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Original Research Article

Spatio-Temporal Dynamics in Urban Land Use/Land Cover Change in Urbanizing Sub-Catchments In The Upper Ewaso Ng'iro North River Basin, Kenya

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Abstract: Massive expansion of urban areas leads to land use/land cover (LULC) changes which significantly alter the hydrology of river basins. Yet, systematic and logical information on the spatio-temporal dynamics of urban LULC changes of African river basins, Kenya inclusive is scanty. This study established the spatio-temporal dynamics in urban LULC change in Nanyuki and Likii sub-catchments in the Upper Ewaso Ng'iro North River Basin from 1985-2018. This was achieved mainly using Landsat satellite images for 1985, 1995, 2008 and 2018, topographic, Open Street and urban plan maps. A pixel based supervised classification using Maximum Likelihood Algorithm and post-classification comparisons were used in the analysis. The study established eleven LULC types, seven of which were urban and four non-urban. In 1985, urban LULC types occupied a relatively small portion of 869Ha (3.4%) but continuously expanded in all directions. Residential LULC registered the highest overall change of 2176.2Ha (8.5%). Overall annual rate of urban LULC change was established at 0.42% with period 1995-2008 having the highest annual rate of 0.98%. These findings can be incorporated in urban spatial planning and in the assessment of the effect of the continuous urban land expansion on the river basin hydrology.

Keywords: Urban Land use/land cover, Spatio-temporal, Urban land expansion, River basin, Hydrology, Satellite, Image, Classification.

1. INTRODUCTION

The last four decades have witnessed a rapid increase in the world urban population. It is projected that 66% of the world population will be urban by the year 2050 (United Nations [UN] [1]. Increased urban population has resulted to unprecedented urban land expansion leading to Land Use/Land Cover (LULC) change [2]. Expansion of urban areas introduces multiple pressures on the hydrology of river basins, with small stream basins baring the greatest effect [3]. This is by particularly changing the landscape, modifying vegetation and soil characteristics, disconnecting natural ecosystems and introducing impervious surfaces (ISs) [4]. This subsequently leads to problems like floods, land and water quality degradation, which negatively affect the quality of human and aquatic life in that river basin [5]. Thus, in order to enhance land and water resources planning in our urban river basin, minimize the negative impacts of urban land expansion on river basin hydrology and subsequently enhance the quality of human and aquatic life therein, systematic and logical information on urban LULC change is necessary.

The urban growth patterns and subsequent changes in LULC differ from one region to another and from time to time due to differences cultural, socioeconomic, historical and environmental, and this similarly applies to the different forms in which urban areas expand [6]. As a result, different approaches and perspectives have been used in assessing the spatio-temporal dynamics in urban LULC changes [7]. But, the use of Remote Sensing (RS) and Geographical Information System (GIS) technologies has gained popularity over the years [8]. This is particularly after the launch of the Earth Resource Technology Satellite (Landsat series) by National Aeronautics and Space Administration (NASA) in 1972 [7]. RS technology provides satellites images which are used in characterizing historical and present LULC attributes and in scenarios analysis. GIS technology on the other hand provides a means to effectively and efficiently store and manipulate data acquired from remotely sensed images and other sources [9]. It has been argued that the Landsat data series is the best in the context of urbanization. This is because the start of the Landsat dataset series, that is, 1972 corresponds with the rapid urban areas expansion especially in Africa and Asia

[10, 7]. Besides, many LULC classification systems have been publicized and provide a way for defining LULC categories from remotely sensed imageries. Examples include Anderson's classification System and the Food and Agricultural Organization Land Cover Classification System (FAO/LCCS) [11]. Some of these classification systems have universal application, but none has been accepted as an international standard [11]. However, the classification system used in a study should meet the classification purpose [12].

Africa is among the continents that experienced the highest rate of urban land expansion in the last four decades [13]. In 2019, Lincoln Institute of Land Policy reported that between 1990 and 2015, the area occupied by cities in less developed countries increased by a factor of 3.5. Nevertheless, the Food and Agriculture Organisation (FAO) produced a general LULC map for Africa through its Africover mapping project [14]. Murayama et al. [7] in addition, established the changes in LULC for major African cities namely Nairobi, Kenya and Bamako, Mali, providing valuable insights into the urban LULC situation in the continent. Other region specific studies include Sahalu [15] in Bahir Dar city, Ethiopia between 1986 and 2010 and Gumindoga et al**.** [16] in Marimba and Mukuvisi catchments in Harare, Zimbabwe between 1986 and 2008. All these studies provided valuable insight into the LULC changes in the African continent. However, the FAO focus was on producing a general LULC map of the continent and not the urban areas. Equally, Murayama et al**.** [7] focused on only two cities in Africa representing a snapshot of urban LULC in Africa. Besides, the study did not establish the rate of urban LULC change for the respective cities. Also, Sahalu [15] and Gumindoga et al**.** [16] lumped various urban LULC classes together which did not allow for a detailed analysis of the different urban LULC types changes. Notwithstanding all the studies revealed different patterns of urban area change indicating that each region was different and therefore likely to experience different change patterns and impact.

In the last few decades, urban centers in the Upper Ewaso Ng'iro North River Basin (UENNRB) have experienced rapid increase in population attributed to natural growth and immigration (Laikipia County Government [LCG], [17]. This has resulted to tremendous expansion in urban land areas converting previous crop, forest and wetlands to settlements [18]. Mungai et al. [19] concluded that land use change and the resultant change in landscape mosaics markedly influenced water flow on the landscape and the geomorphic processes in the basin. Yet, little has been done to establish the spatio-temporal dynamics in urban LULC change in the basin, the information of which may guide urban spatial planning and land and water resources management. The aim of this study therefore was to accurately detail the spatio-temporal dynamics in urban LULC change between 1985 and 2018 in the UENNRB.

2. MATERIALS AND METHODS

2.1 Study area

This study presents urban LULC change in two urbanizing sub-catchments namely; Nanyuki and Likii in the UENNRB, Kenya. The UENNRB constitutes the upper stream section of the Ewaso Ng'iro River Basin which is the largest of the five major river basins that make up the Kenyan drainage network. The basin falls within latitudes 0^0 20' South and 1^0 01' North and longitudes 36^0 10' East and 38^0 00' East and covers approximately 15,251 km^2. The basin is further divided into 3 main sub-basins namely the Ewaso Narok, Ewaso Ng'iro -Mt. Kenya and Ewaso Ng'iro lowland. Nanyuki and Likii sub-catchments are found within Ewaso Ng'iro-Mt. Kenya sub-basin and are drained by Nanyuki and Likii rivers respectively (See Figure 1), which originates from Mount Kenya and flows northwards to joins at the lower end [20]. The two cover approximately 289.7km^2 [21, Nanyuki Water Resource Users Association [NWRUA], [22] with an estimated population of 70,181(Kenya National Bureau of Statistics [KNBS] [23]. Nanyuki Municipality is the main urban centre in the sub-catchments whereby Nanyuki town extends into Likii sub-catchment at the lower end to join the Likii village which is majorly dominated by informal settlements [24]. Settlement patterns in the sub-catchments are influenced by land potential, livelihood zones, infrastructure development, land use system and availability of amenities. Nanyuki municipality is a pocket of high population density and is well served with amenities including good roads, communication network, air strips and commercial and administrative facilities. This coupled with a conducive climate; continue attracting new migrants in the area [22]. The major socio-economic activities in the sub-catchment include large scale and small scale farming, commercial and industrial activities, private large-scale ranches, subsistence irrigation and habitants for wild animals [25].

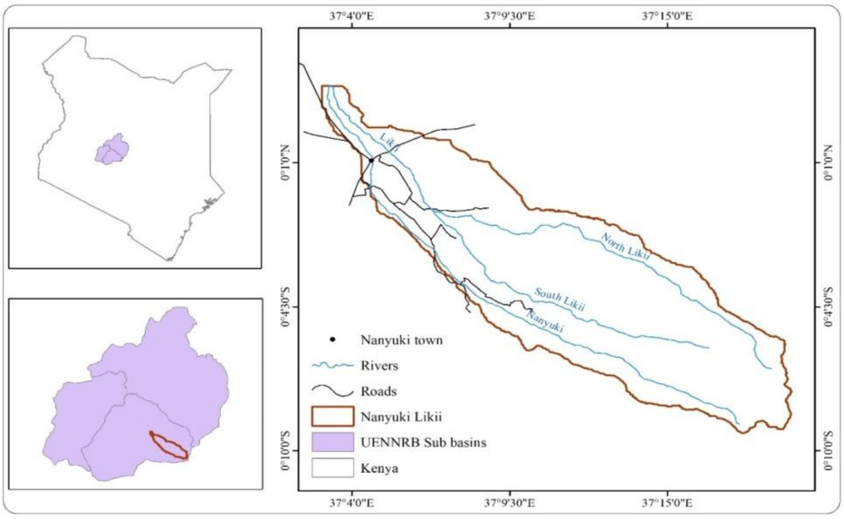


Fig-1: A map showing the Nanyuki and Likii Sub-catchments

2.2 Data sources

Multi-temporal high-resolution satellite remote sensing images shown in Table 1 were used as primary data for this study.

Table-1: Description of the satellite data product used

Satellites	Sensors	Path/Row	Acquisition Date
Landsat 5	TM	168/60	18/01/1985
Landsat 5	TM	168/60	14/01/1995
Landsat 5	TM	168/60	30/08/2008
Landsat 8	OLI & TIRS	168/60	10/9/2018

The images which had a 30m resolution included Landsat 5 Thematic Mapper (TM) for years 1985, 1995, 2008 and Landsat 8 Operational Land Imager (OLI) & Thermal Infrared Sensor (TIRS) for year 2018. They were used in urban LULC classification and change detection. United States Geological Survey [USGS] (n.d.)[38] noted that the sensors aboard the satellite images obtain data in diverse series of frequencies along the electromagnetic spectrum. This is as shown in Table 2 which gives detailed band designations characteristics of Landsat TM and OLI & TIRS.

Table-2: Landsat TM and OLI &TIRS band designations characteristics

Sensor System	Band	Wavelength (micrometers)	Spatial Resolution (meters)
Landsat 5 TM	1	0.45-0.52	30
	2	0.52-0.60	30
	3	0.63-0.69	30
	4	0.76-0.90	30
	5	1.55-1.75	30
	6 TIR	10.40-12.50	120 (30)
	7	2.08-2.35	30
Landsat 8 OLI &TIRS	1	0.43-0.45	30
	2	0.45-0.51	30
	3	0.53-0.59	30
	4	0.64-0.67	30
	5 NIR	0.85-0.88	30
	Pan	0.50-0.68	15
	6 SWIR 1	1.57-1.65	30
	7 SWIR 2	2.11-2.29	30
	10 TIR 1	10.60-11.19	100
	11 TIR 2	11.50-12.51	100
Key	TIR	Thermal Infrared	
	NIR	Near Infrared	
	Pan	Panchromatic	
	SWIR	Short wave Infrared	
(Source: USGS, n.d.)			

In addition, 1: 50,000 topographic maps and urban plans were obtained from Survey of Kenya and LCG urban planning department respectively. These provided information on urban LULC and road network in the sub-catchments. Open Street Maps (OSM) and Google Earth images sourced from the internet were further used in identifying urban LULC and navigating through the sub-catchments. Similarly, surveys using Global Positioning System (GPS) receivers were used to collect ground control points which were used in urban LULC types training and classification accuracy assessment. Moreover, corroborating data was collected using Key Informant (KI) interviews and Focus Group Discussions (FGD) from the residents.

2.3 METHODOLOGY

The methodology used in the study is summarized in the flow chart diagram shown in Figure 2.

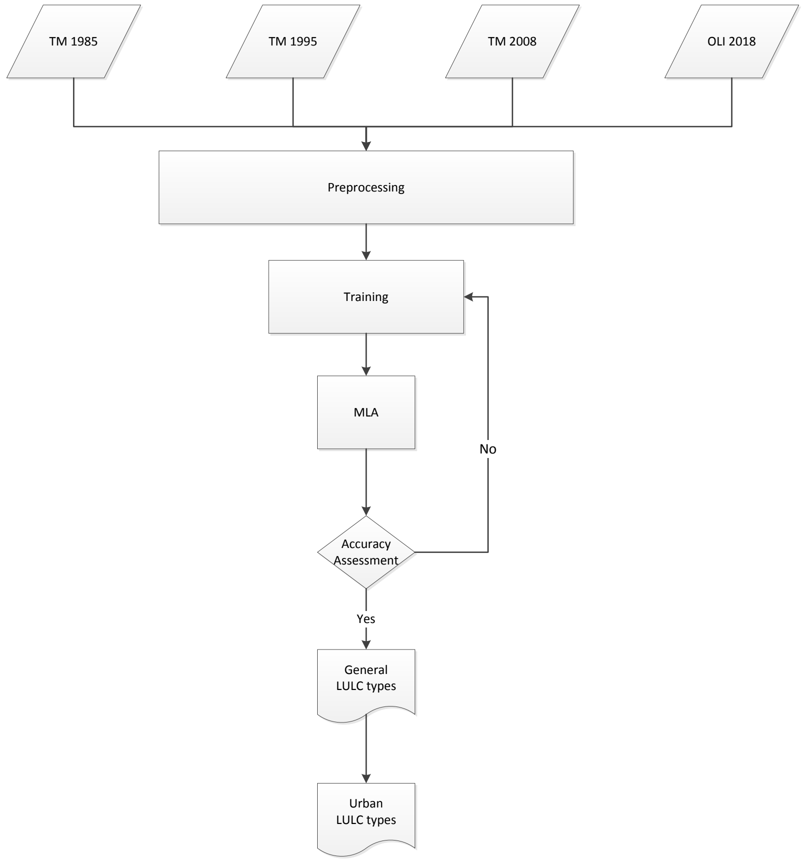


Fig-2: A summary of the study methodology

As shown in figure 2 above, the following steps were involved;

2.3.1 Satellite image pre-processing

Cloud free Landsat imageries downloaded from the USGS website were subjected to atmospheric correction using Dark Object Subtraction 1 (DOS1) method to enable the images to be comparable for change detection. Images were then projected to WGS 84 UTM 37 N. The images were clipped by Nanyuki and Likii sub-catchment shapefile as the Region of Interest (ROI). The individual bands were stacked and displayed as standard false colour (4-3-2 for TM and for 5-4-3 for OLI) composite which is good for urban and vegetation studies [26]. Cumulative stretch was used to enhance the images for easy interpretation.

2.3.2 Satellite image classification

Satellite image classification involved training, choosing the classification algorithm, running the classification and accuracy assessment. The FAO/LCCS as defined by Di Gregorio [12] was used in defining LULC classes. As shown in Table 3 below, the FAO/LCCS is based on a dichotomous approach which divides land cover in a given area into sub categories in hierarchical levels. The first three levels have eight classifiers that distinctively groups any land cover types on the Earth's surface primarily based on presence or absence of vegetation. This is followed by level four classification which is a modular-hierarchical phases that uses additional classifiers strictly within the eight classes in level three to obtain a more detailed finer LULC classes.

Table-3: First three dichotomous levels defining land cover classes in the FAO/LCCS

First Level	Second level	Third level
A. Primarily vegetated areas	A1. Terrestrial areas	A11. Cultivated and managed terrestrial areas
		A12. Natural and semi-natural vegetation
	A2. Aquatic or regularly flooded areas	A23. Cultivated aquatic or regularly flooded areas
		A24. Natural and semi-natural aquatic or regularly flooded areas
B. Primarily non-vegetated areas	B1. Terrestrial areas	B15. Artificial Surfaces and Associated areas
		B16. Bare Areas
	B2. Aquatic or regularly flooded areas	B27. Artificial water bodies, snow and ice
		B28. Natural water bodies, snow and ice
(Source: Di Gregorio, 2005)		

In this study, the study area's LULC was classified into primarily vegetated and primarily non-vegetated areas in the first level of the classification. Level one classes were reclassified in level two and only three classes were established namely; A1 Terrestrial, B1 terrestrial and B2 Aquatic or regularly flooded. Reclassification was further done in level three whereby four classes out of the eight were established, that is, A11 Cultivated and managed terrestrial and A12 Natural and semi-natural vegetation, and B15 Artificial Surfaces and Associated areas and B16 Bare Areas. Since the main focus of this study was urban LULC, B2 Aquatic or regularly flooded was not further reclassified and remained as non-vegetated water body. In addition, B15 Artificial Surfaces and Associated areas was further reclassified into urban LULC classes in level four of the classification while the rest remained as classified in level three. Legend for urban LULC classes were guided by definitions in Di Gregorio [12], Appendix A (pp. 127-129) and Nanyuki Municipality urban plan map to fit the local situation.

Training was carried out using ground truth information obtained using GPS surveys, 1: 50,000 scale topographic maps, Google Earth and open street maps. Furthermore, a pixel based supervised classification using Maximum Likelihood Algorithm (MLA) was used. The training data was converted into shapefiles which were overlain with each standard false colour composite maps i.e. for 1985, 1995, 2008 and 2018, then the LULC classes were digitalised on the computer screen and spectral signatures of the LULC types computed. Subsequently, additional data collected for ground truthing in form of GPS reference data points, topographic maps and OSM was input in Semi-Automatic Classification Plugin in QGIS under post processing procedures and used in accuracy assessment. The resultant error matrix was used to derive Kappa statistics used in evaluation of the classification accuracy. The output maps were then reclassified whereby all non-urban types were put into one class in order to obtain a clear picture of the urban LULC types dynamics.

2.4 Change detection

Post-classification comparison change detection method was used whereby output maps were subjected to area calculation to determine area under each LULC type. This was then used to compute area changes between study years.

3. RESULTS AND DISCUSSION

3.1 Accuracy assessment

Accuracy assessment results were summarized in error matrices and kappa statistics as presented in Table 4.

Table-4: Summary of Error matrices and Kappa statistics

Statistics	1985	1995	2008	2018
Overall Accuracy	94.10%	94.90%	79.60%	86.70%
Kappa Coefficient	0.9	0.9	0.7	0.8

Result in table 4 shows that classification of all satellite images attained an overall accuracy and kappa coefficient of above 79.6% and 0.7 respectively. This implies that all images classification outputs had 70% and above better agreement in classification than by chance. Kappa values of more than 0.80 are indicators of good classification; those between 0.40 and 0.80 indicate moderate performance and those below 0.40, poor classification performance [12; Lillesand et al., [27], as cited in Abubaker et al., [28]. Thus, the images in this study attained a classification performance between 0.7 and 0.9 which fit further image use.

3.2 Spatio-temporal dynamics in urban LULC changes

The aspects considered in this study were urban LULC types, area changes and rate of change which were established mainly through classification of satellite images.

3.2.1 Urban Land use/Land cover types

Classification results for urban LULC types in Nanyuki and Likii Sub-Catchment are shown in Figure 3 A, B, C and D, Figure 4 A, B, C and D and LULC statistics in Table 5.

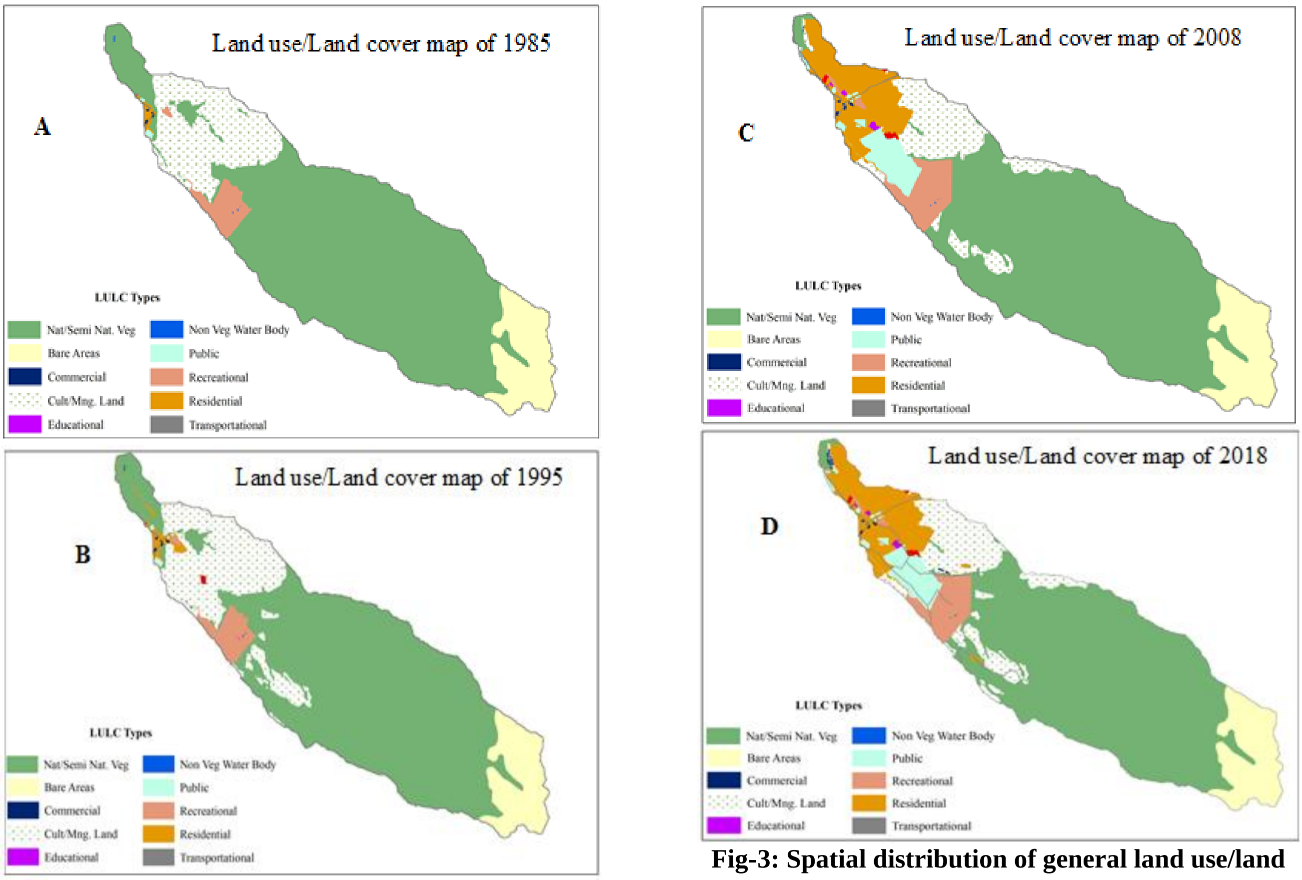


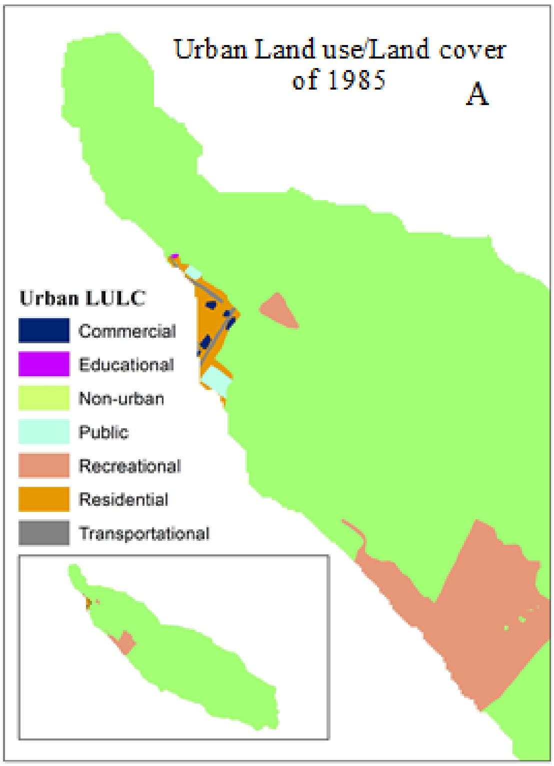
Fig-3: Spatial distribution of general land use/land covers types

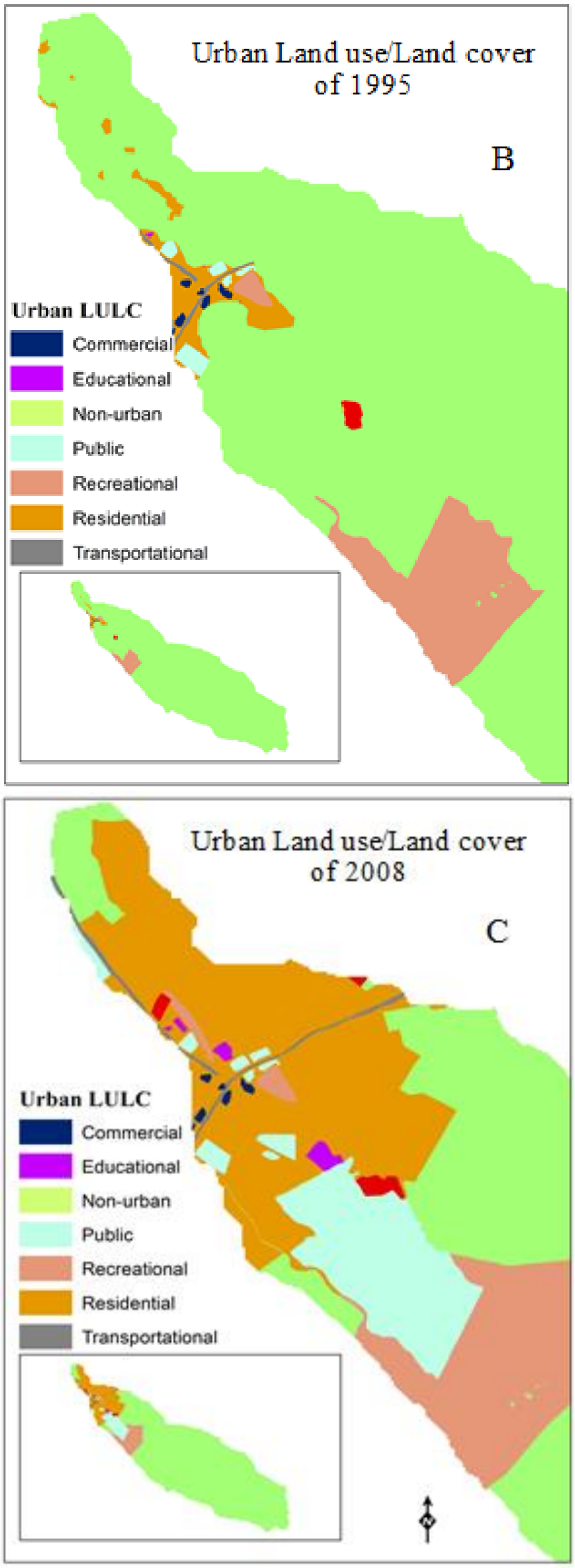
Key:

Nat/Semi Nat. Veg - Natural and Semi-natural vegetation

Cult/Mng. Land - Cultivated/Managed land areas

Non Veg water body- Non-vegetated water body




Urban Land use/Land cover of 1995
B
Urban LULC
Commercial
Educational
Non-urban
Public
Recreational
Residential
Transportational
Urban Land use/Land cover of 2008
C
Urban LULC
Commercial
Educational
Non-urban
Public
Recreational
Residential
Transportational

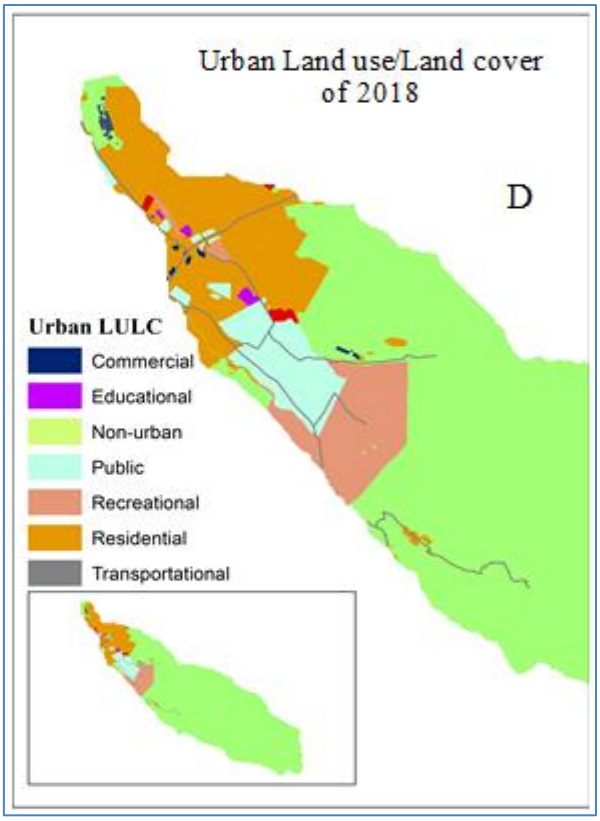


Fig-4: Spatial distribution of urban land use/land cover types

Table-5: General and urban land use/land cover statistics

	1985		**1995**		**2008**		**2018**	
LULC Type	Area (Ha)	Cover (%)	Area (Ha)	Cover (%)	Area (Ha)	Cover (%)	Area (Ha)	Cover (%)
Non-urban Land use/Land cover Types								
Cult/Mng. Land	4006.1	15.6	4613.5	17.9	2643.3	10.3	2931.7	11.4
Bare Areas	2411.6	9.4	2411.6	9.4	2411.8	9.4	2411.6	9.4
Nat/Semi Nat. Veg	18461.8	71.7	17677.1	68.6	16368.6	63.6	15946.6	61.8
Non Veg Water Body	5.3	0	5.3	0	5.3	0	5.3	0
Sub-total	**24884.8**	**96.6**	**24707.6**	**95.9**	**21430.9**	**83.2**	**21295.2**	**82.6**
Urban Land use/Landcover Types								
Commercial	10.9	0	16.2	0.1	16.4	0.1	43.5	0.2
Educational	1	0	1.1	0	35.6	0.1	35.3	0.1
Industrial	0	0	18.5	0.1	42.8	0.2	42.2	0.2
Public land	27	0.1	46.5	0.2	874.2	3.4	823.9	3.2
Recreational	727.1	2.8	727.3	2.8	1069.9	4.2	1052.5	4.1
Residential	87.4	0.3	215.4	0.8	2225.7	8.6	2263.6	8.8
Transportation	15.6	0.1	21.1	0.1	60.1	0.2	197.6	0.8
Sub-total	**869**	**3.4**	**1046.2**	**4.1**	**4322.9**	**16.8**	**4458.6**	**17.4**
GRAND -TOTAL	25753.8	100	25753.8	100	25753.8	100	25753.8	100

Figure 3 A, B, C and D revealed eleven LULC types in the sub-catchments. Four of them, including Nat/Semi Nat. Veg, Cult/Mng. Land, Bare Areas and Non Veg Water Body were categorized as non-urban and seven, including Commercial, Educational, Industrial, Public land, recreational, residential and transportational, as urban. Generally, Nat/Semi Nat. Veg mainly occupied the central part of the sub-catchments towards south-east and was the dominant LULC type throughout the study years. Nevertheless, its area coverage was on a shrinking trend at 18461.8Ha (71.7%) in 1985 and 15946.6Ha (61.8%) in 2018. Cult/Mng. Land was second dominant throughout the study years and mostly occupied the north-west part of the sub-catchments. Similarly, it had a shrinking trend occupying an area of 4006.1Ha (15.6%) in 1985 and 2931.7Ha (11.4%) in 2018. Bare Areas occupied the south-east end of the sub-catchments and was third position in terms of overall dominance covering an area of 2411.6Ha (9.4%) in 1985. Non Veg Water Body occupied the least space of 5.3 Ha (0%) in the non-urban category, and together with Bare Areas, remained relatively the same for the rest of the study years. Other LULC types were mainly urban and as shown in Figure 4 A, B, C and D and Table 5 above, occupied a relatively smaller portion mainly in the north-west part

of the sub-catchments. In particular, recreational and residential were the dominant urban LULC types in 1985 and 1995 occupying 727.1Ha (2.8%) and 87.4Ha (0.3%) for 1985 and 727.3Ha (2.8%) and 215.4Ha (0.8%) for 1995 respectively. There was however a change in dominance in 2008 and 2018 whereby residential dominated with 2225.7Ha (8.6%) and 2263.6Ha (8.8%) in that order. Yet again, recreational and public land were second and third in dominance with 1069.9Ha (4.2%) and 874.4Ha (3.4%) for 2008 and 1052.5Ha (4.1%) and 823.9Ha (3.2%) for 2018 respectively. These results imply that in the years 1985 and 1995, the sub-catchments were majorly in their natural state given that the dominant LULC type was natural and semi-natural vegetation, indicating that there was little pressure especially on the hydrology of the sub-catchments. It can also be deduced that human population in the years was mainly low and rural given that cultivated and managed terrestrial areas came second while the rest of the LULC types, and which were mainly urban, occupied relatively very small areas and since bare areas occupied the peak of Mt. Kenya.

Despite the fact that natural and semi-natural vegetation and cultivated and managed terrestrial areas remained the dominant LULC types in 2008 and 2018, the sub-catchments cannot be said to have remained under relatively natural state. This is especially due to the observed differences in spatial distribution patterns of the various LULC types. As revealed in Figure 3 A and B, there were slight variations in spatial distribution of the various LULC types in 1995 as compared to 1985. Majorly, residential LULC type extended towards the east and north-east direction occupying the land that was previously under cultivated and managed land and natural and semi-natural vegetation respectively. In addition, cultivated and managed land extended towards south-east occupying the land that was previously under natural and semi-natural vegetation. Through FGDs and KI, it was established that between 1984 and 1989, and 1992 and 1993, people were evicted from Mt. Kenya forest and settled in the lower part of the sub-catchments. The eviction could have facilitated clearing of natural vegetation for cultivation and this probably explains the extension of cultivated and managed land. Also, there was entry of industrial LULC type which was not there in the previous study year. The slight extension of the residential and cultivated/managed land LULC types, and the entry of industrial types, could be an indicator of changing narrative towards urbanization. This could probably be due to increase in population both in rural and urban areas, increasing land demand for settlements and food production. This could also mean the beginning of alteration of the sub-catchments hydrology.

There were remarkable differences in spatial distribution of almost all LULC types in 2008 compared to 1995. As seen in Figure 3 B and C, natural and semi-natural vegetation and cultivated and managed terrestrial areas shrunk while many others LULC types expanded. Residential in particular extended from the east in all directions to occupy vast areas of the sub-catchments. Industrial also occupied more areas but in a scattered manner. Also, all other LULC types remarkably expanded. All these differences could be a manifestation of rapidly urbanization and in a spatially unplanned manner. This could probably be due to a rapid increase in population leading to more land demand. Between 1999 and 2009, Nanyuki municipality population increased rapidly at a rate of 4.3% [25]. Also, KI revealed that urban development trends that took place in Nanyuki municipality between 1997 and 2008 were unprecedented which led to its zone plan of 2000 being overtaken by events. Expansion of residential areas at the expense of cultivated and managed lands could also be interpreted to mean rural-urban migration creating urban sprawl and thus changing the landscape and putting more pressure on the hydrology of the sub-catchments. Moreover, Figure 3 D indicates that differences in LULC type's spatial distribution patterns were not as dramatic as the previous study year. Natural and semi-natural vegetation lost a chunk (422Ha) of its cover particularly to cultivated and managed land and residential. This could mean further increase in population both rural and urban that needed more food. In addition, policy allowing change of use of land by the County Government as revealed by KI and FGDs propelled the expansion of residential LULC to other areas that were previously non-residential. This is in addition to rampant land sub-divisions and selling of land to urban dwellers who over time desired to own homes in the expanding peri-urban areas and rural areas where cost of living was considered low. Cropping up of residential areas in other parts of the sub-catchments and expansion of commercial LULC could also be an indicator of upcoming satellite urban centres, which could further have been triggered by expansion in road network as further revealed by the study. The non-dramatic nature of other urban LULC types in year 2018 could also be an indicator of an infill type of urban development whereby vacant or passed-over parcels of land within the urban areas in 2008 were being developed.

Results in figure 4 A, B, C and D and Table 5 further revealed that urban LULC types occupied a relatively small portion, precisely a total of 869Ha (3.4%) in the north-west and towards south east of the sub-catchments. These spread further towards north-west, and slightly towards north-east and south-east occupying a total of 1046.2Ha (4.1%) in 1995. In 2008, urban LULC types spread in all direction from the urban core and covered 4322.9Ha (16.8). But in 2018, they extended slightly and to far flung areas especially in the south-east direction covering a total of 4458.6Ha (17.4%) of the sub-catchments. In addition, total non-urban LULC was 24884.8Ha (96.6%) in 1985, 24707.6Ha (95.9%) in 1995, 21430.9Ha (83.2%) in 2008 and 21295.2Ha (82.6%) in 2018. This could be interpreted to mean that in 1985, urban population was relatively low. It is further likely that in 1985, urban infrastructure was poorly developed given that the percentage coverage of all urban LULC types was relatively small. This was followed by slow urban growth with associated increase in urban population and infrastructure, consequently leading to urban land expansion in 1995. This was then followed by rapid urban growth as the infrastructure became more mature, possibly due to development of industries and expansion in business opportunities which could have attracted more people into urban areas hence the fast urban land expansion in 2008. More people in the urban area meant increased land demand for building residential houses as well as development of other urban infrastructure, all at the expense of non-urban LULC. As space in urban areas become more congested and road network expanded to rural areas, satellite urban centres started sprouting in fur flung areas and stated developing slowly as further depicted by results for year 2018. This implies continuous change in the sub-catchments landscape which might have significantly altered the hydrology.

Many efforts establishing LULC types and their spatial distribution patterns have been carried out around the world and at different spatial-temporal scales. For instance, in an effort to standardize world land cover data, FAO [29] revealed a breakdown of eleven global land cover layers which indicated that tree-covered areas occupied 27.7% of the globe, bare soils 15.2%, grasslands 13.0%, croplands 12.6%, snow and glaciers 9.7%, shrub-covered areas 9.5 %, sparse vegetation 7.7 %, inland water bodies 2.6%, herbaceous vegetation 1.3 %, artificial surfaces 0.6 %, and mangroves 0.1%. Chormański [30] classified LULC in Biala catchment in Bialystok city, Poland, chiefly into two classes namely; built-up areas and agricultural areas. The study established that built-up areas accounted for 20% of Biala catchment in 1977, 40% in 1992 and 46% in 2007, with the development practically taking place in all directions generally at the expense of agricultural areas. Other studies such as Arafat et al. [31] and Hu et al. [32] attained varying numbers of LULC types with varying spatial distribution patterns. Also, the studies that attained the same number of LULC types had varying legends. This could be explained by the scale of the study considered, the LULC classification system used and the level of classification attained. However, even those that used the same LULC classification system like Arafat et al. [31] and Perera et al. [33] did not attain the same number of LULC types or legends. This could further be explained by the uniqueness of every region and the focus of the study. This study produced 11 LULC types which agree with some of the studies here but with varying legend and spatial distribution patterns, which also is observed in most of the studies. According to Mutiga [20], the dominant LULC types in the UENNRB were forest, grassland, bare land and cropland which agree with findings in this study. But, this study went further ahead and classified the urban LULC types and established their spatio-temporal dynamics. But again, Satiprasad [34] reported a contrary trend whereby built up land remained the dominant LULC type for the time periods 1975, 1989, 2000 and 2009 in Howrah city located on the west bank of the Hooghly River. This could be explained by differences in the characteristics of areas under study whereby the study focus was in a city while this study is in a river catchment.

3.2.2 Urban land use/land cover change

In order to establish urban LULC change, data under urban category in Table 5 was subjected to further analysis in Excel whereby area changes in urban LULC types was computed and results presented in Table 6. Only total change in non-urban LULC types was considered in this analysis.

Table-6: Area changes for urban LULC types

	Change 1985-1995		**Change 1995-2008**		**Change 2008-2018**		**Overall change 1985-2018**	
Urban LULC types	Area (Ha)	Cover (%)	Area (Ha)	Cover (%)	Area (Ha)	Cover (%)	Area (Ha)	Cover (%)
Commercial	5.3	0.1	0.2	0	27.1	0.1	32.6	0.2
Educational	0.1	0	34.5	0.1	-0.3	0	34.3	0.1
Industrial	18.5	0.1	24.3	0.1	-0.6	0	42.2	0.2
Public land	19.5	0.1	827.7	3.2	-50.3	-0.2	796.9	3.1
Recreational	0.2	0	342.6	1.4	-17.4	-0.1	325.4	1.3
Residential	128	0.5	2010.3	7.8	37.9	0.2	2176.2	8.5
Transportational	5.5	0	39	0.1	137.5	0.6	182	0.7
Total	**177.1**	**0.8**	**3278.6**	**12.7**	**133.9**	**0.6**	**3589.6**	**14.1**

It is evident from the table 6 that both negative and positive area changes took place. Amongst the three time periods, residential dominated in positive changes of 128Ha (0.5%), 2010.3Ha (7.8%) and 37.9Ha (0.2%) for time periods 1985-1995, 1995-2008 and 2008-2018 respectively. In addition, period 1995-2008 registered the highest positive area changes for all urban LULC types. Moreover, all urban LULC types increased by different magnitudes for the entire study period of 1985-2018, with residential recording the highest overall area changes of 2176.2Ha (8.5%). This was followed by public land at 796.9Ha (3.1%) and recreational 325.4Ha (1.3%) at third position. Overall, urban LULC increased by a total of 3589.6Ha (14.1%)

which implies that the total non-urban LULC decreased by a similar magnitude. KI and FGDs further indicated that changes in the urban core, peri-urban and rural areas for period 1985-1995 were majorly as a result of population increases. While the major changes observed in 1995-2008 could be explained by a rapid increase in population, residents also revealed that the permanent establishment of British Army Training Unit, growth in sand harvesting, tourism and commercial activities, technological changes, cosmopolitan nature of Nanyuki town and a sense of security given that Nanyuki municipality is an army town, attracted more migrants into the sub-catchments which accelerated urban growth. All these factors probably explain the major changes observed between 1995 and 2008. Also, commercial increased by 27.1Ha (0.1%) during time period 2008-2018. This was the highest increase registered for this class. This could be attributed to mushrooming of small urban centres in the other parts of the sub-catchments which could further be attributed to increase in population and probably expansion in road network as seen from the study. In contrast, main negative changes were registered under public land and recreational at -50.3Ha (-0.2%) and -17.4Ha (-0.1%) respectively in the same time period. Again, this could probably be attributed to change in administration of public land with the coming of County Governments, or change of land use by the existing public institution to cater for increased new demands such as building commercial and residential houses and expansion of road network for better service provision.

Generally, this study revealed continuous positive change in total area under urban LULC types. This agrees with many other studies including Hu et al. [32], Murayama et al. [7] and Sahalu [15]. However, the area change characteristics vary from one study to another. This could be explained by the differences in the landscape characteristics of the areas of study, spatial and time temporal scales considered and LULC classification and mapping methodology used among other factors. Nonetheless, while many studies lumped urban LULC types as built up areas, this study established areas change patterns of the different urban LULC types.

3.2.3 Rate of change in urban land use/land cover

To establish the rate of change in urban LULC, total urban LULC in Table 5 was used, whereby, total value for the previous study year was subtracted from total value for the current year, and the output divided by the time interval between the two years. Results were then presented as shown in Figure 5.

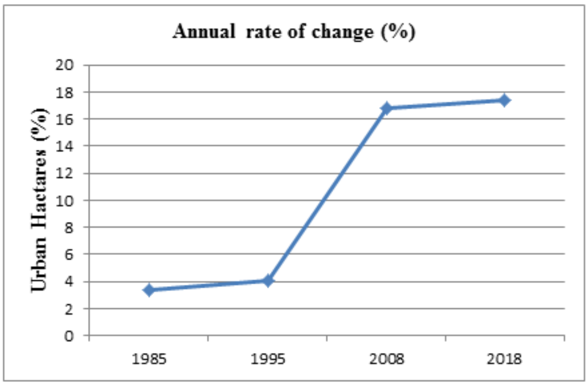


Fig-5: Rate of change in urban Land use/Land cover

Urban LULC occupied 3.4% of the sub-catchment in 1985. This subsequently increased to 4.1%, 16.8% and 17.4% in 1995, 2008 and 2018 respectively. This translates to an annual rate of urban LULC change of 0.07%, 0.98% and 0.06% for time periods 1985-1995, 1995-2008 and 2008-2018 in that order. Also, the entire study period of 1985-2018 had an annual change rate of 0.42% which further translates to a decadal rate of 4.2%. The results indicate a continuous expansion in urban LULC in the form of slow, rapid and then slow expansion which is an indicator of urbanization that has led to a continuous land demand. The population of Nanyuki town, which is the main urban area in this study, was 28,706 in 1989, 49,186 in 1999 and 68,552 in 2009, with period between 1999 and 2009 experiencing a rapid increase in population [17]. This could probably explain the rate of urban LULC change pattern observed. This is in addition to development in urban infrastructure as explained earlier. This notwithstanding, the post-election violence experienced in the country after the 2007 general elections might have accelerated the rate of urban LULC change between 1995 and 2008 due to land demand by new migrants. In addition, the upward trend shown indicates that the area currently under urban LULC will continue increasing in the coming years. Though the rate may not be very high, probably due to an infill type of urban development, the narrative may however change further in the future when the upcoming satellite urban centres peak.

Seto et al**.** [13] established considerable variation in the rates of urban expansion across the globe from 1970-2000. In addition, Mohapatra et al. [35] reported an average decadal growth rate of built-up land of 36.29% in the city of Gwalior in central India from1972-2013. In china, Wang & Lu [36] revealed that urban land growth was apparently accelerated after 2000, from 4.35% per year from 1990-2000 to 6.47% from 2000-2010, and 6.2% from 2010-2015. In Nakuru, Kenya, the urban extent increased at an average annual rate of 2.6% from 1989-2000 and 9.5% from 2000-2014 [37]. These studies show that urban land growth has generally been expansive rather than compact which agrees with findings from this study. However, the rates vary from one study to another which may be explained by differences in spatial-temporal scales of analysis and the socio-economic and political environments of the different regions.

4. CONCLUSIONS AND RECOMMENDATIONS

This study established eleven general LULC types. Four of the types namely; Natural and semi-natural vegetation, Cultivated and managed land, Bare areas and Non-vegetated water body were categorized as non-urban and the remaining seven, that is, Industrial, Recreational, Residential, Public land, Transportational, Commercial and Educational categorized as urban. Both categories demonstrated varying spatial-temporal distribution patterns in terms of area coverage and extension in various directions. Nevertheless, Natural and semi-natural vegetation and Cultivated and managed land remained the dominant LULC type throughout the study period. In 1985, urban LULC types occupied a relatively small portion of the sub-catchments, precisely 869 Ha (3.4%). However, the narrative changed with respect to consecutive study years, and by 2018, 4458.6Ha (17.4%) was under urban LULC. Over the years, urban LULC spread in all directions from the CBD located on the north-west side, with satellite urban centres seen emerging from far flung areas of the sub-catchments. This was at the expense of the non-urban LULC. Residential urban LULC type registered the highest [2176.2Ha (8.5%)] area change. The sub-catchments demonstrated a period (1985-1995) of slow rate of urban LULC change, followed by rapid rate of change (1997-2008), then again, slow rate (2008-2018). Thus, urban land expansion in UENNRB has generally been expansive and will continue expanding in coming years. The cumulative effect of this expansion on the landscape and the hydrology of the river basin should therefore be evaluated by the relevant authorities in order to enhance urban spatial planning and management of land and water resources.

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APPENDICES

Appendix A: Error matrix and Kappa coefficient for the 1985 image classification

Classified	Ref1	Ref2	Ref3	Ref4	Ref5	Ref6	Ref7	Ref8	Ref9	Ref10	Total
1	4	0	0	0	0	0	0	0	0	0	4
2	0	9	2	1	0	0	0	0	0	0	12
3	0	0	16	0	0	0	0	0	0	0	16
4	0	1	0	5	0	0	0	0	0	0	6
5	0	0	0	0	3	0	0	0	0	0	3
6	0	0	0	0	0	7	0	0	0	0	7
7	0	0	0	0	0	0	6	0	0	0	6
8	0	0	0	0	0	0	0	8	0	0	8
9	0	0	0	0	0	0	0	0	2	0	2
10	0	0	0	0	0	0	0	0	0	4	4
Total	4	10	18	6	3	7	6	8	2	4	68
1	Bare areas										
2	Commercial										
3	Cultivated/Managed land areas										
4	Educational										
5	Natural and Semi-natural Vegetation										
6	Non-vegetated water body										
7	Public										
8	Recreational										
9	Residential										
10	Transportational										

Appendix B: Error matrix and Kappa coefficient for the 1995 image classification

Classified	Ref1	Ref2	Ref3	Ref4	Ref5	Ref6	Ref7	Ref8	Ref9	Ref10	Ref11	Total
1	20	0	0	1	0	0	0	0	0	0	0	21
2	0	4	0	0	0	0	0	0	0	0	0	4
3	0	0	33	0	0	0	0	0	0	0	0	33
4	1	0	0	5	0	0	0	0	0	0	0	6
5	0	0	2	0	1	0	0	0	0	0	0	3
6	1	0	0	0	0	8	0	0	0	0	0	9
7	0	0	0	0	0	0	7	0	0	0	0	7
8	0	0	0	0	0	0	0	2	0	0	0	2
9	0	0	0	0	0	0	0	0	6	0	0	6
10	0	0	0	0	0	0	0	0	0	3	0	3
11	0	0	0	0	0	0	0	0	0	0	4	4
Total	22	4	35	6	1	8	7	2	6	3	4	98
Key:												
1	Bare areas											
2	Commercial											
3	Cultivated/Managed land areas											
4	Educational											
5	Industrial											
6	Natural and Semi-natural Vegetation											
7	Non-vegetated water body											
8	Public											
9	Recreational											
10	Residential											
11	Transportational											

Appendix C: Error matrix and Kappa coefficient for the 2008 image classification

Classified	Ref1	Ref2	Ref3	Ref4	Ref5	Ref6	Ref7	Ref8	Ref9	Ref10	Ref11	Total
1	20	0	0	0	0	0	0	0	0	0	0	21
2	0	18	1	0	0	0	0	0	0	0	0	21
3	0	1	5	0	0	0	0	0	0	0	0	9
4	12	2	0	4	0	0	0	0	0	0	0	22
5	0	0	0	0	6	0	0	0	0	0	0	11
6	0	0	0	0	0	3	0	0	0	0	0	9
7	0	1	0	0	0	0	8	0	0	0	0	16
8	3	0	0	0	0	0	0	7	0	0	0	18
9	0	0	0	0	0	0	0	0	1	0	0	10
10	0	0	0	0	0	0	0	0	0	2	0	12
11	0	0	0	0	0	0	0	0	0	0	4	15
Total	35	22	6	4	6	3	8	7	1	2	4	98
Key:												
1	Bare areas											
2	Commercial											
3	Cultivated/Managed land areas											
4	Educational											
5	Industrial											
6	Natural and Semi-natural Vegetation											
7	Non-vegetated water body											
8	Public											
9	Recreational											
10	Residential											
11	Transportational											

Appendix D: Error matrix and Kappa coefficient for the 2018 image classification

Classified	Ref1	Ref2	Ref3	Ref4	Ref5	Ref6	Ref7	Ref8	Ref9	Ref10	Ref11	Total
1	4	0	0	0	0	0	0	0	0	0	0	4
2	0	25	0	0	0	0	0	0	0	0	0	25
3	0	2	18	1	0	0	0	0	0	0	0	21
4	0	0	1	5	0	0	0	0	0	0	0	6
5	0	3	2	0	4	0	2	0	0	1	0	12
6	0	0	1	0	0	8	0	0	0	0	0	9
7	0	0	0	0	0	0	4	0	0	0	0	4
8	0	0	0	0	0	0	0	7	0	0	0	7
9	0	0	0	0	0	0	0	0	2	0	0	2
10	0	0	0	0	0	0	0	0	0	5	0	5
11	0	0	0	0	0	0	0	0	0	0	3	3
Total	4	30	22	6	4	8	6	7	2	6	3	98
Key:												
1	Bare areas											
2	Commercial											
3	Cultivated/Managed land areas											
4	Educational											
5	Industrial											
6	Natural and Semi-natural Vegetation											
7	Non-vegetated water body											
8	Public											
9	Recreational											
10	Residential											
11	Transportational											

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