

Characterization of Chyulu Hills Watershed Ecosystem Services in South-Eastern Kenya

John Warui Kiringe¹, Francis Mwaura² & Fiesta Warinwa³

¹Habitat Planners, P.O. Box 10982-00100 Nairobi, Kenya

²Department of Geography & Environmental Studies, University of Nairobi, Box 30197-00100, Nairobi, Kenya

³African Wildlife Foundation (AWF), P.O. Box 310-00502, Nairobi, Kenya

Correspondence: John Warui Kiringe, Habitat Planners, P.O. Box 10982-00100 Nairobi, Kenya. Tel:254-722-896-632. E-mail: jwkiringe@gmail.com

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Abstract

Water is an important good provided by watersheds and is critical in sustaining life and socio-economic development. This study evaluated water provision in the Chyulu Hills watershed which is one of the important dry land water catchments in Kenya. Surface water discharge was mainly through rivers and springs with the latter being more prevalent than the former while ground water provision was primarily through boreholes and shallow wells. Springs discharged the highest water volume annually estimated at 128.14million m³ or 85.14% of all the water discharged in the watershed, with shallow wells and boreholes discharging the least water. For all the springs found in the watershed, Mzima springs discharged the highest water volume estimated at nearly 113.15 million m³ annually or 88.30% of the water produced by all the springs; and about 75.19% of the water in the entire watershed. Rivers which were active had a total water discharge of about 20.66million m³ per year, with Kibwezi River discharging 17.59 million m³ annually or 85.14% of all the water from rivers. Shallow wells were mainly prevalent at Nthongoni and the Makindu, and their annual water discharge was about 16.96million m³ per year with boreholes contributing 98.87% (approximately 16.76 million m³/yr.) of the ground water, and the rest (19,169.92m³/yr.) being contributed by shallow wells. The total amount of water discharged in the watershed by the combined water source types was about 150.49 million m³/yr.

Keywords: Chyulu Hills, Mzima springs, watershed ecosystem services, water discharge

1. Introduction

Ecosystems are ecological entities comprising of an assemblage of diverse fauna and flora and their supporting abiotic attributes including landscape, climate and hydro-geologic systems (MEA, 2005). Humans are an integral component of ecosystems because all societies depend entirely on the earth's ecosystems (MEA, 2005). While exploitation and modification of ecosystems have contributed to considerable net gains in the economy and human well-being, it has in some instances harmed the socio-economic welfare of communities. Ecosystems generally provide a wide range of goods and services such as; food, clean water, energy, climate regulation, biogeochemical and nutrient cycling, flood disaster mitigation, biodiversity support, spiritual and cultural benefits all which maintains life on earth (Daily et al., 1997; de Groot, Matthew, & Roelof, 2002). Collectively, these benefits are commonly referred to as ecosystem services (MEA, 2000 & 2005) and are usually grouped into four key categories. These include; provisioning services (e.g. food, fresh water and wood fuel), regulating services (e.g. water purification and climate moderation (Moberg & Folke, 1999; Norberg, 1999; Lobo, 2001; de Groot et al., 2002). Others are nutrient balancing and maintenance of the hydrological cycle, cultural services (e.g. worship, recreation and ecotourism) and supporting services (e.g. soil reconditioning and biodiversity support). Nonetheless, an ecosystem does not always offer all the four types of services simultaneously.

An important aspect linked to forests is watershed services which provide water to humans, the environment, flora and fauna biodiversity (Graeme & Brian, 2006; Bruno & Raae, 2012). Such landscapes therefore serve as lifelines to a wide range of beneficiaries in terms of water supply for diverse uses including; domestic functions, industrial activities, irrigation, hydropower generation and human recreation. However, MEA (2005) notes that in the last fifty years, humans have converted and even degraded large swathes of natural forest ecosystems thereby

significantly reducing the magnitude of watershed services. This is a worrisome situation since it's likely to exacerbate current water scarcity (Bergkamp et al., 2003; Pattanayak, 2004; Hulme, 2005; Oki & Kanae, 2006). Further, Wilkie, Holmgren, & Castaneda, 2003) also notes that watershed degradation is rampant in countries where livelihoods of rural people are heavily reliant on exploitation of forest resources. This calls for sustainable management of forests and harmonization of environmental conservation, livelihood needs and socio-economic development aspirations of such communities (IUCN, 1996; UN, 2007). This approach conforms to the United Nation's Convention on Biological Diversity which advocates for balanced management of natural resources for environmental and socio-economic development and stability (UNEP, 1996; Wilkie et al., 2003). Failure to apply such principles in utilization of forests tends to override conservation objectives thereby causing adverse impacts on ecosystem stability and provision of critical watershed services (Kokwaro, 1988).

Naturally, high altitude features like mountains and hills tend to act as water harvesting landscapes making them critical water provision focal sites. Thus, Kenya's mountain forests such as Mt. Kenya, Mt. Elgon, Aberdare Ranges and the Mau Forest Complex as well as hills located in dry areas like Chyulu, Taita, Kirisia, Mathews Range and Kasigau are important water recharge and supply systems in the country. It's therefore estimated that such water towers contribute more than 3.6% of Kenya's national Gross Domestic Product (GDP) (GoK, 2013). In cognizance of this, and given the role they play in sustaining local livelihoods and driving the country's economy, the government has recognized them as critical "Water Towers" whose management has been bestowed to the Kenya Water Towers Agency (KWTA).

Past conservation and management interest for Kenya's water towers has mainly focused on the five main mountain forests namely; Mt. Kenya, the Aberdare Ranges, the Mau Complex, Mt. Elgon and the Cherangani Hills. There has been limited interest on the other smaller water towers especially those in the dry-lands which sustain almost 30% of the country's population including most of the wildlife resources. The Chyulu Hills where this study was done is a critical dry land water catchment in Southern Kenya but its environmental integrity is increasingly threatened by inappropriate human activities like charcoal burning, logging and livestock incursion (Muriuki et al., 2011; Kamau, 2013; Pringle & Quayle, 2014; Wildlife Works, 2014). In view of its role in sustaining the socio-economic welfare of many rural and urban populations and provision of water to large populations of wildlife species, it's imperative that its watershed ecosystem service is understood. Thus, the aim of this study was to characterize the magnitude of watershed service of the Chyulu hills and primarily focused on the following objectives; i) delineate the extent of the watershed and its drainage network, ii) assess water discharge levels, and, iii) compare the magnitude of the watershed service with other ecosystems in Kenya.

2. Area Description

The Chyulu Hills are relatively young volcanos situated in Southern Kenya, nearly 190 Km Southeast of Nairobi City close to the Nairobi-Mombasa highway (Figure 1). They are made up of a series of hills of varying altitude, and form a narrow chain of quaternary volcanoes with a Northwest to Southeast elongation covering nearly 100km between Emali and Mtito Andei townships. Their altitude varies from about 1000mASL (meters above sea level) to nearly of 2175mASL (Simons, 1998), and the entire region has four key landforms (volcanic cinder cones, ash and lapilli fields, lava fields and ancient lava-dam lakes). Geologists estimate the hills may have been formed by volcanic activities which occurred less than 10,000 years ago (Ritter & Kaspar, 1997; KWS, 2007) during the Holocene-Pleistocene era (Saggerson, 1963). However, the most recent volcanic activities in the hills landscape are thought to have occurred in the southern sector giving rise to a geologically young cinder cones and expansive exposed lava cover commonly and locally referred to as *shetani* lava (Saggerson, 1963; Wright, 1982). The lava flow is estimated to be 8Km long, 6Km wide and 5m thick, and was formed around 1855 (± 5 years) (Saggerson, 1963; Nyamweru, 1980). Chyulu lava fields cover an area of nearly 2,000Km² with a length of about 80Km and width of approximately of 30Km, and are made up largely of basaltic lavas and pyroclastics of different geological ages.

Chyulu Hills comprises of a series of about 170 cinder cones, and those in the central sector are aligned in a NNW-SSE direction and most cones are situated above 1400mASL. The cones are comprise of two dissimilar geomorphic components mainly; i) the cone slopes made up of nearly straight, inclined surfaces between the crater rim and the surrounding lava fields, and, ii) craters represented by basin-like, circular or horseshoe shaped rimmed structures at the summit. The cinder cones play a key role of intercepting rainfall across the landscape which in turn recharges the ground water systems associated with the hills. Geologically, the lavas of the Chyulu Hills are broadly grouped into the Pleistocene Northern Chyulu Hills lavas and the Holocene Southern Chyulu Hills lavas (Saggerson, 1963, 1968; Haug & Strecker, 1995; Spath, le Roex & Opiyo-Akech, 2000). The lavas in the north are considered to be fresh, relatively unaltered, vesicular porphyritic and microporphyritic rocks containing large amounts of phenocrysts of olivine while those in the south are largely alkaline basalts and hawite (Spath, Anton & Norbert, 2001) (Figure 2).

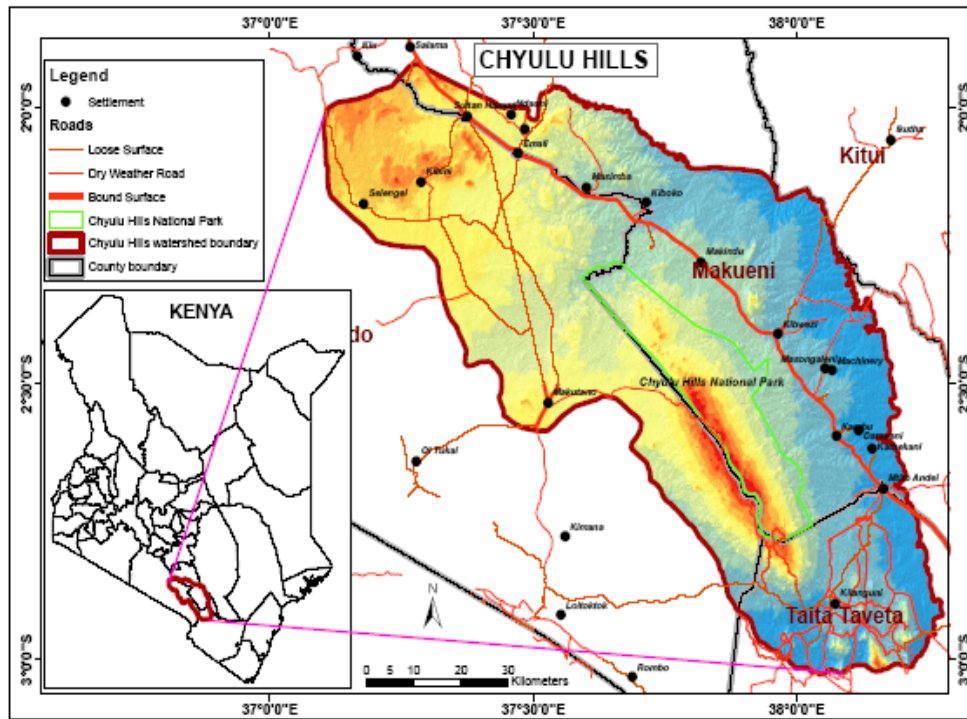


Figure 1. Spatial location of the Chyulu Hills in Southern Kenya

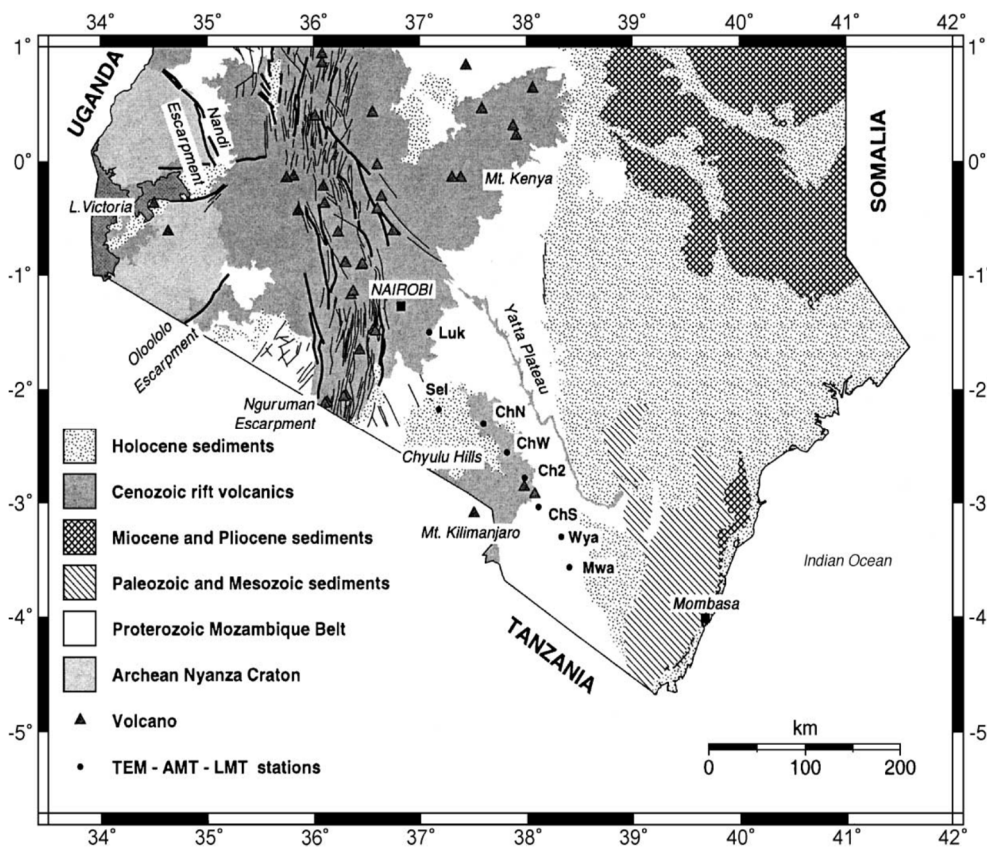


Figure 2. Geology map of Kenya and the Chyulu Hills based on transient electromagnetic (TEM) and broadband magnetotelluric (MT) survey; Stations: Chyulu North (ChN), Chyulu West (ChW), Chyulu 2 (Ch2) and Chyulu South (ChS) (Source: Sakkas et al., 2002)

The general landscape in the Chyulu Hills is characterized by an arid to semi-arid environment, with an annual rainfall of 500mm to 1200mm, and evaporation ranging between 1800mm and 2200mm (Muriuki et al., 2011; Kamau, 2013; Pringle & Quayle, 2014). Rainfall is normally received twice a year with short rains occurring between October and December while the long rains are generally received between March and May (GoK, 2008). May, June and July are normally the coldest months while the hottest months are between September and February (Kamau, 2013). An analysis of available 59 year rainfall data for the hills watershed (1954-2013) shows spatial variation in this attribute with the Northern sector receiving the highest amount of rainfall and the Southern part having the lowest (Figure 3). This rainfall pattern suggests the Northern and Central regions of the hills could be characterized by high groundwater water recharge capacity due to the superior precipitation levels.

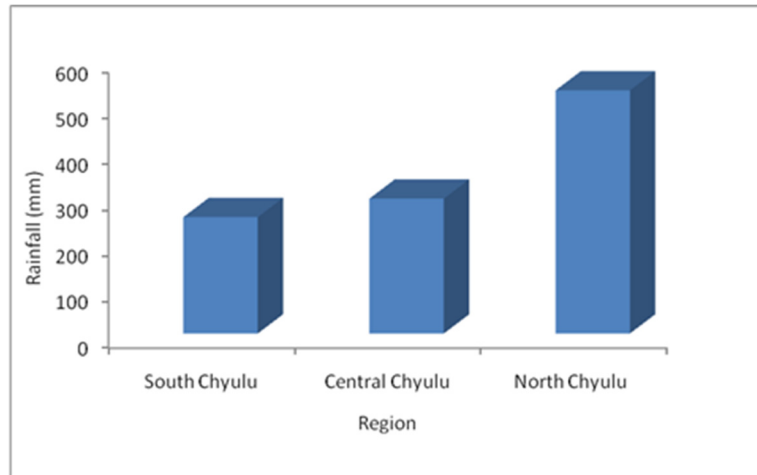


Figure 3. Spatial rainfall pattern in the Chyulu Hills Watershed

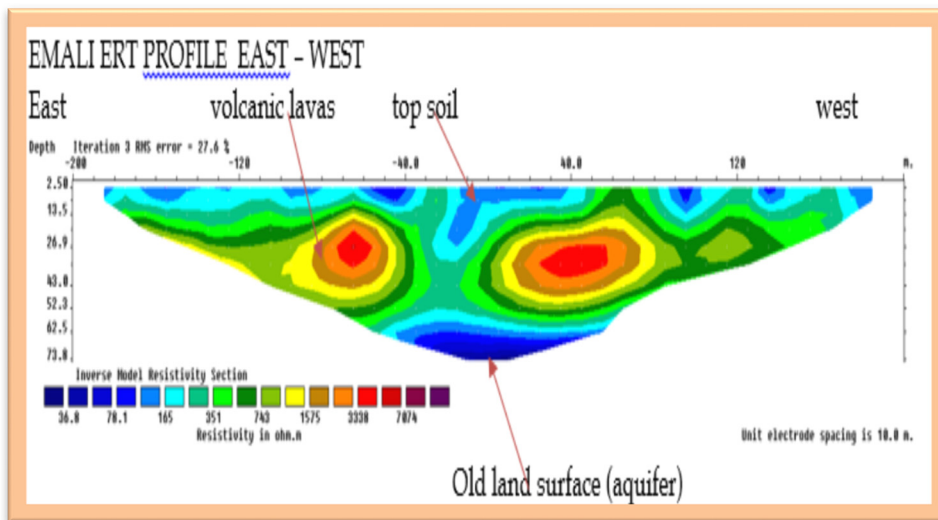


Figure 4. ERT Lund Image of Emali Town along the Nairobi-Mombasa Highway

Water recharge for the Chyulu Aquifer System (CAS) has previously been estimated using soil moisture balance, hydro-chemical data and isotope content (Wrights, 1982; Guston & Mnyamwezi, 1985). The findings have estimated that the recharge accounts for approximately 13% of the total annual precipitation, and this water is recharged to the groundwater system and then flows through groundwater systems to emerge as springs. However, the groundwater is also pumped from the CAS through boreholes and shallow wells. Analysis of lund images of Electrical Resistivity Tomography (ERT) surveys undertaken at Emali Town (Figure 4) and Mbui Nzau (Figure 5) area near Makindu revealed that at the periphery of the Chyulu Hills, the base of the lava flow is exposed especially around the western, northern and southern sides (WRMA, 2015). In Emali area, the base of the lava

flows is exposed along the Muoni seasonal stream while in the Makindu area the base of the volcanic lava flows is observed along the Makindu shallow wells field. In Mbui Nzau which is a remnant of granitoid gneisses, the hill stands out as an inselberg inlier among volcanic pahoehoe lavas. Therefore, the immense thickness of basaltic lavas and tuffs diminishes to a feather edge which is freely exposed at the periphery of the hill. Consequently, the water which enters the permeable parts of the series high up the Chyulu Hills either escapes at the surface as springs or is stored as groundwater.

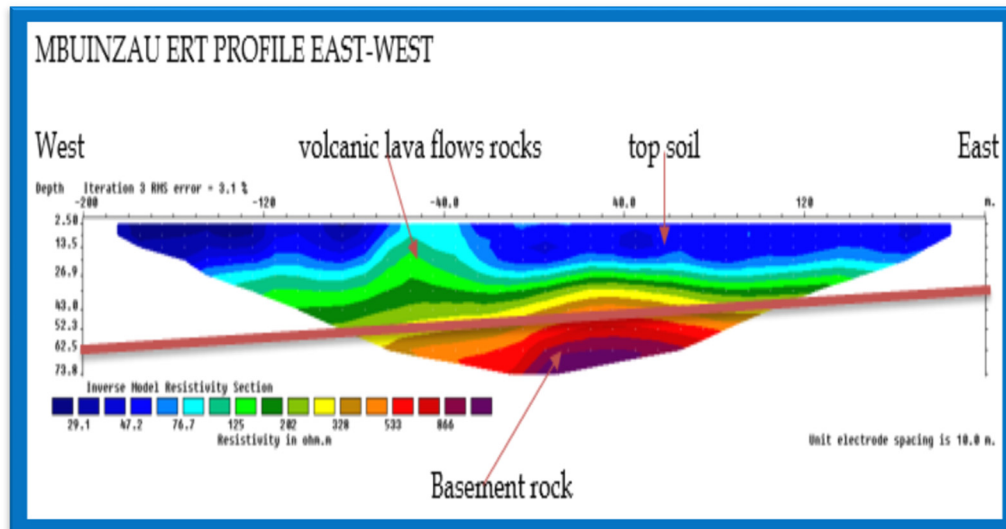


Figure 5. ERT Lund Image of Mbui Nzau area along the Mombasa

3. Methods

3.1 Watershed and Drainage Network Delineation

The Chyulu Hills watershed boundary was delineated based on 30m ASTER Digital Elevation Model (DEM) satellite data in relation to the existing drainage network. The ASTER satellite data was displayed on an ArcGIS software view window and overlaid on the watershed drainage layer. The watershed boundary was then derived by digitizing a polygon guided by the DEM and the direction of surface water flow. The digitized polygon was considered as the Chyulu Hills water watershed and focal point for the watershed ecosystem service study. Satellite imageries were used to establish the spatial extent and lay out of the drainage network within different zones of the watershed (i.e. Northern, Southern, Eastern and Western) as well as the total length (in kilometers) and drainage density of rivers and streams in each zone (length of rivers and streams per km²).

3.2 Water Discharge Estimation

Primary and secondary data were used to estimate water discharge levels. The later comprised past water discharge records for springs and rivers which were sourced from the Water Resources Management (WRMA) offices in Kibwezi and Oloitokitok townships. Primary surface water discharge data was measured on site during fieldwork missions using a field water flow meter (Son Tek ADV Hand held Flow Tracker). Springs where water discharge was measured were; Masimba (Esukuta), little Kiboko, Umani, Kya Kai, Mzima and Olpusare. However, water flow measurements couldn't be done in the following rivers since they were found to have dried up; Kambu, Thange, Makindu and Mtito Andei. Water provision from boreholes and shallow wells were estimated using primary data collected in different zones of the watershed supplemented by secondary data. Acquisition of secondary data involved gathering of technical reports, hydrogeological reports and borehole specific data from the WRMA offices in Kibwezi and Oloitokitok.

4. Results

4.1 Watershed and Drainage Network

The spatial coverage of the Chyulu Hills watershed is estimated to be approximately 7,762.64Km² and covers three counties (Makueni, Taita Taveta, and Kajiado) (Figure 5). In Makueni County, the watershed is concentrated in Makindu and Kibwezi sub-counties while in Kajiado County it's mostly concentrated in the Oloitokitok sub-county. It occupies a small part of Taita Taveta County to the extreme south in the Shetani lava area situated in

Tsavo West National Park, and, lies within the Athi Catchment Area (ACA) and falls under two water resources management units 3F and 3G. The watershed has a number of valuable springs, permanent and ephemeral rivers (Figure 5). The principal rivers are; Greater Kiboko River, Little Kiboko River, Makindu River, Kibwezi River, Kambu River and Mtito Andei River which are all part of the Muuoni River system which discharges into the Athi River.

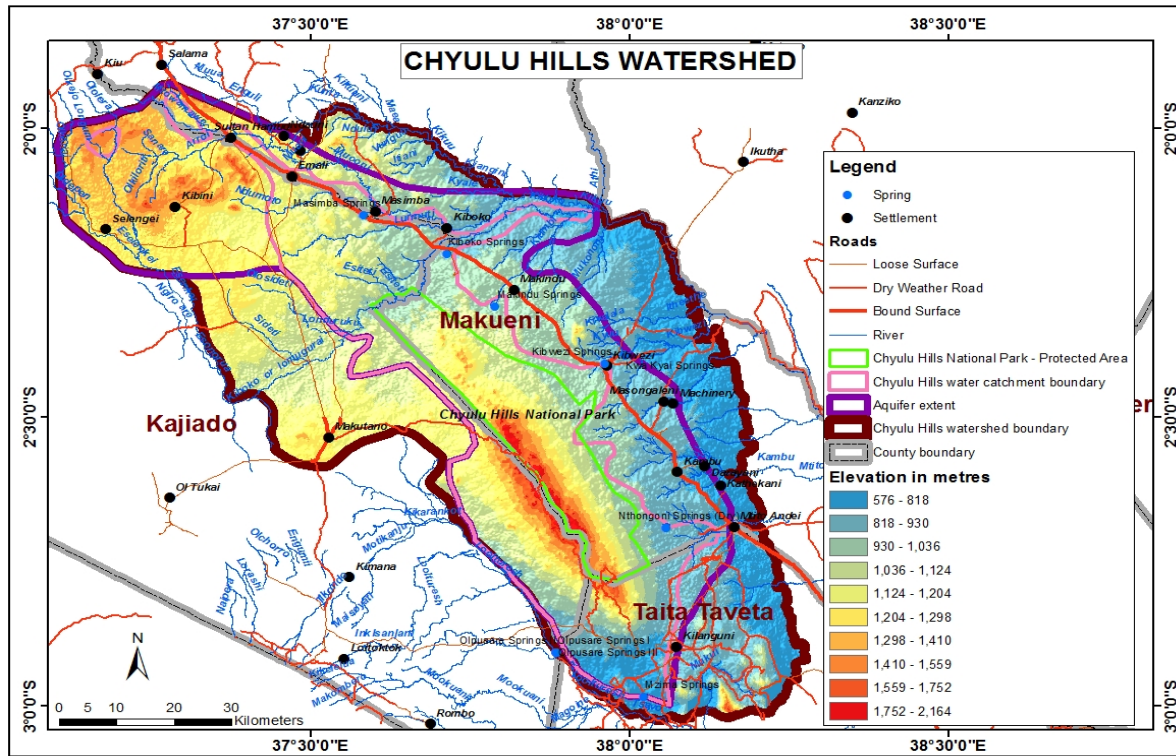


Figure 5. Spatial layout of the Chyulu Hills watershed

The drainage network within the watershed varies from one sector to the other, with the Northern, Eastern and Western zones having a spatial coverage of approximately 4,700Km², 3965Km² and 3788Km² respectively (table 1). These sectors were also characterized by a high density of streams and rivers of about 2,135 Km², 2,074Km² and 827Km² in the Northern, Eastern and Western zones respectively. Overall, this indicates there was a superior drainage density or network on the North-eastern side of the watershed, followed by the South-eastern side which conforms to the high rainfall received in these sectors. The western side had the lowest drainage density (network) because it was on the rain- shadow of the watershed or Chyulu Hills with the watershed being hydrologically more active in the north-eastern zone in response to the rainfall pattern.

Table 1. Spatial coverage and density of the drainage network by watershed zones

Watershed zone	Approximate area (km ²)	Total stream & river length (km)	Drainage density (length of streams & rivers per km ²)
Northern zone	4,704.50	2,135,112.20	2,135
Southern zone	3,049.50	767,051.80	767
Eastern zone	3,965.50	2,074,222.60	2,074
Western zone	3,788.50	827,941.40	827

4.2 Water Discharge

Water in the watershed was discharged through rivers, springs, boreholes and shallow wells found in different zones of the landscape (table 2). In the Northern zone (Masimba-Kiboko-Makindu), the key springs were;

Masimba, Little Kiboko, and Penge while Greater Kiboko (Maangi Uvungu) was the only river found the region. Various boreholes and shallow wells were also found in this zone but most of them were concentrated in urban centers like Makindu town. Similarly surface and ground water discharge systems were found in the Central zone of the watershed (i.e. Kibwezi Region) and the springs in this region included Umani (situated in Kibwezi Forest Reserve) and Kwa Kyai. Boreholes owned privately by institutions, households or community members were also prevalent and were important sources of ground water abstraction. The Southern zone (Kambu-Mtito Andei-Mzima) had no active rivers discharging water and springs were represented by Kambu (Mbulutini) and Mzima with the latter located in Tsavo West National Park. However, the zone had the highest number of shallow wells in the entire watershed which were key water sources for households. The Western zone situated on the Kajiado County had very few water sources with a few scattered boreholes and a single active spring (Olpusare springs) situated at Iltital in Kuku Group Ranch. Table 2 shows the annual water discharges by rivers, springs, shallow wells and boreholes found in different zones of the Chyulu Hills watershed. Compared with other springs, Mzima springs discharged the highest water volume estimated at 113,151,908.60m³/yr which accounted for 88.30% of the water produced by all the springs; and discharged about 75.19% of the water in the entire watershed. Umani springs discharged the second highest water volume at 10,443,874.91m³/yr which was 8.15% of all the water discharged by springs. Collectively, springs discharged about 128,137,639.10m³/yr of water which represented 85.14% of all the discharged by rivers, springs, shallow wells and boreholes. Historically, the Chyulu Hills watershed had numerous rivers but during this study only three of them (Kibwezi River at Kwa Kyai, Greater and Kiboko River and Little Kiboko) were active. Their total annual water discharge was estimated to be 20,660,779.68m³/yr, with Kibwezi River discharging 17,590,361.19m³/yr or 85.14% of all the water from the rivers (table 2).

Table 2. Water discharge levels by different water source types in the Chyulu Hills watershed

Type of water source	Name of water source	Approximate annual water discharge (m ³ /yr)	Total annual water discharge (m ³ /yr)	Percentage contribution to watershed water discharge
Springs	Masimba (Esukuta) Springs	18,662.40	128,137,639.10	85.14
	Little Kiboko	1,528,786.54		
	Penge	129,600.00		
	Umani Springs	10,443,874.91		
	Kwa Kyai Springs	2,547,497.60		
	Kambu (Mbulutini)	52,925.00		
	Mzima	113,151,908.60		
	Olpusare	264,384		
Rivers	Greater Kiboko	1,519,741.44	20,660,779.68	13.74
	Little Kiboko River	1,550,677.05		
	Kibwezi River at Kwa Kyai	17,590,361.19		
Boreholes	All boreholes combined	1,676,377.2	1,695,547.12	1.12
Combined shallow wells	All shallow wells combined	19,169.92		
Estimated total water discharge in the watershed			150,493,965.90m ³ /yr	

Shallow wells and boreholes were the major discharge points for ground water associated with the watershed. In particular, shallow wells were mainly concentrated at Nthongoni area near Mtito Andei followed by environs around Makindu Township. Their annual water discharge was about 16,95,547.12m³/yr with boreholes contributing 98.87% (16,76,377.20m³/yr.) of the water, and the rest (19,169.92m³/yr.) being contributed by shallow wells (table 2). The collective water discharged in the entire watershed by all the water source types (springs, rivers, boreholes and shallow wells) was about 150,493,965.90m³/yr., with springs discharging the highest volume (85.14%) followed by rivers (13.74%). Although shallow wells and boreholes were the most prevalent water source types, their annual water discharge were the least (shallow wells-0.01% and boreholes-1.11%) compared to the surface water source types (rivers and springs).

5. Discussion

Landscape heterogeneity of a watershed is an important environmental attribute that enhances its water harnessing and recharge capacity (Constanza et al., 1997; Farber, Costanza & Wilson, 2002; Hanson, Ranganathan, Iceland, & Finisdore, 2008). Therefore, the expansive and intricate drainage network in the Chyulu Hills watershed especially on the Northern-eastern zone presents an ecologically suitable environment for provision of Watershed Ecosystem Services (WES). This may partly account for the diverse water source types that were found in the zone in form of springs, rivers, boreholes and shallow wells with the latter exclusively for ground water abstraction. Geologically, the Chyulu Hills are considered to be a relatively young volcanic landscape which may have been formed less than 10,000 years, ago (Saggerson, 1963; Ritter & Kaspar, 1997; KWS, 2007). Recent volcanic activities in the region may have occurred in the Southern sector creating a series of cinder cones and expansive lava cover (Wright, 1982; Saggerson, 1963). These geological features and characteristics make the landscape very porous and enables it to suck up rainwater like an expansive sponge, with most of the water percolating into the aquifer such that there is almost no run off in the hills (Guston & Mnyamwezi, 1985; Grossman, 2008). This sub-surface water flow system works its way out along the interface between the volcanics and the underlying basement rock emerging as springs at the tips of lava tongues (Wright, 1982; Guston & Mnyamwezi, 1985). Consequently, the hills play a major hydrological function in recharging various freshwater springs which are found at their foot slopes on the south, eastern and south eastern sectors of the watershed (Wright, 1982; Guston & Mnyamwezi, 1985; Grossman, 2008). In some instances, the water discharge from some of the springs is large enough to form permanently flowing rivers in all seasons like Kibwezi River though in the recent past a majority of the rivers have dried up and are rather ephemeral in their water provision behaviour (Kiringe, Mwaura, Wandera, Kimeu & Gachuga, 2015).

Springs and rivers in the Chyulu Hills watershed are mostly clustered to the north in Masimba, Kiboko, Makindu, Umani, Kibwezi and Kwa Kyai, and also to the south in Kambu, Mzima and Olpusare in Kuku Group Ranch. All except Umani Springs occur at low elevations close to or at the margin between the volcanics and adjacent older basement rocks. In these zones of the watershed there are numerous shallow wells and boreholes especially at Makindu, Kibwezi and Nthongoni which indicates a high occurrence of water resources in the underlying aquifer system. The numerous springs, rivers and underground water abstraction points in these zones are a result of several interacting factors especially the high water recharge capacity by the volcanic cinder cones and lava fields in the watershed (Wright, 1982; Guston & Mnyamwezi, 1985). It's also attributed to the high natural water recharge capacity of the natural vegetation in the Chyulu Hills National Park and Kibwezi Forest Reserve, and the deep seated basement rock which has led to formation of a reliable groundwater aquifer. Other factors include; the hills topographic profile which supports north eastern and southern groundwater seepage and an expansive and elaborate drainage network. The varied topography and attitude of the watershed landscape from about 1000mASL to nearly 2175mASL (Simons, 1998) also creates suitable conditions for formation of relief rainfall. Thus, within the watershed, rainfall may be as high as 1000mm per year in the hills compared to the contiguous rangelands where the annual rainfall ranges from 350mm to 700mm (Western, Groom, & Wordon, 2009; Pringle & Quayle, 2014) presenting favorable conditions for water recharge throughout the year.

Chyulu Hills have a rich heterogeneous vegetation community consisting of woodlands, bushland, grassland and forest patches which are scattered in different parts of the landscape depending on elevation, landform, rainfall, soils and prevalence of fire (Luke, 2003; Pringle & Quayle, 2014; Wildlife Works, 2014; Kiringe et al., 2015). The forest patches are common along the spines of the volcanic cinder cones with the largest patches located around the highest peaks in the central-southern sector of the hills, and are characterized as moist, dense cloud forest (Pringle & Quayle, 2014; Wildlife Works, 2014). The heterogeneous nature of the vegetation therefore provides a massive natural sponge which soaks up most of the rainfall which thereafter percolates into the underlying highly porous rocks and emerges as springs and rivers or through shallow wells and boreholes. According to Pringle & Quayle (2014), water in the Chyulu Hills watershed originates from either rainfall or fog interception, and the latter is associated with the cloud forests found at high elevated zones. The forests normally moisten their immediate environs creating permanent high humidity pockets of air above the forest area resulting in cloudiness and rain showers even during the dry seasons (Grossman, 2008). Without this permanent cloud cover, evapotranspiration would be very high and rain showers during the dry season would not occur. This hydrological phenomenon enhances the forest's value as a water reservoir which then recharges and stabilizes the seasonal flow patterns of springs and rivers within the watershed (Grossman, 2008). Pringle & Quayle (2014) also noted that fog formation and deposition is common on the Chyulu Hills forests and provides an additional source of moisture and subsequent recharge of water in the watershed with an estimated addition of 365mm of rainfall annually.

Water provision in the watershed occurs through springs, rivers, shallow wells and boreholes. However, springs are the major water recharge system accounting for about 85% of all the water produced by the watershed. This shows they are the foundation of water provision in the entire watershed and their preservation and sustenance is important to ensure year round water supply. Out of all the springs, Mzima produced the highest water volume annually accounting for 88% of all the water discharged by the springs, and approximately 75% of all the water discharged by the entire watershed. This indicates it's the most important in water discharge and provision in the watershed. These findings don't vary a lot from past studies with Temberly (1960) estimating the discharge from the springs accounted for 90% of the Chyulu Hills water recharge. However, Wright (1982) considered this an overestimate and instead calculated the discharge at about 70% of the total recharge. Our study found a water discharge of $3.547\text{m}^3/\text{sec}$ $110,325,888\text{m}^3/\text{yr}$ from the springs which is almost similar to past studies by Wright (1982) and Gunston and Mnyamwezi (1985) which found discharge values of $5.5\text{m}^3/\text{sec}$ ($171,072,000\text{m}^3/\text{yr}$) and $5.2\text{m}^3/\text{sec}$ ($161,740,800\text{m}^3/\text{yr}$) respectively.

Rivers discharged the second highest water volume after springs but this accounted for nearly 14% of all the water provided by the watershed. Their water emanated from three rivers only with Kibwezi River (at Kwa Kyai) discharging the highest volume, and contributing approximately 85% of all the water discharged by the rivers. The low water volume discharged by the rivers may be attributed to the fact that most of the former permanent rivers including the Greater Kiboko have become seasonal while Makindu River, Kambu, Thange and Mtito Andei have dried up in the recent past (Pringle & Quayle, 2014; Kiringe et al., 2015). Thus, their past year round water discharge and provision in the watershed has been reduced or lost entirely, and in most cases they provided water for short sessions during the wet season through surface runoff. Shallow wells and boreholes were mainly used to supplement water provided by rivers and springs and were more prevalent in areas where there was no reliable surface water. In spite of the fact that they were common, their overall water provision in the watershed was almost insignificant compared to rivers and springs but they were critical water supply systems in areas where surface water resources were limited or were entirely absent. Further, as the human population and related activities increase, there's a likelihood that surface water won't cope with increased water demand and as such there's a need to encourage water uses to sink more shallow wells and boreholes.

Documentation of water discharge and provision in Kenya's dry land watersheds is limited in spite of the critical role they play in water provision to local communities, livestock and wildlife. However, the estimated total annual water discharge in the Taita Hills watershed is $71,250,650\text{m}^3/\text{yr}$ (Eduardo et al., 2011) which is much lower than the water recharge capacity of the Chyulu Hills watershed. Johanna, Emmah, Paola & Pellikkaa, (2015) also notes that the watershed related ecosystem services in the Taita Hills watershed are declining due to environmental degradation caused by overuse of natural resources. Watkins & Imbumi (2007) indicate that the Mt. Kulal which is located in one of the driest regions in East Africa (Northern Kenya) is a critical water catchment and provides water services to a large community of pastoral communities and their livestock. They estimated the annual water discharged from the watershed to be approximately $52,751,630\text{m}^3/\text{yr}$ which is far much lower than that of the Chyulu Hills watershed. It's likely that the low water service provision of these two watersheds compared to Chyulu Hills is attributed to their location in relatively drier areas and their low rainfall which limits their hydrological capacity to discharge large quantities of water. Our study found numerous shallow wells in Nthongoni area had dried up or drying which may indicate a decline in the hydrological functions of the Chyulu Hills watershed and its ability to discharge water. Some stakeholders also mentioned that the boreholes found in low altitudes further away from the hills appeared to yield less water, and they attributed this partly to deforestation and climate change. These changes are likely to lower the hydrological capacity of the watershed to harness and replenish water.

6. Conclusions and Recommendations

Chyulu Hills watershed is important in water provision in a region characterized by low and unreliable rainfall; and springs are critical surface water discharge sites while boreholes and shallow wells are key water provision systems for ground water. The drainage network in the watershed is mostly concentrated on the North-eastern side and South-eastern, making them more hydrologically active in water provision than the Western zone which is on the rain shadow. Springs and rivers were the main surface water provision systems while shallow wells and boreholes supplied groundwater. However, springs discharged the highest water volume annually while boreholes and shallow wells discharged the least. Therefore springs are the key water discharge systems of the watershed. However, Mzima springs discharged the highest water volume and contributed approximately 88% of all the water discharged by springs; and about 75% of all the water in the watershed making it the major water discharge system. Umani springs discharged the second highest water volume which was about 8% of all the water discharged by springs while Kibwezi River (at Kwa Kyai) discharged 85% of all the water provided by rivers. Some rivers in the

watershed were found to have dried out as well as some shallow wells especially in Nthongoni area, and this might indicate the water provision services of the hills are declining.

Water provided by the Chyulu Hills supports numerous beneficiaries within and beyond its boundaries, and this function needs to be preserved and sustained. An important strategy in achieving this is to ensure the hills are effectively protected to mitigating further vegetation destruction by illegal human activities that are currently rampant. This should be augmented by creating awareness among watershed beneficiaries on interrelatedness of water discharge with the environmental state of the hills, so that they can appreciate and support its conservation. The water resources management authority (WRMA), Kenya Water Towers Agency (KWTA) and County governments of Kibwezi, Taita Taveta and Makueni should collaborate with local communities, Kibwezi and Makindu Water Services Company (KIMAWASCO) and initiate a Payment for Ecosystems Services (PES) system and some of the funds generated should be used to support conservation activities. We also recommend collaborative management of the Chyulu Hills by the Kenya Wildlife Service (KWS) and local communities to create a sense of ownership by the latter in view of the fact that the watershed is the backbone of their livelihoods in regards to water provision. Patterns of water service provision by the watershed should also be documented regularly to understand their status and dynamics.

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