GEOSPATIAL BASED ASSESSMENT OF LAND USE LAND COVER CHANGE AROUND LAKE DEMBEL, OROMIA, ETHIOPIA

Gadisa Kaba Begna

A Thesis Submitted to the department of Architecture
College of Civil Engineering and Architecture (CoCEA),

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Geoinformatics Engineering

Office of Graduate Studies
Adama Science and Technology University

June, 2025
Adama, Ethiopia

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DECLARATION

I declare here by that this Master Thesis entitled ”GEOSPATIAL BASED ASSESSMENT OF LAND USE LAND COVER CHANGE AROUND LAKE DEMBEL, OROMIA, ETHIOPIA” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources ofmaterials that are used for this thesis have been duly acknowledged through citation.

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RECOMMENDATION

We, the advisor(s) of this thesis, hereby certify that we have read and revised version of thesis entitled ”GEOSPATIAL BASED ASSESSMENT OF LAND USE LAND COVER CHANGE AROUND LAKE DEMBEL, OROMIA, ETHIOPIA”. Prepared under our guidance by Gadisa Kaba Begna submitted in partial fulfillment of the requirements for the degree of Masters of Science in Geo-informatics Engineering. Therefore, we recommend the submission of revised version of the thesis to department following the applicable procedures.

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Major Advisor	Signature	Date

APPROVAL OF BOARD OF REVIERS

I, the advisor of the thesis entitled "GEOSPATIAL BASED ASSESSMENT OF LAND USE LAND COVER CHANGE AROUND LAKE DEMBEL, OROMIA, ETHIOPIA". And developed by Gadisa Kaba Begna, hereby certify that the recommendation and suggestions made by the board of examiners are appropriate incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Gadisa Kaba Begna have read and evaluated the thesis entitled "GEOSPATIAL BASED ASSESSMENT OF LAND USE LAND COVER CHANGE IMPACTS ON LAKE DEMBEL, OROMIA, ETHIOPIA" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geo-informatics Engineering.

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LIST OF ACRONYMS

GIS	Geographic Information Systems
RS	Remote Sensing
GPS	Global Positioning Systems
LULC	Land use land cover
GNSS	Global Navigation Satellite System
GEE	Google Earth Engine
ADB	African Development Bank
FAO	Food and Agriculture Organization
IPCC	Intergovernmental Panel on Climate Change

ABSTACT

This study presents a geospatial-based assessment of Land Use Land Cover (LULC) changes around Lake Dembel, Oromia, Ethiopia, over a 20-year period from 2004 to 2024. The analysis aimed to quantify LULC changes, assess land surface temperature (LST) dynamics, and explore their implications for ecosystem health. Landsat satellite imagery for the years 2004 (Landsat 5 TM), 2014 (Landsat 8 OLI/TIRS), and 2024 (Landsat 8 OLI/TIRS) was used. The Maximum Likelihood Classification (MLC) algorithm was employed for supervised classification, supported by ground truth data and high-resolution Google Earth imagery. Accuracy assessment for the 2024 classification achieved an overall accuracy of 89.5% and a Kappa coefficient of 0.88, indicating strong agreement between classified and actual land cover types.The study revealed significant LULC transformations. Built-up areas expanded from 4.37% in 2004 to 12.68% in 2024, a net increase of 8.31%, driven by rapid urbanization around Batu and nearby settlements. Farmland increased from 12.14% to 15.5%, while vegetation cover sharply declined from 15.87% to 6.24%, equivalent to a loss of approximately 62.89 km². Water body coverage decreased from 67.6% (441.21 km²) to 65.68% (428.11 km²), amounting to a 13.1 km² loss, largely due to sedimentation, agricultural water abstraction, and declining inflow.The environmental consequences were assessed through LST analysis, derived from thermal bands of Landsat data using radiometric and emissivity corrections. The results indicated a consistent increase in LST from 17.2°C in 2004 to 23.1°C in 2024, with an average annual increase of 0.3°C. Spatial correlation analysis showed a strong negative relationship between LST and NDVI (R^2 = 0.85 to 0.88), confirming that vegetation loss contributed to surface heating. Similarly, a strong positive correlation was observed between LST and NDBI (R^2 = 0.84 to 0.89), highlighting the heat-retaining effects of expanding built-up areas.The findings serve as a scientific basis for policymakers, planners, and local stakeholders in developing sustainable land and water management interventions within the Rift Valley region.

Keywords: *Land use land covers, Land surface temperature*

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Land Use Land Cover (LULC) change is a major driver of global environmental transformation, affecting climate regulation, biodiversity and ecosystem services (Foley et al., 2005). These changes largely driven by population growth and economic activity have led to widespread deforestation, urban expansion, and agricultural intensification globally (Turner et al., 2007; FAO, 2016).

While trends are concerning, localized assessments are critical. In East Africa's rift valley, a region rich in biodiversity and fresh water resources, LULC changes are particularly pronounced due to intensified farming, infrastructure development, and urban growth (Dessie &Kinlund, 2008; World Bank, 2015).

Ethiopia, a major rift valley country, faces increasing land use pressure due to rapid population growth and its agriculture dependent economy. The country loses approximately 92,000 hectares of forests annually, contributing to soil erosion, water quality decline, and habitat loss (Tadesse et al., 2018).

Lake Dembel, situated in the central Rift valley within the Oromia region, exemplifies these challenges. The Lake Dembel and its surrounding area have experienced substantial land cover changes over the past two decades due to agricultural expansion including floriculture, urbanization especially around Batu town, and demographic growth (Bekele &Alamirew, 2016; Desta et al., 2021). These changes have led to deforestation, soil erosion, and water quality degradation, threatening the ecological balance and sustainability of the Lake.

One significant driver is the expansion of the floriculture industry, which depends heavily on water and agrochemicals. This activity contributes to lake water extraction and pollution (Bekele et al., 2015; Meshesha et al., 2014). Additionally, urban development around Batu town increases impervious surfaces, leading to sedimentation and lake eutrophication (Garedew et al., 2009; Abate, 2011).

Climate change amplifies these pressures through rising temperatures and unpredictable rainfall, further straining water resources and accelerating land degradation (IPCC, 2019; Gashaw et al., 2018). Demographic expansion in the Oromia region from 27 million in 2007 to over 42 million by 2024 (Central Statistical Agency (CSA), 2024) exacerbates pressure on land and water systems.

1.2 Statement of the Problem

Lake Dembel's ecological stability is increasingly threatened by ongoing and rapid LULC changes. Key environmental concerns in the region include:

Deforestation and habitat loss: Forests around the lake have been heavily degraded for agriculture, settlement, and firewood, resulting in biodiversity loss (FAO, 2016).

Agricultural intensification: Large-scale conversion of wetlands and forest to floriculture and farming activities has increased water extraction and chemical input (Belay et al., 2015).

Urban expansion: Rapid settlement growth, especially in Batu, has increased impervious surfaces, accelerating runoff and sedimentation into the lake (Garedew et al., 2009; Abate, 2011).

Water quality degradation: Runoff from farms containing fertilizers and pesticides has reduced water quality, contributing to eutrophication (Meshesha et al., 2014; Zewdie et al., 2020). These problems reflect that the size of features found around Lake Dembel is changed.

Despite growing land use pressure around Lake Dembel, there is insufficient temporal geospatial evidence demonstrating how land use land cover (LULC) changes over the past two decades have impacted key environmental indicators such as lake surface area, and land surface temperature (LST). While several studies have been conducted in other parts of Ethiopia, such as Lake Dembel (Mengistu & Salami, 2007) and the Central Rift Valley lakes (Tadesse et al., 2017) these efforts typically lack long-term temporal depth, do not include Lake Dembel, and rarely link LULC trends directly to hydrological or thermal impacts on lake systems.

This study aims to bridge that gap by examining LULC patterns around Lake Dembel with the combination of LST analysis across 2004, 2014, and 2024 using geospatial tools and field observation. It will identify primary drivers of land cover change and evaluate their environmental implications, informing sustainable land and water management strategies in the region.Existing research lacks actionable insights for policymakers on sustainable land use and conservation strategies.

This Study identifies the key drivers of LULC changes, and provides targeted recommendations for land use planning, conservation strategies, and policy interventions.It offers evidence-based solutions for balancing economic development and ecological sustainability.The year 2004, 2014, and 2024 were selected because of these years are critical phases of Urban expansion, agricultural intensification, and environmental in the study area.

1.3 Research Objectives

General Objective

To assess Land use land cover changes impacts on the Lake Dembel over the past 20 years.

Specific Objectives

- To identify the driving factors influencing LULC changes around Lake Dembel
- To analyze LULC temporal changes around Lake Dembel
- To assess the Implication of LULC and LST Change around Lake Dembel
- To develop the frame work for sustainable conservation around Lake Dembel

1.4 Research questions

- What are the key drivers influencing LULC changes around Lake Dembel?
- What are the spatial and temporal patterns of LULC changes around Lake Dembel during 2004, 2014 and 2024?
- What are the implications of LULC and LST changes around Lake Dembel over the past 20 years?
- How frame work of sustainable conservation of Lake Dembel developed?

1.5 Significance of the Study

The significance of this study lies in its potential contributions to environmental conservation, resource management, and policy-making for Lake and similar ecosystems in Ethiopia's Rift Valley region.

By providing a comprehensive assessment of land use land cover changes over time, this study will improve knowledge about the extent, patterns, and rates of landscape changes around Lake Dembel.

The study was identified the primary socioeconomic and environmental drivers of LULC changes, such as population growth, agricultural expansion, and climate variability. Understanding these factors will allow for more targeted and effective management strategies to mitigate the impact of human activities on the lake's ecosystem.

By analyzing the impacts of LULC changes on Lake Dembel, the study will provide a holistic view of how these changes affect content of the Lake. This will help in evaluating the lake's current condition and the potential risks to its aquatic life, water quality, and surrounding habitats.

Findings from this study will provide actionable insights and recommendations for sustainable land and water management practices around Lake. These recommendations can guide local authorities, conservationists, and policymakers in implementing strategies to protect the lake's resources and reduce degradation.

The study contributed to evidence-based policy formulation by providing data that can support regulations on land use, water resource management, and environmental protection. This can help mitigate future environmental challenges and promote sustainable development in the Lake region.

This study can serve as a model for similar research on other Rift Valley lakes and ecosystems facing comparable pressures from human activities and climate change. The methodology and insights from this study could benefit future studies on LULC changes and their impacts on environment Lake Dembel.

1.6 Scope of the Research

This study focuses on LULC changes detection of around Lake Dembel, analyzing patterns over a 20 years period (2004, 2014, and 2024), that is aimed to observe long term trends and patterns in land use changes. Satellite images from Landsat were used for analysis, with seasonal variations taken into account to assess short-term fluctuations. The study area encompasses the Lake Dembel and 2km buffer zone surrounding of the Lake. The selection of this buffer distance is based on both on both hydrological and land use considerations. Hydrologically, the 2km zone represents the immediate catchment interface where surface runoff, sedimentation, and nutrient inflow have the most direct impact on lake water quality and volume (Gashaw et al., 2018). Land use practices such as farming, grazing, and settlement are often most intensive within this zone, thereby exerting high anthropogenic pressure on lake ecosystems (Bewket& Abebe, 2013). Furthermore, earlier watershed-scale studies (e.g., WoldeYohannes et al., 2018) have shown that LULC changes within 1–3 km of lakes and wetlands are closely correlated with ecological degradation, shoreline retreat, and biodiversity loss. Therefore, the 2 km buffer provides a scientifically grounded spatial boundary to analyze the most sensitive and dynamic land-lake interactions without extending the study area beyond the scope of detailed geospatial monitoring.

The study focused on land cover types in the Lake Dembel, including agricultural land, forested areas, settlement areas, and water bodies. The study analyzed patterns and rates of temporal LULC changes in these lands cover types using satellite imagery and remote sensing techniques.

Temporal Analysis: Investigating built-up, vegetation, farm land, water body and LST changes in three distinct years to determine trends and patterns of land transformation.

Spatial Analysis: Using GIS tools to detect, quantify, and visualize land cover transitions, such as shifts from forests to agricultural or urban areas.

The study applied methodology image classification (supervised), change detection, and validation using ground truth data. Tools such as ArcGIS and Google Earth Engine support the analysis.

CHAPTER TWO: LITERATURE REVIEW

2.1 Theoretical Literature Review

Land use and land cover (LULC) change is a dynamic and multidimensional process that reflects human-environment interactions over time and space. The theoretical understanding of LULC change integrates multiple disciplines, including geography, environmental science, and political ecology. Central to this understanding is the differentiation between land use, which refers to the purpose for which land is used (such as agriculture, grazing, or settlement), and land cover, which denotes the physical and biological surface features of the earth (such as forest, water, or bare land) (Lambin et al., 2003). The temporal and spatial alteration of land use and land cover directly influences ecological processes, hydrology, and socio-economic systems, especially in sensitive ecosystems such as lake basins.

Theoretical perspectives on land use change have evolved over the decades. Early explanations often relied on Malthusian or economic determinist views, attributing land degradation to population growth and subsistence farming pressures. More recent theoretical models adopt a systems thinking approach, emphasizing the interconnectedness of biophysical and socio-economic factors (Verburg et al., 2004). One widely applied framework is the human-environment interaction model, which views land use change as a feedback loop between human decision-making and environmental constraints. This framework highlights how communities adapt to changing land productivity, policy incentives, and resource access, leading to shifts in land use patterns (Turner et al., 2007).

In many sub-Saharan African contexts, including Ethiopia, political ecology theory has been influential in explaining LULC change. This theory considers how institutional power, policy, and historical land tenure systems shape environmental outcomes. In the Ethiopian context, land is state owned, and farmers have usufruct rights, which affect land management practices and investment in long-term land conservation (Crewett & Korf, 2008). Consequently, insecure tenure has often led to unsustainable exploitation of land resources, particularly in areas surrounding lakes where fertile soils and water access attract high human activity.

Drivers of LULC change are diverse and can be categorized thematically. Demographic factors, especially rapid population growth and migration, have consistently exerted pressure on land resources. Ethiopia's population has grown significantly over the past decades, leading to intensified cultivation, encroachment into wetlands, and settlement expansion in areas like the Lake Dembel basin. For example, studies have shown that population-induced demand for food and fuelwood often accelerates deforestation and wetland degradation in lake-adjacent areas (Tekle & Hedlund, 2000; Kindu et al., 2015).

Socio-economic drivers also play a critical role. The expansion of agriculture, both rain-fed and irrigated, is a leading cause of land cover transformation. In the Oromia region, increased demand for cash crops such as khat and maize has led to the conversion of natural vegetation into cultivated land. Pastoralism and livestock grazing further contribute to vegetation clearance and soil compaction, especially during dry seasons when water availability near lakes becomes vital. Additionally, rural poverty and limited livelihood alternatives often force communities to exploit marginal lands, thereby intensifying LULC change (Gebreslassie, 2014).

Environmental and biophysical factors are equally important in driving LULC change. Climatic variability, particularly irregular rainfall and recurrent droughts, significantly affects vegetation cover and agricultural productivity. In lake basins, fluctuations in rainfall alter the hydrological balance and may result in lake shrinkage or seasonal expansion, influencing land use dynamics in adjacent zones. Elevation, slope, and soil fertility are also biophysical determinants that shape land suitability, and thus, land use decisions by local communities (Meshesha et al., 2016).

Policy and institutional dynamics further compound the complexity of LULC change. Government-led development programs such as resettlement schemes and agricultural intensification projects have historically altered land cover patterns. In many Ethiopian lake basins, policies intended to boost food security have led to environmental degradation due to poor planning and lack of ecological consideration. For example, the expansion of irrigated agriculture around rift valley lakes has altered water regimes and displaced wetland ecosystems (Ariti et al., 2015).

Technological drivers, including road construction, water infrastructure development, and increased use of mechanized farming, have also influenced LULC change. While these developments often aim to improve productivity and access, they inadvertently promote the conversion of natural land cover into built-up or agricultural land. Roads, in particular, facilitate human settlement and market access, which tend to increase the rate and extent of land transformation (Seto et al., 2011).

Geospatial technologies, particularly remote sensing and geographic information systems (GIS), have played a critical theoretical and practical role in understanding LULC dynamics. These tools allow for the temporal monitoring of land surface changes and help reveal spatial patterns and trends that are not readily visible through ground-based observation. The theory behind remote sensing is rooted in electromagnetic energy interaction with surface materials, enabling the classification and quantification of land cover types across time periods. In Ethiopia, remotely sensed imagery from Landsat and MODIS platforms has been widely used to assess land degradation, forest loss, and water body shrinkage in lake basins (Belay, 2002; Gashaw et al., 2018).

Moreover, the theoretical approach to LULC change has increasingly emphasized sustainability and resilience. Land use planning now incorporates concepts from resilience theory, which focuses on the capacity of ecosystems and communities to absorb disturbances and maintain essential functions. This is particularly relevant for lake basins like Lake Dembel, which are ecologically fragile and socio-economically important. Sustainable land use management in such contexts must balance the demands of agricultural development, water resource protection, and ecosystem services (Tilahun et al., 2020).

In summary, the theoretical understanding of LULC change is multifaceted, integrating concepts from geography, political economy, environmental science, and systems thinking. The application of geospatial technologies has further enriched these theoretical perspectives by providing empirical evidence to support or challenge prevailing assumptions. The thematic consolidation of drivers demographic, socio-economic, policy-driven, environmental, and technological offers a comprehensive lens through which LULC change in Lake Dembel and similar basins can be understood. This theoretical grounding provides the foundation for assessing real-world empirical patterns, which will be explored in the subsequent section.

2.2 Empirical Literature Review

Empirical studies on land use and land cover change in Ethiopia have increasingly relied on geospatial tools to detect, quantify, and interpret changes across time. These studies provide critical insights into the patterns, rates, and drivers of LULC transformations, particularly in sensitive ecosystems such as lake basins. The Lake Dembel Basin, located within the rift valley system of Oromia, shares key biophysical and socio-economic characteristics with other rift valley lakes, making comparative empirical assessments particularly valuable. Most studies reveal that LULC changes are highly dynamic and are largely shaped by population pressure, agricultural expansion, policy decisions, and climate variability.

In a study by Meshesha et al. (2016), the Lake Ziway watershed experienced substantial land cover transformation between 1973 and 2012, with natural vegetation and wetland areas declining due to expansion of farmland and settlements. Similar patterns have been documented in the Lake Abaya-Chamo Basin, where Bewket and Abebe (2013) observed a marked decrease in forest cover and wetlands, accompanied by an increase in cultivated land and built-up areas. These empirical findings emphasize the intensification of human activities in riparian zones, often at the expense of ecosystem services such as water purification, flood buffering, and biodiversity conservation.

Empirical investigations in the Lake Hawassa catchment by Daba and You (2021) highlighted that between 1985 and 2020, cropland and urban areas expanded rapidly, while forest and grassland declined. Using Landsat imagery, the study found a consistent upward trend in agricultural encroachment, which corresponded with increased sedimentation and a gradual decline in lake volume. These findings resonate with trends observed around Lake Dembel, where rising agricultural activity has altered the hydrological regime and contributed to land degradation along the lake fringe.

In the context of Lake Dembel itself, few direct empirical studies exist, but the basin shares comparable ecological vulnerabilities with other rift valley lakes. Regional-scale assessments, such as those by Gashaw et al. (2018), have used satellite imagery from 1985 to 2015 to map LULC changes across multiple central Ethiopian lake basins. The analysis indicated a consistent decline in woodland and shrubland areas, with a sharp increase in cultivated land. The conversion of vegetated buffer zones into farmland has been a major driver of lake sedimentation and declining water quality. These patterns suggest similar threats may be affecting Lake Dembel, given its location and dependence on agriculture-based livelihoods.

A study by Kindu et al. (2015) in the Munessa-Shashemene landscape, which shares climatic and socio-economic features with the Lake Dembel Basin, reported a 20% reduction in forest cover over three decades, with an increase in settlement and cultivated land. The study applied post-classification comparison methods using Landsat images, and its accuracy assessment yielded over 85% overall classification accuracy. This reinforces the reliability of geospatial methods in assessing LULC dynamics and highlights the extent to which population growth and agricultural intensification are transforming highland and midland ecosystems across Oromia.

Moreover, Ariti et al. (2015) examined the impact of resettlement programs in Ethiopia’s western highlands and found that forestland and grassland were rapidly converted to cropland within five years of settlement. Although the study was conducted outside the rift valley, its findings are relevant for understanding how government policies, particularly those encouraging agricultural expansion, can lead to abrupt landscape transformation. In the case of Lake Dembel, informal resettlement and increased rural-to-rural migration may similarly be contributing to LULC change, as communities seek fertile land near the lake.

Another study by Tadesse et al. (2020) in the Lake Tana basin demonstrated how wetland degradation accelerated due to the conversion of buffer zones into irrigated farmland. The application of supervised classification and change detection techniques over a 30-year period revealed that water bodies had shrunk by nearly 10%, and seasonal swamps were nearly eliminated. These empirical results underscore the hydrological consequences of land use change, particularly the reduced capacity of lake ecosystems to regulate water levels and maintain habitat quality.

Studies focusing on sedimentation trends and water turbidity also offer indirect evidence of LULC impacts. For instance, Alemayehu et al. (2009) examined the hydrological impacts of land degradation in the Gilgel Abay watershed and found that soil erosion and sediment yield increased dramatically following forest clearing and cultivation on steep slopes. Such findings are applicable to the Lake Dembel context, where unregulated cultivation on sloped terrain surrounding the lake likely contributes to sediment influx and lake shallowing.

Empirical studies have also pointed out the role of infrastructure in altering land use patterns. Work by Asfaw et al. (2019) found that road construction in the Lake Ziway area facilitated market access, which in turn spurred commercial agriculture and peri-urban expansion. The empirical linkage between improved access and rapid land transformation is relevant to Lake Dembel, where ongoing infrastructure improvements may be accelerating land cover change through enhanced mobility, land speculation, and settlement growth.

Remote sensing and GIS continue to be the dominant methodological approaches for empirical LULC analysis. The use of multi-temporal Landsat data (TM, ETM+, and OLI) combined with supervised classification algorithms like Maximum Likelihood Classifier (MLC) has enabled researchers to accurately map change trajectories over decadal periods. Ground truthing and accuracy assessments are typically used to validate classification outputs, ensuring that empirical results reflect real-world conditions (Teferi et al., 2013). In the absence of long-term meteorological and field-based ecological data, these geospatial tools remain essential for quantifying and monitoring landscape changes, especially in data-scarce regions like Lake Dembel.

While most empirical studies concur on the major trends decline in vegetation, expansion of cropland, and lake shrinkage some differences emerge in the interpretation of causality. For instance, Gebreslassie (2014) emphasizes population growth as the primary driver, while Gashaw et al. (2018) argue for the synergistic effects of institutional policies and climate variability. These variations highlight the need for locally grounded studies that combine geospatial analysis with socio-economic field surveys to capture nuanced realities.

In synthesis, the empirical literature paints a consistent picture of rapid and often unsustainable land use transformation in Ethiopian lake basins, driven by interlinked human and environmental factors. Although specific studies on Lake Dembel are limited, analogs from nearby lake systems provide a strong empirical foundation for understanding ongoing changes. They also reveal methodological best practices and knowledge gaps that the study aims to address. By applying geospatial tools to assess LULC change over a 20-year period in the Lake Dembel Basin; the study contributes to filling this empirical void while informing sustainable land and water management strategies in the region.

2.3. Research Gap

A key gap in existing literature is the absence of an integrated, temporal study combining satellite imagery with field-level observation to assess LULC changes and long-term analysis of LST on the environment. Most previous studies look at land cover changes only for short temporal changes, without showing how these changes happen over the whole period.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Study Area Description

Lake Dembel is located in the central part of the Ethiopian Rift Valley, approximately 160 kilometers South of Addis Ababa. The lakes cover an area of about 440 km² and the study area covers 650 square kilometers with the buffer of 2KM from the Lake, expected highly changed area of this lake basin. The lake has a maximum depth of 9 meters. It is found at Latitude of 7051' to 80 8'N and Longitude of 38043'to 38057'E. The lake lies at an elevation of 1,636 meters above sea level and is part of the Ethiopian Rift Valley lakes system, with a catchment area that feeds into it through multiple rivers.

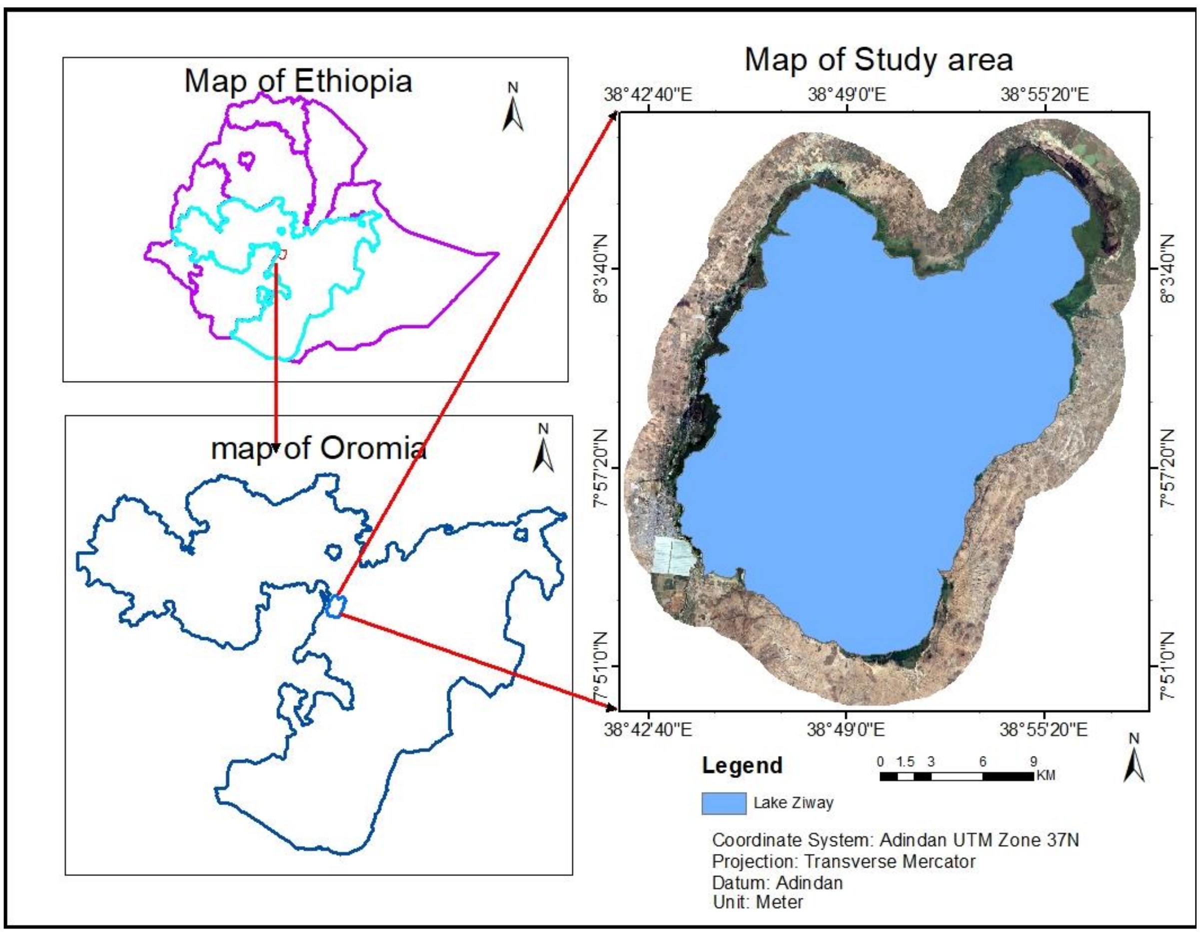

Figure 3.1 Map of study area

The surrounding region is a mixture of urban, agricultural, and natural ecosystems, which are highly dynamic due to increasing human activities.

The surrounding regions have experienced rapid urbanization, agricultural intensification, and land degradation, which have collectively contributed to changes in land use and land cover (LULC). Understanding these changes is crucial for sustainable land management, conservation, and planning efforts. This literature review synthesizes existing research on LULC change detection around Lake, highlighting key findings, methodologies, and research gaps.

The climate is predominantly semi-arid with a bimodal rainfall pattern, having rainy seasons from March to May and again from July to September.

3.2. Descriptions of Methodology

3.2.1 Data Sources

Landsat (Landsat 5, 7, 8, 9): Landsat images provide long-term, medium-resolution data (30m resolution), which is ideal for multi-temporal analysis over decades. Landsat data is freely available from USGS Earth Explorer (USGS, 2023).

Table 3.1 data source

Data type	Data	Source	Purpose
Primary	Field surveys	Research field work	Validation
	Interviews	Community	Understanding
	Hand held GPS data	By researcher	verifications
Secondary	Landsat (Landsat 5, 7, 8, 9)	USGS	LULC analysis
	Historical Topographic map	ESSGS	verifications
	Google earth data	Free online	verifications

3.2.2 Soft ware used

GPS devices for accurate location data collection and high-performance computers for processing large geospatial datasets and running analytical software are used. ArcGIS 10.8: Used for proximity analysis, reclassification, and NDVI (Normalized Difference Vegetation Index) mapping. QGIS 3.30: Applied for LULC classification and LST mapping, providing open-source support for geospatial analyses. ERDAS: Specialized in advanced satellite image processing and correction. Google Earth Pro: Utilized for visual interpretation and cross-validation of spatial features.

Table 3.2 Software used

Num.	Software used	purpose
1	ARCGIS 10.8	Performing geospatial analysis
2	QGIS	Data integrations
3	ERDAS	Processing & correction

ArcGIS: These Geographic Information Systems (GIS) platforms are used for spatial data manipulation, map creation, and visualization. Both are widely used in remote sensing and LULC studies for processing vector and raster data, performing geospatial analysis, and facilitating map production (ESRI, 2019; QGIS Development Team, 2020).

Google Earth Engine (GEE): GEE is a cloud-based platform for accessing and processing satellite imagery on a global scale. It provides access to vast satellite data archives (e.g., Landsat, Sentinel) and has powerful tools for performing time-series analysis (Gorelick et al., 2017).

3.3 LULC Classification Workflow

This study applied a structured workflow to assess Land Use and Land Cover (LULC) changes around Lake Dembel using geospatial techniques. The workflow comprised image acquisition, preprocessing, training sample development, classification, and accuracy validation.

3.3.1 Input Data

Three temporal Landsat satellite images were selected to detect LULC changes over a 20 years period (2004, 2014, and 2024). The datasets used were chosen for their high-quality, dry-season acquisition dates and minimal cloud cover. All images were accessed from the USGS Earth Explorer platform.

Table 3.3 Source of data

Year	Sensor	Path/Row	Acquisition Date	Resolution	Source
2004	Landsat 5 TM	168/055	15/05/2004	30m	USGS Earth explorer
2014	Landsat 8 OLI/TIRS	168/055	20/12/2014	30m	USGS Earth explorer
2024	Landsat 8 OLI/TIRS	168/055	15/12/2024	30m	USGS Earth explorer

3.3.2 Band Combinations

To enhance visual interpretation and class separability, the following false color composites were applied:

Landsat 5 TM (2004): Bands 5 (NIR), 4 (Red), 3 (Green)

Landsat 8 OLI (2014, 2024): Bands 6 (SWIR1), 5 (NIR), 4 (Red)

These band combinations were chosen to differentiate LULC features such as water bodies, vegetation, farmland, and built-up areas.

3.3.3 Training Sample Collection

Training samples were created through visual interpretation, high-resolution Google Earth imagery, and field visits. For validation 120 training samples per image year were collected and distributed across the four primary LULC classes: Water Body, Built-up, Vegetation, and Farmland.

3.3.4 Classification Algorithm Justification

The study employed the Maximum Likelihood Classification (MLC) algorithm for supervised classification of all three temporal images. MLC was chosen based on the following justifications:

Statistical Strength: MLC assumes a normal distribution of spectral data, which aligns with the multispectral Landsat imagery used.

Proven Reliability: It has been widely tested and found effective in previous LULC studies using medium-resolution satellite data.

Comparability: Ensures consistent methodology across years, facilitating accurate multi-temporal change detection.

Probability-based Assignment: MLC uses the probability of pixel assignment, reducing misclassification in overlapping spectral classes.

3.3.5 Ground Truthing Strategy

Field-based ground truthing was conducted during January to February 2024, aligning with the dry season to ensure unobstructed visibility of land cover types.

Total Ground Control Points (GCPs): 120
Tool Used: Handheld GPS and mobile GIS apps
Sampling Strategy: Systematic random sampling across the study area was used.
Validation Distribution: 30 ground truth points per class were used.
For historical data (2004 and 2014), validation was supported by:
Time-series Google Earth imagery
The ground truth dataset was split into 70% for training and 30% for accuracy assessment.

3.3.6 Accuracy Assessment and Confusion Matrix

Accuracy assessment was conducted using the reserved 30% of ground control points. A confusion matrix was generated for each classified map to evaluate reliability. Below is the sample confusion matrix for the 2024 classification, using the four dominant LULC classes.

Sample Confusion Matrix (2024)

Classified features	Water body	Built-up	Vegetation	Farm land	Row Total
Water body	23	0	1	0	24
Built-up	0	20	1	1	22
Vegetation	1	2	25	2	30
Farm land	0	1	2	26	29
Column Total	24	23	29	29	105

Table 3.4 Sample Confusion Matrix (2024)

3.3.7 Accuracy Metrics

To interpret the above confusion matrix, the following accuracy metrics were computed:

A. Overall Accuracy

Overall Accuracy is the ratio of the total number of correctly classified pixels to the total number of reference pixels.

Overall Accuracy = Sum of diagonal elements / Total number of samples

OA= 23 + 20 + 25 + 26/105 = 94/105= 89.5%

This indicates that 89.5% of the classified pixels in the 2024 LULC map correctly match the ground truth data.

B. User’s Accuracy (Commission Error)

User’s Accuracy measures the probability that a pixel classified into a given class actually represents that class on the ground. It helps understand errors of commission (when pixels are incorrectly included in a class).

User’s Accuracy = correctly classified pixels for a class /Total classified pixels in that class (row total)

Class	Correct	Row total	User’s accuracy
Water body	23	24	95.8%
Built-up	20	22	90.9%
Vegetation	25	30	83.3%
Farm land	26	29	89.7%

Table 3.5 User accuracy measures

For example, 95.8% of the pixels classified as "Water Body" are actually water on the ground. This metric is particularly useful for end-users who rely on the map to make land use decisions.

C. Producer’s Accuracy (Omission Error)

Producer’s Accuracy measures the probability that a reference pixel has been correctly classified. It helps identify omission errors (when pixels of a class are left out or misclassified into other classes).

Producer's Accuracy = correctly classified pixels for a class/Actual number of pixels in that class (column total)

Class	Correct	Column total	Producer's accuracy
Water body	23	24	95.8%
Built-up	20	23	87.0%
Vegetation	25	29	86.2%
Farm land	26	29	89.7%

Table 3.6 Producer's accuracy

For instance, 86.2% of the actual vegetation pixels were correctly classified. This metric is particularly important for data producers, helping to assess which classes may have been underrepresented or misclassified.

D. Kappa Coefficient

The Kappa Coefficient (κ) is a statistical measure that accounts for agreement occurring by chance. It ranges from -1 to +1:

Kappa = (Po – Pe) / (1 – Pe)

Po = observed agreement (overall accuracy)

Po=89.5

Pe = expected agreement by chance

Pe=Sum (Row total*Column total / (Total sample^2))

Kappa = 0.88

A kappa value of 0.88 suggests almost perfect agreement, confirming that the classification is highly reliable and not due to random chance.

3.4 Methodological Workflow

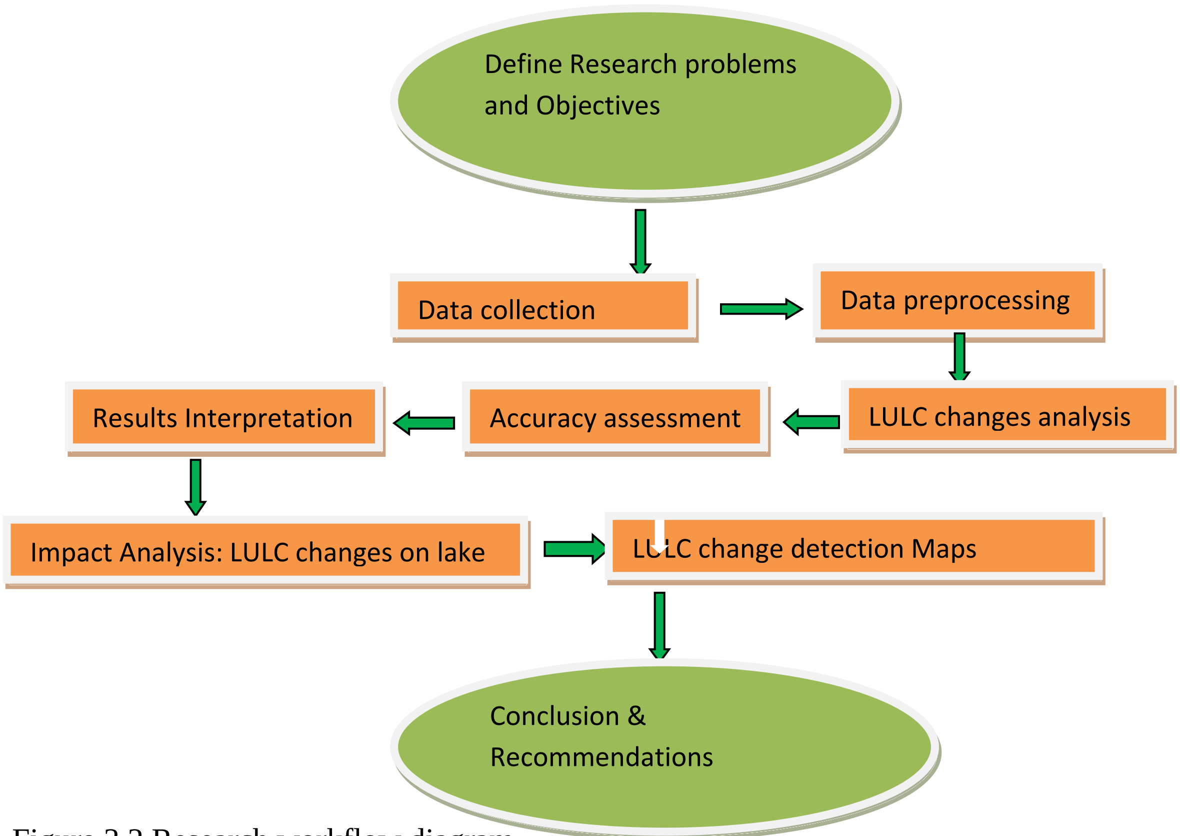

Figure 3.2 Research workflow diagram

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Results

4.1.1 Land Use Land Cover (LULC) Classification and Change Detection

LULC classification for the years 2004, 2014, and 2024 was conducted using supervised classification with the maximum likelihood algorithm. The analysis included four major land cover categories: cultivated land, forest land, settlement, and water body.

4.1.2 LULC Status in 2004

In 2004, Around Lake Dembel was predominantly covered by cultivated land, which accounted for 12.4% of the area. Forest land comprised 15.86%, followed by water bodies (67.6%) and settlements (4.4%).

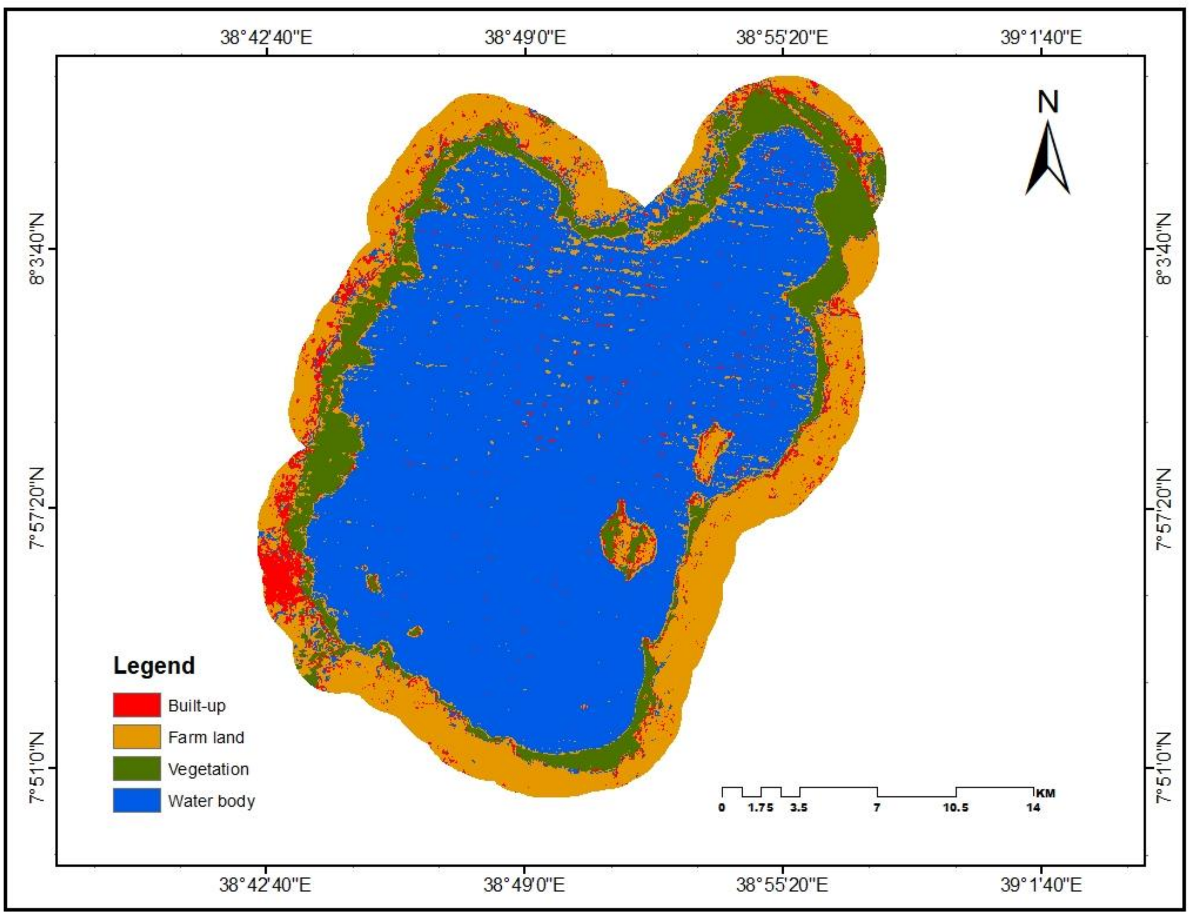

Figure 4.1 LULC Maps of 2004

4.1.3 LULC Status in 2014

By 2014, significant expansion of cultivated land to 13.8% occurred at the expense of forest and water body areas. Forest land decreased to 13.17%, while water bodies reduced to 66.47%. Settlement area expanded to 6.55%, reflecting increased rural–urban transition and population growth.

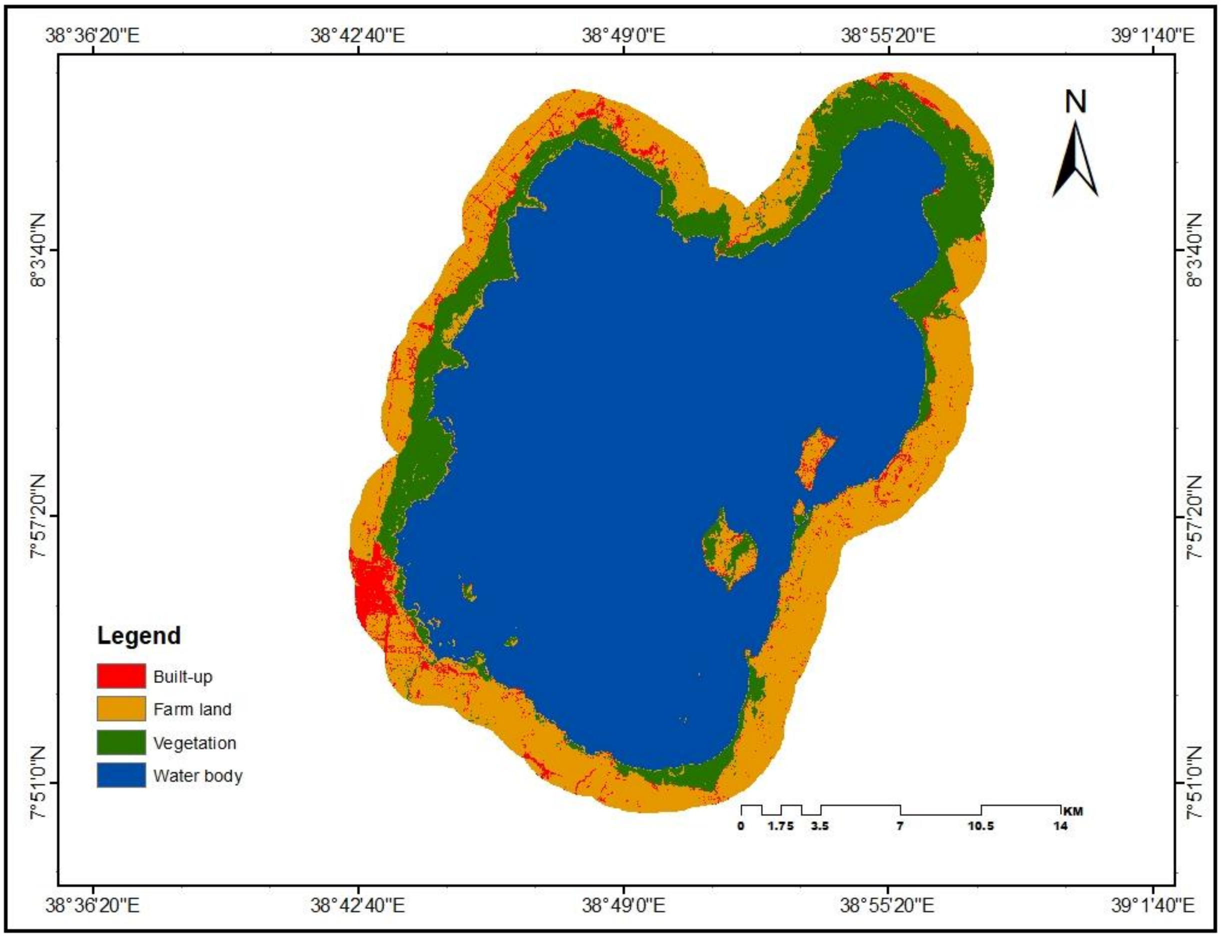

Figure 4.2 LULC Maps of 2014

4.1.4 LULC Status in 2024

In 2024, cultivated land reached 15.4%, while forest cover declined to 6.24%. Water bodies further reduced to 65.68%, and settlement land rose to 12.68%, indicating ongoing anthropogenic pressure on the Lake natural resources.

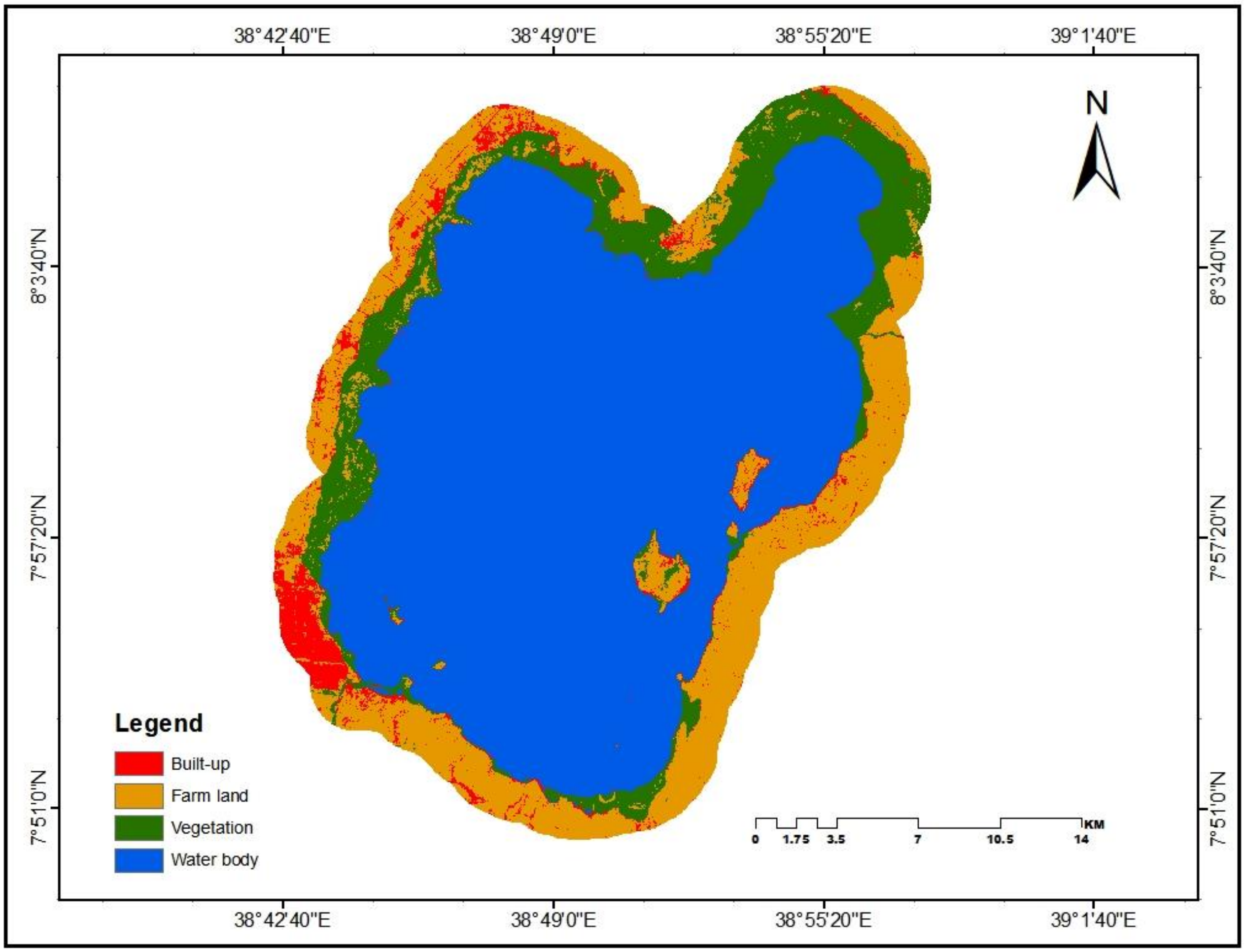

Figure 4.3 LULC Maps of 2024

4.1.5 LULC Change detection

GIS allows for the generation of maps that highlight areas of change between different time periods, providing a visual representation of land use and land cover transitions.

Temporal Animations: GIS can create animations showing how land cover has evolved over time, providing dynamic visualizations of change for presentations or reports. The change detection maps of 2004 to 2014, and 2014 to 2024 were shown below respectively.

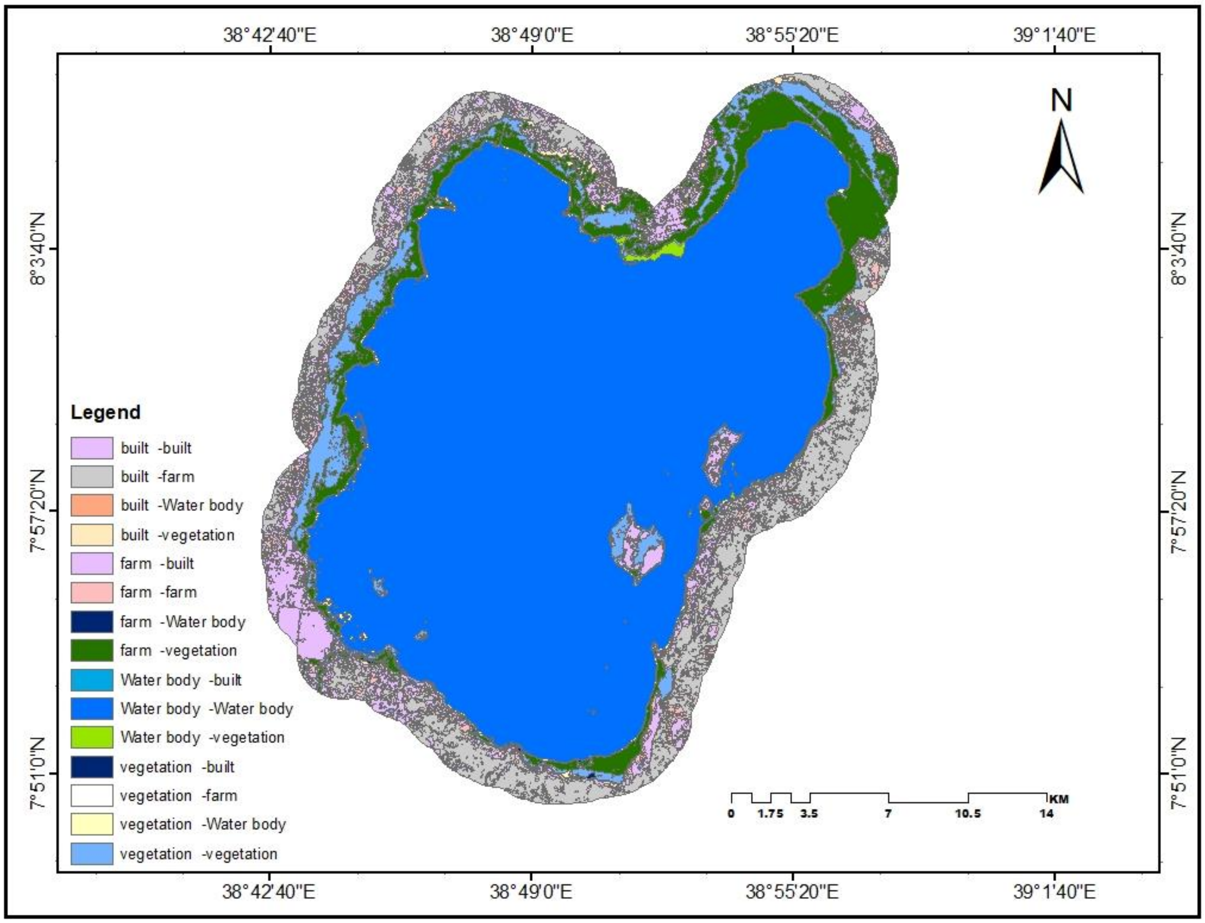

Figure 4.4 LULC changes map of 2004 to 2014

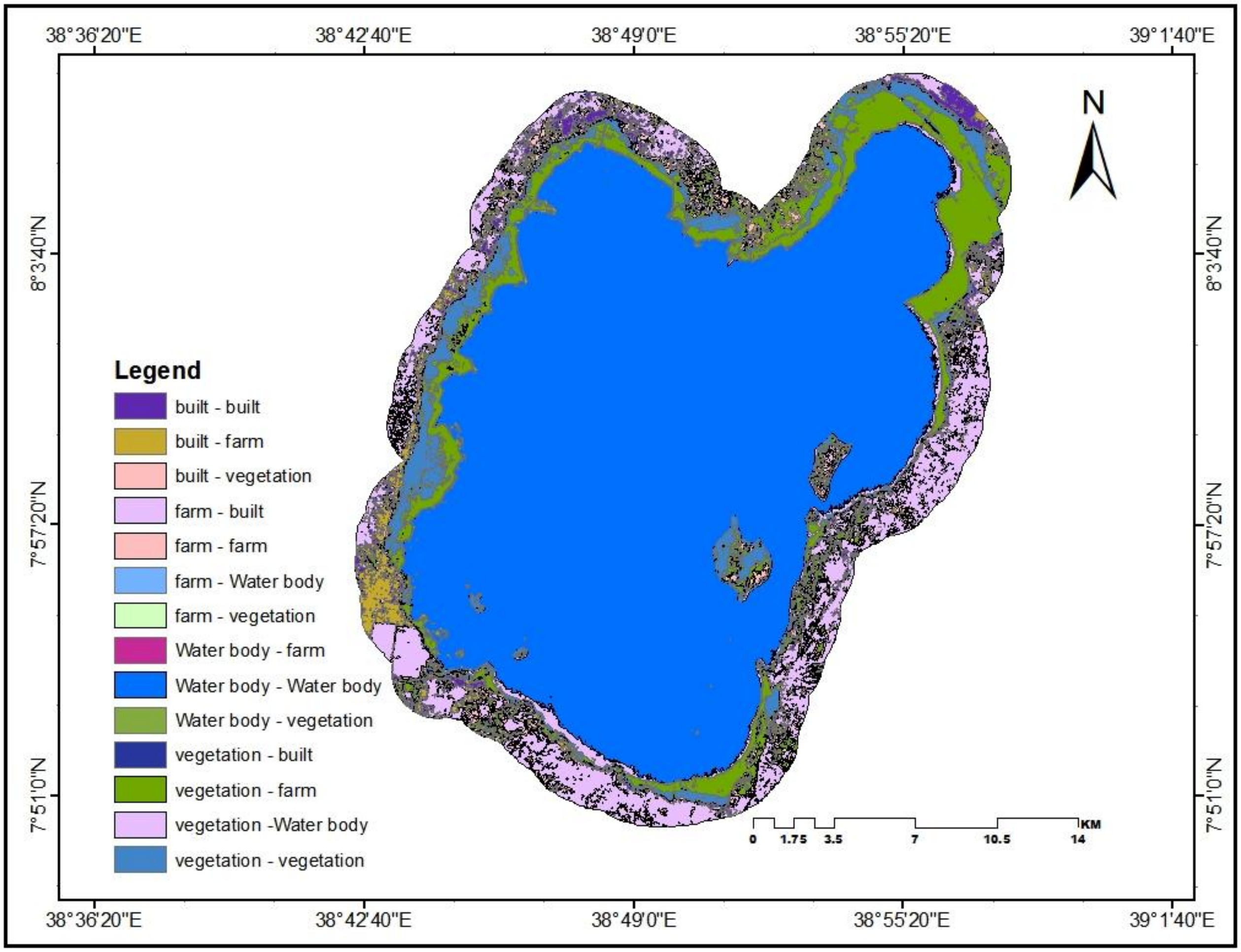

Figure 4.5 LULC changes map of 2014 to 2024

Depending up on the above maps, area change detections from class to class were analyzed as the following table.

LULC change detected	Area of LULC changed in km^2 /2004 to 2014/	Area of LULC changed in km^2 /2014 to 204/
Built up _ Built up	9.5503	11.8888
Built up _ Farm land	0.5312	0.0777
Built up _ Vegetation	0.1006	0.2765
Built up _ Water body	0.0011	0.0003
Farm land _Farm land	21.8003	16.0861
Farm land _Water body	0.0011	0.0008
Farm land _ Vegetation	0.0064	0.7865
Farm land _ Built up	7.0111	12.0312
Vegetation _ Vegetation	35.4004	25.2208

Vegetation _ Farm land	34.0003	48.9876
Vegetation _ Built up	26.8914	31.1004
vegetation _ Water body	0.0074	0.0055
Water body _ Water body	401.1231	400.1002
Water body _ Farm land	2.9934	6.1111
Water body _ Built up	5.7009	13.9804
Water body _ Vegetation	2.8888	2.9966

Table 4.1 LULC Area change by class (2004 to 2024)

years	LULC change detected	Area of LULC /km^2/	Changes in area km^2 2004 to 2014	Changes in area km^2 2014 to 2024	Changes area in % 2004 to 2014	Changes area in % 2014 to 2024
2004	built	28.53				
	farm	79.22				
	vegetation	103.55				
	Water body	441.21				
2014	built	42.77	+14.24		49.5	
	farm	90.12	+10.9		13.76	
	vegetation	86.03	- 17.52		16.92	
	Water body	434.08	- 7.13		1.62	
2024	built	82.67		+39.9		93.29
	farm	100.33		+10.21		11.33
	vegetation	40.66		- 45.37		52.74
	Water body	428.11		- 5.97		1.38

Table 4.2 LULC Trend summary by percentage and area

2004 - 2014 total linear changes = 49.79 km2
2014 – 2024 total linear change = 101.45 km2
Total linear change….151.24km^2

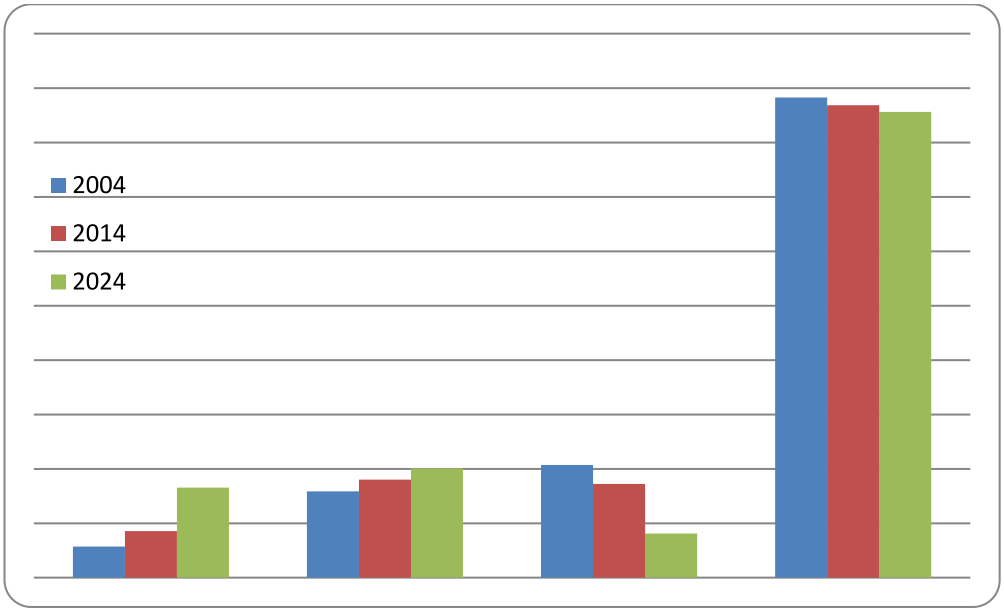

Figure 4.6 LULC trends diagram

No.	Indicator	2004	2014	2024	Trend
1	Built-up Area	4.37%	6.55%	12.68%	Increasing
2	Farmland	12.14%	13.8%	15.5%	Increasing
3	Vegetation	15.87%	13.17%	6.24%	Decreasing
4	Water body	67.6%	66.5%	65.68%	Decreasing
5	LST	17.2°C	19.5°C	23.1°C	Increasing
8	Lake Dembel Ecosystem Status	Stable	Moderate stress	High stress	Degrading

Table 4.3 Empirical analysis of lulc change of the study area

4.1.6 The Impact of LULC change on LST around Lake Dembel

Land cover changes, especially deforestation, can alter the local climate, leading to changes in air and water temperatures. Warmer water temperatures can affect the metabolic rates of aquatic organisms, increase evaporation, and reduce oxygen levels in the lake.

Forests, wetlands, and other natural habitats around lakes act as carbon sinks. When these areas are converted to urban or agricultural land, the capacity for carbon sequestration is reduced, potentially contributing to global warming.

To analyze the changes in surface temperature of Lake Dembel over time, we can apply remote sensing techniques that use satellite data to track variations in Land Surface Temperature (LST). This can help understand how land use and land cover changes (LULC) and urbanization has impacted the local climate, particularly in terms of temperature.

4.1.7 Computing LST

LST Estimation Process in the Study

Land Surface Temperature (LST) plays a critical role in understanding the energy exchange between the Earth's surface and the atmosphere. In the context of this study, LST estimation was crucial for assessing the thermal response of land cover transformations in the Lake Dembel Basin over two decades. This section outlines the step-by-step procedure used to derive LST from Landsat imagery, incorporating both radiometric and emissivity corrections to ensure accuracy. In this study, LST was estimated using Landsat satellite imagery (Landsat 5, 7, 8, 9), particularly focusing on thermal bands. The general steps and equations used are as follows:

1. Conversion of Digital Number (DN) to Spectral Radiance

For Landsat 8:

$L\lambda = ML \times Qcal + AL$

$L\lambda$: TOA (Top of Atmosphere) spectral radiance (Watts/ ($m^2 \cdot sr \cdot \mu m$))

ML: Radiance multiplicative scaling factor (from metadata)

AL: Radiance additive scaling factor (from metadata)

Qcal: Quantized and calibrated standard product pixel values (DN)

Landsat satellite sensors store pixel values as digital numbers (DN), which are not directly interpretable in physical terms. To derive meaningful radiometric information, these DN values must be converted to radiance units. The coefficients and are specific to each Landsat scene and are retrieved from the metadata file (MTL.txt). This step forms the foundation for temperature derivation.

This equation corrects the raw pixel value to radiance using satellite-specific calibration parameters.

2. Conversion of Radiance to Brightness Temperature (BT)

$$BT = \frac{K2}{\ln\left(\frac{K1}{L\lambda}+1\right)}$$

BT: Brightness Temperature in Kelvin

K1, K2: Calibration constants (sensor-specific from metadata)

$L\lambda$: TOA spectral radiance

Brightness temperature represents the temperature of a blackbody that would emit the same amount of radiance as observed. This transformation is derived from Planck’s radiation law and converts radiance values to physical temperature units (Kelvin). For Landsat 8, typical values are K1=774.89 and K2 = 1321.08

This converts the spectral radiance into a physical temperature (in Kelvin), which is later converted to Celsius by subtracting 273.15.

TCelsius = BT - 273.15

3. NDVI Calculation for Emissivity Estimation

NDVI = (NIR - R) / (NIR + R)

NIR: Near infrared band reflectance

Red: Red band reflectance

NDVI is a normalized index used to quantify the presence and health of vegetation. Vegetation reflects strongly in the NIR spectrum while absorbing red light. NDVI values range from -1 to +1, where higher values indicate dense green vegetation.

4. Proportion of Vegetation (PV)

PV = [(NDVI – NDVI min) / (NDVI max -NDVI min)]*^{2}

This equation estimates the fractional vegetation cover, which influences surface emissivity.

5. Land Surface Emissivity (ε)

$\varepsilon = 0.004 \times PV + 0.986$

This equation normalizes NDVI values between their minimum and maximum to estimate the fractional vegetation cover within a pixel. The squaring enhances contrast between values. A higher indicates a larger vegetated area within the pixel, which affects surface emissivity.

6. Final LST Calculation

LST = BT / (1 + (λ * BT / c2) * ln(ε))

Where:

LST: Land Surface Temperature (Kelvin)

λ: Wavelength of emitted radiance (e.g., 10.895 μm for Landsat 8)

C2 = $1.438\times10\text{-}^{2}$m·K

BT: Brightness Temperature

ε: Emissivity

This equation corrects for the effects of surface emissivity and atmospheric conditions to estimate actual surface temperature.

This methodology was applied consistently to Landsat scenes from 2004, 2014, and 2024, enabling multi-temporal LST mapping of the Lake Dembel Basin. By correlating LST results with NDVI and classified LULC maps, the study assessed how deforestation, urbanization, and farm land expansion influenced surface heating across the landscape.

The findings showed:

A rise in LST values in built-up and agricultural areas

A cooling effect in areas with dense vegetation and proximity to the lake

Strong inverse correlation between NDVI and LST, suggesting that vegetation cover plays a key role in surface cooling.

The following maps are showing the LST value of 2004, 2014, and 2024 respectively.

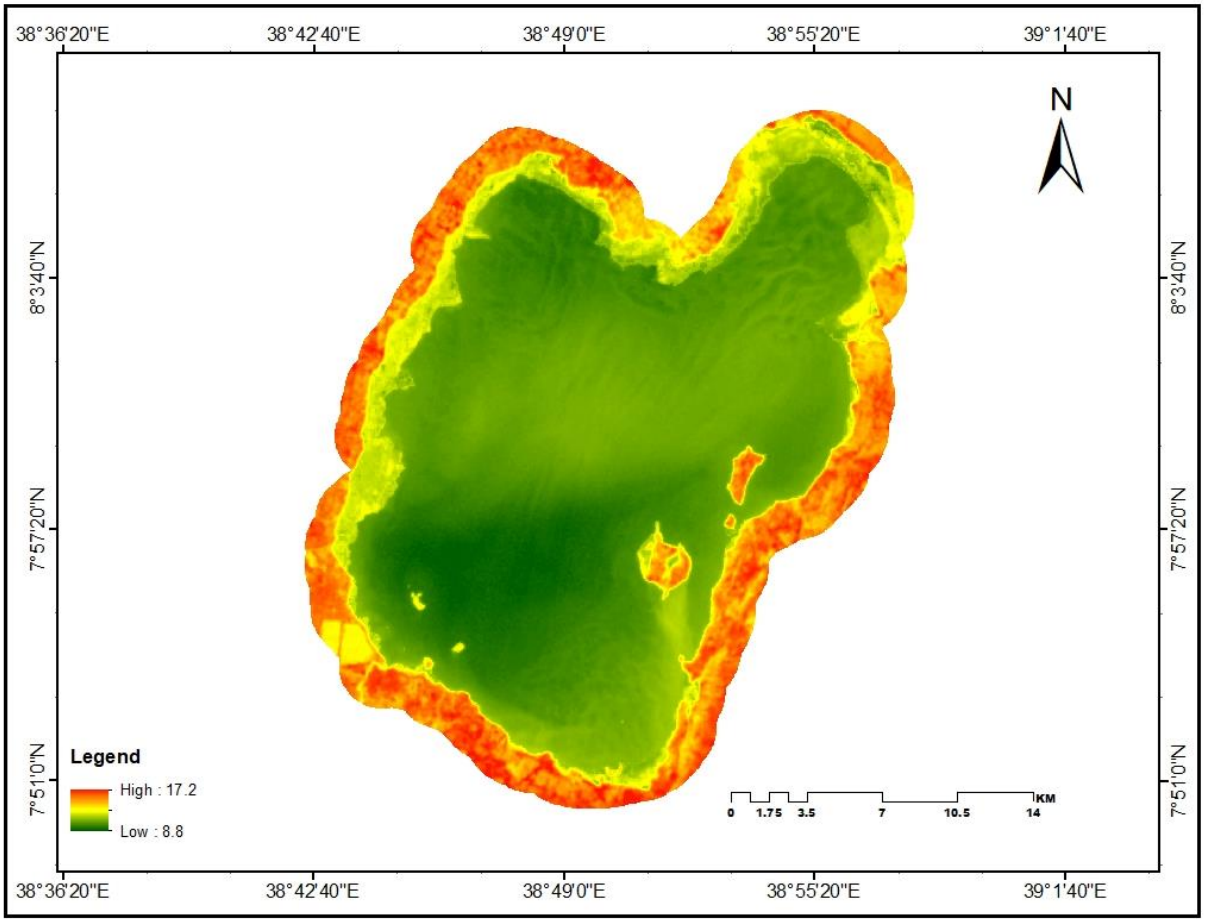

Figure 4.7 LST maps of 2004

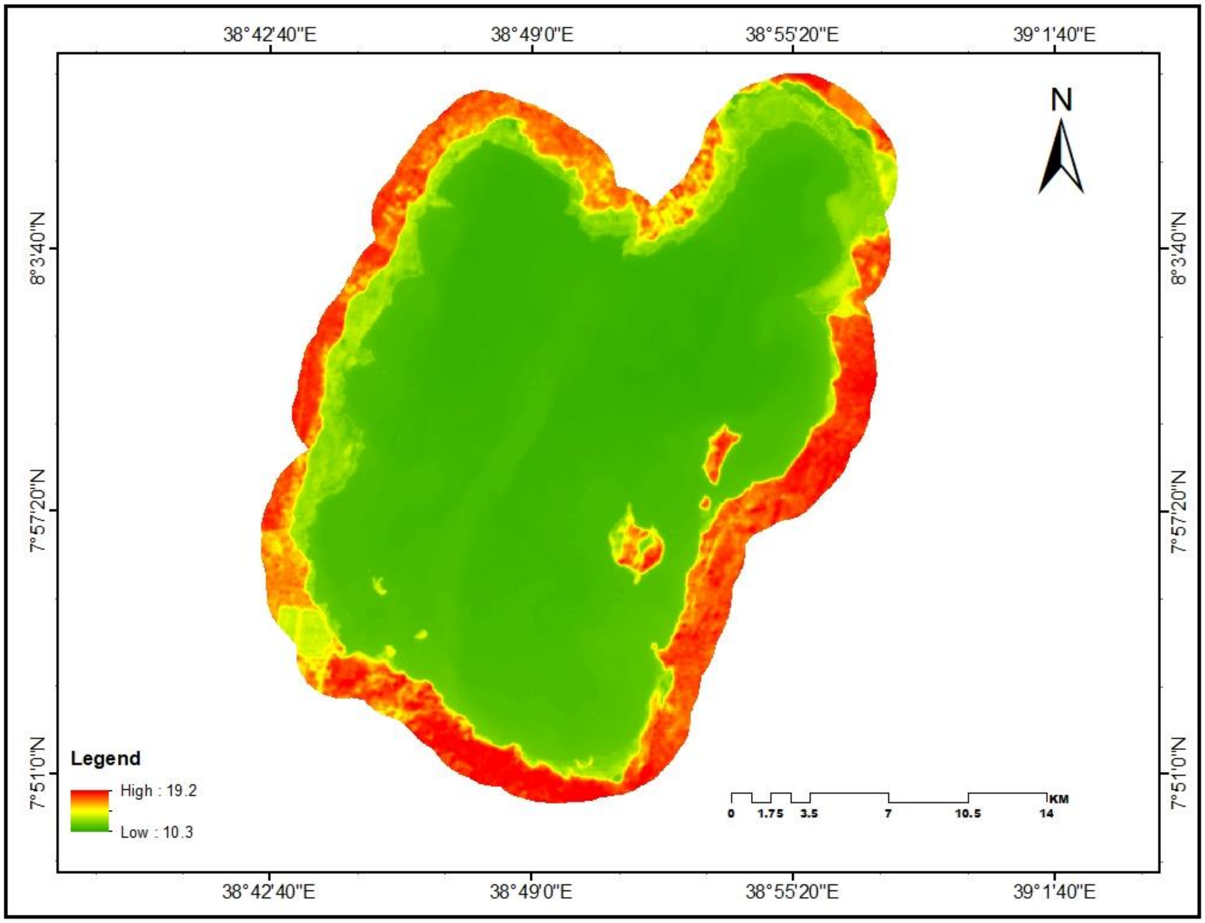

Figure 4.8 LST maps of 2014

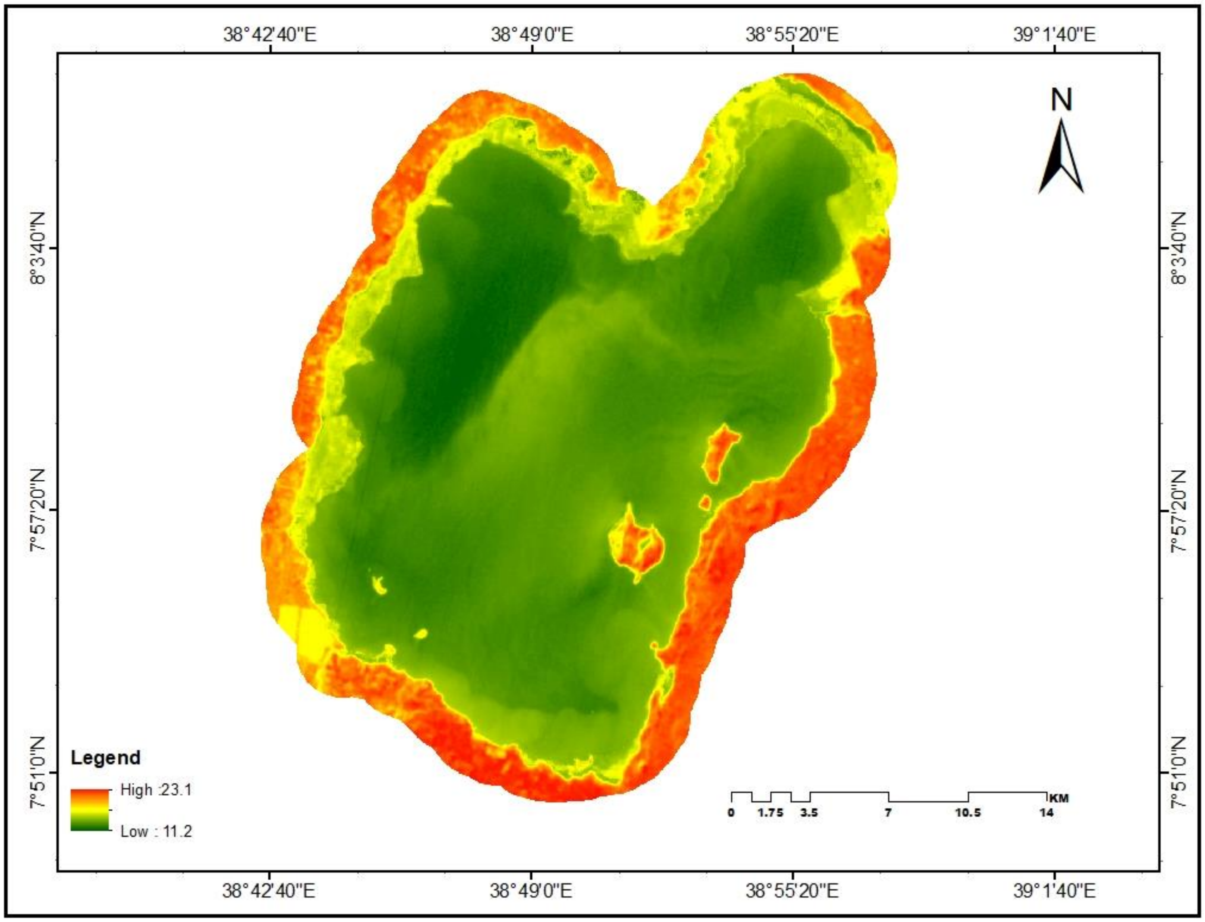

Figure 4.9 LST maps of 2024

years	Temperature changes/highest/ in degree Celsius	
2004	17.2	In average increasing 0.3 degree Celsius yearly
2014	19.2	
2024	23.1	

Table 4.4 Temperature changes of study area

To analyze the correlation between Land Use/Land Cover (LULC) and Land Surface Temperature (LST), we would need to explore how changes in land use impact the surface temperature over time. This type of analysis helps identify the relationship between different types of land cover (e.g., urban, forest, agricultural land) and their corresponding effects on the local surface temperature. Below is a step-by-step guide to carrying out such an analysis.

The goal is to examine whether certain land cover types (urban, agricultural, forest, etc.) have a statistically significant impact on the surface temperature.

Correlation analysis helps determine the strength and nature of the relationship between LULC and LST.

Extract LST Values for Each LULC Class: For each land cover class (e.g., urban, agricultural, forest), extract the corresponding surface temperature values for the relevant time periods.

Average LST for Each LULC Class: For each class (e.g., urban, agricultural, etc.), calculate the average LST over time to analyze the trend.

Pearson Correlation Coefficient: This coefficient quantifies the linear relationship between LULC types and surface temperature. It ranges from -1 (negative correlation) to +1 (positive correlation), where 0 indicates no linear correlation.

Positive Correlation: If urban areas show higher temperatures than agricultural or forest areas, there will be a positive correlation between urban land cover and higher surface temperature.

Negative Correlation: If forests or wetlands tend to have lower temperatures compared to urban areas, the correlation between forest land cover and lower surface temperature will be negative.

Spearman's Rank Correlation: If the relationship between land cover types and surface temperature is not linear, a Spearman's rank correlation can be used to assess monotonic relationships (i.e., whether the relationship is consistently increasing or decreasing, even if not linearly).

Multiple Linear Regressions: If you want to model the effect of different land cover types on surface temperature, you can run a multiple regression analysis. This will allow you to quantify the impact of urban, agricultural, forest, and other land uses on surface temperature, taking into account multiple factors at once.

Urban Areas and Temperature: Urban areas typically show a positive correlation with surface temperature due to the UHI effect. This means that as urbanization increases, the surface temperature would likely increase.

Forested Areas and Temperature: Forested areas tend to show a negative correlation with surface temperature due to the cooling effects of vegetation and evapotranspiration. Higher proportions of forest cover may reduce local surface temperature.

Agricultural Areas: Agricultural land may have an intermediate relationship with temperature. Depending on whether the land is irrigated or not, it may have either a cooling or warming effect. Typically, non-irrigated agricultural land can increase LST, but irrigated land may have lower surface temperatures due to evapotranspiration.

Visualizing the Results

Heat Maps: You can create heat maps to visualize the areas with higher and lower temperatures overlaid with land use types. This will help identify the specific areas where temperature variation is most pronounced due to land cover changes.

Scatter Plots: Create scatter plots to visually inspect the relationship between LST and each LULC class. For example, plot the LST values for urban areas against agricultural areas and forests to visually identify any patterns.

In correlation analysis, R and R^2 are statistical measures used to quantify the strength and direction of the relationship between two variables. R, also known as the Pearson correlation coefficient, measures the strength and direction of the linear relationship between two continuous variables. It ranges from -1 to 1, where 1 indicates a perfect positive linear relationship, -1 indicates a perfect negative linear relationship, and 0 indicates no linear relationship. Positive values (0 to1) mean that as one variable increases, the other variable tends to increase. Negative values (0 to -1) mean that as one variable increases, the other variable tends to decrease. The closer R is to 1 or -1, the stronger the linear relationship between the variables. R2 is the square of the correlation coefficient R. It represents the proportion of the variance in the dependent variable that is predictable from the independent variable(s) and ranges from 0 to 1. A value of 0 indicates that the independent variable explains none of the variance in the dependent variable.

4.1.8 Correlations among LULC and LST

The Analyzed Landsat images from 2004, 2014, and 2024 revealed that NDVI and LST share an inverse relationship. Areas with low NDVI values exhibited high LST, while regions with high NDVI values displayed low LST. In contrast, for water bodies, NDVI and LST showed a direct or positive correlation, as both NDVI and LST values were lower for these areas.

The correlation coefficients (R^2) between NDVI and LST during the study period were recorded at 85.2%, 87.3%, and 88.4% for the respective years. These figures generally reflect a strong negative correlation between NDVI and LST.

The study utilized the land surface temperature (LST) derived from the Landsat thermal band and the interpolated atmospheric temperature of the area, revealing a direct correlation between them. However, the LST trends observed were based on Landsat images captured during dry conditions and the harvesting period. Taking into account the prevailing meteorological conditions and the timing of the Landsat data acquisition, the spatial pattern of the LST was confirmed. Land surface temperature was confirmed through meteorological data and land use land cover (LULC) classifications of the study area, verify by GPS points gathered from the field and Google Earth.

The Analyzed Landsat images from the years 2004, 2014, and 2024 revealed a direct correlation between NDBI and LST, where higher NDBI values are associated with higher LST. The correlation coefficients (R^2 values) for the NDBI-LST relationship during these years were 89.1%, 85.4%, and 84.4% respectively.

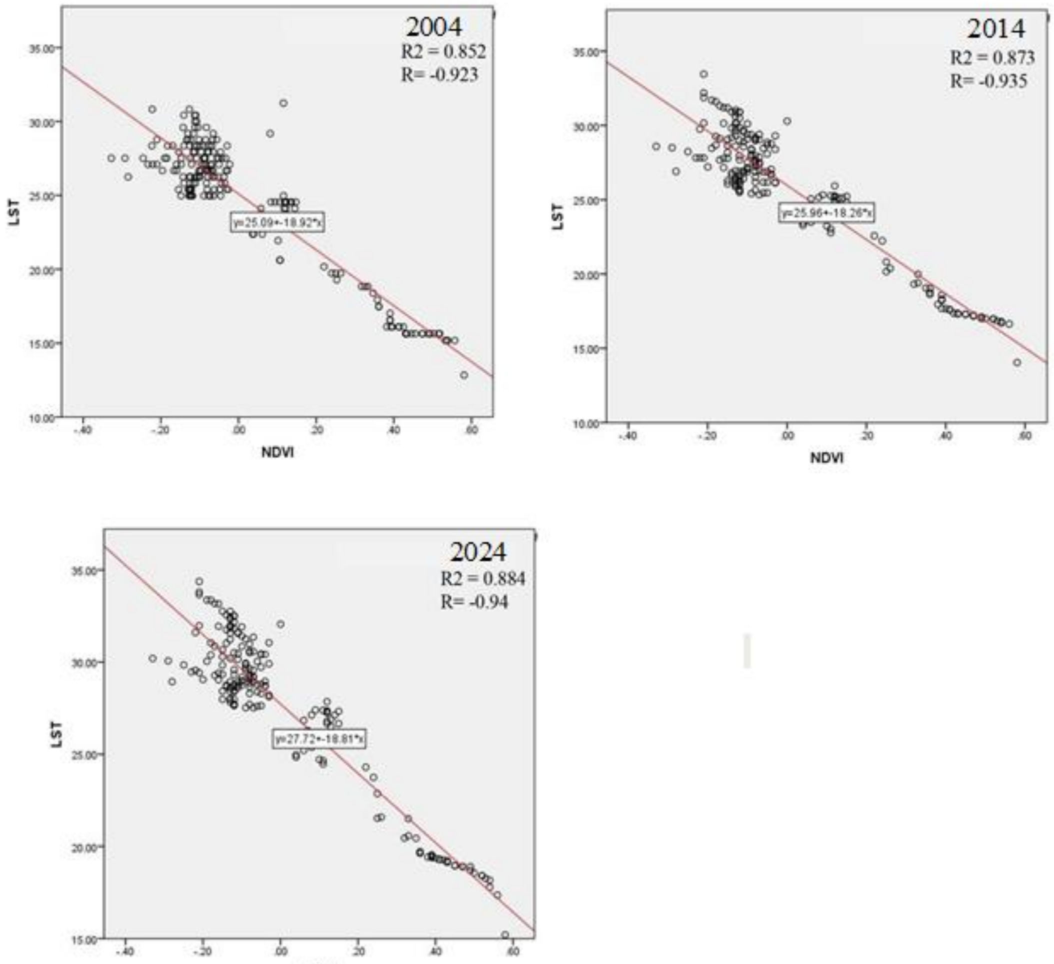

Figure 4.10 NDVI-LST Correlation graph

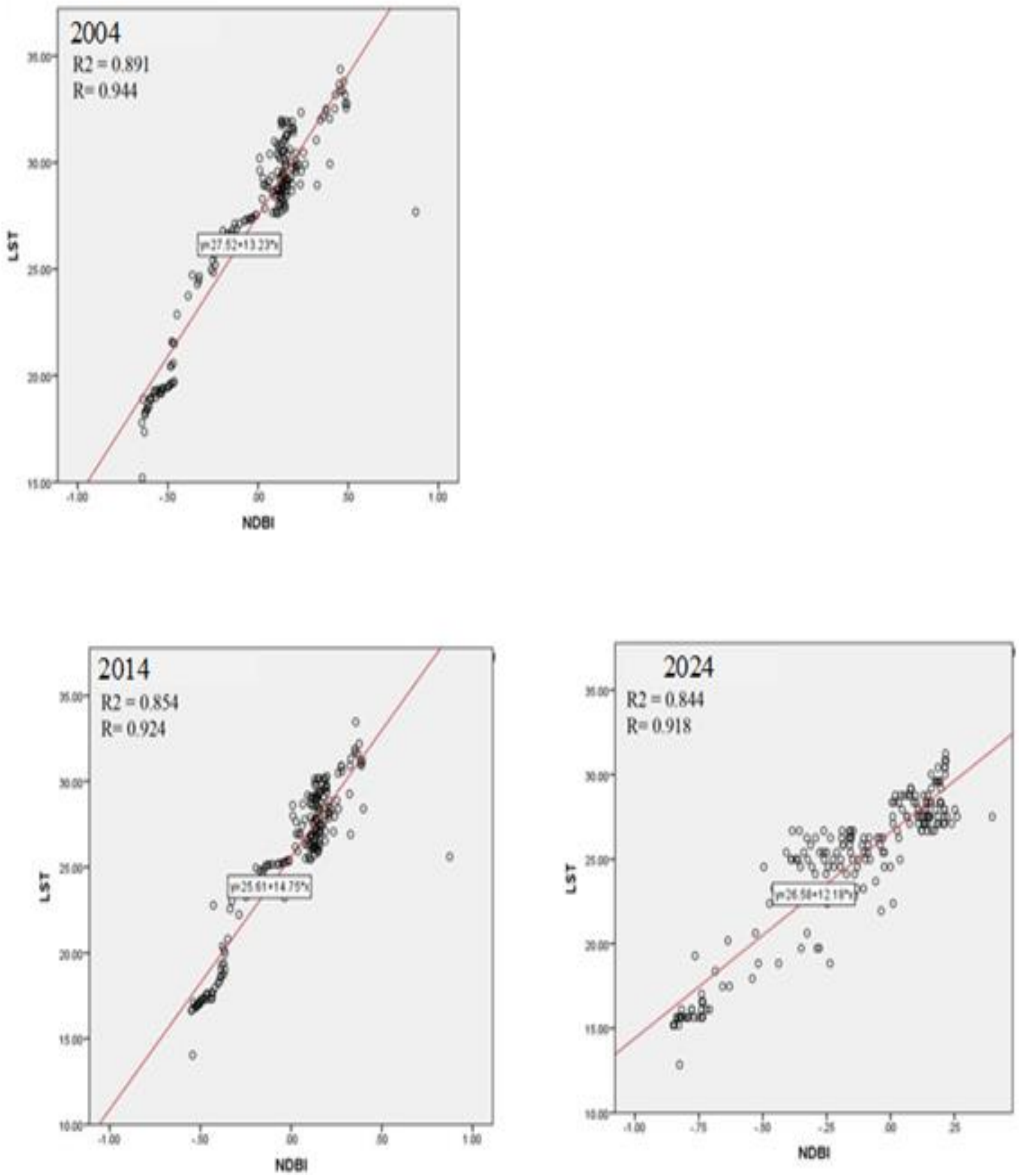

Figure 4.11 NDBI-LST Correlation graph

4.1.9. Framework for the Sustainable Conservation of Lake Dembel

The sustainable conservation of Lake Dembel requires an integrated framework that combines ecological protection, sustainable land use, community participation, effective governance, and scientific monitoring. The goal is to ensure long-term resource management while supporting local livelihoods.

Ecological restoration should focus on protecting wetlands and riparian zones that filter water, reduce erosion, and support biodiversity. Establishing buffer zones and monitoring water quality are critical, alongside controlling pollution and invasive species. Native aquatic vegetation should be promoted to enhance water filtration and ecosystem health.

Sustainable land use practices such as agroforestry, conservation tillage, and chemical-free buffer strips are essential to reduce runoff and soil erosion. Enforcing land use zoning can limit harmful urban or agricultural expansion. Eco-friendly tourism and watershed-based soil conservation (e.g., terracing, cover crops) can further support conservation and economic resilience.

Community involvement is vital. Engaging locals in decision-making, providing training, and supporting alternative livelihoods such as fish farming, eco-tourism, and organic agriculture can reduce dependence on the lake. Awareness programs and market access for sustainable products should also be strengthened.

Integrated water resource management (IWRM) should guide basin-wide planning. A dedicated conservation body should coordinate stakeholders, enforce regulations, and manage resource use. Strong legal frameworks and institutional coordination are needed to address pollution, land encroachment, and unsustainable fishing.

Finally, continuous monitoring and climate-responsive strategies must be adopted. Research on biodiversity, land use, and climate impacts will inform adaptive measures to protect the lake. Aligning these actions with national policies and partnering with global organizations can enhance funding, knowledge sharing, and long-term impact.

4.2. Discussion

The results of the LULC analysis from 2004 to 2024 reveal significant and continuous transformation around Lake Dembel, with notable environmental implications. Vegetation cover experienced a substantial reduction, while agricultural and built-up areas increased rapidly. This shift reflects both the growing population pressure and unregulated land use, especially in riparian and catchment zones. These findings are consistent with studies from similar lake basins in Ethiopia that show a correlation between agricultural expansion and degradation of lake ecosystems (Dinka, 2017; Ayalew & Selassie, 2020).

Between 2004 and 2014, the sharpest reduction occurred in vegetated areas (-17.52%), primarily converted to agriculture. This period marked the beginning of intensified land cultivation and small-scale irrigation, which, although beneficial for local food security, posed risks to the natural buffering capacity of vegetation around the lake. From 2014 to 2024, agricultural land continued to expand (+10.21%) but this phase also saw a notable reduction in water body coverage (–5.97%). The loss of water surface was likely driven by sedimentation, evapotranspiration, and reduced inflow resulting from land degradation and unregulated water use for agriculture.

NDVI values consistently declined indicating reduced vegetation density and productivity across the study area. This decline mirrors the LULC trends and confirms land degradation and diminishing green cover. Simultaneously, Land Surface Temperature (LST) rose from 17.2°C to 23.1°C, showing the warming effect of deforestation and increasing impervious surfaces from urbanization. The inverse correlation between NDVI and LST highlights the ecological consequence of vegetation loss, where areas with sparse vegetation tend to exhibit higher surface temperatures, intensifying water loss and thermal stress on aquatic ecosystems.

Moreover, the expansion of built-up areas contributed to rising NDBI, indicating an increase in sealed and compacted surfaces. The strong positive correlation between LST and NDBI suggests that urban growth directly contributes to surface heating. These changes exacerbate runoff; reduce infiltration, and increase sediment and pollutant loading into the lake, further stressing its ecological balance.

The reduction in water body area by 2% from 2004 to 2024 is of particular concern. This shrinkage, along with surrounding LULC dynamics, is affecting aquatic biodiversity, fisheries, and water availability. The lake is likely experiencing reduced inflow, heightened evaporation, and increased siltation all commonly observed in Ethiopian Rift Valley lakes undergoing similar pressures (Tekleab et al., 2020).

The framework for sustainable conservation developed directly responds to these findings. Protecting vegetation cover, enforcing buffer zones, and implementing sustainable agricultural and land use practices are critical. Community involvement and institutional coordination will also be essential in reversing the current trajectory of degradation. The strong statistical relationships among NDVI, LST, and NDBI affirm the interdependence of land cover, temperature, and urban pressure, emphasizing the need for integrated landscape and watershed management.

Overall, the study confirms that unchecked LULC change, combined with weak enforcement of environmental policies, is contributing to the environmental decline of Lake Dembel. Without strategic intervention, the lake’s ecological and socio-economic functions may be irreversibly compromised.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study investigated the spatiotemporal changes in Land Use Land Cover (LULC) around Lake Dembel over a 20 years period (2004, 2014, and 2024) using geospatial tools, including satellite imagery (Landsat 5 and 8), supervised classification (Maximum Likelihood), and Land Surface Temperature (LST) analysis.

The LULC classification revealed a remarkable increase in built-up areas from 4.37% in 2004 to 12.68% in 2024, reflecting intensified urbanization and settlement growth around Batu town and surrounding rural areas. Similarly, farmland expanded from 12.4% to 15.4%, indicating increased agricultural encroachment, particularly near the lake's riparian zones. Conversely, vegetation cover experienced a dramatic decline from 15.86% to 6.24%, Water body coverage, a direct indicator of lake health, declined from 67.6% (441.21 km²) to 65.68% (428.11 km²) a 13.1 km² reduction, indicating sedimentation, reduced inflow, and increased evaporation. This shrinkage, though seemingly marginal in percentage terms, poses a considerable threat to biodiversity, water availability, fisheries, and the broader hydrological balance of the region.

The thermal assessment revealed a steady and concerning increase in surface temperature. LST values rose from 17.2°C in 2004 to 23.1°C in 2024, with an average annual rise of 0.3°C. Statistical analysis confirmed a strong negative correlation between NDVI and LST (R^2 values between 0.85 and 0.88), indicating that vegetation decline directly contributes to surface warming. Furthermore, the positive correlation between NDBI and LST ($R^2 = 0.84$ to 0.89) confirms that expanding built-up areas exacerbate heat retention and urban thermal buildup, further stressing the ecosystem.

The total LULC transition over the 20 years period amounted to 151.24 km², with the most pronounced shifts occurring in the last decade (2014 to 2024), reflecting an acceleration of land conversion trends. Ecologically, this has led to a shift from a stable lake ecosystem in 2004 to a "high stress" condition by 2024. The surrounding watershed's capacity to buffer runoff, regulate microclimate, and filter pollutants has been compromised due to vegetative and wetland loss.

The study highlights the complex interplay between demographic growth, economic expansion (notably floriculture and settlement), and environmental degradation. Despite past conservation dialogues, the absence of enforceable zoning laws, weak institutional coordination, and insufficient community awareness continue to drive unsustainable land practices.

By integrating geospatial evidence with ground-truthed validation, this research offers robust data to support policy dialogue and conservation planning. It establishes a strong empirical foundation for developing an evidence-based conservation framework that incorporates spatial planning, climate adaptation, ecological restoration, and community participation.

In summary, Lake Dembel is undergoing rapid environmental decline, with measurable land cover losses, thermal stress, and hydrological imbalance. Without immediate and coordinated intervention, the lake's ecological and socio-economic functions may be irreversibly compromised. This study contributes to filling a critical knowledge gap and calls for an urgent shift from reactive land use practices to proactive, integrated watershed governance and long-term environmental stewardship.

This study is limited by the moderate resolution of Landsat imagery, temporal gaps between observations, and reliance on pixel-based classification, which could be improved through the use of high-resolution or multi-temporal data, advanced machine learning algorithms, and field verified training samples.

5.2 Recommendations

The findings presented in this study offer data-driven evidence of these impacts and suggest that urgent, multi-level intervention is required. Only by integrating scientific monitoring, stakeholder collaboration and sustainable land-use policies can the lake's ecosystem services and livelihoods be preserved.

To address these environmental issues and improve future research and management, the following actions are recommended:

Stakeholder	Recommendation	Purpose / Expected Impact
Urban Planners	Enforce spatial planning policies that implement a 2 km ecological buffer zone around Lake Dembel.	Prevent habitat encroachment, reduce sediment and nutrient inflow, and preserve riparian zones.
	Integrate LULC change maps into local and regional development plans.	Align infrastructure and urban expansion with sustainable land use goals.
Policy Makers	Establish a Lake Dembel Basin Conservation and Regulation Authority under Oromia region mandates.	Enable coordinated governance, monitoring, and enforcement of sustainable land policies.
	Develop and enforce land use legislation specific to lakeshore zones and high-risk agricultural areas.	Minimize environmental degradation and ensure legal accountability for land misuse.
Local Stakeholders	Promote community-led reforestation and buffer zone management programs using indigenous knowledge.	Restore degraded land, improve microclimates, and empower community ownership of conservation.
	Facilitate training on eco-friendly farming techniques (e.g., organic inputs, terracing, agroforestry).	Reduce agrochemical runoff, conserve soil, and increase productivity with less environmental harm.
Researchers & Academics	Conduct multi-seasonal and high resolution LULC studies using advanced classification (e.g., Random Forest).	Improve the accuracy and temporal granularity of land change monitoring.
	Establish long-term environmental observatories or collaborate with GEE platforms for continuous monitoring.	Enable predictive modeling and early warning of ecological decline.

Table 5.1 Recommendations for Stakeholders

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