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Spatial and temporal variations in land use and land cover in the Njoro and Kamweti River catchments, Kenya

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Abstract

The Njoro and Kamweti River catchments are productive catchments that have and continue to experience major land use changes with consequences on land cover and the associated environmental resources. It is therefore crucial to understand the type of changes occurring, spatial patterns and the rates at which these changes are occurring. In this study, we quantified the changes in land use and land cover that occurred between 1988 and 2019 identifying areas of change and the average annual rate of change. Thematic Mappers (TM) and Enhanced Thematic Mappers Plus (ETM +) and Sentinel images were obtained for 1988 and 2019. Ground truthing was carried out to enable us to verify the accuracy of the remotely sensed data using in-situ observations to refine the classification output. The results obtained indicated that both catchments have experienced intense land use changes but at different levels. Njoro River catchment's forest cover and shrubland had decreased at a rate of 6.06 Km^2/year and 0.92 Km^2/year respectively and the most increase was recorded in farmlands (3.11 Km^2/year) as the other land use classes also increased. In the Kamweti River catchment, forest cover showed a decrease at a rate of 0.21 Km^2/year and farm lands also a slight decrease of 0.1 Km^2/year while the other land cover classes increased in area coverage during the period 1988-2019. The changes in land use and land cover were attributed to increased demand for food and housing and thus continued degrading the two catchments especially the Njoro River catchment. Results obtained indicated that anthropogenic activities were the major contributing factors to the changes in Land Use Land Cover experienced in both catchments. We recommend continued analysis of the trends and rates of land cover conversions owing to their potential use by development planners. Further, such information is essential when establishing a rational land use policy which is key to sustainable development and the enhancement of livelihoods.

Keywords: *Land use; land cover; anthropogenic activities; change detection; remote sensing; Njoro River catchment*

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Introduction

Land use and land cover (LULC) change detection and analysis have been applied globally and in different ecosystems of the world (Mishra *et al.*, 2019; Serra *et al.*, 2008) to monitor environmental changes and manage natural resources (Twisa & Buchroithner, 2019). Changes in LULC are a key component of global environmental change as they impact climate, ecology, and human society and therefore of concern to policy makers at all levels. The satellite remote sensing data with their repetitive nature have proved to be quite useful in mapping land use/land cover patterns and changes with time (Garcia, 2019). To analyze and understand where LULC changes are occurring and their driving forces, different modeling approaches have been used to enable the prediction of the behavior of natural and human systems (Meyer *et al.,* 1994; Mwaura *et al.,* 2016).

Globally, anthropogenic activities have been the major driving force that has caused a notable change in natural landscapes causing a modification of the global environment (Kirui *et al.,* 2013; Muriithi, 2016; Shukla *et al.,* 2018). This has been noticed especially in areas affected by an increase in the human population, developing technologies and changes in climatic conditions (Twisa & Buchroithner, 2019). In rural areas, land use mostly includes forestry, human settlements, infrastructure development and farming where as in urban areas, land use majors housing, commercials or industries. Changes in land use and land cover modification through land use management, has altered the demand for the available finite natural resources (Kundu *et al.,* 2004).

Research on LULC change is important due to the increased negative implications on ecosystems and links to global, regional and local climate change and variability (Meshesha *et al.,* 2016; Muriithi, 2016). Land use and land cover changes affects both environmental quality and the quality of life and thus impact on the human wellbeing. Some of the concerns linked to the changes in LULC include habitat modification, air and water degradation and a reduction in the quality of life (Hilmi and Sedahmad, 2014). Some of the primary concerns are the effects of land use change on biodiversity, water degradation, soil degradation and the ability of biological systems to support human needs. For instance, there has been a reduction in crop yields due to the changes in land use and land overtime. This forces people to do intensive cultivation to meet their needs. The grazing lands have also become less productive due to the high stocking rates (Shiferaw & Singh, 2011). At the catchment scale, dynamics in land cover impacts on the water quality and quantity due to loss of vegetative cover, which acts as a barrier to the movement of materials into water systems, reducing runoff which significantly increases possible impacts environmental resources (Notter *et al.,* 2007). A study by Wang *et al.,* (2018), in the Xitiaoxi River Basin, analyzed the spatial patterns of LULC changes from 1985 to 2008 and reported that dominant trend of land-use conversion was between forest-grass land and agricultural land, and the diminishing portion of forest-grass land and agricultural land contributed to the expansion of urban land during the period 1985–2008. Similar trend was also pointed out by Birhanu *et al.,* (2019), in the Gumara catchment, Ethiopia, between 1986 and 2015 where the area under forest and grass land was about 11 and 18%, respectively, in 1986, which reduced to 5 and 10%, respectively, in 2015. Also noted was that cultivated land increased from 70% in 1986 to 82% in 2015.

In Kenya, spatio-temporal changes in the land cover states have been studied for instance, Olang *et al.,* (2011), studied the Nyando Basin and reported that the area covered by forests declined by 20% while agricultural fields expanded by 16% between 1973 and 2000. A study in the Tana River Basin by Langat *et al.,* (2019), noted that agricultural land and built-up area increased by 32.57% (184,796 ha) and 26.35% (1460 ha) respectively, while open land, water-bodies and vegetation have decreased by 35.9%, 3.13% and 8.29% respectively within the three window periods between 1987 and 2015. Rapid LULC changes have also occurred in the Lake Nakuru drainage basin, including the entire Eastern Mau, where the Njoro River catchment lies over the last 3 decades. The Eastern Mau forest is part of the largest closed-canopy montane forest ecosystem in Eastern Africa and also among the five important water catchment areas in Kenya and a major sink of carbon dioxide, which is the main driver of global warming and climate change.

In the 1940's, the Njoro River catchment was characterized by sparse population, forestry and large-scale conservative agriculture. Later on, in the 1960's after independence, there was increased settlement of the people who had been displaced during the independence war. This led to subdivision of land, intensive cultivation and urbanization as the large scale farms were converted into small scale farms and plantation forests were gradually lost (Mainuri & Owino, 2013). In 1970, 47% of the area was under natural vegetation, but by 2003, a large percentage of this had been cleared and the number of small-scale farms had grown (Baldyga *et al.,* 2008).

Kamweti region on the other hand climatic factors define the upper tree limit. However, deforestation has significantly raised the lower limit of forest and most of the lower parts of the catchment and the areas which formerly supported forest, are now either under cultivation or have been planted with mostly exotic fast-growing softwoods (Tattersfield *et al.,* 2001). A section of the Kamweti River Catchment is under the Mount Kenya Forest Reserve and the lower side of the catchment is agriculturally productive. Human activities have put pressure on the Forest Reserve through activities such as illegal livestock grazing, uncontrolled logging and shamba agriculture involving localized clearance and temporary cultivation within the forest. In some areas, indigenous forests have been cleared and replanted with fast-growing softwood plantations.

This paper compares the dynamics of LULC changes in two catchments characterized by different levels of anthropogenic disturbances, landscape characteristics and ecology. These regions are within tropics thus could be susceptible to environmental degradation from human activities. In this study, we focused on two objectives: (i) To analyze spatial and temporal variations in LULC changes from 1988, and 2019, and thus determine annual rate of changes in the two catchments, and (ii) To document the types of LULC types in the two catchments which differ in the levels of anthropogenic activities. We hypothesized that the areas characterized by high demand for land for agricultural purposes, human settlements and infrastructural expansion experienced significant changes in land cover.

Materials and Methods

Study Area Description

Njoro River Catchment

The study region, Njoro River Catchment covers an area of 284.39 Km^2. It is located in Kenya's southwestern Rift Valley at 0° 30′ South 35° 20′ East. Within this catchment is the Njoro River with an approximate length of 55 Km discharging into Lake Nakuru (at 1,750 m ASL), first RAMSAR site in Kenya (Figure 1 A). The river traverses forest, agricultural fields, settlements and urban areas before it discharges into the shallow soda lake (Lelo *et al.,* 2005).

The Njoro River catchment's rainfall pattern is a bimodal distribution. The wet season falls between April and August whereas the dry season falls between December and March (Mathooko & Kariuki, 2000). In some sections of the river, the riparian vegetation has been cleared and the canopy cover over this hydro-system ranges from 0% to about 80%. Soils in the Njoro River watershed region range from Humic Acrisols, Phaeozems, Andosols, Planosols, Plinthosols, and Fluvisols. The soil textures in the lower parts of the catchment are clay loams to sandy clay loams. Topographic variation and historical volcanic activity in the area are known to contribute to soil formation (Baldyga *et al.,* 2008).

In the recent past, notable changes in land use and increase in human population have been experienced in the watershed. This has had negative impacts on the available natural resources, human health and wellbeing, the local economy and the types of livelihood systems (Enanga *et al.,* 2011). The upland regions of the watershed have conditions favorable for crop production which has led to the conversion of the available forests and other natural vegetation to small-scale agriculture. Majority of the farmers in the watershed practice crop and livestock production, which has become their main sources of household livelihoods in the watershed. Other socio-economic activities include firewood gathering and selling, charcoal burning and selling, quarrying and sand harvesting.

Kamweti River Catchment

Kamweti area, Figure 1 B, is located approximately latitude 0º 20´S to 0º 22´ S and longitude 30º 25´E to 37 ° 30´E. It is located on the southern slopes of Mount Kenya. The area is dissected by several rivers and streams; the main ones being the Kamweti River and the Kavute River, all of which are tributaries of the Thiba River. The latter drains into the Tana River. These are permanent rivers which supply water not only for the area residents but form the main sources of irrigation water in the Mwea Rice Irrigation Scheme (Kaberia, 2007).

Kamweti area has a cool, moist climate. The mean temperatures range from 16.6°C in the coldest month and 20.1°C degrees Celsius in the warmest month. The rainfall is bimodal with two peaks, one from March to May (long rains) and the other from October to December (short rains). The annual rainfall ranges between 800 mm to 2150 mm (Kaberia, 2007). Kamweti area is characterized by tertiary recent volcanic rocks. The soils are generally strong brown loams derived from volcanic ash and occur in dissected land. In some areas soils are reddish and also have smeary consistence. Brown loamy soils absorb much water and contain (5 to 20%) organic matter. The soils are fertile and well drained with a good permeability and a stable soil structure.

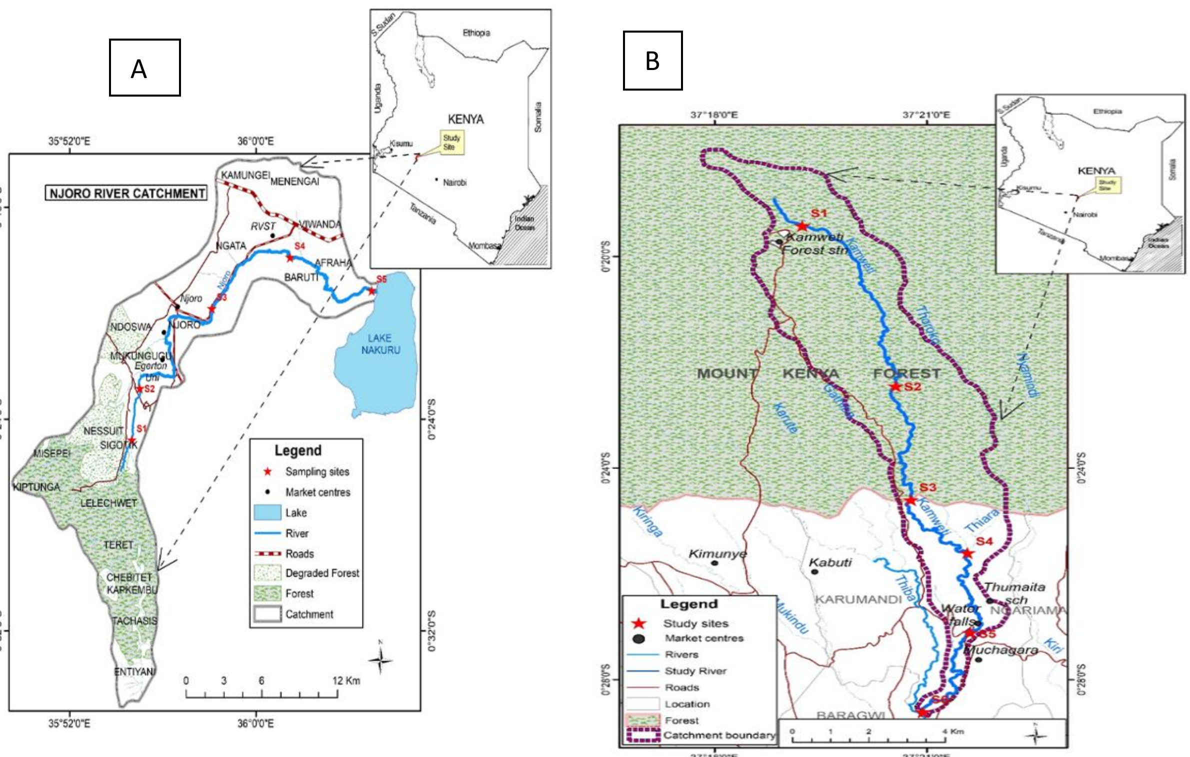


Figure 1. Maps showing the study areas (Source: World Resource Institute GIS data). A: Njoro River Catchment. B: Map of the Kamweti River catchment (Map of Kenya inset)

Kamweti area consists of rocky afro-montane forests at higher elevations and highly diverse riverine forests in the valleys that is well preserved. Upstream of the Kamweti River has been restricted to natural vegetation. The forest consists of both natural and exotic species. The most predominant exotic tree species include *E. saligna* and *C. lusitanica*. Examples of indigenous tree species include *R. melanophloeos* and some of the common shrubs around Mount Kenya are *R. vulgaris*, *V. auriculifera*. *U. diversifolia* is one of the common under-storey naturally growing herb in the forest (Oduma, 2016).

Downstream Kamweti River, the area has been cleared for cultivation. The Nyayo Tea Zone (Kenya tea zone and forest conservation) forms an area of separation between the forest zone and farmers' field. The cultivated area is an undulating high region rising gradually northwards towards Mount Kenya whose highest point reaches 5836 meters above sea level. The average altitude of the cultivated area is 2194 meters above sea level. *Urtica diversifolia* is the main weed species in farmers' coffee or tea plantations and grows to a height of 30-150 cm tall (Kaberia, 2007).

Both the Njoro and the Kamweti River Catchments are highly productive catchments however they differ in terms of ecology, landscape characteristics and human characteristics. The pressure for arable land especially through agriculture and settlements has been on the rise within the Njoro Catchment since 1994 (Baldyga *et al.*, 2008) which has caused a recession of forest cover and affected the forest ecosystem integrity. The anthropogenic pressure and conversion of forests to other land uses in both catchments at different rates makes them important case studies. Efforts have been made by various institutions and community-based organizations (CBOs) to rehabilitate some sections of the Njoro Catchment since the year 2012. The extent of success of these efforts is not well established or documented. Kamweti area, which is considered to be in a "semi-pristine" state and forms a yardstick for evaluating the extent of degradation of the Njoro River Catchment which presents a fragile ecosystem whose natural resource require better management.

Methods used for land use and land cover change detection

Land Use and Land Cover changes in Njoro River and the Kamweti River Catchments for the periods of 1988 and 2019 changes in vegetation patterns were detected using Landsat imagery. Thematic Mappers (TM) and Enhanced Thematic Mappers Plus (ETM +) and Sentinel images were obtained for 1988 and 2019, a period of 31 years in which LULC change can be monitored. An effort was made to acquire cloud free image scenes. The images used were of the same season (wet) which were downloaded from USGS Global Visualization Viewer (http://glovis.usgs.gov). The images used were already geo-referenced to correct alignment, and also they were co-registered to the Universal Transverse Mercator (UTM) projection system (zone: 37N, datum: WGS-84). The purpose was to avoid the need for geo-rectification which would have required the use of ground control points. The details of satellite data are presented in Table 1.

The process applied the use of Remote Sensing and Geographic Information System to evaluate the LULC changes, trends, magnitudes and the emerging environmental consequences in the area for the study period.

Table 1. Remotely sensed data used in the analysis of land use/cover change in the two catchments

Catchment	Satellite sensor	Acquisition date	Path/ Row	Resolution	Season
Njoro River	ETM	30.01.1988	168/60	30 m	Wet
	TM	03.04.2001; 30.01.2010	168/60	30 m	Wet
	Sentinel-2A	12.01.2019	T36 MZE	30 m	Wet
Kamweti River	TM	17.10.1988	168/60	30 m	Wet
	ETM	21.02.2000; 17.07.2010	168/60	30 m	Wet
	Sentinel-2A	28.02.2019	T37 MCV	30 m	Wet

TM = Thematic Mapper sensor; ETM+ = Enhanced Thematic Mapper plus sensor and Sentinel

Satellite data comprised of multi-temporal satellite imageries (Landsat imageries of 1988 and 2019). Image processing done using IDRISI imaging for layer stacking, sub-setting, image classification, recording of features and accuracy assessments. Supervised classification which allows the user to define the areas of interest and recognize the features on the image was carried out to develop training sites. The training sites were collected for the various LULC categories, based on prior knowledge of the study areas and based on the uniformity in appearance using ArcGIS 10. The training sites were then used to create spectral signatures to be used to process land use and land cover classes in unsupervised classification.

To improve on the visualization of different objects on the imagery this study, different color composites were used. Infrared color composite, Near Infrared, and Red were applied in the identification of varied levels of vegetation growth and in separating different shades of vegetation. In the identification of the built-up areas and bare soils, color composites such as Short Wave Infrared, Near Infra-red and Red combination which are sensitive to variations in moisture content were applied (Cheruto *et al.*, 2016). The spectral signatures for the respective LULC types obtained from the satellite imageries were then recorded by use the pixels enclosed by the polygons. Reclassifying classes to assign a common class was carried out by utilization of ARCGIS 10 software, which has the capability of integrating the other data with the extracted information. It was also utilized for displaying and subsequent processing and to enhance the images and clip out the area of interest (Njoro & Kamweti River Catchments) from the images using topographical maps.

Assessing rate of cover change

Assessment of the changes in LULC in the Njoro & Kamweti River Catchments for 1988 and 2019, for the different cover classes, was carried out following Othow *et al.,* (2017) using the formula:

$$\%\text{ Cover change} = \frac{Area_{i\ year\ x} - Area_{i\ year\ x+1}}{\sum_{i=1}^{n} Area_{i\ year\ x}} \times 100\%$$

$$\text{Annual rate } of \text{ change} = \frac{Area_{i\ year\ x} - Area_{i\ year\ x+1}}{t_{years}} \times 100\%$$

$$\%\text{ Annual rate change} = \frac{Area_{i\ year\ x} - Area_{i\ year\ x+1}}{Area_{i\ year\ x} \times t_{years}} \times 100\%$$

According to the formula, the annual rate of change in the study area was computed by dividing the change between first date and the second date by number of years between the dates. The average percentage annual rate of change was derived by dividing the change between dates by the product of area of cover at 1st date multiplied by number of years, expressed as a percentage.

In this study, three sets of remotely sensed images namely Landsat TM, ETM+ and Sentinel were used in the classification of LULC categories into seven different informational classes as described in Table 2. The classes were categorized from the different Landsat images included forests, disturbed forests, farm land, built-up areas, shrublands, bare ground, and water body. The classification was based on the image interpretation and sample trainings created during image classifications.

Table 2. Description of land cover classes used in the two catchments

Cover class	**Description**
Forests (F)	The continuous stand of trees, many of which may attain a height of 50 m including natural forest, mangrove and plantation forest.
Disturbed forests (D F)	Any forest that has been logged and is recovering naturally or artificially
Farm land (F L)	Areas covered with perennial and annual crops
Built-up areas (B U A)	All residential, commercial and industrial area, transportation infrastructure, settlements (may include greenhouse plastic covers).
Shrubland (S L)	Areas of land covered with scattered grasses, shrubs and trees.
Bare-ground (BG)	Areas with no vegetation cover or uncultivated farm lands consisting of exposed soil and rock outcrops.
Water body (WB)	Area of land covered with water.

Results

Land use and Land cover maps of the study areas
The land cover maps for the years 1988 and 2019 based on the Landsat imageries were prepared with seven land-cover types, namely, forests, disturbed forests, farm land, built-up areas, shrublands, bare ground, and water body for the Njoro and Kamweti River Catchments for comparison. Figures 2 and 3 shows the final output of the maps for the two catchments studied showing the substantial changes that have been occurring in the two catchments in the years 1988 and 2019.

A *B*

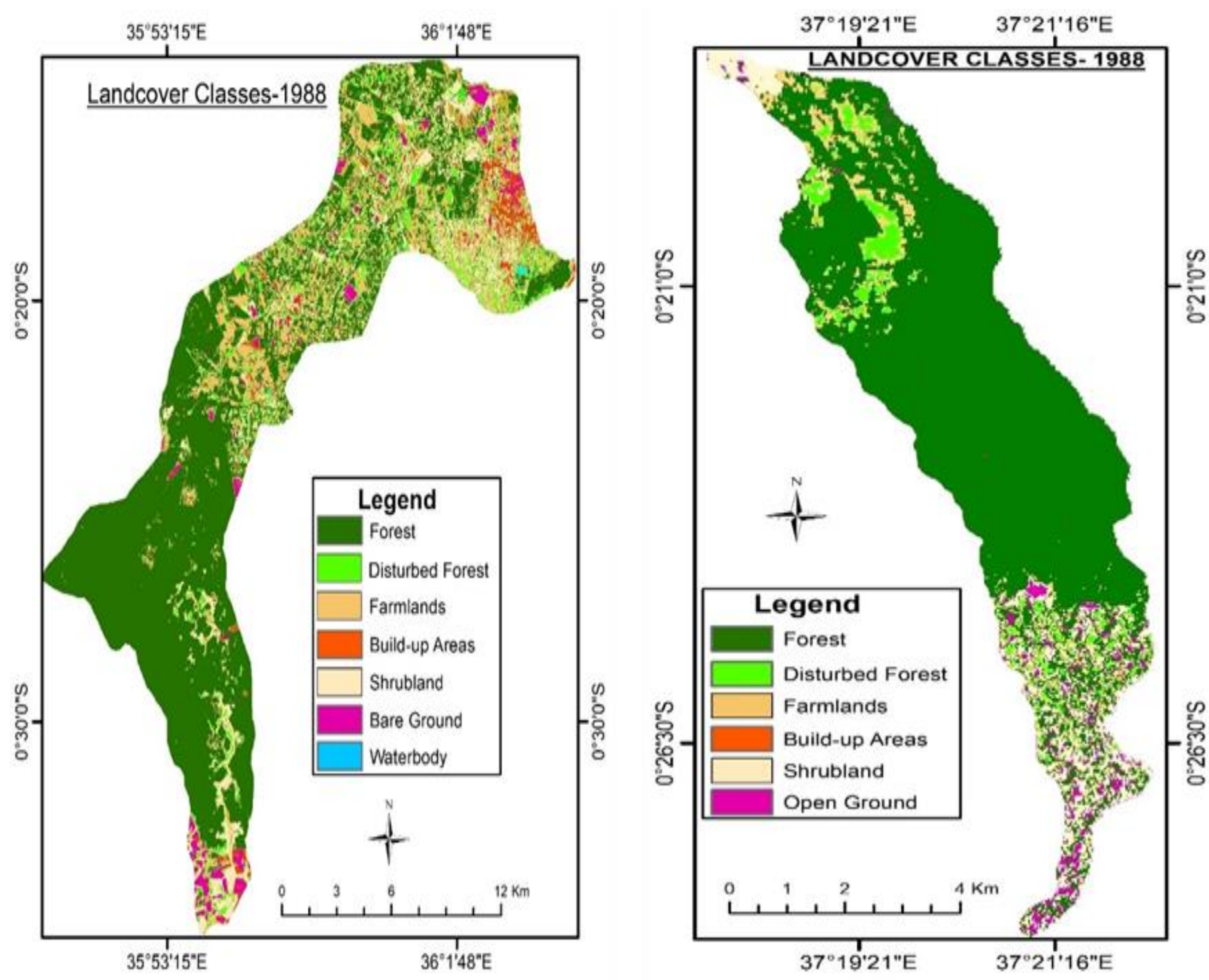


Figure 2. Land cover classifications for the period of 1988: A- Njoro River Catchment B- Kamweti River

A B

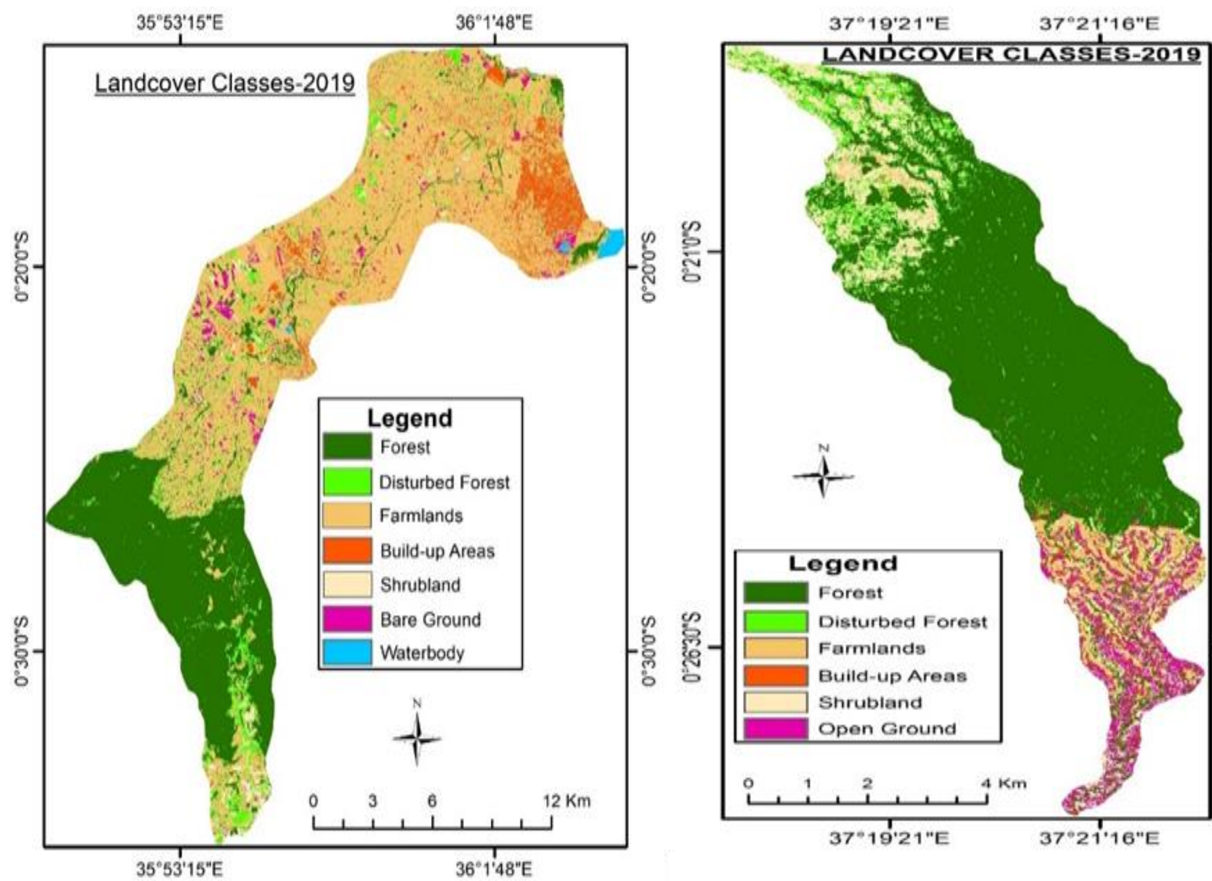


Figure 3. Land cover classifications for the period of 2019: A-Njoro River catchment B- Kamweti River catchment

Spatial and temporal variations in land use and land cover changes

Results from the study indicated that there were major changes in LULC in the two catchments. The Njoro River Catchment has an area of 284.39 Km^2 while Kamweti River Catchment covers an area of 48.33 km^2.

In 1988, the most dominant vegetation class in the Njoro River Catchment (Figure 2A) was forest cover. It had a coverage of 57 % and since then it has shown a decreasing trend to the year 2019 where coverage of 29.31% was recorded. A sharp decline was noted between 1988 and 2001 where forest cover reduced by 26.52% as shown in Table 3 A. Disturbed forests covered 6.94% in 1988 and since then it has been increasing. Kamweti River Catchment (Figure 2 B) on the other hand, in 1988 had a dense canopy of closed forest and also was the most dominant land use and land cover class with a coverage of 36.66 Km^2 (75.87%). In 1988, the disturbed forest coverage was 2.10 Km^2 whereas shrubland covered 4.88 Km^2 (Table 3 B) which dominated mostly on the northwestern section of the catchment. Farmlands covered a smaller area of 3.28 Km^2 and were present mostly along the edges of the forest which were the tea plantations on the ground.

Table 3. Land use and land cover changes for the study period: A-Njoro River catchment and B- Kamweti River catchment

A

	1988		2001		2011		2019	
Class Type	**Cover (sq. km)**	**% Cover (sq. km)**	**Cover (sq. km)**	**% Cover (sq. km)**	**Cover (sq. km)**	**% Cover (sq. km)**	**Cover (sq. km)**	**% Cover (sq. km)**
F	162.11	57.00	86.68	30.48	85.75	30.15	83.36	29.31
D F	19.73	6.94	52.37	18.41	37.69	13.25	19.92	7.00
F L	46.65	16.40	94.99	33.40	119.82	42.13	143.13	50.34
B UA	7.23	2.54	8.61	3.03	11.72	4.12	14.90	5.24
S L	40.40	14.21	33.91	11.92	24.29	8.54	11.87	4.17
B G	8.09	2.85	7.73	2.72	4.85	1.72	9.39	3.30
W B	0.18	0.06	0.1	0.04	0.27	0.09	1.82	0.64
Total	284.39	100	284.39	100	284.39	100	284.39	100

B

	1988		2000		2010		2019	
Class Type	**Cover (sq. km)**	**% Cover (sq. km)**	**Cover (sq. km)**	**% Cover (sq. km)**	**Cover (sq. km)**	**% Cover (sq. km)**	**Cover (sq. km)**	**% Cover (sq. km)**
F	36.66	75.85	28.04	58.02	30.38	62.86	30.13	62.34
D F	2.10	4.34	1.68	3.48	2.81	5.81	3.90	8.07
F L	3.28	6.79	2.76	5.71	1.58	3.27	1.59	3.29
B UA	0.41	0.85	1.38	2.86	1.44	2.98	1.48	3.06
S L	4.88	10.10	11.83	24.48	9.83	20.34	8.25	17.07
B G	1.00	2.07	2.64	5.46	2.29	4.74	2.98	6.17
W B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	48.33	100	48.33	100	48.33	100	48.33	100

***Note**: **F**-Forest, **D F**- Disturbed Forest, **F L**- Farm Land, **B U A**-Built Up Areas, **S L**- Shrub Land, **B G** – Bare Ground, **W B** – Water Body.*

Between 1988 and 2001, forest cover in the Njoro River Catchment reduced by 26.52%. During the second period, between 2001 and 2011, the forest coverage has decreased by 0.93 Km^2 at a rate of 0.09 Km^2/year. In the third period between 2011 and 2019, the forest cover reduced further by 2.39 Km^2 (0.3 Km^2/year) within eight years. In Kamweti River Catchment, between 1988 and 2000, the forest covered an area of 28.04 Km^2 and also it had reduced by 17.85% at an average annual rate of 0.72 Km^2/year (Fig. 3 B). Disturbed forests had reduced to 1.68 Km^2 and farmlands reduced to 2.76 Km^2 however noted was the increase in the area of shrubland to 11.83 Km^2 as shown in Table 3 B.

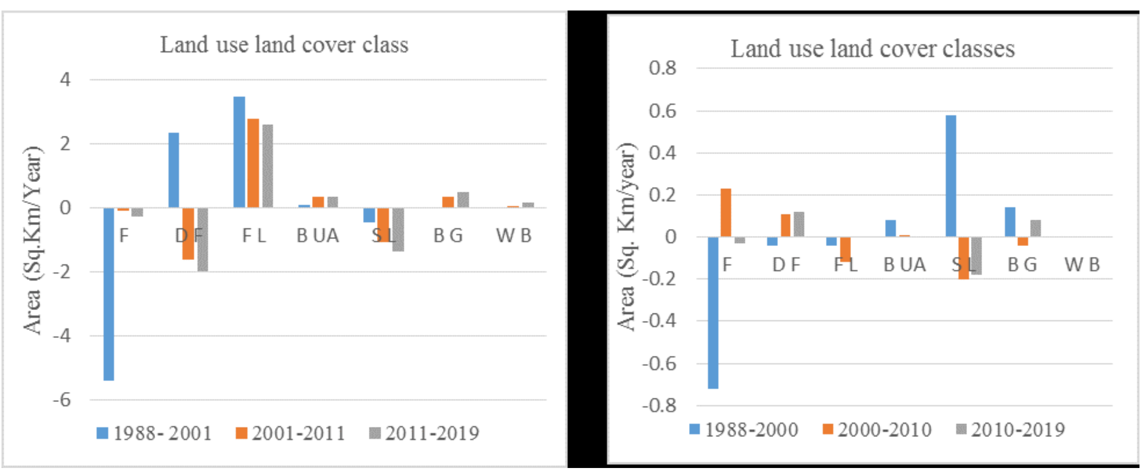
Farmland areas in the Njoro River Catchment in 1988 constituted a spatial coverage of 46.65 Km^2 and it has been in an increasing trend. A greater conversion of vegetation cover into farmlands was noticed between 1988 and 2001 where a change of 48.48 Km^2 occurred with an annual average rate of change of 3.72 Km^2/year. Vegetation cover in the catchment decreased from 51.94% to 40.3% as farmlands increased from 46.65 Km^2 to 143.13 Km^2 as shown in table 3, during the study period at an annual rate of 3.21 Km^2/year. On the contrary the area of farm land coverage in the Kamweti Catchment was noted to be on a decreasing trend where farmlands covered 3.28 Km^2 and in 2019 it covered 1.59 Km^2.

Built-up areas in both catchments during the study periods showed a steady increase. In 1988, the total area of the Njoro River Catchment covered by Built-up areas was 7.23 Km^2 and in 2019 it had increased to 14.9 Km^2 with annual rate of increase of 0.25 Km^2/year within the study period. Bare ground between 1988- 2001 continuously showed a decreasing trend from 2.85 % to 2.72 % in the Njoro River catchment. This occurred at a diminishing rate of 0.36 Km^2/year. Between 1988 and 2019, built up area in Kamweti River catchment was 0.41 Km^2 which increased to 1.48 Km^2.

Water bodies include ponds, springs, streams, and rivers. Kamweti River catchment had a 0% area of water coverage between 1988 and 2019 as shown in table 3 B. In Njoro River catchment water bodies in 1988 covered 0.18 km^2 (0.06%). A decrease to 0.1 km^2 was noted in 2001. In 2011 area of water coverage increased to 0.27 km^2 later followed by a decrease in 2019 to 1.82 km^2 as shown in table 3 A.

The rate of changes of forests, disturbed forests, farm land, built up areas, shrubland, bare ground and water body cover for the study period of the two catchments are presented in Figure 4 A and 4 B. The negative values in the table represents the declined in the proportion of LULC categories in that particular time, whereas the positive values correspond to the increased in the proportion of land covers class in that particular time of the study.

A B



Note: F-Forest, D F- Disturbed Forest, F L- Farm Land, B U A-Built Up Areas, S L- Shrub Land, B G – Bare Ground, W B – Water Body.

Figure 4. Changes in LULC classes in A- Njoro River Catchment and B- Kamweti River Catchment in Km2/year from 1988 to 2019

Discussion

Land use and land cover maps of the study areas

Land cover change detection using remote sensing provided evidence that both catchments were being degraded the causes being attributed to anthropogenic activities such as deforestation, agricultural expansion, infrastructure, riverbank cultivation and the unsustainable utilization of natural resources. Increase in human population have been studied to affects the quality of the environment (Meshesha *et al.*, 2016; Pullanikkatil *et al.*, 2016; Shiferaw & Singh, 2011) some of the impacts being loss of biodiversity, land degradation and increased soil erosion. According to Lambin *et al.*, (2003), an increase in human population and especially in developing countries has led to the clearance of vegetation cover for agricultural purposes due to the increased demand for food.

In this study, similar results were obtained in the Njoro River Catchment where the percentage of farmlands and built up areas have been on the rise at the expense of vegetation cover during the study periods. Baldyga *et al.,* (2008), reported that between 1986 and 2003, about one-fifth of the forests in the upper catchment of Njoro River were lost. The forest loss was partly attributed to illegal encroachments in 1990s and the political decision to excise about 353 km^2 of Eastern Mau forest reserve for human settlement in 2001 (Kweyu *et al.,* 2020). In some sections of the river, water is abstracted for irrigation purposes which reduces amount of river flows. This has encouraged cultivation on the steep slopes and to the river banks where water is available and the suitable environment to support farming. In both catchments, the built up areas were noted to be increasing steadily since 1988 which has put pressure on the building materials eventually leading to land degradation through sand mining and quarries which has impacted the catchment ecosystem and functioning.

Spatial and temporal variations in land use and land cover changes

Land use and land cover dynamics in the two catchments studied have undergone considerable changes over the 31-year period. The reduction of vegetation cover especially in the Njoro River Catchment could be attributed to the expansion of agricultural activities and an increase in human population, which has been studied as LULC driver (Boakye *et al.,* 2008) and has exerted pressure on vegetation cover.

Mainuri and Owino, (2013), reported that the population in the Njoro River Catchment has been on the rise. According to (Baldyga *et al.,* 2004) catchment had a population of about three hundred thousand (300,000) people with more than three thousand (3000) individual farm holding units. However, according to Kenya National Bureau of Statistics, Njoro Sub County registered a population of 238,773 people in 2019 having grown from 23,551 people in 2009 (Kenya National Bureau of Statistics, 2019). Based on the same growth rate, the watershed population may have also grown. The high population growth rates reported coupled with land fragmentation has been studied to exert pressure on land causing soil erosion and other forms of degradation (Boakye *et al.,* 2008) which could be the case in the Njoro River Catchment.

Some of the effects of soil erosion and runoff that can be felt downstream include the siltation of ponds, increase in water-borne diseases, water pollution and sediment deposition on fertile land (Maitima *et al.,* 2009; Meshesha *et al.,* 2016). Nayak *et al.,* (2014), reported that overgrazing in catchments impedes growth of the forest under-storey through trampling of seedlings and juvenile trees, over-browsing of palatable tree species, and increasing soil erosion through the loosening of the topsoil.

In Kamweti River Catchment, the forest class coverage in 2010 had increased to 30.38 km^2 (62.86%). In 2019 a reduction by 0.25 Km^2 was noted (Table 3 B). Also noted was the shrubland decreased by 1.58 km^2 with a corresponding increase in the area of disturbed forests by 1.09 Km^2 and bare land by increases by 0.69 Km^2/year. The main reason for the above changes could be attributed the rising human population and economic growth in the area. A study by Mwaniki and Möller (2015) , reported similar results in some sections of Central Kenya about a massive forest on the decline between 1995 and 2002, and a slight rise of forest areas between 2002 and 2010. At this time the Kenyan government had addressed the issue of deforestation and was putting measures to curb the problem for example through the introduction of the Nyayo Tea Zones which created as a “tea boundary” at the national park (Willkomm *et al.,* 2016).

The area under farmlands in the Njoro River Catchment has been on the increase during the study period at the expense on the vegetation cover. This is evident in areas that were initially covered by grass and shrubs where, farms, built-up areas and settlements now stand. The upper section of the catchment was also a forested area in the year 1988 which has now been converted into arable and built-up lands. A study by Shivoga *et al.,* (2006) pointed out that in the year 2003, the dominant land cover types in the Njoro River Catchment were 5% forest, 7% woodland, 82% agriculture and 6% built-up area. The study revealed that the loss of forest cover in the reserves was by both clear cut and progressive thinning due to poaching by local residents.

The conversion of forest land to agricultural and built-up areas is known to affect the riverine vegetation (Auble *et al.,* 1994; Chebii, 2016; Shiferaw and Singh, 2011) which has been the case in the Njoro catchment where the riparian resource has been pressured (Mathooko, 2001). In comparison to Kamweti River catchment, farm lands in 1988 covered an area of 3.28 Km^2 and since then recording a decrease to 1.59 Km^2 in 2019. This is because a section of the Kamweti River catchment is under the management of Mt. Kenya National Park. It is a gazette forest for both wildlife conservation and limited human activities like livestock foraging and firewood collection which are friendly to conservation. Establishment of tea plantations around the edges of the Mt Kenya forest was a measure to reduce encroachment.

Bare land was being converted into other types of land cover classes. This is due to the availability of farming land coupled with increasing human population growth, it negatively contributed to the decline of bare land. Between 2011 and 2019 bare ground showed an increase to 3.3% this could be due to the increased use of greenhouses in flower farms which are detected as bare by satellites or the satellite images were taken before the planting season. In the Kamweti River catchment, there was decrease in the forest cover as other LULC classes such as the disturbed forests, built-up areas, shrubland and bare ground increased in their areas of coverage. Bare ground increased at a rate of 0.06 Km^2/year between1988 and 2019. The deforestation pattern observed in this catchment was that of a transition from the closed forest, open forest to agriculture and settlement which then transitions to bare land in some instances. A similar trend was also observed in Ethiopia where agriculture and settlement areas had expanded at the expense of forest cover, bare land and grazing land without any significant conservation measures being put in place (Gashaw *et al.,* 2014).

Increases in areas of bare lands, the changes in hydrological response and implications of land use change on soil erosion. The removal or change in vegetation cover, affects the flow of water across the landscape, as well as the amount retained in the soil. Under conditions such as dense natural vegetation cover, the flow of water over land is usually slow, and water infiltrates rates to the soil. With the existence of bare land, water flows more freely across the landscape and does not have an opportunity to infiltrate the soil (Baker & Miller, 2013; Mainuri, 2018). The result is a change in the timing and amount of runoff to the river. Surface flows are also increased, as water rushes from the landscape into the river channel. Changes in the watershed are associated with upland vegetation changes, floods and high flows have increased in recent years within the River Njoro watershed. Increase in soil erosion has been an additional concern, for instance, at Lake Nakuru National Park, reports indicated that sediment yields from the river to the lake were worsening (Mainuri, 2018).

Kamweti River catchment had a 0% area of water coverage between 1988 and 2019 whereas the Njoro River catchment showed a decrease in the first phase and an increase in the second phase and finally a decrease between 2011 and 2019. The possible explanation of this fluctuation of water could be due to the decreased rainfall patterns in the area and the poor water harvesting methods among local people. Due to the changes in land use and land cover, there has also been an increase in surface water runoff while sub-surface and groundwater quantity and quality has also deteriorated. The effect of the land use change in water bodies is seen through the reduction in the natural recharge, and discharge (Guzha *et al.,* 2018). Currently, surface and groundwater sources are dwindling as evidenced in the River Njoro which used to flow throughout the year and now it has become intermittent. Some boreholes which were dug within Egerton University have dried up (Kundu *et al.,* 2004; Shivoga *et al.,* 2006) which has impacted communities especially within the lower portion of the catchment where they rely heavily on community boreholes and urban wells for their water sourcing. Reductions in groundwater recharge was also noted to have affected Lake Nakuru by lowering water available for recharge which could have potential negative impacts on wildlife populations in the park that are dependent on the lake (Baker & Miller, 2013). The recent rise in water levels in Lake Nakuru has been attributed to the excessive river inflows into the lake which results from increasing catchment rainfall coupled with the effects of land use and land cover changes.

Conclusion

Results from the study carried out on the spatial and temporal analysis of LULC change in the Njoro and Kamweti River catchments clearly indicate that changes have occurred over the past 31 years. Most of this changes have been attributed to changing land use patterns in the catchments.

In the Njoro River catchment, between 1988 and 2019, major reductions were noted to have occurred in the area under forest cover and shrubs. Major changes also occurred in areas under farm lands, where in the year 1988, farmlands covered an area of 16.4 % which later increased to 50.34% of the catchment in 2019. It was noted that the areas which were previously covered by forests including the gazette forest were invaded and degraded by human activities and currently remains in a poor state. Vegetation cover have been converted into built up areas and farm lands especially in the upstream areas where they are highly productive due to the fertile soils and availability of water for irrigation. In the Kamweti River catchment, forest cover decreased from 75% to 62.34% between 1988 and 2019 whereas the area under shrubs and disturbed forest increased. During this period also, the built up areas increased whereas the area cover by farmlands decreased from 6. 79% to 3.29%. A section of the catchment is under gazette forest ecosystem of Mt Kenya, which is protected by an organized management. This prevented further encroachment to the forested areas for farming purposes and other activities causing the loss of tree cover by the introduction of the Nyayo Tea zones which acted as a buffer between the local communities and forest.

The changes occurring in both catchments are not only alarming due to the impact on biodiversity and ecological services but also pose a significant challenge to improving both human and catchment health. LULC changes has negative impacts on the ecosystem in form of over cultivation, overgrazing and deforestation. These causes surface runoff which has been associated with high soil erosion and sediment delivery. With increase in soil erosion in the catchments, large quantities of pesticides and fertilizers will be carried along contaminating domestic and livestock water sources. For instance, in Lake Nakuru, the appearance of the algae bloom in the recent past was a sign of eutrophication, indicating a lack of oxygen. This has severe implications on water quality in the lake and can negatively impact fish, bird and animal populations.

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References

Auble, G. T., Friedman, J. M., & Scott, M. L. (1994). Relating riparian vegetation to present and future streamflows. *Ecological Applications*, *4*(3), 544–554.

Baker, T. J., & Miller, S. N. (2013). Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed. *Journal of Hydrology*, *486*, 100–111.

Baldyga, T. J., Miller, S. N., Driese, K. L., & Gichaba, C. M. (2008). Assessing land cover change in Kenya's Mau Forest region using remotely sensed data. *African Journal of Ecology*, *46*(1), 46–54.

Baldyga, T. J., Miller, S. N., Shivoga, W., & Maina-Gichaba, C. (2004). *Assessing the impact of land cover change in Kenya using remote sensing and hydrologic modeling*. 23–28.

Birhanu, A., Masih, I., van der Zaag, P., Nyssen, J., & Cai, X. (2019). Impacts of land use and land cover changes on hydrology of the Gumara catchment, Ethiopia. *Physics and Chemistry of the Earth, Parts A/B/C*, *112*, 165–174.

Boakye, E., Odai, S. N., Adjei, K. A., & Annor, F. O. (2008). Landsat images for assessment of the impact of land use and land cover changes on the Barekese catchment in Ghana. *European Journal of Scientific Research*, *22*(2), 269–278.

Chebii, W. K. (2016). Assessment of Kenya's Montane Forest Ecosystems: A Case Study on the Cherangani Hills in Western Kenya. *International Journal of Science Arts and Commerce*, *1*, 46–58.

Cheruto, M. C., Kauti, M. K., Kisangau, D. P., & Kariuki, P. C. (2016). *Assessment of land use and land cover change using GIS and remote sensing techniques: A case study of Makueni County, Kenya*.

Enanga, E., Shivoga, W., Maina-Gichaba, C., & Creed, I. (2011). Observing changes in riparian buffer strip soil properties related to land use activities in the River Njoro Watershed, Kenya. *Water, Air, & Soil Pollution*, *218*(1–4), 587–601.

Garcia, C. A. C. (2019). *Land Cover Classification Implemented in FPGA*.

Gashaw, T., Bantider, A., & Mahari, A. (2014). Evaluations of land use/land cover changes and land degradation in Dera District, Ethiopia: GIS and remote sensing based analysis. *International Journal of Scientific Research in Environmental Sciences*, *2*(6), 199.

Guzha, A., Rufino, M. C., Okoth, S., Jacobs, S., & Nóbrega, R. (2018). Impacts of land use and land cover change on surface runoff, discharge and low flows: Evidence from East Africa. *Journal of Hydrology: Regional Studies*, *15*, 49–67.

Hilmi, H., & Sedahmad, S. (2014). Land use land cover change detection: A case study: Khartoum state, Sudan, 1972-2006. *Global Journal of Environmental Science and Technology: ISSN*, *3*(1), 088–094.

Kaberia, D. K. (2007). *Participatory Action Research and Testing the Effectiveness of Stinging Nettle as a Biopesticide in Kenya*. University of Wisconsin--Stevens Point.

Kenya National Bureau of Statistics. (2019). *2019 Kenya Population and Housing Census Volume I: Population by County and Sub-County*.

Kirui, K., Kairo, J., Bosire, J., Viergever, K., Rudra, S., Huxham, M., & Briers, R. (2013). Mapping of mangrove forest land cover change along the Kenya coastline using Landsat imagery. *Ocean & Coastal Management*, *83*, 19–24.

Kundu, P., China, S., Chemelil, M., & Onyando, J. (2004). *Detecting and quantifying land cover and land use change in Eastern Mau by Remote Sensing*. *37*, 1–5.

Kweyu, R., Thenya, T., Kiemo, K., & Emborg, J. (2020). The nexus between land cover changes, politics and conflict in Eastern Mau forest complex, Kenya. *Applied Geography*, *114*, 102115.

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, *28*(1), 205–241.

Langat, P. K., Kumar, L., Koech, R., & Ghosh, M. K. (2019). Monitoring of land use/land-cover dynamics using remote sensing: A case of Tana River Basin, Kenya. *Geocarto International*, 1–19.

Lelo, F. K., Chiuri, W., & Jenkins, M. W. (2005). Managing the River Njoro Watershed, Kenya: Conflicting laws, policies, and community priorities. *Republic of South Africa (Eds), African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa, Johannesburg, South Africa*.

Mainuri, Z. G., & Owino, J. O. (2013). Effects of land use and management on aggregate stability and hydraulic conductivity of soils within River Njoro Watershed in Kenya. *International Soil and Water Conservation Research*, *1*(2), 80–87.

Mainuri, Z. G., (2018). Impact of Human Settlement on Land Use/Land Cover Changes in the Middle River Njoro Sub Watershed in Kenya. *European Journal of Multidisciplinary Studies*, *3*(4), 180–188.

Maitima, J. M., Mugatha, S. M., Reid, R. S., Gachimbi, L. N., Majule, A., Lyaruu, H., Pomery, D., Mathai, S., & Mugisha, S. (2009). The linkages between land use change, land degradation and biodiversity across East Africa. *African Journal of Environmental Science and Technology*, *3*(10).

Mathooko, J. M., & Kariuki, S. T. (2000). Disturbances and species distribution of the riparian vegetation of a Rift Valley stream. *African Journal of Ecology*, *38*(2), 123–129.

Meshesha, T. W., Tripathi, S. K., & Khare, D. (2016). Analyses of land use and land cover change dynamics using GIS and remote sensing during 1984 and 2015 in the Beressa Watershed Northern Central Highland of Ethiopia. *Modeling Earth Systems and Environment*, *2*(4), 1–12.

Meyer, W. B., Meyer, W. B., & BL Turner, I. (1994). *Changes in land use and land cover: A global perspective* (Vol. 4). Cambridge University Press.

Mishra, P. K., Rai, A., & Rai, S. C. (2019). Land use and land cover change detection using geospatial techniques in the Sikkim Himalaya, India. *The Egyptian Journal of Remote Sensing and Space Science*.

Muriithi, F. K. (2016). Land use and land cover (LULC) changes in semi-arid sub-watersheds of Laikipia and Athi River basins, Kenya, as influenced by expanding intensive commercial horticulture. *Remote Sensing Applications: Society and Environment*, *3*, 73–88.

Mwaniki, W. M., & Möller, S. M. (2015). Knowledge based multi-source, time series classification: A case study of central region of Kenya. *Applied Geography*, *60*, 58–68.

Mwaura, F., Kiringe, J. W., & Warinwa, F. (2016). Land Cover Dynamics in the Chyulu Watershed Ecosystem, Makueni-Kajiado Counties, Kenya. *International Journal of Agriculture, Forestry and Fisheries*, *4*(3), 17–26.

Nayak, P. K., Oliveira, L. E., & Berkes, F. (2014). Resource degradation, marginalization, and poverty in small-scale fisheries: Threats to social-ecological resilience in India and Brazil. *Ecology and Society*, *19*(2).

Notter, B., MacMillan, L., Viviroli, D., Weingartner, R., & Liniger, H.-P. (2007). Impacts of environmental change on water resources in the Mt. Kenya region. *Journal of Hydrology*, *343*(3–4), 266–278.

Oduma, F. O. (2016). *Effects of stream size and forest type on leaf litter decomposition and macroinvertebrate diversity in Kamweti area, Kenya* [PhD Thesis]. Egerton University.

Olang, L. O., Kundu, P., Bauer, T., & Fürst, J. (2011). Analysis of spatio-temporal land cover changes for hydrological impact assessment within the Nyando River Basin of Kenya. *Environmental Monitoring and Assessment*, *179*(1), 389–401.

Othow, O., Gebre, S., & Gemeda, D. (2017). Analyzing the rate of land use and land cover change and determining the causes of forest cover change in Gog district, Gambella regional state, Ethiopia. *J. Remote Sens. GIS*, *6*(4), 218.

Pullanikkatil, D., Palamuleni, L. G., & Ruhiiga, T. M. (2016). Land use/land cover change and implications for ecosystems services in the Likangala River Catchment, Malawi. *Physics and Chemistry of the Earth, Parts A/B/C*, *93*, 96–103.

Serra, P., Pons, X., & Saurí, D. (2008). Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography*, *28*(3), 189–209.

Shiferaw, A., & Singh, K. (2011). Evaluating the land use and land cover dynamics in Borena Woreda South Wollo Highlands, Ethiopia. *Ethiopian Journal of Business and Economics (The)*, *2*(1).

Shivoga, W., Muchiri, M., Kibichi, S., Odanga, J., Miller, S. N., Baldyga, T. J., & Maina-Gichaba, C. (2006). *Impacts of upland land use on downstream water quality in River Njoro Watershed, Kenya*. *2*, 472–476.

Shukla, A. K., Ojha, C. S. P., Mijic, A., Buytaert, W., Pathak, S., Garg, R. D., & Shukla, S. (2018). Population growth, land use and land cover transformations, and water quality nexus in the Upper Ganga River basin. *Hydrology & Earth System Sciences*, *22*(9).

Tattersfield, P., Warui, C., Seddon, M., & Kiringe, J. (2001). Land-snail faunas of afromontane forests of Mount Kenya, Kenya: Ecology, diversity and distribution patterns. *Journal of Biogeography*, *28*(7), 843–861.

Twisa, S., & Buchroithner, M. F. (2019). Land-Use and Land-Cover (LULC) Change Detection in Wami River Basin, Tanzania. *Land*, *8*(9), 136.

Wang, Q., Xu, Y., Xu, Y., Wu, L., Wang, Y., & Han, L. (2018). Spatial hydrological responses to land use and land cover changes in a typical catchment of the Yangtze River Delta region. *Catena*, *170*, 305–315.

Willkomm, M., Vierneisel, B., & Dannenberg, P. (2016). Land use change dynamics in the Mt. Kenya region–a remotely sensed analysis using RapidEye satellite images. *Zentralblatt Für Geologie Und Paläontologie, Part I (1)*, 23–40.