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Historical and Future Spatial and Temporal Changes in Land Use and Land Cover in the Little Ruaha River Catchment, Tanzania

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Abstract

Increased anthropogenic activities in the Little Ruaha River Catchment have modulated the catchment condition, nevertheless, the future changes as a result of increased anthropogenic activities are unknown. Understanding the future changes is vitally important for the design of appropriate strategies towards sustainable management of the catchment resources. This study applied Remote Sensing and GIS techniques (Jensen & Lulla, 1987) to assess the historical long-term changes in land use and land cover using Landsat satellite images of 1990, 2005 and 2015, and modelled the future change in land use and land cover up to 2040 using the stochastic CA-Markov chain (Almeida et al., 2005). The historical land use and land cover change detection results indicate that between 1990 and 2005 the area under forest changed from 39,872 ha to 22,957 ha, woodland changed from 109,692 ha to 72,809 ha, wetland decreased from 19,157 ha to 11,785 ha, the cultivated land increased from 106,782 ha to 109,047 ha, likewise, the built-up area increased from 9408 ha to 11,674 ha. Results between 2005 and 2015 show the substantial changes where the forest decline from 22,957 ha to 15,950 ha, woodland decreased from 72,809 ha to 58,554 ha and the wetland changed from 11,785 ha to 5622 ha. Cultivated land and built up area increased from 109,047 ha and 11,674 ha to 143,468 ha and 13,765 ha respectively. Generally, the study has revealed the substantial decline in forest, woodland and wetland by 23,922 ha, 51,138 ha and 13,535 ha respectively, and an increase of cultivated land and built up area by 36,668 ha and 4357 ha respectively in 15 years, between 1990 and 2015. The predicted future land use and cover for the next 15 years (2040) showed an overall increase in cultivated land, built up area, grassland and bushland to 24.82%, 2.24%, 25.18% and 20.41% respectively, and a decrease in forest, woodland and wetland in the order of 1.87%, 7.87% and

0.03% respectively. The study concludes that, there have been significant changes in land use and cover in the catchment which likely to impend the sustainability of the catchment productivity, hence recommends the holistic system thinking and analysis approach in management and utilization of catchment resources.

Keywords

GIS, Little Ruaha River, CA Markov Chain, Land Use and Land Cover, Remote Sensing, Tanzania

1. Introduction

The major changes in land use and land cover (LULC) are a result of natural resources utilization. In most of the African countries, particularly in the Sub-Saharan Africa, their livelihood depends on the utilization of natural resources particularly from the forest and wetlands (Adger, 2007; Majule, 2013). This dependency tied with anthropogenic activities have been going on and intensified during the past millennium (Soka & Nzunda, 2014). The continued utilization to meet human needs has resulted in an observable pattern of change in the context of land use and land cover over time. Amongst the impacts is the alteration in the availability of diverse biophysical resources such as soil, vegetation, water and pasture (Ohri & Poonam, 2012). The vegetation cover is one of the important factors which partitions the rainfall into various hydrologic components such as surface runoff, base flow, ground water flow, evapotranspiration, etc., Therefore, the land use change pattern studies play a paramount role in catchment management and hydrological modelling (Lin et al., 2008).

Land use and land cover changes have become a major challenge on the sustainability of the Little Ruaha River catchment (Milder et al., 2013). Land cover change is expected to alter regional hydrologic conditions and results in varieties of impacts on ecosystem functioning (Li et al., 2007) especially river ecosystem. Hydrological alteration of Little Ruaha River catchment is believed to negatively impact not only on the livelihood of people through decreased crop and livestock production (Milder et al., 2013), but also on national economy by impacting the biological diversity of Ruaha National Park as well as sedimentation of Hydroelectric power stations (Buck, 2012).

This paper reports on a case study that has been conducted to understand the changes in land use and land cover in Little Ruaha River Catchment, Tanzania for the periods 1990 and 2015, and the predicted the future changes in LULC up to 2040. The catchment is known for its ecological and economical potentiality and a source of freshwater supply and irrigation for many residents in the rural and urban settlements of the neighboring districts. Also, it is a major source of water for the Ihemi Cluster, which is one of the six clusters identified by the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) (Milder et al., 2013) for agricultural intensification with significant investments in irrigation (Milder et al., 2012). It is believed that aggressive exploitation of the land in the catchment might have affected the land use and land cover pattern and that the changes will be gigantic in the near future following planned development in the catchment. Therefore, this study was conducted to not only to provide understanding on the spatial-temporal dynamics of land use and land cover but also to give baseline information for further study on how land use and land cover change can impact hydrological response and other ecosystem services of the Little Ruaha River catchment.

2. Materials and Methods

2.1. Description of the Study Area

This study was conducted in the Little Ruaha River catchment, one of the three tributaries forming the Great Ruaha River Catchment (GRRC) (**Figure 1**). Geographically the catchment lies within longitudes 35˚2'E and 35˚36'E and, latitudes 7˚11'S and 8˚36'S. Little Ruaha River catchment has been estimated to have 6300 km^2 catchment area and drains parts of Iringa Municipal, Iringa, Kilolo and Mufindi Districts in Iringa Region. The catchment lies within the Ihemi Cluster, one of the six clusters forming the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). Climate in the catchment is highly variable, at both spatial and temporal scales, and is dominantly unimodal with a single rainy season from November to April and correlated with altitude. Average annual rainfall ranges from 500 mm in the lowlands (e.g. rainfall measured at Mtera Met station) to 700 mm in the highlands at Iringa based on average rainfall from 1979 to 2012. The mean annual temperature varies from about 18˚C at higher altitudes to about 28˚C. Elevation ranges from 698 to over 2300 m, above mean sea level (m·asl) (**Figure 1**). Dominant soils in the area include Cambisols, Fluvisols, Leptosols, Lixisols, Nitisols and Solonetz.

2.2. Methods

2.2.1. Data Collection, Tools and Techniques

Appropriate satellite imagery acquisition was done with highly consideration of cloud cover, the seasonality and phonological effects (Kashaigili et al., 2006). Clouds free satellite images with the interval not less than ten years from 1990 to 2015 (**Table 1**) sourced from USGS-GLOVIS (https://glovis.usgs.gov/) were used in assessing temporal and spatial variation of land use/cover change in the study area.

2.2.2. Data Processing and Analysis

To ensure accurate identification of temporal changes and geometric compatibility with other sources of information, images were pre-processed whereby geo-correction was conducted to rectify precisely matching of images. Band stacking and image enhancement was performed using different color composite band combinations to reinforce the tonal distinctions. Images were registered to the

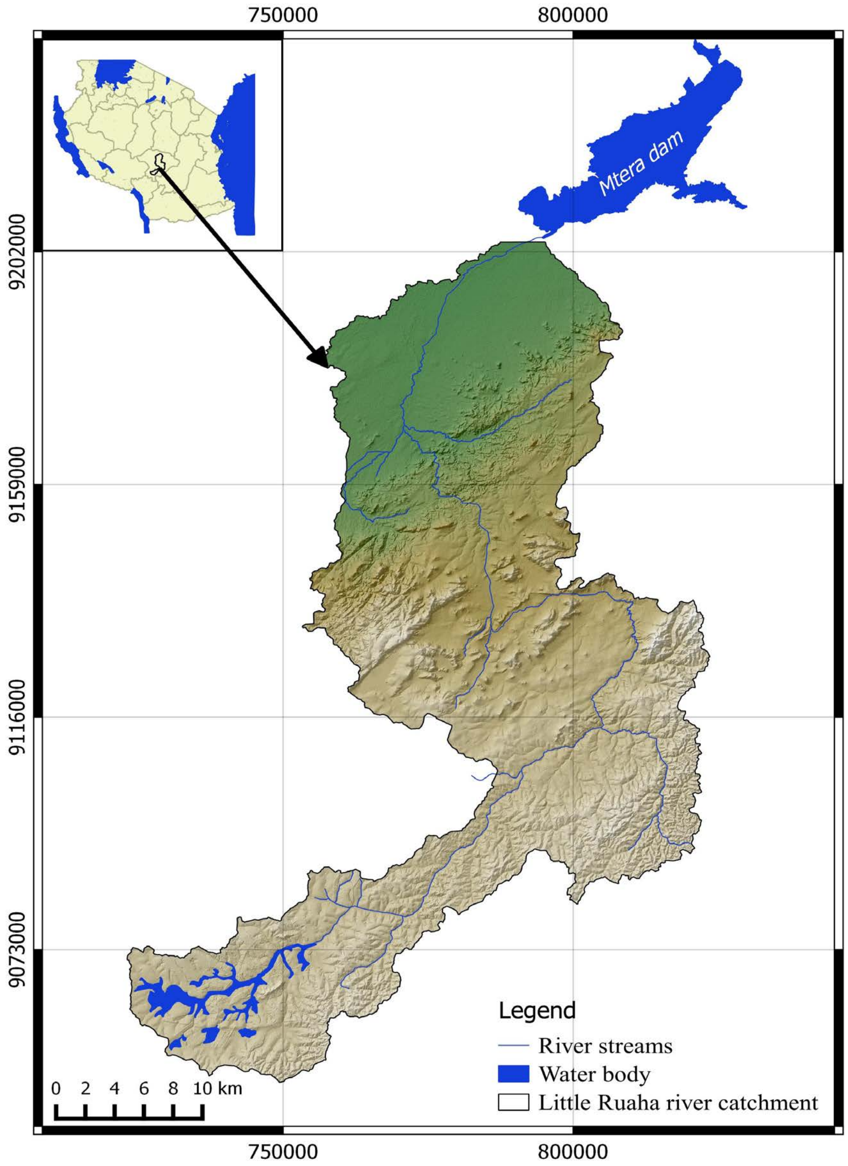

Figure 1. Little Ruaha River catchment.

Table 1. Satellite imagery data used in analysis of land use and land cover change.

Satellite	Sensor	Path/Row	Acquisition date	Season	Cloud cover (%)
Landsat 5	TM	168/65	July 11, 1990	Dry	0
Landsat 5	TM	168/66	July 11, 1990	Dry	0
Landsat 5	TM	168/65	July 20, 2005	Dry	6
Landsat 5	TM	168/66	July 7, 2005	Dry	6
Landsat 8	OLI-TIRS	168/65	October 4, 2015	Dry	9.78
Landsat 8	OLI-TIRS	168/66	October 21, 2015	Dry	0.03

Universal Transverse Mercator (UTM) map coordinate system, Zone 36 South, Datum Arc 1960 (Arc 1960/UTM zone 36S). Image mosaic was conducted to merge together images of the same year with same path and different row so as to create a single image that covers the entire catchment (**Figure 2**).

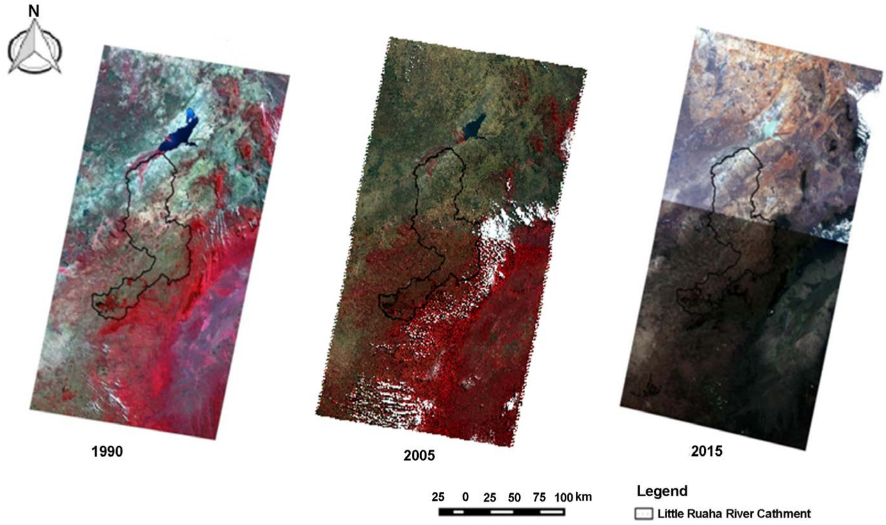

Figure 2. Mosaicked images with overlaid LRRC boundary.

Supervised image classification using Maximum Likelihood Classifier (MLC) was conducted to classify the images. Maximum likelihood classifier is one of the most popular classification algorithms which calculates posterior probability of a pixel belonging into corresponding class based on Bayes theorem (Congedo, 2016). The algorithm used probability density functions to assigns the pixel to the most likely (highest probability value) class (Lillesand & Kiefer, 2002) which increase the accuracy of classification output to resemble to the real world. A base-map for year 2015 was created and used for ground truthing fieldwork. The basis of land cover type nomenclature adopted "The National Forest Resources Monitoring and Assessment (NAFORMA) Field Manual Biophysical survey of 2010" with few modifications to reflect the actual ground conditions (**Table 2**).

The training sites for MLC were identified by inspecting an enhanced color composite imagery. Areas with similar spectral characteristics were trained and assigned respective classes. The Semi-automatic Classification Plugin (SCP) available in QGIS 2.12.1 was applied to classify the image into twelve distinct land cover classes.

Ground truthing was conducted using a hand-held Global Positioning System (GPS) with a base-map of year 2015. The essence of conducting ground truthing was to verify different covers types as described on the base maps and for collection of ground points for the classification accuracy assessment. The error matrices (Congalton, 1991) were prepared and used in computation of Kappa coefficient (K) for the classification accuracy assessment of final image classification. The probability of a classified land cover map corresponds accurately with the ground truthing data assessed by the user's accuracy (Jansen, 2004) and the measures of the agreement of classified maps and ground truthing data assessed by Kappa statistics (Lillesand et al., 2014).

$$K = \frac{\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)}{N^2 - \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)} \tag{1}$$

Table 2. Land use and land cover classification scheme.

Land cover	Description
Forest	Land covered with naturally regenerated native tree species with no clearly visible indications of human activities
Plantation	Artificially established forested area/cultivated land by planting or seeding (Plantation forest, tree farms, woodlots and Tea plantation)
Riverine forest	Forested area adjacent flowing bodies of water such as river, streams and dams
Lake/Dam	Area within body of land, of variable size, filled with water, localized in a basin, which rivers flow into or out of them.
Wetland	Land area that is saturated with water either permanent or seasonally
Woodland	Area of land covered low density trees forming open habitat with plenty of sunlight and limited shade
Wooded rock	Area of land covered with low density trees in a visible exposed mineral rock
Cultivated woodland	Area of land covered with low density and scattered trees with crop cultivation activities
Grassland	Land area dominated by grasses
Bushland	Area dominated with bushes and shrubs
Cultivated land	Farm with crops and harvested cropland
Built up land	Man-made infrastructures (roads and buildings) and settlement (cities and villages)

where N is the total number of sites in the matrix, r is the number of rows in the matrix, x_{ii} is the number in row i and column i, x_{+i} is the total for row i, and x_{i+} is the total for column.

To analyses the changes between different time epochs, change detection analysis was performed. Post classification comparison was used to quantify the extent of land cover changes for the periods 1990, 2005 and 2015. The estimation for the rate of change for the different land covers was computed based on (Kashaigili & Majaliwa, 2010).

$$\%\text{Cover change} = \frac{\text{Area}_{i\ \text{year}\ x} - \text{Area}_{i\ \text{year}\ x+1}}{\sum_{i=1}^{n} \text{Area}_{i\ \text{year}\ x}} \times 100 \quad (2)$$

$$\text{Annual rate of change} = \frac{\text{Area}_{i\ \text{year}\ x} - \text{Area}_{i\ \text{year}\ x+1}}{t_{\text{years}}} \quad (3)$$

$$\%\text{Annual rate of change} = \frac{\text{Area}_{i\ \text{year}\ x} - \text{Area}_{i\ \text{year}\ x+1}}{\text{Area}_{i\ \text{year}\ x} \times t_{\text{years}}} \times 100 \quad (4)$$

$\text{Area}_{i\ \text{year}\ x}$ is the area in hectares (ha) of cover i at the first date;
$\text{Area}_{i\ \text{year}\ x+1}$ is the area in hectares (ha) of cover i at the second date;
$\sum_{i=1}^{n} \text{Area}_{i\ \text{year}\ x}$ is the total cover area at the first;
t_{years} is the period in years between the first and second scene acquisition dates.

2.2.3. Prediction of Future LULCC Using Cellular Automata-Markov Chain

Markov chain is a statistical tool that describes the probability of land use to change from one time period to another by developing a transitional probability matrix between first period and second period based on the spatial neighborhood effects (Wang et al., 2004; Al-Bakri et al., 2013; Araya & Cabral, 2010). A spatial neighborhood effect is the state of neighboring cells to influence the transition of a given cell into different states. This model was based on using and evaluating land use layers of previous years to predicting the spatial distribution of land uses in the future (Wu & Silva, 2010). For better simulation of temporal and spatial patterns of land use changes in quantity and space, the combination of two techniques Markov chain analysis and Cellular automata (CA-Markov) were used.

The simulated model was developed by using IDRISI Selva v.17.0 software (Rutherford et al., 2015) and it involved two main stages which are calculating conversion probability (conversion probability matrix, conversion area matrix and layers of conditional probability) done by using Markov chain analysis, and the second stage was spatial specification of land use coverage simulated based on Cellular Automata spatial operator and multi criteria evaluation (MCE).

2.2.4. CA-Markov Model Set up

In the developing CA Markov model, the classified land use map of 1990 which represent past, and 2015 which represent present time developed in QGIS 2.12.1 were converted into IDRISI data format and selected to be input data into the model, to calculate matrices of conversion probabilities and conversion areas (Transition area matrix and transition probability matrix).

The transition probability matrix (**Table 3**) expresses the likelihood (probability) that a pixel of a given class that will change to any other class (or stay the same) in the next time period. The transition areas matrix (**Table 4**) expresses the total area (in cells) expected to change from the year 2015 to the year of 2040 according to those changes happened from 1990 to 2015.

2.2.5. CA-Markov Model Validation

For model validation the simulated land use/cover map for 2015 was compared with the actual satellite derived land use/cover map based on the Kappa statistics. Then, standard Kappa index was used to check whether the model is valid or not (usually the Kappa Index for a valid model is >70%) (Wen, 2008). If the model has the Kappa Index less than 70% then the suitability map for the land covers and filter used should be repeated based on several considerations. VALIDATE tool was used to compute Kappa statistics for the projected land use/cover.

3. Results

3.1. Land Use and Land Cover Change Assessment

3.1.1. Accuracy

The classified maps showed good agreement with the real world as indicated by

Table 3. Transitional probability matrix for land use/cover change 1990/2015.

Given	Probability of a cell to change (transition) to:											
	FR	PL	RF	WTR	WET	WD	WR	CW	GR	BS	CLT	BLT
FR	0.1718	0.1248	0.0001	0.0001	0	0.0169	0.0031	0.4205	0.0703	0.0301	0.1571	0.0051
PL	0.1113	0.3571	0.0001	0.0001	0	0.0057	0.001	0.1464	0.1619	0.0251	0.1825	0.009
RF	0.0147	0.0046	0.0704	0.0008	0.0311	0.0858	0.0796	0.0153	0.2	0.1274	0.3372	0.0332
WTR	0.0017	0.0054	0.0006	0.292	0.2311	0.0332	0.0388	0.0001	0.0906	0.2089	0.0758	0.0216
WET	0.0134	0.0852	0.0006	0.002	0.1421	0.0786	0.0917	0.0458	0.1622	0.2277	0.1417	0.0093
WD	0.005	0.0039	0.0048	0.0001	0.0052	0.232	0.1841	0.0065	0.1879	0.2305	0.1116	0.0286
WR	0.0087	0.0072	0.0006	0	0.0003	0.0444	0.1381	0.032	0.2147	0.3533	0.1626	0.0381
CW	0.0345	0.0435	0	0	0.0001	0.0289	0.0166	0.2501	0.1603	0.1073	0.3354	0.0234
GR	0.007	0.0216	0	0	0.0061	0.0555	0.0388	0.0408	0.3625	0.1908	0.255	0.0217
BS	0.0117	0.0306	0	0	0.0008	0.1143	0.0373	0.0905	0.2273	0.2597	0.2189	0.0089
CLT	0.0086	0.012	0.0002	0	0.0033	0.0571	0.0418	0.0419	0.2712	0.2064	0.3344	0.0231
BLT	0.0051	0.005	0.0015	0	0.0285	0.0897	0.0357	0.0205	0.2543	0.1329	0.3151	0.1116

FR: Forest, **PL**: Plantation, **RF**: Riverine forest, **WTR**: Water, **WET**: Wetland, **WD**: Woodland, **GR**: Grassland, **WR**: Wooded rock, **CW**: Cultivated woodland, **BS**: Bushl, **CLT**: Cultivated land, **BLT**: Built up.

Table 4. Transitional area matrix for land use/cover change between 1990/2015.

Cell in 1990	Area in cells expected to change in 2015:											
	FR	PL	RF	WTR	WET	WD	WR	CW	GR	BS	CLT	BLT
FR	30,442	22,126	12	26	3	2999	545	74,534	12,465	5337	27,846	907
PL	30,033	96,362	21	26	4	1526	265	39,509	43,679	6769	49,248	2426
RF	177	55	847	10	374	1033	958	184	2407	1534	4058	399
WTR	13	40	4	2132	1687	243	283	1	662	1526	554	158
WET	835	5323	35	122	8879	4911	5727	2858	10,131	14,225	8850	578
WD	3259	2531	3141	36	3406	150,938	119,760	4206	122,233	149,969	72,599	18,598
WR	4209	3489	312	1	123	21,613	67,174	15,584	104,434	171,807	79,069	18,544
CW	21,183	26,753	27	6	49	17,764	10,174	153,702	98,476	65,929	206,090	14,360
GR	11,629	35,770	49	0	10,054	91,847	64,129	67,501	599,338	315,549	421,688	35,914
BS	16,350	42,719	18	2	1094	159,713	52,099	126,528	317,696	362,890	305,895	12,483
CLT	13,756	19,074	363	6	5293	90,991	66,651	66,827	432,309	329,053	533,105	36,848
BLT	780	766	224	0	4366	13,728	5463	3132	38,892	20,333	48,204	17,077

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overall classification accuracies of 99.79%, 98.43%, and 99.25% respectively, for 1990, 2005, and 2015 with their corresponding Kappa statistics of 0.99, 0.98 and 0.99 respectively (Table 5). It is recommended that Kappa value for a good classification performance should be more than 0.80 (Jensen, 2005; Lillesand et al., 2004) and the minimum level of promoted classification overall accuracy in identification of land use classes should be at least 85% (Anderson, 1976).

Table 5. Classification accuracy.

Year	1990	2005	2015
Overall accuracy (%)	99.79	98.43	99.25
Kappa statistic	0.99	0.98	0.99

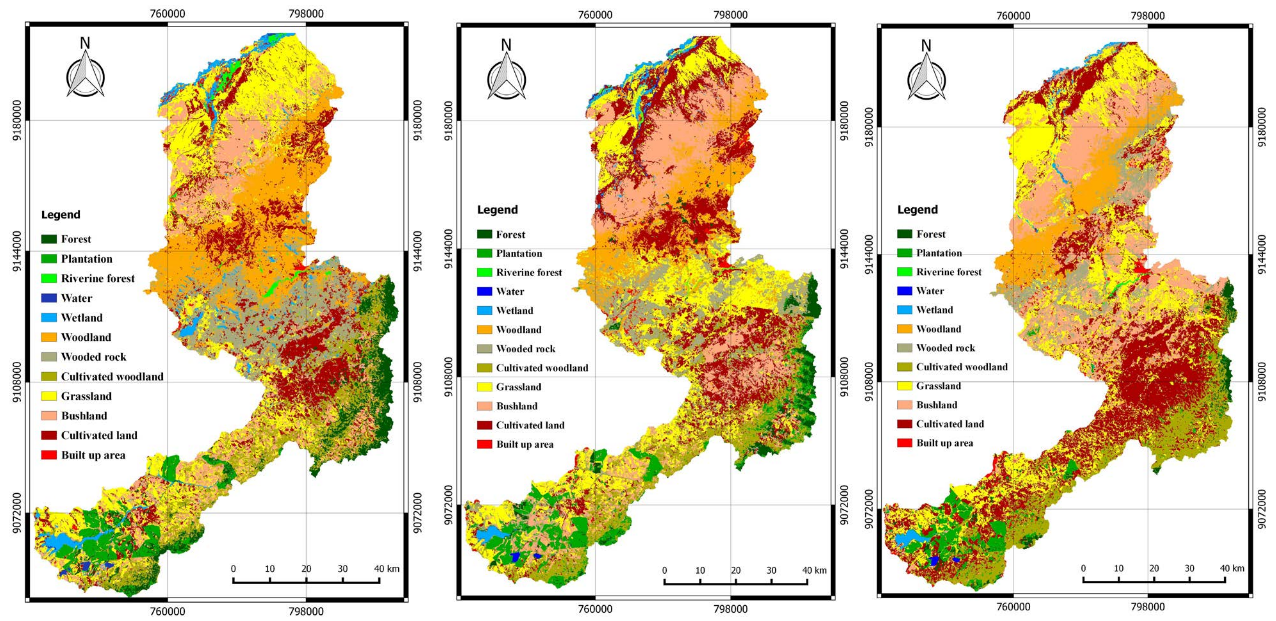
3.1.2. Land Use and Land Cover Change Analysis

The land use and land cover maps for the year 1990, 2005 and 2015 are presented in Figure 3. Generally, maps show variation in land use and land cover coverage between time periods. Table 6 presents the coverage of each land use and land cover class between 1990 and 2005 and between 2005 and 2015. The extent of LULCC including the area change, percentage area change, annual rate of change and percentage annual rate of change for the Little Ruaha River Catchment are summarized. The increased and decreased amount is represented by positive (+) and negative (−) signs respectively.

The results indicate that for the period between 1990 and 2005 the area under Forest which occupied 39,872 ha (6.26%) in 1990, decreased to 22,957 ha (3.6%), indicating a decrease of about −42.2% from its original coverage. Likewise, riverine forest and woodland decreased from 5878 ha (0.92%) and 109,692 ha (17.22%) to 2746 ha (0.43%) and 72,809 ha (11.43%) respectively, showing a decrease of −53.28% and −33.62% for riverine forest and woodland respectively. Water and wetland areas declined from 1752 ha (0.28%) and 19,157 ha (3.01%) to 1202 ha (0.19%) and 11,785 ha (1.85%) indicating a loss of −31.39% for water and −38.48% for wetland between 1990 and 2005. At the same time, cultivated land and built up area showed an increase from 106,782 ha (16.76%) in 1990 to 109,047 ha (17.12%) in 2005 and from 9408 ha (1.48%) to 11,674 ha (1.83%) respectively, indicating a gain of about +2.12% and +24.09% respectively.

For the period between 2005 and 2015, the Forest, riverine forest, woodland, water and wetland declined to 15,950 ha (2.50%), 1083 ha (0.17%), 58,554 ha (9.19%), 757 ha (0.1%) and 5622 ha (0.88%) respectively, indicating percentage loss of −30.52%, −60.56%, −19.58%, 45.34%, and −52.30% respectively. For the same period of time, cultivated land and built up area increased to 143,468 ha (22.52%) and 13,765 ha (2.16%) respectively, indicating a gain of +31.57% for cultivated land and +17.91% for built up area. The area under Forest decreased at a rate of −1127.67 ha/year (−2.83%/year) over a period of 15 year (1990-2005), and −700.70 ha/year (−3.05%/year) over a period of 10 years (2005-2015), likewise, riverine forest, woodland showed a similar trend of decline for both time periods.

The overall land use land cover change from 1990 to 2015 indicate that forest, riverine forest, water, wetland and woodland has declined by 60%, 82%, 63%, 71%, and 47% respectively from their original coverage, while plantation, grassland, bushland, cultivated land and built up area increased by 18%, 25%, 44%, 34% and 46% respectively. Result shows that woodland, forest, and wetland are the most altered ecosystem where by annually decline at the rate of 2045.52



(a) (b) (c)

Figure 3. Classified images of Little Ruaha River Catchment for years (a) 1990 (b) 2005 (c) 2015.

Table 6. Cover area, changed area and rate of change between 1990/2005 and 2005/2015.

Years	1990		2005		2015		1990-2005			2005-2015			1990-2015		
LULC	Cover area (ha)	%	Cover area (ha)	%	Cover area (ha)	%	Change area (ha)	% Change	Annual rate of change	Change area (ha)	% Change	Annual rate of change	Change area (ha)	% Change	Annual rate of change
FR	39,872	6.26	22,957	3.6	15,950	2.5	−16,915	−42.42	−1127.67	−7007	−30.52	−700.70	−23,922	−60.00	−956.88
PL	20,632	3.24	34,068	5.35	24,285	3.81	13,436	+65.12	+895.73	−9783	−28.72	−978.30	+3653	+17.71	146.12
RF	5878	0.92	2746	0.43	1083	0.17	−3132	−53.28	−208.80	−1663	−60.56	−166.30	−4795	−81.58	−191.80
WTR	1752	0.28	1202	0.19	657	0.1	−550	−31.39	−36.67	−545	−45.34	−54.50	−1095	−62.50	−43.80
WET	19,157	3.01	11,785	1.85	5622	0.88	−7372	−38.48	−491.47	−6163	−52.30	−616.30	−13,535	−70.65	−541.40
WD	109,692	17.22	72,809	11.43	58,554	9.19	−36,883	−33.62	−2458.87	−14,255	−19.58	−1425.50	−51,138	−46.62	−2045.52
WR	60,288	9.46	75,121	11.79	43,767	6.87	+14,833	+24.60	+988.87	−31,354	−41.74	−3135.40	−16521	−27.40	−660.84
CW	57,368	9.01	54,517	8.56	55,300	8.68	−2851	−4.97	−190.07	+783	+1.44	+78.30	−2068	−3.60	−82.72
GR	118,784	18.65	129,797	20.38	148,795	23.36	+11,013	+9.27	+734.20	+18,998	+14.64	+1899.80	+30,011	+25.27	+1200.44
BS	87,394	13.72	111,284	17.47	125,759	19.74	+23,890	+27.34	+1592.67	+14,475	+13.01	+1447.50	+38,365	+43.90	+1534.60
CLT	106,782	16.76	109,047	17.12	143,470	22.52	+2265	+2.12	+151.00	+34,423	+31.57	+3442.30	+36,688	+34.36	+1467.52
BLT	9408	1.48	11,674	1.83	13,765	2.16	+2266	+24.09	+151.07	+2091	+17.91	+209.10	+4357	+46.31	+174.28
TOTAL	637,007	100	637,007	100	637,007	100									

FR: Forest, **PL**: Plantation, **RF**: Riverine forest, **WTR**: Water, WET: Wetland, **WD**: Woodland, **WR**: Wooded rock, **CLT**: Cultivated land, **CW**: Cultivated woodland, **GR**: Grassland, **BS**: Bushland, **BLT**: Built up area.

ha/year, 956.88 ha/year and 541.40 ha/year respectively. Riverine forest decline at the rate of 191.80 ha/year while water bodies decline by 43.80 ha/year.

3.1.3. Transformation of Different Land Covers in the Little Ruaha River Catchment

The overall gain and loss and the net change of each land use and land cover category between the period 1990-2005, 2005-2015 and 1990-2015 are summarised in Table 7, and change detection matrix showing the transformation of each land use category presented in Tables 8-10.

The results, clearly reflecting the dynamics of land cover classes in the study area. Forest, Woodland and Wetland were found to be the most transformed ecosystems. As illustrated in Table 7, between 1990 and 2015 forest gain 7893 ha while lose 31,820 ha, corresponding to a net loss of −23,927 ha; woodland gains 28,623 ha and lose 79,766 ha corresponding to a net loss of −51,143 ha followed by wetland which experienced the gain of 2419 ha and lose 15,956 ha equivalents to a net loss of −13,537 ha. Cultivated land, grassland, bushland and built up area was found to have consistently net gain of 36,690 ha, 30,014 ha, 38,370 ha and 4356 ha respectively.

Land covers transition matrix present transformation of each land use category. The numbers in brackets indicates the cover area which remained unchanged and others number indicate the flow of cover that changed from one cover to other cover categories. The results have reviled that all land cover categories changed with varying magnitudes. Major changes that have been noted between 1990 and 2015 include: 16,155 ha of forest was transformed to cultivated woodland and 6035 ha to cultivated land. 23,937 ha of woodland was changed to bushland; 19,510 ha to grassland and 11,588 ha to cultivated land while 4235 ha of wetland was transformed to bushland, 3016 ha to grassland and 2635 ha to cultivated land. Results implying there is encroachment of forest, woodland and wetland by human activities including agriculture.

Table 7. The overall gain and loss of each land use/land cover category.

Land cover	1990-2005			2005-2015			1990-2015		
	Gain (ha)	Loss (ha)	Net change (ha)	Gain (ha)	Loss (ha)	Net change (ha)	Gain (ha)	Loss (ha)	Net change (ha)
Forest	13,324	30411	−17,087	10,909	18,097	−7188	7893	31,820	−23,927
Plantation	21,535	8473	13,062	13,839	23,240	−9401	15,620	11,964	3656
Riverine forest	2133	5166	−3033	715	2424	−1709	597	5391	−4794
Water	256	772	−516	42	481	−439	56	1149	−1093
Wetland	7290	13,911	−6621	2331	9045	−6714	2419	15,956	−13,537
Woodland	32,064	63,850	−31,786	33,202	53,145	−19,943	28,623	79,766	−51,143
Wooded rock	61,171	38,551	22,620	29,222	68,227	−39,005	33,975	50,498	−16,523
Cultivated woodland	38,067	39,811	−1744	36,315	36,521	−206	38,422	40,491	−2069
Grassland	63,623	81,933	−18,310	97,763	53,286	44,477	98,151	68,137	30,014
Bushland	74,190	45,742	28,448	89,438	76,243	13,195	99,072	60,702	38,370
Cultivated land	75,977	65,508	10,469	96,410	69,242	27,168	101,471	64,781	36,690
Builtup area	12,470	7972	4498	10,685	10,920	−235	12,530	8174	4356

Table 8. Change detection matrix for the period of 1990 to 2005.

Cover in 1990 (Ha)	Cover in 2005 (Ha)												
	FR	PL	RF	WTR	WET	WD	WR	CW	GR	BS	CLT	BLT	TOTAL
FR	(9238)	10,721	15	11	27	837	3615	8298	652	3522	2611	102	**39,649**
PL	2333	(12,020)	1	2	2	295	1630	1122	675	1959	429	25	**20,493**
RF	517	111	(652)	21	658	1371	419	177	623	35	1044	190	**5818**
WTR	88	50	135	(839)	245	49	44	1	40	3	100	17	**1611**
WET	1154	1207	962	107	(4610)	1882	5084	818	460	1149	955	133	**18,521**
WD	1743	654	631	10	1560	(46,048)	18545	1410	12,922	8239	15203	2933	**109,898**
WR	519	391	27	0	10	4752	(21,414)	6503	14,210	3112	6682	2345	**59,965**
CW	3043	3484	7	1	9	1067	8440	(17,282)	5232	7275	10,362	891	**57,093**
GR	847	1953	47	28	1045	7105	6351	6359	(39,609)	29,644	25,821	2733	**121,542**
BS	1458	1841	5	2	1147	3503	6593	7278	12270	(41,197)	10,890	755	**86,939**
CLT	1316	1087	108	49	1364	9930	9769	5843	15,301	18,395	(40,786)	2346	**106,294**
BLT	306	36	195	25	1223	1273	681	258	1238	857	1880	(1212)	**9184**
TOTAL	**22,562**	**33,555**	**2785**	**1095**	**11,900**	**78,112**	**82,585**	**55,349**	**103,232**	**115,387**	**116,763**	**13,682**	**637,007**

FR: Forest, **PL**: Plantation, **RF**: Riverine forest, **WTR**: Water, **WET**: Wetland, **WD**: Woodland, **GR**: Grassland, **WR**: Wooded rock, **CW**: Cultivated woodland, **BS**: Bushland, **CLT**: Cultivated land, **BLT**: Built up. Numbers in brackets indicate cover areas that remained unchanged between the two periods of 1990 and 2005.

Table 9. Change detection matrix for the period of 2005 to 2015.

Cover in 2005 (Ha)	Cover in 2015 (Ha)												
	FR	PL	RF	WTR	WET	WD	WR	CW	GR	BS	CLT	BLT	TOTAL
FR	(4867)	2105	72	14	373	970	439	6344	2425	1415	3587	353	**22,964**
PL	4559	(10,312)	14	14	50	390	265	8043	2970	1103	5524	308	**33,552**
RF	32	0	(362)	0	325	217	113	6	522	356	739	114	**2786**
WTR	3	7	0	(615)	80	8	1	3	25	220	79	55	**1096**
WET	7	62	2	8	(2855)	569	244	25	2513	2302	3203	110	**11,900**
WD	398	296	433	1	142	(24,969)	14699	777	9650	18,084	7384	1281	**78,114**
WR	1532	2508	118	5	120	6639	(14,356)	4820	16,270	23,001	11,344	1870	**82,583**
CW	1851	2717	1	0	2	1636	1286	(18,830)	7772	6856	13,476	924	**55,351**
GR	560	1439	40	0	303	1982	3218	2850	(49,946)	15,125	24,765	3004	**103,232**
BS	1053	3356	1	0	62	15,262	6828	7758	17,436	(39,742)	23,959	528	**115985**
CLT	873	1314	15	0	769	4578	1556	5448	34,816	17,735	(46,520)	2138	**115,762**
BLT	41	35	19	0	105	951	573	241	3364	3241	2350	(2762)	**13,682**
TOTAL	**15,776**	**24,151**	**1077**	**657**	**5186**	**58,171**	**43,578**	**55,145**	**147,709**	**129,180**	**142,930**	**13,447**	**637,007**

FR: Forest, **PL**: Plantation, **RF**: Riverine forest, **WTR**: Water, **WET**: Wetland, **WD**: Woodland, **GR**: Grassland, **WR**: Wooded rock, **CW**: Cultivated woodland, **BS**: Bushland, **CLT**: Cultivated land, **BLT**: Built up. Numbers in brackets indicate cover areas that remained unchanged between the two periods of 2005 and 2015.

Table 10. Change detection matrix for the period of 1990 to 2015.

Cover in 1990 (Ha)	Cover in 2015 (Ha)												
	FR	PL	RF	WTR	WET	WD	WR	CW	GR	BS	CLT	BLT	TOTAL
FR	(8058)	4796	3	6	1	650	118	16,155	2702	1157	6035	197	**39,878**
PL	2071	(8668)	1	2	0	105	18	2725	3012	467	3396	167	**20,632**
RF	85	27	(487)	5	180	498	461	88	1160	739	1956	192	**5878**
WTR	3	9	1	(602)	375	54	63	0	147	339	123	35	**1751**
WET	248	1585	11	36	(3133)	1462	1705	851	3016	4235	2635	172	**19089**
WD	520	404	501	6	544	(29,939)	19,116	671	19,510	23,937	11,588	2969	**109,705**
WR	507	420	38	0	15	2604	(9797)	1877	12581	20,697	9525	2234	**60,295**
CW	1861	2351	2	1	4	1561	894	(16,883)	8653	5793	18,109	1262	**57,374**
GR	752	2312	3	0	650	5937	4145	4363	(50,660)	20,397	27,257	2321	**118,797**
BS	959	2506	1	0	64	9371	3057	7424	18,640	(26,702)	17,948	732	**87,404**
CLT	840	1164	22	0	323	5555	4069	4080	26,391	20,088	(42,013)	2249	**106,794**
BLT	47	46	14	0	263	826	329	188	2339	1223	2899	(1236)	**9410**
TOTAL	**15,951**	**24,288**	**1084**	**658**	**5552**	**58,562**	**43,772**	**55,305**	**148,811**	**125,774**	**143,484**	**13,766**	**637,007**

EF: Forest, **PL**: Plantation, **RF**: Riverine forest, **WTR**: Water, **WET**: Wetland, **WD**: Woodland, **GR**: Grassland, **WR**: Wooded rock, **CW**: Cultivated woodland, **BS:** Bushland, **CLT**: Cultivated land, **BLT**: Built up. Numbers in brackets indicate cover areas that remained unchanged between the two periods of 1990 and 2015.

Summary on changed and unchanged cover areas between 1990 and 2015 are presented in Table 11. The percentage changed indicates the percentage area of a particular cover which changed to other covers while the percentage unchanged represents the percentage area of the original area of a particular cover which remained unchanged for a given period (Kashaigili & Majaliwa, 2010). Results shows, the forest cover changed to other forms by 80%, while woodland changed by 72%, cultivated woodland by 71%, wetland and water bodies changed by 83% and 66% respectively, bushland changed by 69%, grassland by 57%, built-up land and cultivated land changed by 87% and 61% respectively. However, some cover areas remained unchanged between 1990 and 2015.

3.2. Future Change in Land Use and Land Cover in the Little Ruaha River Catchment

1) CA-Markov model validation results

Using VALADATE tool, IDRISI gave the standard Kappa of 0.83, Kappa for no information of 0.89, Kappa for grid-cell level location of 0.86 and Kappa for stratum-level location of 0.864 (Figure 4) which are all more than 0.7, as recommended by (Wen, 2008) that the Kappa index of the valid model is > 70%.

2) Probability of future change in land use and land cover

The conditional probability maps that express the probability that each pixel will belong to designated class in the next 25 years are presented in Figure 5(a)-(l). They are called conditional probability maps since this probability is conditional on their current state. Thus, these maps are a cartographical presentation of the transition probability matrix.

Table 11. Changed and unchanged individual land cover between 1990 and 2015.

Cover type	Area unchanged (ha)	Percent unchanged (%)	Area changed (ha)	Percent changed (%)
Forest	8058	20	31,814	80
Plantation	8668	42	11,966	58
Riverine forest	487	8	5391	92
Water	602	34	1150	66
Wetland	3204	17	15,956	83
Woodland	29,939	27	79,466	72
Wooded rock	9797	16	50,498	84
Cultivated woodland	16,883	29	40,492	71
Grassland	50,660	43	68,138	57
Bushland	26,702	31	60,702	69
Cultivated land	42,013	39	64,782	61
Built-up land	1236	13	8173	87

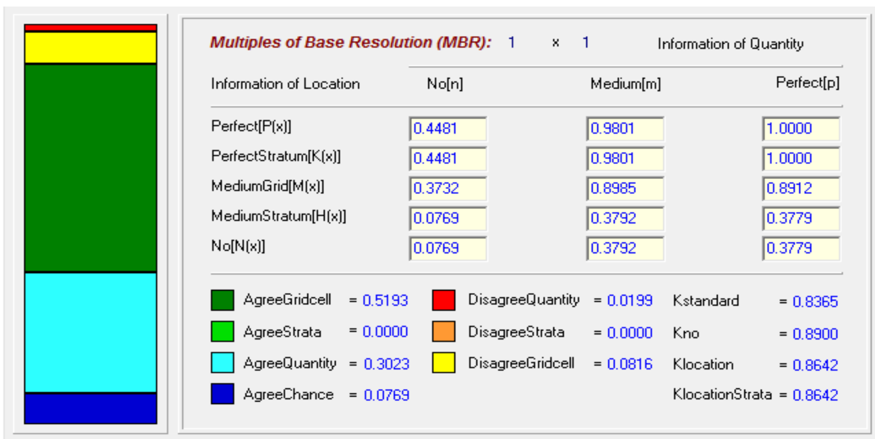
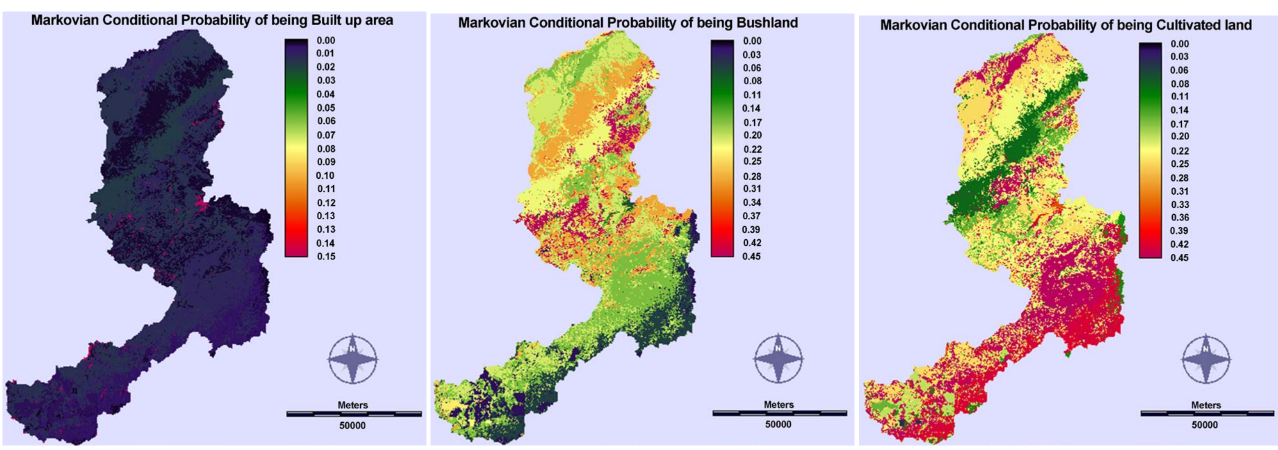


Figure 4. The spatio-statistical output generated in validation process.



(a) (b) (c)

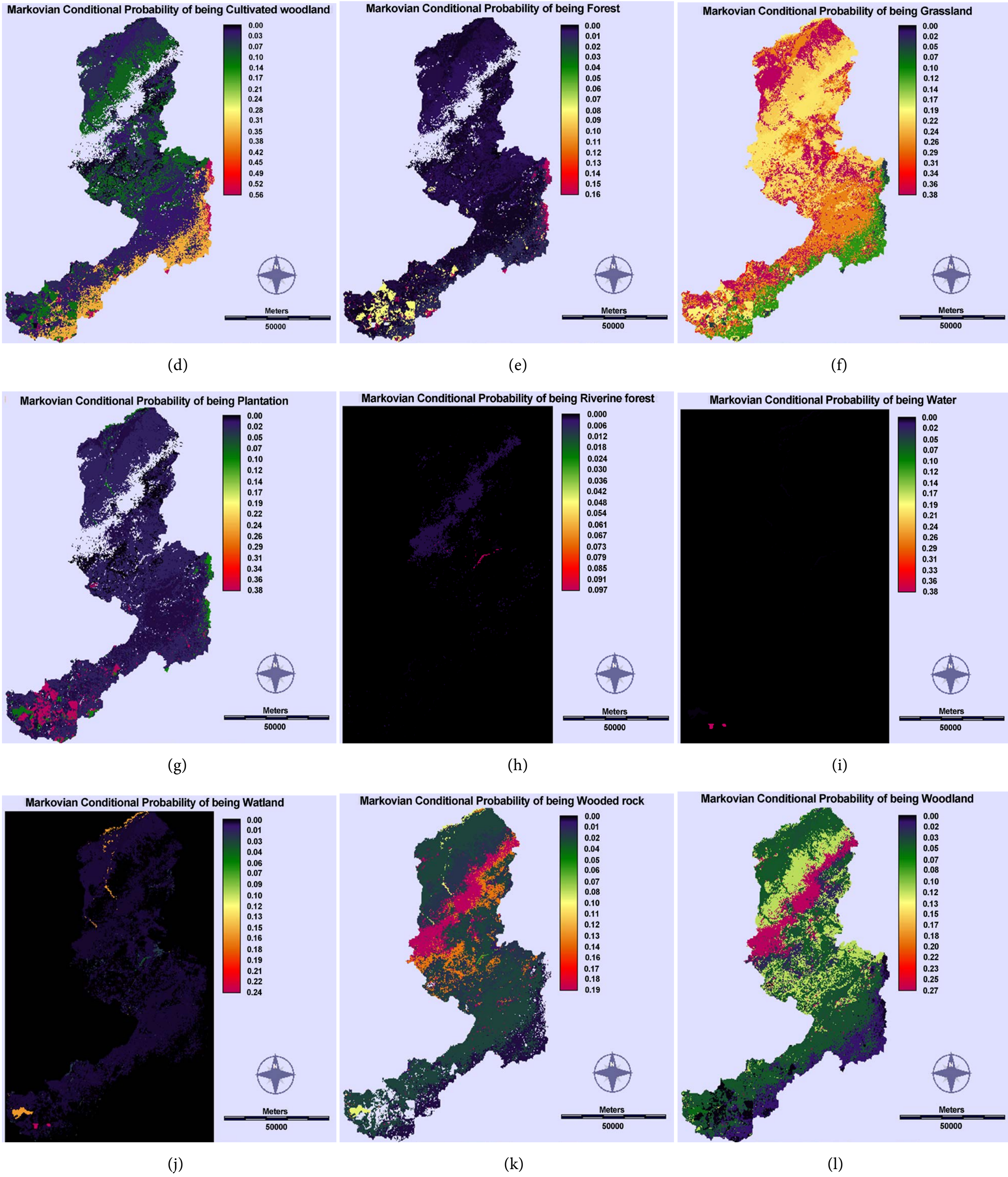


Figure 5. Conditional probability images for each land use/cover. (a) Markovia Conditional probability of being Forest; (b) Markovian Conditional probability of being plantation; (c) Markovian Conditional probability of being riverine forest; (d) Markovian Conditional probability of being water; (e) Markovian Conditional probability of being wetland; (f) Markovian Conditional probability of being woodland; (g) Markovian Conditional probability of being wooded rock; (h) Markovian Conditional probability of being cultivated woodland; (i) Markovian Conditional probability of being grassland; (j) Markovian Conditional probability of being bushland; (k) Markovian Conditional probability of being cultivated land; (l) Markovian Conditional probability of being built up area.

3) Spatial distribution of predicted land use land cover 2040

The land use land cover map for the next 25 years is presented in Figure 6. The statistical analysis of land use land cover for the predicted year 2040 illustrated in Table 12. An overall change in land use and land cover in all the 25 years of prediction revealed that, the grassland will dominate by occupying 25% which is equivalent to 160,422 ha of the catchment followed by cultivated land which is expected to cover 24.82% equivalent to 158,132 ha. Forest coverage will decrease from 15,950 ha (2.5%) existing in 2015 to 11,936 ha (1.87%), riverine forest will decrease from 1083 ha (0.17%) experienced in 2015 to 461 ha (0.07%), woodland will decrease from 157,621 ha (24.74%) existing in 2015 to 135,446 ha (21.26%). Projected decrease in water bodies and wetland whereby water bodies coverage and wetland expected to decrease to 211 ha (0.03%) and 3,183 ha (0.5%) respectively.

4. Discussion

A detailed land cover change analysis map from this study allowed us to better understand the historical and future land cover transitions in the Little Ruaha River catchment. The analysis showed that activities associated with agriculture being the dominant driver of conversion of other land covers especially forest and wetlands.

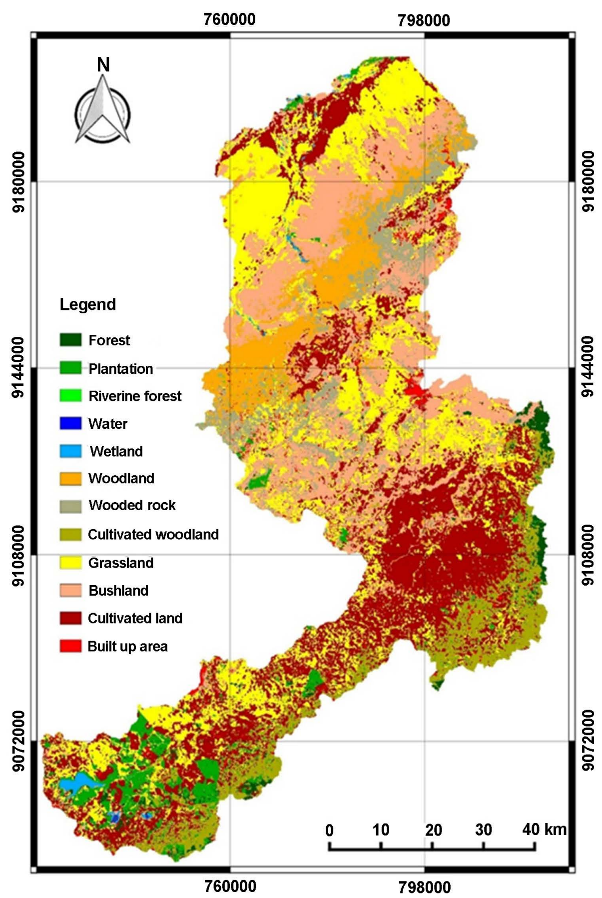


Figure 6. Predicted land use/cover map of Little Ruaha River catchment of 2040.

Table 12. Percentage of predicted land use/cover based on CA-Markov model.

LULC	2040	
	Area (Ha)	Coverage (%)
Forest	11,936	1.87
Plantation	22,950	3.60
Riverine forest	461	0.07
Water	211	0.03
Wetland	3183	0.50
Woodland	50,158	7.87
Wooded rock	35,387	5.56
Cultivated woodland	49,901	7.83
Grassland	160,422	25.18
Bushland	130,023	20.41
Cultivated land	158,132	24.82
Built up	14,243	2.24
Total	**637,007**	**100**

From the results (**Figure 7**) revealed a rapid decrease in forest cover which is direct associated to human encroachments for timber, firewood and medicine and clear and burning for expansion of agricultural farms. This has also been emphasized by local people during ground truthing that fire burning and deforestation has been a serious problem in recent years. Deforestation and degradation in the Little Ruaha River catchment are also influenced by rapid population growth (**Figure 8**) that leads farmers to expand their farmlands and settlement to sustain the livelihood.

The liner decrease in area under water could be attributable to destruction of riparian zones due to valley-bottom farming locally known as *Vinyungu* (**Figure 9**). Bottom valley cultivation (*Vinyungu*) is a most dominating traditional irrigation farming observed during field survey. *Vinyungu*, a type of farming practiced in dry season play a great role in converting wetland into cultivated land in turn threaten the sustainability of wetlands to supply vital ecosystem services especially water discharge. During ground truthing most of farmers observed to practice *Vinyungu* cultivation in dry season. Other factors for the observed decrease of water resource are drying up of water bodies due to decrease in rainfall and increase in competitors' user.

These trends are predicted to increase over the next 25 years. This expansion will result in largescale conversion of forest and wetlands to cultivated land, which will have negative impacts not only to human being but also on the wildlife especially in Ruaha National Park. Nevertheless, is legally protected that means all anthropogenic activities are restricted within, but this important ecosystem can be impacted through blockage of wildlife corridors by agricultural development

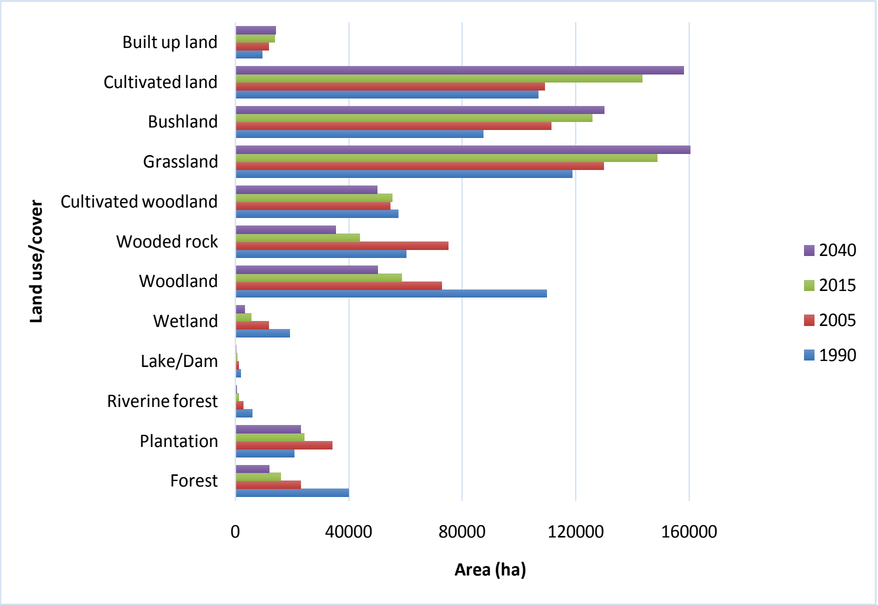


Figure 7. Historical and Predicted Spatial Coverage in Land use/cover in the Little Ruaha River catchment.

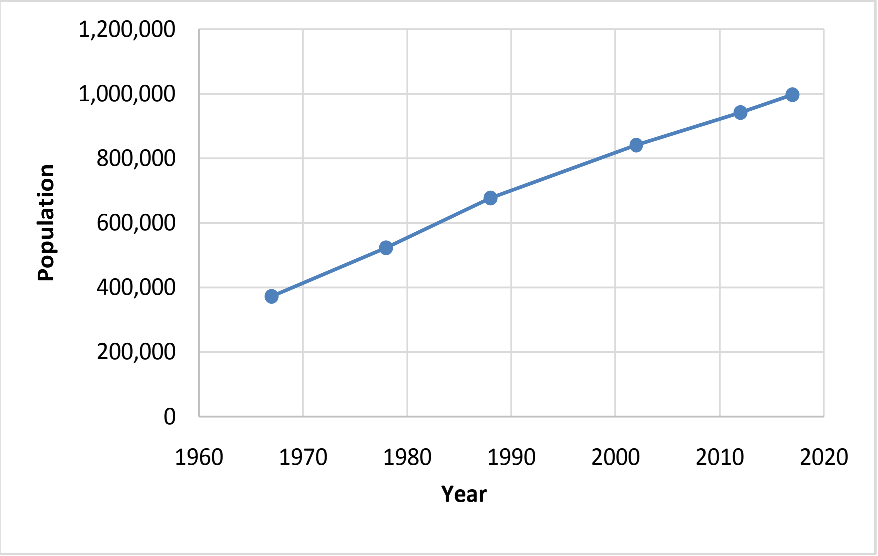


Figure 8. Iringa regional population. Sources: Iringa Region Socio-economic Profile (NBS) (Council, 2013).

Figure 9. Bottom valley cultivation practices (*Vinyungu*).

which in turn can result into wildlife-farmers conflict. Sustainably managing agricultural expansion into ecologically sensitive areas will be important for maintaining wildlife and water resources for the sustainability of the Little Ruaha River catchment. Results from this study support previous findings conducted in southern highland watersheds which found a significant alteration of important and sensitive ecosystems includes forest covers and water bodies (Kashaigili, 2008; Kashaigili & Majaliwa, 2010).

5. Conclusion

This study investigated the land use and land cover dynamics in the Little Ruaha River catchment. It highlights the importance of integrating remote sensing with the accurate classification algorithms for precisely modelling and generating information that could be used to overcome the land use and land cover change problems for the sustainability of the catchment. Furthermore, the study simulating and predicting the future spatial distribution in land use and land cover of the Little Ruaha River catchment based on CA Markov model.

The findings from the study have revealed that the Little Ruaha River Catchment has undergone a notable change in terms of land use and land cover whereby forest, woodland and wetland were found to be the most altered ecosystems. During ground truthing several anthropogenic activities associated to land use land cover transformation were observed which includes forest encroachments, forest fires, expansion of agricultural farms and urbanization as well as unsustainable cultivation resulted to destruction of riparian zones and wetlands. Results from CA Markov model discovered that for the next 25 years (2040) the grassland will dominate in the catchment followed by cultivated land.

The study concludes that, there has been significant changes in land use and cover in the catchment. In order to overcome the land use and land cover change problems for the sustainability of the catchment, the study recommends the holistic system approach in management and utilization of catchment resources. Involvement of many actors and stakeholders to create a multidisciplinary team to ensure sustainable management of Little Ruaha River catchment. Official alone will not be possible to control such large landscape. Authority should take responsible for the whole scene of management while the villagers should also take responsibility in obeying and follow the law and policies governing the proper management of natural resources. Finally, the study recommends on the need of the follow up study to assess the likely impacts of observed LULC change on water balance of the catchment, so as to address whether there will be sufficient water to meet the various water needs in the present and future.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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