Community Forest Committees between 2003 and 2007. It collapsed because of lack of local incentives to protect the forest"* **(IDI).**

F = Farmer; **CP** = Charcoal producers;; **IDI** = In-depth interview; FGD = Focus group discussion.

6). These findings also confirm Akamani et al., (2015) concerning barriers to collaborative forest management initiatives.

When the participants were asked about the implications of Illegal logging, collection and collection of forest fragments (NTFPs), a group of the participants shared their acknowledgement. *"Poor farming practices and illegal harvesting of timber and NTFPs lead to land degradation, including soil erosion leading to loss of vegetation, biodiversity and drying-up of water bodies* **(FGD at Community 5).** This finding is not different from the general opinion of most forest fringe community dwellers (Ayivor et al. 2011; Cobbinah et al. 2015b, a). It affirms the risk forewarned by Derbile et al., (2016) that sustainability aims can be undermined when local land-use decisions fail to contextualize a balance between livelihood, ecosystems and forest reserve sustainability objectives.

4. Conclusion

We examined the magnitudes, trends and rates of YFR LULCC and their effects on carbon stock of the reserve. We also examined the socio-economic characteristics of the inhabitants and the reasons for their livelihood activities in the reserve as well as their roles in the reserve management. Based on Google Earth Engine supervised LULC and carbon emission coefficients, this study provides new insights into the extent of human livelihood activity impacts on vegetation and above-ground carbon stock (AGBCS) in the YFR. Generally, the YFR LULCC is related to socio-economic and ecological factors. The carbon stock increased at the expense of close-df forest biomass aboveground. Most of this increase came from expansion of the open-df while the close-df decreased in size and carbon stock, alongside the close-ghv and open-ghv declines. The YFR is losing AGBCS mostly from its close-df at an annual rate of 6.5%. The close-ghv is also losing its carbon stock at 1.6% per year. Inadequate synergies between indigenes' livelihood expectations and YFR management appear to be yielding marginal results due to conflicting interests of livelihood actors and reserve management goals. Legal/Illegal harvesting of NTFPs, charcoal production, agriculture and other activities occur in the reserve despite the people's knowledge of the forestry laws and regulations. YFR decision-making should engender active involvement of deprived fringe community dwellers' livelihood objectives, integrating SDGs 1, 10, 15, carbon/land degradation neutralities and climate actions alongside REDD+. The authors believe active and informed participation of the less endowed (deprived) fringe community dwellers and stakeholders is critical to achieving carbon neutrality and land degradation neutrality. Vigorous public awareness, communication and education are required for effective participation in decision-making and sustainable integration of livelihood objectives. There is a need for rejuvenation of persuasive enforcement, monitoring, supervision and participatory action to mitigate forest cover and carbon loss. Further research of the YFR LULCC should estimate the carbon stock using remote sensing and integrate qualitative insight from all categories of stakeholders.

The study contributes to the general body of knowledge on earth observation and geospatial science, social and forest ecology toward sustainable forest management and human livelihood development. This is particularly true in the context of YFR LULCC and carbon stock. It advances the theory and practice of sustainable forest fringe community development and beefs up techniques for rapid forest carbon estimation methodologies. It is, therefore, applicable to multiple academic disciplines and multi-sectoral sustainable development practice.

Description of Author's Responsibilities

All authors worked on, read and approved the final manuscript. ***JOA***-initial draft of the manuscript and qualitative data analysis. ***EMA***, ***MM***, ***BYF-M*** and ***RAA*** - development of methodology, review of the manuscript, results and discussion. ***EKD***- geospatial and sustainable development conceptualization, geospatial methodology, quantitative analysis, LULC classification and carbon stock estimation, results/discussion and final draft of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data is available in the supplementary file attached

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jag.2022.102938.

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