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Land Cover Dynamics in the Chyulu Watershed Ecosystem, Makueni-Kajiado Counties, Kenya

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Abstract

The aim of the study was to assess the state of land cover dynamics in the Chyulu Hills watershed ecosystem of Makueni and Kajiado Counties in Kenya by considering the following objectives:- a) assessing the state of land cover in 2015, b) analysing and characterizing land cover transformations in the watershed in 1987, 2001 and 2015, and, c) comparing the forest cover dynamics with those of other studies in Kenya. The forest cover change analysis was undertaken through remote sensing and GIS analysis according to the following broad tasks: a) delineation of watershed ecosystem boundary, b) satellite land cover change analysis and ground trothing, c) comparative analysis with other studies. The analyses showed a decrease in wetland environments (40%), grasslands (24.4%), woodlands (21.9%), and forests (18.6%). The findings showed a major increase in the built environment (96.1%), sisal plantations (74.6%), bare ground (68.8%), and thicket (54.3%). There was a minor increase in the area under irrigated agriculture (18.6%), wooded grassland (11.6%), rain-fed agriculture (7.8%), and bushland (1.3%). The land cover change in the Chyulu watershed ecosystem was quite similar to other watershed ecosystems in the country and will eventually affect the role of the watershed as a critical dryland water tower.

Keywords

Chyulu Hills, Watershed Ecosystem Service, Land Cover Dynamics, Water Supply

1. Introduction

Africa is a continent which is well endowed in natural capital and where sustainable development is dependent on the capacity to efficiently and sustainably manage the natural resources - in particular, water, land and forests for the benefit of all (AfDB 2015). Natural ecosystems such as forests, wetlands, rivers and lakes provide a wide range of goods and services to society including food, water, energy and recreation and can therefore be considered as life insurance assets. Kenya's forest ecosystems represent some of the most important environmental assets which supply numerous day to day household goods such as water, wood fuel, timber, livestock fodder and herbal medicines (Kiringe *et al.*, 2015). They also provide several hidden ecosystems services including climate moderation, carbon sequestration and biodiversity support.

Most forest ecosystems in the country are associated with high altitude environments such as Mount Kenya, the Aberdare Ranges, Mau Escarpment, Mount Elgon and the Cherangani Hills (Kiringe *et al*. 2015). The government of Kenya has consequently gazzeted eighteen (18) water towers in such areas including Mount Kenya, Aberdares Ranges, Mau Forest Complex, Mount Elgon, Cherangani Hills, Chyulu Hills, Huri Hills, Kirisia Hills, Loita Hills, Marmanet Forest, Mathews Range, Kipipiri Hill, Mount Kulal, Mount Marsabit, Mount Njiru, Ndoto Mountains, Nyambene Hills, and Shimba Hills (GoK 2012).

These areas serve as critical water catchments for most rivers in the country and, are also key recharge areas for ground water aquifers. In cognizance of this, and given the role they play in sustaining local livelihoods as well as driving the country's development aspirations and economy, the government has recognized them as critical "water towers" whose management has recently been bestowed to the Kenya Water Towers Agency (KWTA). The KWTA was established in 2009 with a mission of sustainably managing the water towers through coordination and conservation for social-economic development. However, this important effort has not considered all the smaller water towers especially those in the dry-lands which sustain almost 30% of people in Kenya as shown in Table 1.

Table 1. *Dryland water towers in Kenya (Kiringe et al. 2015).*

Mountain/Hill	Size(ha)	Catchment	County/counties
Mt Marsabit	13,675	Lake Paradise, local springs	Marsabit
Mt. Kulal	2,240	Local springs	Marsabit
Matthews Range	26,330	Uaso Nyiro and Milgis rivers	Samburu
Ndoto Mts.	10,155	Milgis rivers, local springs	Samburu
Nyiru Mts.	7,890	Local springs and streams	Samburu
Kirisia Hills	22,340	Uaso Nyiro and Milgis rivers	Samburu
Ol Doinyo Orok	6,575	Local springs and streams	Kajiado
Emali Hills	50	Local springs and streams	Kajiado
Chyulu Hills	4,640	Mzima springs Tsavo and Galana	Makueni, Kajiado, Taita
Machakos Hills	4,290	Athi river, springs and streams	Machakos, Makueni
Ol Doinyo Sabuk	720	Athi River springs and streams	Machakos
Endau Hill	455	Local springs and streams	Kitui
Mutitu Hill	145	Local springs and streams	Kitui
Mumoni Hill	45	Local springs and streams	Kitui
Tugen Hills	7,590	Pekerra, Kerio and Suguta rivers	Baringo
Karasuk Hills	650	Turkwell River, springs	Turkana
Kasigau Mt.	230	Local springs and streams	Taita-Taveta
Maungu Hills	200	Local springs and streams	Taita-Taveta

In spite of the importance of forests in Kenya, these watershed ecosystems have continued to experience widespread land cover changes over the years due to rampant destruction, degradation and even excisions for human settlements (GoK 2013). In the 40-year period between 1970 and 2010, deforestation in the country's water towers amounted to approximately 500 km^2 (Kiringe *et al*. 2015). In Mount Elgon which is the source of the Turkwell River, for example, the woodland and forest cover was reduced substantially by 58% and 34% respectively, between 1995 and 2006. Similarly, the forest cover in the Cherangany Hills reduced from 465 km^2 in 1973 to 239 km^2 in 2009 (GoK 2013). In the Mau Complex, forest cover decreased from 4,695 km^2 in 1985 to 4,041 km^2 in 2010 which translated to an annual decline of about 8.7% (GoK 2013, Ayuyo & Sweta 2014). According to the NCAPD (2009), over 82 km^2 of the Maasai Mau Forest alone was lost through deforestation between 1973 and 2005 while approximately 610 km^2 was lost in 2001 alone through government excisions which were driven largely by political interest.

The size of Aberdares forest, which is electric fenced all round, has been fairly stable with an area of 2,064 km^2 in 1985 which only declined slightly to 2,061 km^2 in 2010 mostly as a result of wildfires in the dry season (GoK 2013).

The deforestation trend in the dryland water towers has been very similar to the national water towers. For instance, in Mt. Marsabit, the forest cover reduced from about 241 km^2 in 1985 to 132 km^2 in 2010 mostly due to the expansion of Marsabit town in addition to other factors (GoK 2013). According to Oroda (2011) the forest cover in the watershed ecosystem decreased by about 32% between 1973 and 2005 mostly due to increased urban population and sedentarization of the pastoral communities. He established that the area under agriculture around the forest increased by about 700% while urbanization in Marsabit town next to the forest expanded by almost 300%.

In Taita Taveta County, the dryland forests of the Taita Hills surprisingly increased from 270 to 414 km^2 between 1985 and 2010 despite a significant increase in human population and increased agriculture and livestock grazing (Pellikka *et al* 2004, GoK 2013). The forest cover change was attributed to increased tree cover outside the forests mainly through agro-forestry practices by the farmers in the area (Pellikka *et al*. 2004, GoK 2013). The Taita Hills which cover an area of about 1000 km^2 constitute the northernmost portion of the Eastern Arc Ecoregion in Kenya. The region which extends to southern Tanzania, is very rich in terms of rare and endemic biodiversity (Bytebier 2001).

Deforestation of watershed ecosystems is known to significantly alter the seasonality and magnitude of stream and river discharge (Karanja *et al*. 1986, Donner 2004, Mustafa *et al*. 2005). Studies have shown that significant changes in hydrological regimes can occur as a result of forest cover and land use changes due to their influence on rainfall interception, evapotranspiration, infiltration and surface runoff which are all dependent on watershed vegetation cover (Marloes 2009). It is therefore necessary to monitor on regular basis, the forest cover dynamics in valued watershed ecosystems especially the dryland water towers because of their critical role as lifelines for the society, livestock and wildlife.

The Chyulu Hills where this study was undertaken is a critical dry-land water tower which supports large populations of people, livestock and wildlife in the Makueni, Kajiado, Taveta and Mombasa counties in terms of water supply (Kiringe *et al*. 2015). There is therefore a serious need to understand and document the state of the watershed ecosystem especially in terms of land cover dynamics which is critical in natural water production. Digital change detection techniques using multi-temporal satellite imagery has emerged as a reliable and cost effective method in the monitoring of spatio-temporal landcover dynamics in watershed ecosystems (Czajkowski & Lawrence 2013, Butt *et al*. 2015, Rawat & Kumar 2015). This approach is convenient because it exploits the regular data acquisition capacity of space technology through the use of satellites for the detection, mapping and quantification of land cover change. The specific objectives of the study were to:- a) assess the state watershed land cover in 2015, b) analyse and characterize the land cover transformations in the watershed between 1987, 2001 and 2015, and, c) compare the forest cover dynamics with those of other studies in Kenya.

2. Methodology

The Chyulu Hills watershed ecosystem which covers approximately 7,763 km^2 is located in southern Kenya approximately 190 km south-east of Nairobi along the Nairobi-Mombasa highway and standard gauge railway (Kiringe *et al*. 2015). It is characterized by an elongated NW-SE chain of small pleistocene-holocene volcanoes extending for about 100 km between Emali and Mtito Andei townships with the summit hills forming the boundary between Makueni, Kajiado and Taita Taveta Counties (Figure 1). The highest peak has an altitude of approximately 2,188m (Ritter & Kaspar 1997). The Chyulu Hills are thought to have originated from recent volcanic eruptions that took place less than 10,000 years ago through hundreds of vents distributed along a NW-SE fracture zone (Ritter & Kaspar 1997). The entire Chyulu volcanic range covers an area of about 2,840 km^2 and is associated with a 44 km thick earth crust (Saggerson 1963, Ojany 1966, Nyamweru 1980, Ritter & Kaspar 1997).

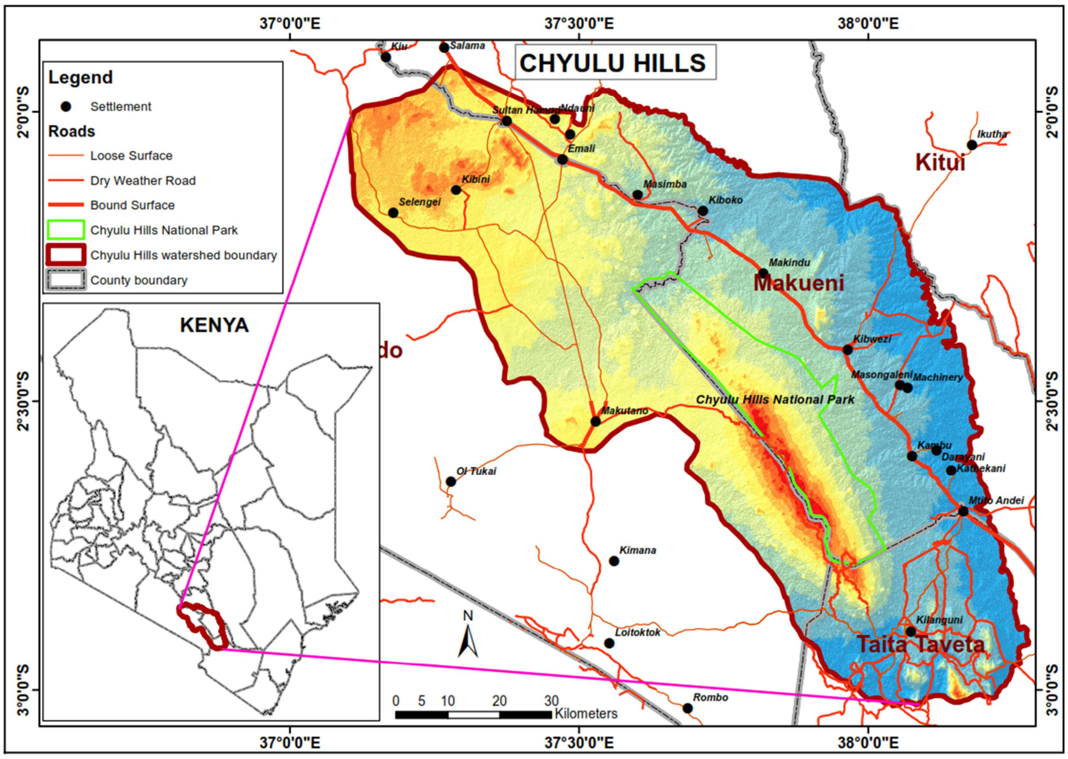


Figure 1. *Location of the Chyulu Hill watershed ecosystem.*

The hills are characterized by a central volcano which is known as Chyulu with pleistocene lava fields in the north and holocene fields in the south (Saggerson 1963). The most recent volcanic eruptions in the area is said to have occurred in the southern zone which has a number of young-looking cinder cones and exposed lava fields such as the Shetani lava. According to Nyamweru (1980) and Ritter & Kaspar (1997), the Shetani lava flow is approximately 8 km long, 6 km wide and 5 m thick and was formed approximately 70-170 years ago. The lava fields at Umani Springs to the north are said to be 200-480 years old (Saggerson 1963, Ojany 1966). Plate 1 shows the Shetani lava surface in southern Chyulu with the Chyulu hills in the background.

Plate 1. *A section of the Shetani lava field in Tsavo West National Park.*

The Chyulu Hills are located in a semi-arid environment which is characterized by bimodal rainfall with the "long rains" falling from March to May and the "short rains" from October to December (Kamau 2013, Kiringe *et al*. 2015). On average, the annual rainfall varies between 350-500 mm in the lowland rangelands and slightly more than 1000 mm/yr in the Chyulu Hills (Kiringe *et al.* 2015). An analysis of the available historical rainfall data for the period of 59 years between 1954 and 2013 showed a clear spatial rainfall pattern with the highest rainfall in Northern Chyulu and the lowest in Southern Chyulu (Kiringe *et al.* 2015).

The Chyulu Hills have a rich vegetation community consisting of about 550 plant taxa (Chuah-Petiot 2001, Pocs & Luke 2007). The vegetation community consists of woodland, bushland, grassland and forest patches which are scattered in different parts of the landscape depending on elevation, landform, rainfall, soils and wildfire. Woodlands, bushland and thicket are common in the plateaus but they give way to open grassland and montane forest patches above 1400 m (Kiringe *et al* 2015). Previous studies have indicated that the natural vegetation is dominated by several tree species, mainly *Acacia tortilis* (Forsk) Hayne, *Adansonia digitata* Linn, *Chionanthus mildbraedii*, *Tamarindus indica* L., *Ficus* spp., *Neoboutonia macrocalyx*, *Tabernae montana stapfiana*, *Prunus africana*, *Strombosia scheffleri*, *Cassipourea malosana*, *Olea capensis*, *Ilex mitis*, *Erythrina abyssinica*, *Juniperus procera* and the blue-stemmed *Commiphora baluensis*. The woodlands and bushlands are characterized by the flat-topped *Acacia abyssinica* and *Acacia mellifera* (Vahl) Benth, *Commiphora africana* (A. Rich) Engl (Bytebier 2001, Chuah-Petiot 2001, Pocs & Luke 2007). The dominant perennial grasses include *Cenchrus ciliaris*, *Enteropogon macrostachyus, Chloris roxburghiana* and *Eragrostis superba*. High precipitation and cooler temperatures at higher elevations also promote establishment of *Khaat* or *miraa* (*Catha edulis*). The East African sandalwood (*Osyris lanceolata*), which is among plant species protected by the International Convention on Endangered Species (CITES) in Kenya is also common in the forest.

Hydrologically, the porous volcanic cinder cones and downhill lava fields in the Chyulu Hills usually intercept rainwater like a giant sponge with most of the water percolating into the aquifer leading to almost no surface runoff (Kiringe *et al*. 2015). The percolated rainwater usually generate significant subterranean water flow which works its way out along the interface between the volcanics and the underlying basement surface later emerging as springs, streams and rivers in the lowlands around the Chyulu hills. Consequently, the hills are recognized as a key hydrological agent in the recharge of a large number of freshwater springs emanating at the foot slopes especially within the northern, eastern and southern sections of the forest ecosystem (Wright 1982, Guston & Mnyamwezi 1985, Grossman 2008).

The core part of the Chyulu watershed is located in a protected area as part of the Chyulu Hills National Park under the management of the Kenya Wildlife Service (KWS) and the Kibwezi Forest Reserve under the Kenya Forest Service (KFS). The western section of the hills constitutes part of the west Chyulu Wildlife Conservation Area which is communally owned by the Maasai Group ranches, namely, Kuku and Imbirikani. The traditional land use in the watershed is pastoralism to the western side of the Chyulu hills and mixed agriculture and livestock husbandry in the eastern side.

The forest cover change analysis was undertaken through remote sensing and GIS analysis according to the following broad tasks: a) delineation of watershed ecosystem boundary, b) satellite land cover change analysis and ground trothing, c) comparative analysis with other land cover studies. The watershed boundary was delineated using medium resolution (30X30 m) Landsat images and ASTER Digital Elevation Model (DEM). The study area was covered by three Landsat image scenes, namely*:* P167R062, P168R061 and P168R062 which were analysed for three years, namely 2015, 2001 and 1987 (Figure 2). The spatial resolution was considered as detailed enough for watershed land cover analysis. The ASTER satellite data was displayed on ArcGIS 10.3 and overlaid on the watershed drainage layer after which the boundary was derived by digitizing a polygon guided by the DEM and the direction of surface water flow.

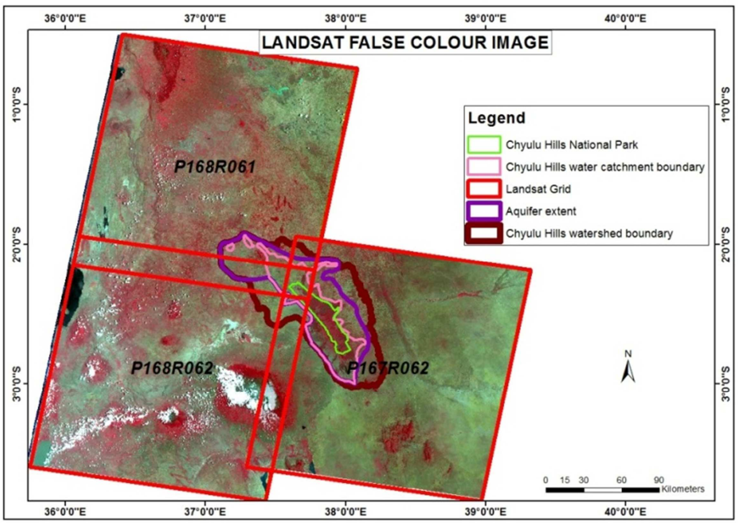


Figure 2. *False colour composite image for the Chyulu region.*

A total of nine (9) satellite images of less than 10% cloud cover were processed for detailed land cover analysis by mosaicking them into one image which culminated in three images for 1987, 2001 and 2015, respectively. The processing also involved creating colour composite images for interpretation and then clipping them based on the watershed boundary. Preliminary satellite image interpretation was undertaken using automatic isoclust image classification using ten different land cover clusters which was supported by ground truthing. The land cover ground truthing was then undertaken through field missions in the study area along two transects, namely, a) Umani-Kibwezi Forest-Mombasa road track (10 km) which was inspected on 14th May 2015 (Figure 3) and, b) Chyulu Hills National Park transect (36 km) which was inspected on 16th May 2015 (Figure 4). The latter was aligned along the road track from the KWS Chyulu National Park Head Office through the lava fields to the Leviathan caves junction and then to the Oldonyo Lodge junction upto the Chyulu Viewpoint Hill past the Satellite Site.

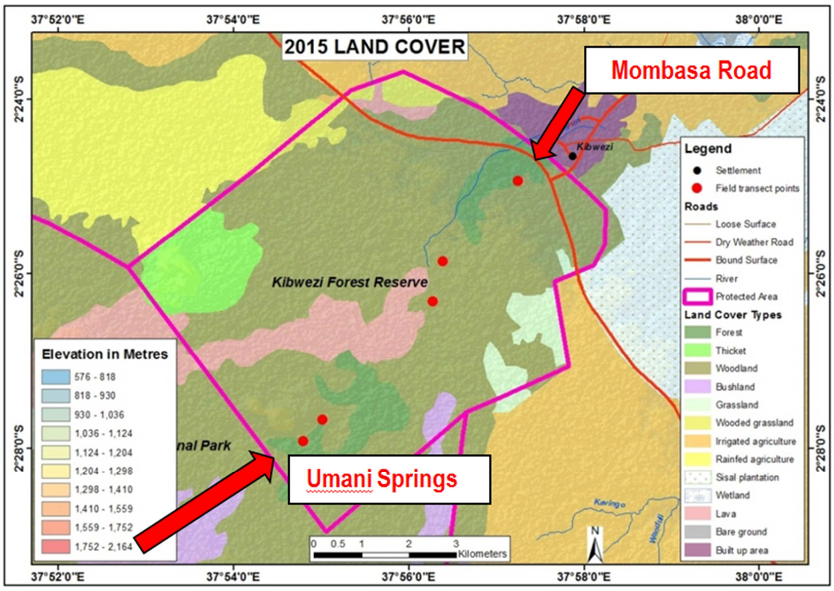


Figure 3. *The route for land cover ground truthing transect 1 in Kibwezi Forest Reserve.*

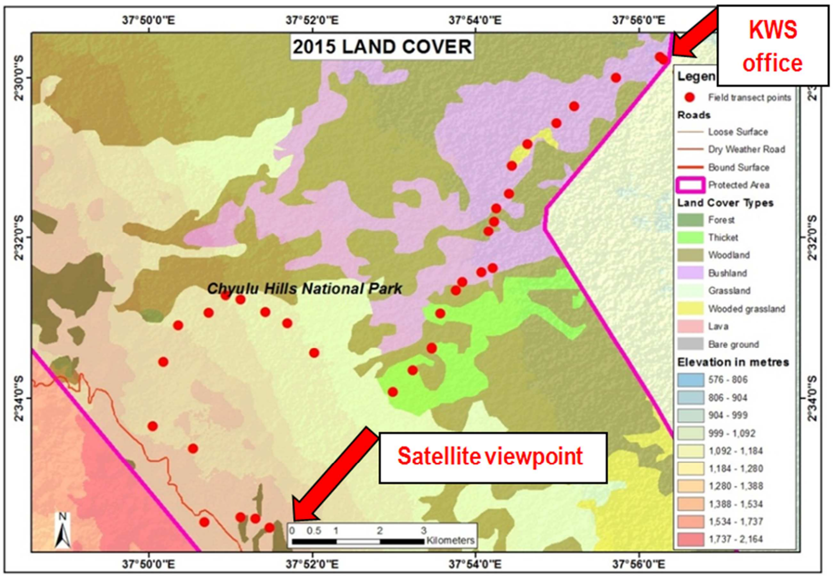


Figure 4. *The route for land cover ground truthing transect 2 in the Chyulu Hills National Park.*

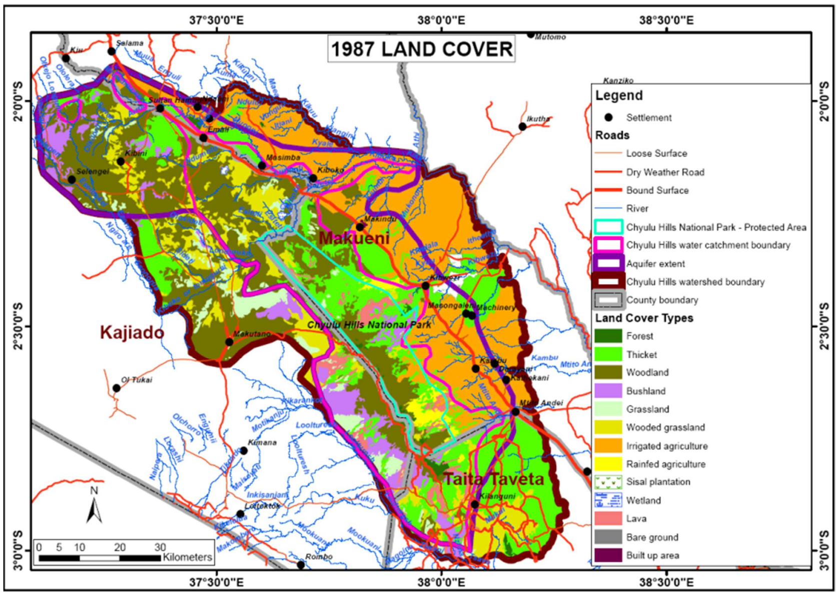
The ground truthing involved a rapid identification of key woody and herbaceous plant species at random observation points along each transect. The elevation at each observation point was recorded using a Garmin GPS unit. The final image interpretation was based on the information collected during the ground truth field missions. This involved the downloading of the ground truth GPS points and overlaying them on the satellite images and then undertaking preliminary image classification using the support information collected at every point. The polygons were then digitized on the satellite images according to areas with homogeneous spectral reflectance. The classification was then extrapolated to the rest of the watershed ecosystem. Finally, land cover GIS layers were created from the 1987, 2001 and 2015 satellite images using the standard IDRISI land cover change modeller.

3. Results and Discussion

Table 2 shows the land cover change statistics based on satellite imagery analyses. Figure 5 shows the land cover status in the Chyulu watershed ecosystem in 1987, 2001 and 2015 from which the statistics in Table 2 were calculated. Figure 6 shows the integrated land cover change within the conservation area of the Chyulu watershed ecosystem for the 1987-2015 period. The change statistics showed a major increase in the built environment (96.1%) followed by sisal plantation (74.6%), bare ground (68.8%), and thicket (54.3%). There was minor increase in the areas under irrigated agriculture (18.6%) as well as wooded grassland (11.6%), rain-fed agriculture (7.8%), and bushland (1.3%). All these cover change statistics can be attributed to the changing landuse especially in terms of expanding urbanization and agriculture within the watershed. In their study on land cover change in the Chyulu Hills for the 1967-1999 period, Muriuki *et al* (2011) recorded a 40% expansion in agricultural land. The findings in this study therefore indicated that agricultural expansion had slowed down by over 10% probably due to the unavailability of additional un-cultivated environment.

Table 2. *Landover change statistics for the Chyulu Hills Watershed (1987-2015).*

Land Cover Type	Area (km^2)			Overall change (1987-2001)	Overall change (2001-2015)	% change
	1987	2001	2015			
Forest	86.4	71.7	70.4	-14.8	-12.9	-18.59
Thicket	850.4	1246.4	1312.3	396.0	65.9	54.32
Woodland	1798.6	1293.1	1405.0	-505.5	111.9	-21.88
Bushland	439.6	458.4	445.2	18.8	-13.2	1.28
Grassland	2065.2	1847.9	1560.8	-217.2	-287.8	-24.43
Wooded grassland	333.6	353.9	372.3	20.4	18.3	11.61
Irrigated agriculture	2000.2	2291.1	2373.1	290.9	81.9	18.64
Rain fed agriculture	20.6	20.8	22.2	0.2	1.4	7.78
Sisal plantation	46.8	60.9	81.7	14.1	20.8	74.61
Wetland	14.7	12.7	8.9	-1.9	-3.9	-39.66
Bare ground	4.2	6.1	7.1	1.9	0.9	68.80
Built up area	8.8	11.9	17.2	3.1	5.4	96.09
Lava	84.8	78.7	77.8	-6.0	-0.9	-8.22
Total area (km^2)	7753.9	7753.9	7753.9			



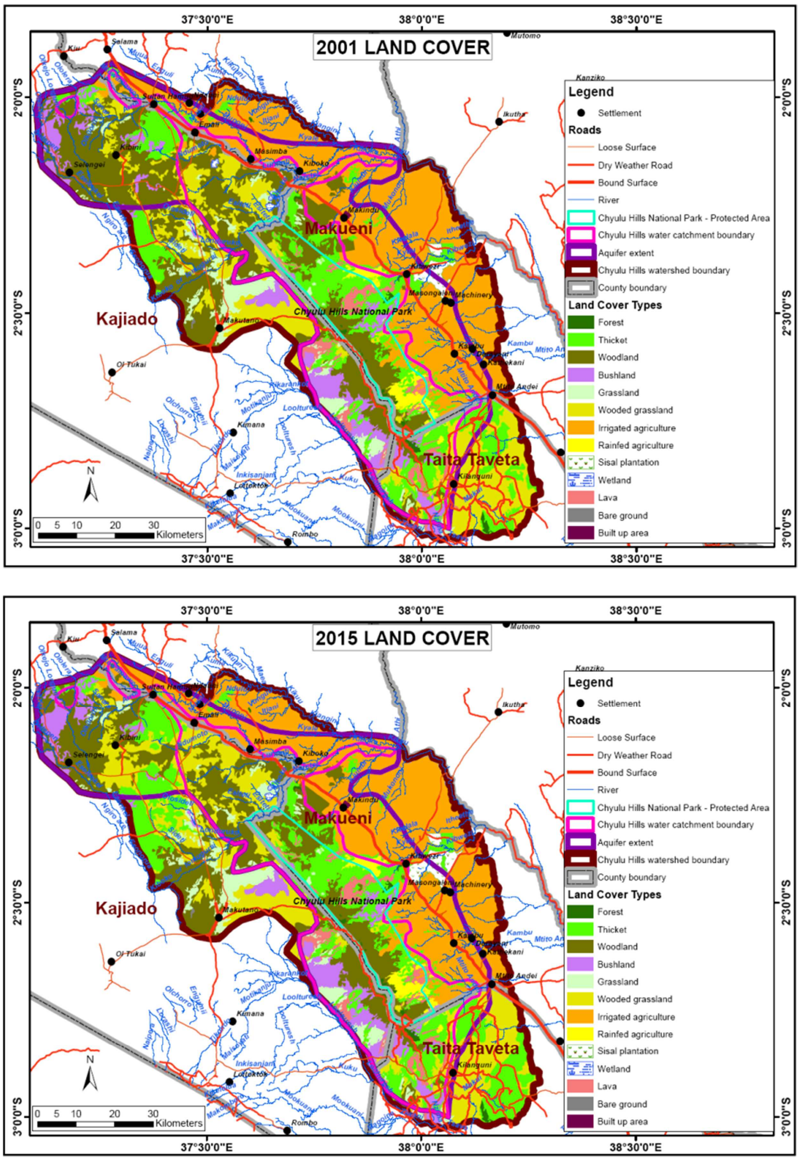


Figure 5 a-c. *Land cover status for the Chyulu watershed ecosystem (1987-2015).*

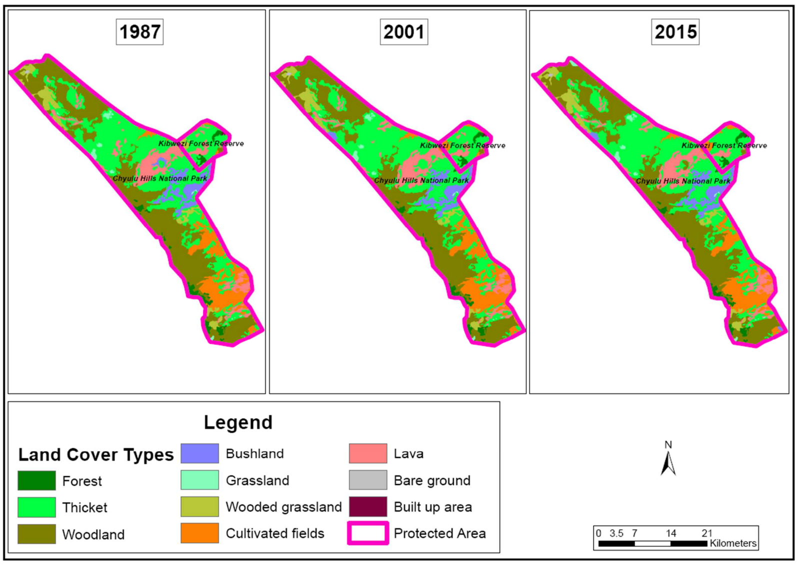


Figure 6. *Land cover change for the Chyulu catchment area (1987-2015).*

There was an overall decrease in wetlands (40%), followed by grasslands (24.4%), woodlands (21.9%), forests (18.6%), and lava surface (8.2%). In their study, Muriuki *et al* (2011) recorded a marginal decrease in forest cover of 1.7% between 1978 and 1999. The higher rate of forest loss which was recorded in this study can be attributed to the high frequency of fires within the national park in recent years. A recent study on the fires by Kamau (2013) established that accidental and intentional fires have become more frequent in the Chyulu Hills especially between May and October with the key driving factors being charcoal burning, honey gathering, pasture propagation, farm preparation and public protest against KWS management. The protest fires are mainly directed to the efforts by KWS to prevent the local people from accessing the park in order to extract valuable goods. The KWS action is well within the non-consumptive policy on the management of natural resources within state protected areas in Kenya.

A comparison of the forest cover dynamics in the Chyulu Hills watershed ecosystem in relation to the national water towers showed that the rate of decline at 18.6% was half the rate of forest cover loss in Mt. Elgon (GoK 2013) and almost double the rate of loss in the Mau Forest Complex (GoK 2013, Ayuyo & Sweta 2014). Similarly, the rate of forest cover decline was almost twice the loss in Mt. Kenya Forest where Ndegwa (2005) estimated a 10.3% loss between 1987 and 2002 with the landscape metrics indicating higher forest fragmentation during the 1976-1987 period compared to the 1987-2002 period.

The differences between the Chyulu Hills and other water towers could be attributed to a number of factors associated with each water tower such as population pressure, climatic conditions and conservation regime. Unlike the Chyulu watershed with a population of less than 200,000, the upper Mt. Kenya watershed (2,700km^2) had a population of over one million in 2009 (NCAPD, 2009) which means that the risk of deforestation is likely to overwhelm the intensive conservation efforts in the area. Apart from the gazettement of the watershed as a national park and forest reserve, Mt. Kenya is also internationally designated as a UNESCO Biosphere Reserve under the Man and Biosphere (MAB) Program. It is also one of the designated World heritage Sites in Kenya.

The findings showed that the rate of forest cover loss in the Chyulu Hills was much higher than the rate in the Taita Hills which are located only some 100km away. In the Taita Hills, Petri *et al.* (2009) established that that although the indigenous forest cover decreased by 50% (260.2 ha) between 1955 and 2004, the overall forest cover decreased only by 2% due to the increased forest plantation cover as well as intensive agroforestry. A large number of woodlots were established in barren and dry areas as well as in degraded forests and household farms. Petri *et al.* (2009) estimated that a total 263.9 ha were converted to forest plantations, while 33.1 ha were restored back to indigenous forest which is very encouraging.

The rate of forest cover loss in the Chyulu Hills was much lower than the 32% decline recorded in Marsabit Forest between 1973 and 2005 (Oroda 2011) although the two dryland water towers have very similar conservation status. However, the rate of forest and woodland loss was much lower compared to the rate of decline for similar ecosystems in Laikipia and Samburu counties such as Mukogodo Forest, Mathew Ranges and Ndoto Forests where Mwaura (2006) recorded a high decline of 68% and 46%, respectively for Laikipia and Samburu counties, in the 1976-2002 period. The difference could be attributed to the higher aridity in Marsabit, Laikipia and Samburu where the communities are also more heavily dependent on the dryland watershed ecosystems for livestock grazing.

One of the reasons for the decline in wetlands in the Chyulu conservation area was heavy abstraction of water from Umani Springs within the Kibwezi Forest Reserve near the David Sheldrick Eco-lodge. The Umani Springs are the principal source of water supply for Kibwezi and Mtito Andei towns and the surrounding settlements. Field observations showed that almost all the water from the springs is collected into a chamber and distributed to consumers. The heavy abstraction contributed to the drying up of the Umani swamp below the springs near the David Sheldrick Eco-lodge because no provision was made for environmental reserve flow as stipulated in the Water Resources Management 2007 guidelines (GoK 2002). The law according to the Water Act 2014 demands that at least 30% of the base flow in a spring or river has to remain in the ecosystem in order to maintain its natural environmental functions (GoK 2002). The slight decrease in the total area of volcanic lava fields could be attributed to the increased concealment by thicket which is the land cover commonly associated with such areas and whose coverage appears to have increased in the recent past.

4. Conclusions and Recommendations

The loss of forest cover in the Chyulu watershed ecosystem between 1987 and 2015 was quite similar to the challenging situation in other valued water towers around the country including the national water towers. The 18.6% and 21.9% decrease in forests and woodlands, respectively within the watershed and especially the core catchment area is not good because it will eventually affect the role of the watershed as a critical dryland water tower for people, livestock and wildlife. The 69% increase in bare ground as well as the 54% expansion in thicket cover is a worrying signal because it clearly indicates proliferation in environmental degradation within the watershed. The findings clearly showed that the watershed ecosystem was experiencing negative land cover dynamics especially through the loss of forests and woodlands despite the government efforts to safeguard it. The main reason is the lack of public awareness and appreciation of the need to maintain a good state of watershed ecosystem health in order to continue enjoying the water production ecosystem services. This fact is usually taken for granted in many parts of Kenya until it is too late.

The findings indicate that strict conservation through the fortress or protectionist conservation model as practiced in the Chyulu Hills might not always be a solution for the long term sustainability of critical watersheds in the country. The sustainable future of such ecosystems appears to be more assured through the promotion of a self-driven conservation culture especially at the grassroot as demonstrated in the case for the Taita Hills. The situation in the Chyulu Hills might require the establishment of Community Forest Associations (CFAs) especially in Makindu and Mangelete which experience high levels of illegal forest incursions by people in search of firewood and charcoal. The CFAs could partner with national and county government in forest conservation as in other parts of the country. This might reduce the high frequency of intentional fires in the Chyulu Hills by overcoming the obstacles associated with the fortress or protectionist conservation. The involvement of the youth is of great importance for this strategy because that might ensure that future societies will be more conservative than the present.

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