The Trend and Magnitude of Land Use and Land Cover Change and their Driving Forces in Lake Tana Basin, Upper Blue Nile, Northwest Ethiopia

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Abstract

Monitoring the trend and magnitude of Land Use and Land Cover (LULC) change and its driving forces in the Basin provides essential information to decision-makers regarding the conservation and management of water resources. The Lake Tana Basin, situated in Ethiopia, serves as a vital ecological and economic hub, supporting diverse ecosystems and local communities. Despite its ecological and hydrological importance, unplanned LULC change predisposes the Basin to environmental problems such as land degradation, loss of habitat and biodiversity, soil erosion, water quantity degradation, and water pollution. The study utilized Geographic Information Science (GIS), Remote Sensing (RS) analysis, and key informants' perceptions to quantify and analyze the trend of spatio-temporal LULC change in the Lake Tana Basin over 20 years (2004–2024). Population increase, conservation efforts, climate change, soil fertility, and income level were assessed as potential drivers of LULC change. A supervised classification method was used on the Google Earth Engine platform to map seven LULC classes: Water Cover, Built-up Area, Forest Cover, Agricultural Land, Bare Land, Grassland, and Wetland. Classification accuracy was validated using confusion error metrics, recording overall accuracies of 86%, 97%, 95%, 93%, and 95% for the years 2004, 2009, 2014, 2019, and 2024, respectively. Post-classification change detection revealed increases in Water Cover (2.16%), Built-up Area (83.41%), Agricultural Land (38.32%), and Bare Land (39.11%), with corresponding reductions in Forest Cover (56.60%), Grassland (72.71%), and Wetland (64.06%). The study revealed that population growth significantly influenced the increase in built-up areas, reduction in forest cover, reduction in grasslands, and loss of wetlands, while an increase in water coverage was linked to climate change, and the expansion of bare land was influenced by soil type. The findings inform evidence-based policies for sustainable land use and conservation planning in the Lake Tana Basin.

Keywords: *Anthropogenic Factors, Land Use and Land Cover, GIS, Remote Sensing, Sustainable Land Use, Basin Conservation*

Introduction

Background Information

Land use and land cover change has emerged as a key focus within the global scientific community (Hailu *et al.*, 2020). Land use (LU) refers to using land for various purposes, including residential, industrial, agricultural, recreational, transportation, or mixed-use (Nedd *et al.*, 2021). On the other hand, land cover (LC) is the biological and physical cover of the land surface, such as water bodies, farmland, forests, wetlands, bare soil, built-up areas, grassland, shrubs, etc. (Sewnet, 2016). Land Use Land Cover is never constant; however, it changes continually due to the dynamic interactions between drivers and the feedback that land-use change provides to those drivers (Lambin *et al*., 2003). Moreover, LULC change is caused by natural phenomena and anthropogenic activities that eventually compel deviations in natural ecosystems (Rather & Dar, 2020). Misguided LULC change distracts natural systems from their ability to serve human needs, exposing people and resources to climate change, socioeconomic crises, and political concerns by diminishing ecosystem services. (Dibaba *et al.,* 2020). For instance, in Africa, it is noted that farmlands, pasture fields, human settlements, and urban centers are quickly replacing natural vegetation throughout (Mangi *et al.*, 2022). Meanwhile, in Ethiopia, Belete *et al.*, (2023) reported a decline in forests, woodlands, shrub lands, grasslands, and wetlands and an expansion in agricultural regions and bare lands over time in the northern part of Ethiopia.

Interest in monitoring the trend and investigating the impact of Land use and Land cover change in ecosystem services is increasing (Geremew, 2013; Namugize *et al.*, 2018; Rimal *et al.,* 2019; Gituanja, 2020). For instance, Hailu *et al*., (2020) observed that Land use and land cover changes accelerate soil erosion rates, causing soil degradation, sedimentation and pollution of water bodies, surface and groundwater reduction, climate variation, and water flow alteration.

Geographic information system (GIS) and remote sensing (RS) techniques have made it possible to study and analyze spatial-temporal LULC change at a low cost, in less time, and with better accuracy (Sewnet, 2016).

Globally, there is no agreement on factors causing LULC change (Sewnet, 2016). However, factors such as population growth, climate variability, soil fertility, slope, forest conservation efforts, and economic status may significantly contribute to LULC change (Dibaba *et al*., 2020, Getachew *et al.*, 2021). These factors lead to deforestation, land degradation, biodiversity and habitat loss, global warming, and increased natural disasters, contributing to global environmental problems such as water quality and quantity degradation (Rather & Dar, 2020). For instance, Getu Engida *et al.*, (2021) observed an increase in urban land, bare land, farmland, and shrubs while a decrease in forest, grassland, water, and wetland within the upper Baro Basin, which were attributed to population growth, which raises the need for agricultural land and buildings for the growing population. Population growth, hastens deforestation actions to create space for agriculture and urban development. A better understanding of land use and land cover change and their drivers is vital for conserving the environment and controlling ecosystem services (Gituanja, 2020).

Statement of the Problem

Despite the ecological and hydrological importance of Lake Tana Basin to the local population of Ethiopia and downstream countries, unplanned LULC change predisposes the basin to environmental problems such as land degradation, loss of habitat and biodiversity, soil erosion, water quantity degradation, and water pollution. These issues contribute to economic challenges such increased water treatment costs, environmental challenges such as erosion of ecosystem service and disruption of water cycles, and social problems such as community displacement, impact on livelihoods, and health risks to the growing population.

Objective of the Study

The Study sought to study:

- To assess the spatio-temporal variation of land use and land cover changes in Lake Tana Basin from 2004-2024
- To investigate the drivers of land use and land cover change in the Lake Tana Basin

Significance of Study

Based on the hydrological and ecological importance of the Lake Tana Basin to the growing population of Ethiopia and its downstream countries, the lake's water quality and quantity continue to deteriorate, posing an alarming threat to future generations who depend on this critical water resource. Land use and land cover change are indicators contributing to the degradation of the lake's water quality. The study examined LULC dynamics and their driving forces. Furthermore, the study accelerates the achievement of several sustainable development goals, including good health and well-being (SDG 3), clean water and sanitation for all (SDG 6), and climate action (SDG 13), both locally and in the downstream counties.

Scope and Assumption of the Study

The study was conducted within the Lake Tana Basin in northwest Ethiopia, which includes the lake and the surrounding watershed areas. More than 90% cloud-free, remotely sensed images of raw Landsat 5 thematic mapper (TM) and Landsat 8 operational land imager (OLI) and the surface reflectance products of MODIS (MOD09A1) were obtained from the United States Geological Survey (USGS) websites spanning 20 years from 2004 to 2024. The processed Landsat images were used to generate spatio-temporal LULC data through a random forest algorithm of supervised classification, and classes were limited to water cover, built-up areas, forest land, agricultural land, bare land, grassland, and wetland. Confusion error matrix assessment was used to assess the accuracy of the generated LULC data. Climate data, Soil fertility, Population growth, economic status and conservation measures were analyzed as potential drivers of LULC change.

Some of the assumptions made include the basin having similar characteristics in terms of climate and the social aspect of the people; finally, the key informants provided truthful answers regarding their views on the drivers of LULC change and the conservation plan in the Lake Tana Basin.

Materials and Methods

Study Area.

Lake Tana Basin is located in northwestern Ethiopia, which lies between 10°55 to 12°45” N latitude and 36°40’ to 38°20’ E, as shown in Figure 1. The Basin covers approximately 15,096 km^2 (Getachew & Manjunatha, 2022). It consists of large land mass, wide wetland, many feeder rivers, numerous forested islands, and Lake Tana, which is a naturally occurring freshwater lake with a surface area of 3000–3600 km^2 having an elevation of 1787 m above sea level (a.s.l) and a maximum depth of 15m (Mehari, 2018).

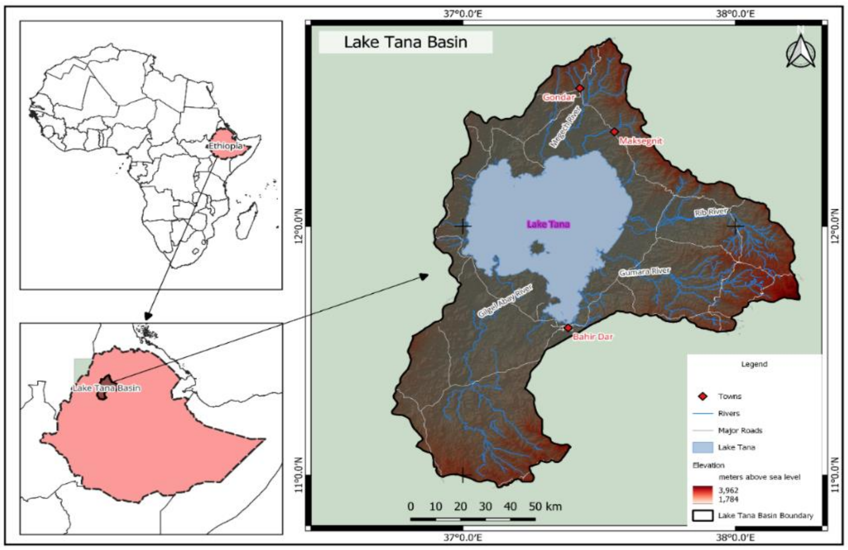

Figure 1: Map of the study area.

Data Collection

More than 90% cloud-free, remotely sensed images of raw Landsat 5 thematic mapper (TM) and Landsat 8 operational land imager (OLI) were obtained from the United States Geological Survey (USGS) websites (https://earthexplorer.usgs.gov) spanning 20 years from 2004 to 2024. The reprocessed Landsat images were used to generate spatio-temporal LULC data through supervised classification using a random forest algorithm, LULC classes were limited to water cover, built-up areas, forest land, agricultural land, bare land, grassland, and wetland. Confusion error matrix was used to assess the accuracy of the generated LULC data. The classified data were exported as TIFF file(Hailu et al., 2020)s, and maps were prepared in QGIS 3.28.11. The classified datasets were then subjected to post-processing procedures that involved a multi-date post-classification comparison change detection analysis. This was done to quantify and confirm the trend of Land use land cover within the Basin.

Qualitative data on the drivers influencing land use and land cover change, as well as the basin conservation plan, were obtained using the designed questionnaires where Key informants, including the Kebele chairperson (chief), village elders, and professionals such as researchers, hydrologist, water resource engineers, environmental scientists, and agricultural extension workers within Lake Tana Basin were interviewed.

Soil map with the following characteristics; soil texture, soil nutrient, soil organic matter, and soil water holding capacity will be downloaded from the ISRIC World Soil information website (https://www.isric.org/explore/isric-soil-data-hub). While Climate data, including rainfall amounts and earth surface temperatures for the study area, were downloaded from the NASA Power website (https://power.larc.nasa.gov/data-access-viewer/). Finally, Population data were obtained by projecting the latest two Ethiopian census reports from 1994 and 2007, considering annual growth rates of 4.6% and 2.89%, respectively. The two provided estimates of the population magnitude from 2004 to 2024.

Results and Discussion

Land Use and Land Cover Accuracy Assessment

Accuracy assessment is used to define the truth about classified images. In this assessment, information gathered from sample reference sites was compared to those obtained from classified images with the help of the confusion error matrix. More than 80 reference training sites were driven from the field observation, Google Earth Pro, and the Existing maps.

According to Anderson (1976), the minimum accuracy value for reliable land cover classification is 85%. The Land use land cover classification for the years 2004, 2009, 2014, 2019, and 2024 resulted in overall accuracy of 86%, 97%, 95%, 93%, and 95% respectively. The assessment results shown in Tables 1 indicate that the overall accuracy of the maps meet the minimum accuracy level, according to Anderson (1976). Producers' and users' accuracy were also calculated, resulting in values ranging from 86% to 100% and 65% to 100%, respectively, for years 2004 to 2024. Water cover shows the highest accuracy in all the assessments due to its unique spectral signature on Landsat images.

Table 1: Summary of Accuracy Assessment From 2004-2024 (%)

Land Cover Classes	2004		2009		2014		2019		2024	
	PA	UA	PA	UA	PA	UA	PA	UA	PA	UA
Water Cover	100	100	100	100	100	100	100	100	100	100
Built-up Area	92	84	99	98	98	97	98	93	97	94
Forest Cover	94	95	99	99	97	97	93	96	100	98
Agricultural land	96	91	100	100	98	99	98	100	98	99
Bare-land	93	91	100	89	100	90	93	74	95	92
Grassland	89	88	98	99	94	86	97	94	96	90
Wetland	86	65	97	93	94	96	100	96	100	90
Overall Accuracy	**89**		**97**		**95**		**93**		**95**	

PA= Producer's Accuracy, UA = User's Accuracy

Land Use and Land Cover Mapping

A pixel-based supervised image classification using random forest algorithm was used to classify the LULC of the years 2004, 2009, 2014, 2019, and 2024. Ground truth points that were used as reference points for classification and accuracy assessment were collected from the field for the year 2024, while the historical data for the previous years were collected from pre-existing maps, Google Earth Pro, and elders' perspectives through interviews. The results in Figure 2, Figure 3 and Table 2 show spatio-temporal dynamics of LULC in the Tana Basin for a period of 20 years from 2004 to 2024.

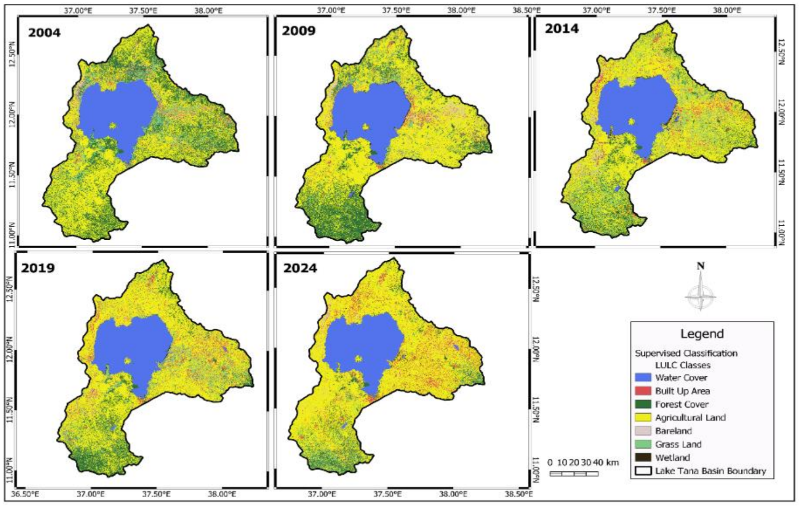

Figure 2: Land use and land cover of the Lake Tana basin in 2004, 2009, 2014, 2019, and 2024

Table 2: Land use and land cover area of Lake Tana basin in (km2 and %) during 2004, 2009, 2014, 2019, and 2014

LULC Classes	**Total Area and Percentages**									
	2004		**2009**		**2014**		**2019**		**2024**	
	(Km^2)	(%)	(Km^2)	(%)	(Km^2)	(%)	(Km^2)	(%)	(Km^2)	(%)
Water cover	3016	20.01	3002	19.91	3039	20.16	3066	20.34	3081	20.44
Built up area	645	4.28	683	4.53	691	4.58	897	5.94	1183	7.85
Forest land	2779	18.43	2503	16.60	1471	9.76	1397	9.26	1206	8.0
Agricultural land	6373	42.27	7187	47.67	7564	50.17	8039	53.32	8815	58.47
Bare land	145	0.96	255	1.69	197	1.31	91	0.60	202	1.34
Grassland	1990	13.20	1354	8.98	2012	13.35	1491	9.89	543	3.60
Wetland	128	0.85	92	0.61	102	0.68	85	0.56	46	0.31
Total	15076	100	15076	100	15076	100	15076	100	15076	100

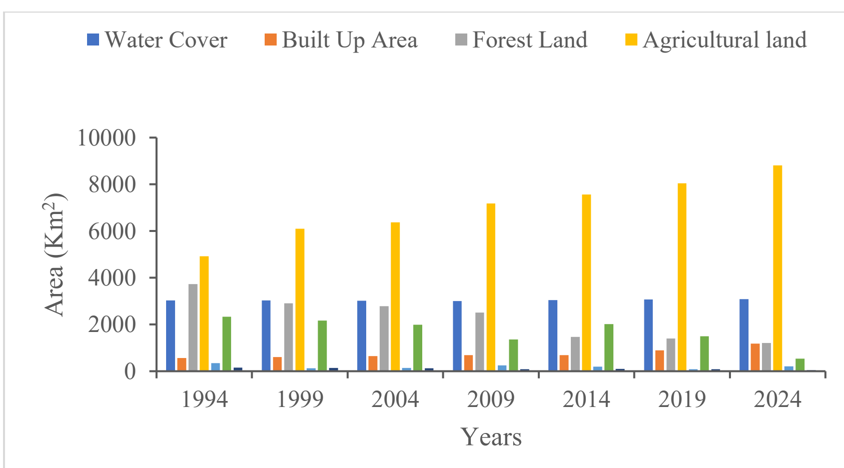

Figure 3: Yearly LULC Status

Change Pattern of LULC Classes

Water Cover

There was a fluctuation in water coverage within the entire Basin in the period under study. In 2004, water coverage was 3016 km^2; the area dropped to 3002 km^2 in 2009. However, between the years 2009 to 2024, water coverage experienced a continuous increase. The area rose to 3039 km² in 2014, further in 2019 increased to 3066 km², and finally, by 2024, it became 3081 km², as depicted in Table 2. According to key informants, five earth dams have been constructed within the Basin since 2009 with the primary purpose of irrigation and domestic water supply. The dams include the Rib Dam for irrigation, created in the upper region of the river Rib, Salamko Dam for irrigation, Angereb Dam for domestic water supply for Gondar town, Shina Dam, and Koga Dam for irrigation purposes.

The decrease in water cover in 2009 was due to the widespread drought conditions experienced in all regions of Ethiopia, which was the second driest period after the drought of 1984 (Viste et al., 2013). However, despite the fluctuating rainfall distribution as shown in figure 7, the water coverage continued to increase. This is a result of the establishment of new dams in the Basin. Gashaw & Fentahun, (2014) also observed increased water coverage in the northern part of the Basin considering establishment of the Megech Dam.

Built-Up Area

Over the entire duration, the built-up area constantly experienced expansion. Initially, in 2004, the area of coverage was 645 km²; it experienced a slight increase to 683 km² by 2009. The major growth occurred in 2014 when it increased to 691 km². This expansion continued to 897 km² by 2019, and finally, in 2024, the built-up area reached 1183 km², as shown in Table 2.

The expansion of built-up area has been recognized globally, and it is highly associated with the increasing world population (Ahmadi et al., 2023). In Ethiopia, apart from the increasing population, the growing urban centers are due to the migration of people from the countryside to the cities (Gibson & Gurmu, 2012). The increased population requires more shelter, transportation, industrialization, and social amenities, which in the process widen the extent of built-up areas and the emergence of new built-up areas. Similarly, in the Lake Tana Basin, the previous studies have recorded the same increasing trend, although at a varying magnitude over time (Geremew, 2013; Wubie et al., 2016; Mehari, 2018; Tewabe & Fentahun, 2020).

Forest Cover

The forest cover experienced a sharp drop from 2004 to 2014, thereby reducing at a low rate from 2014 to 2024. As demonstrated in Table 2, 2004, the forest cover was 2779 km². By 2009, the area had decreased to 2503 km² and declined further to 1471 km² in 2014. From there, the forest cover started decreasing in 2019; the forest cover decreased to 1397 km² in 2019 and finally reduced to 1206 km² by 2024, as shown in Table 2. Key informants observed that the basin is experiencing afforestation, especially when fast-growing trees like eucalyptus are planted purposefully for income generation. This explains the observed reduction trend and why the forest has been decreasing at a low rate since 2014.

The findings are in agreement with previous studies in Ethiopia and, particularly, in the Lake Tana Basin. Liu et al., (2020) noted that forest land was reduced by 2.80 km^2 in Awash sub basin within a period of 20 years from the year 1999 to 2019. Likewise, Geremew (2013) and Mehari *et al.,* (2018) revealed that the forest Land is being taken by the increasing agricultural land and the built-up areas.

Agricultural Land

Agricultural land expanded steadily over the study period. In 2004, it covered 6,373 km². By 2009, this area had increased to 7,187 km². The upward trend continued, reaching 7,564 km² in 2014, 8,039 km² in 2019, and finally expanding to 8,815 km² by 2024, as shown in Table 2. According to the key informants, the increasing agricultural land is mainly due to the increasing demand for food in the growing population of the Basin. Some key informants indicated that the majority of the residents in the Basin depend on agriculture as their primary source of income. Moreover, Lake Tana Basin's favorable soil characteristics also contribute to the increasing agricultural land.

The increasing trend in agricultural land agrees with previous studies. For instance, Gashaw and Fentahun (2014) noted extensive agricultural land expansion in the eastern part of Lake Tana, occurring at the expense of grazing land, shrub land, and forest cover. Additionally, Mehari *et al.* (2018) observed that between 2001 and 2015, farmland increased by 1444.3 km^2, mainly due to the conversion of shrub land to farmland.

Bare-Land

Throughout the study period, there were fluctuations in the amount of bare land, with certain phases experiencing increases and declines trend. Initially, 145 km^2 were covered with bare land in 200 4. This area of coverage had grown to 255 km² by 2009. However, in 2014, the coverage dropped to 197 km², and it further decreased to 91 km² by 2019. Then, in 2024, the coverage of bare land increased again to 202 km², as shown in Table 2. Key informants observed that bare land replaces agricultural land once soil fertility is reduced. With time, grassland recovers and then changes back to agricultural land. The recent rise of bare-land indicates a rapid loss of soil fertility

A study on Lake Tana Basin by Yenealem (2023) noted that bare land increased and reduced at some stages over 29 years from 1986 to 2015. However, there was a drop of 922.3 km^2 for the entire period of study. Tesfa (2016) reported that expanding farming practices in the Ethiopian highlands, where intensive farming is practiced without appropriate conservation practices, has resulted in the depletion of fertile soil.

Grassland

During the study period, grassland coverage decreased generally, with a slight uptick in 2014. Originally, grassland totaled 1990 km² in 2004. The area was substantially smaller in 2009, at 1354 km². The coverage increased slightly to 2012 km² in 2014. But after that, there was a decline to 1491 km² in 2019 and, by 2024, a significant decrease to 543 km², as observed in Table 2. The key informants explained that the decrease in grassland in the Basin is due to overgrazing and the expansion of agricultural land. Similarly, Getachew et al. (2021) observed a decline in grassland in the Basin, quantifying that in 2005, the grassland covered 7.7% of the Basin, while in 2019, the percentage coverage reduced to 3.3%.

Wetland

During the duration of the study, wetland coverage typically decreased, with a brief rise in 2014. By 2009, it had shrunk to 92 km² from 128 km² in 2004. There was a minor rise to 102 km² in 2014. Nevertheless, the downward trend persisted, with wetland coverage falling to 85 km² in 2019 and 46 km² by 2024, as shown in Table 8. Key informants stated that wetlands are being converted to cultivated and residential land over time. Similarly, previous studies in the Basin have noted a decreasing trend. For instance, Wubie et al., (2016) observed that wetlands reduced 30.6% from 1985 to 2005 within the Gumoro sub-basin of Lake Tana Basin.

Extent of Land Use and Land Cover Change from 2004 to 2024

The Land Use and Land Cover changes between two periods (i.e., 2004–2009 and 2009–2014) were quantified using the post-classification image comparison technique (Anteneh, 2022). In this approach, LULC areas for different reference years were first classified individually. Change detection techniques were then applied to analyze the subsequent years over 20 years. A transition matrix model was used to calculate the percentage of detected land use and land cover changes, as demonstrated by Kahsay et al., (2022):

$$\text{Percentage Change} = \frac{\text{Area of final year} - \text{area of initial year}}{\text{Area of initial year}} \times 100$$

Positive results indicate an increase, whereas negative values imply a decrease in the amount of LULC coverage. This model provides a systematic way to measure changes in land use and land cover over time.

Between 2004 and 2009, remarkable changes in land use and land cover were observed. Water cover reduced by 14 km², which is a 0.46% decrease, occurring at a rate of 3 km² per year. The built-up area increased by 38 km² (5.89%) at a rate of 8 km² per year. Forest land experienced an extensive decrease of 276 km² (9.93%), with an annual reduction rate of 55 km². Agricultural land expanded by 814 km² (12.77%) at a rate of 163 km² per year. Bare land also increased by 110 km² (75.86%) at a rate of 22 km² per year. Grassland reduced by 636 km² (31.96%), with an annual decrease of 127 km²; at the same time, Wetland coverage decreased by 36 km² (28.13%), at a rate of 7 km² per year, as shown in table 3. In this period built-up area, agricultural land and bare-land replace the areas that were previously occupied by the water cover, forest land, grassland and the wetland, suggesting human induced drivers through urbanization and agricultural activities.

For the years 2009 to 2014, water cover increased by 37 km² (1.23%) at the rate of 7 km² per year. The built-up area increased by 8 km² (1.17%) at a rate of 2 km² per year. Forest land experienced a major decline by 1032 km² (41.23%) at the rate of 206 km² per year. Agricultural land continued to expand; it grew by 377 km² (5.25%) at the rate of 75 km² per year. Bare land decreased by 58 km² (22.75%) at the rate of 12 km² per year. Grassland substantially increased by 658 km² (48.60%) at a rate of 132 km² per year. Wetland coverage also increased by 10 km² (10.87%), with an annual growth rate of 2 km² per year, as shown in table 3. This implies that during this period water cover, built up area, agricultural land, grassland and wetland expanded at the expense of the forest cover and bare-land revealing the impact of both natural induced drivers mainly climate variability and human induced drivers through infrastructure development and agricultural practices.

Beginning the year 2014 to 2019, water cover increased by 27 km² (0.89%) at an annual rate of 5 km² per year. The built-up area also increased by 206 km² (29.81%), with an annual growth rate of 41 km² per year. While Forest land continued to decline, decreasing by 74 km² (5.03%) at a rate of 15 km² per year. Agricultural land expanded by 475 km² (6.28%) at the rate of 95 km². Bare land decreased by 76 km²

(45.51%) at a rate of 15 km² per year. Grassland coverage was reduced by 491 km² (24.40%) at a rate of 98 km² per year. At the same time, Wetland areas equally decreased by 17 km² (16.67%) at an annual rate of 3 km² per year, as shown in table 3. During this period, water cover, built-up areas, and agricultural land expanded, whereas forest cover, grassland, bare land, and wetlands were reduced, revealing the increased impact of anthropogenic factors on changing the landscape.

Between 2019 and 2024, water cover increased by 15 km² (0.49%) at a rate of 3 km² per year. The built-up area continued to expand and grew by 286 km² (31.88%) at the rate of 57 km² per year, while Forest land decreased by 191 km² (13.67%) at the rate of 38 km² per year. Agricultural land expanded by 776 km² (9.65%) at a rate of 155 km² per year. Bare land increased by 111 km² (121.98%), growing at a rate of 22 km² per year. Grassland decreased by 97 km² (64.30%) at a rate of 195 km² per year. Finally, Wetland areas also reduced by 39 km² (45.88%) at a rate of 8 km² per year, as shown in table 3. This period further illustrates the ongoing influence of anthropogenic drivers in the Lake Tana Basin, as water cover, built-up areas, and agricultural land expanded at the expense of forest cover, grassland, bare land, and wetlands

Table 3: Land Use Land Cover Change Detection at Five-Year Interval from 2004- 2024

LULC Classes	**2004-2009**			**2009-2014**			**2014-2019**			**2019-2024**		
	(Km^2)	(%)	Rate	(Km^2)	(%)	Rate	(Km^2)	(%)	Rate	(Km^2)	(%)	**Rate**
Water Cover	-14	-0.46	-3	37	1.23	7	27	0.89	5	15	0.49	3
Built-up Area	38	5.89	8	8	1.17	2	206	29.81	41	286	31.88	57
Forest Land	-276	-9.93	-55	-1032	41.23	-206	-74	-5.03	-15	-191	-13.67	-38
Agricultural Land	814	12.77	63	377	5.25	75	475	6.28	95	776	9.65	155
Bare-Land	110	75.86	22	-58	22.75	-12	-76	45.51	-15	111	121.98	22
Grassland	-636	31.96	-127	658	48.60	132	-491	24.40	-98	-97	-64.30	-195
Wetland	-36	28.13	-7	10	10.87	2	-17	16.67	-3	-39	-45.88	-8

General LULC Change of the Basin for 20 Years

Throughout the entire study period, various land use and land cover changes were observed. Water cover increased by 65 km², which is a 2.16% rise, with an annual rate of 13 km² per year. At the same time, built-up areas experienced an increase of 538 km², representing 83.41% at an annual rate of 108 km². However, forest land declined by 1573 km², which is 56.60% at the rate of 315 km² per year. At the same period, agricultural land expanded by 2442 km², accounting for a 38.32% increase at the rate of 488 km² per year. Bare land increased by 57 km², which is a 39.31% rise, at the rate of 11 km² per year. In contrast, grassland areas experienced a decrease of 1447 km², which is a 72.71% reduction at the 289 km². Similarly, wetland areas declined by 82 km², which is a 64.06% decrease, at an annual rate of 16 km² per year. Figures 3, and Table 4 show the variation of LULC change from 2004 to 2024. These changes imply that during the previous 20 years, agricultural land, built-up areas, water cover, and bare land have gradually replaced forest land, wetlands, and grass in the Lake Tana Basin. This transformation reflects significant changes in land usage brought about by several socioeconomic variables, including urbanization, population growth, and the need for increased agricultural production.

Key informants pinpointed out that the land use land cover change in the basin has seen wetland, forest land, grazing land, changed to agricultural land and built up and bare-land due to the increasing need for food due to sustain the growing population and infrastructure development.

Likewise, Mehari (2018), reported that the shrinking of forest, wood land, range land, shrub land, water body and bare land are mainly due to the expansion of farmland in the Basin as a result of population growth; lack of appropriate land management policies, legislations and institutions; and lack of awareness.

Table 4: General Land Use and Land Cover Change for 20 Years (2004- 2024)

LULC Classes	2004-2024		
	Area (Km^2)	Area (%)	Rate (Km^2/Year)
Water Cover	65	2.16	13
Built-up Area	538	83.41	108
Forest Land	-1573	-56.60	-315
Agricultural Land	2442	38.32	488
Bare-Land	57	39.31	11
Grassland	-1447	-72.71	-289
Wetland	-82	-64.06	-16

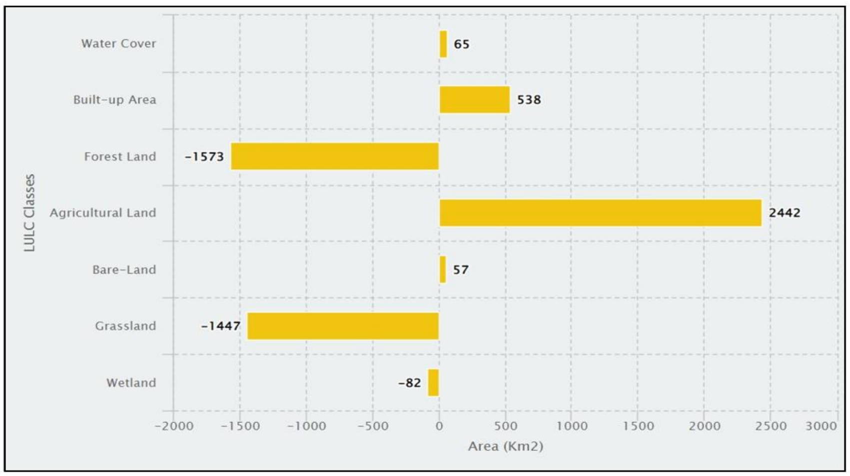

Figure 4: General LULC change from 2004 to 2024

Drivers to LULC Change in Lake Tana Basin

Natural and anthropogenic factors, such as population increase, conservation efforts, climate variability, Soil types and their nutrient characteristics, and Level of come, were assessed as potential drivers of LULC within Lake Tana Basin. The assessment was done by analyzing the key informant's perspective and secondary data about the factors under investigation.

Key informants Perspective

Key informants that, included the professionals and elders working and living in Lake Tana Basin, reviewed the anthropogenic and natural processes under investigation have altered the state of LULC within the Basin to different degrees. Their perceptions of the variability of the LULC classes were ranked by the Likert scale, where the extremely influential, influential, Moderate Influential, Limited influential, and No influence were assigned numbers 5, 4, 3, 2, and 1, respectively.

According to the key informants, various factors influenced land use and land cover changes within the Lake Tana Basin at different levels, as illustrated in Figure 4. Increased Water coverage was predominantly influenced by climate change and soil characteristics, with income levels having the most negligible impact. At the same time, the increase in Built-up areas was primarily driven by population increase, while conservation efforts had the slightest effect. The reduction in Forest cover was mainly influenced by population increase and was least affected by climate change. The increase in Agricultural land expansion was primarily driven by population growth and was least influenced by conservation efforts. The increase in Bare-land was impacted mainly by soil characteristics and conservation efforts, with income levels having minimal influence. The reduction in Grassland areas was predominantly affected by population increase, with soil type being the least influential factor. Lastly, the reduction in wetland area was primarily influenced by population increase, climate change, and income levels, while soil types had the most negligible impact.

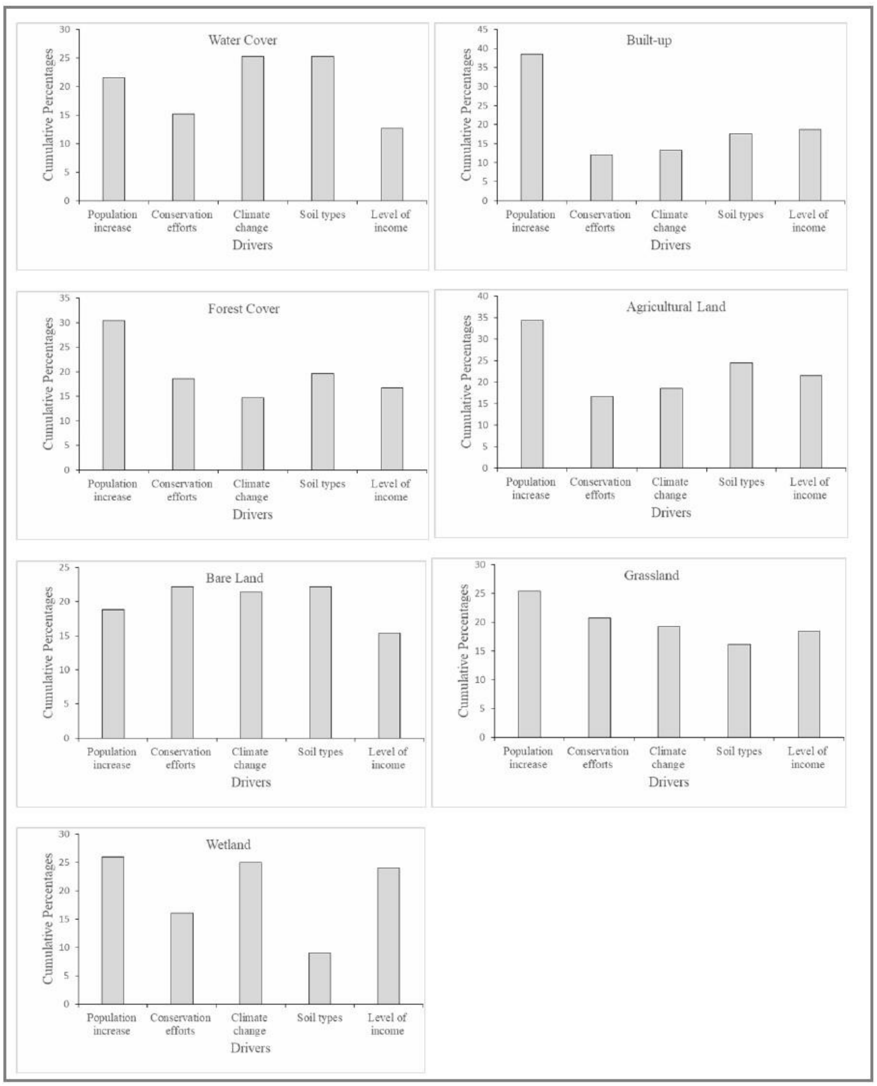

Figure 5: Key informants' perspectives on the drivers of Land use and land cover change.

Analysis of Factors Under Study Using Secondary Data

Population Growth

The population of the 13 districts making up the Lake Tana basin has experienced massive growth. In 2004, the population was projected to be 1,903,789, and by 2007, it had grown to 2,396,700, as recorded in the 2007 Ethiopian Population and Housing Census. The projection for 2024 is 3,450,802, indicating an increase of 1,547,013 from 2004 to 2024 as shown in Figure 6.

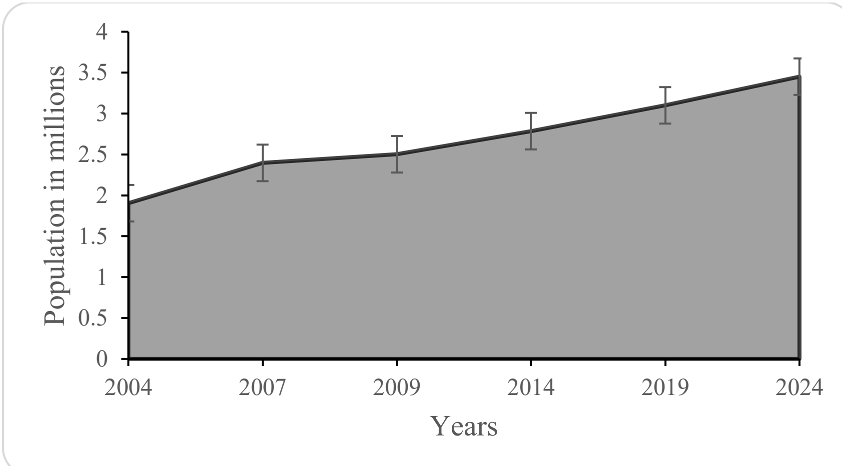

Figure 6 : Lake Tana Basin Population from 2004 to 2024

Population growth has varying degrees of influence on Land Use and Land Cover changes within the basin, as evidenced by the P-values of their linear correlations (Table 5). Agricultural land expansion (P-value = 0.0006) was the most influenced by population growth, followed by the forest cover reduction (P-value = 0.0221), in the third position was the wetland reduction (P-value = 0.0260), in the fourth position was the water cover increase (P-value = 0.580), in the fifth position was built up area increase (P-value = 0.0605), in the sixth position was grassland reduction (P-value = 0.1602) and finally the least influenced by the population growth was the bare-land increase (P-value = 0.9640). These findings confirm that an increase in agricultural land, reduction of forest cover, increase in water coverage, and the built-up area in the Lake Tana Basin are attributed mainly to population growth. The findings are in agreement with the previous studies (Garg et al., 2019; Dibaba et al., 2020; Xu et al., 2020).

Table 5: Linear Relationship Between Population Increase and LULC Variability

LULC	R Square (R^2)	Adjusted R	P-value
Water Cover	0.75	0.67	0.0580
Built-up Area	0.74	0.66	0.0605
Forest Cover	0.86	0.82	0.0221
Agricultural Land	0.99	0.98	0.0006
Bare-land	0.0008	-0.33	0.9640
Grassland	0.53	0.38	0.1602
Wetland	0.85	0.80	0.0260

Climate Variability

The year 2009 experienced the lowest mean rainfall distribution, with an average of 87.99 mm, while 2017 received the highest mean rainfall distribution, with an average of 128.90 mm, as shown in Figure 7.

Similarly, previous researchers have recorded the trend and pattern (Viste et al., 2013; Abebe et al., 2017; Demissie et al., 2022; Tesfaw et al., 2024). As indicated by Tesfaw et al. (2024). Despite the insignificant change in Lake Tana's climate, its variation has influenced LULC and different capacities.

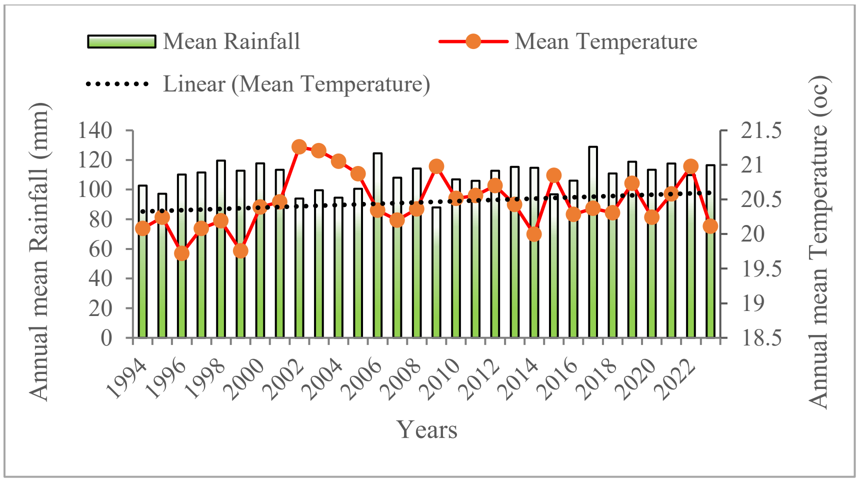

Figure 7: Lake Tana Basin Climate Variation.

Table 6: Linear Relationship Between Rainfall Variability and LULC Variability

LULC	R Square (R^2)	Adjusted R	P-value
Water Cover	0.83	0.78	0.0308
Built-up Area	0.40	0.21	0.2492
Forest Cover	0.89	0.85	0.0161
Agricultural Land	0.58	0.44	0.1343
Bare-land	0.23	-0.02	0.4096
Grassland	0.06	-0.24	0.6816
Wetland	0.27	0.04	0.3602

The R^2-value of linear correlation was used to determine the significance of rainfall variability's influence on land use land cover changes within the basin, as shown in Table 13. It was observed that forest cover reduction (R^2 = 0.89), was greatly influenced by rainfall variability. This was followed by an increase in water cover (R^2 = 0.83). Agricultural land expansion was in the third position with a moderate influence (R^2 = 0.58). The build-up area increase was in the fourth position (R^2 = 0.40). The increase in bare land (R^2 = 0.23) was in the fifth position, and wetland reduction (R = 0.27) was in the sixth position. Finally, grassland reduction was the least influenced by rainfall variability, with an R^2-value of 0.06. The Findings are in agreement with the Key informants, as shown in Figure 5, whereby the increase in water coverage was mainly attributed to climate change in the Basin. The observed upward trajectory of the mean temperature (Figure 7) makes natural forest dry up. Similarly, Mendelsohn & Dinar, (2009) reported that climate change resulted in drought, which led to the reduction of forest cover.

Conservation Efforts on Soil and Water

Extension workers, the Abay Water Resource Authority, and the community have spearheaded practices such as check dams, and planting fast-growing trees, influencing land use and land cover in various ways. These interventions have promoted soil conservation and water management and mitigated land degradation. Additionally, introducing fast-growing tree species has provided a renewable source of timber and fuelwood, reducing pressure on natural forests and aiding in their regeneration. For instance, in the southern part of Lake Tana, farmers have grown fast-maturing trees specifically for harvesting within their farmlands. This approach provides a sustainable wood source and promotes forest land regeneration. Farmers contribute to restoring degraded landscapes and enhancing biodiversity by integrating tree planting with agricultural activities (Figure 8), the upper part shows bare land on a trench; apart from rendering the land unproductive, sediments were being eroded into the lake through soil erosion. After creating check dams, the bare land was converted to grassland, as shown in the lower section. However, Mehari (2018) reported that the fundamental reasons for the degradation of resources in the Lake Tana Basin are political shortcomings, lack of policy and adequate legal framework, and institutional weaknesses.

Figure 8: Soil and Water Conservation efforts (Source; Blue Nile Water Resource Authority)

Lake Tana Soil Types, Nutrient Characteristics and their Proportions

Lake Tana Basin Major soil types include; Vertisols, Luvisols, Cambisols, Fluvisols, Geysols,Leptosols, Regosols, Solonchaks, Xerosals and Nitosolsas (Mehari, 2018).

It was observed that the areas with the major land use and land cover change during the study period (2004-2024) are occupied by the first three major soil types, including Vertisols, Gleysols, and Nitisols. The forest and grass previously covered the areas with vertisols and gleysols. These areas have been changed to agricultural land and Built-up areas. The Nitisoil occupied areas were initially covered by dense forest in 2004, but in 2024 the areas are occupied by fragmented forest, grasses, and agricultural land, as shown in Table 7. Key informants confirmed that if the fertility of a particular area is reduced, it is temporarily abandoned and slowly get converted to bare land. This practice justifies the increasing bare land in the basin. Soil with high fertility is targeted by growing agricultural activities. This explains why the agricultural land is increasing in the Lake Tana Basin.

Table 7: Lake Tana Basin Major Soil Types, Their Nutrient Availability and Proportion Coverage in Percentages

Major Soil Types	Symbols	Texture	Nutrient Availability	Area Coverage (Percentage %)
Vertisols	VR	Silty Loam	Medium to high	28.06
Gleysols	GL	Clay	Low to medium	13.21
Nitisols	NT	Sandy Clay	High	12.99
Xerosols	X	Sandy Loam	Low	11.76
Luvisols	LV	Sandy Clay Loam	Medium to high	11.12
Cambisols	CM	Sandy Clay Loam	Medium to high	8.83
Regosols	RG	Sandy Loam	Low to medium	8.01
Solonchaks	SC	Clay Loam	Low	4.72
Leptosols	LP	Sandy Clay Loam	Low to medium	0.81
Fluvisols	FL	Sandy Clay Loam	Medium to high	0.5
Total				100%

Conclusion and Recommendation

The magnitude of change and the trend of Land use and Land cover classes were analyzed from 2004 to 2024 at an interval of 5 years. According to the results for the 20 years under study, the water coverage increased slightly following the increase in the construction of dams in the Basin. The Built-up area increased mainly in the urban centers such as Bahir Dar City, Gonder, Makesegnit, Addiszemen, Woreta, Debretabore, Wanzaye, and Dangila. The forest cover was reduced greatly due to massive deforestation of trees for firewood and timber and the conversion of forest land to agricultural land. The agricultural land increased mainly due to the increased reliance on farm products and rain-fed agriculture. The Bareland increased slightly, mainly due to the abandonment of unproductive agricultural land and the emergence of droughts. The Grassland was reduced due to overgrazing and conversion to agricultural land. Finally, the wetlands were reduced due to over-exploitation of the products and the conversion of the coverage to agricultural land.

The population increase highly influenced the increase in agricultural land, forest cover reduction, and wetlands. Climate change resulted in a reduction of forest cover and an increase in water cover. Soil fertility has highly impacted the increase in agricultural land and bare land. Conservation efforts have mainly influenced forest cover, which decreases very slowly, and increased agricultural land. The income level has influenced the increasing agricultural land, reduced forest cover, and decreased wetlands.

Recommendation

Based on the results of this study and the conclusions, the following recommendations were made;

- Encourage Sustainable Land Use Management in the Basin by improving and implementing land use policies and practices to minimize the negative impact of LULC changes, such as land degradation.
- Enhance the region's ongoing conservation efforts. Additionally, explore opportunities for integrated watershed management involving stakeholders from various sectors to address issues hindering the conservation of Lake Water.
- More research should be done specifically on the implications of LULC change on ecosystem health and services.

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