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Modeling Spatial and Temporal Dynamics of Land use and Land cover in the Songwe Sub-basin, Tanzania, using Cellular Automata Markov Model

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Abstract

Using the Cellular Automata (CA) Markov Model in combination with Geographic Information System (GIS) and Remote Sensing (RS) technologies, this study examines the spatial and temporal dynamics of land use and land cover (LULC) in the Songwe sub-basin, Tanzania. By combining historical data spanning from 1990 to 2020 at a spatial resolution of 30 meters, the study aims to forecast future LULC changes up to the year 2100. GIS technologies made it easier to spatially analyze and visualize these changes, and LULC data was used to calibrate the CA-Markov model with transition probabilities taken from the historical era. The results highlight significant land use transitions, with significant transitions from woodland and natural vegetation to agricultural land and urban areas. These changes are largely driven by population growth and the rising demand for food production. Forest cover and woodland areas have notably decreased by 54.01% and 59.10%, respectively, while agricultural land has increased by 216.97%. Projections indicate that by 2100, forests and woodlands will largely disappear, being replaced by agricultural land. Additionally, significant reductions in wetlands and water bodies are expected. Rapid urbanization is anticipated to intensify the degradation of natural ecosystems, leading to further strain on hydrological systems. The study recommends the implementation of stronger conservation policies, including the expansion of protected areas for vital habitats, and the promotion of sustainable agricultural practices such as agroforestry and conservation tillage. To enhance long-term ecological resilience, the study also emphasizes the need for ecosystem-based management approaches that prioritize water resource preservation and biodiversity. Additionally, involving local communities in land management decisions is crucial for ensuring the sustainability of natural resources and ecosystem services in the Songwe sub-basin.

Keywords: *Cellular Automata -Markov model; Landsat images; Land use land cover change; Spatial and temporal dynamics; Remote sensing*

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Introduction

Sustainable development is dependent on the preservation of environmental sustainability, which is endangered by changes in land use and land cover (LULC) (Dammag *et al.*, 2023). LULC refers to the way in which the Earth's surface is utilized by humans, such as for agriculture, urban development, forestry, or conservation, as well as the natural cover of the land, such as forests, grasslands, and wetlands (Dammag *et al.*, 2023). LULC alterations are among the most significant land surface modifications, with far-reaching implications for ecosystems and environmental processes. These changes impact hydrology, soil erosion, sedimentation, ecosystem dynamics, biodiversity, climate, and biogeochemical cycles (Leta *et al.*, 2021). The spatial temporal interaction of biophysical and human elements is the basis for land use change (Sigalla *et al.*, 2024), human activities such as deforestation, urbanization, and agricultural growth. These disturbances affect biodiversity, soil erosion, climate change, environmental conservation, pollution, and water resources (Gemmechis, 2022). LULC dynamics are influenced by a variety of factors such as government activities, natural disasters, economic activity, and population shifts (Beroho *et al.*, 2023). Therefore, understanding these changes is critical for evaluating their environmental and socio-economic implications (Beshir *et al.*, 2023).

In recent years, Tanzania has experienced significant shifts in LULC, with notable consequences for ecosystem function and hydrological processes. Studies in East Africa indicate that these changes impact catchment conditions, leading to soil erosion, sedimentation, freshwater scarcity, and water contamination. Particularly in regions such as the Songwe sub-basin, LULC changes have been linked to declining water quality, increasing sedimentation, and land degradation, posing significant challenges to long-term environmental sustainability. The complex relationship between LULC change and environmental degradation underscores the necessity of assessing human-environment interactions at a sub -basin scale (Beroho *et al.*, 2023).

Despite the extensive studies on LULC changes by using GIS, Remote Sensing (RS), and CA-Markov models in land use modeling in various locations, including the Songwe sub-basin there is a lack of literature on their application to simulating and forecasting future LULC trends in the Songwe sub-basin, with an emphasis on both historical dynamics and potential future scenarios. Using GIS and remote sensing methods, this study intends to examine past land use and land cover (LULC) changes in the Songwe sub-basin from 1990 to 2020. It also uses the Cellular Automata-Markov (CA-Markov) model to predict future LULC trends for 2040, 2070, and 2100. This work adds to our understanding of how land use transformation affects ecosystem services in the Songwe sub-basin by providing a thorough analysis of past, current, and future LULC changes. This study aims to provide solutions for enhancing ecosystem sustainability and mitigating hydrological and soil degradation, thereby supporting broader sustainable development initiatives.

Materials and Methods

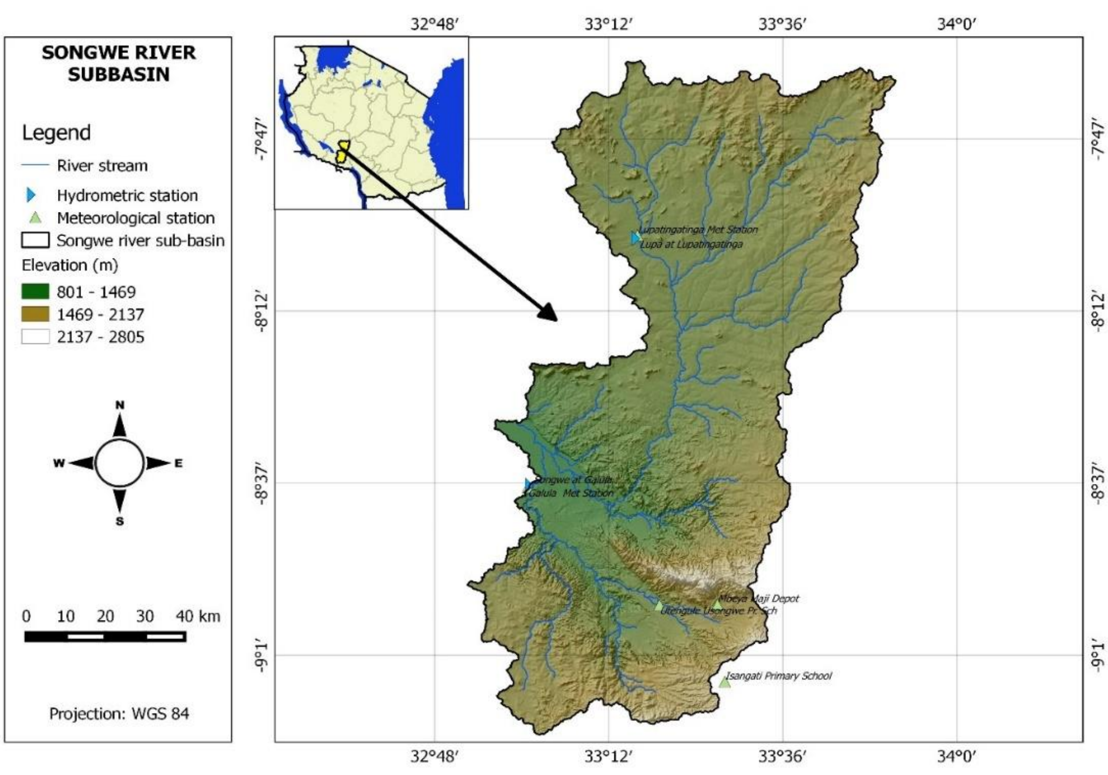
Study Area

The Songwe catchment, encompassing approximately 10,800 km², is located within the eastern Lake Rukwa Basin in the southwestern region of Tanzania. Geographically, it stretches between latitudes 07°40'S and 09°20'S and longitudes 33°00'E and 33°50'E, as detailed by Mwalwiba *et al.*, (2023). This region is characterized by a diverse topography, with numerous hills ranging in elevation from 600 to 2,400 meters above sea level. The catchment area is known for its fertile land and favorable agricultural potential, supported by a tropical climate that brings abundant rainfall and moderate temperatures. The long rainy season, extending from October to May, contributes to the region's agricultural productivity. In contrast, the dry season occurs from June to September. Precipitation levels vary significantly across the catchment, with the highlands receiving an average annual rainfall of 2,600 mm, while the lowlands receive approximately 650 mm. The average temperature within the Songwe catchment ranges from 16°C to 30°C, with variations largely influenced by altitude. The catchment is drained by three primary rivers: Lupa, Songwe, and Zira. These rivers flow across expansive plains before converging and ultimately discharging into Lake Rukwa. The river systems exhibit notable seasonality, with peak flows observed during the wet season and diminished flows during the dry months. River flows typically reach their peak in February and March, while the driest period is recorded in September, with a reduction in flow from July to November. The Songwe catchment serves as a vital source of freshwater for the surrounding regions, including Mbeya City, Songwe District, and Chunya District.

A variety of activities that are essential to the livelihoods of the nearby communities, such as Mbeya City, Songwe District, and Chunya District, are supported by the catchment. The main economic activity is agriculture, especially the production of crops like coffee, tobacco, and maize. The area is home to both large- and small-scale mining operations, industrial operations, and fishing in addition to agriculture. The high speed of urbanization, notably in and around Mbeya City, is further pushing changes in land use and adding to the region's environmental issues. Although the Songwe catchment supports a variety of plants and animals and offers vital ecosystem services like soil fertility, water filtration, and biodiversity support, changes in land use brought about by mining, urbanization, and agricultural growth have resulted in environmental pressures like sedimentation, soil erosion, and deterioration of water quality. These socio-economic activities, combined with the catchment's ecological significance, highlights the importance of understanding the dynamics of land use and land cover changes in the region. Such an understanding is crucial for managing the competing demands of development, environmental sustainability, and water resource conservation.

Figure 1

Map of Songwe District Tanzania the Study Area



Data Collection, Tools and Techniques

Assessing land use land cover change

Data acquisition

The study on the spatial and temporal land use/cover transformation of the Songwe sub-basin utilized Landsat imagery and GIS to analyze changes across four-time epochs: 1990, 2000, 2010, and 2020. In particular, the study used multispectral level-2 data with less than 10% cloud cover from 30-meter-resolution Landsat images. Landsat 5 (TM) from 1990 and 2000, Landsat 5 (TM BUMPER) from 2010, and Landsat 8 (OLI_TIRS) from 2020 are among the chosen images. For these images, the equivalent path/row combinations in various years are 169/65, 169/66, 170/65, and 170/66. The images taken on April 9 (169/65), September 20 (169/66), July 25 (170/65), and September 7 (170/66) of 1990 (Landsat 5-TM (SAM)) showed no cloud cover. Images with 169/66 (August 30), 170/65 (August 10), and 170/66 (August 10) with no cloud cover were utilized in 2000 (Landsat 5-TM (SAM)). Images from 170/65 (May 11) and 170/66 (May 29) were included since they had only 1% cloud cover in 2010 (Landsat 5-TM (BUMPER)). Finally, 169/66 (September 22), 170/65 (August 28), and 170/66 (August 28) 2020 (Landsat 8-OLI_TIRS) images with 0% cloud cover were chosen. This choice preserves a high-quality dataset for analysis while guaranteeing uniformity in temporal and spatial coverage. These images were sourced from the United States Geological Survey's Earth Explorer website (https://earthexplorer.usgs.gov/). For the purpose of establishing precise locational point data for each land-use and land-cover class included in the classification, field observations were conducted before image classification.

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 (Iterative Self- Organizing Data Analysis – ISODATA) image classification was conducted for all images using ERDAS IMAGINE 2016. Maximum of thirty-six (36) land use/cover classes were formulated. The formulated classes were visually interpreted and confirmed through the use of ground truthing data correspond to the images acquisition and hybrid google maps. Using ground truthing data, related classifications were then combined and recorded into main land-use/cover classes following the unsupervised ISODATA classification. This stage guarantees that the classification is more meaningful for analysis and in line with actual data. The ISODATA result was then added to the Maximum Likelihood Classification (MLC) for further refining after the related classes were combined. As a supervised classification technique, the MLC increases accuracy by classifying each pixel according to the most likely land-use/cover class determined by statistical analysis. In this instance, a CCI Global classification method was used, most likely using the Climate Change Initiative Global Land Cover dataset. The main land use/covers classifications covered by the MLC were: forest, woodland, bushland, grassland, water bodies, wetland, cultivated land and built-up areas. 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, and Built-up Areas: Areas where human infrastructure has been developed, such as urban centers, residential areas, roads, and industrial zones.

Accuracy assessment

Kappa coefficient statistics was used to assess the accuracy of final classified image. Reference images for accuracy assessment were developed based on ground truthing data. Confusion matrix techniques was also used to estimate the classification accuracy. Accuracy assessment was conducted for each epoch (1990, 2000, 2010, and 2020) with ground truthing data specific to each period to ensure temporal consistency and reliable validation of the classification results.

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

Where N is the total number of sites in the matrix, r is the number of rows in the matrix, xii 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

This study employed change detection analysis to quantify the extent, rate, and spatial distribution of land use/land cover (LULC) changes across different time periods. The assessment was conducted using a post-classification comparison approach, ensuring a detailed and systematic evaluation of temporal variations in land cover. The study employed post-classification comparisons to identify LULC changes in order to get more accurate and trustworthy results. The estimation for the rate of change for the different land covers was computed based on Kashaigili and Majaliwa, (2010). Satellite images from various time periods were independently classified using this method, and the classified outputs were then compared. This method reduces classification errors that could result from spectrum fluctuations brought on by atmospheric or sensor perturbations by examining classified images rather than raw pixel values.

Predicting future land use land cover change

The study used classified land use and land cover (LULC) maps for 2010 and 2020 to generate conversion probabilities and forecast future changes in LULC. CA-Markov model (Cellular Automata-Markov Chain) was employed to analyze past land use transitions and predict future changes. First, Markov Chain analysis was used to compute a transition probability matrix, which quantified the likelihood of each land use category converting into another over time. The transition areas matrix was generated to estimate the total expected change in each LULC class. IDRISI Selva v.17.0 software facilitated the development and validation of the CA-Markov model, ensuring accurate future predictions. For model validation, the simulated land-use/cover map for 2020 was compared with the actual satellite- derived land-use/cover map based on the Kappa statistics. Then, the standard Kappa index was used to check whether the model is valid

Results

Accuracy

The overall land use land cover classification accuracy for the years 1990, 2000, 2010, and 2020 is 92.01%, 91.74%, 91.96%, and 92.44%, respectively. The overall kappa statistic for all years is 0.90, indicating a strong agreement between the observed and predicted classifications in the Songwe sub basin.

Historical Land Use Land Cover change in Songwe sub basin

Over the past few decades, the Songwe sub-basin has experienced considerable changes in land use and land cover (LULC), mostly due to population growth and agricultural expansion. Significant changes in several land categories are revealed by the examination of Land Use/Land Cover (LULC) variations from 1990 to 2020 (Figure 2). Over the course of the 30-year study period, these changes represent the effects that both natural and human activities had on the terrain. Changes in land use have a significant impact on biodiversity, socioeconomic development, and environmental sustainability. With 32.69% (351,771 ha) of the Songwe sub-basin covered by woodland in 1990, it was the most common land cover. Bushland (27.69%), forest (24.34%), and agricultural land (12.41%) were the next most common land covers. There were notable developments during the next ten years. In 2000, forest cover declined to 29.58% (318,299 hectares) and bushland rose to 33.06% (355,733 ha) as the primary land cover (Table 1). The percentage of forest lands decreased as well, reaching 23.01% (247,548 hectares). The start of the significant agricultural growth began during this time, and it climbed slightly to 12.68% (136,447 ha). The decade spanning from 2000 to 2010 saw a surge in agricultural growth. By 2010, the percentage of land used for agriculture had increased to 25.76% (277,201 ha), almost doubling from the previous ten years. Bushland exhibited a modest decline, but remained considerable at 30.21% (325,086 ha). With a decrease of 23.51% (252,937 ha) and

18.59% (200,039 ha), respectively, woodland and forest areas continued to drop. In line with urbanization tendencies, there was also a discernible rise in built-up areas and grasslands during this time. Agricultural land cover continued to dominate in the most recent decade, 2010–2020, reaching 39.35% (423,346 hectares) at that time.

Table 1

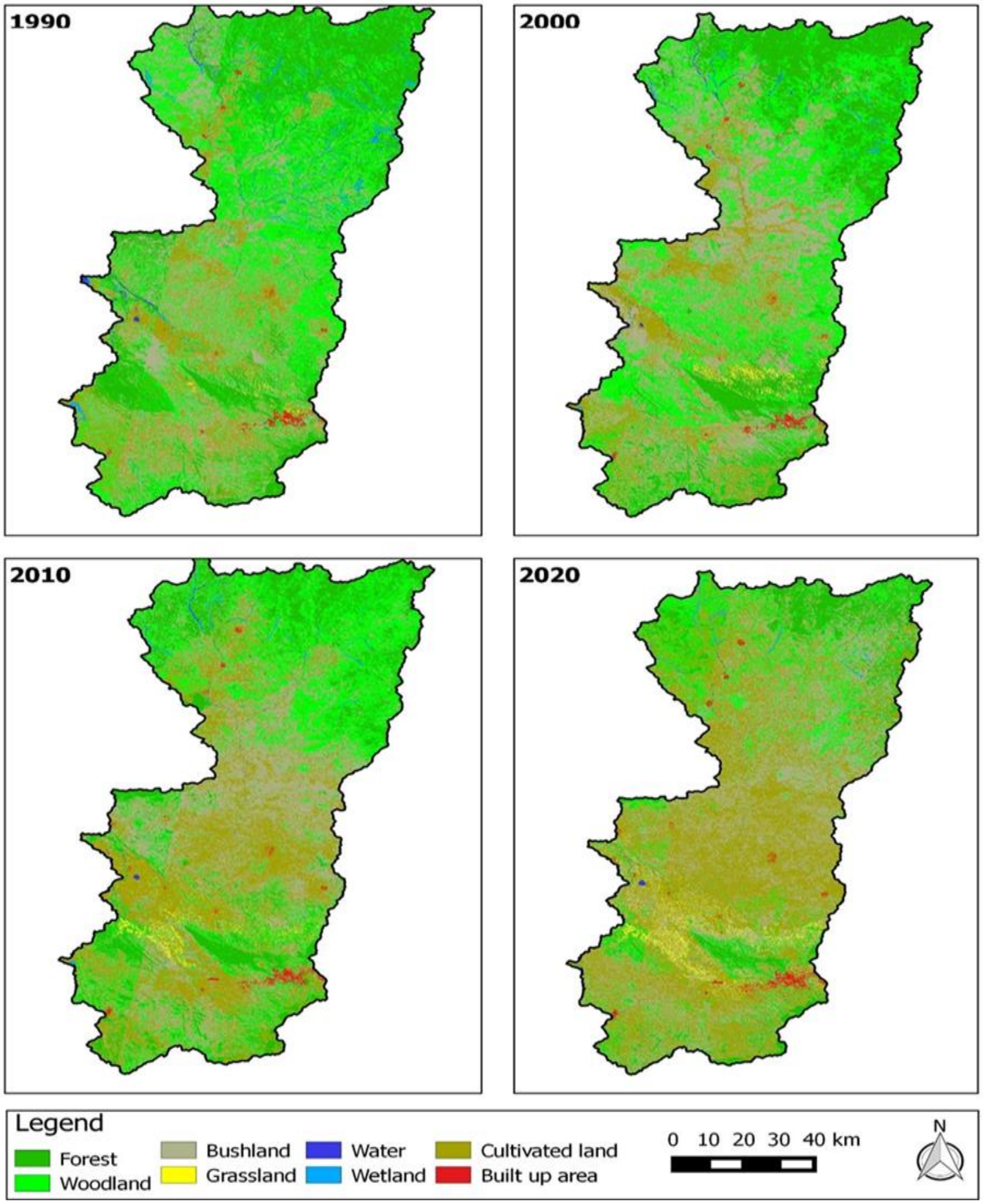
Land Use Land Cover Spatial Coverage in Songwe Sub Basin, Tanzania

Class	1990		2000		2010		2020		1990 - 2000			2000 - 2010			2010 - 2020		
	Area [Ha]	Percentage [%]	Area [Ha]	Percentage [%]	Area [Ha]	Percentage [%]	Area [Ha]	Percentage [%]	Area change (Ha)	Percentage change (%)	Annual Rate of Change (Ha/year)	Area change (Ha)	Percentage change (%)	Annual Rate of Change (Ha/year)	Area change (Ha)	Percentage change (%)	Annual Rate of Change (Ha/year)
Forest	261880	24.34	247548	23.01	200039	18.59	120428	11.19	-14332	-5.47	-1433	-47509	-19.19	-4751	-79611	-39.80	-7961
Woodland	351771	32.69	318299	29.58	252937	23.51	143863	13.37	-33472	-9.52	-3347	-65363	-20.54	-6536	-109073	-43.12	-10907
Bushland	297960	27.69	355733	33.06	325086	30.21	359827	33.42	57773	19.39	5777	-30647	-8.62	-3065	34740	10.69	3474
Grassland	1385	0.13	6164	0.57	9573	0.89	17356	1.61	4779	345.00	478	3409	55.31	341	7783	81.30	778
Water	3942	0.37	2882	0.27	2011	0.19	1293	0.12	-1060	-26.89	-106	-871	-30.22	-87	-719	-35.73	-72
Wetland	21560	2.00	4360	0.41	3760	0.35	3030	0.28	-17200	-79.78	-1720	-600	-13.77	-60	-730	-19.41	-73
Agriculture	133560	12.41	136447	12.68	277201	25.76	423346	39.35	2887	2.16	289	140753	103.16	14075	146146	52.72	14615
Built up	4019	0.37	4643	0.43	5471	0.51	6935	0.64	625	15.54	62	828	17.83	83	1464	26.75	146
Total	1076078	100	1076078	100	1076078	100	1076078	100									

While woodland and forest areas saw considerable declines, falling to 13.37% (143,863 ha) and 11.19% (120,428 ha), respectively, bushland remained sizable at 33.42% (359,827 ha). At 6,935 ha, or 0.64% of the total, the built-up area has increased, indicating the sub-basin's continued urbanization

Figure 2

Land Use/Land Cover Maps for 1990, 2000, 2010, and 2020 at Songwe Sub Basin, Tanzania



Land use/ land cover transition Matrix in the Songwe Sub basin

A thorough understanding of the alterations in land use and land cover (LULC) within the Songwe sub-basin over a three-decade period (1990-2020 is offered by the transition matrices (Table 2, Table 3, Table 4, and Table 5). These matrices show notable changes, particularly with regard to the expansion of agriculture and deforestation. This pattern emphasizes how deforestation and increased agriculture production affect natural ecosystems. Between 1990 and 2000, Deforestation was evident as the forest area shrank from 247,545 hectares to 141,352 hectares. A significant amount of the forest area was converted to cultivated land (3,528 ha), bushland (27,867 ha), and woodland (70,520 ha). Conversion from forest (70,520 ha), bushland (79,976 ha), and grassland (2,506 ha) resulted in an increase in woodland. A significant amount of bushland was converted into woodland (79,976 ha) and cultivated land (61,542 ha). Large-scale increase of farmed land (from 7,535 ha to 136,447 ha), mostly at the expense of bushland, woodland, and forests. The amount of forest cover decreased steadily between 2000 and 2010, reaching 116,344 hectares. significant conversion to scrub (21,766 ha) and woodland (55,317 ha). decrease in woodland as a result of its conversion to bushland (52,271 ha) and farmed land (49,412 ha). The area of bushland grew from 297,960 hectares to 355,733 ha as a result of the conversion of woods. Having undergone substantial conversion from bushland, woodland, and forest, the cultivated land area grew to 277,202 ha. The forest area decreased significantly to 75,179 hectares between 2010 and 2020. continuous conversion of land to different uses, primarily agriculture and forest areas. Forestry was reduced to 61,869 hectares as a result of being turned into wilderness and agricultural land. The area of bushland grew to 359,575 hectares, primarily from woodland and forest. The area under cultivation increased to 423,422 hectares, maintaining the pattern of agricultural growth at the expense of natural ecosystems.

Table 2

Land use land cover transition in Songwe sub-basin Tanzania between 1990 - 2000

	FRST	FRSD	RNGB	RNGE	WATR	WETN	AGRL	BULT	TOTAL
FRST	141352	70520	27867	33	715	3529	3528	0	247545
FRSD	81230	135657	79976	89	885	8497	11976	0	318310
RNGB	30373	119060	139465	497	598	4191	61542	0	355727
RNGE	185	959	2506	259	157	49	2050	0	6164
WATR	487	317	427	0	1226	403	22	0	2882
WETN	693	483	406	0	73	2701	4	0	4360
AGRL	7535	24705	47108	496	287	2189	54127	0	136447
BULT	25	70	206	11	0	1	312	4020	4644
TOTAL	261880	351771	297960	1385	3942	21560	133560	4020	1076078

FRST; Forest FRSD; Woodland RNGB; Bushland RNGE; Grassland WATR; Water WETN; Wetland AGRL; Cultivated land BULT; Built up area

Table 3

Land use land cover transition in Songwe sub-basin, Tanzania between 2000 - 2010

	FRST	FRSD	RNGB	RNGE	WATR	WETN	AGRL	BULT	TOTAL
FRST	116344	55317	21766	389	576	561	5054	47	200054
FRSD	95996	94649	52271	839	287	1034	7762	111	252948
RNGB	23406	115374	147024	2325	273	288	36024	347	325062
RNGE	2150	3011	3170	283	2	0	955	0	9572
WATR	231	119	347	46	1170	16	81	0	2011
WETN	279	143	426	0	451	2301	159	0	3759
AGRL	8950	49412	129641	2281	121	159	85963	675	277202
BULT	194	274	1088	1	1	0	449	3463	5471
TOTAL	247549	318299	355733	6163	2882	4360	136447	4643	1076078

FRST; Forest FRSD; Woodland RNGB; Bushland RNGE; Grassland WATR; Water WETN; Wetland AGRL; Cultivated land BULT; Built up area

Table 4

Land use land cover transition in Songwe sub-basin, Tanzania between 2010 - 2020

	FRST	FRSD	RNGB	RNGE	WATR	WETN	AGRL	BULT	TOTAL
FRST	75179	32482	7759	74	239	260	4528	28	120550
FRSD	46616	61869	27306	215	191	286	7373	64	143920
RNGB	43887	98747	128049	1605	166	139	86787	195	359575
RNGE	708	1015	2630	6371	4	0	6602	19	17350
WATR	127	115	134	2	761	0	154	0	1293
WETN	179	147	168	0	344	2012	188	0	3038
AGRL	33123	58171	158200	1305	305	1063	170214	1042	423422
BULT	219	390	841	0	0	0	1355	4123	6929
TOTAL	200039	252937	325086	9573	2011	3760	277201	5472	1076078

FRST; Forest FRSD; Woodland RNGB; Bushland RNGE; Grassland WATR; Water WETN; Wetland AGRL; Cultivated land BULT; Built up area

Table 5

Land use land cover transition in Songwe sub-basin, Tanzania between 1990 - 2020

	FRST	FRSD	RNGB	RNGE	WATR	WETN	AGRL	BULT	TOTAL
FRST	76991	26317	12792	35	663	1572	2161	11	120541
FRSD	54650	49663	30428	61	526	2724	5972	29	144055
RNGB	76565	129096	100711	434	762	6491	45449	88	359595
RNGE	2672	3965	6392	118	56	42	4095	9	17349
WATR	189	126	105	1	754	25	103	0	1303
WETN	136	479	619	0	213	1580	21	0	3048
AGRL	50452	141537	145580	677	965	9121	74404	526	423261
BULT	226	588	1334	59	2	6	1356	3356	6926
TOTAL	261880	351771	297960	1385	3942	21560	133560	4019	1076078

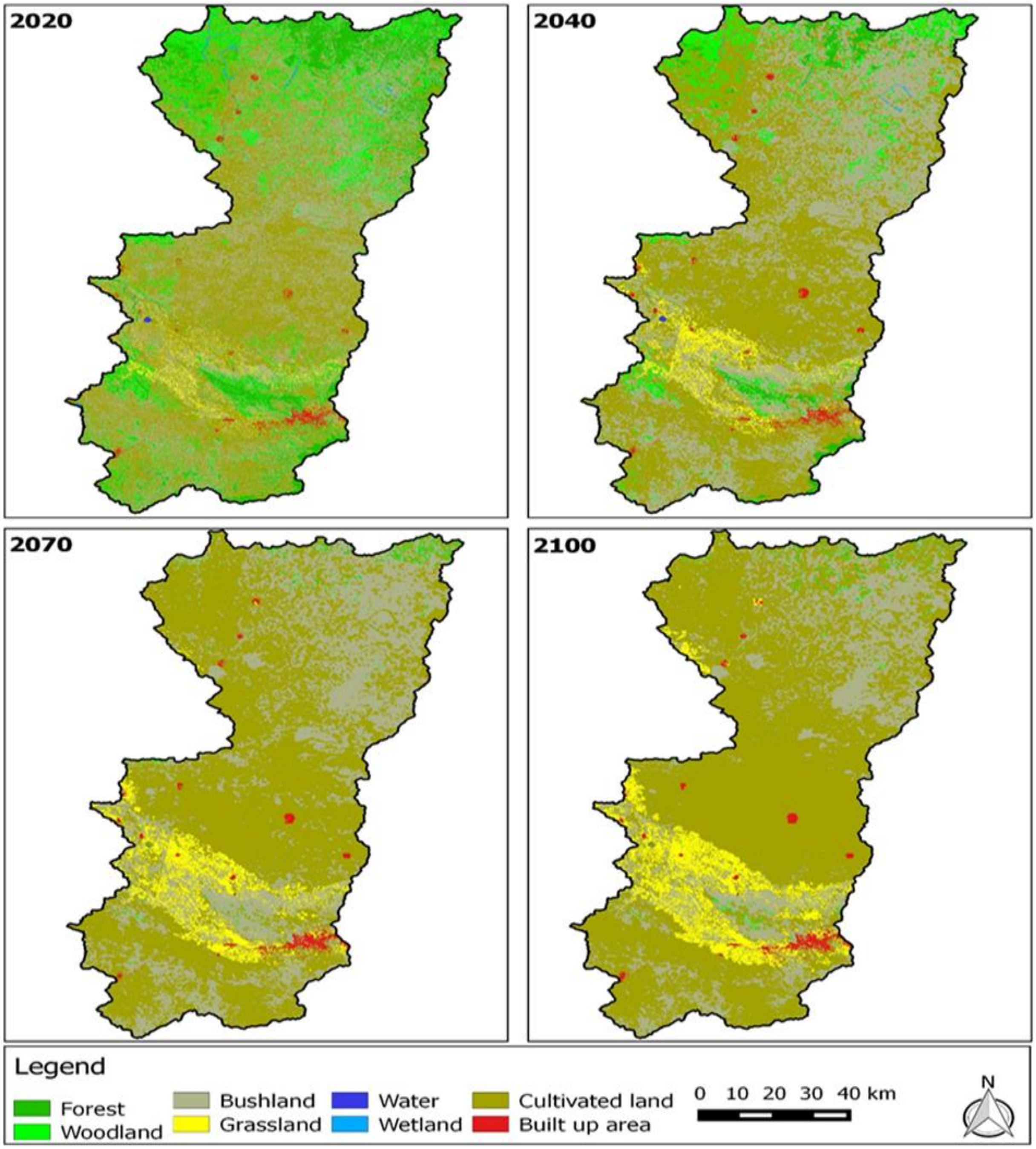
FRST; Forest FRSD; Woodland RNGB; Bushland RNGE; Grassland WATR; Water WETN; Wetland AGRL; Cultivated land BULT; Built up area

Future land use land cover change in Songwe sub basin

In many categories, including forest, woodland, bushland, grassland, water, wetland, cultivated land, and built-up area, the results show the expected distribution of land use and land cover (LULC) from 2020 to 2100 (see Figure 3). Significant variations in land use patterns have been documented over time, especially in the areas of cultivated land, forest cover, and other LULC categories. The expected drop in the forest area between 2020 and 2040 is estimated to be 88,945 hectares (8.24%), or a significant decrease of 120,428 hectares (11.19%) to 31,483 hectares (2.95%). In addition, the woodland area drastically decreases over time, going from 143,863 hectares (13.37%) in 2020 to 71,489 hectares (6.69%) by 2040, a decrease of 72,374 hectares (6.68%). This indicates a widespread shift of natural landscapes into various land uses. Between 2020 and 2040, bushland grew somewhat, from 359,827 hectares (33.42%) to 400,935 hectares (36.74. From 17,356 hectares (1.61%) in 2020 to 34,933 hectares (3.27%) in 2040, the area covered by grasslands grows. Despite its moderate growth, this indicates a trend toward open land area expansion brought about by the conversion of formerly wooded areas into grasslands. During this time, wetlands and bodies of water both declines. There is a decline in both water areas and wetlands from 1,293 hectares (0.12%) to 621 hectares (0.06%) and 3,030 hectares (0.28%) to 1,528 hectares (0.14%). Between 2020 and 2040, the amount of land under cultivation increases dramatically, from 423,346 hectares (39.35%) to 527,035 hectares (49.30%). The increased need for agricultural output, which is probably being driven by population growth and the need for food security, is reflected in this rise of 103,689 hectares (9.95%). Additionally, by 2040, the built-up area will grow, rising from 6,935 hectares (0.64%) to 8,055 hectares (0.75%). Between 2040 and 2070, the amount of forest land decreases even more, with the forest cover decreasing from 31,483 hectares (2.95%) to 3,437 hectares (0.32%). This represents a sharp decline of 28,046 hectares (2.63%) during a 30-year period, suggesting that forest resources are almost depleted and that by 2070 there would be very little forest cover left. A more dramatic decrease occurs in the woodland area, which goes from 71,489 hectares (6.69%) in 2040 to 5,895 hectares (0.55%) in 2070. The majority of woodland areas appear to have been transferred to other land uses, based on the loss of 65,594 hectares (6.14%). In 2070, there will be 360,984 hectares (33.11%) of bushland, down from 400,935 hectares (36.84%) in 2040. This decline of 39,951 hectares (3.73%) shows that even bushland areas are being converted to other land uses, even though they are still the major land cover type. During this time, grassland continues to grow, reaching 61,142 hectares (5.72%) in 2070 from 34,933 hectares (3.27%) in 2040. Wetlands and water bodies are still diminishing; in 2070, wetlands will have shrunk from 1,528 hectares (0.14%) to 92 hectares (0.01%), and water areas will have decreased from 621 hectares (0.06%) in 2040 to 66 hectares (0.01%). The likelihood of these ecosystems disappearing entirely by 2070 suggests extreme environmental stress. There is a significant increase in the amount of land under cultivation, going from 527,035 hectares (49.30%) in 2040 to 634,680 hectares (59.37%) in 2070. The necessity to support a growing population is driving the continued conversion of natural landscapes into agricultural land, as evidenced by the growth of 107,645 hectares (10.07%). The built-up area shows evidence of ongoing urbanization and infrastructure development, growing from 8,055 hectares (0.75%) in 2040 to 9,782 hectares (0.92%) in 2070. The period from 2041 to 2070 sees a continuation of the patterns witnessed in the previous era, with additional losses in forest and woodland areas. By 2070, forests have mostly been converted to other land uses, and the amount of forest cover is almost completely gone. With only 3,249 hectares (0.30%) of forest cover left by 2100 a modest decrease from 3,437 hectares (0.32%) in 2070 forest cover had virtually completely vanished by that time. The fact that forests are almost certain to disappear by 2100 emphasizes how urgent conservation actions must be taken to stop additional loss. From 5,895 hectares (0.55%) in 2070 to 5,817 hectares (0.54%) in 2100, the amount of woodland continues to decrease slightly. The small amount of woodland that remains suggests that this sort of land is no longer an important part of the landscape. From 360,984 hectares (33.11%) in 2070 to 258,109 hectares (23.48%) in 2100 a decrease of 102,875 hectares (9.63%) bushland experiences a steep fall. This notable decline points to additional land conversion, most likely for urban or agricultural uses. By 2100, both wetlands and water bodies will be almost dead; wetlands will have shrunk from 92 hectares (0.01%) to 89 hectares (0.01%), and water areas will have decreased somewhat from 66 hectares (0.01%) to 62 hectares (0.01%) in 2070. Severe environmental degradation is suggested by the almost complete extinction of these habitats. With an increase from 634,680 hectares (59.37%) in 2070 to 711,001 hectares (66.51%) in 2100, arable land continues to be the majority. The increase of 76,321 hectares (7.14%) reflects the ongoing demand for agricultural land, probably at the expense of natural ecosystems. The built-up area shows a slight increase, rising from 9,782 hectares (0.92%) in 2070 to 10,422 hectares (0.97%) in 2100, indicating continued urban development.

Figure 3

Predicted Future Land Use Land Cover Maps for 2040, 2070, and 2100, at Songwe Sub Basin, Tanzania



Discussion

Historical Land Use Land Cover change in Songwe sub- basin

An interesting case study of how human activity and natural processes affect Sub-Saharan African landscapes is the changes in land use and land cover (LULC) in the Songwe sub-basin over the last three decades. Significant trends that not only have local effects but also reflect larger regional and worldwide patterns of environmental change are shown by the analysis of LULC fluctuations from 1990 to 2020. The 0.90 kappa average value indicating a strong agreement between the observed and predicted classifications in the Songwe sub- basin. This value signifies a strong agreement, reinforcing the reliability of our classification process. High kappa values suggest minimal classification errors, providing confidence in the detected LULC changes. Similar patterns of deforestation and agricultural intensification have been reported by studies carried out in other parts of East Africa, including Tanzania's Kilombero Valley and Kenya's Upper Tana River basin. In the Ethiopian Highlands, for example, a recent study by Beshir *et al.,* (2023) found that over a 30-year period, logging and agricultural expansion were the main causes of a 42.76% decline in forest cover. This demonstrates the widespread effect of agricultural operations on woodland areas throughout the region, as evidenced by the 54.01% drop in woodland and the 59.10% reduction in forest cover noted in the Songwe sub-basin. Among the most noteworthy developments during the 30-year period was the tremendous expansion in agricultural land in the Songwe sub-basin, which increased by 216.97%. This development appears to be putting more strain on the Songwe sub-basin's land resources than has been documented in other Sub-Saharan African locations. Increases in built-up areas of 72.57% in the Songwe sub-basin indicate tendencies in urbanization that are representative of larger Sub-Saharan African processes. Rapid urban expansion in the region is attributed to population increase and rural-to-urban migration (Mnyali and Materu, 2021). Consistent with these results is the Songwe sub-basin's growing built-up area, especially the acceleration from 2010 to 2020, which points to a tendency toward more concentrated urban development. The reduction in wetlands and water bodies in the Songwe sub-basin is alarming since these ecosystems play crucial ecological roles; wetlands have shrunk by 85.95% and water bodies by 67.21%. Reports of comparable decreases have been made in other parts of Africa. The growth of 1,153.07% and 20.76%, respectively, in grassland and bushland areas contrasts with patterns in certain other regions where grasslands are frequently turned into agricultural land. The Songwe sub-basin's noticeable increase in grassland, however, would point to changes in land management techniques, perhaps in relation to grazing and other agricultural activities. The historical examination of LULC changes shows clear trends over the decades, with the largest reductions in woodland and forest cover taking place between 1990 and 2010, and then huge increases in agricultural production and urbanization in the decade that followed. These patterns align with the conclusions of recent research conducted by Osman *et al.,* (2023) which emphasized the quickening rate of changes in land cover in emerging countries due to population expansion and economic development. In conclusion, the Songwe sub-basin's LULC changes between 1990 and 2020 are indicative of larger regional and worldwide patterns in the transition of land use. Significant environmental issues faced by many emerging regions are reflected in the sub-basin's extensive deforestation, increased agricultural production, urbanization, and loss of wetlands. Land management techniques and conservation initiatives urgently need to be prioritized in light of these changes' significant effects on biodiversity, climate regulation, and sustainable development.

Land use/ land cover transition in the Songwe Sub- basin

Over the past three decades, there has been a notable decrease in the amount of forest and woodland regions. The main causes of this decrease are conversions to bushland and agricultural land. Climate regulation, carbon sequestration, and biodiversity are all severely impacted by the loss of forest cover. Over all time periods, the amount of land under cultivation has increased steadily and significantly. This trend highlights the increasing strain that agricultural activities driven by population development and the demand for food security are placing on natural environments. Although agricultural growth boosts livelihoods, it endangers the sub-basin's sustainability and ecological balance. Both inflows and outflows have occurred in bushland. Bushland first grew as a result of conversion from woods and forests. The constant change from bushland to agricultural land, however, demonstrated the dynamic character of this land cover type. Wetlands and submerged places have not changed much. Although these ecosystems are still comparatively stable, they are nonetheless susceptible to degradation and invasion from growing agricultural lands. The amount of land that is built up has steadily increased due to infrastructure development and urbanization. Even while the overall area is still tiny in comparison to other land uses, the trend points to growing pressures from development and human settlement.

Future land use land cover change in Songwe sub-basin

The study highlights a significant transformation in land use and land cover within the Songwe sub-basin, driven primarily by urbanization and agricultural expansion. A striking reduction in forest cover from 8.24% in 2020 to just 0.30% by 2100 indicate a severe loss of biodiversity and ecosystem integrity. This tendency is in line with larger worldwide trends, according to which the loss of biodiversity and the degradation of ecosystems are mostly caused by deforestation and land conversion for agriculture (Sigalla *et al.,* 2024). Similarly, woodland areas are expected to decline from 13.37% to 0.54%, reflecting global trends where forests are increasingly converted into farmland to support a growing population. According to Liping *et al.,* (2018), this reflects comparable patterns seen in other areas where forests and woodlands are being destroyed to accommodate an expanding human population. The rapid expansion of cultivated and built-up areas suggests an urgent need to balance food security and environmental conservation (Barbosa de Souza *et al.,* 2023). While grasslands are projected to increase from 3.27% in 2040 to 8.17% in 2100, this rise is likely due to land degradation or grazing needs and is insufficient to compensate for the loss of more complex ecosystems. The near-total disappearance of wetlands and water bodies by 2100 is particularly alarming, as these ecosystems play a crucial role in maintaining water quality, supporting biodiversity, and regulating climate impacts. Without intervention, the projected land use and land cover changes in the Songwe sub-basin could lead to severe environmental challenges, including increased vulnerability to climate change. To mitigate these effects, it is essential to implement targeted strategies such as reforestation programs, which could help restore lost forest cover and enhance carbon sequestration. Promoting agroforestry and sustainable agricultural practices, such as conservation tillage, crop rotation, and integrated land-use planning, would support both food security and environmental conservation.

Despite the valuable insights gained from this study, the study has several limitations, such as the reliance on 30-meter resolution Landsat imagery, while effective for broad-scale LULC analysis, may not fully capture finer land-use details, the CA-Markov model assumes that historical trends will continue, potentially overlooking the influence of unexpected policy interventions, climate variability, and socio-economic shifts. The absence of extensive field validation across different seasons further restricts classification accuracy. To address these limitations, future research should incorporate higher-resolution satellite imagery, develop multi-scenario projections, integrate socio-economic data with LULC models, and quantify the economic value of ecosystem services. Furthermore, participatory GIS approaches involving local communities in land-use planning and management should be explored to enhance sustainable development strategies in Songwe sub-basin.

Conclusion

This study provided the detailed analysis of the spatial and temporal dynamics of land use and land cover (LULC) in the Songwe Sub-Basin, contributing to a deeper understanding of how land use patterns have changed over time in this specific region. With its accurate representation of the sub-basin's dynamic processes, the CA Markov model provides a trustworthy forecast for LULC changes in the future. The findings show a significant change in the patterns of land use, with observable transitions from natural vegetation and wooded regions to agricultural land and urban growth. The growing population and greater need for food production led to a large expansion in the area under cultivation. The growth of urban areas is a sign of increasing pressure from development and human settlement. Flood control, water purification, and wildlife habitats are all seriously threatened by the degradation of wetlands and other bodies of water. Forests and woodlands will almost completely disappear by 2100. The landscape is anticipated to be dominated by agricultural land, which will increase environmental pressure. To balance agricultural expansion with the preservation of natural ecosystems, sustainable land management strategies must be put into place immediately. In order to safeguard the remaining forests, woodlands, wetlands, and water bodies, tougher conservation regulations are urgently needed. Monitoring Land Use and Change (LULC) changes continuously is necessary to assess the success of conservation and land management initiatives in the Songwe sub- basin.

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