THE VALUE OF FOREST ECOSYSTEM SERVICES OF MAU COMPLEX, CHERANGANY AND MT. ELGON, KENYA

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ABSTRACT

Ecosystem services from Kenya's forests have remained largely unmeasured and undervalued. Consequently, the benefits they provide are ignored in most forest management investment decisions.This has led to degradation and conversion of these forest ecosytems to alternative uses. This study was undertaken to value ecosystem services provided by the Mau, Cherangany hills and Mt. Elgon forest ecosystems. Primary data was collected from 1206 households and 148 forest product industry players using structured and semi- structured interviews. Secondary information was obtained from service providers, other published/ unpublished sources and from discussions with experts. Market *prices, Contingent valuation, Cost-based and Benefit Transfer (BT) techniques were applied in estimating total economic values.* Total Economic Value of the three ecosystems is about KES 339 billion (US$ 3.4 billion) per annum. Mau, Cherangany and Mt. Elgon ecosystems contributedKES 184 billion (US$ 1.84 billion), KES 42 billion (US$ 420million) and KES 115 billlion (US$1.15billion) respectively. In the three water towers, regulating services contributed the bulk of Total Economic Value (TEV) with 84% (Mau), 66% (Cherangany) and 93% 9Mt Kenya) underscoring the importance of indirect use values in forest ecosystems. Mau forest ecosystem had the highest regulation value of KES 162 billion followed by Mt. Elgon with KES 109 billion per annum and Cherangany at KES 30.6 billion per annum. Provisioning services contributed 10%, 23% and 4% of TEV for Mau, Cherangany and Mt. Elgon respectively. The TEV estimate from this study is very conservative because it did not encompass of all ecosystem service values. However, this study has provided vital that can assist conservation and management of the three water towers for enhanced livelihood and flow of ecosystem services.

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Keywords Forest, total economic value, ecosystem services, , , cultural, educational services

INTRODUCTION

Forests cover about 25% of the world's land mass and 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, protection watershed and soil and mitigation of global climate change (Landell-Mills and Porras, 2002). However, there is unprecedented increase in deforestation globally. According to the Food and Agriculture Organization (FAO), about 13 million hectares of global forests are cut down and converted to other land uses every year (FAO, 2006). In the period 1990 to 2000, the world lost about 3% of its forest cover to alternative land uses (Adams , 2012). This raises serious concerns about the sustainability of the various services provided by forest ecosystems.

Forest resources in Kenya contribute significantly to the natural resource-based economic production and consumption activities. Direct and indirect forest use values contribute 1% and 13% to Kenya's Gross Domestic Product (GDP) respectively (World Bank, 2000, UNEP, 2012). Mau Forest Complex (MFC); Cherangany and Mt. Elgon forest ecosytems are among five major Water Towers in Kenya. These ecosystems support important functions, that provide critical goods and services such as hydrology, climate regulation, maintenance of natural cycles, conservation of biological diversity, maintenance of soil fertility, wood and non-wood products. Most ecosystem services are not reflected in market decisions by individuals. That is, markets fail to reflect the benefits of non-market ecosystem services due to lack of information about their contribution to human welfare (Nahuelhual *et al.,* 2007; TEEB, 2010; Emerton, 2014; Langat, 2016).

Forest use decisions that ignore these non-market benefits result in suboptimal resource allocation leading to detrimental environmental consequences (TEEB, 2010, UNEP, 2012). The threewater towers face significant losses due to human activities and conversion to alternative land uses. For example, in 2001, East Mau lost about 50% of its original size to human settlement (UNEP *et al.,* 2005). Worldwide, quantifying the value of ecosystem services has become a critical tool in development of sustainable management of ecosystem services (MEA, 2005, TEEB, 2010, De Groot *et al*., 2012,). 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 study provides estimates of TEV of ecosystem services that can assist in development of sustainable management of three water towers in Kenya for enhanced ecosystem services at different scales.

RESEARCH METHODOLOGY

Study sites

General description of the study areas

The three ecosystems (Figure 1) form upper catchments for major rivers, originating as streams and gradually combining to form the rivers that drain into key water bodies. Most of the lakes fed by the rivers originating from the water towers are transboundary resources, making them important catchments not only for the country but also the region. The three water towers have unique fauna that contribute to tourism and foreign-exchange earnings in the country. However, the water tower ecosystems face immense challenges, including encroachment, conversion to agricultural land and human settlement, overgrazing, forest fires, and illegal harvesting and growing conflicts (KFS, 2015).

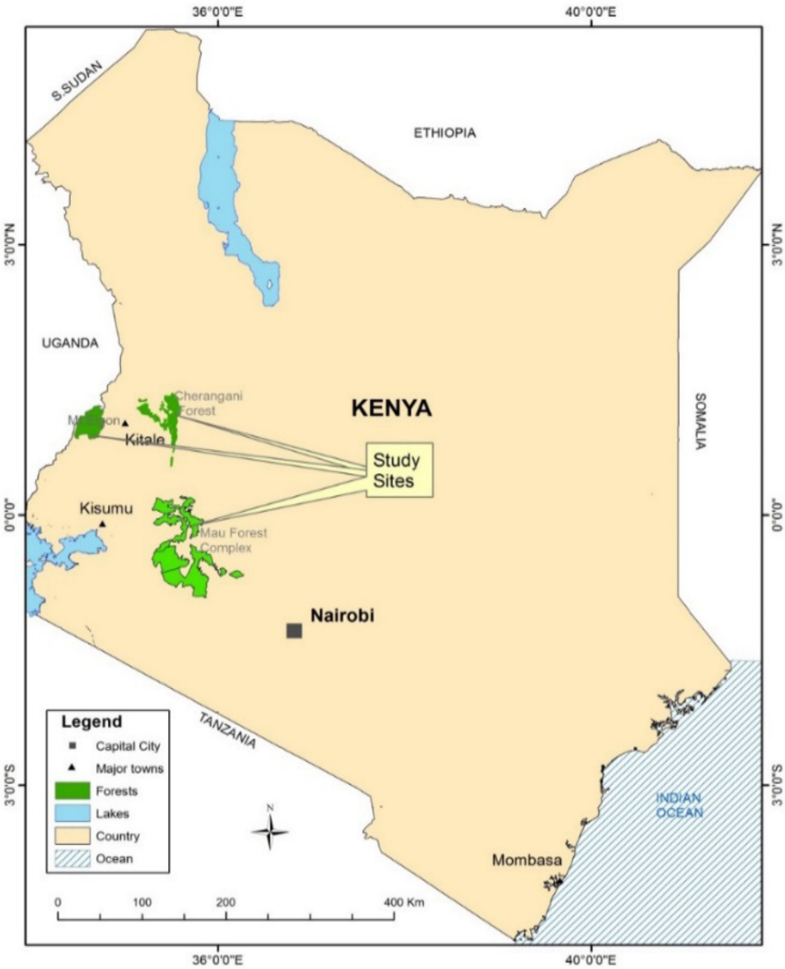

Figure 1. Location of Mau Complex in Rift valley, Cherangany Hills and Mt Elgon ecosystems in western Kenya: Source: Langat *et al*., 2019)

Mau Forest Complex

The Mau Forest Complex forms the largest closed-canopy montane forest ecosystem in East Africa, covering approximately 400,000 hectares. It is situated at 0°30' South, 35°20' East within the Rift Valley region. It is the largest water tower and is the source of twelve rivers which drain into Lake Baringo, Lake Nakuru, Lake Natron, Lake Turkana, and the transboundary Lake Victoria (Nabutola, 2010; Kipkoech *et al*., 2011). The rivers Makalia, Nderit, and Njoro support Lake Nakuru ecosystems- one of the largest bird sanctuaries in the world and an important tourism destination (Langat *et al.*, 2016). Additionally, it is the origin of the Mara River, which is a source of water for the wildlife and livestock in the extensive Mara River Basin and ecosystem—a world-famous site for viewing the spectacular wildebeest migration and other tourism attractions, besides a thriving livestock sector. In addition, the Mau complex has an estimated potential hydropower generation of approximately 508 megawatts (GoK, 2009). However, anthropogenic activities have led to drastic and rapid land fragmentation, deforestation, and destruction of wetlands in fertile upstream areas (Olang and Kundu, 2011). For example, in 2001, the Government excised over 67,000 hectares of forest reserve land, mainly in the Mau Complex (UNEP *et al.*, 2008). The forest is a habitat for wildlife and unique flora. The species diversity has sacred and cultural values to indigenous communities such as the Ogiek, who have lived in the forest and practice a hunter-gatherer lifestyle. The complex supports wood-based industries and trade, and many local communities depend on forest resources for their livelihoods (Nabutola, 2010; Langat *et al.*, 2016).

Cherangany Forest Ecosystem

The Cherangany forest ecosystem is located within an area defined at 1°16' North 35°26'East. The Cherangany forest ecosystem is comprised of forest reserves totalling 114,416 hectares (KFS, 2015) and has unique attractive recreation sites. The Cherangany ecosystem is the source of two major rivers the Nzoia and the Kerio, which drain into Lake Victoria and Turkana respectively. Other rivers include the Mara, Kapolet, Saiwa, Embobut, Siga, and Weiwei. The ecosystem has diversity of floral and animal species and makes its attractive for research and recreation (KFS, 2015). The Saiwa Swamp National Park, which is part of the ecosystem, is habitat to white colobus monkeys, otters, genets, mongooses, bushbucks, and De Brazza's monkeys, as well as the Sitatunga antelope. The bongo antelope (ungulate *Tragelaphus eurycerus*) has been recorded in the ecosystem in the past; although its current status is unknown, the unique fauna attracts tourists in the area. Regionally threatened species found in Cherangany include the bearded vulture (*Gypaetus barbatus*) nesting on the high peaks; the crowned eagle (*Stephanoaetus coronatus*); the red-chested owlet (*Glaucidium tephronotum*); and the purple-throated cuckooshrike (*Campephaga quiscalina*) recently recorded in Kapkanyar Forest. Endemic species in the ecosystem include butterflies like the *Capysjuliae*, which attracts scientists across the world (KFS, 2015). Nevertheless, the ecosystem is facing challenges pressing human activities.

Mt. Elgon Forest Ecosystem

The Mt. Elgon ecosystem lies between 0°52' and 01°25N, and between 34°14' and 34°44E. It is an extensive transboundary resource between Kenya and Uganda—covering 2,223 square kilometres, of which 1,078 square kilometres fall on the Kenyan side. The ecosystem covers an area of about 772,300 hectares—made up of 221,401 hectares of protected areas and 550,899 hectares of farmlands and settlements—of which 180,000 hectares of the forest are in Kenya (Langat *et al*., 2019). The forest is an important regional resource that directly and indirectly supports local .economies. In addition, the ecosystem provides biological, aesthetic, touristic, cultural, educational, employment, resource, and carbon sink values that are significant and could mitigate poverty and the likely negative effects of climate change.

The forest is rich in bamboo, which communities use for sturdy poles and nutritious bamboo shoots (SGS Qualifor, 2007). The Mt. Elgon ecosystem is habitat to 37 "globally threatened" species (22 mammals, 2 insects, and 13 bird species) and is also home to 9 endemic animals, making the area a priority for species conservation. The alpine chat, long-crested eagle, Cape Robin-chat, and yellow-whiskered greenbul are among the 240 documented bird species(Makenzi, 2016). A total of 67 reptiles and amphibians and 179 species of butterflies have also been documented in the Mt. Elgon region (Larsen, 1991; Davenport, 1996; Makenzi, 2016).

Conceptual framework linking ecosystem services and human well-being

There have been discussions in the ecosystem-services literature regarding the need for a unified conceptual framework linking nature's benefits to human welfare. One of the outstanding contributions in this area is the Millennium Ecosystem Assessment (MEA, 2005). The MEA and the total economic value framework (TEV) articulate links between ecosystem services and human well-being and livelihoods. The framework recognizes four main ecosystem values, namely: provisioning services (direct-use values), regulating services, supporting services, and cultural and information services.

Provisioning services include goods or products that are directly used or consumed—food, water, fiber, fodder, medicines, and so on. Regulating services are benefits people obtain as a result of nature's regulation of natural processes—water purification, water storage, climate regulation, erosion control, and so forth. Supporting services are the foundational building blocks of natural systems, including soil formation, nutrient cycling, and pollination. Cultural services refer to non- material or intangible benefits related to spirituality, heritage, aesthetics, recreation, and educational experiences.

Ecosystem services are often described as "direct" or "indirect" depending on the process by which people benefit from ecological processes and functions. Direct-use values include goods consumed, including most provisioning services such as timber, food, and water. Indirect-use values encompass many regulating and supporting services that result in the production of a tangible benefit, such as flood protection or pollination of crops. Non-use values reflect the importance attributed to an aspect of the environment irrespective of its direct use, such as the value placed on knowing that certain landscape features or species exist, even if we do not directly interact with them. The sum total of use and non-use values associated with a landscape is defined as Total Economic Value (Figure 2).

Primary data collection

Primary data was collected from forest-adjacent households of Southwest Mau, Cherangany, and Mt. Elgon.A cross-sectional survey design was used to collect forest use data from sampled households in each ecosystem using structured and semi-structured interview approach and Participatory Rural Appraisal (PRA) techniques from December 2016 to March 2017 (Chambers, 1994). The study population consisted of all households within the 5km distance from the forest boundary. The forest adjacent households in all the three water towers were delineation and mapped using Geographical Information System (GIS) techniques. The total forest adjacent population was estimated using the Kenya National Bureau of Statistics 2009, census data and extrapolated to year 2016. Selection of target villages was made in consultation with the local administration using multistage samapling procedure At the first stage, simple random sampling was used to select from sublocations adjacent to the forest. Secondly, villages were randomly selected frm each of the selected sublocations. Respondent households were selected from household list using simple random and systematic procedures. Villages from 17 sub-locations and 1,206 households were sampled (Table I).

Valuation techniques, data needs and sources

The valuation techniques, data need and sources were identified before the study and this informed the type of data to be collected and their sources. These were identified through rigorous review of Ecosystem Services literature, expert consultation and discussions with experts (annex 1) (Emerton, 2014).

Household forest use surveys

Structured closed questions and semi-structured questions were used to obtain quantitative data on forest use. Data on the following parameters weres collected: frequency of forest use, quantities collected per visit, time spent, number of household members involved, costs of forest activities, costs and benefits of conservation. Socio-economic and demographic data were also obtained from household surveys. The Contingent Valuation Method (CVM) was used to determine Willingness to Pay (WTP) for the maintenance of the forest for medicinal, cultural, and bequest values. CVM surveys were conducted according to the guidelines suggested in Mitchell and Carson (1989), Whittington (2002); Hanley *et al*. (2007), Ojeda *et al*. (2007), Ezebilo and Mattsson (2010), and Riera and Signorello (2013). This involved i) setting up a hypothetical market for medicinal herbs, cultural and bequest values, (ii) describing hypothetical scenarios on conservation measures and a description of a payment vehicle (levy); (iii) obtaining bids by asking respondents to state the maximum amount they would be willing to pay to achieve the conservation objectives; (iv) estimating mean WTP; and aggregating data to total population of the forest adjacent households.

TABLE I -SAMPLED HOUSEHOLDS STUDY SITES OF MAU , CHERANGANY AND MT ELGON ECOSYSTEMS

Forest Ecosystem	Forest Block	Sampled Sub-Location	Total Households	Sampled Households
Mau complex	Southwest Mau	Embomos	918	60
		Siomo	462	52
		Besiobei	696	56
		Chematich	1,150	65
		Chemare	2,789	224
	Subtotal		**6,015**	**457**
Cherangany	Kipkunur	Kipsaiya	532	35
		Kapsumai	1,108	53
		Kapsowar	1,508	83
		Kamasia	370	28
	Chemurkoi	Kibigos	904	63
	Toropket	Kokwongoi	274	18
	Kaisungur	Kimnai	639	44
	Subtotal		**5,335**	**324**
Mt. Elgon	Saboti/Kaboywo	Kaptaleli	713	49
		Kongit	1,071	65
		Kaboywo	823	59
	Trans Nzoia	Kiboroa	1,947	120
		Teldet	2,136	132
	Subtotal		**6,690**	**425**
	Total		**18,040**	**1,206**

Sources: KNBS, 2009, and households' own estimation, 2016

Wood industry and forest trade survey

Wood industry and forest trade survey was aimed at obtaining economic data on wood processing and trade within the major towns and townships adjacent to Mau, Cherangany, and Mt. Elgon ecosystems. To capture exhaustively the various players in the forest industry, a list of all the major timber-based enterprises in the three ecosystems was obtained from Kenya Forest Service (KFS), focusing on primary licensed wood processors (sawmills, plywood mills), integrated sawmills (large, medium, and small) and wood treatment plants. A twenty percent sampling intensity was applied for sawmills in Mau and Cherangany and 50% for Mt. Elgon. Sawmills in Mt. Elgon were small-scale and therefore sampling intensity was increased to compensate for the absence of the other large mill category. The sampling for the small-scale traders was challenging because most of the enterprises were informal and getting an accurate number was difficult and so a snowball sampling strategy with 5 to 10% sampling intensity was adopted due to time and logistical constraints. One hundred and forty-eight (148) forest enterprises were sampled: Mau (69), Cherangany (38) and Mt. Elgon (41) (Table II). The data obtained from wood processing players were: the volume of saw logs (m^3); the proportion of raw materials sourced from the respective forest ecosystem (Mau, Cherangany, and Mt. Elgon); the number of people employed in logging, processing, and sales; and the prices of various wood products. The survey also covered secondary players such as timber, charcoal, firewood, and construction-pole enterprises. The following data were collected from traders: the nature and volume of products (saw logs [m^3], poles [units/year], charcoal [kilograms/year], firewood [kilograms/year] and the number of people employed in processing and business.

TABLE II -SAMPLE SIZE FOR DIFFERENT FOREST ENTERPRISES IN MAU , CHERANGANY AND MT ELGON ECOSYSTEMS

Category of Forest Enterprise		**Number of Enterprises Within the Ecosystem**			**Number Sampled (n)**		
Mau		Cherangany	Mt. Elgon	Mau	Cherangany	Mt. Elgon	
Sawmills	Large	17	2	-	7	1	-
	Medium	62	6	-	13	5	-
	Small	73	43	12	13	4	6
Timber treatment plants		4	7	1	4	3	1
Small-scale enterprise	Charcoal	200	150	150	7	7	7
	Firewood	120	100	100	8	4	8
	Poles	100	100	100	9	6	9
	Timber	300	200	200	8	8	10
Subtotal					69	38	41
Total 148							

Sources: KFS records and own calculation, 2017

Participatory valuation techniques and expert discussion forums

Focus Group Discussions were conducted to establish the ecosystem services (ES) enjoyed by the forest-adjacent households and other stakeholders. The data collected was intended to complement household surveys, forest-products market surveys, and secondary datasets in order to estimate the total economic values (TEV) of the three ecosystems. The participants in the Focus Group Discussions included local administrators, Kenya Forest Service (KFS) officers, Community Forest Association (CFA) officials, Water Resource Users Association (WRUA) officials, religious leaders, village elders and key community leaders of all ages, and county government officers. The discussions were guided through a prepared check list and focused on the history of the ecosystem, products and services, and seasonal fluctuations and their relative importance to different stakeholders. To understand the importance of the products and services enjoyed by local communities from the forest ecosystems, the weighted ranking method (Pebble Distribution Method) was adapted (Lynam *et al*., 2006).

Secondary data collection

Secondary data on the importance of Mau, Cherangany, and Mt. Elgon forest ecosystems to the local communities and their livelihoods were collected from reports, bulletins, and documents from county government departments of agriculture, water, and energy; research organizations; journal articles; and online resources. Agricultural statistics on crop productivity, production costs, and market prices of crops and livestock were obtained from Department of Agriculture sub-county offices. The livestock data from forest-adjacent areas were obtained from the Kenya National Bureau of Statistics (KNBS) 2009 livestock census and extrapolated to 2016 using the 1990 to 2000 annualized livestock population growth rate in Kenya of 3.5 percent (FAO, 2005). The livestock population was converted to tropical livestock units (TLU) using livestock conversion factors (Jahnke, 1982). Livestock dry fodder and water requirements per tropical livestock unit per year were obtained from the literature (Ganesan, 1993). Hydrological data; water yields from rivers; uses related to subsistence, commercial, industrial, irrigation and volumes extracted per year; and borehole characteristics (water yields, costs of drilling and commissioning, and allowable abstractions per year) were obtained from the Water Resources Management Authority (WRMA), Water Service Boards (WSB), and Water Service Providers (WSP). Sediment yield data from various rivers originating from the three water Towers were obtained from published reports and scientific papers (Okelo, 2008, Okungu and Opango, 2005. Forest production data on the size of land under productive forests, harvestable volumes, value of sales per year, revenues from non-extractive uses, licenses and permits, land under Plantation Establishment for Livelihood Improvement Scheme (PELIS), crops grown and estimated production per unit area, and costs of operations were obtained from Kenya Forest Service (at the conservancy and county level (KFS unpublished data,. Tourism data were obtained from Kenya Wild Life Service (KWS , un published data).

Data analysis)

Computation model of total economic value of forests

Comprehensive value to forests include direct-use value (DUV), Indirect use Value (IUV), existence value (EV) and option value (OV). The TEV of forests can be calculated from a combination of all these values by the use of the model given in the form:

$$T_{—ev}=D_{uv}+I_{uv}+E_v+O_{v.........................} \quad 1$$

$T_{ev} = f\ (D_{uv}, I_{uv}, E_v, O_v)$ where, TEV -Total Economic Value; D_{uv} - Direct-Use Value; I_{uv-} Indirect-Use Value; E_v- Existence Value and O_{v-} Option Value

There are quite a number of methods that has been developed by economists to capture the total economic value of forests. Combinations of these methods have been used for this study. There is no one approach that can capture all the forest values. The Table III below shows applicable formulae for estimating ES values.

RESULTS AND DISCUSSIONS

The study identified a diversity of ecosystem services from the three water towers (Table IV; Figure 3). These were: provisioning services, such as fuel wood; construction materials (timber, poles, thatch); fodder; food (fruits, game meat); planted food crops); utility forest soils (murram for constructing roads and buildings, decorative soils); water (domestic, industrial, irrigation use); and hydropower generation. These ES contribute directly to the livelihoods of the local community members through consumption and as inputs to various livelihood activities. In addition, the ES contribute to economic sectors by supplying raw materials and inputs in production processes. The three water towers also support key agricultural sectors by providing irrigation water and soil nutrients. In addition, the water towers provide regulating services such as climate regulation, oxygen generation, water-flow regulation, and water-quality regulation and supporting services, such as soil conservation, nutrient conservation, and pollination. These ES are important to all stakeholders at different levels -local, regional, national, and global. The flow of these ES is important for various economic activities like agriculture, flood control, and provision of quality water for human well-being at different scales. These ES have indirect influences in productive sectors of the economy. For example, about 75% of the local population depends upon agriculture for their livelihoods (KARI, 2012). Furthermore, the water towers provide cultural and education services, such as spiritual, aesthetic, and bequest values. Though these ES are difficult to measure, they remain a very important component to satisfying human values.

The most important direct-use value for the local communities in Mau, Cherangany, and Mt. Elgon is animal fodder, with present values of KES 3.0, 2.2, and 1.0 billion respectively (Table IV). The animal browse and fodder constitutes about one-third of the total monetary value of products which is 30.9% total direct use value obtained by the communities from the water r towers. The weighted contribution of fodder to total household consumptive value is considerably high in all the three water towers, contributing 25%, 40 % and 32% respectively for Mau, Cherangany and Mt. Elgon (Table V; Figure 3). This data underscores the important role the forests play in supporting the livestock industry. The aggregate monetary value of fodder resources (browse and grazing) was KES 7billion. This study confirms that forest grazing contributes significantly to the local economies especially during dry seasons. Similar results were reported by Emerton (2001) and Langat *et al* (2016). Poles for construction and for cash income are very important to households, contributing about 20% to the aggregate monetary value. Water for human and livestock use accounted to 17.8% of direct use value by the local communities.

TABLE III- COMPUTATION MODELS FOR ES VALUES

Ecosystem Service(s)	Equation model	Explanations	References
Direct use Values			
Firewood, fencing/ constructions poles, forest honey, timber, thatching grass, game meat	$T_n=(Q_i*P_i)-C_i))*(\partial*N_i$	Where, Q_i is the quantity of good extracted; P_i is the forest gate price of the product (in the absence of externalities), C_i is the transaction cost (costs of collection, transport, and sale), is the proportion (percentage) of local households deriving benefit from the local forest, and N_i is the total number of forest adjacent (2016)	Godoy *et al*., 1993; Campbell and Luckert, 2002; Langat and Cheboiwo, 2010; Langat *et al*., 2016.
Herbal Medicine	V_m=∑i^n▒(W_i*N_i)	Vm- is the value of medicinal use; W_i- WTP, N_i- number of households in each ecosystems	Ezebilo and Mattsson (2010)
Fodder (Grazing/browse)	$E_f=\left[\frac{TLU*\beta*f_m*\alpha}{\partial}\right]*P_h$	Where E_f is the total value of forest fodder, TLU indicates the tropical livestock units sourcing fodder from forest; β is the proportion of forest fodder in livestock diet; f_m is the minimum fodder requirement for one tropical livestock unit; and α is the rate of technical substitution (RTS) of forest fodder to hay; is the weight of air dry hay (25kg),market price of hay	Ganesan, 1993, Jahnke, 1982, Hufschmidt *et al*., 1983; Emerton, 2001; Gunatilake, 1998; Mogaka, 2001; Emerton, 2014; Langat *et al.*, 2016
Water provision (human and livestock)	$E_{dw}=\left[\frac{(T_i*\delta_i)+(Q_i*N_i)}{\lambda}\right]*C_b$	E_{dw}- Value of domestic water, T_i- total TLUs; δ_i- Average consumption of water /TLU/yr, Q_i- Household consumption of water /yr, λ- average borehole yield/year, C_b- is the cost of drilling borehole and commissioning	Sjaastad *et al*.,2003, Bush, 2009, Padden undated
Industrial and commercial water	$V_{ic}=\sum_{i=1}^{n}(Q_i*P_i)$	Where V_{ic} is the value of industrial and commercial water abstraction, Q_i is the quantity of water and P_i is the current average unit price of water.	Langat *et al*., 2018
Hydropower generation	$V_e=P_e*Q_e$	V_e –is the value of hydroelectric power generated; P_e is the on –grid power tariff; Q_e- is the annual average quantity of hydroelectric power generated	Wang *et al*., 2010
Value added from wood industry and trade	$V_a=\sum_0^n(G_v-(M_c+S_c+FV_c)*N_i$	Where V_a represents the total value added, G_v indicates gross value, M_c signifies material costs, S_c represents the change in stock costs of materials and supplies, and FV_c stands for fixed and variable costs,	Langat *et al*., 2018
Indirect use values			

TABLE III- COMPUTATION MODELS FOR ES VALUES

Ecosystem Service(s)	Equation model	Explanations	References
Soil nutrient conservation	$V_f = d * S * \sum_{i=1}^{n} P_{1i} * P_{2i} * P_{3i}$	Where V_f is the economic value of soil-nutrient conservation of forest land; d-is the reduced erosion of forestland compared to agricultural or non-forest land (t/ha); S_i is the area of forest-vegetation types in hectares; P1i is the content of N,P,K in forest soils (%), P2i is the proportion of pure N,P, K converted to chemical fertilize, P3i is the local price of chemical fertilizer (KES/ton)	Xue and Tisdalle, 2001, Xia and Guangcan, 2002, Xi, 2009, Okelo, 2008, Okungu and Opango, 2005
Soil protection (erosion control)	$V_k = K * G \sum_{n=1}^{n} S_i * (d_i - d_0)$	Where V_k is the economic value of soil-erosion regulation; K is the cost of 1 ton of sediment removal; S_i is the area of forest-vegetation types in hectares; G is the ratio of sediment entering rivers or reservoirs to total soil lost; d_i is the erosivity of all forest vegetation types (tons/ha); and d_o is the erosivity of non-forest land, or agricultural land (tons/ha).	
Water-flow regulation	$V_f = S * (J_0 * K) * (R_0 - R_q) * C_{yt}$	Where V_f represents the value of water-flow regulation; Q represents the increase in water preserved in forest ecosystems, compared to agricultural land (bare land; m^3); S represents the area under forest in hectares (indigenous vegetation only); J represents the annual precipitation runoff of the study area; J_o represents the annual precipitation of the study area; K represents the ratio of precipitation-runoff yield to the total precipitation of the study area; R represents the beneficial coefficient of reduced runoff of forest to non-forest area; R_o represents the precipitation-runoff rate under precipitation-runoff conditions on agricultural land; R_g represents the precipitation-runoff rate under precipitation-runoff conditions in forests; and C_{yt} represents the investment cost of reservoir construction per m^3.	
Water-quality regulation	$V_p = Q_i * P_i$	Where V_p is the value of water purification by the forest; Q_i is the amount of water sourced by adjacent households from the water tower for domestic consumption; and P_i is the unit cost of water treatment.	WHO, 2008

TABLE III- COMPUTATION MODELS FOR ES VALUES

Ecosystem Service(s)	Equation model	Explanations	References
Carbon sequestration	$V_s = Q_i * P_c * S_i$	Where V_s is the release or absorption service value; Q_i is carbon sequestration (CO_2); P_c is the international carbon sequestration price; S_i is the area of each forest type (in hectares).	Kinyanjui *et al*. (2014) Otuoma (2015),IPCC, 2003; Olschewski *et al*., 2010, Xi (2009) Patton *et al*. (2011), World Bank (2014), CDP (2013), Environmental and Energy Study Institute (2012)
Oxygen generation	$V_o = Q_i * P_o * S_i$	Where V_o is the release or absorption service value; Q_i is O_2 generated P_o is the local price of industrial Oxygen in Kenya; S_i is the area of each forest type (in hectares).	Xi (2009), Langat *et al*., 2018
Microclimate influence agriculture	$V_t = \sum_1^n \{\varphi_i * \gamma_i * (P_i) - (C_i) * A_i\}$	V_t- Value attributed microclimate influence φ-factor contribution ratio; -crop yield; P_i- farm gate price of crop, C_i- unit cost of production; A_i-area under crop	Kipkoech *et al*., 2011
Pollination	$V_p = \sum_1^n \{\varphi_i * \gamma_i * (P_i) - (C_i) * A_i\}$	V_p- Value attributed microclimate influence φ-pollination dependence ratio; -crop yield; P_i- farm gate price of crop, C_i- unit cost of production; A_i- area under crop	Kasina *et al*., 2007
Non-use values			
Cultural and spiritual	$V_c = \sum_i^n (W_c * N_c)$	V_c- is the value of cultural use; W_i- WTP, N_c- number of households in each ecosystems using forest	Ezebilo and Mattsson (2010), Langat *et al*., 2018
Bequest	$V_b = \sum_i^n (W_b * N_b)$	V_b- is the value of medicinal use; W_b- WTP, N_b- number of households in each ecosystems	Ezebilo and Mattsson (2010), Langat *et al*., 2018
Option value (pharmaceutical value)	$V_{EM} = BV_{Cx} * \left[\frac{PPP_{GNP\,Kenya}}{PPP_{GNP\,Country\,x}}\right]^E$	Where V_{EM} is the biodiversity value of Mau, Cherangany, and Mt. Elgon forest ecosystems; B is the biodiversity correction factor for the study and policy site; V_{cx} is the Value transfer from study site (country) corrected to 2016; PPP GNP is the purchasing power parity gross national product per capita (World Bank, 2014); and E is the elasticity of values with respect to real income (assumed E=1.00).	Navrud and Brouwer, 2007; UNEP; 2011, World Bank, 2014, Ruitenbeek, 1989

The aggregate monetary value of these products for all the three ecosystems was estimated at KES 23 billion per year, with KES 12.5 billion, 7 billion, and 3.4 billion per year respectively for Mau, Cherangany, and Mt. Elgon (Table IV). The three ecosystems support various wood processing industries through provision of raw materials, creation of employment, and revenue sources to government agencies via permits and licenses. The estimated annual values in the three ecosystems were KES 10.7 billion, KES 3.4 billion, and KES 1.5 billion as valued added to the forest industry, wages, and revenue to government respectively. Furthermore, these ecosystems support small-scale traders, thus supporting livelihoods and local economies.

TABLE IV - AGGREGATE ANNUAL HOUSEHOLDS' CONSUMPTIVE VALUES (2017) PER PRODUCT IN MAU, CHERANGANY AND MT. ELGON ECOSYSTEMS

Forest Product	**Aggregate Annual Value (KES)**				
	Forest Ecosystem			**Aggregate Annual Value (all)**	**Proportion (%)**
	Mau	**Cherangany**	**Mt. Elgon**		
Animal fodder	3,183,031,000	2,808,086,125	1,095,020,804	7,086,137,929	30.9
Poles	2,380,586,000	1,359,887,743	847,733,944	2,257,118,687	20.0
Water	2,958,797,000	758,529,000	366,165,973	1,129,359,973	17.8
Firewood	2,094,128,000	389,615,459	482,308,193	921,173,652	12.9
Fruits	1,457,562,000	190,760,794	115,082,148	305,865,942	7.7
Honey	47,839,000	841,526,994	16,996,108	2,316,085,102	4.0
Charcoal	22,404,000	197,033,558	181,538,745	400,976,303	1.7
Game Meat	196,779,000	95,383,510	46,848,326	190,070,836	1.5
Medicine	15,287,000	225,206,693	88,421,877	510,407,570	1.4
Agricultural tools	60,811,000	64,357,033	76,102,335	201,270,368	0.9
Mushrooms	49,497,000	2,116,823	60,199,640	77,603,463	0.5
Fibers	49,250,000	5,642,414	11,969,635	2,976,409,049	0.3
Thatch grass	4,978,000	26,710,613	13,733,809	2,421,030,422	0.2
Timber	4,665,000	10,275,056	36,905,034	52,158,090	0.2
Murram/soils	23,000	1,202,152	592,815	2,095,922,967	0.0
Total	**12,525,637,000**	**6,976,333,967**	**3,439,619,386**	**22,941,590,353**	**100.0**

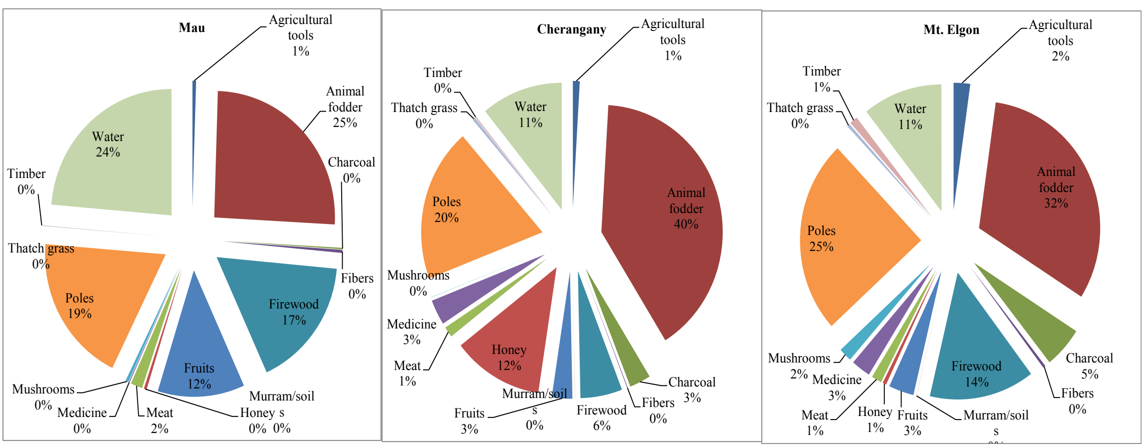

Figure 3. Weighted % contribution of product values to total households' consumptive values in Mau, Cherangany and Mt. Elgon

The study revealed that the total economic value (TEV) of the three ecosystems is about KES 350 billion (USD 3.5 billion) per year (Table V). The Mau forest ecosystem had the highest total monetary value, due to its large size and abundant resources available for various stakeholders. Moreover, the Mau complex neighbors high-population areas highly dependent on the resources. In terms of relative contributions to total value, regulating services comprise the greatest component of TEV at 88.8%, underscoring the importance of indirect-use values in forest ecosystems (Table V ;Figure 4). Provisioning services followed at 9.4%. These results are comparable to a similar study by Kipkoech *et al.* (2011) conducted in three areas of Mau—East Mau, Maasai Mau, and Trans Mara where indirect-use (regulating and supporting) and provisioning services contributed 86% and 12.4% to TEV respectively. The two studies have brought out the importance of indirect-use values, which were hitherto not valued. It should also be noted that Kipkoech *et al.* (2011) study did not exhaust all ES; hence, it inevitably underestimated the TEV of the water towers.

TABLE V- TOTAL ECONOMIC VALUE FOR MAU, CHERANGANY, AND MT. ELGON ECOSYSTEMS

ES Type	ES	Annual value(KES)	Annual value(USD)	% contribution TEV
Provisioning	Timber & non-timber	5,930,051,000	259,300,510	7.4
	Food production	634,770,000	6,347,700	0.2
	Water	3,427,027,000	34,270,270	1.0
	Hydropower	11,983,679,000	119,836,790	3.4
	Option value	309,665,000	3,096,650	0.1
		42,285,192,000	**422,851,920**	**12.1**
Regulating	Water flow	2,960,143,000	29,601,430	0.8
	Water quality	1,155,366,000	11,553,660	0.3
	Carbon sequestration	176,657,067,000	1,766,570,670	50.4
	Oxygen generation	118,461,049,000	1,184,610,490	33.8
	Microclimatic regulation	2,099,161,000	20,991,610	0.6
		301,332,786,000	**3,013,327,860**	**85.9**
Supporting	Soil conservation	1,060,000,000	10,600,000	0.3
	nutrient conservation	4,499,000,000	44,990,000	1.3
	Pollination	930,564,000	9,305,640	0.3
		6,489,564,000	**64,895,640**	**1.85**
Cultural	Cultural and spiritual	235,358,000	2,353,580	0.1
	Bequest	297,905,000	2,979,050	0.1
		533,263,000	**5,332,630**	**0.15**
	TOTAL	**350,640,805,000**	**3,506,408,050**	**100**

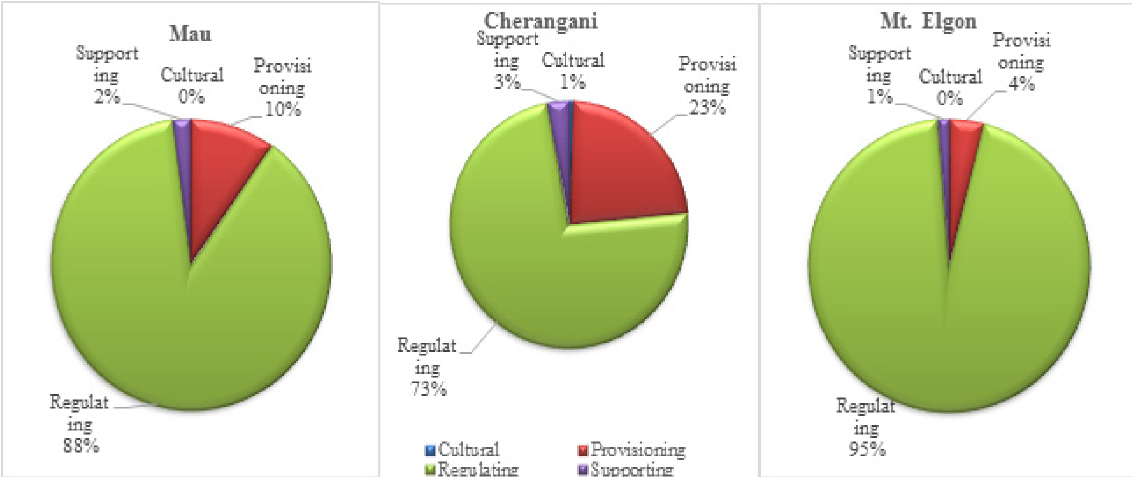

Figure 4. Weighted contribution (%) ES typoes to TEV in Mau, Cherangany Hills, and Mt. Elgon ecosystems

Distribution of benefits of ecosystem services in water towers

Determining the distribution of benefits among different stakeholders in society allows for quantitative analysis of externalities. The benefits valued in this study and where they accrue in the value chain (from local to global) are shown in Table V. Apart from supporting local communities and the national economy, the water towers are important to the global community because of their regulating and supporting services - public and global values.

TABLE V- DISTRIBUTION OF ES BENEFITS AMONG STAKEHOLDERS

Beneficiary	ES	Annual value(KES)	Annual value(USD)	% contribution TEV
Global	Biodiversity	309,665,000	3,096,650	0.1
	Carbon sequestration	176,657,067,000	1,766,570,670	50.4
	Oxygen generation	118,461,049,000	1,184,610,490	33.8
		295,427,781,000	**2,954,277,810**	**84.3**
Local	Cultural and spiritual	235,358,000	2,353,580	0.1
	Bequest	297,905,000	2,979,050	0.1
	Timber & non-timber	25,930,051,000	259,300,510	7.4
	Food production	634,770,000	6,347,700	0.2
	Water	3,427,027,000	34,270,270	1.0
	Soil conservation	1,060,000,000	10,600,000	0.3
	Nutrient Conservation	4,499,000,000	44,990,000	1.3
	Pollination	930,564,000	9,305,640	0.3
		37,014,675,000	**370,146,750**	**10.6**
National	Hydropower	11,983,679,000	119,836,790	3.4
	Water Flow	2,960,143,000	29,601,430	0.8
	Water Quality Regulation	1,155,366,000	11,553,660	0.3
	Microclimatic Regulation	2,099,161,000	20,991,610	0.6
		18,198,349,000	**181,983,490**	**5.19**
	Total	**350,640,805,000**	**3,506,408,050**	**100**

Beyond ecosystem services valuation: policy implications and recommendations

The economic benefits supplied by the water towers ecosystems play a significant role in the livelihoods of local, regional, and national communities, while also contributing significantly to national GDP. Decision making on the sustainable management of these ecosystems can be anchored in these derived economic benefits. Policymakers, including county and national government officials, should therefore fully consider the spatial and temporal ecosystem service provisions in their development plans, and they should consider intelligent resource allocation that reflects the ecological and socioeconomic importance of the Water Towers ecosystems.

Data collected in this study highlight the importance of understanding community dependence on forests when making decisions about natural-resource management. The ways in which households rely on forests, as well as threats to those benefits, vary in space and time. Development efforts are well-served by accounting for the ecosystem service tradeoffs involved at local, regional, and national scales due to the loss of natural forest cover. This study can inform decisions on community dependence and ecosystem resilience as well as promote participatory forest management, as recommended by Kenya's Vision 2030. Ecosystem service values identified will inform public and private investments in water towers conservation. The Kenya Water Towers Agency Strategic Plan 2016–2020 (KWTA, 2016) highlights the importance of ecosystem services valuation in supporting county-level integrated development plans and ecosystem management plans. In addition, the Kenya National Forest Programme 2016–2030 (GoK, 2016) also highlights challenges in forest financing, including; inadequate synthesized data on the TEV of forests and their contribution to the national GDP.

Kenya's Constitution and Vision 2030 target a 10% forest-cover commitment for the country, but without real evidence on the contribution of forests to the national economy, action to meet this goal cannot be effected. This study contributes a more accurate reflection of the contribution of the Kenya Water Towers to the national GDP, and can therefore influence attitudes at all levels and increase commitments to the sustainable management of forest ecosystems that comprise the most significant water tower landscapes in the country.

To further improve upon these assessments, there is need to:

- Improve data collection, storage, and sharing among all stakeholders in the natural-resource sector. For example, the authors faced challenges in accessing existing data on water resources and tourism, while data on livelihoods and the forest industry are poorly developed.
- Build capacity on data collection, processing, use, and reporting for all of the stakeholders, including local, county, and national community-based organizations, such as community forest associations, and water resource users associations.
- Promote collaborative engagement between national-sector agencies and the county governments in information-gathering analysis and use. The disconnect between national government plans and the expectations of the local communities and county governments—for instance, the construction of dams in Itare and Bosto in the Mau ecosystem—highlights this need.
- Incorporate ecosystem-service mapping to identify both strategic areas providing key services and hotspots for intervention measures. A recent unpublished study by CIFOR in Southwest Mau shows an increase in forest degradation, associated with the production of charcoal and domestic energy demand(Cited in Langat *et al*., 2019). This degradation ultimately affects ecosystem-service provisioning. Continuous mapping of the changes in ecosystem integrity and function is needed to define the capacity of the ecosystem to provide various services.
- Develop a continuous monitoring system that considers the effects of climate change on forest conditions, as well as the benefits they provide.
- Accelerate and promote activities aimed at rehabilitating degraded sections of the water towers ecosystems to enhance resilience and adaptation while ensuring the flow of ecosystem services from these landscapes. The government of Kenya has pledged to restore 5.1 million

forest hectares by 2030. This would produce an estimated USD 1,601 million in economic benefits while also sequestering 0.48 gigatons of carbon dioxide.[1] Activities that contribute to this goal, such as the Initiative for Sustainable Landscapes (ISLA Kenya) supported through the Sustainable Trade Initiative aims to restore and conserve 60,000 hectares of the forest by 2030 (www.idhsustianabletrade.com).

- Rehabilitate and protect forests to ensure sustainable ecosystem-service flows. Deforestation is a particular concern in the Mau complex. A recent study by Bewernick (2016) shows a high level of degradation due to charcoal production. A recent study by Otuoma *et al.* (2012) in Southwest Mau indicates a likely loss of water supply and water-quality regulation, due to degradation, as compared to natural forest cover.

- Develop and promote public and private partnerships in ecosystem conservation to ensure the sustainable flow of services from the water tower ecosystems. The public sector has a relatively limited appreciation of the benefits of such partnerships, while the private sector still does not fully realize how much their various economic sectors depend on ecosystem services, such as flash-flood protection, water inputs, and energy supply (Rhino Ark, 2015) Understanding relationships between land-management practices and ecosystem-service benefits can provide a platform for watershed investments at various scales, from community-based programs to landscape-level restoration.

It is important to consider how this ESV assessment contributes to Kenya's capacity to assess its natural capital, a key recommendation in the Kenya Biodiversity Atlas. As these water towers fall under the jurisdictions of various counties, this assessment can inform county-level natural-capital accounting to develop strategies, incentives, and programs that increase the flow of ecosystem services, community empowerment, and sustainable resource use. In partnership with other stakeholders, including community-based organizations, county governments could use this assessment to identify and improve the recording and mapping of ecosystem-service flows. The valuation reported here can also contribute to achieving objectives under the Sustainable Natural Resources Management Thematic Area of the government of Kenya's Green Economy Strategy and Implementation Plan, 2016–2030 (GESIP), recently launched and the Kenya Water Master plan (MENR, 2012). The GESIP specifically outlines the need for a natural-resource accounting system, as well as the application of payment for ecosystem services (PES) programs. Quantifying and valuing ecosystem services flows economically are important preliminary steps in undertaking PES programs to ensure their effectiveness.

CONCLUSION

Countries across Africa and around the globe are increasingly recognizing the critical importance of natural capital to achieve sustainable development goals. Understanding human dependence on forests and the benefits forests provide serves both economic and conservation objectives. This study assessed the value of Kenya's Water Towers at various scales, from their importance for household well-being to their global contribution to climate regulation. This information can form a strong basis for natural-resource management at county and national levels to support an integrated approach to natural-resource stewardship. This study highlights the relevance of forest lands to diverse constituencies as a means to ensure Kenya's social and economic future.

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1 For more information, visit www.bonnchallenge.org/content/kenya.

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ANNEX 1. VALUATION TECHNIQUES, DATA NEEDS , AND INFORMATION SOURCES USED IN ESTIMATING ECOSYSTEM SERVICES VALUES OF MAU COMPLEX, CHERANGANY AND MT. ELGON FOREST ECOSSYTEMS

Ecosystem services	Valuation techniques	Data needs	Data sources
Direct-use values			
Firewood, fencing/ constructions poles, forest honey, timber, thatching grass	Market prices	% of households collecting product; amount harvested; amounted extracted by sawmills; market prices; collection and operation costs	Household surveys; focus group discussion with forest-adjacent communities; KFS records, key informants
Game meat, fruit/ vegetables, fodder	Market prices of substitute or surrogate/ proxies	% of households collecting product; amount harvested; proportion of fodder resources sourced from forests; dry matter requirements per tropical livestock unit (TLU); market prices of substitutes; relevant conversion factors; collection/ production costs	Household surveys, FGD with forest-adjacent communities, literature and expert discussions, institutional records (KFS, KWS, county governments etc.), relevant projects reports
Medicinal herbs	Contingent valuation method (CVM)	% of households collecting product; mean WTP of target population	CVM surveys, census data (KNBS)
Water provision (human and livestock)	Replacement cost	number of households; household water demand /yr; total livestock units; annual livestock water demand; mean yield of local boreholes ; total water demand (human and livestock)	Household surveys, literature, expert consultations, water service boards, engineering estimates (hydro-geologist/ engineers), CCVA study
Industrial/irrigation water use	Market prices	Volume of water extracted by industries, unit price of water charged by WRMA, WSP	WRMA, water service providers (WSP), Irrigation Board, private farms
Hydropower generation	Market prices	Amount of power generated from hydropower stations	Kenya Generation Company (KENGEN), tea companies, literature, expert discussions, CCVA s
A. Indirect use value			
Soil nutrient conservation	Replacement cost	Mean soil loss per hectare on different land use types; nutrient loss per hectare (loss of major nutrients; nutrient-fertilizer conversion ratios; unit price; operation costs; size of forest area	Literature review, market surveys, expert discussions
Soil protection (erosion control)	Avoided cost	Cost of sediment removal; area vegetation types; ratio of sediments to total soil lost; potential erosivity of all types of forest.	Literature, GIS, water service boards expert discussions (environmental /civil engineers)
Water-flow regulation	Avoided cost	Area under forest (indigenous vegetation only); annual precipitation; ratio of runoff to precipitation; beneficial coefficient of reduced runoff of forest to non-forest area; runoff rate under grazing and intact forest; investment cost of reservoir construction per m^3	Literature, expert consultations, water service boards, engineering estimates (hydrogeologist/ engineers), WRA

Ecosystem services	Valuation techniques	Data needs	Data sources
Water-quality regulation	Cost based	Households' consumption of the water supply; unit cost of water treatment	Household surveys; water service providers; bottling companies or other commercial interests; literature
Carbon sequestration	Benefit transfer, market prices	Area under each forest type; average carbon stock per hectare; carbon sequestration (CO_2); the international carbon-sequestration price	GIS vegetation maps; literature; international market prices of CO_2 permits
Oxygen generation	Surrogate prices	Area under forest; relation between photosynthesis and oxygen generation	Literature, price of industrial oxygen production
B. **Non-use values**			
Cultural and bequest	Contingent valuation method	Mean WTP and target population	CVM household surveys, population data (KNBS)
Option value	Benefit transfer	Biodiversity correction factor for the sites; biodiversity value; PPP GNP (purchasing power parity GNP per capita; Elasticity of values with respect to real income)	Literature, PPP GNP indices (World Bank)