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Estimation of the Economic Value for the Consumptive Water Use Ecosystem Service Benefits of the Chyulu Hills Watershed, Kenya

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Abstract

The Chyulu Hills watershed ecosystem is a critical dryland water tower which supports large populations of people, livestock and wildlife in terms of water supply. The objectives of the study were to: - a) delineate the watershed ecosystem boundary based on the drainage network and locate the key water sources, b) undertake a comprehensive water use analysis to establish the consumptive beneficiaries and their consumption levels, and c) estimate the monetary value of the consumptive water use ecosystem service benefits. The watershed ecosystem boundary delineation was based on 30m Landsat imagery using ASTER Digital Elevation Model (DEM) and ArcGIS 10.3. Surface water sources were determined using secondary data and field assessment of springs and rivers while the groundwater sources were inventoried using available borehole records and household surveys of hand dug shallow wells. The water use analysis and monetization was based on both secondary and primary data derived from existing water use records and field interviews, respectively. The estimation of the monetary value was undertaken through the market price method (MPM) using the cost value. The results showed that the Chyulu Hills watershed ecosystem was more hydrologically productive in the north-eastern zone (Kiboko-Makindu-Kibwezi). The watershed ecosystem service beneficiaries were mainly the local domestic water users, small scale irrigators, large scale irrigators, livestock keepers, tourism operators, and conservationists. The average water consumer price was \$0.03 for a 20 litre jerri can of water while the total monetary value for the consumptive water resources was estimated at Ksh46, 676,192 which translated to \$466,862 per annum. The watershed ecosystem service value was highest in the eastern zone (Kibwezi) at approximately Ksh5,906(\$59)/km^2 followed by the northern zone (Masimba-Kiboko-Makindu) at Ksh3,490(\$35)/km^2 and Ksh2,579(\$26)/km^2 in the southern zone (Kambu-Mtito Andei-Mzima Springs). The value was lowest in the western zone (Kajiado) at Ksh5.86 (\$0.05)/km^2. The total economic value (TEV) was much lower than the estimates for other similar dry land water towers in Kenya.

Keywords

Chyulu Hills, Watershed Ecosystem Services, Water Resources, Monetary Value

1. Introduction

Most ecosystems in the world contain a wide range of goods for human use such as food, water, energy, and medicines. They also contribute a wide range of valuable services such climate moderation, biogeochemical cycling, biodiversity support and disaster mitigation, all which sustain life on Earth (Daily *et al*. 1997, de Groot *et al*. 2002, MEA 2005, Ellison *et al*. 2012, Bhatta *et al*. 2014, Rai *et al*. 2015). The services also include those associated with important societal functions such as entertainment and recreation as well as cultural and spiritual rituals including worship. Such services are highly diverse based on cultural practices and other local circumstances. The forest watershed ecosystems in hills and mountains are critical for rural and urban water supply which is a necessity in all countries of the world. Such ecosystems usually serve as hydrologic powerhouses due to their ability to intercept rainfall and serve as natural hubs for water recharge through which spring and river discharge is maintained.

Forest watershed ecosystem services are therefore among the most valued in the world and their necessity for human well-being cannot be overstated especially in terms of water provisioning (de Groot *et al*. 2002, MEA 2005, Fiquepron *et al*. 2013, Bhatta *et al*. 2014). The forest watershed usually intercepts rainfall and funnels it either into a stream, river, lake, or some other water body such as dams and reservoirs. In this way, forested hills and mountains usually enhance rainwater infiltration and underground recharge by creating numerous macro-pores through tree roots which enables water to seep through the soil matrix. This process eventually enables the natural refill of groundwater aquifers from where the water is thereafter discharged gradually through springs, streams and rivers which serve as regulated sources of water for society and the economy. A wide range of landowners usually serve as custodians and stewards of critical forest watershed ecosystems which supply water to both rural and urban users. According to Dudley and Stolton (2003), one-third or 33 out of 105 of the world's cities including Mumbai, New York, Bogotá, Melbourne, Tokyo and Sydney receive their drinking water supplies directly from forest watersheds. In South Africa, the Cape and Drakensberg mountain forest ecosystems are the key sources of water for the cities of Cape Town, Johannesburg and Durban (Pierce *et al*. 2002, Paterson *et al*. 2015).

In Kenya, there are approximately 100 urban centers with populations of between 30,000 and over 3 million (Nairobi City County 2014). Most of these have their own water and sanitation companies which rely on forest watersheds for their water supply. In the City of Nairobi, for instance, the Nairobi City Water and Sewerage Company (NCWSC) supplies over 0.5 million cubic metres of water daily to about 3.2 million people with most of the water originating from the pristine and spectacular slopes of the Aberdares forest (Nairobi City County 2014). In addition, Kenya has over 100 licensed bottled water companies which also depend heavily on various forest watershed ecosystems around the country. In this regard, good management of forest watershed ecosystems is important in order to ensure the sustainability of critical ecosystem services especially water supply.

Despite their importance, many decisions regarding the utilization and conservation of valued forest watersheds are made without adequate consideration of their real monetary value. In most cases, this happens because of inadequate knowledge and lack of understanding on the monetary value of their ecosystem services (Krieger 2001, MEA 2005, Vincent *et al*. 2015). Many people in the world including politicians and policy makers are still not aware that ecosystem services have economic value which is a big hindrance to environmental conservation (de Goot *at al*. 2002, MEA 2005). This situation usually hinders sufficient cost-benefit analysis in order to clearly understand the economic benefits of proposed ecosystem transformations against the likely environmental losses associated with the disturbance of ecosystem services. According to Krieger (2001) and MEA (2005), any goods and services that do not have monetary values are likely not to be accounted in the ecosystem management decision matrix.

1.1. Ecosystem Valuation

Economic valuation of ecosystems is an attempt to assign tangible monetary value to the goods and services accruing from such assets, whether or not their market prices are available or not. It is the process of attaching monetary value to the various benefits in the package of goods and services associated with a particular ecosystem such as a forest, mountain, river, lake or national park. This involves the monetization of such ecosystems in order to determine their overall monetary value and inherent natural capital. The valuation is important because it serves as a reminder that the environment is not 'totally free-of-charge' even though there may be no conventional market for all its goods and services.

In the recent past, interest in the economic values of ecosystem services has increased in many parts of the world (Kremen 2005, MEA 2005). However, although public interest in environmental conservation is rapidly increasing, the level of familiarity with ecosystem capital and its role in conservation policy formulation is still low hence the continued degradation of fundamental natural assets such as forests (de Goot *et al*. 2002, Kremen 2005, AfDB 2015) especially through the 'tragedy of the commons' (Hardin 1968). The monetary value of natural ecosystems is extremely important because it enables policy makers and natural resource managers to make more informed decisions. The economic awareness usually supports decision making by providing ecosystem monetary values around which policy makers can negotiate and make better decisions. In this way, the monetary value coordinates political discussions instead of relying on other inconceivable details whose policy impact is usually low. However, economic valuation of ecosystems is important even beyond policy making because the general public are more likely to respect and protect their local ecosystems more vigilantly if they know the monetary value. Consequently, the IBRD/World Bank (2004) declared that the continued inability to determine and clearly project the monetary value of ecosystem goods and services is likely to result in the continued loss of valued ecosystems which is detrimental for world societies and the economy.

Economic valuation of natural ecosystems and their services is the domain of environmental and resource economists but this branch of economics has continued to lag behind. Such valuation requires a clear identification and classification of goods and services in ecosystems on the forefront after which various valuation tools and methodologies can then be engaged to determine the total economic value as shown in Figure 1. Figure 1 shows that total economic valuation of ecosystems must integrate the ecological, economic and socio-cultural dimensions of such assets (Farber *et al*. 2002, Howarth & Farber 2002, Limburg *et al*. 2002, Wilson & Howarth 2002). Consequently, an accurate valuation requires the comprehensive partitioning of the ecosystem goods and services based on their mode of access and utilization for which the two principal categories of direct and indirect benefits are usually recognized (Figure 2). The direct use benefits are those which require close and direct interaction with ecosystems in order to access their consumptive benefits (e.g. irrigation, fishing, grazing, and logging) and non-consumptive benefits (e.g. game watching, nature photography and worship). The indirect use benefits, on the other hand, are associated with the intangible or invisible services such as weather and climate moderation, biogeochemical cycling and air quality moderation which do not require close interactions between the ecosystem and its beneficiaries.

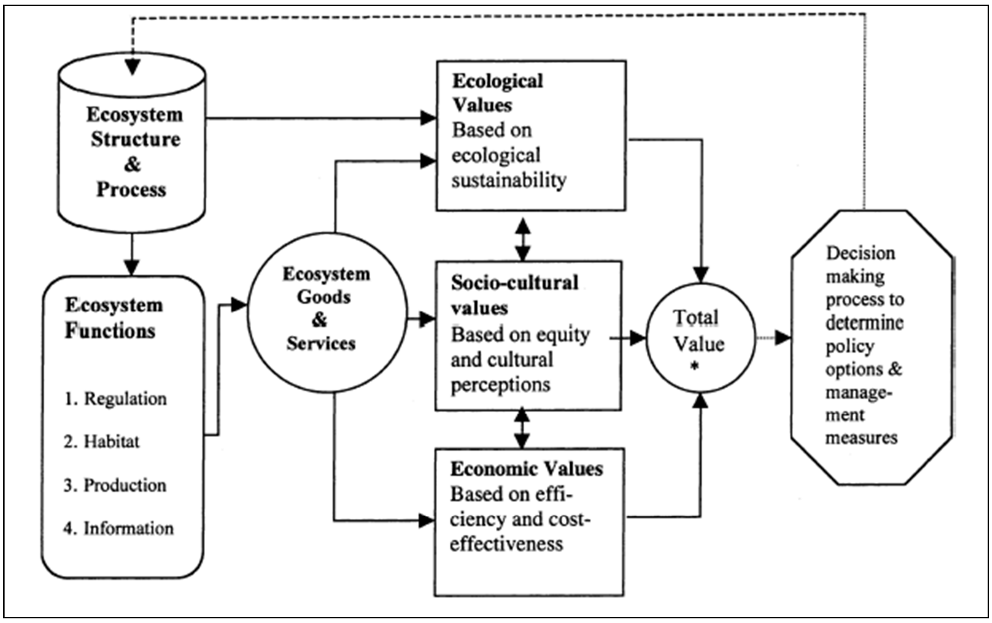

Figure 1. *A framework for the total economic valuation of natural ecosystems (de Groot et al. 2002).*

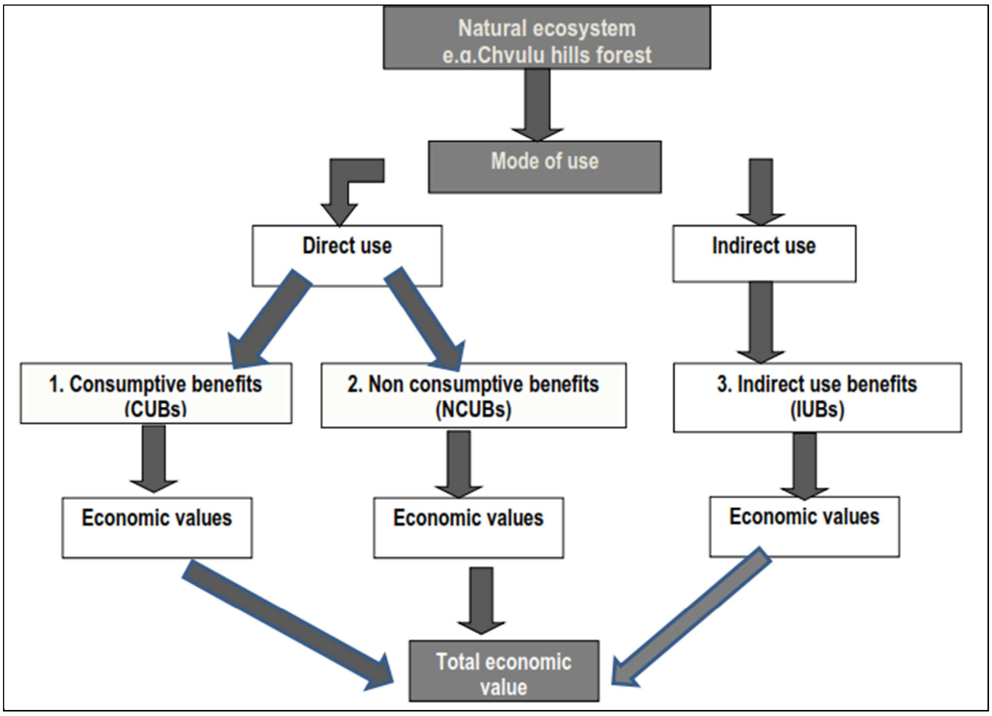

Figure 2. *A framework for portioning natural ecosystem benefits during economic valuation.*

Some experts have argued that ecosystem value and benefits should be considered beyond the direct and indirect uses by also including the non-uses (MEA 2005). This additional dimension is usually associated with non-materialistic and non-anthropocentric doctrines where intangible benefits of ecosystems such as the option, existence and bequeath values are appreciated. The option values are related to the undiscovered or futuristic opportunities such as undiscovered goods (e.g. medicines and fossil fuels), while the existence value is associated with the ecologistic and religioustic doctrines which recognize that all elements in an ecosystem are important and relevant, even without utilization. The bequeath value on the other hand is associated with the desire to reserve ecosystem goods and services for future use including bequeathing them to the future generations. The non-use values of ecosystems have so far been very difficult to integrate in economic valuations probably because of their very diverse and personal nature.

A wide range of tools and methods are applied in the valuation of natural ecosystems. These include tools and methods which elicit value preferences directly from the beneficiaries (such as contingent valuation method - CVM) and those that rely on indirect methods to infer preferences for example, through the travel cost method (TCM), replacement costs, and hedonic pricing (Lovett & Noel 2008). The market price method (MPM) probably provides the simplest approach of estimating the consumptive benefits of ecosystems because it only requires information on the quantity of ecosystem goods and services on one hand and their current market prices on the other in order to estimate the monetary value (MEA 2005, Lovett & Noel 2008). Most experts agree that any valuation that fails to involve the local stakeholders is bound to miss some of the key benefits which are only known by the beneficiaries (Lovett & Noel 2008).

1.2. World Valuation Studies

Although various economic valuations of world ecosystems have been conducted, the effort is still small compared to the demand. At the global level, Constanza who is one of the leading experts in this field has estimated the value of world ecosystems at around US$18 trillion per year with the annual value of forest goods and services at $4.7 trillion out of which climate moderation and food security accounts for 75% of the total value (Constanza *et al*. 1997). Constanza (1997) has also determined the economic value of global forest watershed services in terms of water supply alone and estimated the overall average at $1.2 per acre and $3.2 per acre for the tropical forests probably because of the higher water scarcity in such areas. In the USA, Dunkiel and Sugarman (1998) estimated the total annual consumptive value of the water produced by protected national forests alone at $27 billion. In Kenya, Emerton *et al*. (1998) estimated the annual value of watershed service for various forests around the country including Mount Kenya ($20.4 million), Aberdares ($7.4 million), Mount Elgon ($3.7 million), Cherangani ($0.4 million) and Loita Hills ($2.1 million). Kipkoech *et al*. (2011) estimated a total annual value of $238 million for three blocks in the Mau forest complex, while Kinuthia (2005) estimated the total economic value of the Mukogodo Forest in Laikipia County at $4.9 million using the CVM. Economic valuation of ecosystems in Kenya has also considered a number of wetlands. Navrud and Mungatana (1994), for instance, estimated the value of Lake Nakuru at between $13.7 and 15.1 million using the TCM while Mwaura and Muhata (2009) estimated the total economic value of Ondiri Swamp (≈12 ha) in Kikuyu town at approximately $17,026 per annum which translated to approximately USD1,135 per hectare using the CVM. Elsewhere, Ndungu (2006) estimated the value of Shompole Swamp (≈100 ha) in the Magadi area of Kajiado County at $0.2 million using the MPM.

The Chyulu Hills watershed ecosystem is a very critical dryland water tower which supports large populations of people, livestock and wildlife in the Makueni, Kajiado, Taita Taveta and Mombasa Counties in terms of water supply. The importance of the ecosystem as a water tower has a long history. The Kibwezi springs are, for example, associated with establishment there of the first East African Scottish Mission way back in 1891 almost a decade before the construction of the Kenya-Uganda railway. According to Woodhouse (1991), the railway stations established in Kibwezi area way back in the 1890s were supplied by water from the Umani springs in the Chyulu Hills. Similarly, the water intake at Penge springs in the foot slopes of the Chyulu Hills near Makindu was established by the British colonialists in 1895 in order to sustain the steam locomotives in the Kenya-Uganda railway.

In recent years, the Chyulu watershed ecosystem has been subjected to rampant vegetation degradation through illegal logging, fire wood harvesting, charcoal burning and frequent fires (Pringle & Quayle 2014). Consequently, Kiringe *et al*. (2015) have recently established that some of the springs and rivers in the watershed have dried up which indicates that the water recharge capacity in the Chyulu Hills might be declining. This situation can be attributed to a poor or lack of understanding on the linkage between the watershed ecosystem services and society livelihoods including the economic value of the Chyulu Hills. The overall aim of this study was the need to address this research gap. The specific objectives were therefore to: - a) delineate the watershed ecosystem boundary based on the drainage network and to locate the key water sources, b) undertake a comprehensive water use analysis to establish the various beneficiaries and their water consumption levels, and c) undertake an economic inventory to estimate the monetary value of the consumptive water resources generated by the ecosystem.

2. Methodology

2.1. Study Area

The Chyulu Hills consist of a series of small Pleistocene and Holocene volcanoes stretching for nearly 100km between the Emali and Mtito Andei townships along the Nairobi-Mombasa highway and standard gauge railway. The hills are located about 190km to the south-east of Nairobi at the intersection of Makueni, Kajiado and Taita Taveta counties (Figure 3). The hills are thought to have been formed through volcanic eruptions which occurred less than 10,000 years ago and created an extensive volcanic zone estimated to cover an area of 2,840km^2 with a 44km thick underground crust (Saggerson 1963, Ojany 1966, Nyamweru 1980, Ritter & Kaspar 1997, KWS 2007, Pringle & Quayle 2014). According to Simons (1998) the hills rise from an upland plain at about 1000m to a maximum altitude of 2175m. The Chyulu watershed is part of the Athi drainage basin but is directly associated with two sub-basins, namely, the 3F-Kiboko-Athi sub-basin which is part of the mid-Athi sub-region and the 3G-Lolturesh-Tsavo sub-basin in the Loitokitok sub-region which is part of the Tsavo. The Chyulu Hills are characterized by semi-arid climatic conditions with bimodal rainfall where the "short rains" are mostly received from October to December and the "long rains" from March to May. The high altitude zones receive about 1000mm of annual rainfall while the lowland rangelands receive around 350-500mm (Muriuki *et al*. 2011, Pringle & Quayle, 2014, Kamau, 2013). An analysis of rainfall data for the 1954-2013 period revealed a significant spatial variation in rainfall with the wetter zone in the north and the drier part in the south (Kiringe *et al*. 2015).

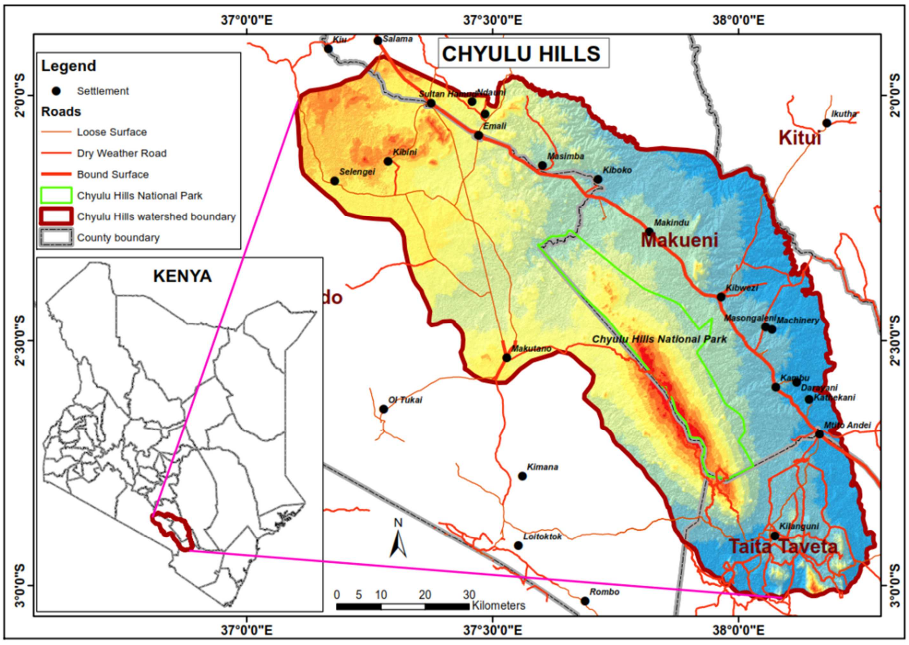

Figure 3. *Location of the Chyulu watershed ecosystem.*

The young nature of the volcanic lava fields in the area makes them very porous which enables them to intercept most of the rainwater in the Chyulu Hills more or less like a giant sponge such that there is almost no surface runoff. This process creates substantial subterranean water flow which works its way between the volcanic and basement rocks, and later emerges either as rivers, streams and springs in the foot-slopes of the Chyulu Hills. Because of this, the hills have been considered as a critical water recharge landscape in the region (Wright 1982, Guston & Mnyamwezi 1985, Grossman 2008, Pringle & Quayle 2014). The Chyulu Hills have traditionally been associated with pastoralism but in the last couple of decades, both rain-fed and irrigated agricultural practices have increased thereby raising the water demand (Pringle & Quayle 2014). The key custodians of the Chyulu Hills ecosystem include the Kenya Wildlife Service (KWS), Kenya Forest Service (KFS) and Kenya Water Towers Agency (KWTA) who are the managers of the Chyulu National Park (CNP), Kibwezi Forest Reserve (KFR) and the Chyulu Water Tower (CWT), respectively.

2.2. Methods

The delineation of the Chyulu Hills watershed boundary was undertaken using 30m Landsat images and the ASTER Digital Elevation Model (DEM). The ASTER satellite data was displayed on ArcGIS 10.3 and overlaid on the drainage layer and the watershed boundary obtained by digitizing a polygon guided by the DEM according to the direction of surface water flow. Thereafter, the watershed network and drainage density was analyzed using the Horton's method (Strahler & Strahler 1998). The analysis of water sources considered both surface and groundwater resources. The mapping of surface water sources was undertaken using secondary data on water discharge records for springs and rivers obtained from the Water Resources Management Authority (WRMA) offices in Kibwezi and Loitokitok as well as the Kibwezi and Makindu Water and Sanitation Company (KIMAWASCO) offices in Kibwezi. Groundwater sources were established using both secondary borehole data as well as primary shallow well data. The secondary borehole data for over 50 water sources was obtained from existing borehole records in the WRMA offices in Kibwezi and Loitokitok. Borehole locations and current water rest levels for selected boreholes were confirmed during fieldwork using a hand held GPS unit, and dipper-T water level meter, respectively. The distribution of hand-dug shallow wells and related water abstraction data was gathered through household based surveys of 40 local farmers in Makindu area adjacent to the Chyulu National Park and an equivalent number in Nthongoni area of Mang'elete region near Mtito Andei.

Water use analysis and monetization was based on both primary and secondary data. The secondary data was derived from existing water use records from the WRMA offices at Kibwezi and Loitokitok as well as the KIMAWASCO office in Kibwezi. The secondary data included; number and typology of water sources and uses, number and types of beneficiaries, water abstraction levels and current water prices. In the primary data collection, field interviews were undertaken with key informants who included; WRMA officers in Kibwezi and Loitokitok, key water service providers including Tana and Athi (TANATHI) Water Service Board, Kibwezi Water & Sewerage Ltd, KIMAWASCO, Kisayani Christian Water Project, Kitengei Community project, Kwa Kyai Cooperative Society, Kiboko-Twaandu and Kambu Community Water and Sanitation Project, Water Resource User Associations (Masimba WRUA, Kiboko WRUA and Makindu WRUA), public research institutions (Kenya Agricultural and Livestock Research Organization and University of Nairobi), tourist facilities (Hunters Lodge) and Kenya Wildlife Service (KWS). Other consultees included pastoralists in Masimba and Iltilal.

Estimation of the monetary value for the consumptive benefits of the Chyulu Hills watershed ecosystem services was based on the water used in various springs, rivers, boreholes and shallow wells. The valuation was done through the market price method (MPM) using the cost value. This involved the consideration of the prevailing water abstraction levels and water sale prices at each site. The pricing was associated with water companies such as KIMAWASCO, private water dealers and communal water retail kiosks. The monetary estimation involved the multiplication of the total raw water abstraction from each source with the current market price to compute the gross value. The valuation inventory did not however consider the water consumption externalities associated with water abstraction costs as well as the treatment and delivery costs.

3. Results and Discussion

The drainage morphometric analysis revealed that the watershed had a network of rivers including Greater Kiboko (Maangi Uvungi), Little Kiboko, Makindu, Kibwezi, Kambu and Mtito Andei which drain eastwards and the Tsavo River which drains southwards with all eventually feeding into the Athi River, the second largest in Kenya (Figure 4). The analysis showed that the watershed is more hydrologically active in the north due to higher rainfall (Table 1). The watershed is characterized by a number of springs which are mostly concentrated to the north-east (Masimba, Kiboko, Makindu, Umani, Kibwezi and Kwa Kyai), the south-east (Kambu and Mang'elete) and south (Mzima and Olpusare). All the springs except Umani Springs are found in low lying areas along the foot line of the Chyulu hills as shown in Figure 4. The Mzima springs apart from serving the City of Mombasa are also a key water source for the Tsavo River which is a lifeline for wildlife in the world famous Tsavo National Park.

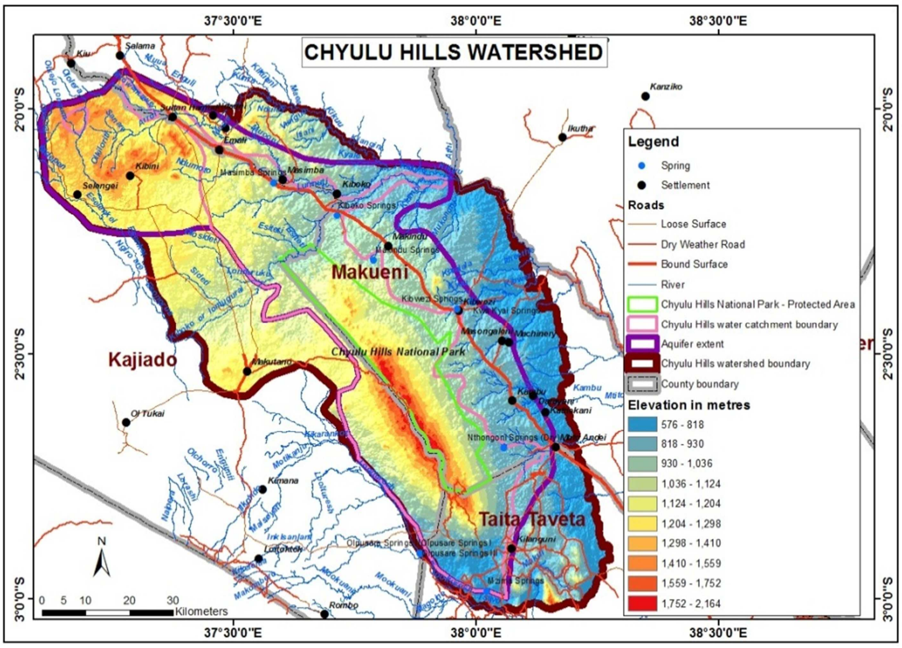

Figure 4. *Rivers and springs in the Chyulu watershed.*

Table 1. Summary of the Chyulu watershed drainage density.

Watershed zone	Approximate area (km^2)	Total stream length (km)	Drainage density (Length of streams per km^2)
Northern zone	4,704	2,135,112	2,135
Southern zone	3,049	767,052	767
Eastern zone	3,965	2,074,223	2,074
Western zone	3,788	827,941	827

The assessment of groundwater sources showed that over 50 boreholes have been sunk in different parts of the watershed with the highest concentration in the north-east (Emali, Makindu and Kibwezi) and south-east (Machinery, Masongaleni, Nthongoni and Mang'elete). In addition, over 50 shallow wells have been dug in upper Makindu area to the north and over 500 in Nthongoni within the Mang'elete area to the south. Figure 5 shows the distribution of borehole and shallow well water sources.

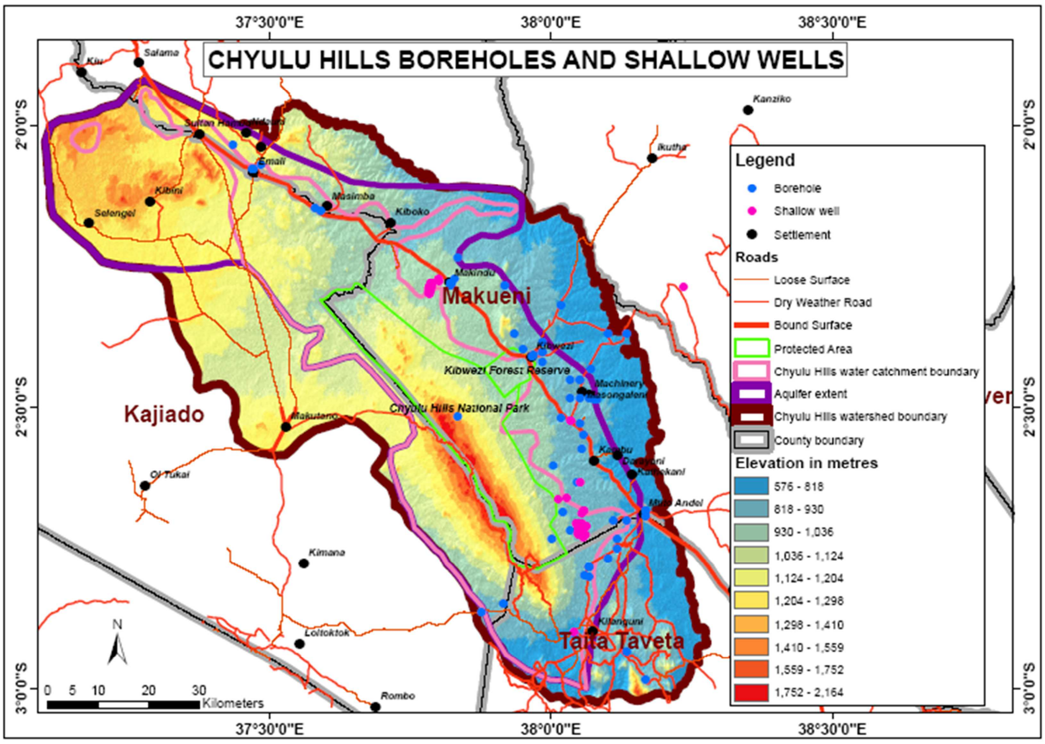

Figure 5. *Distribution of boreholes and shallow wells in the Chyulu watershed.*

The assessment of water users established that there were six categories of beneficiaries, namely:- a) domestic water users, b) small scale irrigators, c) large scale irrigators, d) livestock keepers, e) tourism operators, and, f) conservationists. The domestic water users comprised of local communities who abstracted water from rivers, springs and boreholes for household uses including drinking, cooking and washing. The small scale irrigators were concentrated along the Greater Kiboko River (Maangi Uvungi), Little Kiboko River, Kibwezi River, Kwa Kyai springs and Olpusare springs. Small scale irrigation was also recorded in Makindu and Mang'elete mainly through the use of water from shallow wells. The farmers were growing a wide range of subsistence and commercial crops which included maize, pigeon peas, cow peas, beans, tomatoes, kale, bananas, sorghum, millet, and sweet potatoes. The large scale irrigators included the Kenya Agricultural and Livestock Research Organization (KALRO) in their 155ha research farm at Kiboko where a total of 43ha were under maize, sorghum, millet, pigeon peas irrigation for scientific research in collaboration with the International Maize and Wheat Improvement Center (CIMMYT) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Additionally, the 8,990ha Dwa sisal estate at Kibwezi was abstracting water mainly for sisal production and processing. The 500ha Kya Kyai community irrigation project near DWA sisal estate was undertaking subsistence and commercial irrigation involving the production of maize, beans, ocra, baby corn, kale, sugar cane, chillies, and fruits. This project involved water supply by a cooperative society to individual farmers through a network of canals. The other large scale irrigator in the watershed was the University of Nairobi with a 12,000 acre dryland field research station to the north of Kibwezi town but only less than 5% of the land was under irrigation for scientific research and training.

The livestock water users consisted of the Kajiado Maasai pastoralists in Imbirikani and Kuku Group Ranches on the western side of the Chyulu Hills around the Olpusare springs. The pastoralists were also watering their livestock using a number water pans and boreholes in the area. The Kamba communities on the north-eastern side of the watershed were also watering their livestock in springs and rivers but the consumption levels were difficult to establish. The tourist facilities that were using water from the Chyulu Hills included Mida Holdings through the Hunters Lodge at Kiboko, the David Sheldrick Wildlife Trust (DSWT) Eco-lodge (Umani Lodge) near Umani springs (Kibwezi Springs) in Kibwezi Forest Reserve, the world famous Kilaguni Lodge in Tsavo West National Park, and the Richard Bonham Ol Donyo Lodge in Imbirikani Group Ranch. The conservation users consisted of the water supply for the KWS offices, staff quarters, and camp sites in Chyulu and Tsavo West National Parks. The others were KFS and David Sheldrick Wildlife Trust in Kibwezi Forest Reserve. However, KWS was the only agency pumping water to a number of wildlife watering points in Tsavo West National Park especially during severe droughts.

The estimation of the monetary value for the consumptive water use was undertaken according to the abstraction levels in four zones around the watershed, namely, the northern zone (Masimba-Kiboko-Makindu), central zone (Kibwezi region), southern zone (Kambu-Mtito Andei-Mzima) and western zone (Kajiado). The water users in the four zones were paying differently for the water consumption but the highest price was Ksh4 or $0.04 for a 20 litre jerri can at Machinery and the lowest at Ksh2 or $0.02 per jerri can at Makutana-Muthungini Community Water Project. The average consumer price was therefore estimated at Ksh3 or $0.03 for a 20 litre jerri can. Additionally, the WRMA was charging a regulatory levy of 50 cents or $0.005 per cubic meter for water abstraction in the various water sources in the watershed.

The main water sources in the northern zone (Masimba-Kiboko-Makindu) were the Greater Kiboko River, Masimba and Little Kiboko springs, boreholes and shallow wells. The Greater Kiboko provided water mainly for small scale irrigation and livestock while Masimba and Little Kiboko springs mostly provided water for domestic uses, livestock watering, large scale irrigation and tourism activities. The Masimba borehole provided water for domestic and livestock production while the Sheik Temple borehole in Makindu town provided water mainly for domestic uses. KIMAWASCO was the key water provider in this zone. The water company was supplying domestic water to consumers in Makindu town and the sorroundings. In addition, the shallow wells in upper Makindu provided water for small scale subsistence and commercial irrigation. Table 2 shows the key water users in the northern zone and the value of water consumption which was estimated at Ksh 16,419,130 or $164,191 per year.

Table 2. *Estimated consumptive water and its economic value in the northern zone (Masimba-Kiboko-Makindu).*

Water source	Estimated water yield (m^3 per day)	Estimated annual water yield (m^3 per year)	Unit costs of water per 20 litre jerrican (Ksh)	Estimated annual water value at an average price of Ksh 3 per jerrican
Rivers				
Greater Kiboko (Maangi Uvungu)	20	7,120	0.75	5,340
Springs				
Masimba Springs	80	28,480	0.50	14,240
Little Kiboko Springs				
KALRO (Katumani CIMMYT)	95	34,675	0.75	26,006
KALRO (Katumani ICRISAT)	80	29,200	0.75	21,900
National Rangeland Research Centre	164	59,867	0.75	44,900
Umani Springs - Mada Holdings Ltd (Hunters Lodge)	30	10,950	0.50	5,475
Umani Springs - Kiminz Mutiso	0.65	237	0.50	118
Umani Springs - Kiboko-Twaandu	90	32,850	0.50	16,425
Umani Springs -KIMAWASCO	11,854	4,220,024	0.50	2,110,012
Shallow wells				
Makindu shallow wells	-	580	0.75	13,056
Boreholes				
Masimba 1	120	43,800	0.50	6,570
Thomson W.B.	4.56	15,321	0.50	45,965
P.W.D./M.O.W.D.	4.80	16,128	0.50	48,384
Mutua R. N.	1.50	5,040	0.50	16,120
Masimba 2	120	43,800	0.50	6,570
Sheik Temple	8.10	27,216	0.50	81,648
Jamia Mosque	9	30,3,240	0.50	90,720
A.L.U & S.B	10.62	35,683	0.50	428,198
D.W.D.	9.84	33,062	0.50	99,187
Kindu Hotel	3.40	11,424	0.50	34,272
Generations Hotel	26	87360	0.50	262,080
Total				Ksh. 16,419,130 or $164,191[1]

1 Currency exchange: 1$=100Ksh

The main source of water in the eastern zone (Kibwezi region) was the Umani Springs (Kibwezi Springs) in Kibwezi Forest Reserve which supplied water for domestic uses, livestock watering, small scale irrigation and tourism. KIMAWASCO was the key water provider supplying domestic water from the spring to the urban centres in Kibwezi, Machinery and Mtito Andei. The key tourism water consumer was David Sheldrick Wildlife Trust Eco Lodge (Umani Lodge) while the consumption for large scale irrigation was associated with the DWA sisal plantation and Kwa Kyai cooperative irrigation scheme. Table 3 shows the key water users in the northern zone whose consumptive value was estimated at Ksh 22,379575.60 or $223,796 per year.

Table 3. *Estimated consumptive water and its economic value in the central zone (Kibwezi Region).*

Water source	Estimated water yield (m^3 per day)	Estimated annual water yield (m^3 per year)	Unit costs of water per 20 litre jerrican (Ksh)	Estimated annual water value at an average price of Ksh 3 per jerrican
Umani Springs				
TANATHI WSB (Kibwezi W&S Ltd)	4,708	1,718,420	0.50	859,210
Kibwezi W&S Ltd (1)	1,000	365,000	0.50	182,500
Kibwezi W&S Ltd (2)	1,547	564,753.55	0.50	282,377
David Sheldrick Wildlife Trust	20	7,300	0.50	3,650
Kisayani Christian Project	747	272,582	0.50	136,291
DWA Estate	11,645	4,250,581.95	0.75	3,187,937
Kwa Kyai Cooperative Society	2,454	895,710	0.75	671,783
KIMAWASCO	11,854	4,220,024	0.50	2,110,012
University of Nairobi, Kibwezi Field Station		-	0.50	-
TARDA	16	5,913	0.50	2,957
Boreholes				
D.W.D.	0.42	1,411.2	0.50	4234
D.W.D.NO.2	12.18	40,924.8	0.50	122,774
D.W.D.NO.3	4.5	15,120	0.50	45,360
D.W.A.EST.	2.28	76,608	0.50	229,824
D.W.A.EST.	1.38	4,636.8	0.50	13,910
D.W.A EST.	2.28	76,608	0.50	229,824
D.W.A EST.	11.34	374,102.4	0.50	1,122,307
D.W.A EST.	5.46	18,345.6	0.50	55,037
D.W.A EST.	3.18	7,084.8	0.50	21,254
J. M. Kinyua	4.2	14,112	0.50	42,336
Total				Ksh. 22,379,575.6 0or $223,796

The main sources of water in the southern zone (Kambu-Mtito Andei-Mzima) were the Umani Springs, Kambu Springs (Mbulutini Springs) and Mzima Springs. The other sources included boreholes and shallow wells. The springs were mainly supplying water for domestic uses in urban centers such as Kambu, Machinery, Masongaleni and Mtito Andei as well as rural homes through direct pipeline connection and communal water kiosks. The Mzima springs were also supplying water to Voi town and the coastal City of Mombasa. The boreholes in the area were supplying water for domestic uses and livestock production. Some KWS and private boreholes in this zone were also used for wildlife water supply and tourism activities in the Chyulu Hills National Park and Tsavo West National Park. In addition, water abstraction from shallow wells in the Mange'lete area was used for small scale irrigation, domestic uses and livestock watering. Table 4 shows the key water users in the northern zone whose consumptive value was estimated at Ksh 7,864,345.7 or $78,644 per year.

Table 4. *Estimated consumptive water and its economic value in the southern zone (Kambu-Mtito Andei-Mzima Springs).*

Water source	Estimated water yield (m^3 per day)	Estimated water yield per year (m^3 per year)	Cost per 20 litre units (Ksh)	Estimated annual water value at average price of Ksh 3 per jerrican
Springs				
Kambu (Mbulutini) Springs				
Kambu Water & Sanitation	80	29,200	0.50	14,600
Kitengei Community project	60	21,900	0.50	10,950
Hon. Philip Kaloki	5	1,825	0.50	912.50
Mzima Springs	35,000	12,775,000	0.50	6,387,500
Boreholes				
BH 1181 (Tsavo East National Park)	1.56	5241.6	0.50	15,735
BH 1455 (Tsavo East National Park)	2.04	6854.4	0.50	20,563
BH 2777 (Tsavo West National Park)	0.06	201.6	0.50	605
BH 2778 (Tsavo East National Park)	4.68	15724.8	0.50	47,174
BH 2779 (Tsavo East National Park)	0.06	201.6	0.50	605
BH 2944 (Tsavo West National Park)	13.08	43948.8	0.50	131,846
BH 3092 Tsavo West National Park	5.4	18144	0.50	54,432
BH 3116 (Tsavo West National Park)	5.94	19958.4	0.50	59,875

Water source	**Estimated water yield (m^3 per day)**	**Estimated water yield per year (m^3 per year)**	**Cost per 20 litre units (Ksh)**	**Estimated annual water value at average price of Ksh 3 per jerrican**
D.W.D.	4.56	15,321.6	0.50	45,965
D.W.D.	0.06	201.6	0.50	605
D.W.D.	9.84	33,062.4	0.50	99,187
AFR.SAF.LTD.	1.14	3,830.4	0.50	11,491
D.W.D.	13.2	47,628.0	0.50	142,884
D.W.D.	1.38	4,636.8	0.50	13,910
D.W.D.	7.02	23,587.2	0.50	70,762
Kilimanjaro Club	2.5	8,400	0.50	25,200
Islamic Association	0.39	1,310.4	0.50	3,931
Mangelete WS	13.8	46,368	0.50	139,104
Turner Foundation	17.86	6,009.6	0.50	18,023
Nthongoni (Mangelete) shallow wells	55	20075	0.75	548,480
Total				Ksh. 7,864,346 or $78,644

The main sources of water in the western zone (Kajiado County) included Olpusare springs at IItilal in Kuku Group Ranch as well as boreholes and small pans in the area. The Olpusare springs provided water for domestic use and livestock watering for the Maasai pastoralists. The pastoralists were charging $1 per household per month for the cattle and $0.05 for shoats regardless of the number of animals. In addition, a number of tourist installations in the area such as Oldonyo Lodge and Masai Wildlerness Centre had private boreholes. Table 5 shows the key water users in the northern zone whose consumptive value was estimated at Ksh 23,140 or $241 per year.

Table 5. *Estimated consumptive water and economic value in the western zone (Kajiado).*

Water source	**Estimated yield (m^3 per day)**	**Estimated yield per year (m^3 per year)**	**Cost unit (Ksh)**	**Estimated value at average price of Ksh 3**
Olpusare springs and shallow well	20	7,120	0.5	3,560
KuKu Group Ranch water pans	70	24,920	0.5	12,460
Richard Bonham Oldonyo Lodge borehole	40	14,240	0.5	7,120
Total				Ksh. 23,140 or $241

The overall value for the consumptive water use benefits of the Chyulu Hills watershed ecosystem was estimated at Ksh 46,676,192 or $466,862 per year. The value was highest in the eastern zone (Kibwezi region) at approximately Ksh 5,906/km^2, followed by the northern zone (Masimba-Kiboko-Makindu) at Ksh 3,490/km^2, Ksh 2,579/km^2. The value was lowest in the western zone (Kajiado) at Ksh 5.86/km^2.

There are limited studies on the economic valuation of watershed ecosystem services in the dry land water towers of Kenya. This is a limitation in terms of comparative analysis for the findings in the Chyulu Hills study. However, the total economic value (TEV) estimate for consumptive water use in the Chyulu Hills was considered to be quite low when compared to the estimates for other similar watersheds. Kinuthia (2005), for example, estimated the economic value of water resources in Mukogodo forest ecosystem (260km^2) in Laikipia County using the CVM method by asking people how much they were willing to pay (WTP) for the conservation of the critical watershed ecosystem. He estimated the mean WTP at Ksh 330,089 or $3,300 per household per year for 2,898 households and the aggregate WTP at Ksh 4,289,277 per household per year which translated to a TEV of Ksh 5,117,107,461 or approximately $51,171,075 per year. The TEV for consumptive water use in Mukogodo forest was therefore almost fifty times higher than the value for the Chyulu Hills although the latter is fifteen times bigger in size and produces more water for a much bigger population. The huge variation might be attributed to the different types of valuation methods used in the two studies. Similalrly, the economic value for the consumptive water use benefits of Chyulu Hills watershed ecosystem was also much lower than the value for the Loita Hills in Kenya whose annual value was estimated at US$ 2.1 million by Emerton *et al*. (1998). The difference can be attributed to the fact that livestock water use was not adequately captured in the Chyulu Hills except on the eastern side. The economic value for the consumptive water use benefits of Chyulu Hills watershed ecosystem was equally lower when compared to the values of the larger national water towers as such as Mount Kenya which has been estimated at US$ 20.4 million, Aberdares ($7.4 million), Mount Elgon ($3.7 million), Cherangani ($0.4 million) and Mau ($238 million) as determined by Emerton *et al*. (1998) and (Kipkoech *et al*. 2011). The difference is attributed to the larger size of the national water towers which have more vibrant watershed services compared to the smaller dryland water towers.

The findings in this study concurred with those of a number of other studies such as Pringle and Quayle (2014) in terms of the view that the Chyulu Hills is a very important dryland water tower in that part of Kenya. It was due to this fact that the 60km^2 Kibwezi Forest Reserve was gazetted way back in 1936 during the colonial times (Kiringe *et al*. 2015). Previous studies have estimated that upto 80% of the rainfall in the Chyulu Hills is intercepted by the forest ecosystem and latter discharged at Mzima Springs with the remaining 20% feeding the other springs in the watershed

(Temperley 1955). Apart from Taita Taveta and Mombasa Counties, the watershed services in the Chyulu Hills are shared by Makueni and Kajiado Counties. In terms of local water use, both Makindu and Kibwezi sub-counties in Makueni are the most heavily dependent on the Chyulu watershed, followed by Mashuru and Loitokitok sub counties in Kajiado County. According to the 2009 national population census, a total of 14,766 households and 58,454 people in Makindu County and 37,483 households and 178,315 people in Kibwezi County are almost entirely dependent on the Chyulu watershed ecosystem for their water needs (Kiringe *et al*. 2015). This translates to a total of 236,769 people in about 52,249 households. The local beneficiary population is projected to increase to 68,113 by 2020 and 78,273 by 2030 in Makindu County compared to 207,781 and 238,773, respectively for Kibwezi County (Kiringe *et al*. 2015). The projected growth is likely to overwhelm the capacity of the Chyulu Hills especially due to the recent drying up of some rivers and springs in the area.

4. Conclusions and Recommendations

The lower total economic value (TEV) of consumptive water use benefits in the Chyulu Hills watershed ecosystem in relation to other similar dryland water towers is attributed to the use of different valuation techniques. While this study used the market price method (MPM) using the cost value, most of the other studies used the CVM in terms of the willingness to pay (WTP) for watershed ecosystem services. If the former method is used especially in areas where water supply is considered not to be in short supply or where prices are heavily subsidized, the average water prices would be lower than in areas where the situation is the reverse. The difference also indicates that the CVM can greatly exaggerate the economic value of ecosystem services compared to the MPM probably because the former relies on human perception which can be quite diverse while the latter is based on actual reality in the market. It is possible that the TEV for the consumptive water use benefits in the Chyulu Hills can be much higher if the Benefit Transfer Method (BTM) was used.

The findings showed that the Chyulu Hills watershed is a fountain of life in the region and beyond. The estimation of economic value for consumptive water use showed that the watershed ecosystem is worth a lot of money in terms of water supply. However, like other valued watersheds in the country, it continues to grapple with a wide range of challenges in terms of conservation financing especially for agencies such as KWS, KFS and KWTA who are the joint custodians of the protected watershed ecosystem. Although the WRMA is collecting a regulatory levy from the water service providers and consumers, there is little to show that any of this revenue is trickling back to augment the annual watershed conservation financing provided by the central government. This is mostly hampered by differences in institutional obligations and mandates due to the limited cross-sectoral integration among the various natural resources governance agencies in Kenya. Most of the revenue from the WRMA regulatory levy on water consumption is probably channeled into recurrent expenditure for the agency alone and yet the watershed custodianship effort is mainly borne by KWS and KFS who are on the ground. It is not realistic that the revenue accruing from the economic value of the consumptive water use benefits in the watershed ecosystem should all be allocated to WRMA and the County Government of Makueni through KIMAWASCO while the watershed ecosystem is increasingly degrading.

The situation can be rectified through application of the Payment for Environmental Services (PES) strategy which offers a promising prospect for addressing the challenges of sustainable natural resources management. If a 2% conservation levy was introduced on the annual value of Ksh 46,676,192 or $466,862 in the Chyulu Hills water economy, it would raise almost Ksh 1,000,000 per year which could support watershed conservation activities and ensure sustained water supply. To this end, the Kenya Water Towers Agency (KWTA) in collaboration with the County governments of Makueni should consider establishing a PES framework which will ensure that an agreed percentage of the revenue generated by the Chyulu Hills water consumers such as the Coast Water Board, KIMAWASCO, Kenya Agricultural and Livestock Research Organization (KALRO), DWA Sisal Estate and hoteliers such as Hunters Lodge and Kilaguni Lodge is ploughed back for watershed ecosystem conservation financing. This kind of financing can support and sustain important projects like the gradual fencing of the water tower as was done for the Aberdares Ranges Forest, and where the intervention has significantly reduced human related land cover degradation and enhanced its long-term water provision.

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