



Characterization and monetization of Mount Marsabit ecosystem watershed services, Marsabit County, Kenya

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Abstract

The study aimed at addressing Mount Marsabit ecosystem watershed service valuation information gap by: - a) analyzing the typology and mapping the spatial distribution of water supply points within the forest ecosystem, b) documenting types of water consumers and service beneficiaries and, c) undertaking monetary value estimation of the ecosystem watershed services in terms of the water supply market. The mapping of ecosystem water points involved a physical inventory of three target wards in Marsabit Sub-County, namely Marsabit Central, Sagante/Jaldesa and Karare and recording of GPS locations and thereafter overlying the water sites on a map of the area using ArcGIS. The analysis of water consumers and valuation of the ecosystem watershed service was undertaken through the market price method (MPM) using existing secondary and primary data from relevant offices and from face-to-face interviews of 275 respondents. The findings showed that Marsabit forest ecosystem was supporting a total of 115 active water points which were dominated by shallow wells (68) followed by boreholes (21), water pans (14), springs (4), streams (6), and crater lakes (2). The overall pattern showed boreholes as the principal water access types (47.3%), followed by shallow wells (15.3%), springs (12%), water pans (8.7%), streams (2%), and crater lakes (0.7%). The mountain ecosystem was found to be more hydrologically active on the eastern windward side within the 1300-1300m elevation belt. The overall value of the Mount Marsabit ecosystem watershed service was estimated at Ksh 58,285,026 (\$582,035) per year. It is recommended that Water Resources Authority (WRA), the Kenya Water Towers Agency (KWTA) and the County Government of Marsabit should collaborate with local communities and the local water vendors to initiate a payment for ecosystems services (PES) that will plough back some of the revenue generated from the water market towards conservation of Mount Marsabit Forest ecosystem.

Keywords: *Dryland water tower; mountain ecosystem; watershed services; monetary valuation*

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Introduction

Global societies depend entirely on natural ecosystems such as forests, rivers, lakes and wetlands for their various ecosystem services including food, water, medicines, energy, climate moderation, personal entertainment and spiritual nourishment among other benefits (MEA, 2001). Ecosystem services are often categorized in terms

of both direct and indirect benefits based on the mode of ecosystem service access and utilization (Daily, 1997; de Groot, Matthew & Roelof, 2002). The direct benefits usually require close contact and interaction between societies and their natural ecosystems as in the case of water abstraction and fishing in rivers and lakes.

Indirect benefits such as the role of forests in carbon abstraction and climate moderation do not require direct contact between societies and their natural ecosystems. The direct benefits mostly in form of extraction of tangible ecosystem goods are also known as provisioning services. These are the most highly regarded due to their requirement for human wellbeing (MEA, 2001). Unfortunately, they are also the most destructive to the global ecosystems. In the last 50 years, the demand for ecosystem provisioning services has increased tremendously in response to the rapidly growing world human population (Costanza *et al.*, 1997; MEA, 2005, Jacobs *et al.*, 2014, Ghosh, 2016). Appreciating the nature and economic values of ecosystem services has drawn increased attention due to increased understanding of the intimate link between society and ecosystems. One of the key interests is the role of natural ecosystems in sustaining the increasing demand for water supply for societies both in rural and urban areas around the world.

Water is a critical physiological requirement for all societies in the world regardless of their race or economic status. According to Thomas *et al.*, (2020), the World Health Organization (WHO) recommends the provision of a minimum of 20 litres per person per day and 80-100l/person/day on average for human well-being (drinking, cooking, sanitation and basic hygiene). Consequently, water supply was identified as one of the key issues for the global 2030 agenda in which sustainable development goal 6 (SDG-6) is on water and sanitation. Target 6-1 for SDG-6 aims at ensuring universal and equitable access to safe and affordable drinking water for all by 2030 (Ortigara *et al.*, 2018). Recently, the water supply issue has been on the headlines during the COVID-19 global pandemic because the WHO has earmarked handwashing as one of the most effective actions you can take to reduce the spread of pathogens and prevent infections, including the COVID-19 virus.

Despite the increasing water demand for societies around the world, the Earth has a constant stock of water resources in the hydrosphere which is estimated at 1,386 million cubic meters. Unfortunately, this is dominated by saline water in world oceans and seas ($\approx 94\%$). Only less than 5% of the hydrosphere comprises directly

consumable freshwater in rivers, lakes and underground aquifers. All the water for world societies originates from the oceans and is transferred to consumers in the continents through the water cycle. The water cycle also converts the saline ocean water into consumable freshwater through a wide range of ecosystems services especially precipitation. One of the lifeline ecosystem services on the Earth is watershed services of forested catchments which intercept rainfall from the atmosphere thereby tapping water from oceans by activating surface infiltration and ground water recharge from which springs, streams, rivers and groundwater aquifers are continuously replenished as key sources of water for world societies. In this way, mountain forest ecosystems serve as hydrological power houses by intercepting, storing and distributing rainwater to the surrounding lowlands in a regulated way (Mwaura *et al.*, 2016).

This is one of the key justifications for the UN requirement for the 10% forest cover threshold at country level (Sloan & Sayer, 2015) which was well captured in the 2002 Johannesburg Earth Summit (Rio +10) when the UN water, energy, health, agriculture and biodiversity framework (UN-WEHAB) was launched (WEHAB Working Group (2002). The integrated cross-sectoral management framework highlights the key role of biodiversity including mountain forest ecosystems in water supply among many other benefits.

Mountain forests in Kenya, like in other parts of the world, represent an important part of natural heritage assets which ensure water supply for society. They deliver critical watershed services which sustain water supply at local, national and even regional levels. In cognizance of their important role in sustaining local livelihoods as well as driving the country's development aspirations and economy, the government has recognized high altitude mountains in Kenya as critical "water towers" which are necessary for the realization of SDG-6 targets (especially Target 6.1). Many urban centers in Kenya have their own water supply companies which rely on local or distant forest watersheds for water supply. For example, the City of Nairobi is served by the Nairobi City Water and Sewerage Company (NCWSC) which supplies over 0.5 million cubic

meters of water daily to about 3.2 million people with most of the water originating from the Aberdares forest which is located about 50-80km north of the city. Similarly, a lot of the water consumed in the City of Mombasa originates from Mzima Springs which are recharged by the distant Chyulu Hills Forest which is predominantly in the Makueni County.

The focus on ecosystem watershed services in Kenya is mostly concentrated on the gazetted key water towers in the humid highlands namely; Mount Kenya, Aberdare Ranges, Mount Elgon, Cherang'any hills and the Mau Complex. However, over 80% of the country is characterized by rangelands which heavily rely on dryland water towers (e.g. Chyulu Hills, Mathews Ranges, Loita Hills, Mount Kulal, Huri Hills, Taita Hills, Ndoto Mountains and Mount Marsabit among others). With growing population, Kenya's water demand is on an upward trajectory which calls for a clear understanding of the ecosystem watershed services required to meet the demand (Mogaka *et al.*, 2006). Loss of mountain forest cover, through encroachment by agricultural and human settlement, logging and regular burning ultimately affects water supply (UNEP, 1996; Wilkie, Holmgren, & Castaneda, 2003; Wu, Kim & Hurteau, 2011). Despite this understanding, or lack of it, world societies have greatly affected watershed services through land degradation (MEA, 2005; Wilkie *et al.*, 2003).

The above scenario is attributed to a number of factors. Firstly, is the perception by society of water resources as a free-of-charge and inexhaustible God given commodity whose supply will always be there and should not be an issue of public concern. Secondly, is the insufficient effort towards the documentation of the role of the mountain forest in the provision of critical watershed services, including the economic valuation of such services. Such information is critical for effective education and awareness based on the understanding that ecosystem service consumers are likely to appreciate and safeguard their natural heritage more effectively if they are informed about the characteristics and economic value of such assets. In addition, both the central government and local governments require such information for

policy making, formulation of relevant legal frameworks and other relevant strategies to ensure more effective management of critical water towers. This study was aimed at addressing that ecosystem management information gap with regard to Mount Marsabit ecosystem by focusing on: a) analyzing the typology and mapping the spatial distribution of water access points within the Mount Marsabit forest ecosystem, b) documenting types of ecosystem water consumers and service beneficiaries and, c) undertaking an estimation of the monetary value of the ecosystem watershed services in terms of the water supply market.

Despite the remarkable conservation efforts by government, recent studies have shown that Mt. Marsabit ecosystem is facing serious environmental threats attributed to anthropogenic activities especially agricultural encroachment, overgrazing, fodder, wood harvesting, and charcoal burning (Gachanja *et al.*, 2001; RoK, 2011; Muchura *et al.*, 2014). According to a study by RoK, (2011) there has been tremendous reduction in the size of Marsabit forest which has reduced from about 184km² in 1973 to only about 110 km² which translates to an annual deforestation rate of about 1.6km²/year. This negative transformation poses a serious threat to ecosystem service provision especially with regard to water supply for different sectors in the area including livestock production, agriculture, tourism and urban development. The tremendous reduction in forest cover has greatly suppressed the ecosystem service capacity, especially with regard to the watershed services associated with water supply. In 1995, water discharge at the Bakuli springs, which is the main water source for Marsabit town, was 3,600m³/day while the current discharge has decreased to approximately of 65 m³/day against an increasing water demand (Oroda, 2011; RoK, 2011). This trend, if not addressed, is likely to affect development activities and also become a source of water related armed conflicts in the future especially among the pastoralist communities. The situation requires effective education awareness on the high environmental value of the mountain ecosystem including greater involvement of the water consumers in its conservation financing.

Materials and Methods

Study Area

Mount Marsabit forest ecosystem is located in Marsabit County (70,961.2 km²) which is one of the 47 counties in Kenya bordering, Ethiopia to the north, Turkana County to the west, Samburu County to the south and Wajir and Isiolo counties to the east thereby making it one of the largest in Kenya (County Government of Marsabit (CGoM),

2018). The forest ecosystem has evolved around Mount Marsabit, a solitary mid-elevation (1750m) basaltic shield volcano which serves as the lifeline water tower for the surrounding lowlands including Marsabit town (Gachanja *et al.*, 2001; Jillo, 2013). The ecosystem is situated approximately 560km north of Nairobi in Marsabit Central Sub-County, Saku Constituency of Marsabit County (Figure 1).

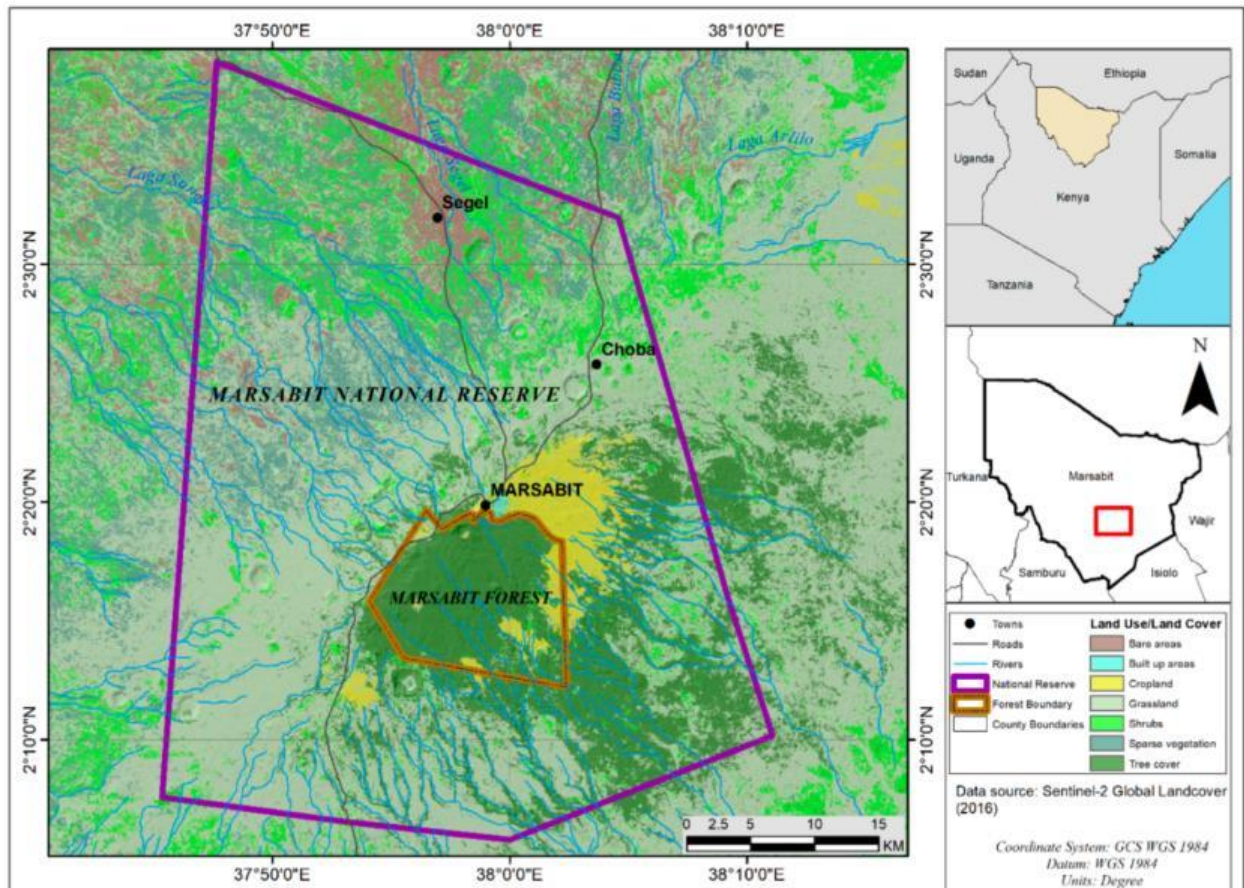


Figure 1. Mount Marsabit Watershed (Ouko *et al.*, 2018)

The area receives an average annual rainfall of 800mm compared to the surrounding lowlands including Chalbi desert which receive an average of 150mm. It is almost like an oasis to the pastoralist communities living adjacent the mountain forest who are intimately connected to the watershed ecosystem because it serves as a lifeline island within a very dry and harsh environment. The surrounding environment is dry and hot with almost permanent high

temperatures of up to 26°C and high evaporation between 1800-2200mm (Maina & Imwati, 2015; Ouko *et al.*, 2018). The mountain attracts relief rainfall from the Indian Ocean which is intercepted by the forest canopy thereby replenishing springs, crater lakes (e.g. Lake Paradise) and seasonal streams (*laggas*) which eventually benefit local communities, their livestock and the wildlife population. The permeable volcanic lava in the mountain

facilitates high infiltration which recharges the groundwater aquifers in the surrounding lowlands. Pastoralism is the main land use and source of livelihood in the region which revolves around the keeping of cattle, sheep, goats, camels and donkeys. A small number of people living in the Songa, Leyai, Badasa, Jaldesa and Jirime areas

also undertake small scale irrigation farming which involves the production of kales, tomatoes, spinach, pepper, onions, maize and fruits. Figure 2 shows the human settlements which depend on Mount Marsabit for their water supply including Marsabit town, the county headquarters.

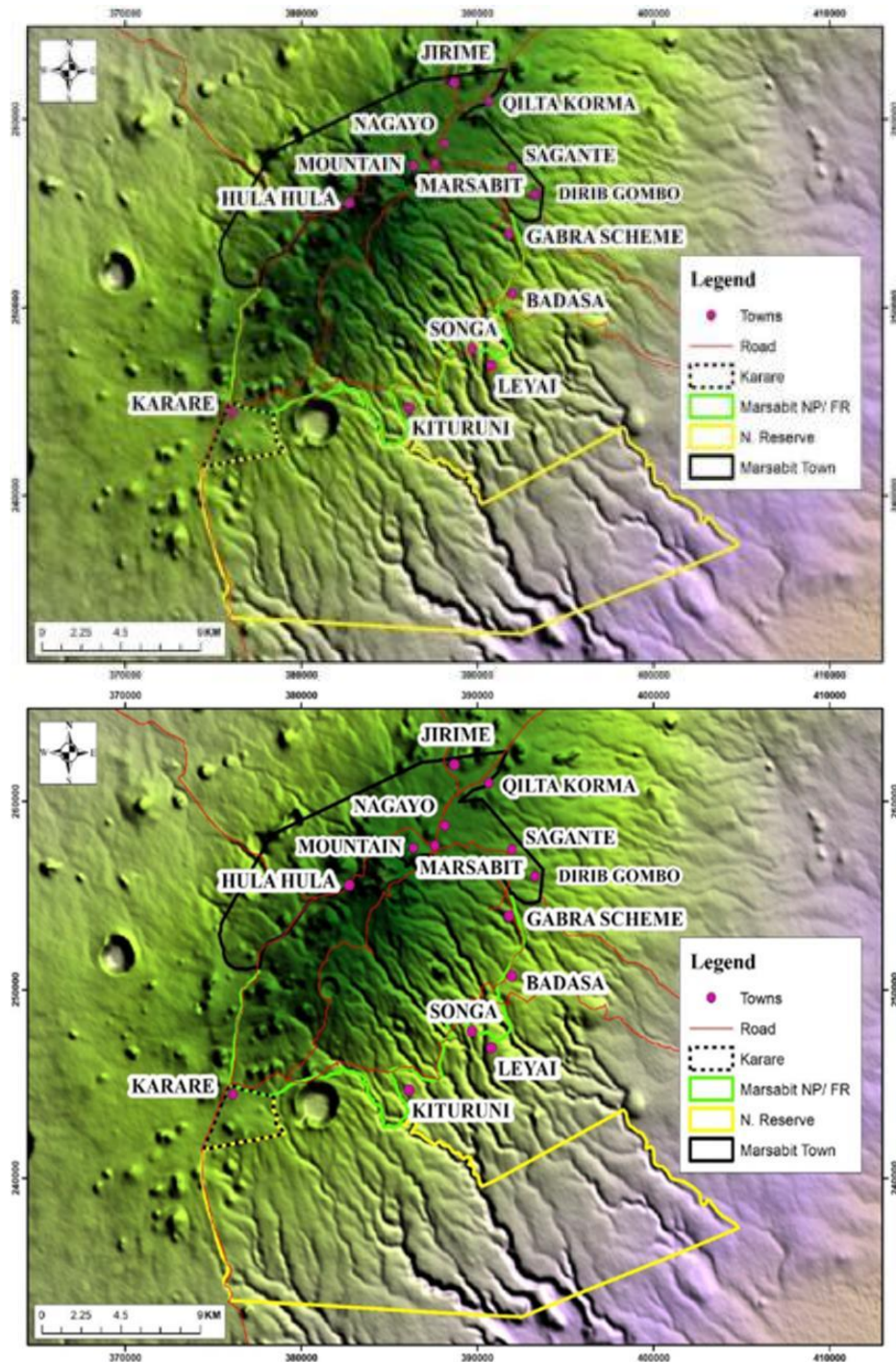


Figure 2. Mount Marsabit watershed service consumption areas (Muhati et al., 2018)

Because of its vital role, especially as a lifeline dryland water tower, Mount Marsabit forest is protected as a Forest Reserve (150km²) which was initially gazetted in the year 1932 and later as a National Reserve in 1948 and is currently under the management of Kenya Forest Service (KFS). It was later designated and also gazetted as a National Park (1,554 km²) in 1949 because of its rich wildlife heritage under the management of Kenya Wildlife Service (Robinson, 2013). The national park has a diversity of wildlife including elephants, buffaloes, Burchell's zebra, the endangered Grevy's zebra, lions, leopard, bushbuck, greater and lesser kudus, grant's gazelles and many other small antelopes, and over 300 species of birds. Consequently, the ecosystem supports some tourism activities due to the recreational role of the national park and forest reserve. Some of the tourism facilities include Marsabit Lodge, the Gof Bongole Resort, and Songa Conservancy Campsite and Lodge.

Analysis of the typology of ecosystem water access points

This involved a physical inventory of the ecosystem and its surrounding in order to locate all the public, private and institutional water access points. This was undertaken by traversing the three target wards in Marsabit Sub-County, namely Marsabit Central, Sagante/Jaldesa and Karare using a vehicle (Figure 2). The inventory was undertaken in November 2018 after the short rains during which the magnitude of the ecosystem service was expected to be clearly visible. A standard recording schedule was used to generate detailed information for each access point in terms of the following standard attributes: - i) location ii) type of water source (e.g. borehole, shallow well, spring, stream, lake, earth dam or water kiosk), iii) water source ownership, iv) functionality status (e.g. active, inactive, under repair) and, v) types of water users. A total of 150 water access points were inspected during the physical inventory.

Spatial analysis of ecosystem water access points

This was integrated in the physical inventory by recording the geographic location of each access

point using a handheld Garmin Global Positioning System (GPS). In addition to geographic location, the GPS was used to record the altitude of the water points. The GPS points were loaded on ArcGIS software and later overlain on a map of the area to generate spatial distribution map of ecosystem water access points.

Monetary valuation of ecosystem watershed services

This was estimated using both primary and secondary data. Primary data collection involved face-to-face interviews with the water consumers at the water access points using a standard questionnaire. The questionnaire was designed to capture the following water related monetary information which included: - i) number of beneficiary households and livestock, ii) quantity of water collected per unit time (e.g. daily, weekly or monthly), iii) water payment/tariff, iv) uses of the water collected from a water point, and v) revenue generated from the use of water (e.g. through tourism and small-scale irrigation). A total of 275 respondents were considered in the study out of a total population of 24,838 people residing in the study area. The sample size was obtained using the formula of Fisher *et al.* (1998); $n = (Z^2pq)/d^2$ where N is the minimum sample size for a statistically significant survey, Z is normal deviant at 95% confidence level. The desired sample size for the study was 384. However, owing to the distance between the water points, homogeneity of the data and above all insecurity issues among the warring communities in the area, we considered sample size of 275.

Secondary data collection was based on the use of existing water abstraction records in the Marsabit regional offices for the Water Resources Authority (WRA), Northern Water Service Board (NWSB) and Marsabit County Water Department (Marsabit Central). The data included quantities of water abstracted from different sources, consumers, payment tariffs and related levies. The secondary data were used to complement the primary data and also confirm water payment tariffs in different areas around the ecosystem.

Additional secondary data were acquired from institutional and private water consumers including KWS, KFS, tourist facilities (e.g. Marsabit Lodge, Gof Bongole) and faith related water supply groups and NGOs (e.g. Community Initiative Facilitation and Assistance). The study used the market price method (MPM) for the estimation of ecosystem watershed service. This involved the determination of quantities and market prices of water abstracted from different water access points which were hydrologically related to the forest watershed. This approach was considered suitable because of its simplicity. The method only requires information on the quantity of ecosystem goods and services and their current market prices in order to estimate the monetary value as explained by Lovett & Noel (2008).

The beneficiary categories of the ecosystem watershed services were used in the estimation of the monetary value for the watershed ecosystem. This was based on an average water price of Ksh 5 per 20 litres jerry can (equivalent to 0.05USD) as provided by the National Drought Management Authority at the time of the study (NDMA, 2017).

The calculation of monetary value for irrigation water use assumed that irrigation was undertaken throughout the entire duration of the annual 5-month dry season in the area. Crop water need in mm/growing periods were obtained from Ministry of Water and Irrigation Manual, (RoK, 2005).

The estimation of monetary value for the commercial water vendors category was undertaken as follows; a) household consumers - amount of water extracted and the selling price, b) water kiosks - consumer households who mostly used electronic water purchase smartcards at Ksh 5 for 20 litres, c) water bowsers - water was retailed at Ksh 5 for a 20 litres, and d) boarding schools - they were assumed to use 50 litres per head per day (RoK 2005) at an average price of Ksh 5 for 20 litres.

The monetary value for tourism operators was estimated according to water consumption at designated tourism facilities multiplied with the market price of water. The value was estimated on full occupancy basis according to facility bed

capacity, star rating category and the National Drought Management Authority (NDMA) water market prices for Marsabit.

The estimation of the water use monetary value for conservation institutions was based on the consumption levels as disclosed by the institutions at an average price of Ksh 5/20ltr (NDMA, 2017). Further, the administrative offices were assumed to consume 25 litres a day/head (after RoK 2005).

Data analysis

Data analysis was undertaken using the Statistical Package for Social Sciences (SPSS) mainly through the computation of descriptive summary statistics including arithmetic mean, standard deviation, percentages and frequencies. The analyzed data were then presented in figures, charts, tables.

Results

Typology and characteristics of ecosystem water access points

The findings of the physical inventory showed that Marsabit Forest ecosystem had 117 active water access points, out of a total of 150 (Table 1). The access points were dominated by shallow wells (68) followed by boreholes (21), water pans (14), springs (4), streams (6), and crater lakes (2). At the time of the study, not all the water sources were operational because many streams and some boreholes (e.g. Dirib Gombo II, Qubi Bagasa) were totally dry.

The boreholes and shallow wells were concentrated in the eastern side of the mountain, which is windward with respect to the Indian Ocean. The principal boreholes included Jaldesa, Dololo Dokatu, Qubi Qallo which are communally owned and Dirib Gombo I which was owned and operated by a muslim welfare group. The shallow wells were mainly clustered in different locations including Sagante, Gabra Scheme, Karatina, Songa, Qarsa and Dirib Gombo (Figure 2). Boreholes and shallow wells were the key sources of water for both household water requirements and livestock watering while springs, streams and crater lakes (Lake Paradise and Sokorte Dika) provided water for the

wildlife. In the lowlands surrounding the mountain ecosystem, groundwater was the key source of water through the sinking of boreholes to serve local community needs including livestock and domestic uses. The principal water access points for the study area were boreholes (47.3%), followed by shallow wells (15.3%),

springs (12%), water pans (8.7%), streams (2%), and crater lakes (0.7%). The minor type of water access were commercial water kiosks (13.3%) mostly supplied from boreholes and springs (Bakuli, Booji) (Table 2).

Table 1. Water sources types in Mount Marsabit Forest Ecosystem

	Water access type	Number of access points
1	Shallow wells	68
2	Boreholes	21
3	Water pans	14
4	Springs	4
5	Streams	6
6	Crater Lakes	2
Total numbers of water access points		115

Table 2. Watershed Point of Water Access

Type of water source	%
Borehole	47.3
Shallow well	15.3
Kiosks	13.3
Spring	12.0
Water pan	8.7
Streams	2.0
Rain water harvesting	0.7
Crater lake	0.7
Total	100.0

The mountain ecosystem was associated with a number of springs including Bakuli, Lchuta and Booji. Bakuli spring, which is owned by the central government, and managed by WRA was key surface water access point. The spring is the main source of water for Marsabit town but the supply is usually insufficient and has to be supplemented by water trucks from boreholes located outside the town area especially Sagante zone boreholes (Dirib and Qubi Qallo). The springs usually supply water mainly through kiosks and a few direct line connections to residential consumers close to the mountain. Only three springs were found to have continuous water flow during the physical inventory. These were Bakuli, which was flowing eastwards towards Marsabit town, Booji which was flowing northwards towards Marsabit

Central, and Lchuta which was flowing south east.

In the rainy season, Mount Marsabit ecosystem generates a few seasonal streams such as Badasa, Leyai, Ilchuta, Songa and Marsabit Lodge which flow into the dry lowland areas but only for a limited period. Lake Paradise at the heart of the mountain ecosystem provides water for wildlife both in the national park and forest reserve. A few water pans have been established in order to tap surface runoff from the mountain ecosystem mainly for livestock water supply but they contribute less than 10%. The study established that only 0.7% of the consumers relied on roof-based rain water harvesting as an alternative option beyond the forest watershed service (Table 2). It was established that water supply by mountain springs, streams and crater lakes was

inadequate in the dry season pushing wildlife out of the forest to the communal water resources leading to human-wildlife conflict.

Spatial distribution of water access points in the ecosystem

Figure 3 shows the geospatial map of water access points around the Marsabit forest ecosystem. It shows that the ecosystem is more hydrologically active on the eastern side which is also the

windward side. Majority of the water sources are concentrated within the 1300-1300m elevation belt which is also the zone of intensive agriculture and urbanization (Figure 1). The spatial pattern for the water access points indicated that the distribution of human settlements including the location of Marsabit town is largely associated with the availability of the forest ecosystem watershed service.

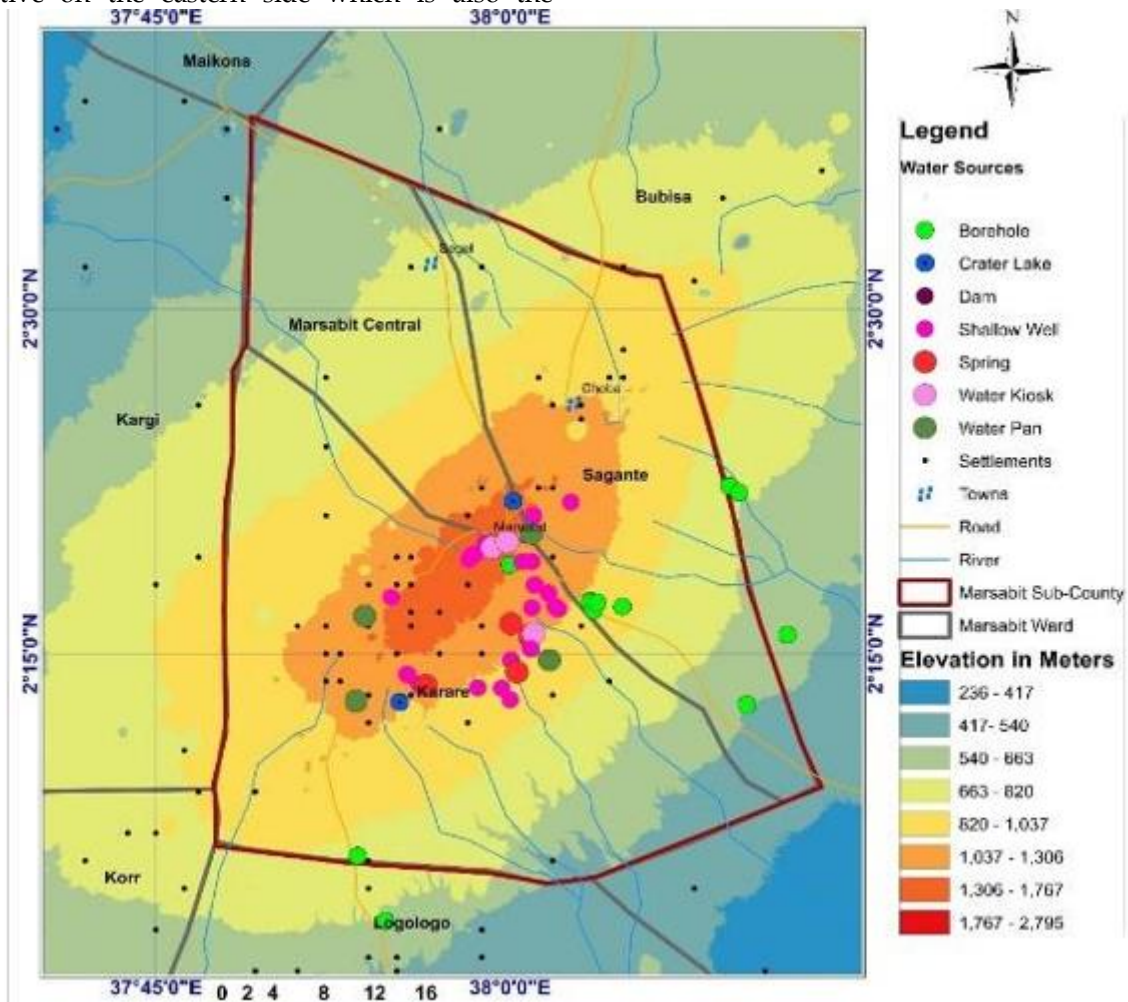


Figure 1. Geospatial distribution of water access points in Mount Marsabit ecosystem

Table 3. Estimated annual values of domestic water use in Mt. Marsabit

Point of water access	Estimated water yield L/day	Estimated annual water yield L/year	Number of dependent households	Estimated annual water value at an average price of Ksh 5 per jerrican
Marsabit Central				
Shallow Wells				
El Aite shallow well	7,360	2,686,400	80	100,740
Karatina Shallow wells	11,040	4,029,600	120	151,110
El Jarso Shallow Well	1,288	470,120	14	117,530
Springs				
Bakuli Springs	216,384	78,980,160	2,352	2,961,756
Bore Hole				
Shegel (I) Borehole	93,840	34,251,600	1020	8,562,900
Water Pans				
Haro Haroubu Water Pan	64,400	23,506,000	700	881,475
Haro Boota water pan	133,400	48,691,000	1450	1,825,913
Sagante/Badasa				
Shallow Wells				
Sagante Shallow Wells	110,400	40,296,000	1200	1,511,100
Gabra Scheme Shallow Wells	46,000	16,790,000	500	629,625
Springs				
Badasa Springs	143,520	52,384,800	1560	1,964,430
Bore Hole				
Badasa Midroc Bore Hole	23,920	8,730,800	260	2,182,700
Water Pans				
Jey Jey Badasa Pan	6,440	2,350,600	70	88,148
Shallow Wells				
Diriib Gombo Shallow Wells	73,600	26,864,000	800	1,007,400
El Qarsa Shallow Wells	73,600	26,864,000	800	1,007,400
Bore Holes				
Kubi Qallo Borehole	21,160	7,723,400	230	1,930,850

Point of water access	Estimated water yield L/day	Estimated annual water yield L/year	Number of dependent households	Estimated annual water value at an average price of Ksh 5 per jerrican
Dololo Dokatu Borehole	4,140	1,511,100	45	377,775
Diriib Gombo (I) Borehole	6,440	2,350,600	70	587,650
Diriib Muslim Borehole	1840	671,600	20	167,900
Jaldesa Borehole	6,440	2,350,600	70	587,650
St Paul Sec. Borehole	1,840	671,600	20	167,900
Karare				
Shallow Wells				
Songa Shallow Wells	7,728	2,820,720	84	105,777
Ula Ula Wells	16,100	5,876,500	175	220,369
El Lekope wells	5,336	1,947,640	58	73,037
Serenanayeki Shallow wells	4,140	1,511,100	45	56,666
Lchuta shallow Wells	4,140	1,511,100	45	56,666
Ewaso Wells	4,600	1,679,000	50	62,963
Lng'urus shallow Wells	11,040	4,029,600	120	151,110
Water Pans				
Lelelai water pan	3,680	1,343,200	40	50,370
Springs				
Songa Springs	110,400	40,296,000	1200	1,511,100
Lchuta Springs	101,200	36,938,000	1100	1,385,175
Total				30,485,185

Note. The points of water access were separated per ward (Marsabit central, Sagante/Jaldesa and Karare) to show distribution and hydrological productivity of each of the ecosystem zone.

Monetary valuation of ecosystem watershed service

The findings of the face-to-face interviews with water consumers in the Mt. Marsabit ecosystem showed that 99.4% of all the 275 respondents were direct beneficiaries of the ecosystem watershed service with only 0.6% as non-beneficiaries relying on water from Logologo area, which is outside Mount Marsabit watershed boundary. Majority of the beneficiaries (54.5%) were domestic water users, followed by livestock keepers (31.6%), small scale irrigators (7.3%), commercial water dealers (2.9%), tourism operators (2.5%) and conservation organizations (1.1%). The six categories were used in the

estimation of the monetary value for the ecosystem watershed.

Domestic household users

The valuation was based on the total number of beneficiary households for various water access points. This was based on an average household size of 4.6 occupants per household (KNBS, 2009) and the WHO minimum daily water requirement of 20 litres/person/day and an average water price of Ksh 5 per 20l (NDMA, 2017). Table 3 shows the monetary value for domestic water use in different types of water access points.

Livestock keepers

Livestock watering was mainly reliant on boreholes, shallow wells, forest springs, crater lakes and water pans. The estimation of the monetary value for this category involved the consideration of the total number of livestock watered at various water access points multiplied

by the average daily livestock water requirement for different livestock species as provided by the Water Resources Authority (Table 4, WRMA, 2013). Table 5 shows the monetary value for the livestock water use in different types of water access points.

Table 4. Summary of average livestock water requirements

Livestock Type	Liters per capita per day
Cattle	33.25
Camel	43.5
Sheep	5.5
Goat	5.5
Donkey	22.5

Source: WRMA (2013)

Table 4. Summary of monetary value for livestock water use in different water access points

Point of water access	Type of livestock (numbers)						Livestock Total	Water requirement L/day	Water requirement L/year	Estimated annual water value at average price of Ksh 5/Jerry can
	Cows	Camel	Goats	Sheep	Donkey					
Marsabit Central										
Crater Lake										
Gof Jirime	50	20	150	100	20	340	4,907	685,390	25,702	
Shallow Wells										
Karatina Shallow wells	200	30	200	100	30	560	10,280	1,547,760	58,041	
Bore Hole										
Shegel (I) Borehole	500	200	700	400	80	1,880	33,175	4,919,500	1,229,875	
Shegel (II) Borehole	400	300	500	300	50	1,550	31,875	4,750,000	1,187,500	
Sagante/Badasa										
Shallow Wells										
Sagante Shallow Wells	500	100	200	150	20	970	23,350	2,165,020	541,255	
Gabra Scheme Shallow Wells	300	100	300	250	30	980	18,025	2,672,300	100,211	
El Nadeni Shallow Wells	400	20	400	200	50	1,070	18,595	2,784,240	104,420	

Point of water access	Type of livestock (numbers)					Livestock Total	Water requirement L/day	Water requirement L/year	Estimated annual water value at average price of Ksh 5/Jerry can
	Cows	Camel	Goats	Sheep	Donkey				
Bore Hole									
Midroc Borehole	50	-	100	150	10	310	3,263	449,150	112,288
Jey Jey Badasa Pan	200	-	200	100	20	520	8,750	1,302,600	48,848
Sagante/Jaldesa/Dirib									
Shallow Wells									
Diriib Gombo Shallow Wells	100	50	200	100	10	460	7,375	1,067,700	266,925
El Qarsa Shallow Wells	500	150	300	150	50	1,150	26,750	4,887,380	1,221,845
Bore Holes									
Kubi Qallo Borehole	700	200	500	400	100	1,900	39,175	5,936,100	1,484,025
Kubi Qallo China Borehole	500	100	300	200	40	1,140	24,625	3,727,900	931,975
Dololo Dokatu Borehole	700	100	400	200	50	1,450	32,050	4,869,300	1,217,325
Diriib Gombo (I) Borehole	500	100	300	100	30	1,030	23,850	3,623,900	905,975
Jaldesa Borehole	700	150	400	200	100	1,550	35,350	5,433,900	1,358,475
Diriib Gombo (II) Borehole	300	50	200	150	20	720	14,525	2,180,500	545,125
Karare									
Lake									
Gof Bongole	200	50	300	100	50	700	12,150	1,830,800	457,700
Shallow Wells									
Songa Shallow Wells	200	100	300	100	50	750	14,325	2,161,400	81,053
Ula Ula Wells	100	50	200	100	50	500	8,275	1,254,900	313,725
El Lekope	200	50	200	150	30	630	11,425	1,708,600	64,073
Serenanayeki wells	200	30	200	100	20	550	10,055	1,500,960	56,286
Lchuta shallow Wells	400	100	200	100	50	850	20,425	2,907,600	109,035
Ewaso Wells	200	50	300	100	50	700	12,150	1,830,800	68,655

Point of water access	Type of livestock (numbers)					Livestock Total	Water requirement L/day	Water requirement L/year	Estimated annual water value at average price of Ksh 5/Jerry can
	Cows	Camel	Goats	Sheep	Donkey				
Lng'urus shallow Wells	400	100	200	50	30	780	19,700	3,019,400	113,228
Water Pans									
Silango water pan	200	80	300	150	20	750	13,055	1,917,360	71,901
Subtotal	8,700	2,280	7,550	4,200	1,060	23790	477,480	71,134,460	
Total value									12,675,466

Note. The points of water access were separated per ward (Marsabit central, Sagante/Jaldesa and Karare) to show livestock distribution and hydrological productivity of each of the ecosystem zone.

Small scale farmers

This category was mostly based in the Songa Leyai, Badasa, Jaldesa and Jirime areas where a small population engaged in household crop irrigation using shallow wells, springs, borehole and Crater Lake. The water demand for this category was based on the estimates developed by Millennium Water Alliance for Marsabit area (IRC-WASH, (2014)). Table 6 shows the monetary value for the small-scale irrigation water use during the dry season; during the rainy season the crops are mostly rain fed.

Table 5. Estimated annual monetary value of water use by small scale farmers

Crops grown	Water Sources (Point supplying small scale farmers)	Crop water need mm/growing period	Growing period (days)
Kales	Songa Shallow wells	500	90
Tomatoes		600	140 (Inc. in nursery)
Spinach	Leyai-Kituruni	600	90
Pepper		900	120
Onions	Gof Jirime Crater	550	130 (Inc. in nursery)
Fruits: Mellon	Jaldesa borehole	800	140
Maize		600	110
Beans		500	120
Khat (Miraa)	RAIN FED	-	-
Cow pea		500	110
Coriander (Dania)		140	45
Irrigation water demand m ³ /day	14m ³ /day		
Irrigation water need m ³ /year	2142m ³ /year		
Total (Estimated annual water vale at an average price of Ksh. 5 per jerry can)	Ksh 535,500		

Commercial water vendors and users

Commercial vendors constituted 2.9% of the Marsabit ecosystem watershed service beneficiaries. The vendors accessed water mainly from springs and boreholes and sold it to the residents especially within Marsabit town.

Boarding schools in the area were also considered as part of this category. **Table 7** shows the monetary value for water use by commercial vendors.

Table 6. Estimated annual monetary value for commercial water vendors

Commercial water vendors/users	Beneficiary HH	Water Source	Estimated abstracted water per day (L/day)	Estimated annual water (L/year)	Estimated water value at an average price of Ksh 5
Posta Kiosk	1900		380,000	9,500,000	2,375,000
Shauriyako Kiosk	1248	Bakuli Spring	249,600	6,240,000	1,560,000
Dirib Gombo Kiosk	2000	Muslim Borehole	200,000	5,000,000	1,250,000
Badasa Kiosk	1134	Badasa (Booji) Spring	104,328	12,519,360	3,129,840
Bowser supplies	-	Borehole	36,720	7,711,200	1,927,080
Sasura Girls Sec.	350	Borehole	17,500	4,532,500	1,133,125
St Paul Sec. School	200	St Paul Borehole	10,000	2,590,000	647,500
Total					12,022,545

Tourism operators

Tourism is important and can generate revenue through visitors. Additionally, the comfort of tourist facilities is commonly gauged according to the level of water supply reliability. Marsabit had a number of facilities identified and documented

which was used in calculation of the consumptive value of the tourism operators' beneficiaries' category. **Table 8** shows the monetary value for water use by tourism establishments in the Mount Marsabit ecosystem.

Table 7. Estimated annual tourism operator's consumptive values

Facility type	Star rating	Number	Bed capacity	Price (Ksh)		Water litres per day		Value per unit of water (Ksh/L)	Water Source
				Per bed	Total	Per Bed	Total		
High class	5	0	-	25,000	-	-	-	8	Qubi Qallo Borehole
	4	2	45	5000	225,000	600	27,000		
Medium	3	3	88	3000	264,000		26,400	10	Dirib

class	2	3	69	2,500	172,500	300	20,700	8	Borehole
Low class	1	2	47	1,500	70,500		2,350	30	Kamboe
Total	0	15	359	1000	359,000	50	17,950	20	
					1,091,000		94,400	12	

Conservation institutions

This category was associated with water supply for the Kenya Wildlife Service (KWS) and Kenya Forest Service (KFS) stations within the Marsabit National Park and Forest Reserve, respectively, which included offices, staff quarters, and camp

sites. Jaldesa and Songa conservancies which were operated under the Northern Rangeland Trust (NRT) were included in this category. **Table 9** shows the monetary value for water use by conservation institutions in the Mount Marsabit ecosystem.

Table 8. Estimated annual monetary value of water use by conservation institutions

Conservationists	Water Source	HH number	Office Staff number	Offices Litres/day		Estimated Abstracted water (L/day)	Estimated Annual water L/year)	Estimated annual water value at an average price of Ksh 5 per jerrican
				per head	Total			
KWS	KWS	64	32		+800	6,688	2,441,120	610,280
KFS	borehole	48	24	25	+600	5,016	1,830,840	457,710
Songa conservancy	Songa Shallow wells	16	10	25	+250	1,722	628,530	157,132.5
Jaldesa Conservancy	Jaldesa Borehole	26	14	25	+350	2,742		250,207.5
Total								1,475,330

Total monetary value

The overall value of the Mount Marsabit ecosystem watershed service based on the six categories of water use was estimated at Ksh 58,285,026 or \$582,035 per year. This can be considered as the revenue which the mountain forest ecosystem generates each year for all the water consumers in the area. The value was highest in the eastern zone (Sagante/Jaldesa) covering an area of 624 km² at approximately Ksh 30,477,943, followed by the central zone (Marsabit) covering 877 km² at Ksh 22,105,532 and lowest in the western zone (Karare/Songa) at Ksh 5,701,550.

Discussion

Most of the Latin America rural dwellers have perception that forest ecosystem greatly contributes to provision of water supply. A study by Johson and Baltodano, (2004), on community perception revealed forest ecosystem's ability to intercept rainfall and replenish water sources, thereby contributing to water supply. The perception seems to be common among rural dwellers in Marsabit as well. From the study in Marsabit forest ecosystem, the locals perceived the water quality to be good. This confirms the role forests plays in absorbing and, filtering the water and improving its quality. Further, a study

by Calder *et al.*, (2007) revealed that forest ecosystem protects soils, reducing soil erosion and siltation of water bodies.

The typology of water sources in the Marsabit dryland water tower (150km²) resembles those in other ecosystems of similar nature. A study by Kiringe *et al.*, (2016), for example, recorded different types of water sources in Kirisia forest ecosystem watershed (≈700km²) in neighbouring Samburu County including earth dams, water pans, shallow wells, boreholes, springs and streams. However, unlike the situation in Marsabit forest, the Kirisia forest ecosystem watershed service was dominated by earth dams and water pans as the water sources supporting the highest population including Maralal town. This was followed by boreholes while streams, springs and shallow wells were used by the least number of watershed service beneficiaries (Kiringe *et al.*, 2016). In the Chyulu Hills (741km²), the key water sources are dominated by springs, rivers, boreholes and shallow wells (Mwaura *et al.*, 2016). The difference in the typology of water sources is related to both the size of the water tower and climatic conditions. The smaller the size of the water tower, the fewer the springs, streams and rivers especially in very dry areas which appear to be the case for Marsabit water tower.

Unlike the situation in other dryland water towers, there is limited investment on rainwater harvesting through the use of water pans in Marsabit as an alternative option for supplementing the existing water sources which are increasingly becoming overwhelmed by the high-water demand. This has been identified for similar areas in Sub-Saharan Africa (Amede *et al.*, 2014). Alternative water supply options will become increasingly necessary due to the increasing demand for water resources against the expected negative impacts of climate change in Kenya (RoK, 2009). According to Muhati *et al.*, (2018) Marsabit town has continued to suffer acute water stress in recent years due to reduction in supply from Bakuli spring which is strongly linked to over abstraction. All the 27 sub-locations in Saku sub-county with a population of 79,181 entirely depend on Mount Marsabit ecosystem for their water provision (KNBS, 2020).

According to Otele *et al.*, (2020) Marsabit is likely to experience high population growth in five to ten years, owing to high fertility rate. Marsabit has a fertility rate of 5 which is higher than the national average of 3.9 (KNBS, 2012).

The valuation estimate of the Mount Marsabit water tower at Ksh 58,285,026 or \$582,035 per year is quite similar to the monetary estimates for other dryland water towers in Kenya despite its smaller size. A study by Mwaura *et al.*, (2016), for example estimated a lower monetary value for the water resources in the Chyulu Hills (consumptive use only) at Ksh 46, 676,192 (≈\$466,862) per annum. 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. However, the Chyulu Hills is in a less dry environment with several other alternative water supply options compared to Marsabit including the Athi River which transverses the area.

The economic value of watershed services for the Marsabit water tower was lower when compared to the Mukogodo dryland forest (260km²) in Laikipia county where a study by Kinuthia (2005), estimated the economic value of water resources using the contingent valuation method (CVM) by asking local people in the area how much they were willing to pay (WTP) for the conservation of the forest 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 Ksh 5,117,107,461 or approximately \$51,171,075 per year. The difference is attributed to the valuation methods used, on one hand, as well as the fact that the scope of the Mukogodo valuation considered other ecosystem benefits beyond watershed services. Unlike the MPM which deals with the actual market situation, the CVM is based on perceived values based on hypothetical market scenarios.

The economic value of watershed services for the Marsabit water tower was lower when compared to the values of the larger national water towers

in Kenya such as Mount Kenya which has been estimated at US\$ 20.4 million, Aberdares (\$7.4 million), Mount Elgon (\$3.7 million), Cherang'any (\$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.

Conclusion and Recommendations

The findings showed that the Marsabit water tower is characterized by different types of water sources which are dominated by shallow wells and boreholes with the latter as the major source due to the dry conditions and higher reliance on groundwater. The high-water demand in the Marsabit area was mostly associated with household domestic water uses and livestock watering because pastoralism is the key economic sector. The findings are consistent with those of other studies which indicate that isolated dryland mountain ecosystems play a fundamental role in water production and supply in areas associated with poor and unreliable rainfall. The spatial analysis of ecosystem water access points showed that most of the water sources are concentrated on the eastern side of the water tower which is also the windward side in relation to the Indian Ocean. This has strongly influenced the distribution of human settlements in the area including the location of Marsabit town.

The valuation estimate of the Mount Marsabit water tower at Ksh 58,285,026 or \$582,035 per year signifies the high importance of dryland water towers despite their small sizes. It is expected that the information generated in this

study will be useful in enhancing awareness among various water users on the linkage between the mountain ecosystem and water supply in order to raise the level of community education and public awareness (CEPA) towards such ecosystems. It is expected that this will raise public motivation for ecosystem conservation financing. In this regard, it is recommended that the WRA, Kenya Water Towers Agency (KWTA) and the County Government of Marsabit should collaborate with local communities and the local water vendors to initiate a Payment for Ecosystems Services (PES) scheme that will plough back some of the revenue generated from the water market towards conservation financing in the Mount Marsabit Forest ecosystem. In the same vein, there is need for water consumers to be encouraged to embrace the use of alternative water sources such as rainwater harvesting in order to reduce the pressure on the Marsabit water tower.

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