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Influence of Land Use and Land Cover Change on Water Quality in Lake Tana Basin, Upper Blue Nile, Northwest Ethiopia

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Abstract

Lake Tana Basin, located in northwest Ethiopia, is an important ecological and hydrological system supporting diverse plant and animal life. It is the source of the Blue Nile River, an essential water resource offering multiple services to millions of people in Ethiopia, Sudan, and Egypt. However, due to changes in land use and land cover (LULC), the basin is at risk of Water quality deterioration. The study adopted a mixed-methods research design that comprised of a cross-sectional survey, ecological survey and finally desktop research that involved literature search, to investigate Land Use/Land Cover (LULC) changes and their impact on water quality parameters such as Turbidity and Chlorophyll *a*. Landsat 5 thematic mapper (TM) and Landsat 8 operational land imager (OLI) were used to generate temporal LULC change for 20 years (2004 – 2024). At the same period, the surface reflectance products of MODIS Terra (MOD09A1) and measured selected water quality parameters were used to develop equations for predicting time series water quality. The equations were developed, validated and adopted to predict Turbidity and Chlorophyll *a* respectively. The relationship of LULC change and the dynamics of Turbidity and Chlorophyll *a* concentration were analyzed by ANOVA, which indicated that the increase in Turbidity was highly influenced by the rise in Agricultural land and least influenced by the increase of Bare-land at a P-value of 0.00892 and 0.655 respectively. Similarly, the surge in chlorophyll *a* concentration was highly influenced by the increase in the Built-up area and least affected by the increase in Bare-land at a P-value of 0.0049 and 0.918 respectively. The study recommends implementing sustainable LU and water management strategies to mitigate the negative impacts of LC changes, such as deforestation, increased agricultural land, and urban expansion, leading to heightened water turbidity and chlorophyll *a* concentration in Lake Tana over.

Keywords: *Chlorophyll a; Geographical Information Systems; Land Use/Land Cover; Remote Sensing; Turbidity*

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Introduction

Water makes up about 70% of the earth's surface, making it the most valuable natural resource globally, without which life would not exist (Barbarossa *et al*., 2021). It naturally exists in different locations and forms, including water on the earth's surface, below the ground, (Dudgeon *et al*., 2006) and in the air (Mehari, 2018). Freshwater only constitutes about 0.01% of the world's water (Dudgeon *et al.*, 2006). Despite their small percentage, freshwater resources are significant as they provide multiple social, ecological, and economic services for industrial, domestic, and agricultural uses (Mucheye *et al.*, 2022). Lake Tana is the largest freshwater lake in Ethiopia, providing numerous ecosystem services for the local people in Ethiopia and the downstream countries of Sudan and Egypt (Mucheye *et al.*, 2022). It is the source of the Blue Nile River, which contributes up to 62% of the total Nile Basin water (Mehari, 2018).

Water resource management is critical for meeting present demands while also ensuring long-term sustainability (Geremew, 2013). However, freshwater resources worldwide face severe threats from land use and land cover (LULC) change attributed to natural processes and anthropogenic activities that compromise their natural functionalities. For instance, drinking water quality in Peshawar district, Pakistan, has deteriorated, with elevated levels of pH, conductivity, calcium, chloride, and magnesium observed near urban areas (Ahmad *et al*., 2021). Additionally, nitrate concentrations have risen near agricultural land due to the excessive use of fertilizers. Therefore, there is an urgent need to comprehend the relationship between different land use and land cover changes taking place in the land masses bordering water bodies and water turbidity, and chlorophyll *a*

Turbid water contains particulates that act as a haven for hazardous germs, blocking fish gills, thus limiting their growth and reducing their capture efficiency (Omer, 2019; Kulkarni, 2011) In addition, turbid water may contain heavy metals like Chromium, Mercury, Cadmium and Lead, as well as many dangerous organic pollutants such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons, and many pesticides posing significant health hazards to both humans and aquatic ecosystems (Kulkarni, 2011). Chlorophyll *a* concentration depicts the presence of algae blooms that can deplete oxygen levels in the water, leading to fish kills and other aquatic life losses (Kulkarni, 2011). Furthermore, some algae produce toxins that harm aquatic organisms and can threaten human health if water is used for drinking or recreation.

Understanding the relationship between different LULC changes in the catchment areas and how the selected water quality parameters impact the fundamental needs of humans is necessary for the conservation plans in the Basin (Fentahun, 2020). This information is crucial to policymakers and planners in developing strategies to mitigate the adverse effects of future LULC change (Geremew, 2013). Geographic information science and remote sensing techniques have made it possible to study and analyze spatio-temporal LULC change and water quality parameters, such as turbidity, and chlorophyll *a,* at a low cost in less time with better accuracy (Sewnet, 2016). Therefore, the study aims to show the relationship between LULC change and the selected water quality parameters while evaluating the major driving forces leading to LULC change within Lake Tana Basin.

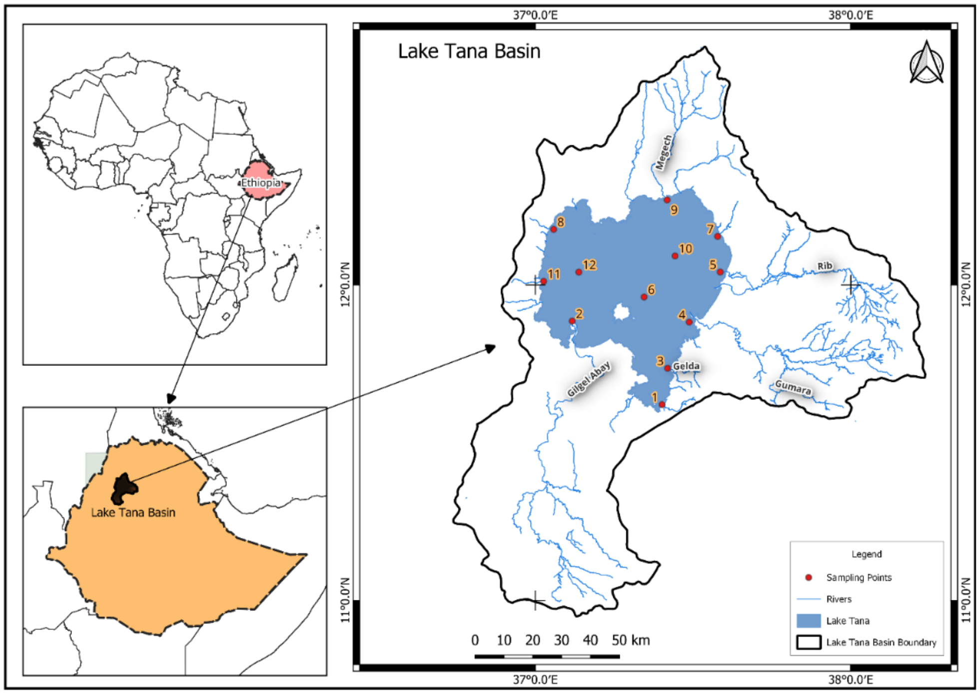
Material and Methods

Study Area

Lake Tana Basin is located in northwestern Ethiopia, which lies between Latitude 10°55 to 12°45″ N and Longitude and 36°40′ to 38°20′ E (Figure 1). The Basin covers approximately 15,096 km^2 (Mucheye *et al*., 2022). It comprises a massive land mass, wide wetlands, multiple feeder rivers, numerous forested islands, and Lake Tana, which is a naturally occurring freshwater lake with a surface area of 3000-3600 km^2, at an elevation of about 1787 m above sea level (a.s.l), and a maximum depth of 15 m (Mehari, 2018).

Figure 1

Map of Lake Tana Basin, Ethiopia.



Data Collection

Water quality, including Turbidity and Chlorophyll *a*, were analyzed in the Bahir Dar Institute of Technology water quality laboratory.

Turbidity was determined by using a Hach 2100 N turbidimeter. Prior to measurement, the instrument was calibrated using a 0.1–7500 NTU as directed in the kit.

Chlorophyll *a* concentrations were measured using the acetone extraction method. Samples were filtered through a 0.47 µm glass fibre filter (Whatman GF/C) using Gellman polycarbonate filtration towers under low-to-moderate vacuum (10–40 cm Hg). The extracts were then cleared by centrifugation at 4000 rpm for 20 minutes. Absorbance measurements were taken before and after acidification. Sample and standard absorbance were measured at 750 nm and 664 nm (denoted as 750b, 664b, 750a, and 665a, respectively). The concentration of chlorophyll *a* in the extract was evaluated using a spectrophotometer equipped with a Perkin-Elmer Lambda 35 UV/VIS spectrophotometer. The spectrophotometer had a 1 nm spectral bandwidth and used optically matched 4 cm plastic cuvettes.

The study employed a mixed-method approach combining both remotely sensed data and in-situ measurements to monitor changes in water quality and land use land cover (LULC) within the study area. 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) from 2004 to 2024. Our selection was primarily focused on acquiring images that were cloud-free to ensure data quality. The reprocessed Landsat images were used to generate temporal LULC data through supervised classification using a random forest algorithm (Alam *et al.*, 2020). The generated LULC classes include water cover, built-up areas, forest land, agricultural land, bare-land, grassland, and wetland. 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 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.

Point Secondary data on water quality parameters were obtained from the Bahir Dar University Institute, the Department of Civil and Water Resource Engineering. Both primary and secondary water quality data were used to develop the equations for predicting selected water quality parameters and for their validations. Considering to Womber, (2021), the band values of surface reflectance of Modis (MOD09Q1.061 Terra) of spatial resolution 250m and wavelength range of 620nm-876nm were extracted from the respective sampling points, recorded on the same date of sampling/ in-situ measurement in the google earth engine platform. Various band types, band combinations and band ratios were tested with the measured data, whereby the types or combinations that generated the highest R^2 values were validated and adopted to predict time series Turbidity and Chlorophyll *a*.

Results

Accuracy Assessments

An accuracy assessment is performed to determine the truth behind classified images. The confusion error matrix was used in this assessment to compare information received from sample reference sites to that obtained from classified images. More than 80 reference training sites were identified using field observations, Google Earth Pro, and existing maps.

Anderson (1976) defines the minimum accuracy value for reliable land cover classification as 85%. Land use land cover classification for the years 2004, 2009, 2014, 2019, and 2024 yielded overall accuracy of 86%, 97%, 95%, 93%, and 95%, respectively. The assessment results given in Table 1 reveal that the maps' overall correctness meets Anderson's (1976) minimum accuracy level. The accuracy of producers and consumers was also calculated, resulting in values ranging from 86% to 100% and 65% to 100%, respectively, over the years 2004–2024. Water cover has the best accuracy in all assessments because to its distinct spectral signature on Landsat imagery.

Table 1

Summary of accuracy assessment from 2004-2024 (%) in Lake Tana Basin, Ethiopia

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

Temporal Magnitude of Land Use and Land Cover of Lake Tana Basin

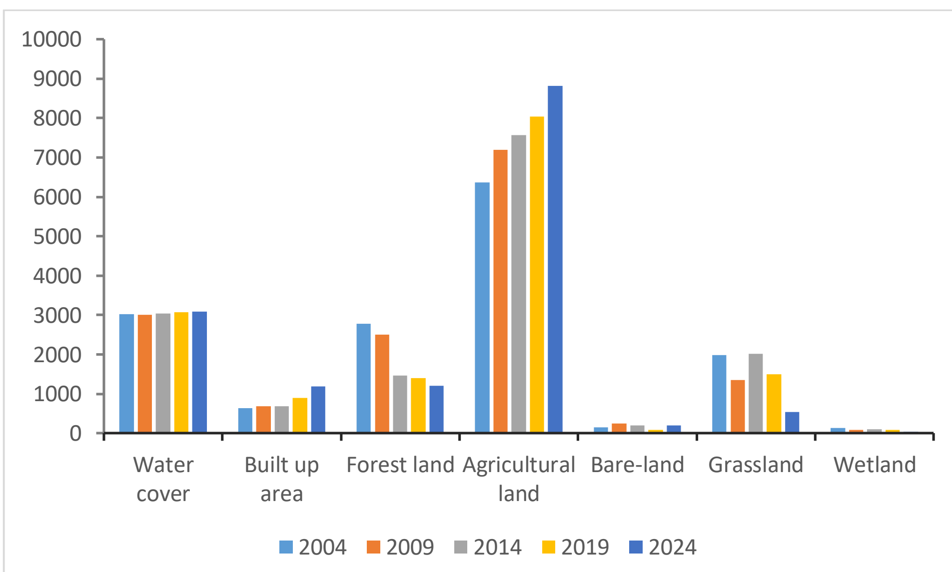
Table 2

Land use and land cover area of Lake Tana basin, Ethiopia (in Km²) during 2004, 2009, 2014, 2019, and 2024.

Total Area and Percentages					
LULC Classes	**2004** (Km²)	**2009** (Km²)	**2014** (Km²)	**2019** (Km²)	**2024** **(Km²)**
Water cover	3016	3002	3039	3066	3081
Built up area	645	683	691	897	1183
Forest land	2779	2503	1471	1397	1206
Agricultural land	6373	7187	7564	8039	8815
Bare-land	145	255	197	91	202
Grassland	1990	1354	2012	1491	543
Wetland	128	92	102	85	46
Total	**15076**	**15076**	**15076**	**15076**	**15076**

Figure 2

General trend of Land Use and Land Cover in Lake Tana Basin, Ethiopia



Between 2004 and 2024, the basin experienced significant land and water coverage shifts driven by increasing human activity as indicated in (Table 2 and Figure 2). Water coverage initially decreased slightly from 3016 km² in 2004 to 3002 km² in 2009 but steadily grew to 3081 km² by 2024, reflecting a modest 2.1% increase over the study period. The built-up area expanded rapidly, nearly doubling from 645 km² in 2004 to 1183 km² by 2024, with the most significant growth occurring after 2014. Forest cover, however, faced drastic declines, shrinking by more than half from 2779 km² in 2004 to 1206 km² by 2024, particularly during the 2009–2014 period, highlighting rapid deforestation. Meanwhile, agricultural land steadily increased from 6373 km² in 2004 to 8815 km² in 2024, reflecting a 38.4% expansion, likely driven by growing food production demands. Grasslands saw a general decline, dropping from 1990 km² in 2004 to just 543 km² by 2024, despite a temporary recovery in 2014. Wetlands also suffered, decreasing from 128 km² in 2004 to 46 km² by 2024, with a brief increase in 2014. Bare land fluctuated, rising from 145 km² in 2004 to 255 km² in 2009 before settling at 202 km² in 2024. The overall, trends reflect the basin's shift toward more built-up and agricultural areas at the expense of forests, grasslands, and wetlands, with significant environmental implications, especially the sharp reduction in forest cover, which could affect biodiversity, water regulation, and climate stability

Water quality prediction using remotely sensed images

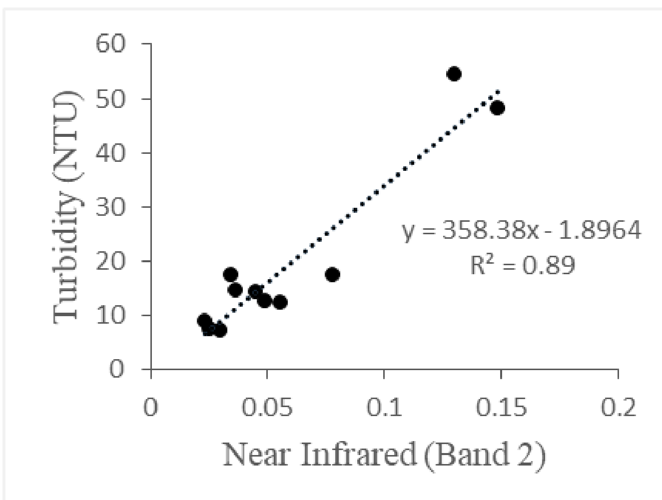
The primary data collected on 26th March 2024 from 12 designated points (Figure 1), as well as historical secondary data of different points within Lake Tana and band values of surface reflectance from MODIS (MOD09Q1.061 Terra 250m), were used to develop and validate equations that were adopted to predict time series Turbidity and Chlorophyll *a* from 2004 to 2024.

Turbidity

The near-infrared (Band 2) generated the highest linear correlation coefficient (R^2 = 0.89) with the measured Turbidity. (Figure 3) shows a simple linear regression equation of the measured Turbidity and the Near Infrared Band.

Figure 3

Simple linear regression of the Turbidity and Near Infrared Band in Lake Tana Basin, Ethiopia



Validation of the equation.

The equation was validated with the previously collected data from April 2020 and October 2021 (Source: Bahir Dar University, Civil and Water Resource Department). The linear equation comparing the predicted Turbidity (NTU) with the measured Turbidity (NTU) in April 2020 and October 2021 generated R^2 values of 0.72 and 0.73, respectively.

The equation as shown in figure 3, proved to be consistent; therefore, Turbidity (NTU) = 358.38nir – 1.8964 was adopted to predict the time series Turbidity of the Lake.

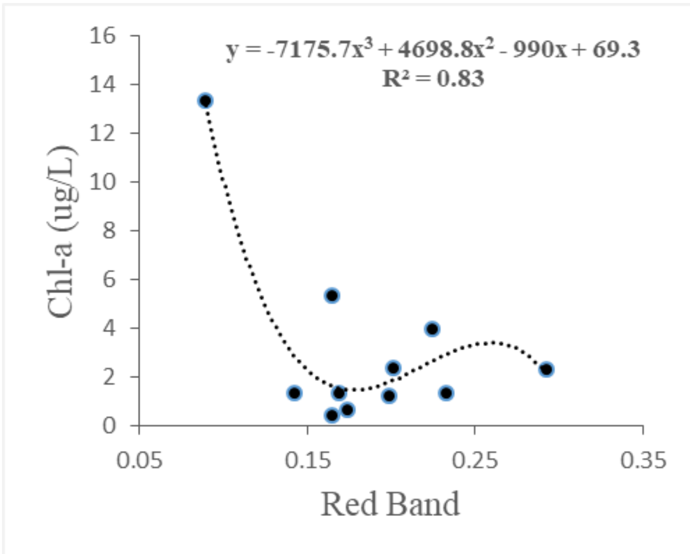
Chlorophyll a

The red band (Band 1) showed the highest polynomial correlation coefficient (R^2 = 0.83) with the measured Chlorophyll *a* in October 2021 (Source: Bahir Dar University, Civil and Water

Resource Department). (Figure 4) shows the exponential equation of chlorophyll *a* with the Red Band.

Figure 4

Exponential linear equation of chlorophyll a and Red Band in Lake Tana Basin, Ethiopia



Validation of the equation

The equation was validated with the data previously collected in August 2016 and March 2017 (Source: Bahir Dar University, Civil and Water Resource Department) and the field measured data of March 2024. The linear equation comparing the predicted Chlorophyll *a* (ug/L) with the measured Chlorophyll *a* (ug/L) in August 2016, March 2017, and March 2024 generated an R^2 value of 0.75, 0.50, and 0.63, respectively.

The equation, Chlrophyll-a = $-7175x^3 + 4698.8x^2 - 990x + 69.3$, as shown in figure 4 proved consistent and was adopted to predict the lake's time series Chlorophyll *a*

Table 3

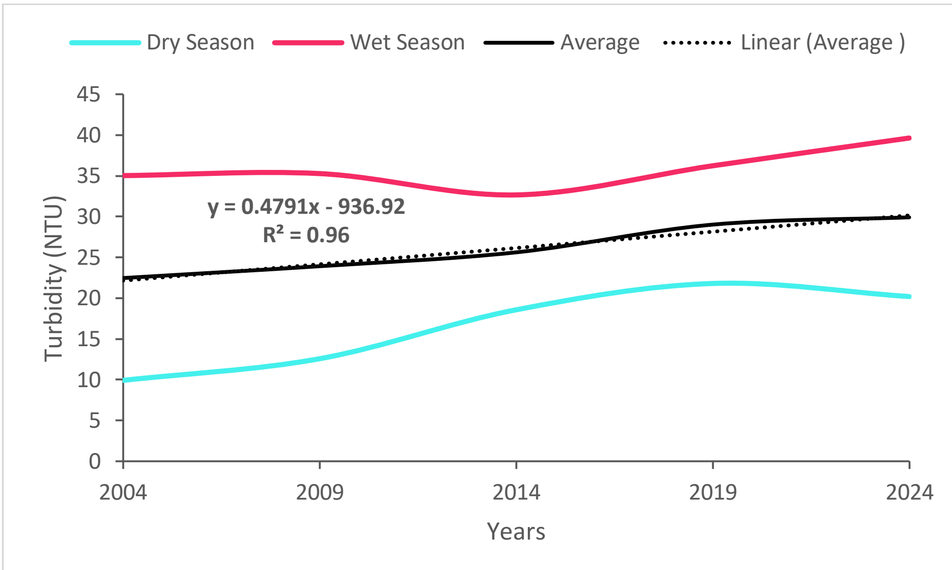
Trend of the predicted Turbidity (NTU) from 2004 to 2024 in Lake Tana Basin, Ethiopia

Turbidity (NTU) 2004 – 2024			
Years	Dry Season	Wet Season	Average
2004	9.87	35.01	22.44
2009	12.52	35.26	23.89
2014	18.53	32.65	25.59
2019	21.76	36.21	28.98
2024	20.15	39.61	29.88

According to (Table 3 and Figure 5), the average turbidity of the sampled sites showed a clear upward trend throughout the study period. Starting from 2004, the average turbidity was 22.44 NTU, which increased to 23.89 NTU in 2009, 25.59 NTU in 2014, 28.98 NTU in 2019, and 29.88 NTU in 2024.

Figure 5

Trend of Turbidity from 2004 to 2024 in Lake Tana Basin, Ethiopia



Trend of the predicted Chlorophyll a (ug/L) from 2004 to 2024

The average chlorophyll *a* concentration at the sampled sites increased significantly over the study period. In 2004, the average value was 5.12 ug/L. In 2009, this increased to 5.55 ug/L but decreased to 5.04 ug/L in 2014. In 2019, the average was 7.04 ug/L, but by 2024, it had increased significantly to 13.01 ug/L (Table 4 and Figure 6).

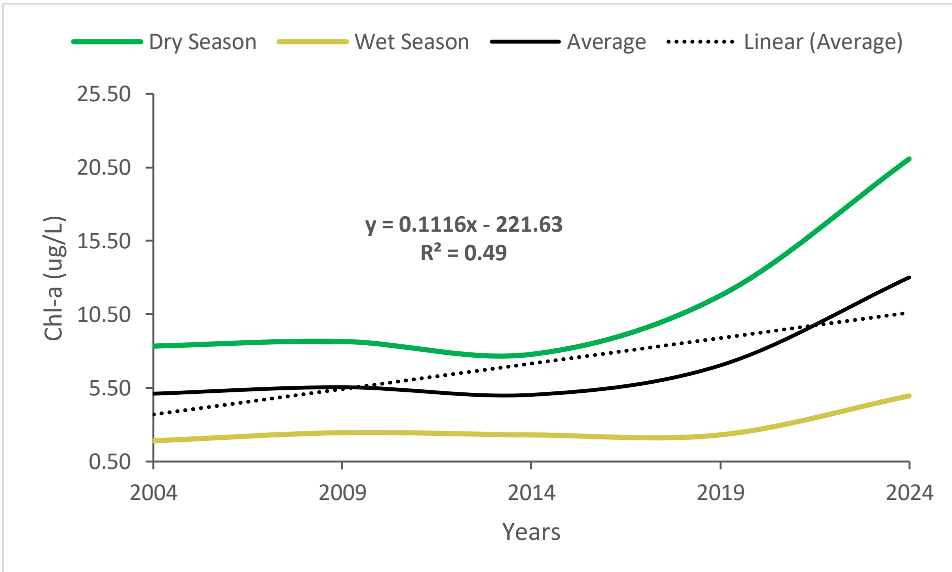
Table 4

Trend of Chlorophyll-a from 2004 to 2024 in Lake Tana Basin, Ethiopia

Chlorophyll *a* (ug/L) 2004 – 2024			
Years	**Dry Season**	**Wet Season**	**Average**
2004	8.34	1.90	5.12
2009	8.65	2.46	5.55
2014	7.78	2.30	5.04
2019	11.77	2.30	7.04
2024	21.06	4.96	13.01

Figure 6

Trend of Chlorophyll a from 2004 to 2024 in Lake Tana Basin, Ethiopia



The increased level of Chlorophyll *a* content in Lake Tana was seen by the presence of a kind phytoplankton species seen mostly in the southern and central part of the Lake (Figure 7).

Figure 7

Chlorophyll a in Lake Tana, Ethiopia.

Relationship of Water Quality Parameters and the Land Use and Land Cover within the Lake Tana Basin

Table 5

Analysis of Variance (ANOVA) of the selected Parameter and LULC classes in Lake Tana Basin, Ethiopia

Parameters	LULC	Df	Sum Sq	Mean Sq	F Value	P
Turbidity	Agricultural Land	1	38.03	38.03	37.02	0.00892**
	Forest Cover	1	34.36	34.36	15.29	0.0297*
	Grassland	1	20.06	20.06	2.859	0.189
	Built-up Area	1	33.26	33.26	12.71	0.0377*
	Wetland	1	30.76	30.76	8.919	0.0583
	Water Cover	1	36.93	36.93	26.55	0.0142*
	Bare-Land	1	3.09	3.087	0.244	0.655
Chlorophyll *a*	Agricultural Land	1	31.70	31.7	6.899	0.0786
	Forest Cover	1	16.72	16.71	1.743	0.278
	Grassland	1	38.60	38.60	16.83	0.0262*
	Built-up Area	1	43.16	43.16	55.72	0.0049**
	Wetland	1	37.10	37.10	13.27	0.0357*
	Water Cover	1	27.84	27.84	4.736	0.118
	Bare-Land	1	0.19	0.187	0.012	0.918

Implication of LULC change on Lake Water Turbidity Levels

According to (Table 5), increase in agricultural land in the Basin showed the most vital relationship with the increasing turbidity in Lake Tana, with a statistical significance level of 0.01 and p-value of 0.00892, followed by increased water cover with statistical significance of 0.5 and p-value of 0.0142, reduction of forest cover contributed to the increasing turbidity in the third position having statistical significance of 0.5 and p-value of 0.0297, Increase in Built up area was also found importance in the fourth position with statistical significance of 0.5 and p-value of 0.0377. While the reduction of wetland became in the fifth position, having a statistical significance of 0.1 with a p-value of 0.0583, indicating moderate importance, the decrease in grassland and increase in bare-land were the least contributors, having a statistical significance of 0.1 and p-values of 0.189 and 0.655 respectively. Therefore, the expansion of agricultural land, the rise of the water cover, the destruction of the forest cover, the increase in built-up area, and the reduction of the wetland were considered observed as the major drivers of the increased Turbidity of Lake Tana over time.

Implication of LULC change on Lake Water Chlorophyll a Content

According to (Table 4), the increases in the built-up area within Lake Tana Basin had the highest correlation with the increasing chlorophyll *a* concentrations, with a statistical significance level of 0.01 and a p-value of 0.0049. It was followed by a decrease in grassland, with a statistical significance level of 0.05 and a p-value of 0.0262. The reduction of wetlands contributed to an increase in chlorophyll *a* concentration in the third position with a statistical significance level of 0.05 and a p-value of 0.0357. An increase in agricultural land ranked fourth position, with a statistical significance level of 0.1 and a p-value of 0.0786. While an increase in water cover was in the fifth position, having a statistical significance level of 0.1 and a p-value of 0.118, indicating moderate importance, the reduction in forest cover and bare land were the least contributors, having p-values of 0.278 and 0.918, respectively. Therefore, the growth of built-up areas, reduction of grassland and wetlands, and increase in agricultural land were observed as the major drivers of increased chlorophyll *a* concentration over time.

Discussion

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 in Lake Tana Basin, the water coverage continued to increase. This is a result of the establishment of new dams in the Basin.

The expansion of built-up areas has been recognized globally, and it is highly associated with the increasing world population (Ahmadi *et al*., 2023). In Ethiopia, besides the increasing population, the growing urban centers are due to the migration of people from the countryside to the cities (Gibson and 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. Furthermore, 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; Fentahun, 2020).

According to Geremew (2013) and Mehari *et al.,* (2018) the forest Land is being taken by the increasing agricultural land and the built-up areas. Similarly, 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 km2, mainly due to the conversion of shrub land to farmland.

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 km2 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.

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%. Similarly, previous studies in the Basin 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.

The band choice of MODDIS, the Near-infrared (Band 2), to predict Turbidity agrees with previous studies (Ayana *et al*., 2015; Womber *et al*., 2021). At the same time, the choice of the Red (Band 1) aligns with previous global and local research (Omondi *et al*., 2023; Ouma *et al*., 2020).

The consistent increase in average turbidity highlights an overall decline in water quality over the past 20 years. The highest turbidity levels were consistently recorded during the wet season, revealing how LULC changes in the land mass of the Basin influence the Lake water quality. Previous studies have shown the increasing trend of turbidity in Lake Tana (Womber *et al.,* 2021; Leggesse *et al.,* 2023). Moges *et al.,* (2017) reported that Lake Tana's water quality is deteriorating over time, with turbidity increasing at a slope of 0.64 using the Mann-Kendall trend test. At the same time, the rising trend in average chlorophyll *a* levels suggests a considerable degradation in water quality over the last 20 years. During the dry season, the general concentration of Chlorophyll *a* was observed to be higher than in the wet season due to the cleaning effect of floating algae and phytoplankton by the moving water downstream. Similarly, Womber *et al.,* 2021 observed that during the dry season, there is a rapid growth of microscopic algae or cyanobacteria in the water; however, during the rainy period, Lake Tana becomes free of algal particles. A similar trend was observed by Ouma *et al.,* (2020) in a study conducted in two Dams in Eldoret, Kenya.

The increase in agricultural land in the Basin was found to have the most impact on increasing turbidity. Agricultural activities speed up erosional changes in the soil and improve connectivity through artificial drainage networks to the water bodies (Sherriff *et al.,* 2015). Similarly, Abate *et al*., (2017) suggested that continued cultivation leads to the loss of organic matter and a decline in soil aggregate stability, resulting in silt concentration in Lake Tana. Moreover, key informants observed the increased number of fertilizers used per hectare within the Lake Tana Basin, indicating a loss of soil fertility. As agricultural land expands, the run-off from these areas likely carries more sediments and farming chemicals into water bodies, leading to higher turbidity levels. The increased water cover in the Lake Tana Basin, resulting mainly from the construction of more dams on the rivers draining into Lake Tana, significantly impacts turbidity levels, marking it the second most influential factor after agricultural land. Key informants observed that irrigation water used in the farms is channeled into the rivers and eventually the lake.

Moreover, the decrease in forest cover within the Lake Tana Basin represents the third significant contributor to increased turbidity in Lake Tana. As forest cover decreases, less vegetation supports the soil and filters run-off, resulting in increased soil erosion and sedimentation in the dams within the basin and Lake Tana, potentially increasing turbidity levels in the Lake. As confirmed by Namugize *et al.* (2018), vegetation, especially in the water catchment, reduces run-off and soil erosion, thereby reducing turbidity. Additionally, Namugize *et al.* (2018) observed that when the closed savannah increased, turbidity levels decreased. Additionally, vegetation in the study area, especially in the water catchment, was noted to reduce run-off and soil erosion, thereby reducing turbidity. The increase in built-up area was equally significant in contributing to the increased Turbidity in Lake Tana, mainly due to urban run-off. Gituanja, (2020) findings revealed that high turbidity was observed in areas dominated by settlement land use, indicating non-point pollution from the settlement areas. Wetlands protect water turbidity by acting as natural filters, trapping particles, thereby minimizing erosion and sediment movement into water bodies (Sileshi *et al.,* 2020). The reduction of wetland in Lake Tana reduced the effectiveness of the functions of the wetland in trapping particles

The rise of the built-up area within Lake Tana Basin was found to be the most significant contributor to the increasing chlorophyll *a* content in the Lake. Run-off from the surface of built-up areas, as well as municipal and industrial discharges, increases the loading of nutrients, metals, pesticides, and other contaminants into streams (Paul and Meyer, 2008; Bassi and Kumar, 2017). Key informants pointed out that cities within the Tana Basin, such as Gonder and Bahir Dar, do not have waste treatment programs. Therefore, their industrial and domestic waste finds its way to Lake Tana and the Blue Nile River, thus stimulating the growth of phytoplankton. Reduction of grassland and wetland in the Basin proved to be the second most contributor of the increased Chlorophyll *a* content in the Lake over time. Lane *et al.* (2007) reported that grasslands and wetlands act as natural filters, capturing and absorbing nutrients before they reach water bodies.

Moreover, grasslands absorb run-off and maintain soil, whereas wetlands filter pollutants and nutrients through complex physical, chemical, and biological processes. When grassland and wetlands are reduced, more nutrients reach the lake, which promotes phytoplankton development and raises chlorophyll *a* levels. The increase in agricultural land in the Basin also played a significant role in increasing chlorophyll *a* levels. The crop categories grown in the Basin include cereals, legumes, root crops, oil crops, vegetables, and fruit crops (Abera, 2017). Both chemical and organic fertilizers are used in the basin. Common chemical fertilizers include urea, ammonium phosphate, and nitrate-based fertilizers, which are rich in nitrogen and phosphorus. Ayele and Atlabachew (2021) reported that nutrient-rich run-off from the agricultural land induces eutrophication in Lake Tana, increasing Chlorophyll *a* content in the Lake.

Conclusion

The study focused on the impact of Land use and land cover change in the Basin on water quality, especially Turbidity and Chlorophyll *a*, in Lake Tana. 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, especially in the urban areas like Bahir Dar City, Gonder, Makesegnit, Addiszemen, Woreta, Debretabore, Wanzaye, and Dangila. The forest cover has been severely diminished due to massive tree destruction for fuel and timber and the conversion of forest land to agricultural land. The increase in agricultural land was driven primarily by a greater reliance on farm products and rain-fed agriculture. The Bare-land expanded marginally; this is mainly owing to the abandoning of unproductive agricultural land and the rise of drought situations. Overgrazing and conversion to agricultural land have diminished the amount of grassland. Finally, the wetlands were reduced as a result of over-exploitation of the products and conversion of the area to agricultural land.

The lake's average Turbidity increased from 22.41 NTU in 2004 to 29.88 NTU in 2024, with maximum Turbidity experienced in the wet season. Likewise, the average concentration of chlorophyll *a* increased from 5.12 ug/L in 2004 to 13.01 ug/L in 2024. However, the concentration was higher during the dry season and lower in the wet season. This was due to the cleaning of phytoplankton and algae by the rain and moving water downstream.

The increasing Turbidity in the lake correlated highly with the increasing agricultural land at a statistical significance of 0.01, followed by increasing water cover, reduction of forest cover, and increase of built-area, respectively, at a statistical significance of 0.5, while moderately affected by the reduction of wetlands and least affected by the reduction of the grassland and increase Bare-land. The increasing concentration of chlorophyll *a* was highly affected by the increase in built-up area at a statistical significance of 0.01, followed by a reduction of grassland and wetlands, respectively, at a statistical significance of 0.5. At the same time, the chlorophyll *a* concentration was moderately affected by the increasing agricultural land and increasing water cover, respectively, at a statistical significance of 0.1 and the least affected bare land.

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