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THE VALUE OF SELECTED ECOSYSTEM SERVICES: A CASE STUDY OF EAST MAU FOREST ECOSYSTEM, KENYA

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ABSTRACT

The ecosystem services from Kenya's forest ecosystems have remained largely unmeasured and undervalued. Consequently, the benefits they provide are ignored in most forest management and conservation decisions. This has led to degradation and conversion to alternative uses. To provide a sound basis for decision making in forest management, it is important to estimate economic values provided by East Mau. This study relied on data collected from households using structured interviews and secondary data from published and unpublished sources. The total indirect use values (soil functions, hydrological functions, climate regulation values) from East Mau forest ecosystem was about US$219 million (KES 20billion). The economic values of nutrient cycling, erosion control, water flow and quality regulation were US$13.30, US$ 4.50 ha-1yr-1, US$ 1421.03 ha-1yr-1 and US $12.83 HH-1yr-1 respectively. The annual value for carbon sequestration and oxygen generation was US$3308.05 ha-1yr-1 and 1365.13 ha-1yr-1 respectively. These results provide valuable information on the magnitude of the selected ecosystem services that could be relevant in decision-making concerning conservation and management of East Mau forest ecosystem for enhanced ecosystem services and livelihoods.

Contribution/Originality: This study is one of very few studies which have quantified indirect use values of forest ecosystem in Kenya. The study has provided valuable information on the magnitude of the selected ecosystem services relevant to sustainable conservation and management of forest ecosystems for enhanced ecosystem services and livelihoods

1. INTRODUCTION

Forests are critical in provisioning of various commodities and services such as water, food, medicine, fuel wood, fodder and timber. Forests also provide a wide range of environmental services that support biodiversity conservation, watershed protection, protection of soil and mitigate global climate change [1, 2]. However, there is unprecedented increase in deforestation globally. It is estimated that 1 billion to over 6 billion ha of the global landscapes are degraded [3] resulting in diminished land productivity and impacting negatively on the flow of Ecosystem Services. For example, it is estimated that 60% of the ecosystems services are being degraded through unsustainable land use conversions leading to massive emission of Green House Gases [2]. It is estimated that one billion people live in degraded areas, which represent 15 percent of the Earth's population, and one third of the world's population is considered to be affected by land degradation [4]. This raises serious concerns about the sustainability of the various ecosystem services provided by the forest ecosystems.

Forest resources in Kenya contribute significantly to the natural resource-based economic production and consumption activities [5]. Mau Forest Complex (MFC) is one the critical forest ecosystems in Kenya. This forest ecosystem supports important functions, which provide critical ecosystem services and goods such as hydrological services, climate regulation, maintenance of natural cycles, conservation of biological diversity, maintenance of soil fertility, and wood and non-wood products. Most ecosystem services are not reflected in market decisions by individuals i.e. the markets fail to reflect the benefits of non-market ecosystem services due to the lack of information about their contribution to human welfare [2, 6, 7].

Forest use decisions that ignore these non-market benefits of forest ecosystems result in suboptimal resource allocation leading to detrimental environmental consequences [6, 7]. East Mau forest, part of the Mau Forest Complex in Kenya continues to face significant losses due human activities and conversion to alternative land uses. For example, in 2001, East Mau lost about 50% of its original size to human settlement [8]. Worldwide, quantifying the value of ecosystem services has become a critical tool in development of sustainable management of ecosystem services [7, 9, 10]. However, in Kenya knowledge on the magnitude and value of forest ecosystems services is still limited and consequently most policy decisions on management and conservation have often disregarded important ecosystem values. This paper provides estimates of selected ecosystem services that can assist in development of sustainable management of East Mau forest ecosystem for enhanced ecosystem services at different scales -locally, nationally, regionally and globally.

2. MATERIALS AND METHODS

2.1. Study Site

East Mau forest is located about 50 Km south of Nakuru Town at 35° 58' 00" E and 00° 32' 00" S, altitude range of 1200 and 2600m (Figure 1). It has an area of approximately 280 km². The forest is an important watershed within the Mau Forest Complex, feeding major rivers and streams that make up the hydrological systems of Lake Victoria and inland Lakes of Nakuru, Baringo and Natron.

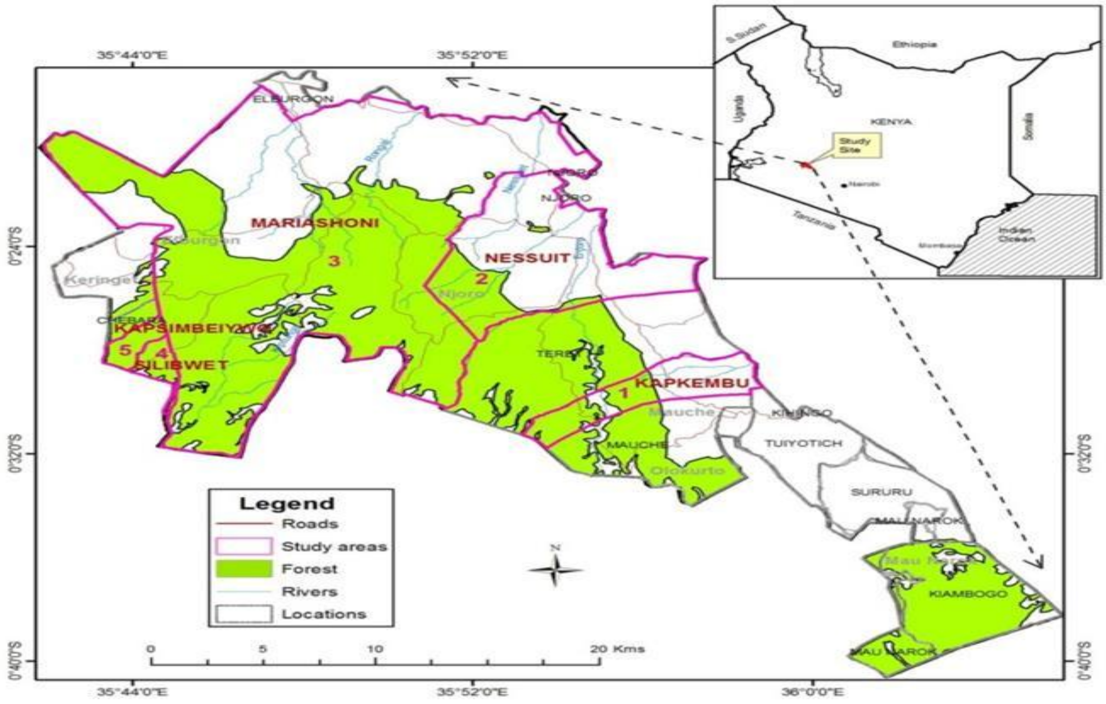


Figure-1. Map of the study area in East Mau forest in Kenya

Source: Data from Regional Center for Mapping of Resources for Development and own GIS mapping

The forest is home to indigenous forest dwellers – the Ogiek community. It is also an important habitat for the endangered mammals e.g. the yellow-backed duiker *(Cephalophus sylvicultor)* and the African Golden Cat (*Felis aurata*) and other important fauna such as: Giant Forest Hog, Gazelle, Buffalo, Leopard, Hyena, Antelope, Monkey and small animals like the Giant African Genet, Tree Hyrax, and Honey badger [11]. The climate within the study area is characterized by a trimodal precipitation pattern with the long and intense rains from April to June; short rains in August; and shorter, less intense rains from November to December with mean monthly rainfall between 30mm to 120mm and total annual precipitation of 1200mm. The mean annual temperatures range between12–16°C, with greatest diurnal variation during the dry season [12].

2.2. Data Collection

Secondary data was collected from published and unpublished. The data used in computation of economic values were those from the study site or similar sites in Kenya.

2.3. Valuation Methods

Regulation and supportive functions of forest ecosystem are not traded in the market and therefore it is difficult to attach monetary values but these functions and services are important for human wellbeing. However, economists have developed valuation techniques which are broadly categorized into 3; namely: stated preferences, revealed preferences and benefit transfer [13]. Cost based methods (replacement and avoided costs) are increasingly being applied to value ecosystem services [14] and these approaches were applied in this study. Due to complexities in ecosystem, they have been discussions on what to measure in valuation of ecosystem functions. Recent ecosystem valuation literature has emphasized the need to focus on the end products (benefits) to avoid the prospect of double accounting of ecosystem functions, intermediate services and final services [15, 16]. Forest ecosystem provides indirect use benefits through flows of services such as hydrological services (provision of quality and quantity water for human use and livestock, watershed protection), Soil functions (soil nutrient cycling, soil protection) and climate regulation (carbon sequestration, oxygen regulation) which in turn generate socio-economic value to the local and downstream populations [15-17]. Loss and damage to forest would affect those on-site and off-site in terms of livelihoods and economic options foregone from services provided by this forest ecosystem.

2.3.1. Determination of Economic Values of Selected Ecosystem Services

Soil Nutrient Cycling. The soil nutrient cycling value was estimated using replacement cost approach. The principle behind this approach is to calculate the cost of damage under consideration and to put the value on it using the equivalent cost of replacing the product or service [6, 18]. The economic value of nutrient cycling was determined based on assumed economic loss arising from soil and fertility if erosion occurred. Therefore, the soil nutrient cycling value of East Mau was estimated by determining the likely on-site effect of soil erosion due to deforestation by using data of soil loss for indigenous forest converted to agricultural use (without natural forest scenario) [18, 19] and estimating the soil nutrients loss and placing the value of the equivalent cost of commercial (artificial) fertilizer using the following steps: (a) using the mean soil loss per hectare (erosion rate) on different land use types [20, 21] (b) using nutrient loss data estimated from stream input loads to Lake Nakuru from River Njoro [22] (c) valuing the nutrient loss per hectare (loss of major nutrients i.e. nitrogen, phosphorus, and potassium) by taking the cost of each nutrient in commercial fertilizer replacement based on nutrient-fertilizer conversion ratios. These ratios were computed using the concentrations reported for commercial fertilizers and real prices of fertilizers for 2015 and (d) extrapolating to the entire area of East Mau forest.

Soil conservation value. The soil conservation value was estimated based on avoided cost of sediment removals from artificial reservoir [18] and applying the formula below:

$$V_k = K.G.(\sum_{i=0}^{n} s_i * [d_i - d_0]) \quad \ldots\ldots 1$$

Where:

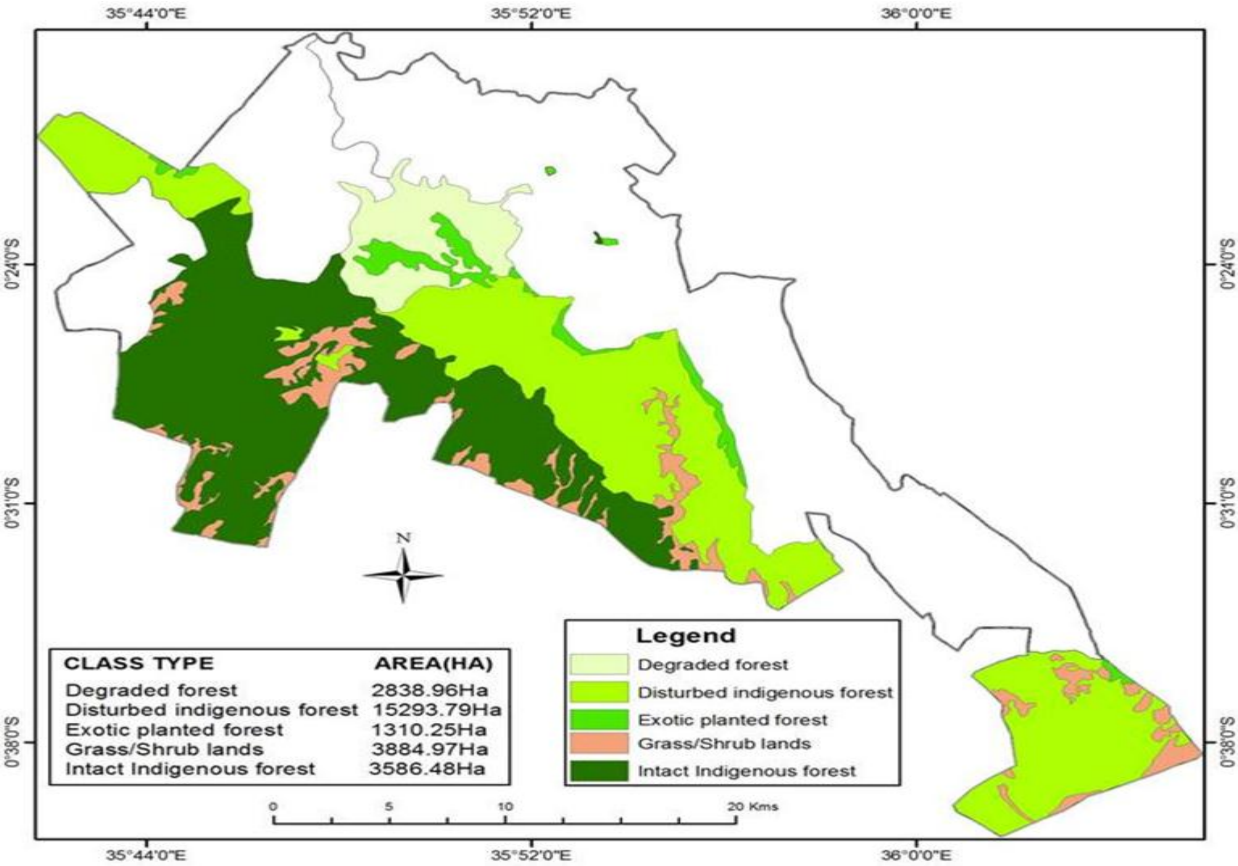
V_k _ Economic value of soil conservation; K - Unit cost of sediment removal [23] S_i - Area of forest of all types (ha); G - Ratio of amount of sediments reservoirs to total soil lost; d_i - Erosivity of all types of forest(t/ha); d_o - Erosivity of non-forest land (t/ha) (Agricultural land).

In this paper, the average cost of sediment removal in Kenya was taken to be KES 236.87m^{-3} or 178.09[1] /= per ton. This was based on average de-silting cost of Pans and Small Dams in Kenya for year 2010/2011 period [23]. Bulk density of 1330kgm^{-3} was assumed for sediment (Silt soil). The ratio of sediments entering rivers or reservoirs to total soil loss was assumed at 50% or G=0.5. The soil erosivity values were based on a study in East Mau [21, 22] (Table 1) and the area covered by each vegetation types of East Mau forest.

Table-1. Soil loss and runoff under different land use types in East Mau

Land use type	Soil loss(t/ha)	Mean surface runoff(ml)
Agricultural land	8.57	920.00
Deforested forest area	3.16	860.00
Grazing/pastures	1.48	1200.00
Exotic forest	0.06	380.00
Indigenous forest	0.00	20.00

Source: Okelo, et al. [21]; Okelo [20]



CLASS TYPE	AREA(HA)
Degraded forest	2838.96Ha
Disturbed indigenous forest	15293.79Ha
Exotic planted forest	1310.25Ha
Grass/Shrub lands	3884.97Ha
Intact Indigenous forest	3586.48Ha

Figure-2. Map of East Mau showing vegetation types and area coverage

Source: Data from Regional Center for Mapping of Resources for Development and own GIS mapping

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[1] This is equivalent to USD 1.8, based on exchange rate of 1USD= KES 100

The Regional Centre for Mapping of Resources for Development

Carbon sequestration value. Carbon sequestration economic value was determined based on published biomass and carbon stock data in forest vegetation from Mau forest and Kakamega forest in Kenya [24, 25] (Table 2). It was assumed that since, the East Mau study site is part of the larger Mau Complex-the biomass data for indigenous vegetation could be applied. Similarly, data on biomass and carbon stock of plantation species (Pines and Cypress) from Kakamega forest was applied. Kakamega forest has similar climatic and soil conditions to East Mau.

Table-2. Data used in estimation of Carbon sequestration value in East Mau

Vegetation/type	Mean AGB, Mg/ha	Carbon stock Mg/ha	Source(s)
Open forest	37.78	18.89	[24]
Moderately dense forest	71.56	35.78	
Very dense forest	265.90	132.95	
Bamboo forest/grassland	137.99	69.00	
Cypress plantation	267.20	133.60	[25]
Pine plantation	242.80	121.40	

Source: Kinyanjui, et al. [24]; Otuoma [25]

The carbon sequestration economic value was calculated in 4 main stages: (i) Determination of area covered by different vegetation types by delineating vegetation types using Landsat and GIS techniques and producing vegetation – area map (Figure 2). (ii) Assigning ecosystem-based carbon content values to these vegetation types by equating to a range of carbon content per unit area. Carbon stock was assumed to be 50% of the biomass density [26] (iii) Estimating the carbon content for each vegetation type and aggregating for the whole of East Mau and (iv) Calculating the CO$_2$ equivalent by multiplying per ha carbon stock by a factor of 3.7 [27]. The economic value of carbon sequestration potentials for each forest type was computed using the net production of forests each year using the formula 2 [18, 19].

$$V = Q * P * S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2$$

Where:

V—Release or absorption service value; Q-Carbon sequestration (CO$_2$); P—International carbon sequestration price; S—Area of each forest type (ha)

Price per unit of carbon dioxide in carbon market was based extensive review of literature on carbon trade. The cost of carbon sequestration varies from region to region, and also from country to country. The average price in the Clean Development Mechanism (CDM) was \$10.5 per ton of CO$_2$. The World Bank [28] reports indicated that the average price of carbon based on carbon tax is about US\$11.38 and the average price in the Emission Trading Schemes (ETS) cluster around US\$ 12/tCO$_2$. An average of carbon tax and ETS of US\$11.40/tCO$_2$ was adopted.

Oxygen generation value. Oxygen generation capacity was estimated based on carbon sequestration, using the photosynthesis reaction equation [18, 19].

$$6CO_2\ (264g) + 12H_2O\ (180g) \quad C_6H_{12}O_6\ (180g) + 6O_2\ (192g) \ldots\ldots\ldots\ldots .3$$

$$\downarrow$$

$$\text{Polysaccharide (162g cellulose or starch)}$$

According to the equation above, 1 ton of CO$_2$ absorbed will release 0.73 ton O$_2$. The Economic value of O$_2$ generation for all vegetation types were calculated using the total potential quantity of O$_2$ generated multiplied by the average cost of industrial oxygen production in Kenya at KES 580 (US\$6.45) per ton.

Water flow regulation value. The rainfall storage method was applied to estimate water flow regulation functions Xue and Tisdalle [18] and Xi [19] was adopted.

$$V = Q * C_{yt} \ldots\ldots 4$$

$$Q = S * J * R \ldots\ldots 5$$

$$J = J_o * K$$

$$R = R_o - R_g$$

Where:

Q—Increase in water preserved in forest ecosystems, compared to bare land (m^3);

S—Area under forest in ha (indigenous vegetation only) =31719.23ha (Fig.2)

J—Annual precipitation runoff of the study area =615 [20]

J_o—Annual precipitation of the study area =1500 [11]

K—Ratio of precipitation runoff yield to total precipitation of the study area; = 0.41

R—Beneficial coefficient of reduced runoff of forest to non-forest area

R_o—Precipitation runoff rate under precipitation runoff condition in grazing area (%) =80 [20]

R_g—Precipitation runoff rate under precipitation runoff condition in forests (%) =1.33

C_{yt}—Investment cost of reservoir construction per m^3=254.34 [23]

Water quality regulation value. The water quality service provision by the forest was estimated using avoided cost method [19].

$$V = Q * P \ldots\ldots 6$$

Where:

V—Value of water purification by forest; Q—Amount of water preserved in ecosystems (the households' consumption of the water supply); P—Unit cost of impurity removal for local water supply. The unit cost of treatment was obtained from local Kenyan data in a World Health Organization (WHO) report [29].

2.4. Results and Discussions

East Mau contributes to soil nutrient cycling and soil erosion protection. These values were estimated using replacement and avoided cost approaches. The average value of East Mau for soil nutrient cycling was about KES 1 378.15 (US$ 13.30 ha^{-1}yr^{-1}). The total value for East Mau was KES 44 100 832.44 (US$ 490 009.20). The soil protection value was about KES 14 996 853.96 (US$ 166 631.70) based on cost avoided in de-silting of dams equivalent to about KES 405 (US$4.5) ha^{-1}yr^{-1}). The nutrient soil value is substantially lower than US$26.3 ha^{-1}yr^{-1} for temperate Chilean rain forest [6] and US$1102 for Xishuangbanna Biodiversity hotspot in China [19].

This comparison showed substantial variation which may be partly explained by variation in environmental factors such as soil type, topography, rainfall, human agro-ecological and demographic factors of the different sites [30]. Estimating the economic impacts of nutrient loss and erosion are complicated by the fact that the impacts are time dependent and influenced by spatial scope and this was outside the scope of this study. None the less the soils functions values should be factored in the total economic value or otherwise the conservation area may be undervalued [31].

The role of East Mau in climate change was estimated based on avoided cost of climate change impacts through carbon sequestration and process of maintenance of oxygen cycle. The potential value of East Mau for carbon sequestration and oxygen generation values was estimated at KES 11billion (US$ 122,119,854.40 or US$3,308.05 ha^{-1}yr^{-1}) and 4.5billion (US$50million) or 1365.13 ha^{-1}yr^{-1}) (Table 3 and 4) and these two values account for about 80% of the economic value. These carbon sequestration and oxygen generation values are slightly higher than values reported of 2195 and 938 $ha^{-1}yr^{-1}$reported by Xi [19] and Ferraro, et al. [30]; Pearce [32] for tropical forests. The present values were estimated based on secondary data from studies in Kenya whose accuracy and applicability to the study area is not known and therefore there is a likelihood of over or under-estimation.

Table-3. Carbon sequestration value by vegetation type in East Mau

Vegetation type	Area(ha)	AGB (tons/ha)	Carbon stock tons/ha	CO_2 sequestration tons/ha	Value	
					(KES)	(US$)
Indigenous Intact forest	13,586.48	265.90	132.95	491.92	6,857,161,535.24	76,190,683.72
Disturbed indigenous forest	18,132.75	71.56	35.78	132.39	2,462,935,819.78	27,365,953.55
Bamboo/grassland	3,886.48	137.99	69.00	255.28	1,017,942,251.67	11,310,469.46
Cypress plantation	1,056.00	267.20	133.60	494.32	535,573,969.92	5,950,821.89
Pine plantation	254.25	242.80	121.40	449.18	117,173,319.39	1301,925.77
Total					10,990,786,896.00	122,119,854.40

Table-4. Oxygen generation values by vegetation type in East Mau

Vegetation type	Area(ha)	Carbon stock tons/ha	CO_2 sequestration tons/ha	Oxygen generated tons/ha	Value	
					(KES)	(US$)
Indigenous Intact forest	13,586.48	132.95	491.92	359.10	2,829,748,727.12	31,441,652.52
Disturbed indigenous forest	18,132.75	35.78	132.39	96.64	1,016,381,117.05	11,293,123.52
Bamboo/grassland	3,886.48	69.00	255.28	186.36	420,074,804.44	4,667,497.83
Cypress plantation	1,056.00	133.60	494.32	360.85	221,015,612.93	2,455,729.03
Pine plantation	254.25	121.40	449.18	327.90	48,353,979.95	537,266.44
Total					4,535,574,241.49	50,395,269.35

East Mau is an important watershed for Lake Nakuru, Baringo and major rivers originate from it. It is the source of Rivers Njoro, Makalia, Rongai and Mara river and therefore important in maintenance of water flows, water equilibrium and purification. The mechanism of watershed protection of forest is manifested in the retention of water by the crown, trunk, undergrowth vegetation, forest litter and soil through which water is relocated to regulate availability of surface water and runoff. The forest is often referred to as a "sponge" and "green reservoir" for its immense osmosis effect and watershed protection capacity [18, 19]. By regulating runoffs, forests can contribute to delay in flood peak and reducing flood volumes; in dry seasons, forests gradually release absorbed water to increase river flow and relieve droughts [30, 32].

Table-5. The potential water purification value of East Mau forest ecosystem

Parameter	Units
Daily water demand (litres/household)	87.80
Number of household neighboring Mau	43,527.00
Proportion of households sourcing from forest	0.68
Total water demand liters/day	3,821,670.60
Potential yearly water demand (L) (100% households)	1,394,909,769.00
Actual yearly demand of water from forest (L)	951,328,462.46
Unit cost of local water treatment system (KES)/litre [33]	0.045
Value of water quality purification (KES)	42, 640, 385.81
Value of water quality purification (US$)	47, 782.06
Value of water quality purification(US/household/year)	10.88
Value/hectare/year (US$)	12.83

Source: Household Surveys (2015) and own computation

The water flow regulation function of East Mau was estimated based on water storage [19] method and the total value of this service was found to be about KES 4, 056,671,002.27 (US $45,074,122.25) or equivalent to KES

127 893.11 (US$ 1,421.03) ha^{-1}yr^{-1}. The value for water purification was about KES 43million (for all household and translates to about KES 1000 (US $11.0) per household per year or US$12.83ha^{-1} (Table 5). This result is higher than reported values for watershed functions of US$85 per hectare of forest [30, 31] and 540 ha^{-1}yr^{-1} [19]. This study reported the gross values which might have caused overestimation. The water purification value of forest ecosystem of US$12.83ha^{-1} was lower than that reported by Elias, et al. [14] of US$ 123.80 to 250.90 ha^{-1}yr^{-1} and that US$ 3.64 to 165.96 ha^{-1}yr^{-1} reported by Pearce [32]. The values are varied depending on the method applied in valuation and nature of forest ecosystem under consideration.

The economic value of East Mau ecosystem services was about KES 20billion/year (US$ 219mill) (Table 6) with carbon sequestration and oxygen generation contributing (79%) of the total value. This was followed by water flow regulation functions (20.6%). The values reported in this paper were conservative estimates because not all ecosystem services were considered.

Table-6. Summary of elected ecosystem values of East Mau forest ecosystem

Ecosystem service	Value			% total
	KES	US$	US$ha^{-1}yr^{-1}	
Soil nutrient cycling	44,100,832.44	490,009.20	13.30	0.2
Soil protection	14,996,853.96	166,631.70	4.50	0.1
Water flow regulation	4,056,671,002.00	45,074,122.25	1421.03	20.6
Water quality regulation	42,460,385.81	471,782.06	12.83	0.2
Carbon sequestration	10,990,786,896.00	122,119,854.40	3308.05	55.8
Oxygen generation	4,535,574,242.49	50,395,269.35	1365.13	23.0
Total	19,684,590,213.00	218,717,669.00		100.0

NB: Conversion rate of 1US$=KES 90.00

3. CONCLUSION

The economic values of ecosystem services (soil functions, hydrological functions, climate regulation values) from East Mau forest ecosystem was about KES 20billion (US$219 million. The soils functions of East Mau totaled KES 59mil (US$660,000, water-flow regulation was about KES 4billion (US$ 45million), carbon sequestration-about KES 11billion (US $122million) and Oxygen cycling was about KES 4.5billion (US$50million). Carbon sequestration and oxygen generation values accounted for 80% of the economic value. The nutrient cycling, erosion control, water-flow and quality regulation values were US$15.31, US$ 101.1 ha^{-1}yr^{-1}, US$ 1421.03 ha^{-1}yr^{-1} and US $11.0 household^{-1}yr^{-1} respectively. The annual value for carbon sequestration and oxygen generation was US$3308.05 ha^{-1}yr^{-1} and 1365.13 ha^{-1}yr^{-1} respectively. This paper provides valuable information on the magnitude ecosystem service that could be applied decision-making concerning conservation and management of East Mau and similar forest ecosystem for enhanced ecosystem services and livelihoods.

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