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Research article

Advancing multiple ecosystem service assessment in the tropics: Evidence from Barekese and Owabi watersheds in Ghana

Samuel Ayesu[a,*], Olivia Agbyenyaga[b], Victor Rex Barnes[b], Adwoa Gyamfi[c], Richard Krobea Asante[a]

[a] Resource Management Support Centre, Forestry Commission, Ghana
[b] Department of Agroforestry, Kwame Nkrumah University of Science and Technology, Ghana
[c] School of Nursing, Kwame Nkrumah University of Science and Technology, Ghana

A R T I C L E I N F O

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A B S T R A C T

Watershed ecosystems are important for the provision of multiple ecosystem services (ES) that are critical to human welfare. Few studies particularly in the tropics assess the multiple ecosystem services, economic value, and effect of land use change on economic value. This paper provides evidence of the quantitative. economic value and effect of land use change on the economic value of watershed ESs from Barekese and Owabi in Ghana. Geospatial analysis and the stated preference method were used for the study. Primary and secondary data were collected from households, institutions, and other sources to quantify and estimate ecosystem services. The geospatial analysis showed that forest degradation and deforestation have increased over the last three decades in the watershed with settlements and cropland being the major land use changes. The two watersheds provide many ecosystem services, including provisioning services (water, fuelwood, bushmeat, fish), regulating services (carbon sequestration, water supply, water purification, soil fertility), and cultural services (ecotourism). An aggregated economic value for the ESs of GH₵ 707.701 x 10^6 (\$144.428 x 10^6) was estimated for the two watersheds. For the different sites, the economic value for the Barekese and Owabi watersheds were \$110.645 x 10^6 (\$6609.06/ha/yr) and \$33.783 x 10^6 (\$5857.76/ha/yr) respectively. Our analysis showed that conversion of forest to other land uses resulted in a significant reduction in the value of ecosystem services. Conversion of the watershed to Tree Crop, Food Crop, Grassland or Settlement could reduce the economic value of ESs by 4%–80 %. The study demonstrates that ecosystem services assessment could provide important information for conservation and development policies related to watershed management in the tropics. To ensure ecosystem service supply, the risks of land use change should be considered in watershed conservation strategies including land use zoning and adaptive management systems.

1. Introduction

Watersheds are important ecosystems that provide numerous benefits in the form of ecosystem services. Globally, ecosystem services are categorized into four basic groups: provisioning, regulating, supporting and cultural [1–4]. The third category of

* Corresponding author.
E-mail address: sayesu.rmsc@fcghana.org (S. Ayesu).

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supporting services is not normally included, as it might cause double-counting errors [5–7]. Healthy forested watersheds generate many services including water purification, water supply, stabilizing soils, recreational and aesthetic benefits. Ecosystem services are more and more growingly promoted for documentation of the benefits humans place on nature [1,5,8]. These services represent the values nature delivers to society [1,9]. In many cases, these benefits are common goods and therefore there is little or no motivation for those who benefit to sustainably manage these ecosystems [9,10]. It has, however, been contended that choices about ecosystem management involve costs (or forgone benefits) and may be degraded if not driven by a specific framework of value [11–13]. It is often difficult to compensate those that may be affected by negative outcomes including biodiversity loss and reduction in ecosystem services. Moreover, most ecosystem services are not traded in conventional markets and therefore often are not considered in economic decisions [9]. It further points out that since ecosystem services are rarely mainstreamed into conventional markets, these services usually receive little or no attention in policies regarding nature conservation.

The ecosystem services approaches are considered by most people as promising, contributing well to the consideration of ecosystems in the decision-making process in view of the numerous benefits of nature and related trade-offs [14–16]. Decisions to change natural ecosystems frequently do not give much attention to the implications of land transformation on ecosystem services or the loss of those services. This overlook comes from our inadequate understanding of how alterations in ecosystems determine the level of services that such systems deliver and our incomplete knowledge concerning the importance of apparently insignificant ecosystem components. Maybe the foremost important factor is that not many ecosystem services have well-recognized monetary values. This has a great impact, in so far as various decisions regarding resource use are taken by weighing costs and benefits [17–19,19,20]. There's growing consensus concerning the significance of integrating "ecosystem services" into conservation planning but measuring the quantity and values of the services remains limited [21], particularly in most countries of the tropics.

Estimating the monetary worth of ecosystem services is perceived or seen by many as a way to integrate economic and biophysical issues to address the disregard of ES in decision-making [9,11,22]. The prospect of this to inform sustainable development is acknowledged by policy-makers, resource managers and the research community [9,20,23]. Among the reasons most people are concerned about ecosystem degradation is that they offer important services that could be lost through degradation [20,23,24]. Since the late 1960s, there has been a rising interest in the assessment and valuation of the multiple benefits offered by ecosystems. This interest is driven by a growing awareness that the services generated by natural and semi-natural ecosystems are frequently underrated in decision-making [5,12,13]. Subsequently, valuation of ecosystem services has gained considerable interest in scientific literature [2,5,9,25]. Additionally, several studies provide guides or frameworks for valuing ecosystem services [2,5,9].

On many occasions, alterations in ecosystems and therefore the services they provide are incremental. Most of those incremental changes could be predictable. However, sometimes the modifications of an ecosystem and its services could be huge in scale and costly, hard, or impractical to reverse [26,27]. Gradual failure of a system's resilience prepares the way for considerable shifts that arise as the ecosystem goes beyond a certain tolerance level as a result of perturbation [28,29]. Poverty, population increase, and ecosystem conditions are strongly linked and aggravate each other [25,30]. The feedback that makes the cycle of ecosystem degradation and poverty is not fully understood. Poverty reduction is usually contingent on access to dependable provision ecosystem services [31]. Many decisions concerning ecosystem services include compromises [32] and these compromises arise among various ES and between present and future delivery of a service [25,26,26].

Over the past 50 years, to satisfy the rapidly increasing food, fresh water, fiber, and fuel needs, the activities of humans have negatively affected watersheds on a scale and at a faster rate than at any other time in history [1,25]. Human changes to ecosystems increase the likelihood of nonlinear changes in ecosystems [33], which greatly increases the danger to the ecosystem. Among them, land use activities like agriculture, urbanization, mining, and infrastructure development have caused considerable changes to ecosystems [34,35]. Arguably, the threat to the ecosystem triggered by changes in land use has accelerated dramatically [36]. Evaluating the effect of changes in land use is very important to decision-makers to elucidate the impact of land use changes on ecosystem conditions and processes, which is beneficial for promoting protection and enduring conservation actions [37,38]. Land use change as a major factor of global change, not only causes ecological disruptions like biodiversity and forest loss [38] but also contributes to changes in ecosystem structure and function as well as their resilience that considerably results in large amplification in ecosystem risk.

Despite increasing recognition of the value of watersheds in supporting human welfare, there are limited examples of research providing a comprehensive accounting of the multiple watershed ecosystem services in the tropics and developing countries like Ghana [19,39,40]. Most of the research assessing ES investigate either single or narrow sets of ESs [25,41]. Many of the studies tend to investigate either social or ecological dimensions [42]. Nevertheless, at the present, a few studies analyze how land use change affect the availability of ecosystem services, particularly within the tropics [25,41–43,43,44]. Other studies investigated the ecological impact assessment of land use change from an ecosystem service degradation perspective to determine future risk [20,41,45]. For instance, a study by [46] quantified the effect of degradation in current and future ecosystem services in China by estimating differences in grain productivity, nitrogen emissions and ecosystem productivity due to changes in land use. At present, the challenges of land use change and environmental conservation at various scales are getting increasingly prominent. Whereas the influence of changes in land use on ecosystems is deepening, it's becoming increasingly urgent to evaluate the risks of changes in land use on ecosystem services [47].

The situation is not different in Ghana, where the annual deforestation rate is reported to be 3 % [48,48], which is greater than the annual rate of 0.6 % for the Western and Central Africa subregions [49,50]. With increasing socio-economic development, urbanization and population increase over the past decades, the rural-urban migration is growing in Ghana, with many of the people relocating to peri-urban areas [43,51]. The geographic and temporal changes in land use indicate the degree and nature of interaction among humans and nature at different scales [43,52,53]. The Atwima Nwabiagya District is among the fastest-growing districts in Ghana, and this means that urbanization coupled with other land-use changes may considerably affect ecosystem services provision, like those provided by the Barekese and Owabi watersheds. The Barekese and Owabi watersheds are the main source of water supply to more than 100,000 households and over one million people [43,54].

Furthermore, the ecosystem services generated by most watersheds in Ghana have not been characterized or valued both from biophysical and socio-economic perspectives. In a few cases single ecosystem services have been assessed [55] but watershed generate multiple benefits that need to quantified and monetary value assigned to them [55.39]. In 2023, Ghana launched the Natural Capital Accounting Project to document the country's natural assets. In this regard, the local and regional importance of the Barekese and Owabi watershed as a RAMSAR site provides a considerable opportunity to provide evidence of the enormous ecosystem services these sites provide to society to rally support for their conservation. Also, several studies have reported significant land use changes in the Barekese and Owabi watersheds over the last two decades [43,52,56]. These changes may have considerable influence on ecosystem processes and therefore the ecosystem benefits produced by the Barekese and Owabi watersheds. Such benefits, however, have neither been assessed nor quantified and have not been considered in the resource management plans and decision-making regarding the watersheds. It is in this regard that this study was initiated to contribute to providing empirical evidence on watershed benefits in Ghana. Therefore, the objectives of the research were to quantify the ecosystem services generated by Owabi and Barekese watersheds, estimate the monetary value of the ecosystem services and determine ecosystem condition and how ecosystem change will affect the value of ecosystem services.

2. Methodology

2.1. Study site description

The Owabi and Barekese watersheds are situated between latitude 1°42′00″W and longitude 6°44′50″N (Fig. 1) and are in the Atwima Nwabiagya District. The Barekese and Owabi watersheds cover a total area of 5767.30 ha and 16,741.53 ha respectively. The watersheds record annual temperatures and rainfall of 24.6°C–27.8 °C and 1402 mm respectively. The topography is largely undulating with a mean elevation of 77 m above sea level. The vegetation is typically Moist Semi deciduous forest with major waterbodies found in the district include Offin and Owabi rivers. The Government of Ghana constructed a dam over these major rivers to provide water for local and industrial use purposes. The Owabi and Barekese dams are the source of water for the residents of Kumasi and its environs [53,57]. The two sites are important sources of water for over 100,000 households (over one million people) in the Atwima

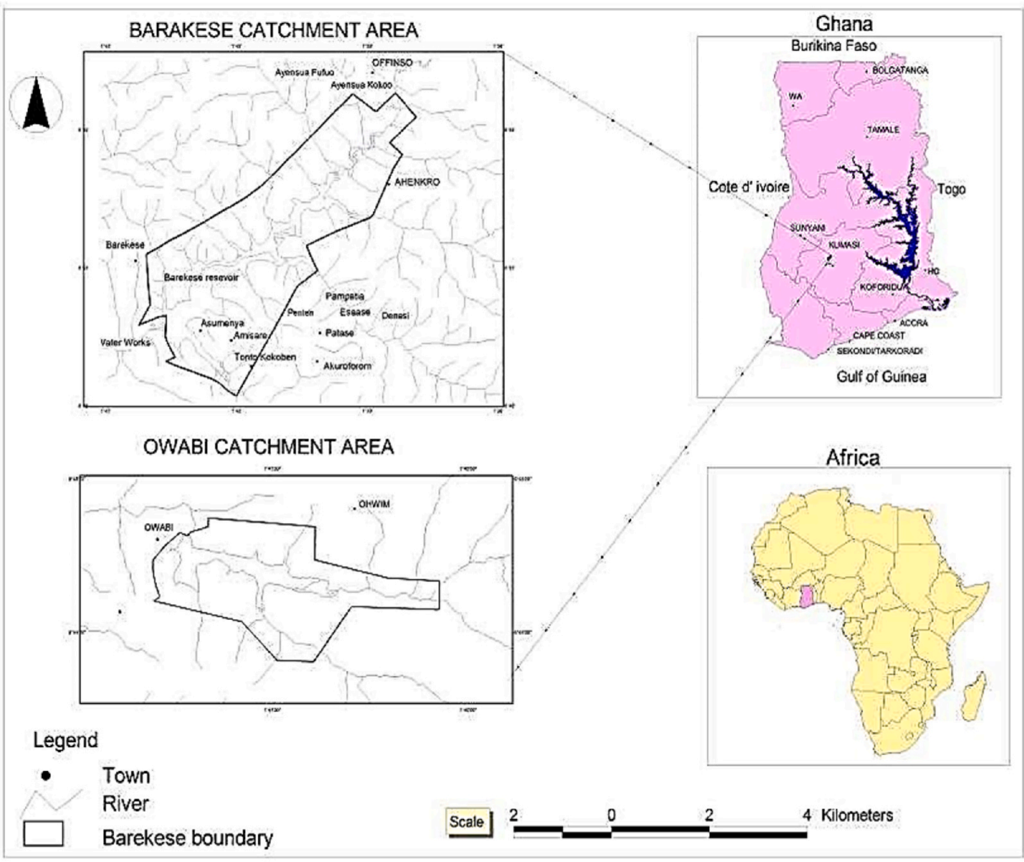

Fig. 1. Location map of the Barekese and Owabi watersheds.

Nwabiagya District and Kumasi Metropolis [54]. The watersheds are also refuge area for diverse fauna and flora as well as contribute to carbon sequestration, hydrology, water purification and erosion control, among others. The predominant soils are the Bekwai-Nzema/Oda Associations and Kumasi-Asuansi/Nta-Offin Associations [58]. The soils are good for cultivation of tree crops (orange, mangoes, oil palm plantations, cocoa, avocado pear) and arable crops (yams, maize, cocoyam, cassava, plantain, etc.) among others. There are many valleys without flowing streams, that are good for agricultural crops like sugarcane, vegetables and rice. Forest degradation and deforestation in the watershed have been driven by expansion in agricultural activities, settlements and sand winning [54,57].

2.2. Materials and methods

2.2.1. Landcover mapping and analysis

Ecosystem services are inherently linked to and dependent on ecosystem conditions; therefore, the first essential step is to identify relevant ecosystems, habitats, or land use to assign to them relevant ecosystem services and value them. The source of the spatial ecosystem data for the valuation was taken from land-use/land cover analysis undertaken using Landsat satellite imagery. The land use classification followed the IPCC and national land-use classes including Forest class (Open forest, Close forest), Cropland, Grassland and Settlement [59]. The spatial extent (in ha) for various land use classes were calculated for each epoch and the extent of each land-use change were estimated using Equation (1) [60].

$$C = at_2 - at_1 \qquad \text{Equation 1}$$

where, C is land use type change in extent for the initial time (t_1) and final time (t_2):

at_1, land use extent at time t_1;
at_2 land use extent at time t_2.

2.2.2. Valuation methods

The multiple ecosystem services provided by the two watersheds were evaluated and this included provisioning, regulating/maintenance, and cultural services. It is important to note that other services such as pollination, flood protection, among others were not included in the analysis due to lack of information or data. In this regard, the analysis is an underestimate of the value of ecosystem services generated by the two watersheds. Information and data for the analysis were collected from both primary and secondary sources. Secondary information was collected from existing reports, bulletins, articles and journals, Ghana Water Company Limited,

Table 1
Description of ecosystem service, valuation methods and valuation procedure.

Ecosystem services category	Ecosystem service subtype	Benefit	Valuation method	Valuation procedure	Literature
Provisioning	Provisioning services	Drinking water, timber, bushmeat, etc.	Contingency Valuation (Willingness To Pay)	The Contingency Valuation People's willingness to pay for a benefit x total number of people. Net economic values were derived from the difference between the cost of production of service and gross income/price from the sale or use of service.	[19,61, 62]
Regulating/ maintenance	Carbon sequestration	Reducing green house effect	Market price and damage cost	Amount of carbon fixed x carbon price per unit. The carbon sequestration service was estimated based on carbon stock estimated for the different land uses in the Barekese and Owabi watersheds (Ayesu, 2020).	[19,63]
	Oxygen release	Oxygen release	Replacement cost	Amount of carbon fixed x Oxgyen price per unit. Estimation of oxygen release capacity were derived from carbon sequestration based on photosynthesis reaction (Xi, 2009).	[63]
	Nutrient cycling	Accumulating nutrients	Replacement cost and market price	Maintained nutrient (NPK) amount valued at market price of mixed fertilizers in Japan.Estimation of the value of nutrient cycling in soil was assessed using the replacement cost method. The monetary value for this service was estimated using the supposed loss as result of soil erosion occurred under alternative land use (Xi, 2009; Xue and Tisdalle, 2001 in Ref. [61]) and determining the soil nutrient loss and a corresponding price of commercial fertilizer on market.	[62,64]
	Water purification	Absorbing/ decomposing pollutants	Replacement cost	Amount of water for domestic and industrial use x unit cost of treatment in dams in Ghana (Xi, 2009 in Lang et al., 2018).	[19,62, 64]
Cultural	Recreation	Ecotourism	Entry fees	Number of annual visitors x Individual entry fees for recreational activities	[62]

Note: Adapted from [62,64].

Wildlife Division, Ministry of Agriculture, Offin district and COCOBoD. These are indicated in relevant places in the text or references. Secondary data on the quantity of water supplied to consumers, cost of water treatment and revenue generated annually were collected from the database of Ghana Water Company Limited (GWCL), while the quantity and cost of annual fertilizer application were obtained from Cocoa Board (CoCoBoD) and Ministry of Food and Agriculture. Information on the revenue generated from ecotourism over the last five years was collected from the GWCL and Wildlife Division. Primary data was collected from local communities on benefits derived from the watersheds The ecosystem services and valuation methods used for the study are described in detail below and analysis is indicated in supplementary data. The data are for the year 2018 or the latest available. The estimates in Ghana Cedis (GH') were converted to equivalent $ value using the exchange rate for 2018 (1 $ = 4.9). Table 1 summarizes the ecosystem services, valuation method, and procedures used for the study.

2.2.3. Provisioning and cultural services

For most of the ecosystem services, the monetary value was obtained through market valuation techniques based on current prices. Depending on the service being investigated, secondary data such as production estimates, current use levels and land cover areas, were also necessary to complete the valuation. The study was conducted using the Stated Preference method which an optimum technique for valuing multiple ecosystem services simultaneously [19,19]. This technique utilizes questionnaires to elicit information from people on the amount they are willing to pay for a service. The CVM studies were conducted using an open-ended (OE) questionnaire to elicit information from the respondents on water and forest ecosystem services. The survey instrument was a questionnaire that was developed based on discussions with experts from Ghana Water Company Limited, Wildlife Division, and opinion leaders in some of the catchment communities. A total of 390 households were randomly sampled with 30 households per community interviewed. The overall sample size for the survey was 390 households and it was determined using the [65]. Primary data was generated through household surveys, and expert interviews. Thirteen communities were selected from both upstream and downstream communities for the survey. Nine of these communities were selected from downstream (Daban, Ohwim, Easaase, Adankwame, Barekese, Nkwanta-kese, Maaban and Asuofia) and four from upstream (Aboabo, Abuakwa, Patasi and Santasi). The selection of communities was based on information collected from the GWCL, Wildlife Division, and other studies that indicated those communities that benefit from the watershed. Further information was collected to determine the net economic value for the provisioning services only [61]. The Net economic values were determined from the Gross economic value for the provisioning services using the difference between the cost of production of a service and gross income/price from the sale or use of the service. It was estimated using equation 2

$$N = Vp - [Cl + Ct + Ci + Oc] \quad \text{Equation 2}$$

N=Net economic value of the product:

Value of product (Vp) = [Quantity of product (kg) * Per unit price (GH₵)]
Annual Cost of Labour (Cl)
Annual cost of transportation (Ct)
Annual cost of inputs and equipment (Ci)
Other costs (Oc)

2.2.4. Regulating services

Nutrient cycling. Estimation of the value of nutrient cycling in soil was assessed using the replacement cost method. Information on the rate of soil losses (Tables S1a and 1b) was sourced from the Soil Research Institute, Ghana. The rationale was to compute the damage cost and assign the value to the service using a comparable cost of substituting the service. The monetary value for this service was estimated using the supposed loss as a result of soil erosion that occurred under alternative land use [66,64 in 63] and determining

Table 2
Total quantity of fertilizer applied annually for cultivated tree and arable crops in the Barekese and Owabi watersheds in Ghana.

Site	Crop	Unit	Type	Quantity/ha	Area	Price/ha (GH ₵)	Total Quantity (kg)	Econ. value (GH ₵)	Econ. value ($)
Owabi	Maize	kg	NPK	250	537.59	187	34,397.75	100,529.52	20,516.23
	Maize	kg	Urea	50	537.59	70	26,879.55	37,631.37	7679.87
	Rice	kg	NPK	312	9.23	187	2880.06	1726.19	352.28
	Rice	kg	Urea	50	9.23	70	461.55	646.17	131.87
	Cocoa	Litre	Conventional granula	350	163.17	80	57,110.71	13,053.88	2664.06
Total								**153,587.12**	31,344.31
Barekese	Maize	kg	NPK	250	3248.17	187	812,042.77	607,407.99	123,960.81
	Maize	kg	Urea	50	3248.17	70	162,408.55	227,371.98	46,402.44
	Rice	kg	NPK	312	55.77	187	17,401.56	10,429.78	2128.53
	Rice	kg	Urea	50	55.77	70	2788.71	3904.20	796.78
	Cocoa	Litre	Conventional granula	350	985.91	80	45,067.85	78872.65118	16,096.46
Total								**927,986.60**	189,385.02

Source. Ministry of Agriculture and CoCoBoD, Ghana, 2018. Analysis of raw data by the authors the soil nutrient loss and a corresponding price of commercial fertilizer on market (Table 2). The steps applied were: (i) erosion rate (average topsoil loss per hectare) for each landcover of land-use (iii) minimum amount of fertilizer applied annually by farmers to improve soil fertility (ii) calculating the major nutrient loss (Nitrogen, Potassium (K) and Phosphorus (P)) per unit (hectare) based on the price of fertilizer sold on the market for the year 2018 using information derived from COCOBOD and the Ministry of Food and Agriculture.

Carbon sequestration value. The carbon sequestration service was estimated based on carbon stock estimated for the different land uses in the Barekese and Owabi watersheds [58]. The total economic value was estimated in four stages: (i) Using remote sensing techniques, the spatial extent (ha) of different land-uses estimated. (ii) Estimate the mean carbon stock per hectare for each land use type and aggregating for the whole for the Barekse and Owabi watersheds by multiplying the mean value by the total area of each land use. (iv) Determine the Carbon dioxide equivalent (CO_2-e) by multiplying the mean carbon per hectare by a constant value of 3.67 (or 44/12) [66]. The carbon sequestration monetary value for each forest type was calculated using Equation (3) [63]. Detailed carbon calculations are provided in Table 3, S2 and S3.

$$T = C * P * S \qquad \text{Equation 3}$$

where:

T–Total carbon sequestration value (GH₵ or $)
C - Carbon sequestration (CO_2)
P–Carbon dioxide price per ton (GH₵ or $)
S–Extent of each landuse (ha)

The unit price of CO_2 used in the calculation was based on an extensive review of the carbon market. The price of carbon varied widely, with a mean price for Clean Development Mechanisms of $10.5/ton t$CO_2$-e, World Bank documents provided a mean carbon price derived from carbon tax of approximately $11.38, and a mean price for most Emission Trading Schemes approximately $ 12/tCO_2-e. Using this information, an average of $11.40/t$CO_2$ was used for the computation [19].

Oxygen release value. Estimation of oxygen release capacity was derived from carbon sequestration based on photosynthesis reaction [67]. The chemical reaction below indicates the production of Oxygen.

$$6CO_2\,(264\ g) + 12H_2O\,(180\ g) \longrightarrow C_6H_{12}O_6\,(180\ g) + 6O_2\,(192\ g)$$

$$\downarrow$$

Polysaccharides (162-g cellulose or starch)

As per equation (3), for every ton of CO_2 that is absorbed yields 0.73 tons of Oxygen (O_2) [63]. Therefore, the monetary value of O_2 generated for the different land-uses was estimated based on a product of the total amount of O_2 generation and the cost for a ton of commercial generation of oxygen in Ghana at GH₵31.6 ($6.4/t$O_2$) in 2018 (personal communication). Refer to Table 4, S4 and S5 for detailed

$$V = Q * P \qquad \text{Equation 4}$$

where:

V—Value of Oxygen (O_2) generated (GH₵ or $)

Table 3
Description of landuse and landcover types, extent and mean carbon stocks (tC/ha), and carbon dioxide equivalent.

Site	Landuse	Area (ha)	Mean (tC/ha)	Mean (tCO_2e/ha)
Owabi	Closed Forest	570.72	276.07	1013.18
	Open forest	1139.66	177.72	652.23
	Tree crop	223.00	85.44	313.56
	Food crop	1223.48	58.97	216.42
	Grassland	624.25	44.06	161.70
	Settlement	1986.14	18.40	67.53
Total		**5767.25**		
Barekese	Closed Forest	2743.98	168.36	617.88
	Open forest	3154.29	102.35	375.62
	Tree crop	1285.90	74.02	271.65
	Food crop	6999.51	57.50	211.03
	Grassland	1625.89	45.75	167.90
	Settlement	931.96	18.40	67.53
Total		**16,741.53**		**1711.61**

Source [58].

Table 4
Mean, total and economic value of Oxygen release for the different landcover types in the Barekese and Owabi watershed.

Site	Land use	Mean (tO_2/ha)	Total (tO_2)	Economic value (GH₵)	Economic value ($)
Owabi	Closed Forest	738.95	421,732.04	13.495 x 10^6	2.754 x 10^6
	Open forest	475.69	542,133.07	17.348 x 10^6	3.540 x 10^6
	Tree crop	228.69	50,998.85	1.631 x 10^6	333,053.72
	Food crop	157.84	193,117.79	6.179 x 10^6	1.261 x 10^6
	Grassland	117.93	73,620.26	2.355 x 10^6	480,785.36
	Settlement	49.25	97,818.72	3.130 x 10^6	638,816.12
Total			**1.379 x**	**26.793 x 10^6**	**9.008 x 10^6**
Barekese	Closed Forest	451.05	1.237 x 10^6	39,605 x10^6	8082 x 10^6
	Open forest	274.21	864,924.88	27.677 x 10^6	5648 x 10^6
	Tree crop	198.31	255,002.95	8.160 x 10^6	1,665x10^6
	Food crop	154.05	1.078 x 10^6	34,504 x 10^6	7.041 x 10
	Grassland	122.57	199,283.43	6.377 x 10^6	1.301 x 10^6
	Settlement	49.29	45,941.38	1.470 x 10^6	300,025.33
Total			**3.681 x 10^6**	**117.795 x 10^6**	**24.039 x 10^6**

Table 5
Cost of production (GH₵) for drinking water treatment for Barekese and Owabi dams within the watershed.

Year	Barekese (GHC)	Owabi (GHC)
2006	1.931 x 10^6	651,406.92
2007	2.146 x 10^6.	478,417.74
2008	3.578 x 10^6	549,102.75
2009	3.403 x 10^6	738,862.13
2010	5.395 x 10^6	825,776.43
2011	6.230 x 10^6	2,081,655.01
2012	5.758 x 10^6	1,596,251.49
2013	8.224 x 10^6	1,498,145.09
2014	29.107 x 10^6	3,014,017.23
2015	15.570 x 10^6	2,095,957.46
2016	20.643 x 10^6	3,043,563.00
2017	22.973 x 10	4,334,040.72
2018	22,0.047 x 10^6	4,450,488.87
Mean GHC)	**11.308 x 10^6**	**1,950,591.14**
Mean ($)	**2.307 x 10^6**	**398,079.82**
SE	**2.756 x 10^6**	**426,801.16**
Min	**1.931 x 10^6**	**478,417.74**
Max	**29.107 x 10^6**	**4,450,488.87**

Source. Ghana Water Company Limited, 2018 unpublished

Q—Quantity of Oxygen (O_2) generated (tons);
P— Unit cost of Oxygen commercially produced in Ghana (GH₵ or $).

Water purification value. The avoided cost method was used to calculate the service provided by the forest and land uses [66].

$$V = Q * P \quad \text{Equation 5}$$

where:

V—Value of water purification improvement by watershed.
Q— Total volume of water supply to households (m3);
P—Unit cost of water treatment (GH₵ or $)

2.2.5. Scenario setting

As global and local population increase and development have greatly accelerated the demand for Ecosystem supply services, land use change altered ecosystems [68]. Growing pressure on ecosystems has contributed to a decline in assistance, and flow of ESs [69, 70]. Thus, it is important to avoid, adapt to, or manage the risk of ecosystem degradation through scenarios of the future of ESs.

In many times, alterations in ecosystem conditions and services are incremental. Most of the gradual modifications were predictable. However, the degree of alteration is sometimes considerably large in scale and not easy, costly, or not feasible to reverse [26]. The Barekese and Owabi watersheds are at present experiencing the expansion of infrastructure development and agricultural expansion due of population increase and migration [54]. Therefore, we have fully considered the relevant planning and development policies of the local governments in the district. The scenario setting looked at potential ecosystem condition trajectories based on possible future pathways. We examined how variations in ecosystem conditions could affect ecosystem provision because of forest degradation and deforestation within the watershed. The scenarios developed for the study include a set of potential futures for the land cover in the watersheds. There is no particular year linked with the scenarios, however, a period of several decades (~50 years). An analysis of how these scenarios will affect the value of ecosystem services, particularly lost monetary values was conducted. Future

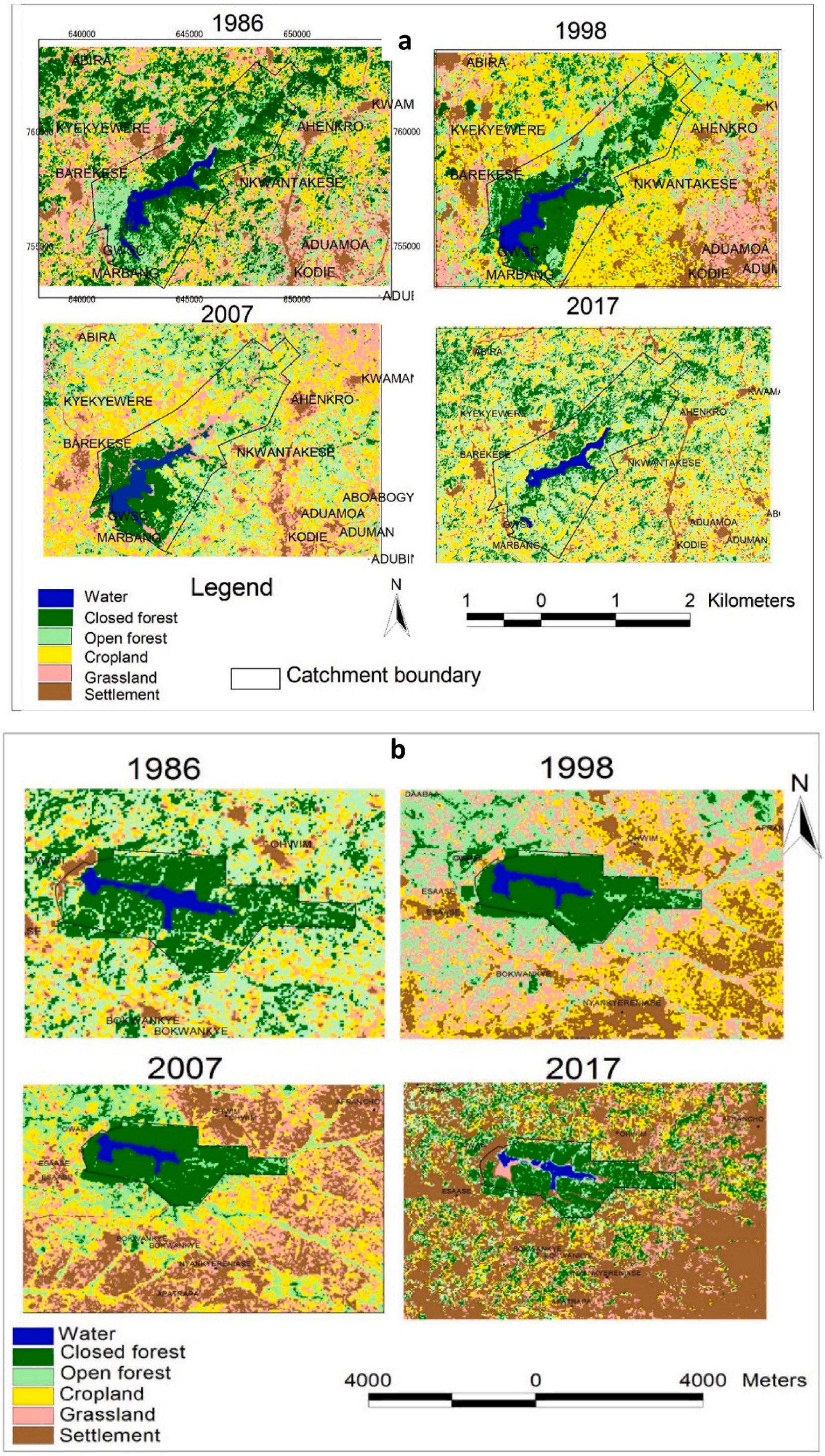

Fig. 2. Land use changes between 1986 and 2017 in the a. Barekese watershed and b. Owabi watersheds in Ghana.

state and trajectory for the watersheds are described below:

- **Scenario 1:** Current condition (Business As Usual): Mosaic landscape with multiple land use and vegetation cover types because of incremental changes in land use and land cover types
- **Scenario 2:** Improvement (Closed Forest): Reforestation through tree planting and natural regeneration of the watershed leads to increased cover over the entire land scape
- **Scenario 3:** Forest degradation (Open Forest): Degradation of primary closed canopy forest to secondary forest leading to large trees removed with open canopy forest being predominant
- **Scenario 4:** Pasture (Grassland): The landscape is dominated by grass but is denuded of tree cover or characterized by scattered trees in the landscape
- **Scenario 5:** Food security (Tree crop): Conversion of the watershed landscape for cultivating tree crops like cocoa, citrus, oil palm, etc., for livelihood
- **Scenario 6:** Food security (Food crops): Conversion of the watershed landscape for the cultivation of annual crops like Plantain, maize, etc., for livelihood
- **Scenario 7:** Urbanization (Settlement): A situation where the vegetation within the watershed may be converted to human settlements to provide for shelter

To assess the future changes in the economic value of ESs because of different management regimes, various scenarios (future outlooks) with different land uses were constructed. Inherently, the future is uncertain, with limited existing land-use models for the Barekese and Owabi watersheds ([19]). Furthermore, extrapolating historical trends does not appear to reflect possible long-term conditions for watersheds. As a result, the study employed hypothetical future trajectories for potential end situations. In this regard, these situations are not static for a given instant in time, rather depict a particular circumstance regardless of time. It is vital to note that these scenarios do not mean future forecasts (since this is fundamentally unpredictable).but rather serve as a “what if” that is, if land use ends up like this due to policies and management, “this or that” may occur to the value of ESs. The Scenarios were based on land use changes and socio-economic information collected during the study.

3. Results

3.1. Ecosystem condition

Analysis of changes in land use and ecosystem condition was conducted for four epochs (1986, 1998, 2007 and 2017) for the Barekese and Owabi watersheds (Fig. 2a and b; Table 6). The Barekese and Owabi watersheds experienced substantial changes in land uses between 1986 and 2017. Over fifty percent of the original forest was lost through forest degradation and deforestation. Most of the forest cover was converted to cropland and settlement. In the Owabi watershed, forest loss was mainly driven by the expansion of human settlements. Between 1986 and 2017. human settlements expanded exponentially by 12-fold from 184ha in 1986–2286.14ha in 2017 (Fig. 2a). The rate of deforestation is more rapid and extensive in the south-eastern part of the watershed. Similarly, over the same period, conversion of forest to cropland simultaneously occurred in the Barekese watershed. Also, the area under grassland almost doubled between 1986 and 2017 from 338.94 ha to 524.25 ha accordingly. On the other hand, the area under Cropland more than doubled from 3259.39 ha to 8785ha in 2017 in 30 years (Fig. 2b). Forest losses within the watersheds were mainly due to conversion of close forest and open forest categories. In case of the Barekese watershed, previously covered by grassland were also converted to cropland. Deforestation predominantly occurred in the western part of the Barekese watershed. Changes in ecosystem condition in the Barekese watershed over the last three decades have led to a considerable reduction in riparian forest. However,

Table 6
Spatial and temporal changes in land-use between 1986 and 2017 in the Barekese and Owabi watersheds. Area change with negative (−) signs represent a loss in area.

Site	Land-use	Area (ha)				Area change (ha)		
		1986	1998	2007	2017	1986–1998	1998–2007	2007–2017
Owabi	Wetland	56.79	67.98	57.5	64.41	11.19	−10.48	6.91
	Closed Forest	1098.9	683.7	654.8	470.72	415.2	28.9	184.08
	Open forest	3379.37	1281.21	1037.17	1139.66	2098.16	244.04	−102.49
	Cropland	765.72	1547.67	1341.72	1346.48	−781.95	205.95	−4.76
	Grassland	338.94	1313.44	1376.52	524.25	−974.5	−63.08	852.27
	Settlement	184.32	941.23	1357.04	2286.14	−756.91	−415.81	−929.1
Total		**5767.30**	**5767.30**	**5767.30**	**5767.30**			
Barekese	Wetland	265.20	300.4	310.15	184.58	−35.17	−9.75	−125.57
	Closed Forest	5031	2630.91	1601.79	2753.98	2400.09	1029.12	−1152.19
	Open forest	3759.39	2269.07	2903.94	2794.29	1490.32	−634.87	109.65
	Cropland	3447.09	7214.7	7964.94	8785	−3767.61	−750.24	−820.06
	Grassland	3529.8	2656.63	2671.63	1475.89	873.17	−15	1195.74
	Settlement	974.25	1970.22	1599.22	931.96	−995.97	371	667.26
Total		**16,741.53**	**16,741.53**	**16,741.53**	**16,741.12**			

riparian vegetation in the Owabi watershed compared to the Barekese watershed remained largely intact over the last three decades.

3.2. Ecosystem benefits

3.2.1. Provisioning services

A significant amountof provisioning services is derived from the two watersheds (Table 7). The community members are highly dependent on the watersheds for multiple products including drinking water, bushmeat, timber, snails, building poles, among others. Generally, the quantity of provisioning services extracted from the Barekese watershed was higher than those harvested from the Owabi watershed. A total of 800 m^3 of timber was estimated to be harvested annually within the Barekese watershed, but no timber extraction was recorded for the Owabi watershed. A total of 32.087×10^6 m^3 of water was annually consumed by beneficiaries from upstream and downstream communities from the two watersheds, but the quantities were considerably higher for water produced from Barekese compared to the Owabi watershed. Fuel wood harvested annually from the two catchment areas was 146.44 tons. Approximately 105 tons of fish were harvested from the two watersheds, but the quantity harvested from Barekese was significantly higher than that from the Owabi watershed. Concerning the amount of bushmeat extracted annually from the two watersheds, an estimate of 10.6 tons was estimated. The species extracted were mostly small mammals and primates. Bark, leaves and roots were extracted for medicinal purposes and were estimated to be 0.8 tons. A considerable quantity of building poles, mostly bamboos extracted annually, was 16 tons. Approximately 0.42 tons of snails are harvested annually from the two sites. The major food crops cultivated in the area include maize, plantain, cassava, rice and cocoa. These crops are estimated to annually yield 10,935.7 tons of food. Cassava is a major food crop grown within the watershed, followed by maize. A significant number of the community members are engaged in fishing and it is estimated that over 50 fishermen are involved in fishing activities.

3.2.2. Regulating services

Four regulating services were evaluated, including climate regulation (carbon sequestration), water purification, oxygen release and soil fertility. Regulating services generated by the Barekese watershed were generally higher than the Owabi watershed (Table 8). A total of 7.273x 10^6 CO_2-e was sequestered in the different land uses (Close forest, Open forest, Cropland, Grassland and Settlement) in the two watersheds.

Mean carbon values generated from field assessment in the landuses classes conducted within the two watershed (Ayesu, 2020) were used to calculate the contribution of the sites to carbon sequestration. The amount of carbon sequestered per unit area by the Owabi watershed generally (328 tCO_2-e/ha) was slightly higher than that within the Barekese watershed (301 tCO_2-e/ha). The contribution of the watersheds to oxygen release was estimated to be 5.060 x 10^6 tO_2 for the two sites (Table S4).

On the other hand, the water purification service was evaluated using the replacement cost based on the treatment costs required to improve water quality. The mean annual quantity of chemicals used in water treatment was 2757×10^6 kg of alum/polymer, hydrated lime, calcium hypochlorite, KMnO4 and chlorine gas. Other chemicals used were excluded either due to their negligible quantities or the lack of consistent in the data available between 2006 and 2018.

Soil fertility services analysis was based on annual crop fertilizer requirements (NPK) for major tree and food crops cultivated in the area. It is estimated that a total of 1.561×10^6 kg of fertilizer is applied annually within the two watersheds as the minimum quantity required to compensate for the erosion of soil nutrients through topsoil removal and the deficit in the rate of soil formation under crop land-use systems (Table S7). Detailed information on procedures is presented in the supplementary information.

Table 7
Type and quantity of provisioning services generated from the Barekese and Owabi watersheds in 2019.

Service	Unit	Annual harvest/consumption				Total
		Barekese watershed		Owabi watershed		
		Quantity/ha/yr	Total	Quantity/ha/yr	Total	
Timber	m^3	5.70	95,391.00			95,391.00
Water	m^3	1726.45	28.903 x 10^6	552.15	3.184 x 10^6	32,087 x 10^6
Fuelwood	kg	5.64	94,340.00	9.03	52,100.00	146,440.00
Bushmeat	kg	0.06	950	0.15	875	1825.00
Fishes	kg	17.92	300,000.00	17.34	100,000.00	400,000.00
Medicinal	kg	0.04	600	0.03	200	800
Building poles	kg	0.57	9500.00	1.13	6500.00	16,000.00
Seed/fruits	kg			0.23	1300.00	1300.00
Snails	kg	0.09	1545.00	0.32	1850.00	3395.00
Mushroom	kg	0.00		0.17	965	965
Maize	kg	446.24	7.470 x 10^6	214.39	1.236 x 10^6	8.707 x 10^6
Cassava	kg	2679.70	44.862 x 10^6	1287.44	7.424 x 10	52.287 x 10^6
Rice	kg	0.01	161.19	0.005	26.68	187.87
Plantain	kg	771.33	12.913 x 10^6	370.58	2.137 x 10^6	15.050 x 10^6
Cocoa	kg	49.47	828,162.84	23.77	137,065.71	965,228.55

Table 8
Type and quantity of regulation services generated by the Barekese and Owabi watersheds.

Service	Unit	Annual harvest/consumption				Total
		Barekese watershed		Owabi watershed		
		Quantity/ha/yr	Total	Quantity/ha/yr	Total	
Carbon sequestration	ton	301.17	5.042 x 10^6	327.94	1891 x 10^6	6933 x 10^6
Oxygen release	ton	219.88	3.681 x 10^6	239.18	1379 x 10^6	5060 x 10^6
Water purification	kg	153.08	2.562 x 10^6	33.70	194,381.83	2757 x 10^6
Soil fertility	kg	80.02	1.339 x 10^6	38.45	221,779.62	1561 x 10^6

3.2.3. Cultural services

The two watersheds serve as important sites for tourists annually because of the dams and the forest catchment at Owabi which is also a Wildlife Sanctuary/Ramsar site. Annually, a total of 6928 people visited the two sites (Table 9). The visitations to the Barekese watershed were approximately 20 times the number that patronized the Owabi watershed. Minimum and maximum visitations varied between 40 and 8450 tourists.

3.3. Economic value of ecosystem services

Here, estimates of the monetary value of ecosystem services are presented in Table 10 for the different categories of ESs in each site. The estimates were generated per unit area and total values. The net economic estimate of key ecosystem benefits generated by the two watersheds was estimated to be 707.701 x 10^6 (\$144.428 x 10^6) for the provisioning, regulating and cultural services. This value represents an aggregation of the total economic value of all the services assessed in the two sites. When disaggregated, the economic value of ecosystem services annually derived from the Barekese watershed of GH₵ 542.164 x 10^6 (\$110.645 x 10^6) was significantly ($t = 1.917$, $P = 0.03$) higher than the Owabi watershed value of GH₵165.537 x 10^6 (\$33.783 x 10^6). When the net economic value was calculated per hectare, GH₵ 28,703.00/ha/yr (\$5857.76/ha/yr) and GH₵ 32,384.41/ha/yr (\$6609.06/ha/yr) were estimated respectively for the Barekese watershed and Owabi watershed.

Among the three service categories, the regulating services contributed most (76%–89 %) to the monetary value of the services supplied by both watersheds respectively. Cultural services which mainly involved ecotourism contributed least to the monetary estimate of ecosystem services. Among the regulatory services, carbon sequestration and oxygen release contributed a significant proportion. Drinking water supply was the most prominent among the provisioning services in terms of its contribution to net economic value of GH₵ 9.226 x 10^6 (\$1882 x 10^6) and GH₵ 90.142 x 10^6 (\$18.396 x 10^6) for Owabi and Barekese watersheds. Apart from drinking water supply, cultivated goods also contributed substantially to the economic benefit derived from the two watersheds (Table 5). Harvesting of fish from the water represented a substantial income of GH₵3.516 x 10^6 (\$717,642.65) to the fringe communities. The annual average for the last five years' revenue of GH₵ 13,856.00 generated from ecotourism was very low. The analysis shows that the value of ES is significant not just for the local economy but also at the regional level.

3.4. Economic value under different land use scenarios

An analysis of the results of the seven scenarios were based on the monetary value of ecosystem situation are presented in Table 11. The assessment was carried using the business-as-usual (BAU)which represents the current condition of the watersheds situation as the baseline. Among the seven watershed management scenarios, the closed forest (\$ 229,280,619.39) yielded the highest net economic value benefit. Typically, the monetary value decreased with increasing forest degradation and intensification of land use. Settlement yielded the lowest monetary value (\$22,273,851.07) compared to the other scenarios considered for the two sites. The difference in economic benefit was significant between sites ($df = 1$, $F = 30.428$, $P = 0.000$) and among projected land-use change scenarios ($df = 6$, $F = 3.651$, $P = 0.003$). This means that forest degradation and deforestation may lead to a substantial decrease in the economic value of ESs. Using the BAU as the baseline situation, conversions of watershed vegetation to closed forest and Open form could result in 2.5 and 1.5 increase in ecosystem services whiles land use changes to Tree Crop, Food Crop, Grassland and Settlement reduced ES value by 4 %, 20 %, 48 % and 80 % respectively. Conversion of natural forest ecosystems to agricultural land, grassland and settlement scenarios resulted in negative monetary values for values (Fig. 3). Although generally we are confident the results presented are a meaningful comparison among the alternative states, there are varying degrees of uncertainty associated with the accuracy and precision of the data for each ecosystem service.

Table 9
Type and quantity of cultural services generated from the Barekese and Owabi watersheds.

Site	Product	Unit	Annual visits	Minimum	Maximum
Owabi	Eco-tourism	Number	257.00	40.00	386.00
Barekese	Eco-tourism	Number	6671.00	3400.00	8450.00

Table 10
Economic value of ecosystem services for the Barekese and Owabi watersheds.

Site	Service category	Product	GH₵/ha/yr		Total (GH₵)		$/ha/yr		Total ($)	
			Gross value	Net value	Gross value	Net value	Gross value	Net value	Gross value	Net value
Owabi watershed	Provisioning services	**Water**	1938.04	1599.82	11.177 x 10^6	9.226 x 10^6	136.25	12.47	2.281 x 10^6	1.882 x 10^6
		Fuelwood	78.03	54.62	450,000.00	315,000.00	5.49	3.84	91,836.73	64,285.71
		Bushmeat	10.14	6.59	58,500.00	38,025.00	0.71	0.46	11,938.78	7760.20
		Fishes	130.04	91.03	750,000.00	525,000.00	9.14	6.40	153,061.22	107,142.86
		Medicinal	1.06	0.74	6100.00	4270.00	0.07	0.05	1244.90	871.43
		Building poles	32.73	22.91	188,750.00	132,125.00	2.30	1.61	38,520.41	26,964.29
		Seed/fruits	4.78	3.34	27,540.00	19,278.00	0.34	0.24	5620.41	3934.29
		Snails	8.50	6.37	49,000.00	36,750.00	0.60	0.45	10,000.00	7500.00
		Maize	724.04	506.83	4.175 x 10^6	2.922 x 10^6	50.90	35.63	852,186.12	596,530.29
		Cassava	687.43	481.20	3.964 x 10^6	2.775 x 10^6	48.33	33.83	809,103.67	566,372.57
		Rice	0.03	0.02	157.15	110	0.00	0.00	32.07	22.45
		Plantain	509.04	356.33	2935 x 10^6	2.055 x 10^6	35.79	25.05	599,136.68	419,395.67
		Cocoa	6.27	4.39	36,170.12	25,319.08	0.44	0.31	7381.66	5167.16
	Regulatory services	Carbon sequestration	17,676.18	17,676.18	101,942 x 10^6	101.942 x 10^6	1242.70	1242.70	20.804 x 10^6	20.804 x 10^6
		Oxygen release	7500.74	7500.74	44,258 x 10^6	44,258 x 10^6	527.33	527.33	8828 x 10^6	8828 x 10^6
		Water purification	338.22	338.22	1950 x 10^6	1950 x 10^6	23.78	23.78	398,079.82	398,079.82
		Soil fertility	53.26	53.26	307,174.24	307,174.24	3.74	3.74	62,688.62	62,688.62
	Cultural serv.	Eco-tourism	0.41	0.41	2342.60	2342.60	0.03	0.03	478.08	478.08
Subtotal			**29,698.93**	**28,703.00**	**171.281 x 10^6**	**165.537 x 10^6**	**6061.01**	**5857.76**	**34.955 x 10^6**	**33.783 x 10^6**
Barekese watershed	Provisioning services	Timber	496.20	297.72	2861 x 10^6	1717 x 10^6	34.88	20.93	584,026.53	350,415.92
		Water (Pipe)	17,590.86	15,630.03	101,45 x 10^6	90.142 x 10^6	1236.70	1098.85	20.704 x 10^6	18.396 x 10^6
		Fuelwood	65.43	65.12	377,360.00	375,560.00	4.60	4.58	77,012.24	76,644.90
		Bushmeat	6.92	6.76	39,900.00	38,980.00	0.49	0.48	8142.86	7955.10
		Fishes	520.18	518.70	3.0 x 10^6	2991 x10^6	36.57	36.47	612,244.90	610,499.80
		Medicinal	2.08	2.08	12,000.00	11,975.00	0.15	0.15	2448.98	2443.88
		Building poles	82.36	82.33	475,000.00	474,820.00	5.79	5.79	96,938.78	96,902.04
		Fruits	11.70	11.66	67,500.00	67,225.00	0.82	0.82	13,775.51	13,719.39
		Snails	9.38	9.36	54,075.00	53,985.00	0.66	0.66	11,035.71	11,017.35
		Maize	2072.61	1450.83	11.953 x 10^6	8,367, x 10^6	145.71	102.00	2.439 x 10^6	1.707 x 10^6
		Cassava	3419.25	2393.48	19.719 x 10^6	13.803 x 10^6	240.39	168.27	4.024 x 10^6	2,817, x 10^6
		Rice	0.11	0.07	612.51	428.76	0.01	0.01	125	87.5
		Plantain	2798.83	1959.18	16,141 x 10^6	11,299 x 10^6	196.77	137.74	3294 x 10^6	2305 x 10^6
		Cocoa	1136.81	795.77	6.556 x 10^6	4.589 x 10^6	79.92	55.95	1338 x 10^6	936,612.73
	Regulating services	Carbon sequestration	47,127.49	47,127.49	271.795 x 10^6	271.795 x 10^6	3313.23	3313.23	55.468 x 10^6	55,468 x 10^6
		Oxygen release	21,371.94	21,371.94	123,257,347.50	123,257,347.50	1502.52	1502.52	25.154 x x 10^6	25,154 x 10^6
		Water purification	1960.83	1960.83	11.308 x 10^6	11.308 x 10^6	137.85	137.85	2307 x 10^6	2307 x 10^6
		Soil fertility	321.81	321.81	1855 x 10^6	1855 x 10^6	22.62	22.62	378,770.04	378,770.04
	Cultural serv.	Eco-tourism	2.31	2.31	13,342.00	13,342.00	0.16	0.16	2722.86	2722.86
Subtotal			**34,103.28**	**32,384.41**	**570.941 x 10^6**	**542.164 x 10^6**	**6959.85**	**6609.06**	**116,518 x 10^6**	**110.645 x 10^6**
Total			**32,974.79**	**31,441.15**	**742.222 x 10^6**	**707.701 x 10^6**	**6729.55**	**6416.56**	**151,473 x 10^6**	**144.428 x 10^6**

Exchange rate $1 = GH₵4.9 for 2018. Bank of Ghana.

Table 11
Net economic value (GH₵ and $) of ecosystem service value under different land-use scenarios.

Site	Service	Business-As-Usual	Closed forest	Open forest	Tree Crop	Food crop	Grassland	Settlement
Owabi	Provisioning	18.064 x 10^6	11,155 x 10^6	10.640 x 10^6	39.209 x 10^6	39.050 x 10^6	3.504 x 10^6	996,660.00
	Regulatory	148.249 x 10^6	460.070 x 10^6	299.387 x 10^6	140.719 x 10^6	97.165 x 10^6	78.086 x 10^6	30.882 x 10^6
	Cultural	2342.60	4685.20	1874.08	468.52	234.26	234.26	46.85
Subtotal (GH₵)		**166.316 x 10^6**	**471.230 x 10^6**	**310 × 029 × 10^6**	**179.929 x 10^6**	**136.215 x 10^6**	**81.591 x 10^6**	**31.879 x 10^6**
Barekese	Provisioning	34.338 x 10^6	102.699 x 10^6	58.357 x 10^6	54.670 x 10^6	116.335 x 10^6	12.270 x 10^6	1.699 x 10^6
	Regulatory	411.107 x 10^6	851.857 x 10^6	538.509 x 10^6	357,952 x 10^6	274,653 x 10^6	226.068 x 10^6	88.540 x 10^6
	Cultural	13,342.00	26,684.00	10,673.60	2668.40	1334.20	1334.20	266.84
Subtotal (GH₵)		**445.459 x 10^6**	**954.583 x 10^6**	**596.878 x 10^6**	**412.626 x 10^6**	**390.989 x 10^6**	**238.340 x 10^6**	**90.240 x 10^6**
Total (GH₵)		**611.775 x 10^6**	**1.425 x 10^9**	**906.907 x 10^6**	**592.555 x 10^6**	**527.205 x 10^6**	**319.931 x 10^6**	**122.120 x 10^6**
Total ($)		**124.852 x 10^6**	**290.982 x 10^6**	**185.083 x 10^6**	**120,929 x 10^6**	**107.592 x 10^6**	**65.292 x 10^6**	**24.922 x 10^6**

Exchange rate $1 = GH₵4.9 for 2018. Bank of Ghana.

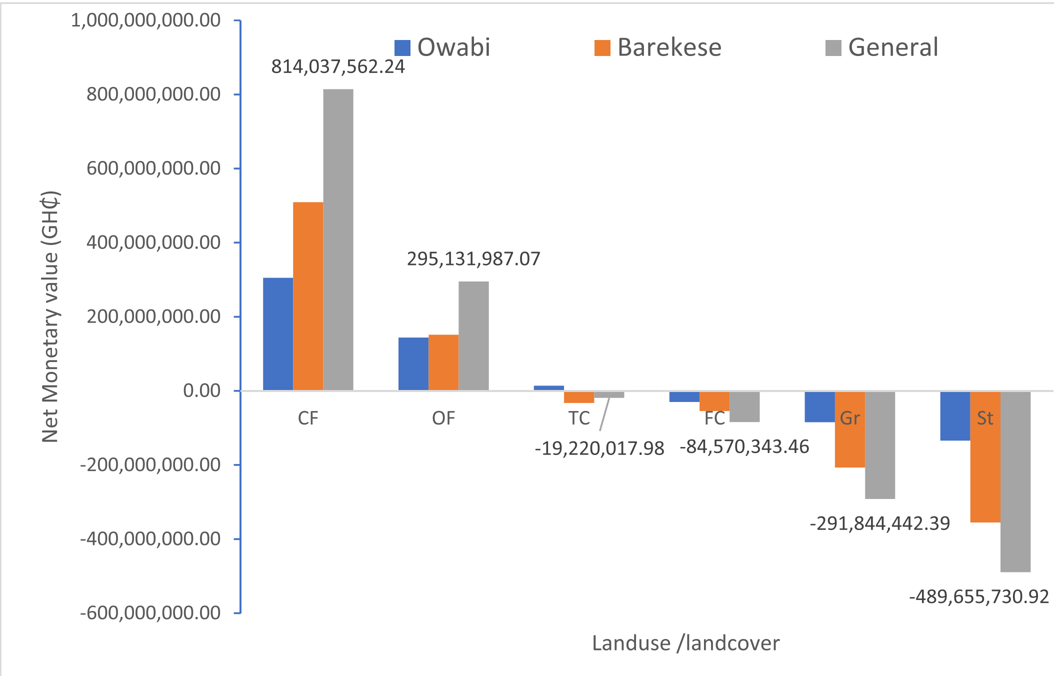

Fig. 3. Net monetary value under different land use scenarios in the Barekese ad Owabi.
watersheds using business -as-usual as the baseline condition. CF=Close forest, OF=Open forest, TC = Tree Crop, FC=Food Crop, Gr = Grassland and St = Settlement.

4. Discussion

4.1. Landuse change

The loss of natural forest cover has become a major concern in the twenty-first century. The watershed's deforestation rate of 33 % is significantly greater than the national deforestation rate of 3 % [48] and the annual deforestation rate of 0.6 % for Western and Central Africa [49,50]. Human activities have significantly altered the forest cover of the Barekese and Owabi basins throughout time. This finding is consistent with previous research that have demonstrated forest loss because of land use change [50,52,56,71]. These studies revealed that trends in land-use changes in most emerging countries tilted towards forest loss and the increase in farmlands and settlements. These land-use change trends have been consistent over the last three decades in the watersheds. Sadly, there is a change from undisturbed dense to open vegetation, intensively managed farmland, and settlements. This development is most evident in the Owabi watershed that is located in the southern portion of the Atwima Nwabiagya District. The Owabi watershed is a rapidly urbanizing area due to its closeness to the Kumasi Metropolis (densely populated) as opposed to the Barekese watershed that situated in the northern half which found in a more rural environment [54,57]. Evidence from other studies suggests that population increase, illegal logging, urbanization and wildfires are the main drivers of forest loss in the watersheds [43,48,52,53]. Furthermore, the cost of accommodation and land for building in the Kumasi Metropolis are very expensive and therefore many of people working this Metropolis consider the Atwima Nwabiagya District appropriate option because of its proximity with relatively cheaper residential facilities and lands [54,57]. Perhaps what is interesting is that most people moving to peri-urban areas due to urban-rural migration which has steadily been growing in Ghana because of increasing socio-economic development and urbanization [51,57,72]. Spatial patterns of changes in land use reflect the intensity and distribution of the interaction of humans and nature at various spatial scales [53,73]. It is therefore imperative that conservation measures are put in place to enhance protection and restoration of degraded areas in the watersheds [73,74].

4.2. Ecosystem services

The study provides detailed information on watershed level ecosystem services in the Owabi and Barekese watersheds. The study found that the local communities are heavily dependent on Barekese and Owabi watersheds for multiple ecosystem services notably water, timber, medicinal plants, building materials, bushmeat, among others. Over one million people are dependent on the multiple ES provided by the watersheds [43,57]. Beneficiaries of the ecosystem services range from rural, peri-urban and urban populations in the Atwima Nwabiagya District and Kumasi Metropolitan Assemblies. Though the watershed provides multiple benefits, food and water were found to be very important ecosystem services generated by the two watersheds. This predominance of food and water services partly is due to the construction of a dam within the two watersheds and the mosaic landscape characterized by extensive areas of cropland [52,54]. The dam service serves as major water source for industrial and domestic purposes. These ESs contribute significantly to meeting the basic needs of the local people including food, shelter and drinking water. The diverse benefits derived from the watershed demonstrated the diverse interest in the watersheds. However, there are crosscutting demands from a majority of the populace for food and drinking water which suggests that the people who live there are concerned about the availability of both [75,76]. However, some of the benefits provided by the watersheds contribute to mitigating global climate change through carbon sequestration and oxygen release. Though this study found the most extracted ES to be water and crop, this observation contrasts with a study conducted in the Atewa Range Forest Reserve in Ghana, where timber harvesting was the most extracted ES [19]. Other studies found that based on peoples' needs, impact, governance, demographic and socio-economic perspectives, people may place different demands on ecosystem services [77].

Recent research has shown that focusing on single ecosystem services might result in knowledge gaps that can only be addressed using integrative and holistic approaches to assessing numerous ecosystem services [75]. Watersheds are a highly productive, multifunctional, and valuable ecosystem that provides a complex array of goods and services to society. Several studies have highlighted the numerous benefits derived from ecosystems including carbon sequestration, seeds, fruits, bushmeat, feed and breeding grounds for fisheries and benefits that support subsistence and cash economies [19,78–80]. Other studies also found that homstead forest provided provided local people with vegetables, fruit, fuelwoods and timber [76,81,82]. [83] found that homestead forest in Fatikchari, Bangladesh were a source of raw materials including fuelwood, seasonal fruits, and building materials which was a major source of livelihood for the local people. The study provides evidence of the ecological and socio-economic importance of the Barekese and Owabi watersheds at local and regional level. These services are important for both upstream and downstream communities as well as critical for industrial and healthcare. It is important however, to note that describing, and where possible quantifying, these functions does not always entail that the functions can coexist under particular management regimes [84,85].

We also found that the quantity of product generated from the Owabi and Barekese watersheds were proportional to the size of the site. The Barekese watershed generated higher quantity of ecosystem services compared to the Owabi watershed and this was partly because the Barekese watershed covers a larger spatial area, approximately three times that covered by the Owabi watershed. Similar observations were made by [83] that total ecosystem services generated from homestead gardens were proportional to their size. Furthermore, the lower quantity of services recorded for the Owabi watershed could also be attributed to portions of it gazetted as a Wildlife Sanctuary which imposes restriction on entry and utilization of provisioning services [43,54]. The characterization of the ecosystem services generated by the Barekese and Owabi watershed is the first comprehensive assessment undertaken in these sites and the benefits highlight the importance of watersheds and therefore the need to conserve them [75] to ensure sustainable flow of these ecosystem services.

4.3. Ecosystem value

The Barekese and Owabi watersheds generate ecosystem services of enormous monetary value to society. The net monetary value of ecosystem services for the Barekese watershed was estimated to be GH₵542,164,572.55 ($110,645,831.15) and GH₵ 165,537,386.39 ($33,783,140.08) for the Owabi watershed. These estimates are considered conservative, because it largely excludes many other ecosystem services generated by the two watersheds. The value of the services is very significant within the context of the local and regional economy. There are few examples of studies that quantify and value the multiple ecosystem services in Ghana and in the tropics. The estimate for the Owabi watershed is less than the $90.4 million estimated for the Atewa Range Forest Reserve in Ghana [19] whiles the estimate for Barekese is higher. Our estimates are comparable other studies in Himalayan protected area, Nepal of

$1740 million [61], $ 217 million for six regulation services in the East Mau Forest Ecosystems in Kenya [63], between $ 1.427–1.482 billion for Japan in the Oku Aizu forest reserve [62], $ 62.04 million for the Dehdez forest in Iran [86] and $129.84 million for the Veun Sai-Siem Pang National Park [87]. [9] also estimated global ESs value to be USD 125 trillion/yr. It is evident from the various studies that there are large variations in the monetary value of ESs. Empirical studies vary widely in their use of evaluating techniques, the products and services valued, and therefore the type and geographical location of the ecosystem considered [9,19,55,88]. These variation in method, scope of ecosystem services and economic development of the countries have been acknowledged to influence the monetary value [61–63].

Interestingly, the monetary value of ESs produced by the two watersheds was related to the surface area, although this was not the only determinant variable. It has been observed that most values of ecosystem service have nonconstant returns to scale with certain values of service show lessening returns to scale, i.e., adding an extra area to a huge ecosystem increases the value of ecosystem services compared to a lesser ecosystem [6,61,88,89]. Other studies in Bangladesh and Kenya also made similar observations that ecosystem values are related to size [63,83]. The Barekese watershed, which comparably covers a bigger surface area than the Owabi watershed contributes $110,645,831.15 (79.3 %) to the total ES value of $144,428,971.23. Another reason for this outcome is that part of the Owabi watershed has been declared a protected area and therefore imposes restrictions on access to certain watershed resources by fringing communities and other users [54]. However, in the case of the Barekese watershed, there's virtually little restriction on the exploitation of forest resources because it wholly managed by the Ghana Water Company Limited which is mainly concerned with provision of drinking water and not forest management [54].

The analysis also revealed that cultivated crops and water consumption contributed significantly to the monetary estimate of ecosystem services within the watersheds. This observation could be attributed to construction of a dam in the two watersheds which serves as the main source of water for households and industries [57]. The Ghana Water Company Limited presently supplies water from the two dams to over 100,000 households (roughly over one million people) found in the Atwima Nwabiagya District Assembly and Kumasi Metropolitan Assembly [54,57]; and also, the vegetation cover is typically mosaic landscape, dominated by cropland due to spatial and temporal alteration in land use [52,54]. The croplands cover a substantial part of the watersheds more predominantly in the case of the Barekese watersheds and therefore contribute considerably to the value of ecosystem services.

Our findings also revealed that the per unit area value of GH₵ 32,384.41/ha/yr ($6609.06/ha/yr) and GH₵ 28,703.00/ha/yr ($5857.76/ha/yr) estimated for Barekese and Owabi watersheds respectively were higher than the $3896.55/ha/yr for the Atewa Range Forest Reserve in Ghana [19], but lower than the $ 17,016–17,671/ha/yr for a site in Japan (Ninan and Inoue, 2013) and $110, 000/ha/yr for Himalayan protected area, Nepal [61]. The per unit area monetary values for ES vary widely among studies conducted in different geographical areas and scales. Evaluating these differences in estimates, the challenges of the application of market and non-market valuation could be realized. These monetary values are sensitive to the methods used and prices of commodity [62]. Past studies that highlight the shortcomings of economic appraisal are numerous, taking note that the currencies used could be relatively unstable or subject to high inflation, the market-based approaches suffer from similar defects as the markets [62,90,91].

It is important to acknowledge that dynamic issues and environmental circumstances may also alter the supply and values of ecosystem services [62,91]. Likewise, the potential of ES provision and sustainable supply, demand and potential demand could frequently be unclear to decipher [21,92], and their varied application is commonly obvious in practice owing to the context from which the investigations emanate from [93]. Given that most watersheds are confronted with competing demands, it's important to explore possible other options for the conservation of these areas. Due to this, monetary valuation perspective could be a useful tool for translating the multiple benefits of ecosystems and their services for people and society into a common language. Furthermore, the valuation of natural capital or ES is a requirement for the creation of a market-based mechanism like payment of ecosystem services to incentivize conservation efforts and boost the flow of ESs [92,94]. Though characterizing the nature and benefits is seen as important, however, but valuation of ES in monetary terms may be more convincing in decision-making and, therefore, promote mainstreaming into policies [92,95–97].

It should be seen as a tool for supporting the watershed and nature conservation by recognizing its importance to the economy and society. Quantifying and estimating the price of watershed resources may provide additional information to support conservation goals such as protecting biodiversity and natural habitats. Assessing and communicating ecosystem values employing a monetary metric could also help increase awareness among policymakers and resource managers and assist in identifying social welfare-improving actions and decisions concerning nature conservation and its benefits. Particularly, when addressing ecosystem goods and services on spatial and temporal scales and where there is no market system, except in the case of many-provisioning services. However, it important to acknowledge in many cases, when assessing more complex services like regulation or cultural services, such valuation could also be neither suitable nor needed nor sufficient or practical [98].

Nevertheless, as has been highlighted in other studies, the interpretation of monetary value should be treated with care to avoid the commodification of nature, which is undoubtedly not the target [9,62,90–92].

4.4. Implications of land use changes on value of ES

The spatio-temporal changes in land-use have been reported to mediate the availability of several ESs and could either facilitate their loss or improvement [99]. Temporal changes in landscape pattern could disrupt various ecological functions and processes [45, 100]. These changes could, on the other hand, amplify the susceptibility of ecosystems and large fluctuations in ES supply [1,101]. In the past decades, the products and benefits that nature provides have greatly declined [1,45,62,101,102] due to conversion of forest ecosystems. Like several others [20,41], many tropical watersheds, including the case study sites, are found in areas that typically do not provide adequate conservation measures.

This phenomenon is also evident in the two watersheds where a significant area of forest has been transformed to cropland and settlements and in Ghana, where annual deforestation rate is 3 % [48]. The knock effect is that it affects the quantity of ES generated and monetary value. From the findings of the study, forest degradation and deforestation led to a reduction in the monetary value of ES generated by the Owabi and Barekese watersheds. In particular, the conversion of natural ecosystems to agricultural land > grassland > settlement led to reduction (negative value) in the monetary value of ESs. Previous studies elsewhere found huge differences in the total annual ESs values for four scenarios because of land-use and management decisions [9,45]. For instance, Costanza et al., 2014 estimated global ES values as $ 125 trillion/yr in 2011. This value represented a reduction of USD 20.2 trillion/yr from 1997 because of land use changes and management [9]. A change of USD 81 trillion/yr for the global ESs value was reported for the Fortress World and Great Transition scenarios and it indicated that this change could imply life or death for several people, particularly in poor countries [45,103]. Given the negative impact of land use change on watersheds [104,105], it's fair to say that watershed management strategies must change.

Inadequate consideration of integrated watershed ESs in management plans highlights a few of the common weaknesses of watersheds, including land use zoning, as a principle for ecosystem-based management [20,41,54,106]. There is increasing acknowledgment that measures to enhance the supply multiple ecosystem services are now desired at various scales [101,107,108]. Sadly, in most complicated social–ecological settings, where the link between people and nature are constantly shifting, our knowledge of social-ecological paradigms is usually not enough to foresee the outcomes of undesired initiatives. It evident in fast urbanizing watersheds where conflicts between ecological protection and socio-economic development exist, elucidating the linkages between ESs and human welfare is crucial for sustainable development [75]. Our findings will contribute to mainstreaming ecosystem service into development plans and watershed management plans. If the public and institutions understood the importance of nature in tropical countries like Ghana, it would entail more support for conservation and, because of that, an improvement in human wellbeing. In practice, there is a significant deal of attention in establishing the scientific foundation, financing mechanisms, and policies for incorporating natural capital into large-scale resource- and land-use choices [75,109]. Progressively, this study represents a major contribution to scientific knowledge on the importance of the bundle of ESs in the tropical regions.

4.4.1. *Limitation of the study*

The scenarios developed in this study were mainly based on linear pathways for a set of possible futures for land uses within the watersheds. There are no specific years linked with the scenarios, however, generally a period of many decades (~50 years) can be perceived. The scenarios were based on the assumptions that the watershed could in future be entirely covered by a single land use type. However, land use changes are non-linear and could proceed along different trajectories. Considering that different mechanistic pathways and drivers lead to varying outcomes [110], failing to integrate these the assessment of ES trade-offs and synergies that elucidates the intensity of the drivers is likely to lead to ineffective policy solutions [111]. Trade-off or synergistic linkages associated with ESs are induced by drivers such as environmental changes and policy decisions, and the processes. Failure to incorporate these complex relationships between mechanisms and drivers could lead to poorly informed conservation planning decisions. Linkages between ESs could happen as trade-offs. These connections are triggered by endogenous or exogenous modifications to an ecological system [110–112].

Land use change a critical factor in global change, is a subject that is receiving significant attention within the domain of modeling. In the past decades, several LUCC models have been developed to support land management and to improve understanding, evaluation and projection on the potential effect of LUCC on ecosystem functions. Several methods and models for LUCC modeling, most of those are empirical methods such as Land use Change Modeller [99,110,112], APOLUS [113,114], Cellular Automata [112,115], INVEST [116,117], ARIES [118], CLUE-S [119], DINAMICA EGO [120] and CA_MARKOV [121]. Modeling, mostly if conducted using a spatially explicit technique, is a vital method for exploring and projecting future alternative scenarios and for describing quantitatively important processes [110].

The LUCC models include a several methodological approaches, classified in numerous ways [99,122]. These models comprise either dynamic or static, non-spatial or spatial (studying patterns of modification or rates of alteration), deductive or inductive (focused on correlations vs. definite process descriptions), pattern-based or agent-based (i.e., simulation of decision-makers or underlying behavior inference). These models analyze large information i.e. biophysical and socioeconomic variables, remotely sensed images, scenarios, etc.), often integrated in GIS [99,112,123]. Some of the models integrate "top-down" and "bottom-up" procedures that can display different scenarios for various land use patterns and assessing the possible effects of LUCC in a spatially defined way [124,99,125].

It is acknowledged that the lack of application of some of these models in the current study as a major drawback to the generalization of the results and conclusions on its implications for watershed management within the Barekese and Owabi sites. Therefore, future scenarios regarding scenarios need to take into consideration the application of these models in the land use changes and the potential land use trajectories to effectively inform resource management and policy decisions.

5. Conclusion

The study represents a first attempt towards an integrated and comprehensive assessment of the benefits and value of the multiple ESs generated by the Owabi and Barekese watersheds. Land use changes have accelerated, and facilitated forest degradation and loss within the two watersheds.

Our analyses highlight significant ecosystem service benefits (provisioning, regulating and cultural services) from the Barekese and Owabi watersheds. These benefits are not only local (water users, bushmeat), but also global (biodiversity, climate regulation) in scale.

These benefits translate to a net economic value of ecosystem services GH₵ 707,701,958.93 ($144,428,971.23) generated annually by the two watersheds which illustrates its importance to society. The study demonstrates that forest degradation and deforestation could negatively affect the monetary value of ecosystem services. While this study highlights the importance and value of ES generated by the watersheds in moist forests, it also clearly illustrates the potential consequences of forest degradation and deforestation on the value of ES. Equally, forest degradation and deforestation will cause the global community to lose because of reduced climate regulation, whereas local communities would have gained by being able to increase their agricultural activities and fuelwood collection due to change in land use. The adverse impacts of changes in land-use could affect the health of downstream users (including over 1 million inhabitants in the Kumasi Metropolis) and the profits of the Ghana Water Company Limited (which would lead to increased cost of production). In addition, local and neighboring communities will lose access to the income associated with recreational visits.

The concepts of natural capital accounting are increasingly becoming valuable ways to pinpoint the degree of linkage between humans and nature. Quantification and monetary values of the ecosystem services also reflect the site's contribution to local and regional economic development, which should be considered by both policy makers and resource managers in resource management decisions. The application of ecosystem assessment and valuation tools could provide economic information critical in the planning of watershed conservation at a time when competing demands are growing steadily. It is recommended that future research could further explore the application of various modelling tools to evaluate trade-offs under different management objectives and their implications for sustainable management of the Owabi and Barekese watersheds.

Data and code availability statement

The manuscript standardized dataset associated with this article have been deposited at (https://datadryad.org/stash/share/OnhSv73dqfyu1z7vqvtnyo8782OXqdkRPrCBfJLIXJE)] with accession numbers [Dryad. https://doi.org/10.5061/dryad.5x69p8dcr].

CRediT authorship contribution statement

Samuel Ayesu: Writing – original draft, Software, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Olivia Agbyenyaga:** Writing – review & editing, Supervision, Methodology. **Victor Rex Barnes:** Writing – review & editing, Supervision, Formal analysis. **Adwoa Gyamfi:** Writing – review & editing, Methodology, Formal analysis. **Richard Krobea Asante:** Software, Methodology, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Samuel Ayesu reports financial support was provided by International Tropical Timber Organisation. Samuel Ayesu reports a relationship with International Tropical Timber Organisation that includes: travel reimbursement. No.

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Appendix A. Supplementary data

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