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Future Trade-Off for Water Resource Allocation: The Role of Land Cover/Land Use Change

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Abstract: Global croplands, pastures, plantations, and human settlement areas have expanded in recent decades, accompanied by large increases in energy, water, and fertilizer consumption, along with considerable losses of biodiversity. In sub-Saharan Africa, policies are implemented without critical consideration e.g., agricultural expansions impair ecosystem services of the several river basins. The current study has studied landuse/cover and associated rate of change for four-time epochs i.e., 1991, 2001, 2011 and 2021. This employed remote sensing and GIS techniques for LULC analysis while future projection was modelled using cellular automata and Markov chain. The Kappa coefficient statistics were used to assess the accuracy of final classified image while reference images for accuracy assessment were developed based on ground truthing. Overall change results between 1991 and 2021, showed that major percentage loss in area were experienced by water, forest, woodland and wetland which decreased by 8,222Ha (44.11%), 426,161Ha (35.72%), 399,584Ha (35.01%) and 105,186Ha (34.82%). On the other hand, percentage increase in area during the same period were experienced in cultivated land, built up areas and grasslands which increased by 659,346Ha (205.28%), 11,894Ha (159.93%) and 33,547Ha (98.47%). However, even with the expanding thirsty sectors water discharged out of the catchment is on increment at a rate of 498.6 $m^3/s/year$. For dualistic benefits, agroforest practices are recommended along with participatory law enforcement and capacity building of local communities through their institutions.

Keywords: land use/land cover; remote sensing and GIS; water allocation; water resource management

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1. Introduction

Water shortages due to the spatially uneven distribution of water the resources have become a key global issue threatening the water security and restricting the sustainable development of society and the economy [1–4]. The water shortages, coupled with the increasing demand for water, has intensified the conflicts among water users [5]. Studies have proven that such problems can be effectively alleviated through an informed water resources allocation mission [6,7]. However, water resource allocation is a highly complex risk decision-making problem issue with multilevel, multistage, multiagent, multi-objective, and nonlinear correlations. All these are usually affected by conflicting objectives and socio-economic conditions [8]. Global croplands, pastures, plantations, and human settlement areas have expanded in recent decades, accompanied by large increases in energy, water, and fertilizer consumption, along with considerable losses of biodiversity [9,10]. Such changes in land use/land cover have enabled humans to appropriate an increasing share of the planet's resources, but they also potentially undermine the capacity of ecosystems to sustain food production, maintain freshwater and forest resources, regulate climate and air quality, and ameliorate infectious diseases [9].

The land use/land cover change is a hybrid phenomenon. While on one hand land use denotes human employment of the land for a number of social and economic activities, the land cover denotes the physical and biotic character of the land surface as observed naturally or after alteration following the human activities [11–13]. Land use/land cover change causes a number of effects manifested in the biodiversity, hydrological cycle, land productivity and the sustainability of natural environment [14,15]. Continuous from the previous and in the coming years land use/land cover dynamics has been playing a wide role of driving force in alteration of the global environment [15]. Furthermore, land use/land cover can significantly impact the availability of water resources in a watershed and hence affect water resource allocation. Thus, managing water resources allocation and their know-how on how they are affected by the land use/land cover are essential in watershed development.

In many parts of Africa including Tanzania, scholars have indicated a declining state of natural vegetation, for instance, which are replaced by altered land use/land cover following human social-economic activities. In sub-Saharan Africa, projections shows that, land use/land cover changes will further alter regional hydrologic conditions and results in varieties of impacts on ecosystem functioning [16,17]. On one hand, many land use/land cover practices are absolutely essential for humanity, because they provide critical natural resources and ecosystem services, such as food, fiber, shelter, and freshwater. On the other hand, some forms of land use/land cover are degrading the ecosystems and services upon which we depend. Common understanding of the causes of land use/land cover change is dominated by simplifications which, in turn, underlie many ineffective environment-development policies [18]. Understanding the trend of land use/land cover change in a particular place is a good place to begin to address the impacts born out of these changes especially in water resource allocation.

Kilombero River Catchment (KRC) as is the case for many other parts of Tanzania, is sparsely gauged to assist in determining the impacts of land use/land cover change over time [19,20]. The current study has employed Remote Sensing (RS) and Geographic Information System (GIS) to understand the historical and project LULC change in the KRC. RS techniques have been in use since earlier 70's by employing optical and thermal sensors mounted in moving objects such as boats, aircraft, and satellites to provide both spatial and temporal information needed to monitor changes on earth's surface [21,22]. GIS on the other hand, denotes systems that are used to store, retrieve, analyze and display data that are represented spatially or geographically [23]. Integration of remotely sensed data, global positioning system (GPS), and GIS technologies provides a valuable tool for monitoring and assessing earth's surfaces [23,24]. Remotely sensed data can be used to create a permanent geographically located database to provide a baseline for future comparisons. The integrated use of remotely sensed data, GPS, and GIS enables researchers and managers to develop management plans for a variety of natural resource management applications [24].

With the hindsight of how and the extent that land use/land cover change have impacted important catchments such as the Great Ruaha River Catchment[1] [25–28], the Wami-Ruvu River catchment[2] [28–30] and others, it is imperative to study critical catchments such as the KRC which makes more than 60% of the Rufiji Basin water flows to the Indian ocean [31,32]. In addition, the ctachment feeds the 2000MW hydro-electric production (HEP), the Nyerere HEP formally known as Siegler's Gorge [33], and the largest east African mangrove forest and a mix of iconic ecosystems in between [34–36]. Establishing a founded understanding of the historical, the current and the future trends of land use/land cover change, provides a solid foundation upon which development objectives and constraints can be pegged. This research paper therefore, was inspired by the three critical research questions:

[1] GRRC feeds 2nd largest national parks in Africa i.e., the Ruaha National Park and propels more than 50% of potential installed hydropower generation potential in Tanzania (before the 2000 MW of Nyerere HEP which is under construction).

[2] Ruvu catchment form the water towers for the largest commercial city of Tanzania, The Dar es Salaam.

i. What is the historical, current and future land-use and land-cover trend for Kilombero River Catchment?
ii. What is the rate of change of natural ecosystems services offered by this catchment?
iii. In the face of these changes, what are the policy tradeoffs given the role that KRC is poised to play in the national economy?

2. Material and Methods

2.1. Study Area

The current assessment focused within the hydrologic boundaries of the Kilombero River Catchment (Figure 1) which is part of Tanzania's largest hydrologic basin, the Rufiji River Basin (RRB) spreading across the 177,420 km² (about 20% of Tanzania land mass). Kilombero River Catchment in particular extends between Longitudes 34°00'E - 37°20'E and Latitudes 07°40'S - 10°00'S and covers an area of approximately 40,000 km² [31]. The cross section of the catchment (Figure 2) is characteristic of a graben structure with Udzungwa mountain ranges and Mbarika escarpments forming the northly and southerly crests respectively while the middle part (the flood plain) forming the trough extending around 1967 km² [37,38]. This middle part constitutes one of the largest wetlands in east Africa i.e., Kibasira wetland which is at around 300 m above mean sea level [39] and most of its area is internationally designated as a Ramsar site for its environmental significance [40]. Kilombero River Catchment is the most important catchment in respect of agriculture, energy production, natural resources and flow to RRB [40]. Tributaries contributing to Kilombero River Catchment are: Lumemo, Luipa, Mngeta, Kihansi, Mpanga, Mnyela, Ruhuji and Furua. Most areas of KRC are situated in the administrative region of Morogoro where its most developed center (Ifakara) is found some 400 km from Dar es Salaam.

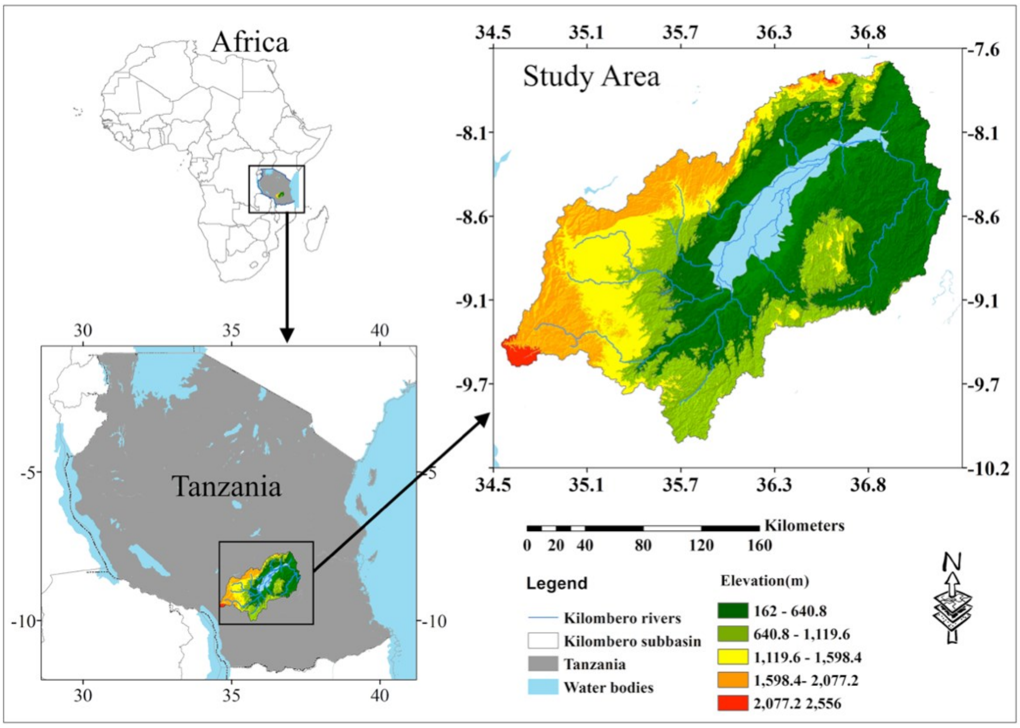

Figure 1. The study area of Kilombelo River Catchment.

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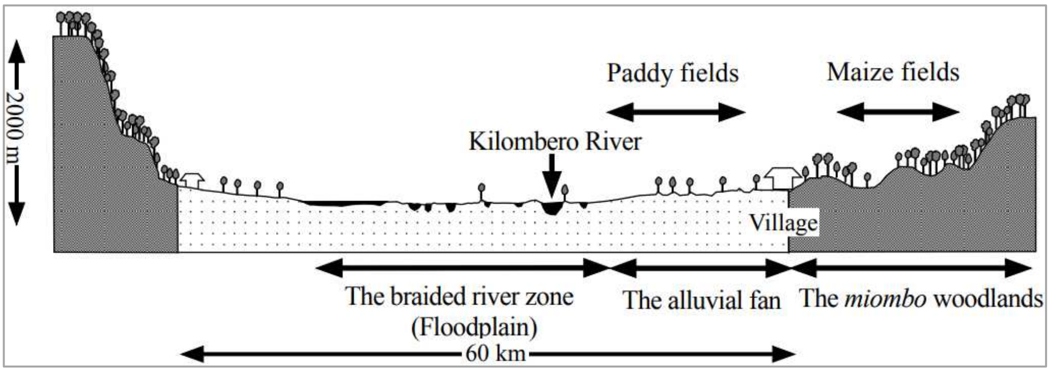

Figure 2. Cross-section of the Kilombero River Catchment – adopted from [37].

2.2. Data Acquisition

Spatial and temporal land use/land cover transformation for KRC was detected for four-time epochs of 1991, 2001, 2011 and 2021 based on the analysis of remote sensed Landsat imagery and GIS. The selection of time epochs was meant to coincide with changes in national water policies since its first promulgation of 1991. Appropriate Landsat imageries were acquired from the United States Geological Survey (https://earthexplorer.usgs.gov/) i.e., a 30m resolution, multispectral level-1 data with cloud cover less than 10% (Table 1). Field observations were made prior to image classification to establish accurate locational point data for each land use/land cover class included in the classification. During ground truthing, the total of eight (8) major land use/land covers were identified which are forest, woodland, bushland, grassland, water bodies, wetland, cultivated land and built up areas (Table 2**Error! Reference source not found.**).

Table 1. Satellite Imagery Data.

Year	Spacecraft ID	Sensor ID	Path/Row	Acquisition Date	Cloud Cover (%)
1991	Landsat 5	TM (SAM)	167/65	05/06/1991	4
		TM (SAM)	167/66	24/08/1991	10
		TM (SAM)	168/65	15/08/1991	2
		TM (SAM)	168/66	15/08/1991	8
		TM (SAM)	168/67	15/08/1991	4
2001	Landsat 7	ETM (SAM)	167/65	07/07/2000	2
		ETM (SAM)	167/66	07/07/2000	1
		ETM (SAM)	168/65	06/09/2002	1
		ETM (SAM)	168/66	18/06/2002	7
		ETM (SAM)	168/67	18/06/2002	10
2011	Landsat 5/7	ETM (BUMPER)	167/65	08/07/2012	6
		ETM (BMPER)	167/66	23/08/2011	10
		TM (SAM)	168/65	21/07/2011	3
		TM (SAM)	168/66	05/07/2011	3
		TM (SAM)	168/67	05/07/2011	5
2021	Landsat 8	OLI_TIRS	167/65	26/08/2021	13
		OLI_TIRS	167/66	09/07/2021	1
		OLI_TIRS	168/65	05/11/2021	2

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		OLI_TIRS	168/66	24/11/2021	2
		OLI_TIRS	168/67	24/11/2021	1

Table 2. Land Use/Land Cover Classification Scheme.

Land Use/Land Cover	Description
Forest	Area of land covered with at least 10% tree crown cover, naturally grown or planted and or 50% or more shrub and tree regeneration cover
Woodland	Area of land covered with low density trees with height between forming closed to open habitat with plenty of sunlight and limited shade
Bushland	Area dominated with bushes and shrubs with occasional short emergent trees
Grassland	Land area dominated by grasses
Water body	Area within body of land, 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 including valley bottoms
Cultivated land	Area subjected to agricultural production farms with crops and harvested crop land
Built up area	Manmade infrastructure (roads and buildings) and settlement (town and villages)

2.3. Image Pre-Processing and Classification

Images were geometrically rectified to ensure geometric compatibility and registered to the UTM map coordinate system UTM zone 37 South, Spheroid Clarke 1880, Datum Arc 1960. 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 clusters. The unsupervised image classification was conducted for all images using ERDAS IMAGINE. Maximum of thirty-six (36) land use/land cover classes were formulated. The formulated classes were visually interpreted and confirmed through the use of ground truthing data and hybrid google maps. Similar classes were joined and re-coded into general classes based on the classification scheme established during ground truthing (Table 2).

2.4. Accuracy Assessment and Change Detection Analysis

Kappa coefficient statistics were used to assess the accuracy of final classified image (*Equation 1*) while reference images for accuracy assessment were developed based on ground truthing data.

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

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.

Change detection analysis conducted to quantify, extent, rate and location of changes in land-use between different time epochs. The study used post-classification comparisons to assess land-use and land-cover changes. The approach identifies changes by comparing independently classified multi-date images pixel-by-pixel using a change-detection matrix [41]. The estimation for the rate of change for the different land covers was computed based on [42].

2.5. Predicting Future Land Use/Land Cover Change

Cellular automata and Markov chain (CA – Markov) analysis were used to predict the spatial distribution of land use/ land cover in the future. Classified land use/land cover map for 2011 which represent past and 2021 which represent current were used to generate conditional transition probabilities (Table 3) which later used simulate land use/land cover for the 2031 and 2041. Markov chain is a statistical tool that describes the probability of land use/land cover 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 [43–45]. Spatial neighborhood effect is the state of neighboring cells to influence the transition of a given cell into different states [25]. This model was based on using and evaluating land use/land cover layers of previous years to predicting the spatial distribution of land use/land cover in the future [46]. For better simulation of temporal and spatial patterns of land use/land cover changes in quantity and space, the combination of two techniques Markov chain analysis and Cellular automata (CA-Markov) were used.

Table 3. Conditional transition probabilities**.**

Assigned	Probability of Changing to							
	FRST	FRSD	RNGB	RNGE	WATR	WETN	CULT	BULT
FRST	0.5620	0.2071	0.2001	0.0033	0.0004	0.0004	0.0264	0.0004
FRSD	0.1174	0.3510	0.4532	0.0129	0.0002	0.0022	0.0624	0.0006
RNGB	0.0855	0.1676	0.5174	0.0346	0.0003	0.0049	0.1873	0.0023
RNGE	0.0087	0.0087	0.3084	0.3346	0.0003	0.0004	0.3356	0.0033
WATR	0.0413	0.1201	0.0886	0.0035	0.669	0.0260	0.0515	0.0001
WETN	0.0039	0.0303	0.0595	0.0051	0.0028	0.6302	0.2682	0
CULT	0.0592	0.0192	0.1374	0.0176	0.0002	0.0011	0.7540	0.0114
BULT	0.0157	0.0290	0.0844	0.0416	0.0001	0	0.1858	0.6434

Note: FRST= Forest; FRSD= Woodland; RNGB= Bushland; RNGE= Grassland; WATR= Water; WETN= Wetland; CULT= Cultivated land; BULT= Built up area.

2.6. CA-Markov Model Set-Up and Validation

The simulated model was developed by using IDRISI Selva v.17.0 software [47]. In the developing CA Markov model, the classified land use map of 2011 which represent past, and 2021 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). For model validation the simulated land use/cover map for 2021 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%) [48]. 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.

3. Results

3.1. Accuracy assessment

Table 4 shows the producers accuracy (PA), user's accuracy (UA), overall accuracies and kappa statistics of the various land use/land cover classes in the Kilombero River Catchment maps for different periods. The overall land use/land cover classification accuracy for the years 1991, 2001, 2011

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and 2021 is 92.01%, 91.74%, 91.96% and 92.44% respectively, with the overall kappa statistics of 0.90 for all year. The accuracy result indicates that the classification accuracy is above 0.8, showing high agreement, which is acceptable for the classification, detection, and prediction of land use/land cover in the Kilombero River Catchment.

Table 4. Accuracy assessment for 1991, 2001, 2011 and 2021 images classification at Kilombero River Catchment.

Land Use/Land Cover	1991		2001		2011		2021	
	PA	UA	PA	UA	PA	UA	PA	UA
Forest	90.88	79.12	90.88	79.88	90.36	86.94	87.74	81.38
Woodland	82.10	73.70	82.10	73.70	86.45	72.88	81.86	78.06
Bushland	88.20	96.03	88.20	96.03	88.80	95.23	92.21	96.93
Grassland	95.93	99.87	95.93	99.87	95.93	99.87	96.06	95.88
Water	94.89	89.56	94.89	94.09	97.87	99.57	97.87	100.00
Wetland	99.06	99.66	99.69	99.66	99.08	99.69	99.64	100.00
Cultivated land	99.34	95.45	95.55	93.36	88.80	96.54	88.91	94.88
Built-up area	99.56	100.00	90.63	84.65	99.56	68.36	99.14	68.69
Overall Accuracy	**92.01**		**91.74**		**91.96**		**92.44**	
Kappa	**0.90**		**0.90**		**0.09**		**0.90**	

3.2. Historical Land use/Land Cover Change Pattern

The areas under different land use/land cover types and percentage are given in Table 5. The land use/land cover percentage graph and maps for the years 1991, 2001, 2011 and 2021 are presented in Figure 3 and Figure 4 respectively. Table 5 shows that land use/land cover for year 1991 was dominated by forest (1,192,996 Ha) followed by woodland (1,141,382 Ha), bushland (1,019,128 Ha), cultivated land (321,188 Ha), wetland (302,098 Ha), grassland (34,067 Ha), water (18,641 Ha) and built up area (7,437 Ha). For the year 2001, land use/land cover was dominated by forest (1,177,109 Ha), woodland (1,121,891 Ha), bushland (1,029,224 Ha), cultivated land (340,472 Ha), wetland (311,029 Ha), grassland (33,500 Ha), water (15,075 Ha) and built up area (8,615 Ha). Moreover, the dominant land use/land cover for the year 2011 was woodland (1,114,763 Ha) followed by bushland (972,794Ha), forest (844,527 Ha), cultivated land (776,118 Ha), wetland (256,250 Ha), grassland (44,310 Ha), built up area (19,331 Ha) and water (11,578 Ha). For the last year of the study period i.e., 2021 the dominant land use/land cover was bushland (1,253,491 Ha) followed by cultivated land (980,534 Ha), forest (766,835 Ha), woodland (714,798 Ha), wetland (196,912 Ha), grassland (67,614 Ha), built up area (19,331 Ha) and water (10,419 Ha).

Table 5. Results for Land use/land cover for 1991, 2001, 2011 and 2021 showing the area and percentage of each category at Kilombero River Catchment.

Year	1991		2001		2011		2021	
Unit	Ha	%	Ha	%	Ha	%	Ha	%
Forest	1,192,996	29.55	1,177,109	29.16	844,527	20.92	766,835	19.00
Woodland	1,141,382	28.27	1,121,891	27.79	1,114,763	27.61	741,798	18.37
Bushland	1,019,128	25.25	1,029,224	25.50	972,794	24.10	1,253,491	31.05
Grassland	34,067	0.84	33,500	0.83	44,310	1.10	67,614	1.67
Water	18,641	0.46	15,095	0.37	11,578	0.29	10,419	0.26
Wetland	302,098	7.48	311,029	7.70	256,250	6.35	196,912	4.88
Cultivated land	321,188	7.96	340,472	8.43	776,181	19.23	980,534	24.29

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Built up area	7,437	0.18	8,615	0.21	16,531	0.41	19,331	0.48
Total	**4,036,935**	**100**	**4,036,935**	**100**	**4,036,935**	**100**	**4,036,935**	**100**

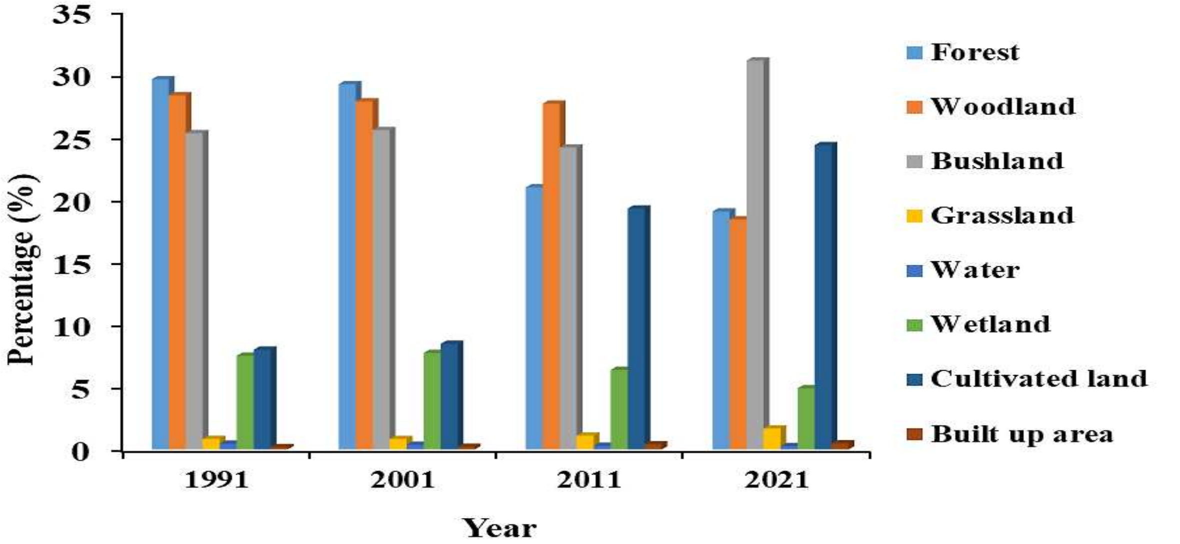

Figure 3. Land use/land cover graph for 1991, 2001, 2011 and 2021 at Kilombero River Catchment.

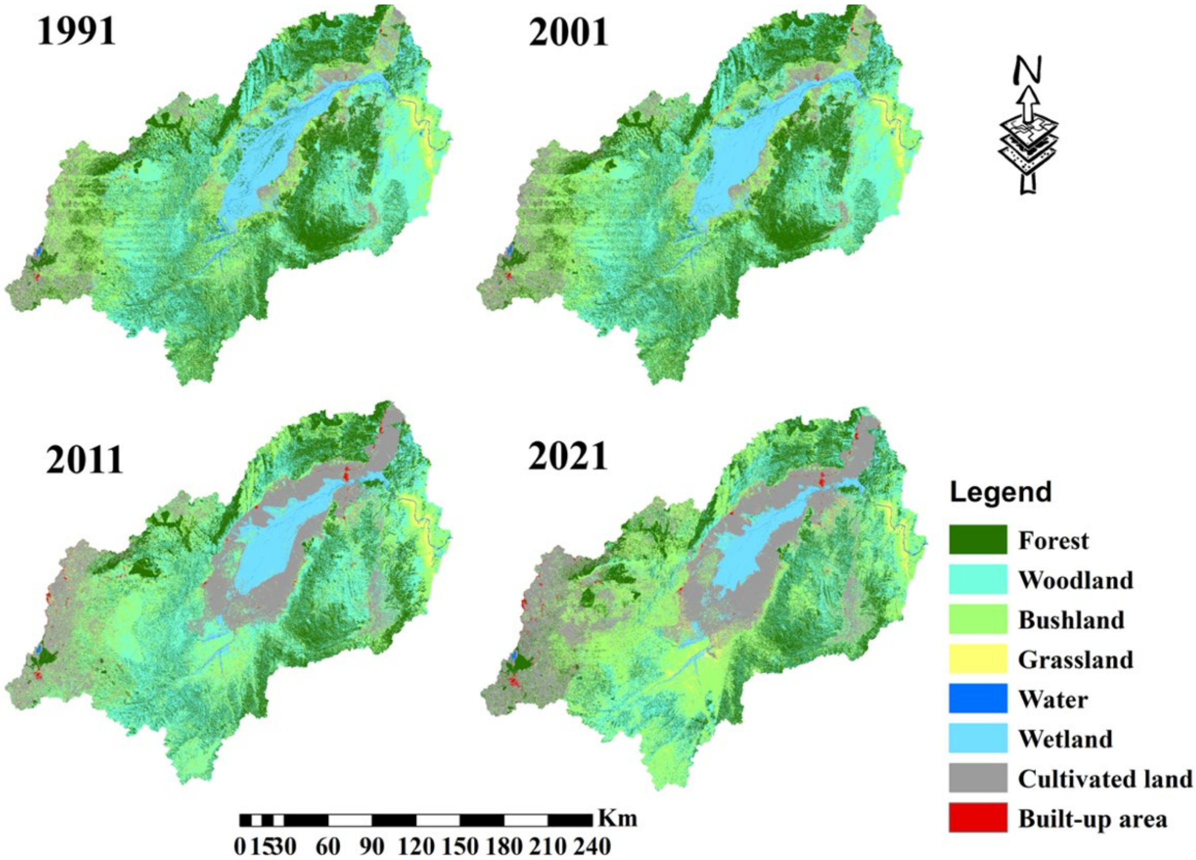

Figure 4. Land use/land cover maps for 1991, 2001, 2011, and 2021 at Kilombero River Catchment.

The changes in land use/land cover for the study period of 1991 - 2001, 2001 - 2011, and 2011 - 2021 are given in Table 6 and illustrated in Figure 4. During the study period 1991 - 2001, woodland experience maximum decreased by 19,492 Ha followed by forest (15,887 Ha), water (3,546 Ha) and grassland (567 Ha) while maximum increasing was observed on cultivated land (19,284 Ha) followed by bushland (10,096 Ha), wetland (8,932 Ha) and built up area (1,179 Ha). The maximum annually

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decrease was observed on woodland (1,949 Ha) followed by forest (1,589 Ha), water (355 Ha) and grassland (57 Ha) while maximum annual increase were observed on cultivated land (1,928 Ha) followed by bushland (1,010 Ha), wetland (893 Ha) and built up area (118 Ha). During the study period 2001 - 2011, the results showed an increase of cultivated land (435,710 Ha), grassland (10,810 Ha) and built-up area (7,916 Ha) while the decrease was observed on forest (332,582 Ha), bushland (56,430 Ha), wetland (54,779 Ha), woodland (7,128 Ha) and water (3,517 Ha). Furthermore, maximum annually decrease was observed on forest (33,258 Ha) followed by bushland (5,643 Ha), wetland (5,478 Ha), woodland (713 Ha) and water (352 Ha) while maximum annually increase was observed on cultivated land (43,571 Ha), grassland (1,081 Ha) and built-up area (792 Ha). During the study period 2011 – 2021 maximum increasing was observed on bushland (280,698 Ha), followed by cultivated land (204,353 Ha), grassland (23,304 Ha) and built-up area (2,800 Ha) while maximum decrease was observed on woodland (372,965 Ha) followed by forest (77,692 Ha), wetland (59,338 Ha) and water (1,159 Ha). Moreover, maximum annually decrease was observed on woodland (37,297 Ha) followed by forest (7,769 Ha), wetland (5,934 Ha) and water (116 Ha) while maximum annually increase was observed on bushland (28,070 Ha) followed by cultivated land (20,435 Ha), grassland (2,330 Ha) and built-up area (280 Ha).

Table 6. Results for Land use/land cover showing the area changed, percentage change and annual rate of change at Kilombero River Catchment.

Year	1991 - 2001			2001 - 2011			2011 - 2021			1991 - 2021		
Unit	Ha	%	Ha/Yr	Ha	%	Ha/Yr	Ha	%	Ha/Yr	Ha	%	Ha/Yr
Forest	-15,887	-1.3	-1,589	-332,582	-28.3	-33,258	-77,692	-9.2	-7,769	-426,161	-35.7	-14,205
Woodland	-19,491	-1.7	-1,949	-7,128	-0.6	-713	-372,965	-33.5	-37,297	-399,584	-35	-13,319
Bushland	10,096	1.0	1,010	-56,430	-5.5	-5,643	280,697	28.9	28,070	234,363	23	7,812
Grassland	-567	-1.7	-57	10,810	32.3	1,081	23,304	52.6	2,330	33,547	98.5	1,118
Water	-3,546	-19	-355	-3,517	-23.3	-352	-1,159	-10	-116	-8,222	-44.1	-274
Wetland	8,931	3	893	-54,779	-17.6	-5,478	-59,338	-23.2	-5,934	-105,186	-34.8	-3,506
Cultivated	19,284	6.0	1,928	435,709	128	43,571	204,353	26.3	20,435	659,346	205.3	21,978
Built up	1,178	15.8	118	7,916	91.9	792	2,800	16.9	280	11,894	159.9	396

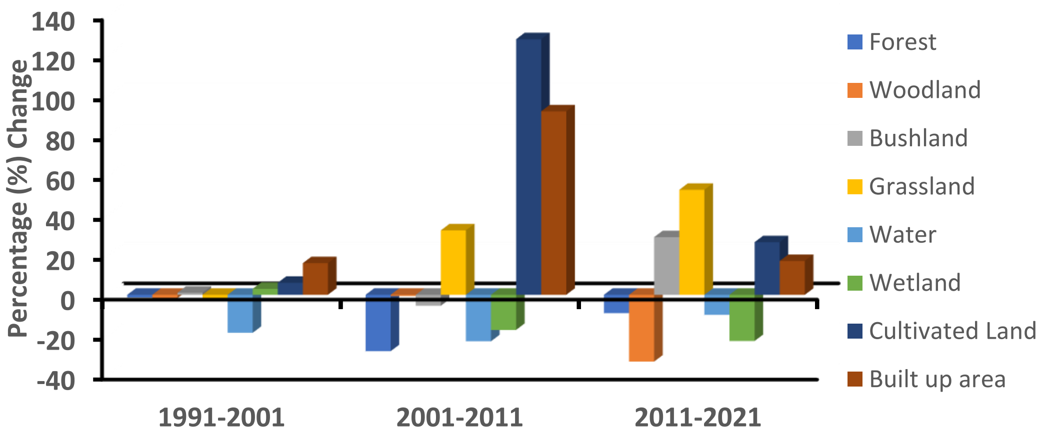

Figure 5. Historical land use/land cover changes for time span 1991 – 2001; 2001 – 2011 and 2011 - 2021.

3.3. Land Use/Land Cover Change Detection Matrix

Table 7 to Table 10 indicates the areas changed based on the change matrix cross-tabulation from 1991 to 2021 whereby land use/land cover class is compared to one another. For the study period between 1991 and 2021 (Table 7), among all the land use/land cover types, the forest experienced a maximum net loss (-426,123 Ha), followed by woodland (-399,615 Ha), wetland (105,187 Ha), and water (-8,220 Ha). On the other hand, cultivated land experience maximum net gain (659,346 Ha) followed by bushland (234,373 Ha), grassland (33,547 Ha) and built up area (11,879 Ha). During the study duration (1991- 2021), the maximum amount of land under forest remained intact i.e., 528,049 Ha. This is followed by bushland (442,391 Ha), woodland (398,012 Ha), cultivated land (241,550 Ha), wetland (170,230 Ha), grassland (16,796 Ha), water (8,596 Ha) and built up area (5,237 Ha). During the study period between 1991 and 2001 as summarized in Table 8, woodland experienced the most net loss (-19,491 Ha) followed by forest (-15,886 Ha), water (-3,545 Ha) and grassland (-568 Ha). The landuse/landcover that experienced net gain in area were led by cultivated land (19,285 Ha) followed by bushland (10,095 Ha), wetland (8,932 Ha) and lastly was the built up areas (1,178 Ha). During the study duration (1991- 2001), a total of 1,165,330 Ha forest remained intact, followed by woodland (1,114,670 Ha), bushland (987,618 Ha), cultivated land (317,416 Ha), wetland (298,632 Ha), grassland (33,317 Ha), water (15,076 Ha) and built up area (6,893 Ha).

Table 9 indicates the areas changed based on the change matrix cross-tabulation from 2001 to 2011. According to this, cultivated land had experienced the most net gain (435,721 Ha), followed by grassland (10,809 Ha) and built up areas (7,915 Ha). Furthermore, forest experience the most net loss in land mass (-332,574 Ha) followed by bushland (-56,430 Ha), wetland (-54,778 Ha), woodland (-7,147 Ha) and water (-3,516 Ha). During the same study period, the most area under woodland remained intact (830,707 Ha), followed by forest (742,548 Ha), bushland (684,154 Ha), cultivated land (288,257 Ha), wetland (234,274 Ha), grassland (33,500 Ha), water (10,058 Ha) and built up area (8,615 Ha). Table 10 shows the areas changed based on the change matrix cross-tabulation from 2011 to 2021. The woodland had experienced the most net loss (-372,978 Ha), followed by forests (-77,686 Ha), wetland (-59,339 Ha) and water (-1,160 Ha). Furthermore, bushland experience the most net gain (280,699 Ha) followed by cultivated land (204,374 Ha), grassland (23,305 Ha) and built up area (2,785 Ha) During this study period, cultivated land had the most area that remained intact (688,477 Ha), followed by bushland (592,540 Ha), forest (558,295 Ha), woodland (460,304 Ha), wetland (189,978 Ha), grassland (17,439 Ha), built up area (12,511 Ha) and water (9,112 Ha).

Table 7. Land use/land cover detection matrix during the period 1991 – 2021.

Changing from:1991	Area Change to 2021									Net change (Ha)
	FRST	FRSD	RNGB	RNGE	WATR	WETN	CULT	BULT	LOSS	
FRST	**528,049**	234,022	275,309	8,531	832	15,163	130,260	829	**664,946**	-426,123
FRSD	158,889	**1,991**	463,685	10,166	302	3,645	106,025	660	**743,372**	-399,615
RNGB	61,785	92,919	**442,391**	24,808	148	2,193	390,911	3,973	**576,737**	234,373
RNGE	155	316	11,654	**16,796**	7	10	5,071	58	**17,271**	33,547
WATR	809	1,714	2,319	196	**8,596**	3,288	1,690	27	**10,043**	-8,220
WETN	838	8,053	17,284	1,021	414	**170,230**	104,073	184	**131,867**	-105,187
CULT	16,216	6,498	40,264	5,812	120	2,381	**241,550**	8,347	**79,638**	659,346
BULT	131	235	595	284	0	0	954	**5,237**	**2,199**	11,879
GAIN	**238,823**	**343,757**	**811,110**	**50,818**	**1,823**	**26,680**	**738,984**	**14,078**	**1,561,127**	

Note: FRST= Forest; FRSD= Woodland; RNGB= Bushland; RNGE= Grassland; WATR= Water; WETN= Wetland; CULT= Cultivated land; BULT= Built up area. The bold numbers on the diagonal represent unchanged land use/land cover proportions from 1991 to 2021 while the others are the areas changed from one class to another.

Table 8. Land use/land cover detection matrix during the period 1991 – 2001.

Changing from:1991	Area Change to 2001									Net change (Ha)
	FRST	FRSD	RNGB	RNGE	WATR	WETN	CULT	BULT	LOSS	
FRST	**1,165,330**	3,331	12,672	0	0	10,815	835	11	**27,664**	-15,886
FRSD	3,346	**1,114,670**	23,056	0	0	0	107	202	**26,711**	-19,491
RNGB	7,081	3,603	**987,618**	174	8	31	20,141	473	**31,511**	10,095
RNGE	2	0	172	**33,317**	0	0	577	0	**751**	-568
WATR	1,210	197	446	9	**15,076**	1,551	131	21	**3,565**	-3,545
WETN	106	89	2,289	0	12	**298,632**	969	0	**3,465**	8,932
CULT	31	0	2,726	0	0	0	**317,416**	1,015	**3,772**	19,285
BULT	2	0	245	0	0	0	297	**6,893**	**544**	1,178
GAIN	**11,778**	**7,220**	**41,606**	**183**	**20**	**12,397**	**23,057**	**1,722**	**70,319**	

Note: FRST= Forest; FRSD= Woodland; RNGB= Bushland; RNGE= Grassland; WATR= Water; WETN= Wetland; CULT= Cultivated land; BULT= Built up area. The bold numbers on the diagonal represent unchanged land use/land cover proportions from 1991 to 2001 while the others are the areas changed from one class to another.

Table 9. Land use/land cover detection matrix during the period 2001 – 2011.

Changing from:2001	Area Change to 2011									Net change (Ha)
	FRST	FRSD	RNGB	RNGE	WATR	WETN	CULT	BULT	LOSS	
FRST	**742,548**	242,722	102,891	493	904	9,508	77,577	457	**434,552**	-332,574
FRSD	80,626	**830,707**	151,851	589	226	2,437	55,434	20	**291,183**	-7,147
RNGB	15,965	33,574	**684,154**	574	7	1,776	292,367	826	**345,089**	-56,430
RNGE	0	0	0	**33,500**	0	0	0	0	**0**	10,809
WATR	1,012	389	966	155	**10,058**	2,117	396	1	**5,036**	-3,516
WETN	251	2,248	11,130	486	319	**234,274**	62,151	170	**76,755**	-54,778
CULT	4,124	5,103	21,821	8,512	64	6,139	**288,257**	6,441	**52,204**	435,721
BULT	0	0	0	0	0	0	0	**8,615**	**0**	7,915
GAIN	**101,978**	**284,036**	**288,659**	**10,809**	**1,520**	**21,977**	**487,925**	**7,915**	**770,267**	

Note: FRST= Forest; FRSD= Woodland; RNGB= Bushland; RNGE= Grassland; WATR= Water; WETN= Wetland; CULT= Cultivated land; BULT= Built up area. The bold numbers on the diagonal represent unchanged land use/land cover proportions from 2001 to 2011 while the others are the areas changed from one class to another.

Table 10. Land use/land cover detection matrix during the period 2011 – 2021.

Changing from:2011	Area Change to 2021									Net change (Ha)
	FRST	FRSD	RNGB	RNGE	WATR	WETN	CULT	BULT	LOSS	
FRST	**558,295**	135,303	130,717	2,172	263	244	17,224	234	**286,157**	-77,686
FRSD	118,408	**460,304**	456,918	13,006	200	2,219	62,935	604	**654,290**	-372,978
RNGB	67,442	132,180	**592,540**	27,325	255	3,874	147,745	1776	**380,597**	280,699
RNGE	350	351	12,452	**17,439**	12	16	13,550	132	**26,863**	23,305
WATR	307	895	660	26	**9,112**	194	383	1	**2,466**	-1,160
WETN	693	5,425	10,667	913	506	**189,978**	48,062	2	**66,268**	-59,339

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CULT	21,094	6,832	48,931	6257	69	382	**688,477**	4,054	**87,619**	204,374
BULT	177	326	951	469	1	0	2,094	**12,511**	**4,018**	2,785
GAIN	**208,471**	**281,312**	**661,296**	**50,168**	**1,306**	**6,929**	**291,993**	**6,803**	**1,222,121**	

Note: FRST= Forest; FRSD= Woodland; RNGB= Bushland; RNGE= Grassland; WATR= Water; WETN= Wetland; CULT= Cultivated land; BULT= Built up area. The bold numbers on the diagonal represent unchanged land use/land cover proportions from 2011 to 2021 while the others are the areas changed from one class to another.

3.4. Future Land Use/Land Cover Simulation for 2031 and 2041

The validation target, kappa index of agreement (KIA) was used for the 2021 land use/land cover predictions, which were acceptable to both the actual and the predicted land use/land cover. All the kappa results showed an acceptable standard greater than 80% which confirmed that the prediction accuracy was reasonable for future land use/land cover prediction. The kappa statistics were as follows: K_{no} is 0.93, $K_{location}$ is 0.95, K_{Strata} is 0.95, and $K_{standard}$ is 0.91. The corrected percentage for each type of land use/land cover was over 90%, so the model was satisfactory for making predictions for 2031 and 2041 respectively. The predicted areas of land under different land use/land cover types and percentage are given in Table 11. The respective land use/land cover for this projected period are presented in Figure 6 and Figure 7 below. Table 11 shows that land use/land cover for projected year 2031 will be dominated by bushland (1,309,248 Ha) followed by cultivated land (1,120,396 Ha), forest (685,239 Ha), woodland (657,047 Ha), wetland (133,897 Ha), grassland (97,030 Ha), built up area (25,918 Ha) and water (8,159 Ha). For the projected year 2041, land use/land cover will be dominated by bushland (1,364,920 Ha) followed by cultivated land (1,260,186 Ha), forest (603,307 Ha), woodland (571,806 Ha), grassland (126,654 Ha), wetland (71,291 Ha), built up area (32,742 Ha) and water (6,028 Ha).

Table 11. Results for Land use/land cover for 2021, projected 2031 and 2041 showing the area and percentage of each category at Kilombero River Catchment**.**

Year	**2021**		**2031**		**2041**	
Unit	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
Forest	766,835	19.00	685,239	16.98	603,307	14.95
Woodland	741,798	18.37	657,047	16.27	571,806	14.16
Bushland	1,253,491	31.05	1,309,248	32.44	1,364,920	33.81
Grassland	67,614	1.67	97,030	2.40	126,654	3.14
Water	10,419	0.26	8,159	0.20	6,028	0.15
Wetland	196,912	4.88	133,897	3.32	71,291	1.77
Cultivated land	980,534	24.29	1,120,396	27.76	1,260,186	31.22
Built up area	19,331	0.48	25,918	0.64	32,742	0.81
Total	**4,036,935**	**100**	**4,036,935**	**100**	**4,036,935**	**100**

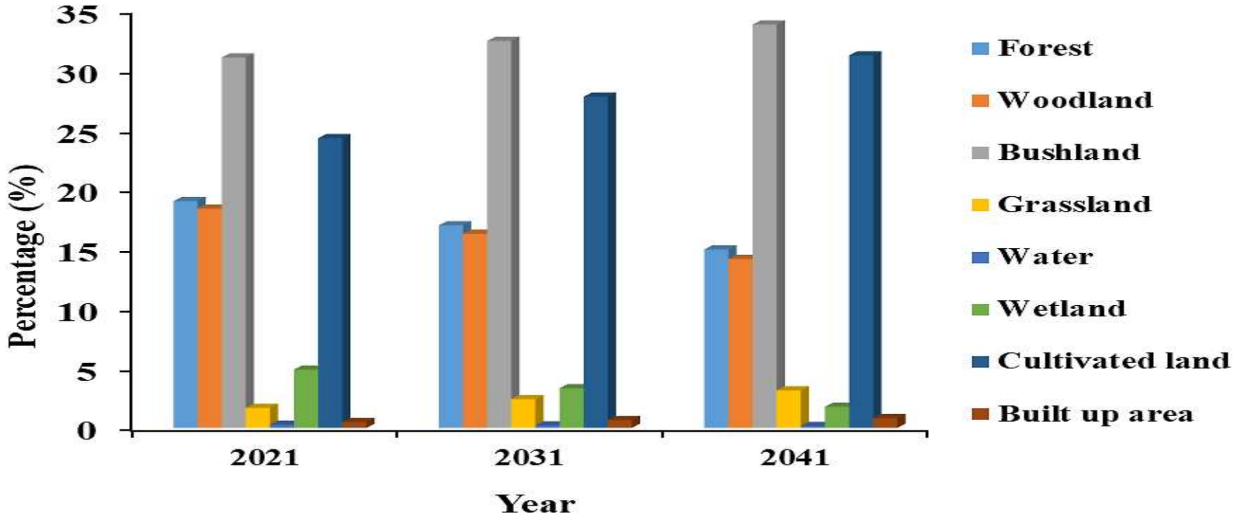

Figure 6. Land use/land cover graph for 2021 and projected 2031 and 2041 at Kilombero River Catchment.

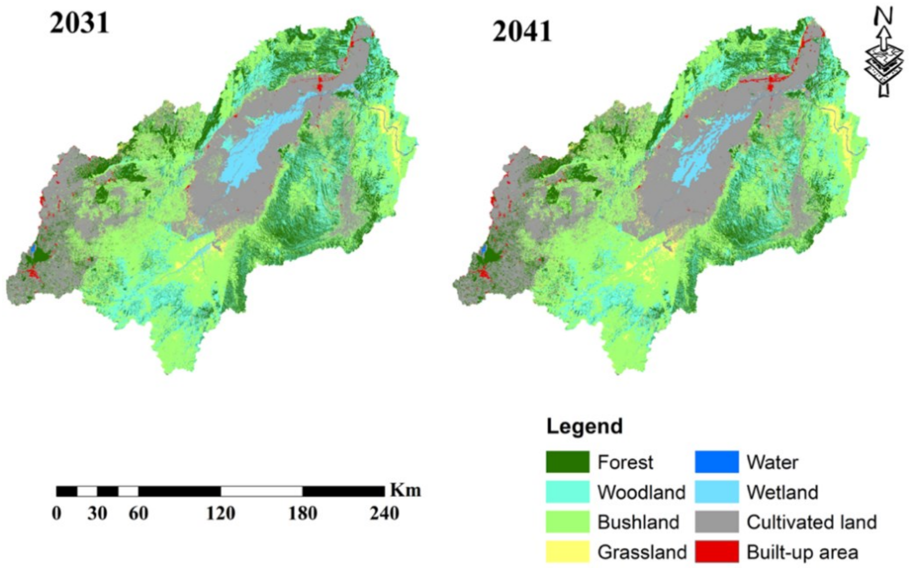

Figure 7. Projected land use/land cover maps for 2031 and 2041 at Kilombero River Catchment.

The projected changes in land use/land cover for the period 2021 – 2031 and 2031 - 2041 are given in Table 12. It is expected that from 2021 - 2031, woodland will experience maximum decreased by 84,751 Ha followed by forest (81,596Ha), wetland (63,015 Ha) and water (2,260 Ha) while maximum increasing will be observed on cultivated land (139,862 Ha) followed by bushland (55,757 Ha), grassland (29,416 Ha) and built up area 6,587 Ha). The maximum annually decrease is expected on woodland (8,475 Ha) followed by forest (8,160 Ha), wetland (6,302 Ha) and water (226 Ha) while the maximum annually increase is expected on cultivated land (13,986 Ha) followed by bushland (5,576 Ha), grassland (2,942 Ha) and built up area (659 Ha). Moreover, the projected changes for the period 2031 – 2041 maximum decrease is expected on woodland (85,241 Ha) followed by forest (81,931 Ha), wetland (62,606 Ha) and water (2,131 Ha) while maximum increase is expected on cultivated land (13,979 Ha) followed by bushland (55,672 Ha), grassland (29,624 Ha) and built up area (6,824 Ha). The maximum annually decrease is expected on woodland (8,524 Ha) followed by forest (8,193 Ha),

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wetland (6,261 Ha) while maximum annually increase is expected on cultivated land (13,979 Ha) followed by bushland (5,567 Ha), grassland (2,962 Ha) and built up are (682 Ha).

Table 12. Projected land use/land cover showing the area changed, percentage change and annual rate change for 2031 and 2041.

Year	2021 - 2031			2031 - 2041		
Unit	Ha	%	Ha/Year	Ha	%	Ha/Year
Forest	-81,596	-10.64	-8,160	-81,931	-11.96	-8,193
Woodland	-84,751	-11.43	-8,475	-85,241	-12.97	-8,524
Bushland	55,757	4.45	5,576	55,672	4.25	5,567
Grassland	29,416	43.51	2,942	29,624	30.53	2,962
Water	-2,260	-21.69	-226	-2,131	-26.12	-213
Wetland	-63,015	-32.00	-6,302	-62,606	-46.76	-6,261
Cultivated land	139,862	14.26	13,986	139,790	12.48	13,979
Built up area	6,587	34.08	659	6,824	26.33	682

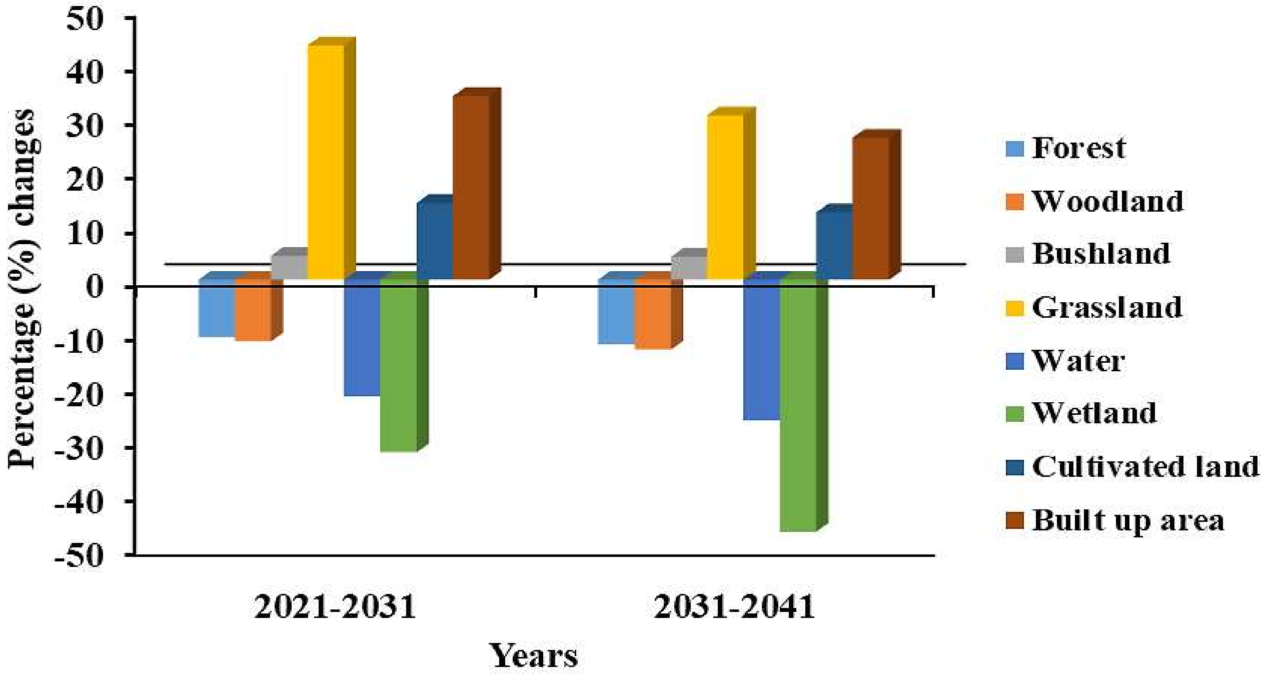

Figure 8. Projected land use/land cover changes in 2021 - 2031 and 2031 - 2041 at the Kilombero River Catchment.

4. Discussion

The assessment of LULC for this paper considered four-time epochs i.e., 1991, 2001, 2011 and 2021. We have also projected the same for the next two decades i.e., 2031 and 2041. The selected time epochs were meant to coincide well with the national population census whose growth contributes to most of the LULC changes. Furthermore, results of the national census, trigger major policy changes e.g., the national water policy that was firstly promulgated in 1991 followed by 2002 [49] and the current drafting that started around 2022 population census. The projections were meant to coincide with the 2030 global and Africa targets i.e., the sustainable development goals (SDG) [50] and the African forest landscape restoration initiative (AFR100) that is a county-led effort to bring 100 million Ha of land in Africa into restoration by 2030 [51,52]. Across the time epochs, the LULC classification accuracy was above 90% whereas Kappa statistics was 0.90 which shows high agreement and hence acceptable for the classification, detection, and prediction of land use/land cover [53–55].

Analysis of LULC for each of the study years shows a growing transformation from domination of forests, woodland and bushland to bushland and cultivated land as the top dominant LULC from 1991 to 2021 and as projected to 2031 and 2041. Considering that bushlands are essentially abandoned farmlands due to occasional implementation of conservation policy and flooded farms [56,57] it means cultivated land has the most overall growing dominance in the study area. Furthermore, results show more shrinking landmass under wetland and water which raises a red flag on water availability in the catchment. However, a parallel study by authors [58] shows a diametric result (i.e., consistent increase of water discharge at a rate of 498.6 $m^3/s/year$) at the most downstream gauge station i.e., Kilombero at Swero (1KB17) which is located in the protected Selous game reserve. This can be explained by, either the fact that all hydroclimatic parameters show favorable trend as discussed in [58] or that changing LULC generated more sediment that has altered the cross section of the pretty much abandoned gauge station due to budget and accessibility through the game reserve (observed data between 29th Nov 1957 and 31st Dec 1981). Otherwise, the huge growing dominance of cultivated land would have caused a declining trend of water discharged at this strategic gauge station.

In addition, conversion of LULC to more cultivated land creates loose soils that are swept by floods meaning soil and water quality is changed. This is from the known detrimental effects of agricultural practices on soil quality which include, erosion, desertification, salinization, compaction, and pollution [59]. On the other hand, farm inputs causes eutrophication that ultimately leads to the reduction of oxygen in water, the release and accumulation of toxic substances in water and sediments-polluting the aquatic environment, which can lead to the death of aquatic organisms, ecosystems and humans that may inadvertently drink or be exposed to the polluted water [60,61].

This study also studied specific alteration of LULC from one such LULC to another. This is based on a change matrix cross-tabulation across the time epoch. The same shows that in the time span of 1991 – 2001, 2001 – 2011, 2011 – 2021 and overall, 1991 – 2021, forests and woodland lost the most landmass as compared to cultivated land and bushland that have gained the most. Although there was a consistent increase in land mass under cultivation, the period between 2001 to 2011 experienced the most significant jump. This could be attributed to three major government policies i.e., big results now (BRN) of 2013, *kilimo kwanza* initiative (KKI) translated as prioritization of agriculture of June 2009 and establishment of southern agricultural growth corridor (SAGCOT) by 2010. All of them are based on a need to link the local peasantry farmers with agribusiness actors across the corridor (including Kilombero which form the most consequential cluster). Furthermore, privatization and establishment of big sugarcane where Kilombero sugar company limited (KSCL) took over by 1998 and expanded significantly around 2005/06 following their initiative to build the Kidatu bridge and associated road improvement which also spearheaded agriculture expansion in the catchment. In addition, Kilombero plantations limited (KPL) was privatized and expanded paddy farming activities by 2008-2010. Both plantations introduced and supported out grower farmers who expanded just as much as the plantations themselves. However, implementation of the just enacted water resources management act No. 11 of 2009 and following the establishment of record number of water users' association (WUA) in the catchment saw the decline of cultivated land within the protected wetland and river buffer. This increased bushland (abandoned farms) and reduced the declination of areas occupied by water. Wetland continued to decline since abandoned farms (bushlands) were yet to rejuvenate to proper wetlands.

5. Conclusion

This study has carried out LULC assessment and its implication to water availability in the Kilomebro river catchment (KRC). The former considered four-time epochs viz. 1991, 2001, 2011 and 2021 and were then projected into two subsequent decades i.e., 2031 and 2041. These were pegged against the key drivers or targets nationally to regionally/globally. The assessment has demonstrated the LULC transformation in KRC following the major government policies and/or anthropogenic dynamics. This has shown that alarming growth rate of areas under cultivation vs shrinkage of land mass occupied by water and/or wetlands. However, growth of the water thirsty sector seems to not impact the water availability at the most downstream gauging station i.e., Kilombero at Swero (1KB17). Nevertheless, this station is located in the undeveloped game reserve area whose station assessment is not frequent and has not been operational since 31st December 1981.

The assessment has also indicated the steeper LULC conversion to cultivated towards 2010 during which government introduced major agricultural programs in the SAGCOT area especially Kilombero cluster. With the ongoing access infrastructure development and expansion plans in this cluster, more LULC conversion to cultivated land and settlements is expected as indicated in the project future. This will inevitably impact water availability in the catchment and hence impact other water uses especially the environment and government flagship projects e.g., the Nyerere hydropower project downstream of Kilombero catchment that contributes to more than 60% of flow.

The following recommendations are proposed from this assessment:

a) Reevaluation of the status of Swero (1KB17) gauging station cross section to ascertain the credibility of the ratting curve and hence the discharge data generated from its stuff gauge reading.
b) Implement agroforest policy to obtain duo objectives i.e., on conservation (land and water) and support economic growth from agriculture which is the main economic activity.
c) Evaluate the implementability and socio-economic impact of 60m buffer zone from any water source as required in the water resources management act No 11 of 2009 and the national environmental management act No. 20 of 2004.
d) Continuous capacity building on locals (through WUAs and other institutions) and participatory law enforcement embedding water and natural resources management.

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