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Land Use and Land Cover Change and its Drivers in Lake Singida Catchment, Tanzania

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Abstract

Lakes and their catchments provide essential resources and ecosystem services. However, these global resources are impacted by various anthropogenic activities that drive changes in land use and land cover. The study that generated data for this paper used Landsat TM (1991), ETM+ (2000, 2010), and OLI (2020) satellite imagery to examine land use and land cover change in the Lake Singida catchment. To identify drivers for change, we engaged 19 key informants, conducted surveys of 382 household heads, and reviewed secondary data, including meteorological records, population statistics, and the FAO/UNESCO soil database. We employed purposive sampling for key informants, and random sampling for household heads. Land use types were categorized using supervised classification with the maximum likelihood classifier in ArcMap 10.7. The qualitative data were analysed through content analysis in MAXQDA (version 20), while quantitative data were assessed using IBM SPSS Statistics (version 21) and Microsoft Excel, 2016. The results depict an increase in agricultural land, bare land, built-up area and water body features by 1%, 29%, 13%, and 2%, respectively; and a decrease of bushland and grassland by 7% and 40%, respectively. The key drivers of these changes include climate change, poor soil conditions, population growth, in-migration, land demand, mode of land ownership, land size, urbanization, livestock grazing, human-induced fires, grass-cutting, and traditional salt extraction. These results offer valuable insights into land use dynamics, and highlight the need for sustainable land use planning to conserve natural habitats in the Lake Singida catchment; hence informing broader environmental policy.

Keywords: *land use, land cover change, drivers, catchment, remote sensing*

1. Introduction

Lakes and their catchments provide vital resources for both humans and natural communities worldwide, playing essential roles in carbon cycling, climate regulation, and the delivery of crucial ecosystem services (Tranvik et al., 2009b; Downing, 2010; Grizzetti et al., 2019). Also, they significantly contribute to local economies by supporting livelihoods and offering recreational opportunities, such as boating and picnicking (Fleming & Cook, 2008; Lin & Matzarakis, 2008; Corrigan et al., 2009; Lamsal et al., 2015). Globally, lakes play a crucial role in

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air purification and carbon sequestration; accounting for approximately 20% of terrestrial carbon storage, which enhances human well-being (Tranvik et al., 2009a). In countries like the USA, lakes are associated with the creation of 1.3m jobs; while in China they are responsible for the production of 47.48m tons of fish (Vaccaro et al. 2009; Jia et al., 2013; Rau et al., 2020). Despite these potential benefits, many lakes in the world are under serious threats from widespread changes in land use and land cover; including deforestation, pollution, and disruption of water resources (Cerqueira et al., 2020; Wade et al., 2020; Lynas et al., 2021). Consequently, it is critical to investigate these dynamics and their driving factors to inform responsible authorities, and facilitate effective management and conservation of lake ecosystems.

Between 1990 and 2020, global studies indicated a reduction in forest cover by 7.1%, leading to rampant water pollution in central Germany; and the disruption of the nitrogen cycle in the Great Lakes of the USA (Guiry et al., 2020; Kong et al., 2022; Farrokhi et al., 2023). Additionally, land use changes—such as unplanned agriculture and other activities—have largely resulted in greenhouse gas emissions, estimated at 0.9 [0.1–1.7] GtC yr^{-1}, further disrupting the natural hydrological systems of lakes (IPCC, 2019). The Global International Water Assessment identified human-induced pollution and unsustainable exploitation of fisheries and other living resources as critical concerns in East African lakes (Odada et al., 2003). Changes—such as deforestation, soil erosion, desertification and atmospheric pollution—have caused serious degradation in Lake Victoria, Malawi and Tanganyika (Beeton, 2002). Therefore, investigating the dynamics of land use change and its drivers is crucial for informing decision-making and policy design, thereon enabling the development of sustainable strategies that help alleviate the degradation of lakes and their surrounding areas both at the catchment and global scales. However, information on these phenomena remains insufficient.

Several authors have researched land use change and its drivers globally. For instance, studies in China by Wu et al. (2023) and Wang et al. (2021a, b) identified social factors, population growth, climate change, natural influences, agriculture, and construction activities as significant drivers of land use change in the Nansihu Lake, Waihe, and Trim River Basins. Similarly, Fukushima et al. (2007) noted that population growth and rapid urbanization were key contributors to high deforestation rates in Lake Kasumigaura, Japan. In Ethiopia, research revealed various drivers—including agricultural expansion, urban development, institutional factors, socioeconomic changes, technological advancements, and demographic shifts—leading to substantial deforestation and rapid urbanization in the Upper Blue Nile, Lake Hawassa, and Finchaa catchments (Belay & Mengistu, 2019; Degife et al., 2019; Dibaba et al., 2020). In Tanzania, human activities, population growth, market demand, price incentives, infrastructural development, and biophysical factors have been identified as the principal causes of land use change around the Lake Victoria Basin and Kilombero Valley floodplain (Msofe et al., 2019; Mugo et al., 2020).

Although the existing body of literature on land use change drivers is extensive, however, there remains a notable research gap concerning the Lake Singida catchment. Despite efforts by scholars such as Kaliba et al. (2009), Bell (2019), Mussa et al. (2020), and Kimati et al. (2022) to investigate various aspects of land use change, their studies have largely failed to establish a comprehensive connection between land use alterations and their driving factors. These investigations predominantly addressed issues such as groundwater contamination, salt concentration in aquatic systems, groundwater recharge dynamics across different land use categories, and the development of flood models. Consequently, critical questions regarding the extent and specific drivers of land use change in the Lake Singida catchment remain inadequately explored. It is this that underscores the necessity for a targeted research that not only delineates the patterns of land use transformation, but also articulates the underlying socio-economic and environmental drivers, thereby contributing to a more comprehensive understanding of land use dynamics in this ecologically significant region. Also, addressing this gap is essential for informed policy-making and sustainable land management practices. Thus, the paper's objectives were twofold: (i) to assess the dynamics of land use change from 1991 to 2020; and (ii) to identify the drivers of land use change during this period.

2. Theoretical Framework

The generation of the data for this paper was guided by the Driver, Pressure, State, Impact and Response (DPSIR) Framework, which is used in decision-making to assess the interactions between society and the environment (Tscherning et al., 2012). This framework was deemed a valuable tool for identifying the dynamics of land use change and their drivers, offering essential insights into the causes and forces behind such changes. The Human Environmental Model (HIE) was also utilized to understand the dynamics of land use change and their associated drivers. This model operates under the principles of source, sink, life support, and impacts on welfare (Hammond et al., 1995). In this regard, the model provides extra advantage in examining the drivers of land use change through its elements that deal with the exploitation of natural resources for various purposes within the catchment area. Both frameworks served as descriptive tools for understanding the causes of land use change.

3. Context and Methods

3.1 Study Area

The study was carried out in the Lake Singida catchment (Figure 1), which is located in the Internal Drainage Basin of Central Tanzania, at 4^0 57' 0" S and 4^0 43' 30" S of latitude, and 34^0 39^0 E and 34^0 48^0 E of longitude (URT, 2008). Urbanization is the predominant environmental practice in the area, while agriculture and grazing represent other additional unplanned land use practices that pose serious environmental challenges. The primary water bodies for this site include Singidani, Kindai, and Munangi lakes; while rivers are seasonal lasting from December to May; and dry out from June to November. Recently, flooding and waterlogging have emerged as other significant environmental challenges during the rainy season that affect humans and other ecosystem (IDBWB, 2020).

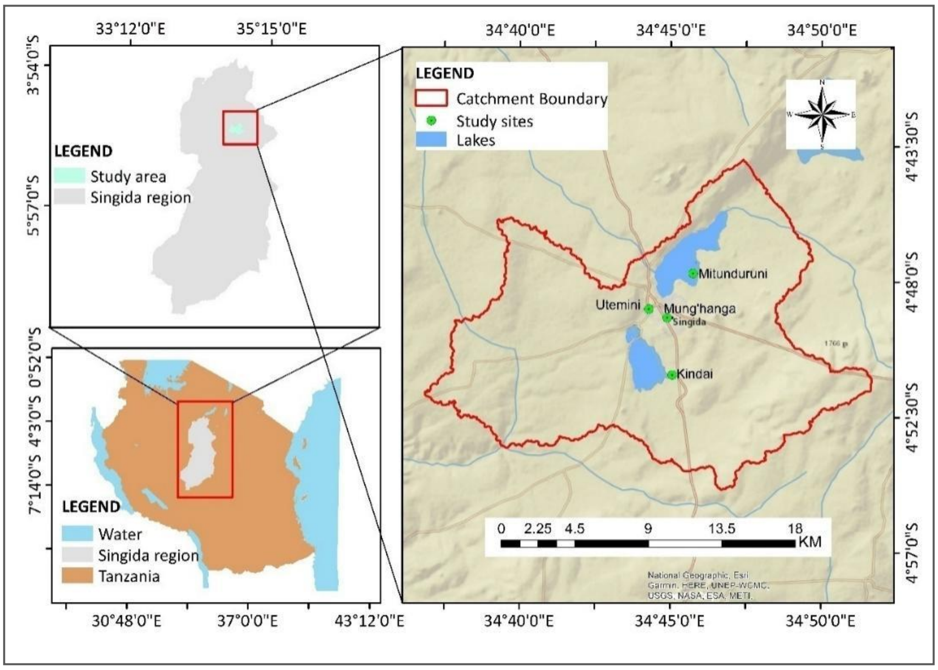


Figure 1: Location of Lake Singida Catchment in Singida Region
Source: National Bureau of Statistics (2022); United States Geological Survey (2022).

Four wards located in the Singida municipality—Mitunduruni, Kindai, Mughanga, and Utemini—were involved in this study. These wards were purposively selected due to their accessibility and relative significance in relation to the Lake Singida catchment, as well as the land use changes occurring in them. A systematic random sampling technique was employed to select both households and heads of households for the survey. A total of 382 respondents were involved in the study (Table 1).

Table 1: The Study Sample Size

Ward	Population	No. of Households	Sample Size
Mitunduruni	10,503	2334	110
Kindai	12,658	2944	139
Mughanga	2,046	418	20
Utemini	11,269	2398	113
	36,476	**8094**	**382**

Source: Housing and Population Census 2012 (URT, 2012).

3. 2 Data Collection Methods and Analysis

3.2.1 Household Survey

The data were collected using a household survey, where questionnaires were administered at the household level. The household questionnaires included both open-ended and closed-ended questions; and were conducted using the Kobo Toolbox to gather information on the demographics of households, and drivers of land use change. The collected data were then transferred into Microsoft Excel 2016 for accuracy checking and editing. Subsequently, the data were imported into the IBM SPSS Statistics software (version 21) for analysis, where descriptive statistics were performed to understand the extent of the drivers of land use change in the study area.

3.2.2 Key Informant Interview

Key informant interview from elders, ward executive officers (WEO), and officials from various departments within the Singida Municipality were also conducted to get the insights into the drivers of land use change. These informants were thought appropriate due to their extensive knowledge and experience related to the topic under investigation. In total, 19 key informants were purposively selected for interview. The collected information was transcribed and reviewed multiple times to identify and categorize recurring themes. Finally, the data was analysed using content analysis in MAXQDA 2020, after being copied from Microsoft Word 2016.

3.2.3 Remote Sensing Methods

Satellite images, Landsat 5 (Thematic Mapper), Landsat 7 (Enhanced Thematic Mapper Plus), and Landsat 8 (Operational Land Imager) were used to assess the extent of land use and land cover change. These images were acquired from the United States Geological Survey (USGS), where they are accessible at the website link https://www.earthexploer. Free cloud environments, particularly during the dry season (June to September), were the main focus for data acquisition. This consideration ensured image data clarity, and the overall detailed information on satellite image properties is outlined in Table 2.

Table 2: **Characteristics of Satellite Images Gathered for Lake Singida Catchment**

Satellite	Sensor	Year	Resolution	Path/ Row	Cloud Cover
Landsat 5	Thematic Mapper	1991	30m		
Landsat 7	Thematic Mapper Plus	2000	30m	169/063	<10%
Landsat 7	Thematic Mapper Plus	2010	30m		
Landsat 8	Operational Land Imager	2020	30m		

Source: United States Geological Survey (2022)

3.2.4 Image Pre-processing and Classification

In ArcMap 10.7, the downloaded satellite images were pre-processed using cloud masking, band stacking, and clipping. Conversely, geometric transformation involving the Universal Transverse Mercator (UTM) Arc 1960 coordinate system was applied to minimize distortions caused by the earth's curvature and rotation. These steps ensured that atmospheric errors, image alignment, and geospatial accuracy were properly addressed, which is crucial for reliable remote sensing analysis. The final pre-processed images were exported as GeoTIFF files to retain georeferencing information, including spatial and coordinate data, making them suitable for further GIS applications.

The images were classified using supervised classification under the maximum likelihood classifier to identify different categories of land use classes. Adopting this procedure, the training sites were created to represent different classes of land use from the interpretation of satellite images. Subsequently, the post-classification method was also implemented in the Google Earth software, and the research for this paper identified six distinct land use classes as detailed in Table 3.

Table 3: Categories of Land Use and Land Cover and their Descriptions

Land use class	Description
Agriculture	Cultivated land consisting of crops or remains of crops.
Buildings	Constructed land consisting of buildings and other man-made structures.
Bushland	Vegetation land consisting of low shrubs, bushes, and scattered trees.
Bare land	Land devoid of vegetation consisting of bare soil and rocks.
Grassland	Grass vegetation type of land or livestock grazing land.
Water bodies	Surface water consists of Lake Singidani, Kindai and Munangi.

Source: Field Survey (2022).

3.2.5 Transect Walk and Field Observation Methods

Transect walks were organized during which 300 data points were collected using a GPS device to validate the accuracy of the land use classifications. For each land use category, 50 points were gathered as recommended by Wulder et al. (2006), who state that collecting 30 to 50 samples is appropriate for small areas to maintain precision. Additionally, the field observation method was utilized to supplement information collected through household survey and informant interviews, with photographs taken to document various land use types.

The recorded GPS data were compared with the classified results to assess the accuracy of maps. The data were processed and analysed simultaneously using the Google Earth software and ArcMap 10.7.

Photographic data were visually analysed to identify land use types and their associated drivers of change. This process involved systematically reviewing the images to detect patterns and characteristics indicative of land use transformation. Factors such as land clearing, human-induced fires, urban expansion, livestock grazing and agricultural practices were examined to understand their impact on land use dynamics.

3.2.6 Meteorological Data, Population and Soil Data

The rainfall and temperature data (1991–2020) from the Tanzania Meteorological Authority (TMA) were utilized to understand their influence on land use and land cover changes. This climatic data helped identify the relationship between weather parameters and shifts in water body features, providing insights into how climatic variations can drive land use dynamics. Additionally, population data from the Tanzania population and housing censuses of 1967, 1978, 2012, and 2022 were reviewed to reveal the impact of demographic changes on land use dynamics within the study area. Analysing this data also shed light on how the trend in population growth affects land demand, which is critical for understanding the socio-economic pressures influencing land use. Furthermore, digital soil data from the FAO/UNESCO database were employed to examine the role of edaphic characteristics in the identified land use changes. This data is essential for assessing the suitability of different land types for agricultural and other uses, highlighting how soil quality influences land use decisions.

The collected data were quantitatively analysed to provide a comprehensive assessment of the demographic and environmental factors affecting land use and land cover transformations. This approach was evident in the careful examination of rainfall and temperature data, where accuracy was prioritized through techniques such as filling in missing values and removing outliers. The population data were systematically organized in Microsoft Excel 2016 and subsequently analysed using descriptive statistics to identify patterns over time. Soil data shapefiles were clipped to focus on the study area, and analysed in ArcMap 10.7 to compare with the observed trends in land use.

4. Results

4.1 Spatial and Temporal Distribution of Land Use/Cover Change

Figure 2 illustrates the distribution of six land use categories—buildings, agriculture, bare land, bushland, grassland, and water bodies—across different temporal and spatial scales. Water body features—including Lake Singidani, Kindai, and Munangi—are concentrated in the centre of the catchment. In 2020, built-up areas expanded, likely due to population growth. In 1991, grassland and bushland dominated the region; however, their extents have declined over the years, giving way for the occupation of bare land.

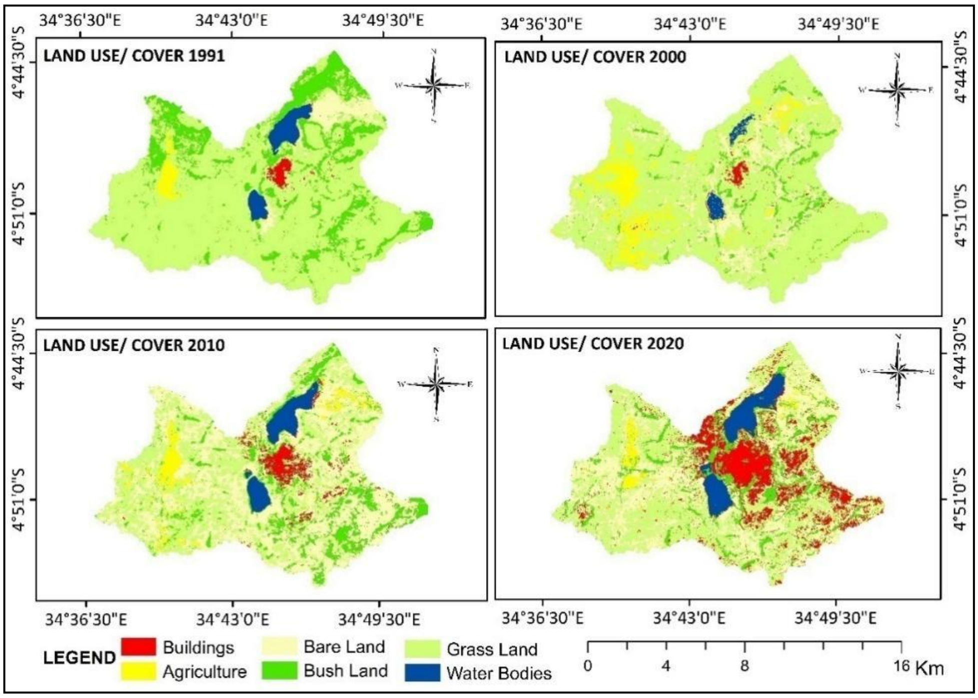


Figure 2: **Land Use and Land Cover Change in the Lake Singida Catchment for the Year 1991, 2020**
Source: Field Survey (2022)

In the western section, agricultural practices were prevalent, experiencing significant growth in 2000, but declining by 2020. These distributions highlight the dynamic and varied nature of land use within the catchment, reflecting the interplay between natural features and human activities interaction.

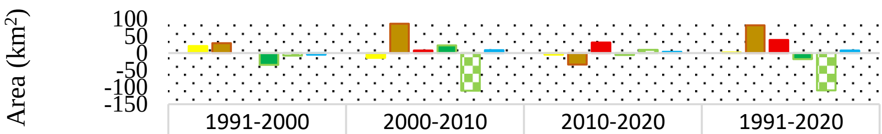
4.2 Land Use/Land Cover Changes in the Lake Singida Catchment

The results in Table 4 show the changes in land use categories in the study area between 1991 and 2020. Significant increases were observed in agriculture (1%), bare land (29%), buildings (13%), and water bodies (2%). Conversely, decreases were noted in bushland (7%) and grassland (40%). Between 1991 and 2000, agriculture increased by 8%, and bare land by 10%; while bushland decreased by 13%, grassland by 3%, and water bodies by 2%. There was no change in buildings during this period. Between 2010 and 2020, buildings increased by 11%, grassland by 3%, and water bodies by 1%; whereas agriculture, bare land, and bushland declined by 2%, 12%, and 3%, respectively. Significant trends in land use and land cover (LULC) changes from 1991 to 2020 are also summarized in in Figure 3. During the period 1991–2000, agriculture saw a slight increase, while bare land rose notably, and bushland experienced a significant decline.

Table 4: Summary of Quantitative Information on Land Use Change (%) in the Study Area

Years	1991	2000	Change	2010	2020	Change	Overall Change
Area (%)	%	%	+/-	%	%	+/-	+/-
Agriculture	1%	9%	+8%	4%	2%	-2%	+1
Bare land	4%	14%	+10%	45%	33%	-12%	+29
Buildings	1%	1%	0%	3%	14%	+11%	+13
Bushland	17%	4%	-13%	13%	10%	-3%	-7
Grassland	74%	71%	-3%	31%	34%	3%	-40
Water bodies	3%	1%	-2%	4%	5%	1%	+2

Source: Field Survey (2022).



	1991-2000	2000-2010	2010-2020	1991-2020
Agriculture	21	-14	-5	2
Bareland	29	86	-34	81
Buildings	0	7	31	38
Bushland	-35	23	-6	-18
Grassland	-8	-110	9	-109
Water bodies	-5	8	4	7

Years

Figure 3: Temporal Loss/Gains Trends (km²) in Land Use and Land Cover Change in the Study Area.
Source: Field Survey (2022)

The following decade (2000–2010) marked substantial growth in buildings, indicating urban expansion. In contrast, agriculture and bushland faced further declines from 2011 to 2020, although grassland showed a slight recovery. Water bodies fluctuated minimally, resulting in a slight overall gain. These trends highlight the complex interactions among land use types, and underscore the need for effective land management to balance urban development with ecological preservation.

4.3 Transition Matrix for Land Use Categories in the Lake Singida Catchment

The transition matrix is one of the methods used to reveal the spatial-temporal dynamics of specific land cover in tabular form (Bagwan & Sopan Gavali, 2023). The table consists of systematic arrays of land cover from 1991 to 2020, with the diagonals representing areas where land cover remained unchanged during the conversion; and the columns and rows representing gains and losses, respectively (Suleiman et al., 2017). The transition matrix results, as presented in Table 5, reveal that most of the bushland and grassland were converted into other forms of land cover than the rest of the land use. Specifically, bushland and grassland were converted into 12km^2 and 73km^2 of bare lands, respectively. However, the rest of the land use experienced minimal conversions during this period as shown in Table 5.

Table 5: Transition Matrix of Land Use and Land Cover Change (1991–2020)

LULC Class		2020						Total
		Agr	*BarL*	*B*	*BL*	*GL*	*WB*	
1991	Agriculture (Agr)	2	1	0	1	0	0	4
	Bare land (BarL)	1	6	1	1	0	2	12
	Buildings (B)	0	0	2	0	0	1	3
	Bush land (BL)	0	12	3	12	18	1	48
	Grassland (GL)	2	73	34	16	76	3	204
	Water body (WB)	0	0	1	0	0	8	9
	Total	**6**	**92**	**42**	**30**	**95**	**15**	**280**

Source; Field Survey, 2022.

Between 1991 and 2000, grassland was converted into 16km^2 of agriculture and 30km^2 of bare lands. The area of bushland also underwent into 28km^2 of grasslands, while the rest of the conversions never exceeded 8km^2 of land use and land cover during the same period (Table 6).

Table 6: Transition Matrix of Land Use and Land Cover Change (1991–2000)

LULC class		2000						Total
		Agr	*BarL*	*B*	*BL*	*GL*	*WB*	
1991	Agriculture (Agr)	4	0	0	0	1	0	4
	Bare land (BarL)	3	3	0	0	6	0	12
	Buildings (B)	0	0	2	0	1	0	3
	Bush land (BL)	3	7	0	9	28	0	48
	Grassland (GL)	16	30	1	3	155	0	205
	Water body (WB)	0	0	0	0	4	3	9
	Total	**25**	**41**	**3**	**12**	**196**	**3**	**280**

Source; Field Survey, 2022.

Between 2000 and 2010, the area previously devoid of vegetation regained by 92km^2 of grassland, and bushland also converted to 25km^2 of grasslands. Also, the water body areas converted to 6km^2 of grasslands. Agriculture remained stable by 6km^2, while none of it underwent to bare land, buildings, bushlands and water body; but it was converted to 5km^2 of grasslands (Table 7).

Table 7: Transition Matrix of Land Use and Land Cover Change (2000–2010)

	LULC class	2010						Total
		Agr	*BarL*	*B*	*BL*	*GL*	*WB*	
2000	Agriculture (Agr)	6	0	0	0	5	0	11
	Bare land (BarL)	6	24	0	3	92	0	126
	Buildings (B)	0	1	1	0	7	0	10
	Bush land (BL)	2	3	0	4	25	0	35
	Grassland (GL)	10	11	0	4	61	0	86
	Water body (WB)	0	1	1	0	6	3	12
	Total	**25**	**41**	**3**	**12**	**196**	**3**	**280**

Source; Field Survey, 2022.

In the final decade (2010–2020), grassland and bushlands continued experiencing conversions into 11km² and 44km² of bare lands, respectively. During this period, buildings were converted into 17km² of bare lands, 7km² of bushland, and 9km² of grasslands. The rest of the conversions also occurred during this period, but were between 1km² and 10km² (Table 8).

Table 8: Transition Matrix of Land Use and Land Cover Change (2010–2020)

	LULC class	2020						Total
		Agr	*BarL*	*B*	*BL*	*GL*	*WB*	
2010	Agriculture (Agr)	3	1	0	0	1	0	6
	Bare land (BarL)	5	50	0	8	29	0	92
	Buildings (B)	0	17	8	7	9	0	41
	Bush land (BL)	1	11	0	8	9	0	30
	Grassland (GL)	2	44	1	12	37	0	95
	Water body (WB)	0	3	1	1	0	12	16
	Total	**11**	**126**	**10**	**36**	**86**	**12**	**280**

Source: Field Survey, 2022.

4.4 Drivers for Land Use Change in the Study Site

4.4.1 Increase in Rainfall and Temperature

Figure 4 illustrates the trend in climate variability, revealing a significant increase in rainfall trend in the Lake Singida catchment from 1991 to 2020.

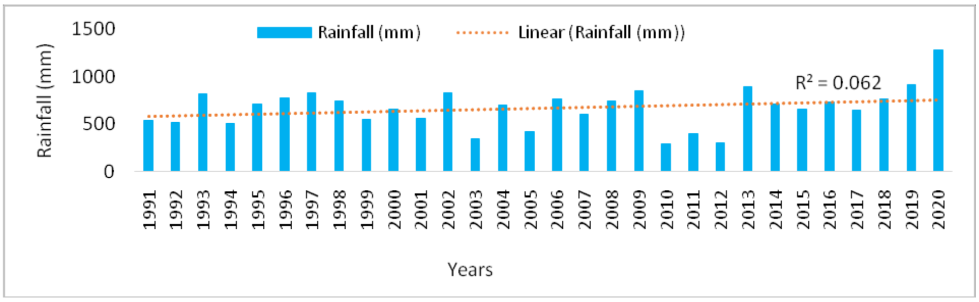


Figure 4: Trends in Rainfall Variability in the Study Area

We can observe in Figure 4 that there were notable fluctuations in rainfall, indicating a dynamic climate pattern. Years with rainfall exceeding 800mm included 1993, 1997, 2002, 2009, 2013, and 2019; with 2020 recording the highest rainfall. The decreases below 400mm were observed in 2003, 2010, and 2012; while the remaining years experienced rainfall levels between 400mm and 800mm.

On the other hand, Figure 5 reveal that the study area experienced an overall temperature increase, with fluctuations in both the minimum and maximum ranges. These changes may have directly influenced water body features through water recharge and evaporations.

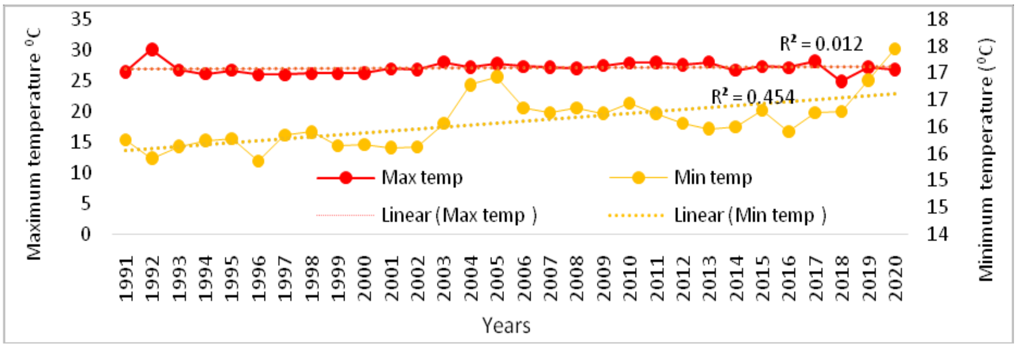


Figure 5: Trends in Temperature Variability in the Study Area

Source: Field Survey (2022)

For instance, the significant rainfall increases in 2020 led to severe flooding of the lakes, leading to the destruction of homes, infrastructure, and properties. This observation was also supported by responses from key informant interview, as reported by one respondent:

> *"In recent times, due to heavy rainfall, the lake levels have increased to the extent of causing floods and waterlogging in nearby areas, which is contrary to the past, when people grazed livestock and children played football in the area"* ***(MKI1–Lake Singida Catchment, October, 2022)***.

This statement highlights the transformative impact of recent climatic changes, particularly the increase in rainfall observed in 2020, which led to notable changes in the waterbody features as part of the land cover in the area. Conversely, the low rainfall, together with temperature increases, may have also resulted in the decline and drying of water body features, as said by one respondent:

> *"During the drought years, when the lake dried up, we would collect salt from the lakebed, and sell it to people in faraway areas with better harvests to trade for food"* **(*MKI2–Lake Singida Catchment, October, 2022*)**.

Although the specific year is not mentioned in this narration, it is clear that a decline in rainfall accompanied by rising temperatures led to the drying of the lake, resulting in shifts to other forms of land cover, such as bare land; and the emergence of grasslands or pastures within the Lake Singida catchment.

Overall, these climate changes contribute to hydrological alterations in the area, reshaping its landscapes and land use categories.

4.4.2 Unfavourable Edaphic Conditions

The analysis of the FAO/UNESCO digital soil classification using ArcMap 10.7 revealed that the catchment is predominantly composed of Ferric Acrisol soil, as shown in Figure 6. Igwe (2003) argues that this type of soil is highly susceptible to erosion. The high degradation rate, which reached 50% in 2012 in central Tanzania, can be attributed to the characteristics of this soil (URT, 2021).

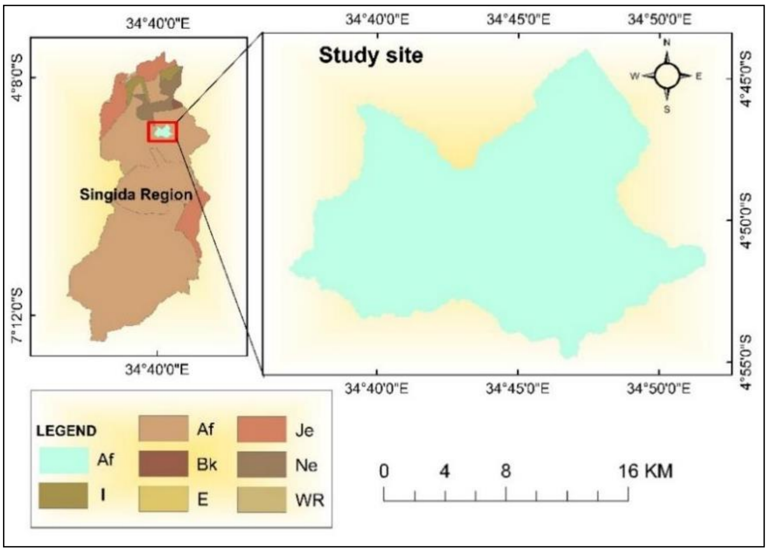


Figure 6: Identified Soil Type in the Area

Source: Field Survey (2022).

An in-depth interview with one of the key informants also indicated that the soil conditions around the lakes are saline, a factor that restricts plant growth and limits vegetation cover in the area; as narrated below:

> *"The soils around the lakes have high salinity levels. We previously attempted to grow trees, but they ultimately dried up. We would appreciate guidance on the best tree species that could thrive in this area"* ***(MKI13–Lake Singida Catchment, October 2022)***.

These conditions have led to sparse bushlands and grasslands, while the extent of bare land has increased, as shown by the Landsat analysis from 1991 to 2020. The implications of these edaphic factors are critical for understanding land use change in the Lake Singida catchment. The erosion-prone nature of Ferric Acrisol not only affects vegetation cover but also influences agricultural practices and overall land management strategies. As a result, the ongoing degradation and the shift towards bare land can be seen as direct consequences of these soil characteristics, underscoring the need for sustainable land use practices that consider soil health and erosion control.

4.4.3 Population Growth and Migration Factor

Figure 7 illustrates the overall population growth in Singida Municipal, showing a net increase of 223,000 people from 1967 to 2022, according to the national population database. The household survey, however, indicated that a significant portion of the population originated from various areas within the catchment, as depicted in Figures 8, 9 and 10.

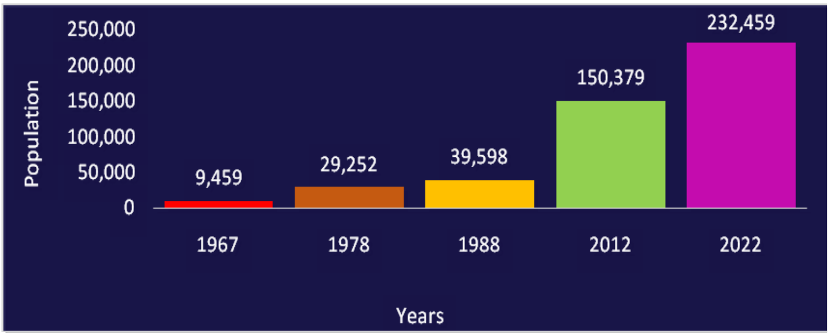


Figure 7: Trends in Population Growth in Singida Municipal

Source: Barke and Sowden (1992); URT (2012); NBS (2022).

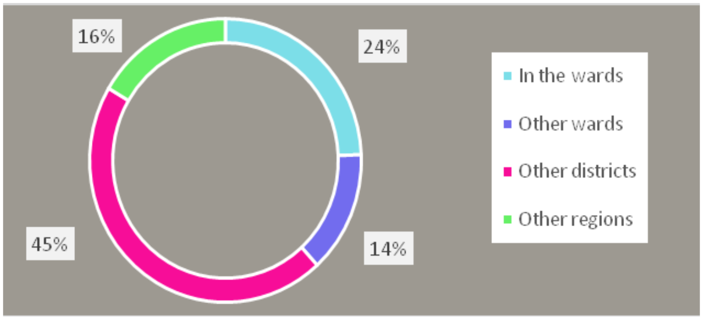


Figure 8: Origin of Respondents in the Lake Singida Catchment

Source: Field Survey (2022).

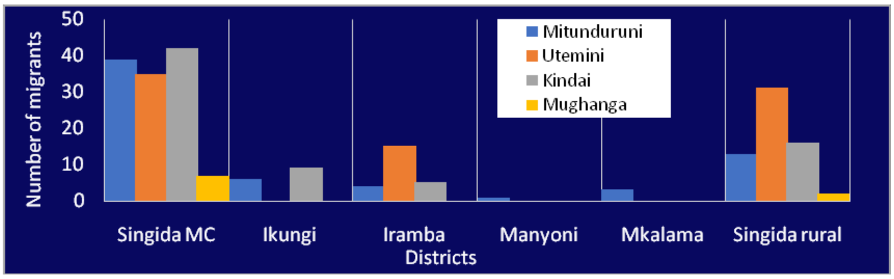


Figure 9: District of Origin of Migrants in the Study Sites

Source: Field Survey (2022).

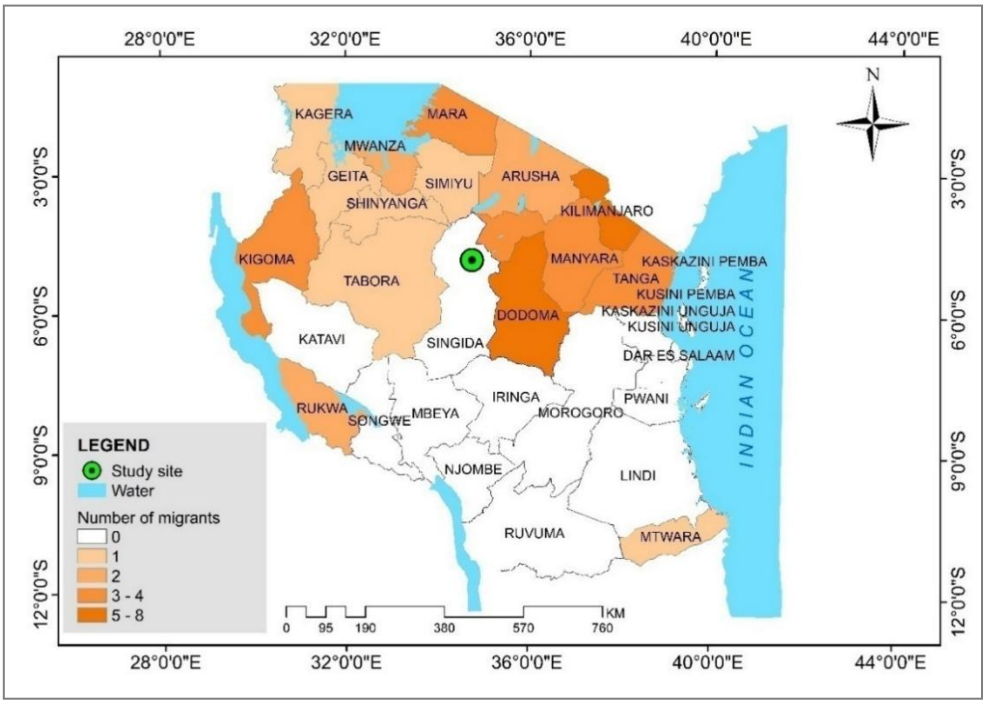


Figure 10: Regions of Migrants in the Study Site

Source: Tanzania National Population, (2012); Field Survey (2022).

Given that the study site is situated in an urban town with numerous attractions, the surveyed households identified a range of factors influencing their migration, as presented in Figure 11. These factors encompass both social and economic motives within the Lake Singida catchment.

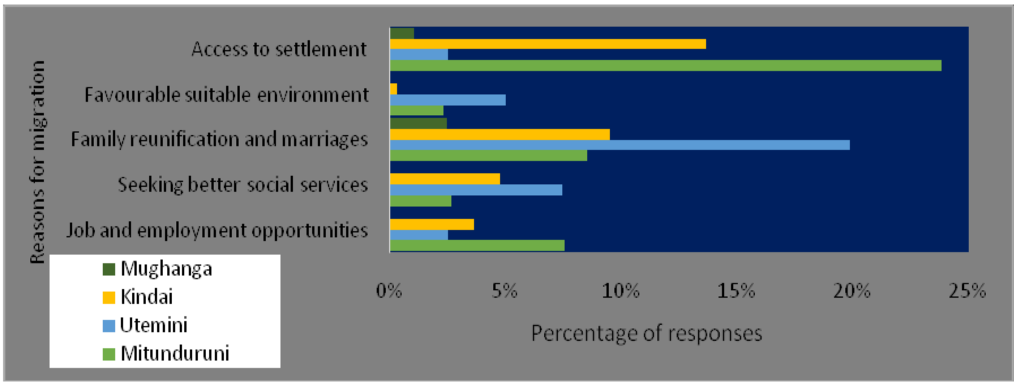


Figure 11: Perceived Reasons for Migration in the Study Area

Source: Field Survey (2022).

This substantial demographic shift, including migration, is associated with the expansion of built-up areas, driven by the growing demand for housing, infrastructure, and services. As urbanization progresses, there is a corresponding increase in bare lands resulting from the conversion of natural landscapes. While agricultural development has seen minimal growth, the pressure to meet the food needs of the expanding population has intensified land use practices. However, this urban and agricultural expansion has significantly declined bushlands and grasslands, as these vital ecosystems are increasingly converted for development and agricultural purposes. This trend poses challenges for biodiversity and ecosystem stability within the Lake Singida catchment.

4.4.4 Characterization of Land Demand, Ownership and Land Size

Figure 12 characterizes land demand, revealing that the majority of respondents wanted to own more plots of land. Specifically, the results were recorded highest in Kindai, followed by Mitunduruni and Utemini wards; while Mughanga exhibited the lowest demand. This tendency was motivated by respondents' land ownership rights and sizes of plots as shown in Tables 9 and 10.

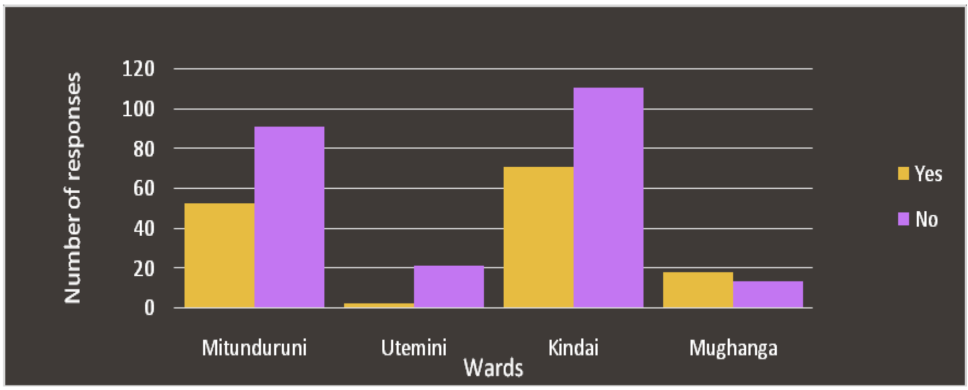


Figure 12: Response on Land Satisfaction in the Study Area

Source: Field Survey (2022).

Table 9: Land Ownership Rights of the Respondents

Wards	Family Inherited	Purchased	Rented	Total
Mitunduruni	38	88	18	**144**
Utemini	2	21	1	**24**
Kindai	33	142	7	**182**
Mughanga	24	8	0	**32**
Total	**97**	**258**	**26**	**382**

Source: Field Survey (2022).

Table 10: **Size of Plots in the Study Area**

Wards	Land in Hectares							
	<1	*1–2*	*3–4*	*5–6*	*7–8*	*9–10*	*Above 10*	*Total*
Mitunduruni	103	37	1	1	1	1	0	**144**
Utemini	22	2	0	0	0	0	0	**24**
Kindai	160	21	0	0	0	0	1	**182**
Mughanga	17	13	2	0	0	0	0	**32**
Total	**302**	**72**	**3**	**1**	**1**	**1**	**1**	**382**

Source: Field Survey (2022).

Key factors contributing to this demand include increasing population density, the desire to diversify economic activities through building rental houses, and cultural expectations regarding land ownership. Consequently, the catchment area faces increased vulnerability to changes in natural habitats due to human activities, including construction and urban expansion. As populations grow and economies develop, the need for housing, infrastructure, and agricultural production intensifies; often converting agricultural and natural lands into built environments, and prompting the intensification of existing farms. In addition, infrastructure demands necessitate clearing vegetation and reshaping landscapes, which can degrade ecosystems and diminish biodiversity. This characterization of land has significant implications for environmental health and land management practices.

4.4.5 Other Perceived Drivers of Land Use Change

As presented in Figure 13, respondents perceived different drivers for land use change. Drivers like urbanization contributed most to land use change, followed by agriculture, grazing, fire burning, grass cutting and traditional salt-making. According to the respondents,

- Urbanization has significantly converted land previously used for farming and grazing, resulting in substantial loss of natural vegetation and a reduction in land designated for grazing.
- Agriculture—now consisting of vegetables that supply food markets—was once a dominant practice in the site. It also continues to transform the natural land cover; however, it is now conducted minimally in fresh wetlands along the lakes.
- While livestock keeping persists on a smaller scale, some families have adopted zero grazing; with feed grass being collected from the catchment.
- While fire burning along the roads is common, grass cutting is also conducted as an alternative economic activity for making baskets (Figure 14d).
- Due to resource dependence, some respondents engage in traditional salt-making, where dry soil is collected, mixed in water containers, and allowed to evaporate in pans. This practice contributes to soil erosion, and discourages vegetation growth along the lakes.

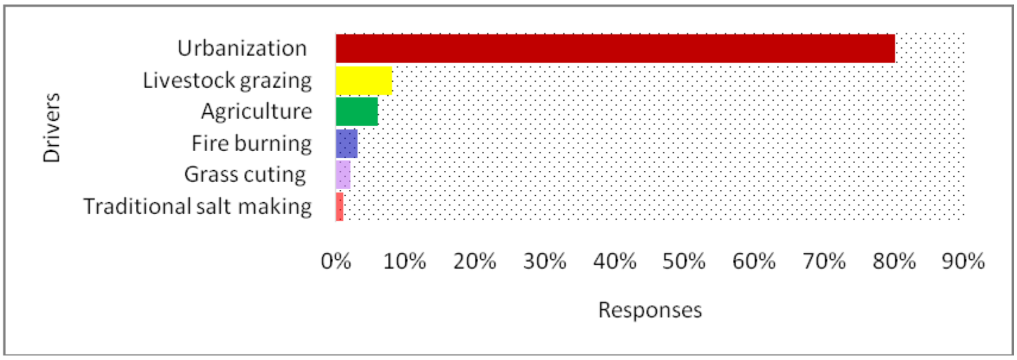


Figure 13: Other Perceived Drivers of Land Use Change
Source: Field Survey (2022)

Figure 14: **(a) livestock grazing, (b) drying grass after cutting for basket making, (c) vegetable farming, (d) burnt vegetation along the road and (e) and (f) traditional salt making in the lake Singida catchment**
Source: Field Survey (2022).

Grazing is a common practice in the catchment area: reducing pastures, leaving the land bare, and making it prone to erosion (Figure 14a). Additionally, grass cutting occurs in the catchment (Figure 14b), where tall grasses near water bodies are removed for purposes such as making baskets and crafting ornaments.

This practice further contributes to the extensive removal of grassland, and increases the amount of bare land in the catchment. Fire burning is another prevalent activity, conducted to intentionally clear roads (Figure 14d); however, it negatively impacts the natural vegetation in the catchment.

5. Discussion

This paper has presented the first comprehensive analysis of land use dynamics and their underlying drivers within the Lake Singida catchment, Tanzania, making a significant contribution to the existing literature, particularly given the absence of prior research in this area. The results, derived from remote sensing data, reveal substantial land use changes between 1991 and 2020. Specifically, increases were observed in agriculture, bare land, built-up areas, and water body features; while grasslands and bushlands experienced significant declines. These changes—supported by household surveys, key informant interviews, and secondary data sources—are discussed in relation to identified drivers, including climate change, population growth, in-migration factor, land demand, mode of land ownership, land size, urbanization, agriculture, grazing, grass-cutting, fire-burning, and salt extraction.

These findings highlight the dramatic landscape transformation of the Lake Singida catchment over the past three decades. The increase in agriculture and built-up areas correlates directly with drivers identified in the study, such as natural population growth and in-migration factors. As the population expands, the demand for housing and food production intensifies, leading to the conversion of natural landscapes into agricultural fields and urban areas. The simultaneous rise in bare land and water bodies suggests changes in land management practices and hydrological dynamics, possibly linked to intensified agricultural activities and urban infrastructure expansion. The recent increase in rainfall may have significantly influenced changes in water bodies, contributing to rising water levels and subsequent flooding of lakes within the catchment area. Conversely, the decline in bushland and grassland may be attributed to these drivers, along with practices such as fire burning, livestock grazing, grass cutting, and salt extraction; indicating a loss of natural habitats that could have serious implications for biodiversity and ecosystem services in the area.

The results align with prior regional studies, such as those by Deche et al. (2023), which similarly identified the expansion of agriculture, rural settlement, and water body features at the expense of forestland, bushland, and grassland in the upper Awashi Basin of central Rift Valley, Ethiopia. Both studies highlight the reduction in vegetation cover due to comparable anthropogenic activities that affect ecosystems previously occupied by natural vegetation. The assertion that forests have never been a dominant feature in the Lake Singida catchment contrasts with results from tropical studies. For instance, McMahon et al. (2010) reported increases in forest cover due to natural disturbance recovery. This discrepancy may stem from ecological differences, as our study site is situated in a dryland urban area, whereas McMahon's research focused on a tropical site less impacted by urban activities. The increase in built-up areas corroborates results from various studies, including those by Sun et al. (2016), Zhai et al. (2021), and Deche et al. (2023): all of which document significant urban expansion. For example, the city of Wuhan in China expanded by 228%, whereas our findings indicate a 13% increase in built-up areas within the catchment. Though these figures vary in magnitude, they both demonstrate a growing trend of buildings, reflecting rapid development in urban areas.

The observed population growth and migration add to the drivers of land use change evident in water catchments globally. Climate change, particularly increased rainfall, has emerged as a significant driver of land cover changes, with many East African basins experiencing floods and waterlogging disasters. Thus, the dynamics observed in the Lake Singida catchment both align with, and diverge from, land use changes seen within and beyond the study site. These variations and similarities underscore the complex interplay of the driving forces, highlighting the vulnerability of ecosystems and human activities to significant environmental changes.

While the identified drivers provide a robust framework for understanding land use dynamics, alternative explanations merit consideration. For instance, changes in government policies, such as the villagization program initiated in 1974, may have influenced land use patterns by promoting the conversion of natural areas to agricultural practices or urban centres (Lazaro et al., 2017). This historic program facilitated community consolidation from scattered settlements into village land, contributing to the development of current towns, including those in the Lake Singida catchment. Additionally, external economic factors—such as market demand for agricultural products or incentives for urban development—could further drive these changes. Future research should explore these dimensions to offer a more nuanced understanding of the complexities surrounding land use change.

The implications of these results are substantial for environmental sustainability, climate control, and overall human welfare. The observed increases in agriculture underscore the necessity of enhancing food production to support population growth; while the expansion of built-up areas highlights the importance of infrastructure development. However, these anthropogenic practices have significantly contributed to a decline in vegetation cover, resulting in biodiversity loss, soil degradation, pollution, and increased pressure on local resources. Although the expansion of water bodies may indicate beneficial changes in land use and hydrological dynamics, it raises concerns about water quality and availability, potentially impacting aquatic ecosystems and increasing the risk of flooding in adjacent areas (IDBWB, 2020). Grasslands and bushlands provide essential habitats for numerous species; hence their decline poses serious environmental risks, including diminished ecosystem services. This deterioration jeopardizes the survival of species that depend on these ecosystems and ultimately threatens human well-being and environmental health. Collectively, these results underscore the urgent need for comprehensive urban planning, sustainable economic development, and effective conservation strategies to restore lost vegetation cover within the catchment.

The study that generated the data for this paper has several limitations that warrant consideration. First, its focus on the Lake Singida catchment may limit the generalizability of the results to other regions. Second, while the paper emphasizes human activities as primary drivers of land use change, it overlooks the influence of other factors—such as government policies and external market access—which also shape these dynamics. To address the specified gaps, future research could explore other catchments with similar ecological characteristics to enhance comparability, and investigate a broader range of human and natural factors to provide a more comprehensive understanding of land use changes and their drivers in the Lake Singida catchment.

6. Conclusion

This paper examined land use dynamics in the Lake Singida catchment from 1991 to 2020, revealing substantial changes, including increases in agriculture, built-up areas, bare land, and water bodies; while grasslands and bushlands have declined. These changes are driven by climate change, population growth, in-migration, soil conditions, land demand, mode of land ownership, land size, agriculture, urbanization, livestock grazing, fire burning, and salt extraction. The decline of grasslands and bushlands highlights critical environmental implications; including reduced biodiversity, habitat loss, soil erosion, diminished water quality, and altered ecosystem functioning. Despite these challenges, human advancement and increased food production—as evidenced by the rise in buildings and agricultural practices—play a significant role in the region's development, guiding land managers toward sustainable land use planning that considers these multiple drivers. However, the study overlooks the influence of government policies, external market access, and other natural factors essential for shaping land use dynamics. Thus, future research should address these aspects and explore other catchments with similar ecological characteristics to enhance comparability. Overall, this research provides valuable insights into land use dynamics, and underscores the importance of sustainable land use planning to mitigate adverse impacts on natural ecosystems and local communities, ultimately contributing to global sustainability efforts.

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