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Spatial-TemporalLand Use and Land Cover Changesinthe Stony Athi Sub-Catchment, Kenya

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Abstract: *Land use and land cover changes have been identified as one of the main human induced activities altering environmental systems. This is because of the ability of anthropogenic activities to cause land degradation, loss of biodiversity, global warming, flooding as well as groundwater quantity and quality. Like other parts of the world, arid and semi-arid areas in Kenya has been experiencing rapid land use and land cover changes over the past few decades due to changes in land policy, change in sedentary lifestyles, population growth and urbanization. An assessment of land use and land cover changes that have taken place over a period of 33 years was carried out in the Stony Athi sub-catchment between January 2018 and June 2018. The study was done using a remote sensing approach on a geographical information system platform. The widely used parametric classifier, the supervised maximum likelihood classification, was used to classify four satellite images for the years 1984, 1995, 2005 and 2017 and the classification accuracy verified using the kappa coefficient. Post-classification detection method was used for change detection. The significance of the results were tested using the chi-square goodness of fit, accepted at $p < 0.05$. The sub-catchment was classified into six categories namely; built-up areas, agricultural land, grassland, shrub land, mixed forest and bare land with an overall accuracy of over 90% and kappa accuracy of more than 0.9. Significant changes ($p < 0.05$) were observed in all the land use and land cover classes with an increase in built-up areas (0.04% in 1984 - 3.4% in 2017), agricultural land(0.06% in 1984 - 0.7% in 2017) and grasslands (58.2% in 1984 - 71.6% in 2017), but a decrease in shrub land(37.1% in 1984 - 21.1% in 2017) and mixed forest (2.5% in 1984 - 1.4% in 2017). Marginal changes were detected in bare land(2.1% in 1984 - 2.0% in 2017). Results from this study indicate and recommend the necessity to understand the trends of land use and land cover changes in order to develop competent policy decisions on land use planning and management of natural resources for sustainability.*

Key Words: *Land use and land cover change; Change detection; Stony Athi sub-catchment.*

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I. Introduction

Throughout the entire history of mankind, human utilization of land resources has resulted in significant changes ofland use and land cover (LULC). Population growth, urbanization and migration to areas deemed favourable for agriculture increasespressure on landwhich in turn results toecosystem fragmentation (Malaki*et al.*, 2017; Mbau, 2013). Arid and semi-arid areas in Kenya have been experiencing rapid LULC changes for the past few decades mainly due to changes in land policies that have transformed former pastoral communal land into several land use systems including group and individual ranches, private holdings, agricultural farms and urban centres(Morara*et al*., 2014, GoK, 2014).The Stony Athi sub-catchment represents a case where changes in land tenure, proximity to the capital city of Kenya, urbanization and immigration are causing rapid LULC changes.The area has been gaining popularity for those seeking relatively cheap land for settlement, agricultural and industrial activities. As a result there has been increased LULC changes from the natural land cover of grasslands, shrub land and mixed forests to urban and rural settlements as well as agricultural and commercial use. The ensuing landscape of the sub-catchment is today dotted with private homes, institutions, commercial buildings as well as large scale flower and horticulture farms.The consequent land sub-division, expansion of settlements, cultivation, fences and development of infrastructure have adversely affected both wildlife and livestock populations alike (Ogutu*et al*. (2014).For this reason, there is a need to understand the pattern and trends of LULC changes in the area in order to develop competent policy decisions on land use planning and management of natural resources for sustainability.The main objective of this study therefore was to examine the spatial-temporal land use and land cover changes in the sub-catchment from 1984 to 2017 using remotely sensed data and Geographical Information System (GIS). Remote sensing and GIS are effective tools for detecting objects and phenomena change and have been widely used for detecting land use and land cover changes by various authors such as Alqurashi& Kumar, 2013; Mbau, 2013;Nyamasyo&Kihima, 2014; Butt*et al.,* 2015;Malaki*et al.,* 2017;Zhang*et al*., 2017; Jiménez*et al*., 2018; Gong*et al.,* 2018.

II. Materials and Methods

2.1 Study Area

The Stony Athi sub-catchment is bounded by latitudes 1°28'S and 1°50'S and longitudes 36°40'E and 37°15'E covering an area of about 1,745 sq.km (Figure 1). The larger part of the sub-catchment (71%) lies in Kajiado County, 27% in MachakosCounty and 2% in Makueni County. It is part of the head-waters of the Athi River, which is the second largest river in Kenya. The sub-catchment lies in the semi-arid Athi-Kapiti plains which gently slopesfrom west to east with relief ranging from 2,082m in the west to 1493 m above sea level with a mean of 1787 m.

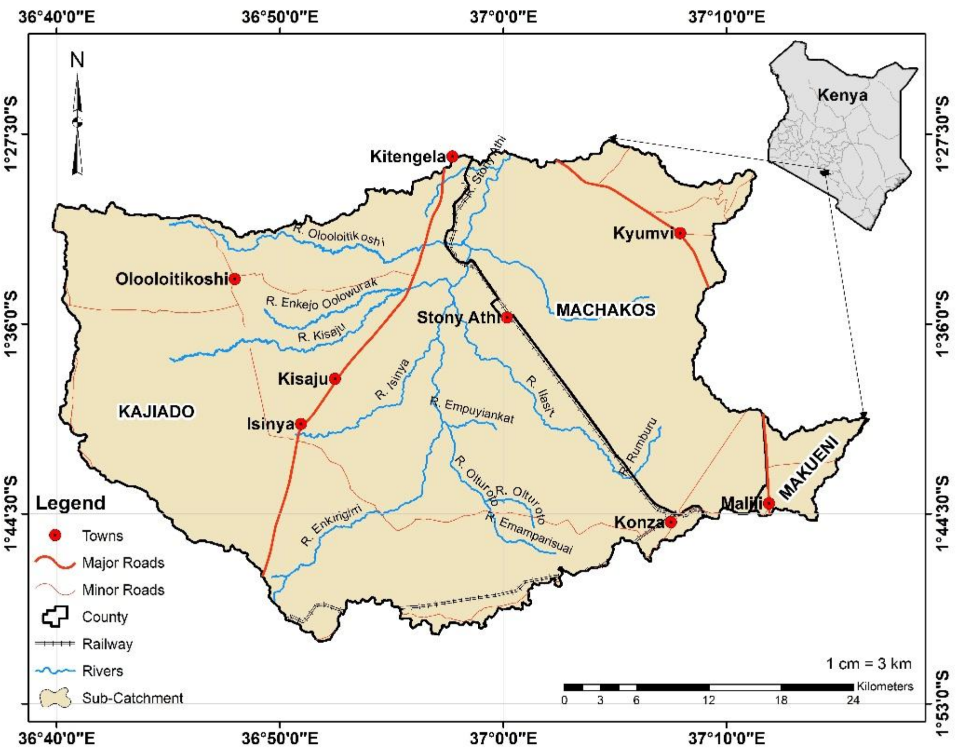

Figure 1: A map of the Stony Athi sub-catchment with inset showing its location in Kenya.

2.2 Data Acquisition

Two types of data were used in this study; satellite images in conjunction with ground truth observations as proposed by Kumar *et al.,* (2014). Satellite data comprising of four multi-temporal images for the years 1984, 1995, 2005 and 2017 wereacquired from the USGS Earth Explorer website https://earthexplorer.usgs.gov/ (U.S. Geological Survey, 2015) (Table 1). Ground truth data in form of ground reference points was collected during a field survey conducted in January to March 2018using a hand held Geographical Positioning System (GPS)set.

Table 1: Landsat multi-spectral images used in the study

Date of acquisition	*Satellite Sensor*	*Path/Row*	*Bands*	*Spatial Resolution*
27/08/1984	Landsat 5 Thematic Mapper ™	168/61	Blue, Green, Red, Near IR, Mid IR	30 m
30/01/1995	Landsat 5 Thematic Mapper ™	168/61	Blue, Green, Red, Near IR, Mid IR	30 m
01/01/2005	Landsat 7 Enhanced Thematic Mapper (ETM+)	168/61	Blue, Green, Red, Near IR, Mid IR	30 m
28/12/2017	Landsat 8 OLI/TIRS	168/61	Blue, Green, Red, Near IR, SW IR2	30 m

OLS-TIRS - operational land imager and thematic infrared sensor, TM - thematic mapper; ETM+ - enhanced thematic mapper plus

2.3 ImagePre-processing and Classification

The satellite images were pre-processed in ArcMap 10.3 using the standard image pre-processing techniques namely, extraction, layer stacking,geo-referencing, image enhancement andsub-setting as described by Young*et al*. (2017).The images were pre-processed by applying the band combination composite tool to create a multi band after which a sub-set was obtained after clipping the individual composite scenes. A supervised maximum likelihood approach was used for image spectral classificationby assigning per-pixel signatures and differentiating the sub-catchment into different categories to generate thematic maps for the respective years of interest.

2.4 Accuracy Assessment

The four land use thematic maps were validated by conducting an accuracy assessment with ground truth data collected from the field survey.In this study, Landsat 8 OLI/TIRS 2017 image was used as the reference image for which the ground truth data likely equates. The classification accuracy for each image was assessed using a classification error matrix from which the user's and producer's accuracies for each LULC category, overall accuracy and kappa index of agreement were computed according to the procedures described by Congaltonand Green, (2019).

2.5 Change Detection

The post-classification change detection method was used for land use and land cover change detection. This approach allowed the determination of the differences between independently classified temporal images.The maps were then compared on a pixel by pixel basis using a change detection matrix.Each LULC change category was computed as a percentage of the total study area while spatial change was done through crosstabulation method(Comber *et al*., 2016).Chi-square goodness of fit was used to determine whether there weretemporal significant changes and significant differences accepted at $p \leq 0.05$ (Zeng*et al*., 2015).

III. Results and Discussion

Sixland use and land cover categories were established in this study namely; built-up area, agricultural land, grassland, shrub-land, mixed forest and bare land (Table 2).The land use and land cover thematic maps for the years 1984, 1995, 2005 and 2017 for the Stony Athi Sub-catchment are presented in Figure 2. The overall classification accuracy in all the satellite images was greater than 90%, while the overall kappa index of agreement was more than 0.90, indicating an acceptable level of agreement (Table 3). The United States Geological Survey has approved the kappa coefficient of 85% as the minimum requirement for land use classification with Landsat data (Varamesh*et al*., 2017).

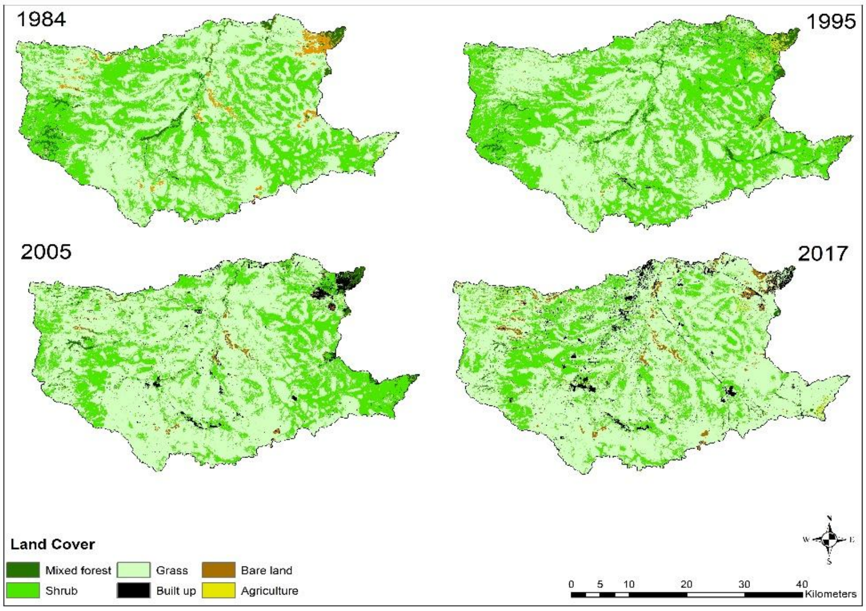

Figure 2: Land use and land cover thematic maps of Stony Athi sub-catchment for the four temporal periods (1984, 1995, 2005 and 2017). An increase in built up area (black) and a decrease in shrub-land (green) is evident.

Table 2: LULC categories delineated on the basis of supervised classification.

LULC Category	*LULC Description*
Built-up area	Urban and rural settlements including roads.
Agricultural land	Land areas under cultivation.
Grassland	Land areas dominated by savannah grass and scattered shrubs.
Shrub land	Land areas dominated by natural shrubs with sparse trees.
Mixed forest	Mixed trees and undergrowth bush including trees along drainage channels.
Bare land	Land areas of exposed soil or rock with occasional scattered trees.

Table 3: Accuracy assessment for the Landsat image classifications.

Date of acquisition	*Satellite sensor*	*Overall accuracy*	*Kappa coefficient*
27/08/1984	Landsat 5 Thematic Mapper ™	94.6	0.93
30/01/1995	Landsat 5 Thematic Mapper ™	94.5	0.93
01/01/2005	Landsat 7 Enhanced Thematic Mapper (ETM+)	95.8	0.95
28/12/2017	Landsat 8 OLI/TIRS	95.9	0.95

In 1984, out of the total area of 1,745 km2 of the Stony Athi sub-catchment, built-up area occupied only 0.64 km2 while agricultural land was 4.1 km2; grassland, 1,016.4 km2; shrub land, 647.7 km2; mixed forest, 44.0 km2; and bare land, 35.8 km2. By 2017built-up area occupied 59.5 km2; agricultural land, 11.6 km2; grassland, 1,250 km2; shrub land, 368 km2; mixed forest, 23.7 km2; and bare land, 32.6 km2 (Table 4& Figure 3). Built up areas sequentially increased from a coverage of 0.64 km2 in 1984 to 4.1 km2 in 1995, then to 33.4 km2 in 2005 and finally to 59.5 km2 representing an overall 9197% increase. Agricultural land also showed the same trend from1.04 km2 in 1984, 6.2km2in 1995 to 11.6 km2 in 2017, but with a drop in 2005 (3.7km2) representing an overall increase of 1019% (Table 5&Figure 4). This can be attributed to the rapid increase and demand for land for settlement, agricultural and commercial activities. The natural land cover comprised of grasslands, shrub land and mixed forests decreased from a combined coverage of 97.8% in 1984 to 94.1% from 1984 to 2017 representing a decrease of about 45%.However, grasslands showed the mostoverall increaseof 233.6 km2 while shrub land showed the most decrease of 279.7 km2 representing 23% and 46.1% respectively (Figure 3). This can be attributed to the fact that built up areasretained a coverage of grass compared to shrubs and mixed forests. Bare land showed a marginal overall decrease from 35.8 km2 in 1984 to 32.6 km2in 2017 representing 8.9% decrease. Grasslands, shrubs and mixed forests dominate the land cover and are mainly used for wildlife and livestock grazing. Built-up land category comprising of urban and rural settlements is spread in all parts of the area, but most of the growth of built-up land is along the main road networks such as Kitengela, Kisaju and Isinya along the Nairobi-Namanga Road, Kyumbi and Malili along the Nairobi-Mombasa Road as well as Ololooitikoshi along the Isinya-Kiserian Road. Agricultural land is mostly concentrated in the north-eastern parts on the slopes ofMua Hills, south eastern parts around Malili and parts of the north-western sections around Olooloitikoshi. Bare grounds comprised of either rock or soil are mostly concentrated along the dry drainage channels where rock is exposed in high gradient areas and where sand has accumulated in low gradient areas.

Table 4: LULC Area in Stony Athi Sub-catchment - 1984 to 2017

	1984		***1995***		***2005***		***2017***	
LULC	***Area (km^2)***	***%***	***Area (km^2)***	***%***	***Area (km^2)***	***%***	***Area (km^2)***	***%***
Built-up area	0.64	0.04	4.1	0.2	33.4	2.0	59.5	3.4
Agricultural land	1.04	0.06	6.2	0.4	3.7	0.2	11.6	0.7
Grassland	1016.4	58.2	910.0	52.1	1175.5	67.4	1250.0	71.6
Shrub land	647.7	37.1	765.7	44.0	486.2	28.0	368.0	21.1
Mixed forest	44.0	2.5	57.5	3.3	34.0	2.0	23.7	1.4
Bare land	35.8	2.1	2.08	0.1	12.6	0.7	32.6	2.0
Total	**1,745**	**100**	**1,745**	**100**	**1,745**	**100**	**1,745**	**100**

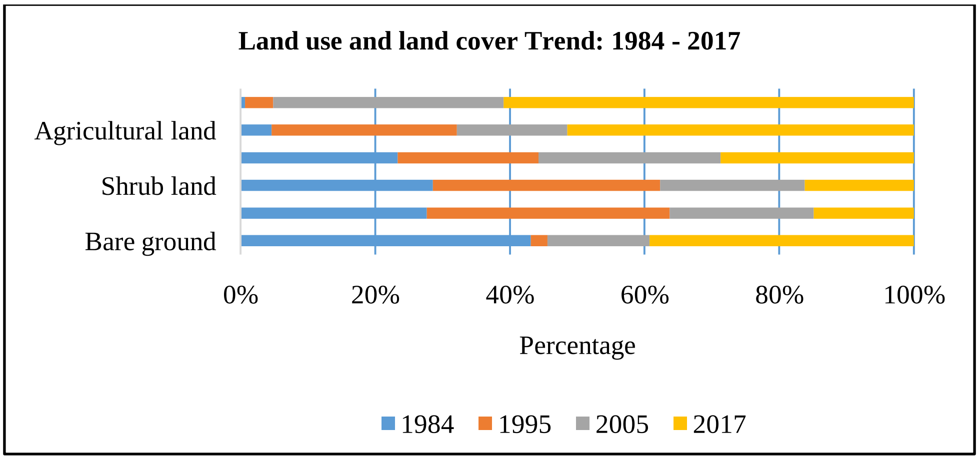

Figure 3: Land use and land cover trends: 1984 – 2017. An increase in built up area and agricultural land, but a decrease in shrub land and mixed forest over the 33 year period is evident.

Table 5: LULC Changes in Stony Athi sub-catchment - 1984 to 2017

1984-1995	*1995-2005*		*2005-2017*				*1984-2017*	
LULC	***Area (km^2)***	***%***	***Area (km^2)***	***%***	***Area (km^2)***	***%***	***Area (km^2)***	***%***
Built-up area	3.46	540.6	29.3	714.6	26.1	78	59.0	9197
Agricultural land	5.16	496.2	-2.5	-40.3	7.9	213.5	10.6	1019
Grassland	-106.4	-10.5	265.5	29.2	74.5	6.3	233.6	23.0
Shrub land	118	18.2	-279.5	-36.5	-118.2	-24.3	-279.7	-43.2
Mixed forest	13.5	30.5	-23.5	-41.0	-10.3	-30.3	-20.3	-46.1
Bare land	-33.7	-94.1	10.5	504.8	20	158.7	-3.2	-8.9

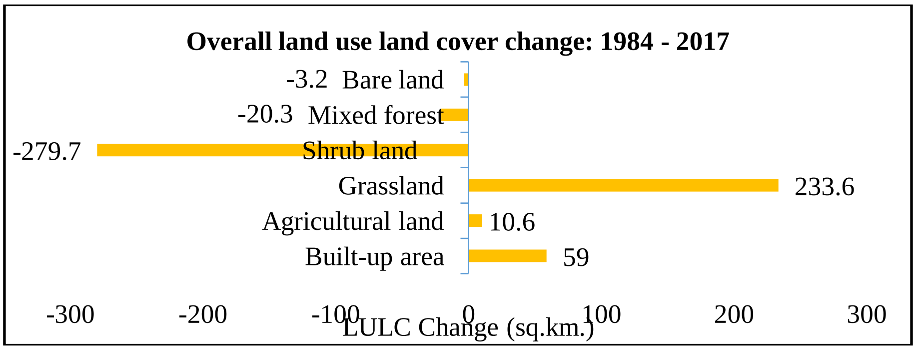

Figure 4: Overall land use land cover change: 1984 – 2017. Overall, built up area, agricultural land and grassland expanded at the expense of shrub land, mixed forest and bare land

The resultsalso revealed various shifts in land use and land cover within the sub-catchment.Losses and gains of the different land use and land cover categories were evaluated from 1984 to 1995, 1995 to 2015 and 2015 to 2017 and presented in form of matrices(Table 6).Overall, built up area, agricultural land and grassland expanded at the expense of shrub land, mixed forest and bare land between 1984 and 2017.From 1984 to 1995, 46.2%, 10.8%, 74.2%, 77.7%, 49.7% and 4.6% of built up area, agricultural land, grassland, shrub land, mixed forest and bare lands, respectively remained under the same LULC categories. However, there were also conversions from one category to another within the same period. There were significant conversions from agricultural land to shrub land (73.8%) and to mixed forest (13.9%). 17.2%, 34.2%, 28.7% and 15.1% of what was bare land in 1984 was converted to agricultural land, grassland, shrub land and mixed forest by the year 1995, respectively, while 29.8%, 12.8% and 10.4% of what was built up area was converted to grasslands, shrub land, and mixed forest, respectively. 23.3% of grass land, 39.0% of mixed forest was converted to shrub land while 20.1% of shrub lands was converted to grassland, respectively.

The second comparison made from 1995 to 2005 indicated that 57.8%, 2.9%, 89.5%, 51.2%, 31.5% and 57.3% of built up area, agricultural land, grassland, shrub land, mixed forest and bare lands, respectively, remained under the same categories. However, 34.9%, 9.42% and 26.4% of agricultural land, mixed forest and bare land was converted to built-up area while 33.0% and 7.2 % of built up area was converted to grassland and shrub land, respectively. 14.8%, 29.3% and 15.5% of agricultural land was converted to grassland, shrub land and mixed forest, respectively. Significant conversion to grassland also emanated from shrub land (45.8%), mixed forest (26.8%) and bare land (11.6%). The table also shows that 7.9% and 30.3% of shrub land in 2005 resulted from to grass land and mixed forest.

Finally, comparison made from to 2005 to 2017 showed that 40.7%, 7.3%, 82.5%, 44.2%, 21.6% and 79.3% of built up area, agricultural land, grassland, shrub land, mixed forest and bare lands, respectively, remained under the same categories. 5.8%, and 11.5% of agricultural land and mixed forest was converted to built-up area while 38.5 % and 17.2% of built up area was converted to grassland and bare land, respectively. There was a strong conversional relationship from agricultural land (62.8%), shrub land (50.1%), mixed forest (56.6%) and bare land (16.0%) to grassland. Overall, built up area, agricultural land and grassland expanded at the expense of shrub land, mixed forest and bare land between 1984 and 2017.

Table 6: Change detection matrices of 1984 to 1995, 1995 to 2005, and 2015 to 2017

	1995	Built-up area	Agricultural land	Grassland	Shrub land	Forest	Bare land
	LULC Class	**% Area**	**% Area**	**% Area**	**% Area**	**% Area**	**% Area**
1984	Built-up area	46.16	0.75	29.76	12.80	10.38	0.14
	Agricultural land	0.13	10.84	1.27	73.84	13.92	0.00
	Grass land	0.19	0.62	74.23	23.30	1.65	0.02
	Shrub land	0.21	0.16	20.08	77.70	1.85	0.00
	Mixed forest	0.27	6.10	4.91	38.92	49.71	0.09
	Bare ground	0.23	17.19	34.20	28.70	15.05	4.63
	TOTAL	**47.19**	**35.66**	**164.44**	**255.27**	**92.55**	**4.88**
	2005	Built-up area	Agricultural land	Grass land	Shrub land	Forest	Bare land
	LULC Class	**% Area**	**% Area**	**% Area**	**% Area**	**% Area**	**% Area**
1995	Built-up area	57.84	0.12	33.04	7.24	1.47	0.29
	Agricultural land	34.92	2.85	14.79	29.28	15.50	2.66
	Grass land	1.30	0.08	89.47	7.90	0.33	0.91
	Shrub land	1.05	0.22	45.82	51.17	1.41	0.33
	Mixed forest	9.42	1.44	26.75	30.31	31.51	0.57
	Bare ground	26.39	0.21	11.64	2.37	2.10	57.29
	TOTAL	**130.93**	**4.92**	**221.51**	**128.27**	**52.32**	**62.05**
	2017	Built-up area	Agricultural land	Grass land	Shrub land	Forest	Bare land
	LULC Class	**% Area**	**% Area**	**% Area**	**% Area**	**% Area**	**% Area**
2005	Built-up area	40.65	0.58	38.51	1.20	1.85	17.23
	Agricultural land	5.78	7.33	62.76	14.36	8.93	0.84
	Grass land	2.75	0.39	82.51	12.80	0.54	1.02
	Shrub land	1.80	1.10	50.13	44.24	1.87	0.85
	Mixed forest	11.54	3.63	56.60	4.58	21.61	2.05
	Bare ground	4.50	0.05	15.98	0.02	0.11	79.33
	TOTAL	**67.01**	**13.08**	**306.49**	**77.20**	**34.91**	**101.32**

The non-parametric chi-square goodness of fit test was used to determine whether the observed land use and land cover changes were significant. Significant changes ($p<0.05$) were observed for all land useand land cover changes (Table 7).Built up areas, grasslands, shrub land and bare land showed significant changes of $p<0.01$. Only Agricultural land indicated a change of $p>0.01$.

Table 7: Chi-Squaregoodness of fit for LULC in the sub-catchment- 1984 to 2017

LULC	***1984*** ***Area (km^2)***	***1995*** ***Area (km^2)***	***2005*** ***Area (km^2)***	***2017*** ***Area (km^2)***	***X^2***	***df***	***p***
Built-up area	0.64	4.1	33.4	59.5	93.8	3	<0.00001
Agricultural land	1.04	6.2	3.7	11.6	10.8	3	0.0128
Grassland	1016.4	910.0	1175.5	1250.0	65.0	3	<0.00001
Shrub land	647.7	765.7	486.2	368.0	162.5	3	<0.00001
Mixed forest	44.0	57.5	34.0	23.7	15.7	3	0.0013
Bare land	35.8	2.08	12.6	32.6	37.6	3	<0.00001

IV. Conclusion and Recommendations

The Stony Athi sub-catchment is one of the arid and semi-arid area in Kenya that's is developing to a peri-urban area. However,the natural land cover of grasslands, shrubs and mixed forests isstill dominant with livestock grazing as the major land use over the past three decades. Based on this study, there are indications that there are significant land use and land coverchanges during over the period, 1984 to 2017.Chi-square goodness of fit, with significant changes accepted at $p<0.05$,indicated that significant portions of the natural land coverhave experienced a declining trend in recent years with an increase in agricultural land and built-up land used for farming, settlement and commercial activities.Changes were observed in all the land use and land cover classes with an increase in built-up areas (0.04% in 1984 - 3.4% in 2017), agricultural land (0.06% in 1984 - 0.7% in 2017), grasslands (58.2% in 1984 - 71.6% in 2017), but a decrease in shrub land (37.1% in 1984 - 21.1% in 2017), mixed forest (2.5% in 1984 - 1.4% in 2017). Marginal changes were detected in bare grounds

(2.1% in 1984 - 2.0% in 2017). These changes can be attributed to anthropogenic activities with urbanization and immigration being the main drivers of land use and land cover changes within the sub-catchment. There is competition between the natural land cover, agriculture and built-up areas over space, whichhas the potential to affect the sustainability of the ecosystem if proper management of land is not taken into account. Results from this study indicate and recommend the necessity to understand the trends of land use and land cover changes in order to develop competent policy decisions on land use planning and management of natural resources for sustainability.

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