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# Land-Use Change Analysis in Mt. Kenya Forest Landscape its Potential in Biodiversity Management Policing


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## Abstract

*On the matter of climate change and sustainability, natural vegetation, particularly forests, plays the single most important function. They are critical environmental regulators through their role as carbon sinks; notwithstanding their significance as drivers of ecosystem functions by acting as habitats for many species of flora and fauna. Understanding their spatial distribution and structure is, therefore, critical in making environmental decisions by governments and conservation actors. It is precisely important given the exponential population rise in areas adjacent to protected areas causing a corresponding rise in the demand for settlement and farming land, and its associated resources. Conducted in July 2021, this study sought to assess and provide spatial data on land use in the Mt. Kenya Forest complex, a major water catchment and bio-geographical region in Kenya. It broadly sought to investigate, through high-resolution satellite imagery, forest cover change in the landscape over the period 2008 - 2018. The major vegetation forms were also analyzed and documented. Supplemental data was derived from a systematic literature survey from scientific databases and reports along with grey literature sources. From the analysis, the first 5-year period, 2008 – 2013, reported a decrease of forest cover by -1.18%. However, the second phase, 2013 – 2018, recorded an increase in forested area by +1.5%. From a general point of view, the analysis reported a notable increase in forest cover and a decrease in non-forest land. This study concludes that biodiversity management policing and land use practices have an effect on sustainability of protected landscapes. With the understanding that rural communities are "custodians" of natural resources, the study recommends a balanced trade-off between forest resources exploitation and protection through continued implementation of the existing national and county natural resources and sustainability* *management policies. This study recommends further analysis of other main forest ecosystems in Kenya and using other habitat health indicators.*

**Keywords:** Biodiversity, Conservation, Climate Change, Ecosystems, Land Use Changes, Mt. Kenya Landscape, Protected Areas, Sustainability

## INTRODUCTION

From a global perspective, studies are awash with and recognize the central role of protected forest landscapes and ecosystems in conservation and sustainability management (for instance, Lindroth et al., 2009; Moomaw et al., 2019; Myneni et al., 2001; Pan et al., 2011; Pugh et al., 2019; Malmsheimer et al., 2008; Thompson et al., 2009). They are important players in the management and regulation of climate change impacts by acting as carbon sinks and environmental regulators. The Protected Areas (hereinafter abbreviated as PAs) also provide habitats and important dispersal areas for wildlife ensuring genetic variation and biological diversity, an important aspect in conservation management efforts (Nei, 1987; Thiong'o, 2020). Importantly, they have a cultural significance (Govigli et al., 2020; Govigli, Efthymiou and Stara, 2021) and are vital sources of livelihoods for many communities in developing countries around the world (Dahdouh-Guebas *et al.,* 2000; Nerfa, Rhemtulla and Zerriffi, 2020; Pirmohammadi et al., 2020; Shackleton and Shackleton, 2004; Tesfaye et al., 2011; Trædal and Vedeld, 2018; Uwemeye et al., 2020). This is especially because most PAs are located within rural areas where most communities live. With imminent urbanization and an ever-rising population in rural rangelands, a corresponding demand for land for individual and commercial use is certain (Winkler et al., 2021; Zhao et al., 2022; Lambin and Meyfroidt, 2011; De Maria, 2019).

This phenomenon is exacerbated by the political nature of the land question, particularly in developing countries such as Kenya. There is also the factor of international investors who continue to express unprecedented interest in farmlands and other large-scale land-related investments including residential and industrial developments (De Maria, 2019; Winkler et al., 2021; Güneralp et al., 2020). The ensuing dilemma from the commodification of land and land resources is constrained spaces for biodiversity conservation and environmental protection.

The understanding underscores the importance of records on land use structure in view to inform planning and zoning policies and in tackling societal challenges including natural resources loss, climate change, water shortage, and food insecurity (see Newmark and McNeally, 2018; Lambin and Meyfroidt, 2011; Winkler et al., 2021; Tesfaye et al., 2011; Thompson et al., 2009; Tewabe and Fentahun, 2020; Abebe et al., 2022; Manono, Thiong'o, and Wishitemi, 2022a; Manono, Thiong'o, and Wishitemi, 2022b; Bufebo and Elias, 2021 among others). In Kenya, this mandate is with the Kenya Forest Service (KFS) but unfortunately, at the time of this study, there lacked a comprehensive and up-to-date record documenting this. Further, a study by Mathenge (2018), postulates that no single authority clearly gives the exact state of Kenya's forest cover with 2016 reports from United Nations Food and Agriculture Organization (UNFAO) and the Global Forest Watch (GFW) presenting contrasting sets of data. The most recent authoritative record is a 2015 Global Forest Resources Assessment (FRA) geospatial survey that reported a national forest cover of 7.6% (FAO, 2015). This has the implication that majority of the forest landscapes in terms of land use remain unknown.

In an attempt to partly fill the gap in literature and spatial data gap on Kenya's forest ecosystems, this study sought to analyze land use changes in Kenya's forest landscape; one of the five water-catchment areas in Kenya (others include the Aberdare Ranges, Cherangani Hills, the Mau Complex Forest, and Mt Elgon forest).

The choice of Mt. Kenya as the study site was informed by several reasons. Firstly, being the single largest undisturbed and natural bio-geographical region in Kenya, the world heritage site is perhaps the most important natural forest landscape in Kenya (Bussmann and Beck, 1995; Nyaligu and Weeks, 2013). Secondly, the Mt. Kenya Forest is host to a world-famous national park and supports a large biodiversity of close to 1000 species of wildlife including big mammals and rare species of flora and fauna (Kideghesho et al., 2007; Bussmann and Beck, 1995). Most importantly, the landscape is a direct lifeline to hundreds of thousands of inhabitants through pastoralism, agriculture, hydroelectric power production, and tourism (Emerton, 1999; Kimani, 2007; Ojany, 1993). In fact, the forest is a source of water for close to half of the Kenyan population (Emerton, 1999; Wass, 1995). This perhaps explains why the Mt. Kenya region is one, if not the most densely populated part of rural Kenya (Mbuba, 2019).

## MATERIAL AND METHODS

The study was desk-based[1], using a combination of remote sensing and systematic literature review techniques. The study site was Mt. Kenya Forest landscape, situated between 36°45′ E, 0° 50′S and 38°10′ E, 1° 07′S within Central Kenya, and to the Northeast of Nairobi (Borona, 2017). While using appropriate and usable high-resolution satellite imagery to quantify forest cover change in the landscape over the analysis period, this research studied, mapped, and documented the major land use forms and vegetation in the landscape. Supplemental data to assist this was derived from systematic literature survey along with grey literature sources. Specifically, the study interrogated land use changes using satellite imagery samples for the years 2008, 2013 and 2018. The years were chosen as they provide an equal 5-year period between them for fair image sampling. 2008 acted as the base year, 2015 as the pivotal year (comparative midpoint) and 2018 as the current year of study). Vegetation classification, area, and percentage land cover change were calculated using ArcGIS zonal geometry tools - Maps and Geodata, 2018 and ESRI, 2016. In the identification and discrimination of land-cover types and to generate forest cover maps, unsupervised classification (Maximum likelihood) was performed in ArcGIS (Stow *et al.*, 2004). Using the results of unsupervised classification, Google earth imagery, advanced classification (supervised) and general familiarity of the study area, possible land-cover classes were identified and used to make useful conclusions on land-cover trend. Arc Map 10.3 was used to process and analyze images using supervised NDVI spectral reflectance bands for Landsat 7 (ETM+) and Landsat 8 (OLI and TIRS) (Weiss *et al*., 2004).

Percentage[2] rate of forest cover change was then calculated using the formula below;

$$\boldsymbol{r} = \{\frac{\mathbf{1}}{t2 - t1}\} \text{ x In } \{\frac{\text{A2}}{\text{A1}}\}$$

[1] This, however, had the limitation in that the study lacked real time surface observations (ground truthing), an important aspect in verifying satellite imagery

[2] Percentage cover of each raster zone (vegetation type classification areas) was calculated by dividing each cell value by the sum of all values*100

Where A1 and A2 indicate forest area[3] at the beginning and at the end of the analysis period respectively. t1 and t2 on the other hand correspond to the year at the beginning and end of the analysis respectively. The preference for usable Landsat images for analysis was mainly on the basis of resolution level (tier 1) and the percentage of cloud cover (Alavipanah et al., 2010; Olson et al., 2004; Yi-Hua, 2011). This is an important consideration as the presence of cloudy conditions and/or humidity in an area hampers the acquisition of high-quality images for analysis (Kinoti and Mwende, 2019). With the foregoing in mind, the study applied a careful selection of images with at most 8% cloud cover that were acquired in the early months of the year of study for minimal humidity. This avoided the challenge of misclassification of land use and vegetation cover forms (Asner, 2001). Where the highly calibrated Landsat 8 OLI images available were deemed unusable due to high cloud cover and/or the presence of gapped areas, Landsat 7 was used (Table 1). The specification imagery and selection criteria for satellite imagery, and issues encountered are indicated in Tables 1 and 2 respectively.

***Table 1: Case specification of satellite Imagery used for images in analysis*[4]**

| LS | Dated | Status | Gapped Area | Issues/challenges |
|---|---|---|---|---|
| LandSat 5 | 30-Sep-08 | 7% CC | No | Main sites covered with clouds |
| LandSat 5 | 14-Sep-08 | 56%CC | No | Main sites covered with clouds |
| LandSat 5 | 10-Jun-08 | 47% CC | No | Main sites covered with clouds |
| LandSat 7 | 22-Sep-08 | BS + 9 % CC | Yes | Gap |
| LandSat 7 | 6-Sep-08 | BS + 11 % CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 18-Jun-08 | BS + 35% CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 2-Jun-08 | BS + 11 % CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 17-May-08 | BS + 30% CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 1-May-08 | BS + 28% CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 14-Mar-08 | BS + 29% CC | Yes | Gap |
| LandSat 7 | 27-Feb-08 | BS + 6% CC | Yes | Gap *(selected for analysis on the basis of low cloud cover)* |
| LandSat 7 | 26-Jan-08 | BS + 7% CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 25-Dec-07 | BS +10% CC | Yes | Main sites covered with clouds |
| LandSat 7 | 9-Dec-07 | BS +39% CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 7-Nov-07 | BS+ 66% CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 22-Oct-07 | BS + 73% CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 6-Oct-07 | BS + 13% CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 20-Sep-07 | BS + 6% CC | Yes | Gap |
| LandSat 7 | 4-Sep-07 | BS + 53% CC | Yes | Cloud Cover + Gap |
| LandSat 7 | 19-Aug-07 | BS + 33% CC | Yes | Cloud Cover + Gap |

[3]Total area of raster zones (study area) was calculated using zonal geometry (calculated as number of pixels per sqm) tools in ArcGIS, then adding up the individual zonal areas. Values were then multiplied by 0.0001 to get the result in hectares (1sqm = 0.0001 ha) (Maps & Geodata, 2018)

[4] **Tables legend:** LS= Landsat; OLI=Operational Land Imager; TIRS = Thermal Infrared Sensor; CC = Cloud Cover; BS = Bare Soil; Landsat= Earth-observing operational satellites (the version numbers represent updates over the years); ETM= Enhanced Thematic Mapper; L1 TP= Level 1 Precision Terrain.

*Table 2: Selection criteria of satellite images and issues encountered*

| Dated | Sensor | Cloud Cover (%) | Gapped area | Issue |
|---|---|---|---|---|
| 27-Feb-08 | LS 7 ETM+ L1 TP | 6 | Yes | Yes |
| 23-May-13 | LS 8 OLI_TIRS_L1TP | 8.09 | Nil | No |
| 29-Jan-18 | LS 8 OLI_TIRS_L1TP | 0.03 | Nil | No |
| Satellite images were downloaded via https://earthexplorer.usgs.gov/ | | | | |

To corroborate the satellite imagery results, we further conducted a survey in *google.scholar* and *Web of Knowledge* using key phrases from the title – *TOPIC*: ("land use" OR "land cover" OR "vegetation cover" OR "forest cover") *AND* TOPIC: ("Kenya") *AND* TOPIC: ("protected area*" OR "protected landscape*" OR "nature reserve") Timespan: All years. Databases: WOS, BCI, BIOSIS, DRCI, KJD, MEDLINE, RSCI, SCIELO. Search language=Auto) to identify whether scholarly works have attempted to address the research question. Reports from several institutions including United Nations Food and Agriculture Organization (UNFAO), the Global Forest Watch (GFW), Global Forest Resources Assessment (FRA), Kenya Wildlife Conservancies Association (KWCA), and National Climate Change Action Plan (NCCA) were also interrogated. This study also sought information from several government and institutional websites that are charged with the management, monitoring, reporting or evaluating forest resources. These included the Kenya Forests Service, Kenya Wildlife service, Kenya Vision 2030 and the Ministry of Environment and Forestry. A PRISMA flow chart (Table 1.0) was then used to summarize the analysis results (Page et al., 2020).

## RESULTS

A Landsat 7 Enhanced Thematic Mapper with a Level 1 Precision Terrain (LS7 ETM+ L1 TP) was used for 2008 land cover change analysis. Although several images for the year had resolution issues (see table 2.0), an image captured in the low humid month of February and with a cloud cover of 6% was deemed usable and was thus utilized. Following a land cover analysis for the year, over half of the land area was found to be covered with mountain and bamboo forests (67.2%) while the transitional alpine forest had a vegetation cover of 17%. Approximately 5% was under cultivation. Bare/burnt land had an area of approximately 0.5%. This represented approximately 174,600ha, 45,200ha, 14,500ha and 1,200ha respectively. Of the total land area of approx. 280,750ha, an approximate land area of 24,000ha had the grassland vegetation type (see Figure 1).

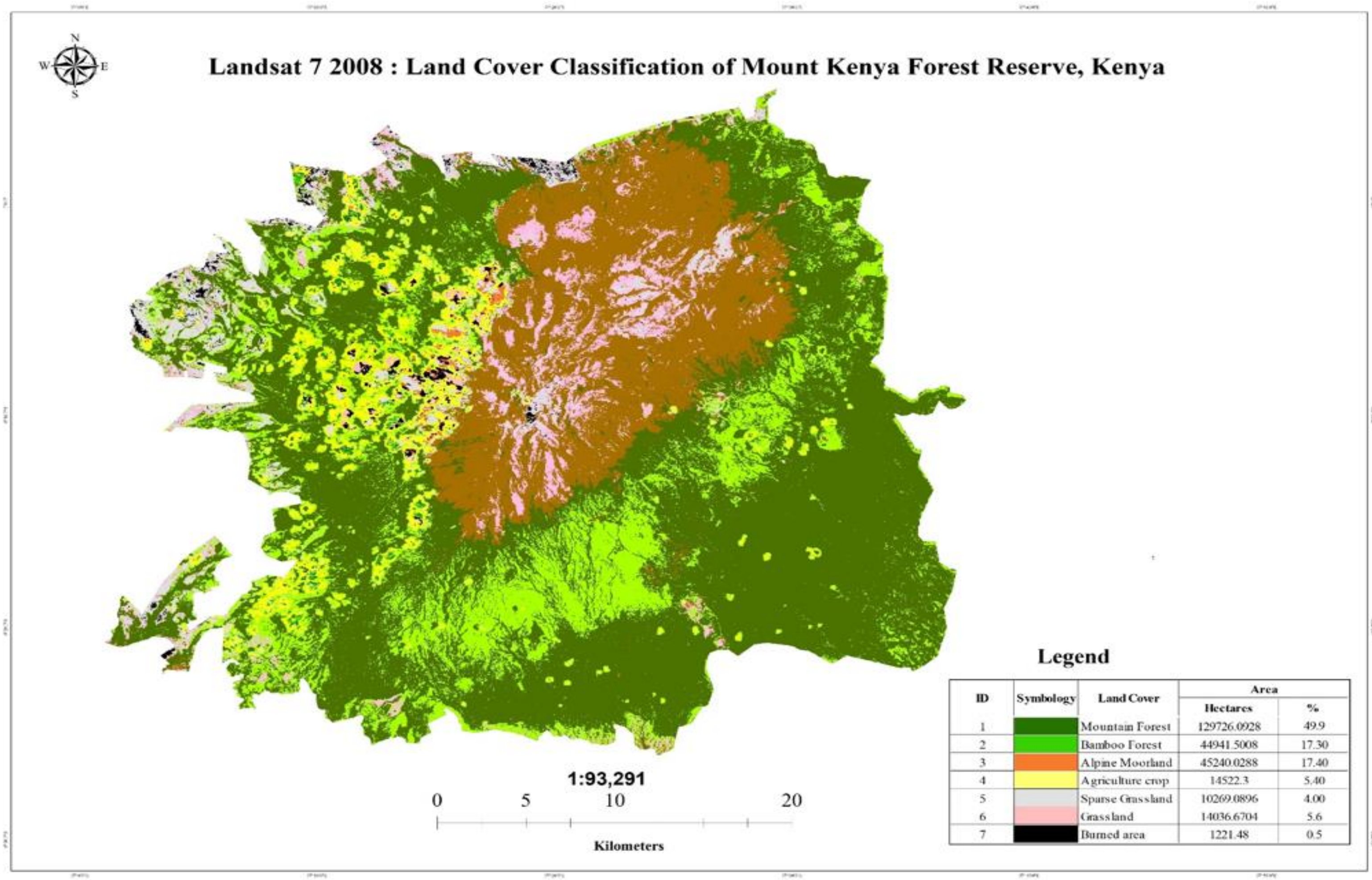



*Figure 1: Land cover classification for 2008*

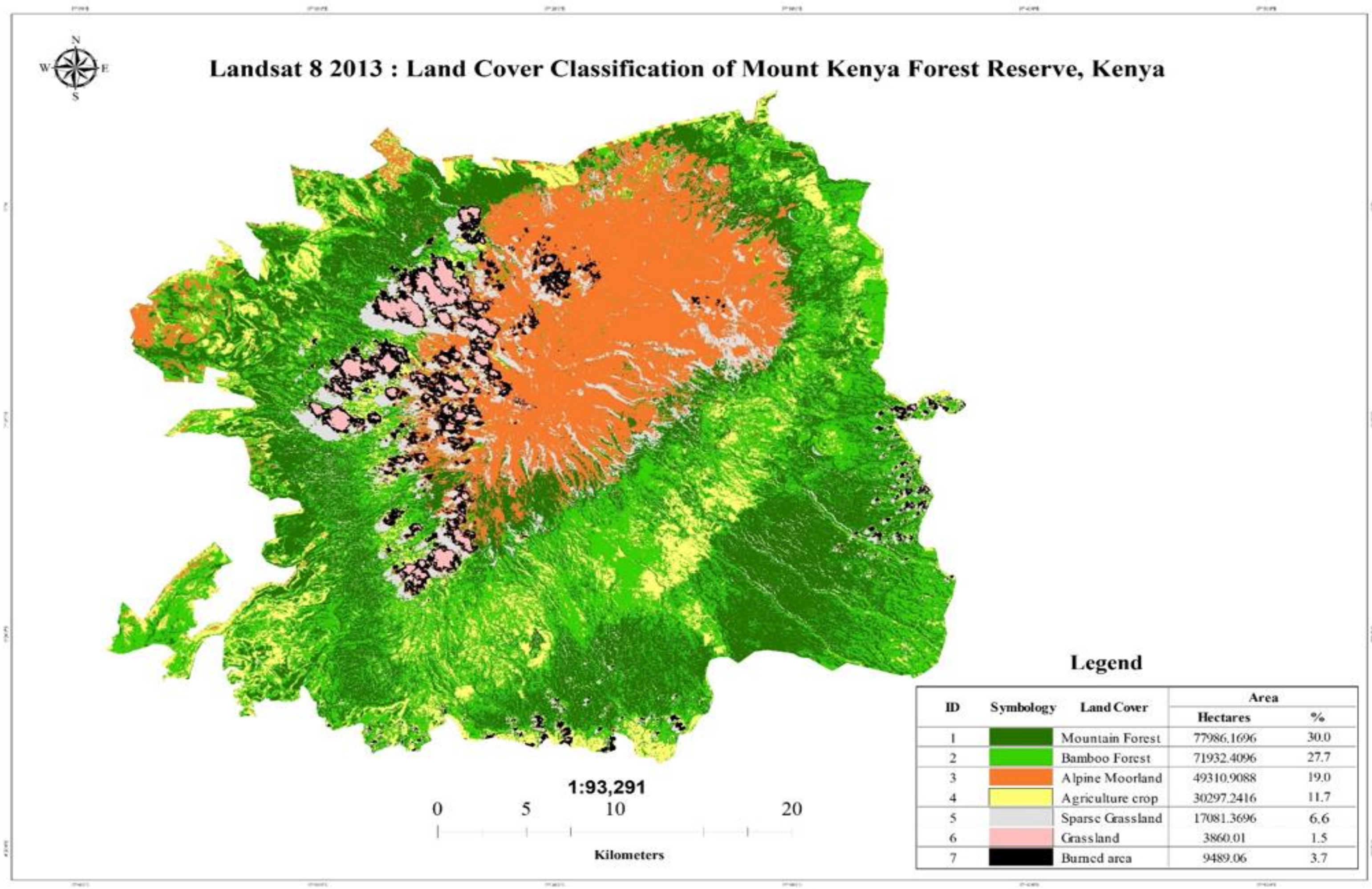



*Figure 2: Land cover classification for 2013*

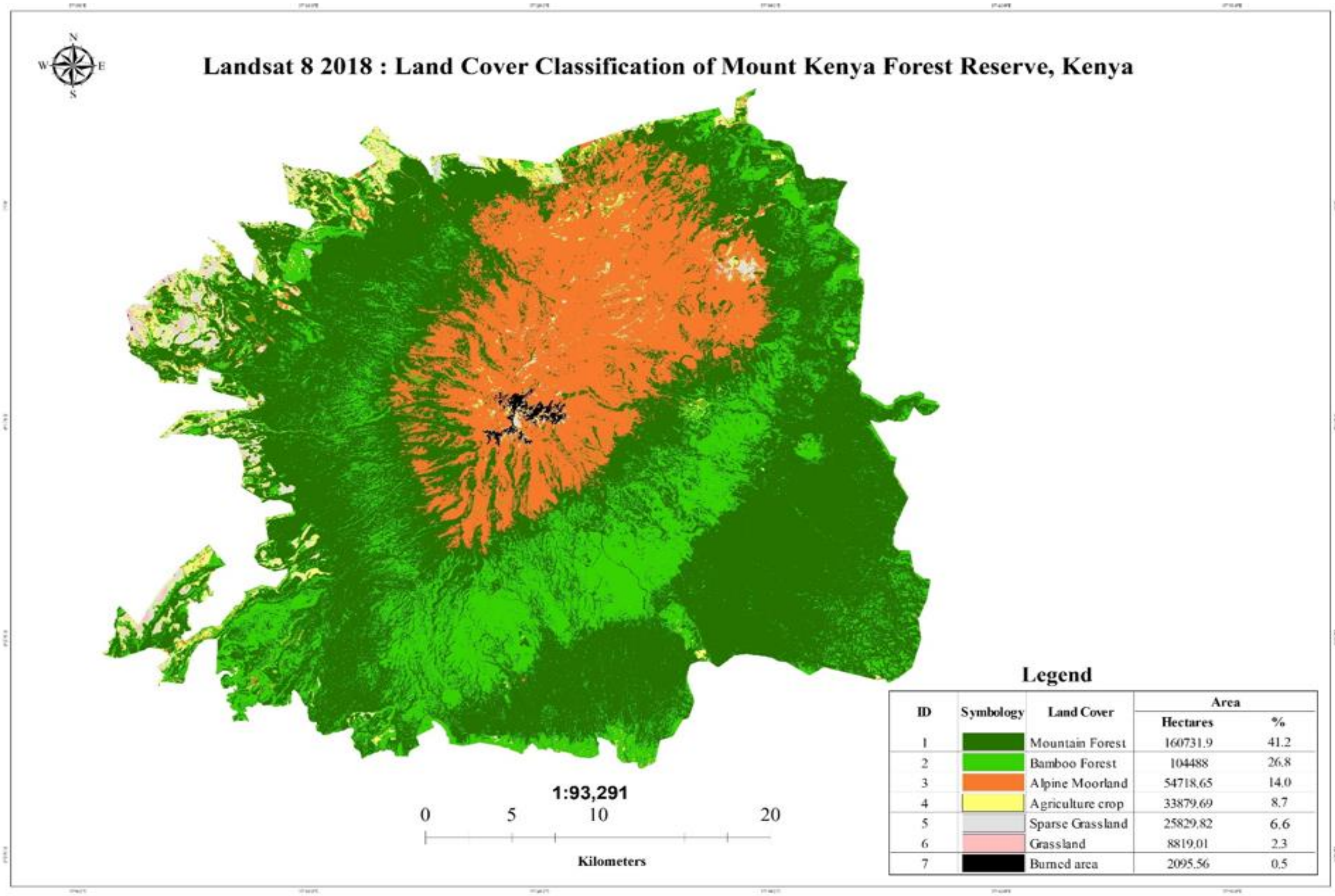



*Figure 3: Land cover classification for 2018*

For the 2013 vegetation cover mapping, a Landsat 8 Operational Land Imager and Thermal Infrared Sensor (LS8 OLI_TIRS_L1TP) was used. The selected image had the highest resolution (Tier 1) and a fairly low cloud cover of 8% and no gapped areas (table 3.0). It was thus deemed fit for use in drawing credible analysis results (USGS, 2018; Alavipanah et al., 2010). The classification showed that around 30% of the area was covered with mountain forest. This translated to an approximate land area of 79,000ha. On the other hand, the bamboo comprised of a 28% while 19% of the land area included the alpine moorland. An estimated 21,000 ha representing 8% of the forest landscape included the grassland. Interestingly, the forest area had decreased by 10% compared to the survey in 2008. Additionally, bare land and areas under agriculture had increased by a similar percentage. Figure 2 compares and summarizes this.

The 2018 land cover analysis also utilized a Landsat 8 Operational Land Imager and Thermal Infrared Sensor with a level 1 precision image (LS 8 OLI_TIRS_L1TP) (see Table 3). The mapping results showed that nearly half the area was densely covered with mountain forest while more than one-quarter of the landscape had bamboo vegetation. This represents a slight increase of forested area as compared to the 2013 analysis. Other land cover/vegetation types surveyed included grassland, agricultural cropland, moorland and alpine moorland (figure 3.0). Specifically, and from the statistics, 41.2% representing a land area of 160,700ha was covered with mountain rainforest. Further, 26.75% of the land area was covered with bamboo forest and 14.01% with Alpine Moorland. A considerable portion (8.67%) was currently under cultivation. Figure 3 summarizes the spatial and statistical distribution of vegetation in the area.

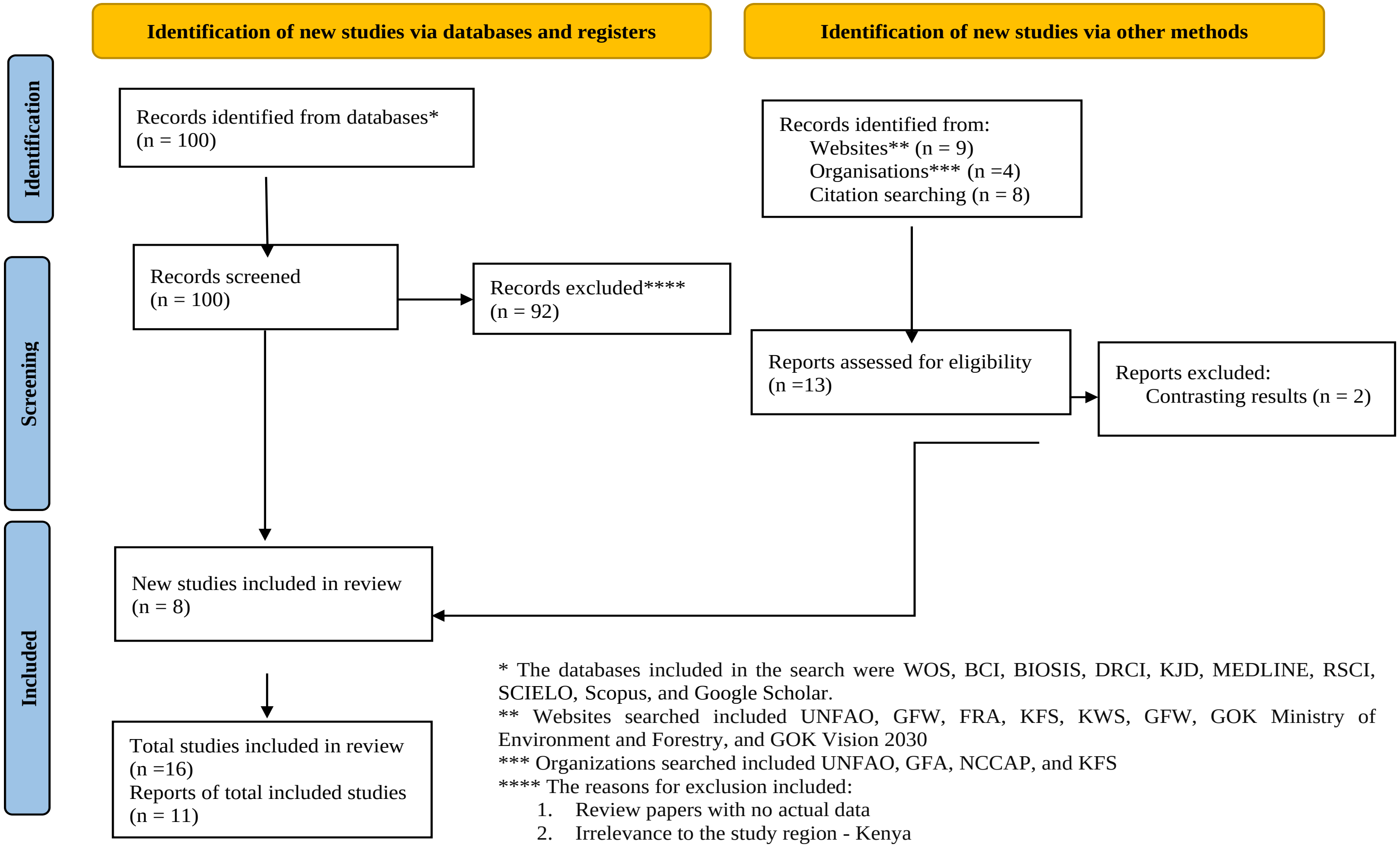
Summarily, the analysis of Mt. Kenya land cover change reported a significant decrease by -1.7% in the mountain forest for the period 2008-2013 while a negative annual growth rate for grassland (-0.3%) was reported. However, data depicted an increase in other vegetation types as summarized in Table 3.

***Table 3: Summary of annual rate of land use changes in Mount Kenya***

| **Land-Cover Types** | **Annual Rate of change (%)** | |
|---|---|---|
| | **2008-2013** | **2013-2018** |
| Mountain Forest | -1.7 | 0.93 |
| Bamboo Forest | 0.9 | -0.08 |
| Alpine Moorland | 0.1 | -0.41 |
| Agricultural farmland | 0.5 | -0.25 |
| Sparse Grassland | 0.2 | 0.00 |
| Grassland | -0.3 | 0.06 |
| Burned area | 0.3 | -0.26 |

Literature review search produced a total of 100 publications while 13 institutional works in the form of reports, press releases, periodicals, and/or policy guidelines were gathered (see illustration 4.0, below). There was also an analysis of 9 websites ranging from state departmental websites and webpages of multinational players involved in forest policing, monitoring, and/or management. After an assortment through an inclusion and exclusion criteria (Figure 4), only 8 publications and 11 reports were identified as potentially mapping vegetation cover or at least describing land use dynamics in some of the landscapes in Kenya. Citation search produced a further 8 publications out of which 3 were mapping Mt. Kenya. A total of 16 publications were thus used in the review and are as follows: Eckert *et* *al.* (2017) surveyed the foothills of Mt. Kenya, Estes *et al.* (2012) assessed land-cover in the Serengeti ecosystem, Muriuki *et al.* (2011) conducted a survey on the Chyulu Hills, Muriuki *et al*. (2017) surveyed the Mara River Basin, Tabor *et al.* (2010) surveyed the coastal Kenya, Ndubi (2018) and Were et al. (2013) surveyed the Eastern Mau forest reserve and Lake Nakuru drainage basin respectively, while Owuor *et al.* (2017) examined ecosystem services of Mida Creek, Kenya. Some of these studies such as Muriuki *et al.* (2011), Estes *et al.* (2012), and Eckert *et al.* (2017) do not exactly inventorise land use/vegetation cover per se but compares land cover with other subjects including human settlement and agricultural expansion respectively. A more recent study by Williams *et al.* in 2018 and that by Borona in 2017 evaluated group ranches in Kenya, and people-forest relationships in Nyandarua forest reserve respectively. Perhaps the most authoritative analysis mapping Mt. Kenya forest landscape was that conducted by Wilkomm et al. (2016) who surveyed land use changes between 2010 and 2015. A related, much older study was Ndegwa's 2015 analysis that looked into the landscape's land use changes in 1976, 1987 and 2002. Olson et al (2004) on the other hand surveyed land use changes on the Eastern slopes of Mt. Kenya. This inconclusive data generally confirms that at the time of this study, there was a paucity of literature on Kenya's forest landscapes and land use changes. It was on this basis that this analysis on the Mt. Kenya ecosystem was sought.

Of the 13 institutional reports, 2, although presenting important background literature, were excluded from the study due to contrasting data on land use changes. Literature from the websites corroborated the review and analysis results particularly on policy and practice.




* The databases included in the search were WOS, BCI, BIOSIS, DRCI, KJD, MEDLINE, RSCI, SCIELO, Scopus, and Google Scholar.
** Websites searched included UNFAO, GFW, FRA, KFS, KWS, GFW, GOK Ministry of Environment and Forestry, and GOK Vision 2030
*** Organizations searched included UNFAO, GFA, NCCAP, and KFS
**** The reasons for exclusion included:

1. Review papers with no actual data
2. Irrelevance to the study region - Kenya
3. Not relevant to the research question and variables

Adapted (modified) from Page et al. (2020).

*Figure 4: PRISMA flow diagram for systematic review results*

## DISCUSSION AND INTERPRETATION OF RESULTS

Generally, the study reported a considerable decline in forest cover for the period 2008 to 2013 (-1.18%). However, there was a slight increase of 1.5% between 2013 and 2018. In the contrary, non-forest cover increased for the period 2008 - 2013 and decreased between 2013-2018. The summary results are shown in Table 5.

***Table 5: Annual rate of forest cover change in Mt. Kenya landscape***

| Land cover types | 2008 | | 2013 | | 2018 | | Rate of change (%) | |
|---|---|---|---|---|---|---|---|---|
| | **Land area (Ha.)** | **% cover** | **Land area (Ha.)** | **% cover** | **Land area (Ha.)** | **% cover** | **Phase 1** | **Phase 2** |
| **Forest** | 174,667.6 | 67.2 | 149,918.6 | 57.7 | 265,219.9 | 67.9 | -1.2 | +1.5 |
| **Non forest** | 85,289.6 | 32.9 | 110,038.6 | 42.3 | 125,342.7 | 32.1 | +1.9 | -2.0 |

From the satellite imagery and analysis results, and as indicated by the Kenya Forest Service survey in 2010, montane forest forms the key ecosystem type in Mt. Kenya while a considerably large section is covered with bamboo forest (see also Kimutai and Wanatabe, 2016; Emerton, 1999; Ndegwa, 2005 and Peltorinne, 2004). Other vegetation types identified in the landscape include alpine moorland, grassland, and mixed vegetation.

Being a world heritage site, it was anticipated that the study site was densely covered with vegetation cover (mainly tropical montane forest) and with very minimal or no human activities. However, satellite imagery results depicted human activities in several areas of the landscape (see figures 1.0, 2.0, and 3.0). This could be responsible for the drastic changes in forest cover as confirmed by the presence of burnt land, open grounds possibly cleared for settlement and farmland. Previous studies have also reported the same findings – see Ndegwa (2005) and Wilkomm et al. (2016)

Specifically, the findings reported a reduction in the forest land (mainly mountain rainforest) in the first analysis period (2008-2013) by 9.5% (from 67.2% forest cover in 2008 to 57.7% cover in 2013). Encroachment of the forest area, expansion in population, and typical development in areas adjacent the rich landscapes are some of the factors that could be responsible for the sudden decline (KFS, 2010; Grace et al., 2014). Moreover, the rich volcanic soils conducive for agriculture, tree life that could provide food sources and building materials, ample monsoon rainfall, and generally the favorable climatic conditions of the area may have caused destructive exploitation by the populations living in the neighboring areas (Justus and Yu, 2014). This is more so given communities in the rural neighborhood of Mt. Kenya Forest actually relies on the forest for livelihood through agriculture and tourism. Further, neglect and ineffective policy implementation, monitoring, and management may have momentarily left the natural resource open to unsustainable exploitation and destruction (Evans et al., 2020; Gardner, 2020; Paxton, 2020; Nyaupane, 2020; Sandbrook, Gómez-Baggethun and Adams, 2020).

In the second phase, 2013-2018, there was a notable positive change in forest cover, possibly due to the conservation efforts by the KFS under the Kenya Forest Service management plan (2010 to 2019); the introduction of a perimeter buffer zone around the landscape; and the enactment of firm protection policies and laws such as fines and prosecution of those culpable (KWCA, 2017; KWS, *n.d*; Musyoki *et al.*, 2016; Wasonga, 2017). These rehabilitation and conservation initiatives could have impacted to the more than 10.2%

recovery (from 57.7% in 2013 to 67.91% in 2018). This translates to approximately 1.5% annual rate of forest gain (see Table 6). There was also a significant decrease in land under cultivation, bare land, and burnt areas by <10%, representing a 2.01% annual rate of change between the said periods.

*Table 6: Land cover and annual percentile change summary*

| Land-Cover Types | % of Land Cover | | | Annual Rate of Change (%) | |
|---|---|---|---|---|---|
| | 2008 | 2013 | 2018 | Phase 1 | Phase 2 |
| Forest (Montane and Bamboo) | 67.2 | 57.7 | 67.91 | -1.18 | +1.5 |
| Non-forest (mainly Farmland, burnt area, and bare land) | 32.9 | 42.3 | 32.09 | +1.85 | -2.01 |

**Land use mapping of protected forest landscapes: Significance to local communities and the politics of conservation in Kenya**

With over sixty (60) major protected areas that embrace various ecosystem types, Kenya is recognized as among the most bio-diverse countries in the world (Campbell, 2014; Newmark and McNeally, 2018; USAID, 2017). Among these are forest landscapes which have important uses including providing water catchment areas, sources of livelihood for adjacent local inhabitants, ensuring biological diversity, and providing habitat and dispersal areas for wildlife (Bremer and Farley, 2010; Dahdouh-Guebas et al., 2000).

However, and as reported in this study's analysis results, the resources have been under threat from unsustainable use through over exploitation by loggers, agricultural expansion, and encroachment by the rural communities (Ogweno et al., 2008). This mostly affects the lowland areas which are in close proximity to community areas. That provides an opportunity for the people to encroach forests for fuel, farming, settlement and livestock rearing (Peltorinne, 2004). A classic example is the 1986 Government of Kenya (GOK) tea estates project, an agricultural initiative that involved carving out land from forest reserves and trust lands in highland areas for farming. Locally known as Nyayo tea zones, the move was meant to create buffer zones/belts around the forests to protect them from exploitative human activities - perhaps this is what satellite imagery captured under agricultural crop cover – see figure 3.0. However, the restrictive and protectionist move may not have been very effective after all as human presence in the zones seems to open up the areas for further use owing to poorly enforced policies that encourage degrading human actions – see fragmented and burnt regions in figures 1.0 and 2.0. In fact, the tea plantation is seen by many as a commercial activity undertaken by the government at the expense of pursuing tree cover (Masinde and Karanja, 2011). Further, and as indicated by Kinoti and Mwende (2019), lack of a targeted surveying on the exposed regions of the forest derails rehabilitation efforts.

Further, studies show that with an exponential increase in human population in areas adjacent protected landscapes, many tropical rainforests are in the danger of fragmentation (Estes et al., 2012; Jones et al., 2012; Nyaligu and Weeks, 2013; Muriuki et al., 2011). This would negatively affect ecosystem functions (Muhati, Olago and Olaka, 2018; Were et al., 2013) as many of these have national parks within them (examples are the Mt. Kenya Forest that houses the Mt. Kenya National Park, the Aberdares forest hosting the Aberdares National

Park, Kakamega forest with the Kakamega national reserve and snake park, and Mau Forest landscape with the world famous Maasai Mara National Reserve and several conservancies). In view of the foregoing, the study results corroborate a 1990-2000 survey by the Kenya Ministry of Environment and Natural Resources in 2016 (now Ministry of Environment and Forestry) analyzing change in the general forest cover in the country that reported a decrease in forest land by 0.54% and an increase in land under agricultural use by 1.75%. The loss was seen amid the presence of government directorates and several environmental enactments on protection of forest resources. Further and from a policy perspective, a preliminary search revealed that there exist contrasting approaches on resource - the Kenya Wildlife Service, a branch of the Ministry of Environment, water and Natural Resources charged with the protection of wildlife advocates for a total protection of all resources including forests. On the contrary, another state department, the Kenya Forest Service, charged with protection of forests and forest resources allow for some use (consumptive or otherwise) exploitation of the resources. This is an interesting phenomenon as both authorities are within the same ministry and government. This perhaps justifies the ineffectiveness in conservation management initiatives in the Mt. Kenya landscape and in other important regions such as the Mau escarpment. These government policy inefficiencies and inactions expose the biodiversity-rich areas to unsustainable and exploitative activities that threaten perpetual posterity of resources for future use.

## CONCLUSION AND RECOMMENDATION

Understanding how and why land-use (forests in this case) change over time is pertinent in policing for environmental management and conservation efforts. This research partly fills the existing literature and spatial data gap on Kenya's forest ecosystems. This research, however, could be extended to other protected landscapes and biodiversity hotspots in Kenya. It is also important to conduct further, possibly comparative, research using other biodiversity/habitat health and sustainability indicators other than land cover change. These may include specific factors such as natural and planted forests change, change in forest area, and canopy cover loss, a measure of forest degradation among others for a more authoritative report on the landscape health and vitality. In this COVID-19 dispensation, this is particularly important given the attention on the pandemic thereby causing an unintended neglect of conservation efforts by governments. This study would also recommend a further study on the ecosystem utilizing ground truthing which was a limitation in the current study. Regarding deleterious human activities causing a decline in forest land, continuous involvement of the local community leaders in decision making and conservation policy planning is imperative.

### Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

### Author Contributions

The authors of this research have all made an intellectual contribution to the work. ST conceptualized the study, collected data, and analysed it; ST, GK, and BO prepared the manuscript, interpreted results, and proofed the work following review.

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