AFRICA CENTER OF EXCELLENCE FOR WATER MANAGEMENT

ADDIS ABABA UNIVERSITY

Land Use and Land Cover Changes in Relation to Ecosystem Services in Lake Koka Catchment

M.Sc. Thesis

By

Tensay Teshome Adane

A thesis submitted to the African Centre of Excellence for Water Management (ACEWM) in partial fulfillment of the requirement for a Master's Degree in Water Management (Aquatic Ecosystems Management) of Addis Ababa University

June, 2024

Addis Ababa, Ethiopia

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Co-Advisor: Dr. Tibebu Kassawmar

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ABBREVIATIONS/ACRONYMS

DO	Dissolved oxygen
ENVI	Environment for visualizing images
EPA	Environmental Protection Authority
ERDAS:	Earth Resource Data Analysis System
ESs	Ecosystem services
FDGs	Focus group discussions
GIS and RS	Geographic information system and remote sensing
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
LULCC	Land use/land covers change
MEA	Millennium ecosystem assessment
NDVI	Normalized different vegetation index
PCC	Post-classification comparison
SPSS	Statistical package for the social sciences
TSI	Trophic State Index
UTM	Universal transverse Mercator
WGS	World geodetic system

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Abstract

Lake Koka, a rift valley lake in Ethiopia, provides critical ecosystem services (ESs), such as hydroelectric power generation, domestic water supply, irrigation, recreation, and fisheries. However, the lake is severely threatened by anthropogenic activities, particularly land use and land cover change (LULCC) in the catchment area. This study aimed to map and quantify the dynamics of ESs, specifically the trophic status index, nutrient delivery ratio, and socioeconomic impact associated with LULCC in the Lake Koka catchment from 1991 to 2021. Landsat images were analyzed using ARC GIS 10.7.1, ENVI v5.3, and ERDAS IMAGINE 15 software to assess LULCC. The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model was employed to estimate nutrient delivery ratios. Five major land use types were identified, with increased settlements and forestland over the study period. The trophic status index indicated a hypertrophic state in the lake. These results suggest that LULCC and anthropogenic activities have drastically impacted the ESs provided by the watershed, particularly provisioning services. Deforestation and the expansion of agricultural land, coupled with using fertilizers, pesticides, and insecticides, have led to increased nutrient and chemical transport to lakes through runoff, resulting in eutrophication and frequent algal blooms. In general, the catchment's ecosystem services are greatly affected by changes in LULC.

Keywords/Phrases: Ecosystem services; InVEST model; land use/land cover; trophic status index; Lake Koka.

CHAPTER ONE

1. INTRODUCTION

1.1. Background and justification

Ecosystem services (ESs) represent the benefits humans obtain from ecosystems (MEA 2005). ES includes supporting, regulating, provisioning, and cultural services. Aquatic ecosystems provide drinking water, fish, irrigation, power generation, transportation, and aesthetic value (Lakew Wondimu, 2014). Correspondingly, human well-being is fundamentally dependent on these services, and the amount and quality of ES depends on the types of ecosystems, their status, and land use/land cover in the catchment (Woubshet Negussie et al., 2019).

ES are closely related to land cover and land use (LCLU), and they change over time and space (Woubshet Negussie et al., 2019). The key ES has been deteriorating, particularly in developing countries, owing to rapid economic development, intense human activities, agricultural expansion, and urbanization. Agriculture is regarded as a major cause of surface water quality degradation, which affects ES (Schoumans et al.,2014). Thus, ES, its structure, and functions are greatly influenced by changes in the patterns, practices, and intensity of land use land cover (LULC).

Ethiopia has many economically important freshwater ecosystems including lakes, reservoirs, rivers, and wetlands. These ecosystems provide critical ecological services to the local ecosystem, particularly to the livelihoods of the poor. However, many of them are under increasing pressure owing to anthropogenic impacts and are facing serious challenges such as ecosystem degradation, water contamination, pollution, shoreline modification, irrational water utilization, and a lack of effective management (cf. Zhong et al., 2019). Agriculture, pollution, and the introduction of exotic species (and subsequent invasion) are anthropogenic elements that affect aquatic ecosystems and, thus, ES (Sahle Tesfaye, 2019). Thus, providing food, timber, energy, housing, and other goods and services while maintaining ecosystem functions and biodiversity that underpin their sustainable supply is a great challenge of our time.

Lake Koka, a rift valley lake in Ethiopia, is of socioeconomic importance including hydroelectric power generation, domestic water supply, irrigation, recreation, and fisheries (Kassahun Tessema et al., 2020). Thus, to provide a better understanding of changes in degrading ecosystems and the potential for ecosystem restoration, ESs have been identified as an ecological concept that has been important for policymakers and practitioners in recent years (Eyasu Elias et al., 2019).

To understand the drivers of ecosystem service changes, it is important to understand how these changes occur both spatially and temporally. Therefore, this study evaluated land cover changes over the past 30 years (1991–2021) in the catchment of Lake Koka using satellite images to understand the trend of changes and how they might influence ecosystem services (provisioning ecosystem services, for example). The focus includes land cover changes of important types, including woodlands, urban areas, and agricultural land, which are linked to ecosystem services in the catchment. People living in this catchment depend heavily on the lake's provisioning ecosystem services for their well-being; thus, it is necessary to understand the status of ES maintenance. Correspondingly, the current ES of the lake catchment area was assessed and compared with previous services using the InVEST model, interviews, and group discussions. In this study, a trophic state index was determined to demonstrate the water quality of the lake, which TSI also influences the ES.

1.2. Statement of the problems

Ethiopia has more than 11 freshwater lakes, nine saline lakes, numerous rivers, and over 12 major wetland areas. Many lakes are located in the Rift Valley, which is central to the economic development of the country. Lake Koka, located in the central Ethiopian Rift Valley, is an artificial lake built in 1960 to generate hydroelectric power (Bulo Feyisa and Mekonnen Bersisa 2019). Currently, the lake has several socioeconomic uses including hydroelectric power generation, domestic water supply, drinking water, irrigation, recreation, and fisheries (Kassahun Tessema et al., 2020). However, the lake is now under severe threat because of point and nonpoint pollution. Once a forested area is deforested and degraded, the catchment is replaced by agriculture-based activities that use fertilizers, pesticides, and insecticides. Nutrients and chemicals are transported to lakes through runoff, resulting in eutrophication and frequent algal blooms. Cyanobacterial blooms produce cyanotoxins on the Amudde side of the Koka Reservoir (Tadesse Fetahi 2019; Wubshet Zewde et al. 2018; Yeshiemebet Major et al. 2018). Sedimentation is also high (Graichen,2011; Kloos & Legesse,2011; Gregersen, 2007).

Several studies have been conducted on Lake Koka concerning various ecosystem components (water quality, heavy metals, water hyacinth, and fisheries) (Wubshet Zewde et al., 2018; Yeshiemebet Major et al., 2018). However, ESs have not been comprehensively assessed based on land-cover changes in the catchment. Therefore, this study aimed to determine LULC changes using GIS, remote sensing, and the InVEST NDR Model to assess the nutrient delivery ratio.

Furthermore, ESs were assessed through household surveys, interviews, and group discussions. A trophic state index, which determines the ES, was also developed to demonstrate the current water quality of the lake. The findings of this study will provide inputs for policy formulation, restoration, and sustainable lake resource management.

1.3. Research Objective

1.3.1. General objective

The general objective of this study was to assess the impact of land use and land cover changes on Lake Koka Ecosystem services and recommend sustainable restoration and development techniques for improved livelihood and ecosystem health.

1.3.2. Specific objectives

- ❖ To assess the spatial and temporal LULC changes on the lake catchment
- ❖ To determine the physicochemical parameter and trophic status of the lake and compare it with the historical data
- ❖ To assess the ecosystem service of the lake concerning LULC changes using interviews and group discussion

1.4. Research questions

- ➢ What are the current water quality and trophic status of Lake Koka?
- ➢ What have been the trends in land use and land-cover changes in the Lake Koka catchment over the last 30 years?
- ➢ Do changes in land use and cover have a significant effect on the ecosystem services of Lake Koka?

1.5. Significance of the study

This study supports previous research on lakes and reservoirs in Ethiopia. Currently, lakes and reservoirs are under severe threat, and this study will provide information for the protection and management of lakes/reservoirs. This study also updates the existing literature.

This study determined the economic and ecological impact of Lake Koka. It shows the dynamics of ecosystem services regarding land use, land cover, and land management changes. It will also inform decision-makers about management options.

The benefits of this study include the local community, government, researchers, and NGOs working in the community.

1.6. Scope of the study

The present study was conducted in the Lake Koka catchment area. The application of GIS and remote sensing will help gain new insights into water resource problems. It was not possible to cover all aspects of the study area with stated objectives, owing to time and resource restrictions. Therefore, limiting the scope of the problem to a manageable objective was preferable. Hence, this study focused on the ecosystem service dynamics of LULC and land management and did not include the watershed of the entire catchment area.

This study assessed the ecosystem services of Lake Koka regarding land use/land cover and land management changes.

1.7. Organization of the thesis

This thesis is organized into five chapters; chapter one presents the background, statement of the problem, objectives, significance, scope, and limitations of the study. Chapter two presents a literature review in which a general review of the current knowledge relevant to the research topic is provided. Chapter three describes the study area, methodology, and data collection techniques. The results obtained using various methods and the discussion are presented in chapter four. Finally, the conclusions and recommendations are presented in chapter five.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Ecosystem Services

The concept of ‘ecosystem services’ is a relatively recent development that dates back to the 1960s and the beginning of the 1970s (Wangai et al., 2016). The Millennium Ecosystem Assessment (MA) (2005) defines ecosystem services as ‘‘the benefits that humans obtain from ecosystems.”

Ecosystem services refer to all benefits directly or indirectly obtained by human beings from an ecosystem, and they mainly include provisioning, regulating, supporting, and cultural services. (Ma et al., 2020).

With the rapid growth of human demand, ESs can no longer be considered free “goods” due to the rising threats of their loss and degradation to present and future generations. Several studies on ESs have been conducted worldwide. to understand their true value (Zhong et al., 2019).

2.2. Specific Ecosystem Services

According to MEA (2005), ESs are the benefits that people obtain from ecosystems, which MA describes as provisioning, regulating, supporting, and providing cultural services. Ecosystem services include products such as food, fuel, and fiber; regulating services such as climate regulation and disease control; and nonmaterial benefits such as spiritual or aesthetic benefits. Changes in these services can affect human well-being in several ways.

2.2.1. Provisioning ES

Provisioning services are products obtained from ecosystems, such as food, fuel, fiber, fresh water, and genetic resources.

2.2.2. Regulating ES

Regulating services are benefits that people obtain from the regulation of ecosystem processes, including air quality maintenance, climate regulation, erosion control, regulation of human diseases, and water purification.

2.2.3. Supporting ES

Supporting services are necessary for the production of all other ecosystem services such as primary production, oxygen production, and soil formation.

2.2.4. Cultural ES

Cultural services are the non-material benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.

2.3. Ecosystem Services Derived from Lakes

Schellenberg et al (2013) have divided Lake Ecosystem services into four types: (1) services that are globally recognized via treaty obligations, (2) services that provide resources directly, (3) services that support and regulate useful ecosystem processes and components, and (4) culturally important services.

2.4. Land Use and Land Cover Change: Definitions and Concepts

Land use and land cover (LULC) are distinct yet closely linked characteristics of Earth’s surface. Land use describes the ways and purposes for which human beings employ land and its resources. Land cover refers to the ecological state and physical appearance of the land surface, such as closed forests, woodlands, or grasslands (Fasika Alemayehu et al., 2019).

Land use and land cover change (LUCC) are fundamental to global changes that influence the relationship between humans and natural systems in many aspects of the social and physical environments. (Rai et al., 2018).

2.5. Application of Remote Sensing and GIS on LULCC

Since detailed LULC maps are lacking for several countries or regions, remote sensing data is considered a valuable source of LULC data. (Kandziora et al., 2014).

Interest in investigating the impact of LULC on ES at the local and global scales is growing. LULC datasets, which provide detailed information on ecosystem patterns, processes, and data to process, analyze, and model LULC changes and ES impacts, are now freely available (Rimal et al., 2019).

2.6. Land use and Land cover Change Studies in Ethiopia

Motuma Shiferaw et al., (2021) In his review of 25 articles, very recent articles on LULCCs in Ethiopia pointed out that the predominant methods to classify lands are unsupervised and maximum likelihood supervised classification, generally performed via GIS and ERDAS Imagine software. Most studies have used key informant interviews, focal group discussions, and ground truth data to validate the information retrieved from satellite images. There was a large variability among the classes analyzed, but the most common ones were agricultural land, forest, grazing land, water bodies, swamp areas, shrublands, barren land, etc.

2.7. Impact of Land use and cover change on ecosystem services

Land use and land cover (LULC) changes have a direct impact on ecosystems and their associated services (Fang, Z et al., 2022).

Land use and land cover changes have extensive impacts on ecosystem services. The impact of anthropogenic and environmental stressors on natural ecosystems can propagate ecosystem functions that may impede ecosystem services. With the accelerated pace of economic development, industrialization, and urbanization, anthropogenic disturbances in the natural environment are becoming more prevalent, resulting in an increasing trend of domestication and ecosystem vulnerability. (Liu et al., 2019).

Because ecosystem service changes by land use and land cover changes are important indicators and early warnings of ecological changes this study was conducted.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the study area

Lake Koka is one of the rift valley lakes-chains of lakes that lie entirely in the southern part of the Ethiopian rift valley. It is located between $8^0 2´$ and $8^0 26´$N latitude, 39^0 to $39^0 10´$E longitude, and has an altitude elevation of 1660 m above sea level. (Derribew Hailu et al., 2020).

It was artificially created to produce and supply hydroelectric power since 1960 (EPA, 2003). The lake has maximum and mean depths of 14 and 9m, respectively. The Awash and Mojo (tributary to Awash) rivers flow into the lake.

The other main habitats are the surrounding farmlands, partly protected woodland beside the dam site, and the river and hot-spring areas below the dam. Crop cultivation has expanded, and the only large trees left in the area are figs, for example, *Ficus vasta* and a few others generally associated with churches or other ceremonial places. The main activity in the area is farming, and the most widely grown crop is *Eragrostis tef*. Farmers use alluvial soil around the lake to grow horticultural crops and pulses, particularly haricot beans (BirdLife International, 2020).

More than 15,000 local people rely heavily on the lake for drinking, animal watering, cleaning, fishing, and traditional irrigation practices. However, the lake is heavily polluted by direct discharge of effluents and agricultural activities in the catchment. The nearby inhabitants suffer from poor sanitation and waterborne diseases, such as chronic diarrhea, which result from drinking polluted water. (Seyoum Akele, 2011).

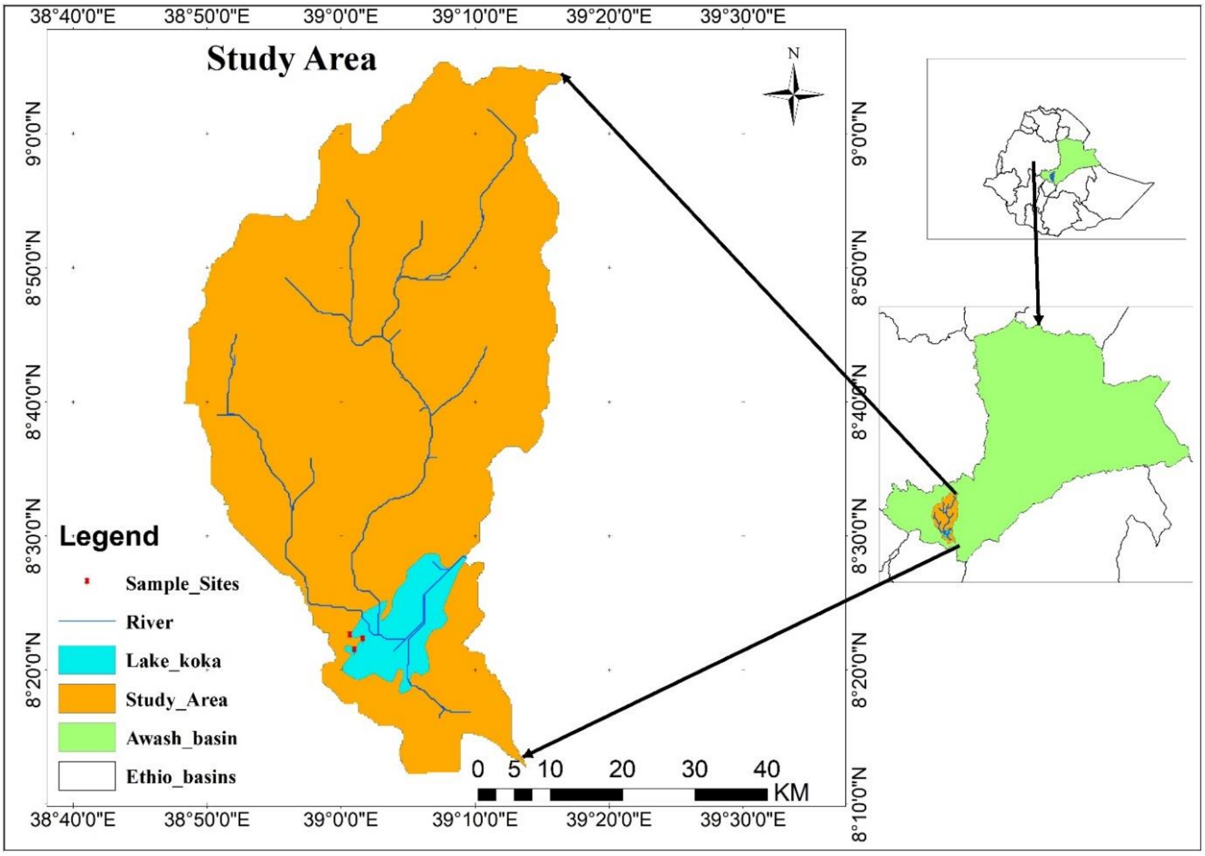

Figure 3. 1: Map of the study area

3.2. Data collection approaches

3.2.1. Sampling Technique

Purposive sampling

This type of sampling is a non-probability sampling technique, whereby purposive sampling is a strategy in which particular settings, persons, or events are deliberately selected to provide important information that cannot be obtained from other choices. It is where the researcher includes cases or participants in the sample because they believe that they warrant inclusion. (Taherdoost, 2018)

This study was designed as quantitative and qualitative research. Non-probability sampling was used whereas purposive sampling was chosen because the data was deliberately selected to provide important information. Both primary and secondary data were used in this study, which was acquired through different means and sources. Primary data were ground reference data, direct field observations, semi-structured interviews, structural household questionnaires, focus group discussions (FDGs), and key informant interviews. The household survey questionnaire consisted of three sections. The first section captured direct and indirect ESs. The second section captured general information about the access and use of Lake ESs, and the third section asked for detailed information about each ES's changes, impact, vulnerability, and coping strategies.

Both key informants and FGD members were asked open-ended questions concerning the key characteristics of their environment, and historical relations between the environment (biophysical, political, and socio-economic) and rural society. Furthermore, issues related to the historical trends of forest cover change, biodiversity loss, threats to ecosystem services, and forest management across different regimes were discussed. Field observations were also made through a transect walk.

The secondary data was compiled from related literature, research reports, government documents, and reviews of different legislation.

3.2.2. Measurements of physicochemical parameters and nutrient analysis

Temperature, DO (dissolved oxygen), pH, and electrical conductivity (EC) were measured using a multimeter probe (HQ40d), and the Secchi disc depth (ZSD) or water transparency was measured using a Secchi disc of 20 cm diameter, the depth of the sampling site of the lake was measured by PLASTIMO Eco sounder. Turbidity was determined using a turbidity meter (OAKTON 1T_100). All physicochemical parameters were measured *on-site* during sample collection.

Concentrations of inorganic nutrients (nitrate, nitrite,..) were determined in the limnology laboratory of Addis Ababa University following the procedures outlined in APHA (1999). All water samples used for nutrient analyses were filtered through glass fiber filters (Whatman GF/F), except for total phosphorus (TP), for which an unfiltered water sample was used.

Ammonium (NH_4) was analyzed using the phenate method, while nitrate (NO_3-N) was analyzed by the sodium salicylate method APHA (1995) and nitrite (NO_2-N) by diazotization with sulfanilamide and coupling with the N-1-naphthyl ethylenediamine di-HCl colorimetric method. The absorbance of NH_4-N, NO_3-N, and NO_2-N was measured using a JENWAY 6405 spectrophotometer at 640 nm, 420 nm, and 543 nm, respectively. Total phosphorus (TP) and soluble reactive phosphorus (SRP) after ammonium persulfate digestion were analyzed using the ascorbic acid method (APHA, 1999). Silica (SiO_2) was estimated using the molybdo-silicate method. The absorbance of TP, SRP, and SiO_2 was read using a JENWAY 6405 spectrophotometer at 880 nm and 410 nm, respectively. All inorganic nutrient absorbance readings were converted to actual concentrations by using standard curves.

3.2.3. Trophic status index (TSI) of Lake Koka

Table 3. 1: Location of sampling sites

Site	Latitude (N)	Longitude (E)	Altitude (m)	Depth (m)
S1	8°21'30.06"	39°.0'17.064"	1583m	3.9m
S2	8°21'25.56"	39°.0'5.976"	1589m	2.6m
S3	8°22'53.508"	39°.0'27"	1589m	_

Three samples (surface water in one sampling period) were collected from each site from a wooden boat on 08 December 2022. Polyethylene bottles (1000 mL) were used, which were washed three times with sample water. After collection, samples were preserved in an ice cooler (~4 C) until arrival at the Addis Ababa University limnology laboratory, followed by immediate analysis. The location and characteristics of each sampling point were recorded (Table 3.1) and chlorophyll *a* (Chl-*a*) was analyzed.

The trophic state index of Lake Koka was calculated based on the concentrations of TP and Chl-a (Lamparelli, 2004). The formulae for reservoir TSIs (Lamparelli, 2004) are as follows:

$$\text{TSI (Chl-a)} = \frac{10\times (6 - (0.92 - 0.34 \times \ln[chl-a])}{\ln 2}$$

$$\text{TSI (TP)} = \frac{10 \times (6 - (1.77 - 0.42 \times \ln [\text{TP}]))}{\ln 2}$$

Where; [Chl-a] is the chlorophyll-a concentration in µg/L,

[TP] is the total phosphorus concentration in µg/L and ln is the natural logarithm.

TSI_{Lamp} is the simple arithmetic average of the indices for Chl-a and TP.

$$\text{TSI Lamp} = \frac{\text{TSI (Chl}-\text{a) + TSI (TP)}}{2}$$

The TSI classification is based on Lamparelli (2004).

Table 3. 2: Classification and ranges of variation in TSI.

TSI value	Classification
TSI ≤ 47	Ultraoligotrophic
47 < TSI ≤ 52	Oligotrophic
52 < TSI ≤ 59	Mesotrophic
59 < TSI ≤ 63	Eutrophic
TSI > 67	Hyper eutrophic

Source: Lamparelli (2004), CETESB (2009)

3.2.4. Satellite images pre-processing and land use classification

3.2.4.1. Land Sat Images

In this study, dry season Landsat images of land use/land cover (LULC) from 1991, 2003, and 2021 were obtained from spectral Landsat imagery for the present study, with a spatial resolution of 30 m retrieved from the United States Geological Survey Website (USGS, https://earthexplorer.usgs.gov/) using the Worldwide Reference System Path 168 and Row 54. Atmospheric correction and geometrical rectification were performed before interpretation. The criteria were used to select Landsat imagery for developing a land-cover database for the Lake Koka catchment. All images were captured during the dry season (January, February, and December) in Ethiopia to obtain clear distinctive phenology and diverse land cover characteristics.

All data were projected to the Universal Transverse Mercator (UTM) projection system zone 37N and data from the World Geodetic System 1984 (WGS 1984) to ensure consistency between datasets during analysis.

Approximately 200 representative training pixels for all classes were selected based on stratified random sampling for the 1991, 2003, and 2021 images. A dataset of approximately 152 points and a ground-truth classified image were collected to assess the generated prediction maps.

Table 3. 3: Details of Landsat images used in the study

Satellite	Sensor	Path/Row	Acquisition Date	Spatial Resolution(m)	Spectral Bands Used
Landsat 8	OLI-TIRS	168/54	19/11/1991	30	B2 -B5
Landsat 7	ETM^+	168/54	12/1/2003	30	B1- B4
Landsat 5	TM	168/54	7/12/2021	30	B1- B4

3.2.5. InVEST Model

InVEST is intended to inform natural resource management decisions. It describes how changes in ecosystems are likely to result in changes in the flow of benefits to people. (Sharp et al., 2020a).

NDR: Nutrient Delivery Ratio

The goal of the InVEST nutrient delivery model is to map the nutrient sources in watersheds and their transport to streams. These spatial data can be used to evaluate the nutrient retention services provided by natural vegetation. Retention service is especially important for surface water quality issues, and it can be valued in economic or social terms, such as avoiding treatment costs or improving water security through access to safe drinking water. (Sharp et al., 2020a).

Nutrient Loads

Loads are the nutrient sources associated with each pixel of the landscape. (Sharp et al., 2020a).

Nutrient Delivery

Two delivery ratios were computed: one for nutrients transported by surface flow, and the other for subsurface flow.

Surface NDR

The surface NDR is the product of a delivery factor, representing the ability of downstream pixels to transport nutrients without retention, and a topographic index, representing the position on the landscape. For a pixel i:

$$NDR_i = NDR_{0,i}\left(1+\exp\left(\frac{IC_i - IC_0}{k}\right)\right)^{-1}$$

where IC_0 and k are calibration parameters, IC_i is a topographic index, and NDR_0, i is the proportion of a nutrient that is not retained by downstream pixels (irrespective of the position of the pixel on the landscape).

Subsurface NDR

The expression for subsurface NDR is a simple exponential decay with distance to stream, plateauing at the value corresponding to the user-defined maximum subsurface nutrient retention:

$$NDR_{subs,i} = 1 - eff_{subs}\left(1 - e^{\frac{-5\cdot\ell}{\ell_{subs}}}\right)$$

where

• eff_{subs} is the maximum nutrient retention efficiency that can be reached through subsurface flow (i.e. retention due to biochemical degradation in soils),

• ℓ_{subs} is the subsurface flow retention length, i.e., the distance after which it can be assumed that soil retains nutrients at its maximum capacity,

• ℓ_i is the distance from the pixel to the stream.

Nutrient export

Nutrient export from each pixel i is calculated as the product of the load and NDR:

$$x_{exp_i} = load_{surf,i}\cdot NDR_{surf,i} + load_{subs,i}\cdot NDR_{subs,i}$$

The total nutrient at the outlet of each user-defined watershed is the sum of the contributions from all pixels within the watershed:

$$x_{exp_{tot}} = \sum_i x_{exp_i}$$

Data Needs

Workspace, Digital elevation model (DEM), Land use/land cover, Nutrient runoff proxy, Watersheds, Biophysical Table, Threshold flow accumulation, Borselli k parameter, Subsurface Critical Length (Nitrogen or Phosphorus) and Subsurface Maximum Retention Efficiency (Nitrogen or Phosphorus).

3.3. Data processing

3.3.1. Image pre-processing

Image preprocessing was performed using ENVI 5.3 because of its wide range of tools for image preprocessing, flexibility in image display, and ability to process large multispectral remote sensing data. At this stage, the visual quality of the image was enhanced by manipulating the digital pixel values through a process known as contrast enhancement. The goal of image enhancement is to improve the visual interpretability of an image by increasing the apparent distinction between the features. The brightness differences of the image were improved uniformly by adjusting the bright and dark pixels such that the intermediate values had better contrast.

3.3.2. Normalized difference vegetation index

The well-known and widely used NDVI is a simple, but effective index for quantifying green vegetation. It normalizes the green leaf scattering at near-infrared wavelengths with chlorophyll absorption at red wavelengths. The value range of NDVI is -1 to 1. Negative NDVI values (values approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. Low positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1). It is a good proxy for live green vegetation; the normalized difference vegetation index, abbreviated NDVI, will be computed as

$$NDVI := \texttt{Index}(NIR, RED) = \frac{NIR - RED}{NIR + RED}$$

3.3.3. Classification of land use and land cover change image

Land use/land cover was classified based on the study area's physiographical knowledge, visual interpretation using historical Google Earth images, supporting supplementary data, and prior knowledge of the researcher regarding local knowledge of the study area. The study area was classified into five categories (forest land, settlements, bare land, agricultural land, and waterbody) using the spectral signature. Stratified random sampling techniques were employed to collect 152 points for accuracy assessment. The land classes were verified using in-situ field observations. Reference data were retrieved from Google Earth. Kappa coefficient and user accuracy derived from the error matrix were used to determine the accuracy of the classification assessment. The 2021 LULC imagery was subjected to a minimum of 80% overall accuracy and used as a reference to classify historical images. Were captured to compare phenological data during the study period, with the historical images (1991, 2003, and 2021) being further visually interpreted taking into account image tone, texture, shape, and class patterns. LULC change analysis was further determined using the post-classification comparison (PCC) technique, which is reported in a cross-tabulation matrix. ArcGIS software version 10.7.1, was used to compute the LULC change-traditional matrix to quantify the area converted from a particular LULC class to another LULC category during the study period. The annual rate of change was determined as shown in the equation below:

$$r = \left(\frac{1}{t^{2} - t^{1}}\right) * \ln\left(\frac{S_2}{s_1}\right)$$

where r is the annual rate of change for each class and S_1 and S_2 are the areas of each LULC class at times t^1 and t^2, respectively.

Supervised Classification and Maximum Likelihood Classifier (MLC)

Supervised Classification is based on the classification of unknown identity pixels by using samples of known identity pixels. The analyst selects these samples or training areas under their supervision. Three steps are involved in supervised classification: (1) the training stage, which consists of identifying representative training areas and developing a numerical description of the spectral attributes of each land cover type in the scene, referred to as a training set or training areas; (2) in the classification stage, each pixel in the image data set is assigned to a land cover class. (3) The process output is a matrix of interpreted land cover category types (Lillesand and Kiefer, 2002). In general, supervised classifications are more accurate than unsupervised classifications provided that the classes are correctly identified by the analyst, which means that significant knowledge and skills of the analyst are required. In addition, the supervised classification process was user controlled.

In this study, a maximum likelihood classifier (MLC) was used. MLC is a parametric statistical method in which the analyst supervises the classification by identifying training areas. These training areas were then described numerically and presented to a computer algorithm. The computer algorithm then classifies the pixels of the entire scene, on which we classify the spectral class that appears to be the most alike. During classification, all unclassified pixels are assigned a class membership based on the relative likelihood of the pixel occurring within each class probability density function.

Table 3. 4: Land cover classification scheme

No	LULC Class	Description
1	Forest land	Protected forests, plantations, deciduous forests, mixed forest lands, and forests on customary land
2	Settlement	Residential, commercial and service, industrial, socioeconomic infrastructure, and mixed urban and other urban, transportation, roads
3	Bare land	Areas with little or no vegetation cover, open lands, eroded gullies, and exposed rocks
4	Agricultural land	cultivated and uncultivated agricultural lands areas, such as farmlands, crop fields including fallow lands/plots, and horticultural lands
5	Waterbody	Rivers, streams, permanent open water, lakes, ponds, wetlands, reservoirs

3.3.4. Accuracy assessment

Accuracy assessment, sometimes known as the confusion matrix, is an important step that helps in determining the accuracy of the classification, particularly for pixels in a given class. Accuracy analysis helps to quantitatively assess the classification performance and determine the quality of information from remotely sensed data. This process helps to determine how effectively pixels are grouped into the correct feature classes after classification. The columns of the accuracy assessment show the number of pixels per class for the reference data and the rows show the number of pixels per class for the classified image. Google Earth imagery for

2021 will be used for accuracy by comparing them to classified images. The accuracy of a classified image refers to the extent to which it agrees with the set of reference data. Most quantitative methods to assess classification accuracy involve an error matrix built from two datasets: remotely sensed map classification and Google Earth reference data. The reference data were taken from Google Earth, and Google Earth was used as a base map.

Reference data were collected for each class type and compared against the classified image using a contingency matrix.

Post-Classification Change Detection

There are four critical aspects of change detection in natural resource monitoring. (1) determining whether a change has occurred, (2) determining the nature of the change, (3) measuring the aerial extent of change, and (4) evaluating the spatial pattern of change when data from similar or comparable satellite sensors are available. Post-classification change detection can be used to examine change detection over a long period when one type of remotely sensed data is not available. Post-classification refers to a comparison of spectral classifications for different dates produced independently. This method compares two independently classified land use/land cover maps derived from images taken on two different dates. The main advantage of post-classification is that the two dates are identical. The principal advantage of post-classification is that the two dates of imagery are separately classified, thereby minimizing the problem of radiometric calibration between dates.

3.4. Statistical Analysis

Qualitative data were decoded, translated into English, and analyzed using content analysis of related themes. The analysis involved coding to generate initial themes among the codes and reviewing and naming the themes. The identification of related themes was based on historical patterns within the data. On the other hand, Geospatial LULC Landsat satellite data were analyzed using GIS and remote sensing approaches. ERDAS IMAGINE 2015 (for image classification), ArcGIS version 10.7.1(for mapping), and ENVi 5.3 software were used. Quantitative data were analyzed using descriptive and inferential statistics. SPSS version 26 was used for data analysis.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Land Use and Land Cover

4.1.1. Normalized difference vegetation index

In this study, it has been observed that the vegetation cover was more in 1991 and 2003 with maximum NDVI values of 0.68 and 0.66, respectively. The highest value indicates healthy vegetation. The vegetation cover decreased by 2021, with an NDVI value of 0.59. The normalized difference vegetation index results for 1991, 2003, and 2021 are presented in Figure 4.1.

Table 4. 1: Statistical information of NDVI value for the years 1991, 2003, and 2021

Year	Min	Max	Mean	Std
1991	-0.45	0.68	0.065	0.118
2003	-0.5	0.66	-0.25	0.103
2021	-0.23	0.59	0.141	0.093

Where, Min = Minimum, Max = Maximum, Std = Standard deviation

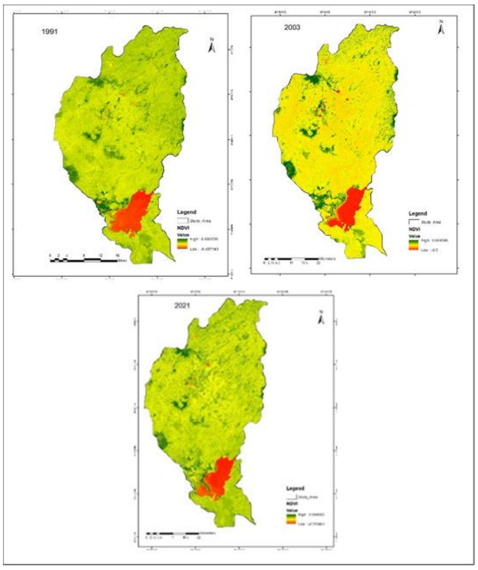

Figure 4. 1: Normalized difference vegetation index maps of the study area (1991, 2003, and 2021)

The findings indicated that, in comparison to 1991, the average vegetation cover had reduced in 2003.

4.1.2. Land Use Land Cover Classification Accuracy

Overall, the producer, user accuracy, and Kappa values were used to assess the accuracy of the classified maps. Therefore, the results of the accuracy assessment are tabulated in Table 4.2. The classified map was used for further analysis because the land use land cover accuracy was within the acceptable range.

Table 4. 2: Accuracy Assessment Result for 2021 LULC Map

		Ground truth data							
	Class name	Forest	Settlement	Bare land	Agricultural land	Waterbody	Row Total	User accuracy	KC for each Category
Classified Image	Forest land	32	0	0	0	1	33	96.97%	0.9622
	Settlement	0	29	1	6	0	36	80.55%	0.7301
	Bare land	0	4	24	0	0	28	85.72%	0.920
	Agricultural land	3	2	0	25	0	30	83.3%	0.789
	Waterbody	0	0	0	4	21	25	84%	0.877
	Column Total	35	35	25	35	22	152	100%	1.00
	Producers Accuracy	91.43%	82.86%	96%	71.42%	95.45%			

Overall Accuracy = (132/152) 86.18% Users accuracy=number correct/classified total

Overall Kappa Coefficient = 0.7521 Producers accuracy=number correct/reference total

4.1.3. Land use Land Cover Maps

From the multi-date images of 1991, 2003, and 2021, five LULC classes were created and their maps were prepared. A technique for identifying a known class of distributions as the maximum for a given statistic is called MLC. These known classes are forest lands, settlements, bare land, agricultural lands, and water bodies (Table 4.3 and Fig. 4.2). The land use/ land cover (LULC) of the study area is depicted in amount and on a thematic map in Table 4.3 and Fig. 4.2. According to the LULC classification, agricultural land dominated the landscape in the initial research period (1991), accounting for over 80.61 %, followed by forest land (6.79

%), water bodies (6.57 %), and bare land (3.81 %). Similarly, agricultural land (78.32 %) and forest land (8.17 %) covered most of the total catchment area in 2003, followed by water bodies (6.59 %), bare land (4.45 %), and settlement (2.47 %). Agricultural lands covered over two-thirds of the study area (72.20 %) in the last study period (2021), with forest lands (9.97 %), settlements (7.38 %), water bodies (6.09 %), and bare land (4.37 %). Agricultural land areas became dominant land-use types in all research periods, with 251,951 ha, 244,776 ha, and 225,665.7 ha for 1991, 2003, and 2021, respectively (Table 4.3). This increment was caused by an increase in the population, which increased the need for land for agriculture and led to deforestation in the area. Similarly, the built-up and barren land areas increased during the three study periods.

Table 4. 3: Land cover distribution for 1991,2003 and 2021

	Year					
	1991		2003		2021	
Class Name	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest land	21209.1	6.79	25536.9	8.17	31154.4	9.97
Setllement	6960.42	2.23	7731.52	2.47	23051.6	7.38
Bare land	11896	3.81	13899.2	4.45	13642.5	4.37
Agricultural land	251951	80.61	244776	78.32	225665.7	72.20
Waterbody	20521	6.57	20593.9	6.59	19023.3	6.09
Total	312537.52	100	312537.52	100	312537.52	100

Source: Computed from satellite images

(a) (b)

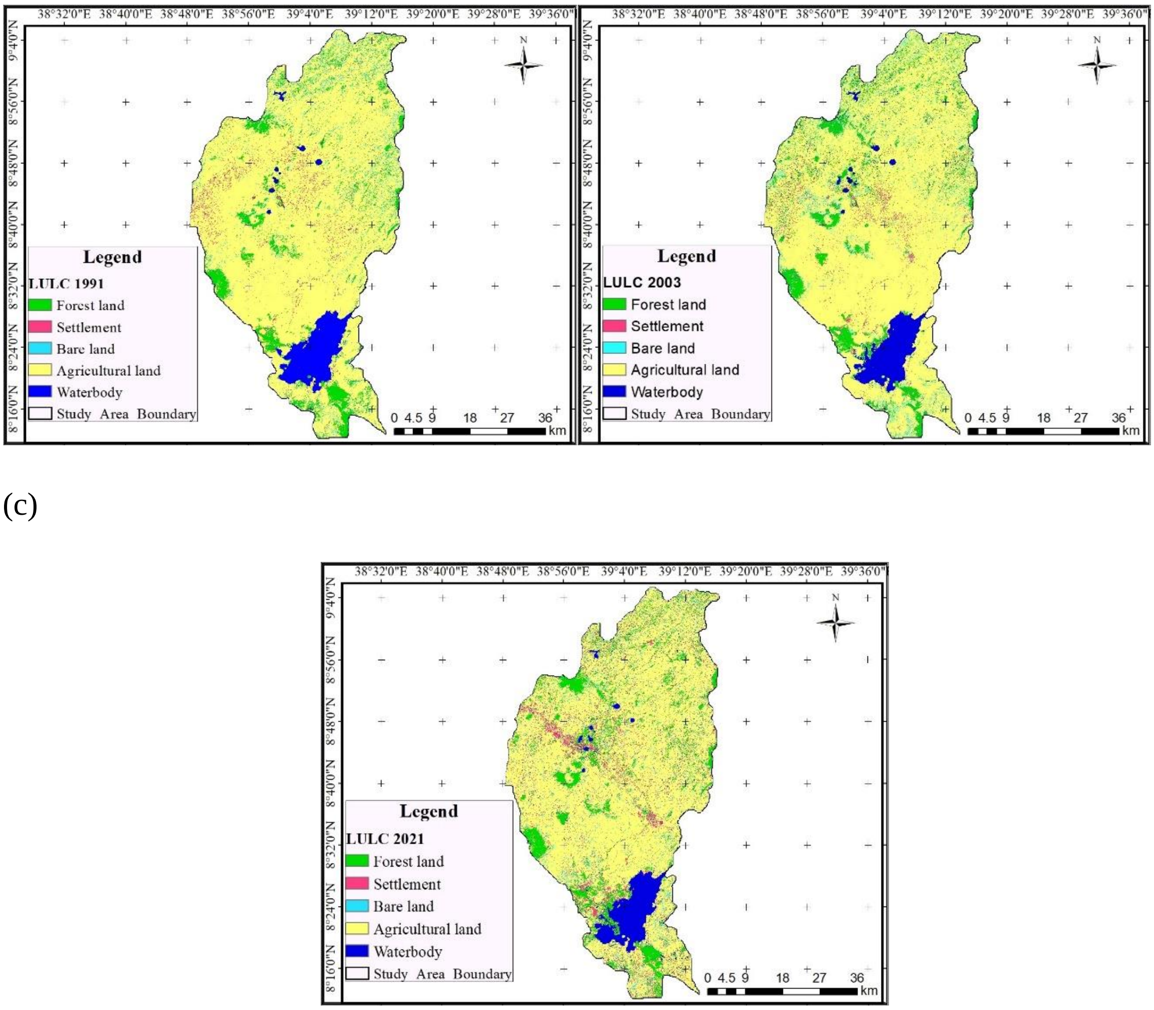

Figure 4. 2: Land Use Land Cover of Lake Koka Catchment in periods (a) 1991, (b) 2003, and (c) 2021.

4.1.4. Land Use Land Cover Change Detection

Post Classification

According to the land use and land cover classification obtained from three time periods (1991, 2003, 2021), change detection was assessed using the abovementioned methods.

Rate of change of land use land cover

The rate of land use and land cover change throughout the selected periods in the Lake Koka watershed showed periodic fluctuations.

Table 4. 4: Areal changes in 1991-2003, 2003-2021, and 1991-2021

Land cover class	1991-2003		2003-2021		1991-2021	
	[ha]	[%]	[ha]	[%]	[ha]	[%]
Forest land	4327.8	1.38	5617.5	1.8	9945.3	3.18
Settlement	771.1	0.24	15320.08	5.33	16091.18	5.15
Bare land	2003.2	0.64	-256.7	-0.08	1746.5	0.56
Agricultural land	-7175	-2.29	-19.110.3	-6.12	-26,285.3	-8.41
Waterbody	72.9	0.02	-1,570.9	-0.5	-1498.7	-0.48

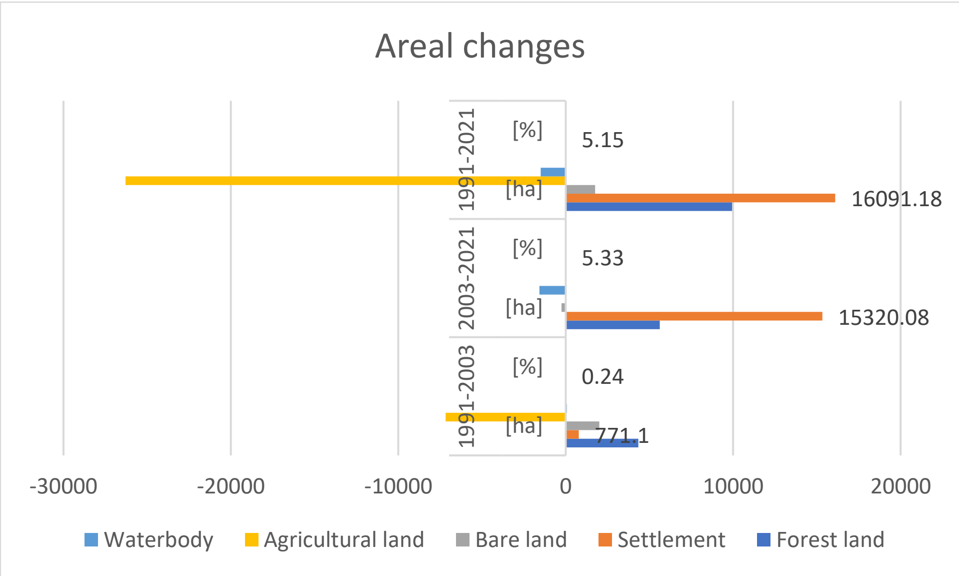

Figure 4. 3: Comparison of positive and negative changes in land cover.

The analysis of land cover change revealed that the study area has undergone considerable changes over time. Figure 4.2 depicts the land cover maps for 1991, 2003, and 2021, providing an image of the changes.

Additionally, Table 4.3 presents the areal distribution of land cover for the three years, offering quantitative insights into the changes.

Table 4.4 presents the land cover changes at three study intervals: 1991–2003, 2003–2021, and 1991–2021. Figure 4.3 shows a graphical representation of percentage changes.

Between 1991 and 2003, there was an observable increase in forest land, expanding from 21,209.1 ha (6.79% of the study area) to 25,536.9 ha (8.17%). This trend continued, with settlement growing to 23051.6 ha (7.38%) by 2021. Meanwhile, water bodies experienced a notable decline from 20521 ha (6.57%) in 1991 to 19,023.3 ha (6.09%) in 2021. The area of bare land increased from 11896 ha (3.81%) in 1991 to 13899.2 ha (4.45%) in 2003 but subsequently decreased to 13,642.5 ha (4.37%) in 2021. Agricultural land, which showed the largest cover over the years, was slightly reduced to 225,665.7 ha (72.20%) by 2021.

Table 4. 5: Transition matrix of land cover change (ha) (A)1991–2003, (B)2003-2021, (C)1991-2021.

A

		2003					
		Forest land	Settlement	Bare land	Agricultural land	Waterbody	
1991	Forest land	11702.87	0.31	403.19	9101.88	0.88	21209.13
	Settlement	216.94	1181.3	93.6	5467.68	0.9	6960.42
	Bare land	0.89	241.11	2078.44	9574.92	0.66	11896.02
	Agricultural land	13341.2	6197.04	11317.9	220631	464.72	251951.9
	Waterbody	275.02	112.23	6.15	0.86	20126.7	20520.96
		25536.92	7731.99	13899.28	244776.3	20593.86	

B

		2021					
		Forest land	Settlement	Bare land	Agricultural land	Waterbody	
1991	Forest land	11491.78	1114.64	0.13	8602.02	0.56	21209.13
	Settlement	0.44	1347.59	63.81	5547.87	0.71	6960.42
	Bare land	591.34	1081.35	1180.13	8884.44	158.76	11896.02
	Agricultural land	16435.5	19179.6	12366.5	202811	1338.53	252131.1
	Waterbody	2635.4	328.4	31.95	0.59	17524.7	20521.04
		31154.46	23051.58	13642.52	225845.9	19023.26	312717.7

C

		2021					
		Forest land	Settlement	Bare land	Agricultural land	Waterbody	
2003	Forest land	12703.1	1423.17	579.51	10831	0.01	25536.79
	Settlement	0.45	1908.48	99	5723.1	0.96	7731.99
	Bare land	1802.07	1457.28	1093.05	9276.75	270.09	13899.24
	Agricultural land	13765.6	18187.6	11833	199834	1155.49	244775.7
	Waterbody	2883.25	75.12	37.98	0.88	17596.7	20593.93
		31154.47	23051.65	13642.54	225665.7	19023.25	

The land cover transition matrices presented in Tables 4.5 (A, B, and C) provide detailed information on the transformations between different land cover classes during specific time intervals: 1991–2000, 2003–2021, and 1991–2021.

4.2. Physico-chemical parameters of Koka Reservoir

The mean (±SD) value of water temperature at the sampling sites ranged from 21.33±0.15 °C at Site 1 to 29.7±0°C at Site 3, and there was significant variation in the value of temperature among the sampling sites. This temperature difference might be due to the time of sampling and season. The water temperature recorded for Lake Koka varied from 21.33 ± 0.15°C at the open water sampling site(S1) to 29.97 ± 0°C at the near inlet of the Awash River sampling site(S3). Surface water temperatures of all sampling sites were comparable to research results reported by Lakew Wondimu (21- 26 °C; 2014) for Lake Koka.

The mean (±SD) value of EC at the sampling sites ranged from 459±0.58 µS cm^{-1} at Site 1 to 626.33±2.52 µS cm^{-1} at Site 3 ($p < 0.05$).

The mean (±SD) value of dissolved oxygen (mgL^{-1}) ranged from 8.43±0.05 at Site 2 to 9.41±0.04 at Site 1 ($p<0.05$). The mean (±SD) value of pH ranged from 9.65±0.12 at Site 2 to 10.06 ±0.23 at Site 3 ($P<0.05$).

The concentration of nutrients Ammonia, Nitrate, soluble reactive phosphate, and total phosphorus also indicated significant variation among the sampling sites. However, higher values of Ammonia and TP were found at Site 3. The concentrations of ammonia mean (±SD) (ug L^{-1}) ranged from 109.19±0.82 at Site 1 to 870.62±8.61 at Site 3 ($p<0.05$). The TP mean value in mgL^{-1} ranged from 694.8 ±14 to 809.47±42.44 at Site 3 ($p<0.05$).

Those results are nearly the same of other authors (Tigist Zewde et al.,2018, Yeshiemebet Major et al.,2018; Kassahun Tessema et al.,2020)

Table 4.6. Spatial variations of physico-chemical parameters were recorded for the sampling sites of the present study at Lake Koka (Dec. 2022).

Table 4. 6: Physico-chemical parameters and some nutrients

Parameters	**Site 1**	**Site 2**	**Site 3**
Temp. (°C)	21.33±0.15	22.4±0.17	29.7±0
ZSD/Seci. (m)	0.16±0	0.13±0	-
Turbidity (NTU)	95.03±12.94	66.2±1.95	478.33±7.02
pH	9.65±0.15	9.95±0.12	10.06±0.23
DO (mg L^{-1})	9.41±0.04	8.43±0.05	9.34±0.29
NO_2^- (nitrite (µg/l))	3.84±0.02	3.25±0.04	4.31±0.01
NO_3^- (nitrate(µg/l))	16.76±0.82	7.24±0.82	2.95±0.82
NH_4 (µg/l)	109.19±0.82	123.48±0.82	870.62±8.61
SRP (µg/l)	292.8±8.00	260.8±7.21	309.47±5.77
TP (µg/l)	740.13±15.28	694.8±14	809.47±42.44
silica (mg/l)	2.88±0.10	4.95±0.14	1.95±0.10
Chl a (µg/l)	122.07±8.17	154.14±4.08	441.94±6.17
EC (us/cm)	459.33±0.58	467.33±0.58	626.33±2.52

Sampling Sites (mean ± standard deviations, n=3)

The pH of Lake Koka was found to be slightly alkaline. In the present study, the pH ranged from 9.65 to 10.06, which is comparable to the result reported by Lakew Wondimu (2014, 6.13 – 8.6 for Koka Reservoir); Amare Shiberu *et al.,* (2017, 7.12 –7.46 for Awash River) and Nigatu Ebisa (2010, 7.29 – 8.4 for Geffersa Reservoir).

The highest turbidity (478.33 NTU) was recorded at Site 3, while the lowest (66.2 NTU) was observed at Site 3 sampling site near the inlet Awash River. The Awash River, which is heavily contaminated by uncontrolled waste disposal from nearby industrial, residential, and agricultural activities, might be the cause of the highest turbidity in the vicinity of its inlet. Excessive turbidity has an impact on filter feeders, visual predators, photosynthesis, and recreational uses. The Awash and Mojo rivers are the lake's main sources of wastewater pollution.

Dissolved oxygen is an important indicator of water quality, ecological status, productivity, and health of a Lake. The DO (mg L-1) in the present study ranged from 8.43 ± 0.05 at S2 to 9.41 ± 0.04 at S1. This finding is closely similar to the values reported for Legedadi Reservoir (10 ± 2.25, Birhanu Hailu, 2017).

The mean + SE concentration of NH4 (ug L-1) ranged from 109.19 ± 0.82 in open water to 870.62 ± 8.61 near the inlet Awash River sampling site. This might be occurring due to industrial, and municipal wastewater discharges and human excreta disposed along the course of river. High NH4 concentration is an indication of toxicity to aquatic biota and downstream users through drinking and fishing (Kassahun Tessema, 2018).

4.3. Trophic Status Index (TSI) of Lake Koka

Trophic state index values of Koka Reservoir were calculated using total phosphorus (TP) and Chl *a* data of all sampling sites based on the models developed for tropical waters (Table 4.7) (Lamparelli,2004).

(Note: S1- Open water, S2- water hyacinth infested area, S3- near inlet Awash River sampling site). The classifications of the Lake trophic state derived from the average values found in the calculations of the TSI for each sample point show a Hyper-eutrophic state at all sites (Table 4.7-).

Table 4. 7: Trophic State Indices

Lamparelli, (2004)	Sites	TP (µg L-1)	Chl-a (µg L-1)	TSI(TP)	TSI (Chl-a)	TSI of Sampling sites	Trophic status
	S1	740.1333	122.067	70.3	74.5	72.4	Hyper eutrophic
	S2	694.8	154.143	71.44	74.11	72.78	Hyper eutrophic
	S3	809.4667	441.936	76.64	75.09	75.86	Hyper eutrophic

The hyper-eutrophic state of Lake is attributed to high inputs of anthropogenic wastes (sewage), animal dung, and agricultural waste (Dar et al., 2021), leading to accelerated growth of phytoplankton (Malik et al., 2017) and macrophytic biomass. Furthermore, the higher trophic levels of the Lakes are influenced by the drastic change in LULC in the immediate catchment, mainly cultivated lands and unplanned urbanization, which generate excessive nutrient loads (Wu and Wang, 2012; Li et al., 2017; Mushtaq and Lala, 2017).

Overall, these data indicate the involvement of human activities in nutrient enrichment in lakes, including poor waste management, urbanization, and agricultural practices. The enrichment of nutrients causes algae and other aquatic plants to proliferate, which has detrimental effects on the ecological balance and water quality of lakes.

4.4. The InVEST Nutrient Delivery Ratio model

The Nutrient Delivery Ratio (NDR) model outputs include raster maps of nutrient load and nutrient export as well as a shapefile with an attribute table where results for nutrient load and export are aggregated to the watershed. In Figure 4.4 (Phosphorus baseline load per surface), red areas. show the highest phosphorus loads, which correspond to agricultural land covers and vegetated urban areas. Light red and pink areas with lower phosphorus loads cover forests and urban areas (Figure 4.4). yellow areas with much lower phosphorus loads correspond to roads and other hard surfaces, whereas blue areas with the lowest phosphorus loads are mostly covered by water or rocks (Figure 4.4).

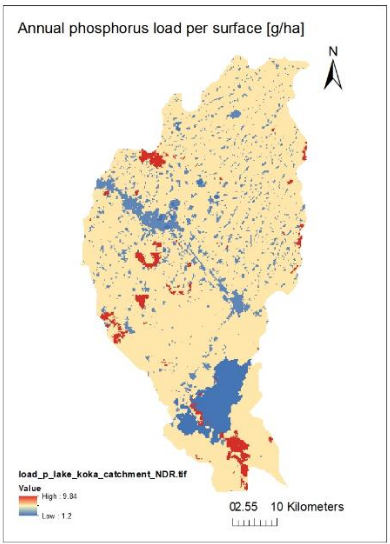

Figure 4. 4: Annual Phosphorus load [g/ha]

Below, the nitrogen load (Figure 4.5) shows a similar pattern to the phosphorus load (Figure 4.4), but the orange and yellow areas are hardly present. This indicates a bigger difference between red areas which correspond to cropland and all other land cover types (Figure 4.5).

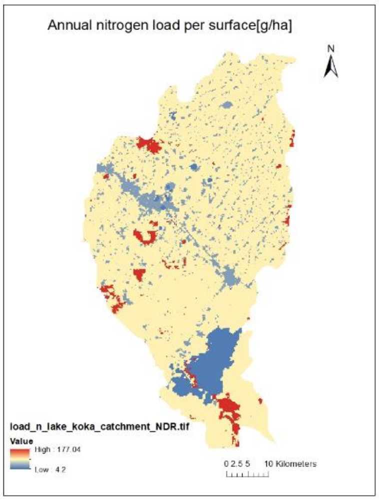

Figure 4. 5: Annual Nitrogen load [g/ha]

The highest phosphorus retention is observed downslope around agriculture and waterbodies (Figure 4.6) where nutrients from the catchment are concentrated.

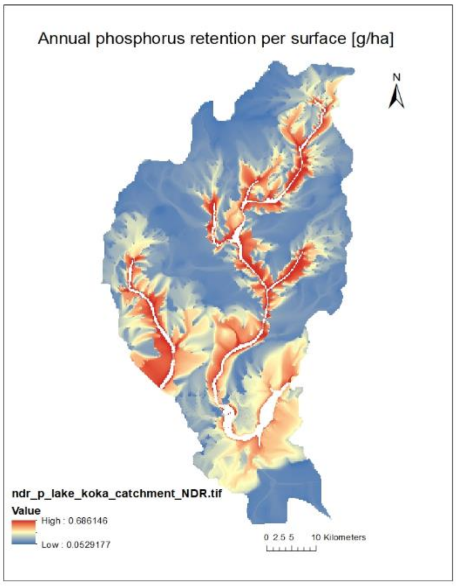

Figure 4. 6: Annual phosphorus retention [g/ha]

Nutrient retention service

The NDR model only includes a limited number of spatial-temporal variables that influence nutrient transport from land into streams (Redhead et al., 2018).

The results obtained from the NDR model are within the order of magnitude of these values: 3.63kg/ha for the nitrogen load and 0.0395kg/ha for the phosphorus load.

The total amount of nutrients retained by the watershed depends on the distribution of land use/land cover (LULC) types but is also a function of the initial nutrient load and the size of the watershed (Figure 4.6). These are important criteria to account for when deciding how and which watersheds to invest in for land restoration or conservation initiatives. The watershed retaining the most nutrients overall may not be the most productive when the retention service is evaluated per hectare or concerning the initial nutrient load.

The more land cover with a high retention efficiency value, the higher the retention in the landscape, because for each pixel, the model computes the proportion of nutrients that are not retained by downstream pixels (NDR): $NDR_{0,i} = 1 - eff'_i$ *(Sharp et al., 2017).*

4.5. Demographic characteristics of respondents

The demographic characteristics of the respondents from the districts are indicated in Table 4.8. Results from the 166 respondents indicate that of the total, 9% (n = 15) had no formal education, with 53% (n = 88) in primary school, and 23% (n = 39) accounted for middle/junior high school and above while 13% (n =21) attended high school, 2% (*n* = 3) first degree/tertiary/post-secondary and no second degree and above.

Table 4. 8: Demographic characteristics of respondents.

Respondents' Characteristics	Types	Total
Gender	Male 155	166
	Female 11	
Education	No formal education	15 (9%)
	Primary school	88 (53%)
	Middle school/ Junior high school	39 (23%)
	High school	21 (13%)
	First degree/Tertiary/Post-secondary	3 (2%)
	Second-degree and above	0

4.6. Ecosystem service (ESs) of Lake Koka

Respondents' views towards provisioning, regulating, cultural, and supporting ESs of Lake Koka were assessed using seventeen items (Table 4.9): 8 provisioning services, 3 regulating services, 2 cultural, and 4 supporting services. Respondents rated the highest score for provisioning services such as fish (food), irrigation, and livestock watering. The ratings of the respondents' views of the lake's ESs are provisioning services, regulating services, cultural services, and supporting services respectively.

Table 4. 9: Benefits from Lake Koka ESs

Lake ESs	Percent								
	1	2	3	4	5	M	SD	Mdn	Mo
Direct Benefits									
Agricultural production	1.2	3.6	20.5	31.3	43.4	4.12	0.94	4	5
Fisheries	0.6	2.4	20.5	43.4	33.1	4.06	0.83	4	4
Trees for timber	0.6	1.2	13.9	38.6	45.8	4.28	0.79	4	5
Fuelwood			9.6	41	49.4	4.40	0.66	4	5

Herbal/medicinal plant	0.6	1.2	4.2	44	50	4.42	0.69	5	5
Reeds		1.8	6	54.8	37.3	4.28	0.66	4	4
Water		1.8	4.8	66.9	26.5	4.18	0.60	4	4
Tourism		1.8	4.8	44	49.4	4.41	0.67	4	5
Scientific interest		2.4	3.6	33.1	60.8	4.52	0.68	5	5
Transport		1.8	6	38.6	53.6	4.44	0.69	5	5
Sand mining	0.6	1.2	6	22.3	69.9	4.60	0.71	5	5
Indirect Benefits									
Water reservoir	0.6	2.4	4.8	38	54.2	4.43	0.75	5	5
Water source		1.8	5.4	30.1	62.7	4.54	0.68	5	5
Biodiversity reservoir	1.8	8.4	19.3	42.2	28.3	3.87	0.98	4	4
Protected species (e.g. hippopotamus)		6	8.4	51.8	33.7	4.13	0.81	4	4
Mitigation of climate change		4.8	9	33.1	53	4.34	0.84	5	5
Flood control		6.6	13.3	37.3	42.8	4.16	0.90	4	5

Note: 1 = Very unimportant, 2 = Not important, 3 = Neutral, 4 = Important, 5 = Very important, M = mean, SD = standard deviation, Mdn = median, Mo = mode

Regarding the participants, the primary fish species that are being targeted in Lake Koka are Nile Tilapia (*Oreochromis niloticus)*, African Catfish *(Clarias gariepinus*), common carp (*Cyprinus carpio*), and *Labeobarbus intermedius*, known locally as ʼKoroso', 'Ambaza', 'Duba (Geja)/Abasamual' and 'Nechasa (Bilcha)', respectively.

Human pressures such as overexploitation, habitat deterioration, pollution, etc., endanger these resources, which sustain the livelihoods of fishing communities. Additionally, FGDs noted that Lake Koka's fish productivity is decreasing and has become unreliable in maintaining the poor community's income-generating activities. For instance, most participants stated that although *some locals depend on fishing for their living, fishing is unregulated. Fish output is thus* *steadily declining, and certain fish species are vanishing from the lake. Using water from the lake for irrigation farming comes next to fishing.* As noted by the vast majority of respondents local populations use the lake's provisioning services for commercial and subsistence needs. Lake Koka's ES benefits to the local population were also investigated during FGDs. Participants in the discussion said that local vegetables such as tomatoes, peppers, cabbage, and onions, and crops such as wheat, bean, barley, teff, corn, fruits such as watermelon, etc. are important local items that are grown with the help of this lake's water and shipped all across the country. Participants in the survey also indicate that sand, reeds, and some medicinal plants found are utilized in the area surrounding the lake. For instance, Regarding the advantages that the lake has provided for the community, Participants recapped the advantages by stating: *"A few of us sustain for our families by fishing on this lake. Additionally, it offers advantages to those without jobs. Our animals drink the lake water. Some residents make their living by cooking fish to sell around the lake, a practice particularly practiced by women. On the shores of this lake, local groups also carry out spiritual and religious activities(waqefaanna)."*

4.7. Degradation impacts

Numerous respondents strongly believe that free and easy access to lake provisioning services for the local communities has exacerbated the lake's condition. They believe the causes are deforestation, industrial expansion, agricultural expansion, etc. According to the data, the key influences on lake sustainability were local human activities. Participants, for instance, described these effects by stating, "*The lake is free to use for everyone. The lake is being significantly impacted by the growth of agriculture in the surrounding area. The lake is under strain from a growing population in the area in several ways. For instance, the lake is currently being polluted by wastes from industries, urbanization, and chemicals coming out of agriculture/farms. We used to utilize the lake's water for drinking and household purposes, but the lake's extreme pollution worries us now. Nevertheless, thus far, the issues surrounding the lake have no bearing on the local government or community.* The vast majority of respondents, however, were unaware of the current legislative guidelines governing lake maintenance and usage. Nearly all of the survey respondents also saw that local governments fail to notify the communities when regulations are in place to assist them in managing the lake.

4.8. Preferred level of management

The respondents indicated different priorities for Lake Koka's optimal management in the future. To achieve these different priorities, the management team must consider a variety of factors, such as the lake's ecological health, recreational use, and potential for economic development. By taking these factors into account, the management team can develop a comprehensive plan that balances the lake's competing priorities and ensures long-term sustainability for future generations. The majority of respondents ranked developing a "preferred level of lake management" as a "high priority." By protecting from intensive farming and grazing, protecting from overfishing, protecting from chemical run-off from nearby industries and destructive activities, and plantation of new trees in the degraded areas of the lake catchment. One effective method for preserving the environment around the lake is by implementing sustainable farming practices, reducing the number of livestock, preventing pollution from factories and other sources, and reforesting the damaged areas in the lake's watershed. Another strategy for preserving the environment around the lake is by promoting eco-friendly tourism, encouraging local communities to participate in conservation efforts, and monitoring and regulating the use of pesticides and other harmful chemicals in the area.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions

The current study assessed the ecosystem service of Lake Koka in relation to land use and land cover changes. The conclusion drawn from the study was as follows:

The change in LULC covers the study period from 1991 to 2021. From the result, the settlement and Forest land have been significantly increased from time to time. During the same period significant reduction in waterbody and agricultural land occurred.

According to the physicochemical and trophic state index features, the water quality of Lake Koka is currently extremely polluted. Domestic, industrial, agricultural, and other urban wastes from point and non-point sources could cause this problem. According to the WHO and EU's recommended standard values, the lake's water is unfit for drinking or domestic use without treatment.

The Lake Koka ESs promote socioeconomic growth both locally and nationally. Ecosystem services of many kinds, including provisioning, regulating, cultural, and supporting ones, are offered by Lake Koka. Nonetheless, the lake's ESs are mostly concerned with service provision. But at the moment, anthropogenic pressures are having an effect on the lake and the long-term viability of its ESs provision. To preserve the long-term viability of the lake's ecosystem services, it is essential to address the anthropogenic pressures that are currently affecting it.

5.2. Recommendations

To control and reduce the threats of the lake and its catchment, the following recommendations are forwarded,

- Creating awareness of the local community on sustainable ecosystem services utilization
- Protecting the lake shore through developing buffer zone
- Controlling point and non-point sources of pollutants.

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APPENDICES

Appendix 1: Questionnaires

Survey Questionnaire

Ecosystem Service Dynamics of Lake Koka in Relation to Land Use/Land Cover Changes

Date of interview: ………………………………………………….

Name of enumerator ………………………………………………..

Background Information

I would like to ask you some questions that would assist you, other local communities, and the government in determining how to improve the ecosystem services status of Lake Koka.

As you are already aware, your perception and observation regarding the lake and your choice of various management options affect the ecosystem service contribution and improvement of the catchment of the Lake. So you are kindly requested to give information on your perception and observation of the Lake Koka ecosystem and to select your most preferred catchment management options. The information you provide will be essential to estimate how much the ecosystem is valuable to the country in general and to your community in particular to have a common understanding of the problems of the area.

These questions usually take about 15-30 minutes. We are interviewing a sample of about 384 of the local community around Lake Koka, so your input is considered very valuable to this survey. The information you give will be treated as confidential.

Section: 1.

Direct and indirect ecosystem services

A. How far do you live from the Lake Koka ecosystem?

1. in less than 100 meters near the reservoir

2. More than 100 meters from the reservoir

B. Please indicate which benefits you are aware of, which are from the Lake Koka catchment and are of importance to your household. ***Use the following score***:

1 = Very unimportant 3 = Neutral 5 = Very important

2 = Not important 4 = Important

DIRECT BENEFITS	**Aware 1=Yes, 2=No**	**1**	**2**	**3**	**4**	**5**
Agricultural production						
Fisheries						
Trees for timber						
Fuelwood						
Herbal/medicinal plant						

Reeds						
Water						
Tourism						
Scientific interest						
Transport						
Sand mining						
INDIRECT BENEFITS	**Aware Yes =1,No =2**	**1**	**2**	**3**	**4**	**5**
Water reservoir						
Water source						
Biodiversity reservoir						
Protected species (e.g. hippopotamus)						

Mitigation of climate change						
Flood control						

Land use in Lake Koka system

a. Do you own land near the lake?

1. Yes 2. No

b. Do you have agricultural land somewhere else than near the lake?

1. Yes 2. No

c. What is your total land holding size? ………………….ha

d. What is the land size under cultivation? …………………ha

e. What are the crop types grown near the lake on your land? ………………

Section: 2.

General information about access and use of Lake ESs

1. How many kilometers/meters is your home far from Lake Koka? _________________

2. For what purpose are you using Lake Koka? (Multiple choices are possible).

A. Source of drinking ________ B. Irrigation __________

C. For fishing _________ D. Recreation _________

E. Educational, research, and cultural contribution

F. As a source of agricultural land G. Others (please specify) ______________________

3. Lake Koka ecosystem has been extremely degraded and many plant and animal species have disappeared.

1. Strongly agree 2. Agree 3. Undecided 4. Disagree 5. Strongly disagree

4. If your answer to question number 3 is agreed, what are these species that have disappeared extinct?

Animals	Plants
……………………	1. ……………………..
……………………	2. ………………………
…………………….	3. …………………….....

Fish species	Birds
……………………..	1. ………………………
……………………..	2. ………………………
…………………….	3. ………………………

Section: 3

ES benefits and degradation impacts

Part 1: communities' attitudes towards the protection of the Koka reservoir system

1. For what purpose are you using Lake Koka? (Multiple choices are possible).

A. Source of drinking ________ B. Irrigation __________

C. For fishing _________ D. Recreation _________

E. Educational, research, and cultural contribution

F. As a source of agricultural land G. Others (please specify) ______________________

2. What do you think the protection of the Koka reservoir system is to you?

1. Very important 3. Less important

2. Important 4. Not important at all

3. To what extent do you perceive the current status of Koka reservoir is an issue worth discussing?

1. Critical 4. Less serious

2. Very serious 5. Not important

3. Serious

4. Do you think the Koka reservoir system can deplete/deteriorate?

1. Yes 2. No

5. What do you think are the major factors for the degradation of this ecosystem?

1. Deforestation_____ 2. Industrial expansion ______ 3.Agricultural expansions _______ 4. Resettlements ______ 5. Climate change/global warming ________ 6. Other factors (please specify) ______

Part 2: coping strategy

a. Are you or any person in the household a member of a group of environmental interest?

1. Yes 2. No

Answer this question (b) only if you got no to question (a) above

b. Have you or any person in the household been employed in conservation activities?

1. Yes 2. No

c. Do you have access to tap water?

1. Yes 2. No

3. If yes, how long does it take to go to that water source from your residence? …………

d. Do you have access to electricity? 1. Yes 2. No

e. How far do you live from the nearest market?

1. Less than 500 metres

2. More than 500 metres

f. How far do you live from the nearest main road?

1. Less than 500 metres

2. More than 500 metres

g. How many visits do you receive per month from the officer in charge of the environment? ……

Part 3: Preferred level of management (Koka lake/watershed)

Who can manage the catchment?

Family

a. Strongly disagree **b**. disagree **c.** neither agree or disagree **d.** agree **e.** strongly agree

Community

a. Strongly disagree **b**. disagree **c.** neither agree or disagree **d.** agree **e.** strongly agree

Government

a. Strongly disagree **b**. disagree **c.** neither agree or disagree **d.** agree **e.** strongly agree

What measures should be taken to improve the Lake Koka ecosystem in quantity (area coverage) and quality? (Multiple choices are possible)

a) It should be protected from intensive farming and grazing.

b) It should be protected from overfishing.

c) It should be protected totally from chemical run-off from nearby industries and destructive activity.

d) Plantation of new trees in the degraded areas of the lake.

e) Others (please specify)

Section 4: Other Information

“We will soon be ending this interview. Before we end it, I would like to ask some questions about you and your family.”

1. Are you

a. Male **b.** female

2. What is your age?

a. Under 24 **b.** 25 to 34 **c.** 35 to 44 **d.** 45 to 54 **e.** 55 to 64 **f.** Over 65

3. What is your highest level of education?

a. No formal education **b**. Primary school **c.** Middle school/ Junior high school **d.** High school

e. First degree/Tertiary/Post-secondary **f.** Second-degree and above

4. What is the highest level of education of the most educated member of your household?

a. No formal education **b**. Primary school **c.** Middle School/ Junior high school **d.** High school

e. First degree/Tertiary/Post-secondary **f.** Second-degree and above

5. How many people (children and adults) live in your household? ……………….

6. How many people in your household contribute to the household income? …………………………

7. Land: Mean farm plot size: Mean of two reported farming parcels in hectares

……………………………………

8. How much was your last year's total household income from all sources?

A. less than Birr 1000 **b.** between Birr 1000 and 2000 **c.** between Birr 2000 and 3000 **d.** between Birr 3000 and 4000 **e.** between Birr 4000 and 5000 **f.** More than Birr 5000

9. How much of your last year's total household income do you think came from Lake Koka area activity?

Birr …………………………………………

"Thank you for your contribution to this survey. We hope to use these results to determine how best to provide affordable and desirable management of ecosystem services degradation problem of the Koka Reservoir/lake area. We promise to contact you if we need additional information"

Appendix 2: Focus Group Discussions

Focus Group Discussion Questions

What are the most important ecosystem services from the four categories?

Provisioning services

Regulation services

Supporting services

Cultural services

Appendix 3: Checklists for Ecosystem Services

Checklists for ecosystem services

Provisioning services		Remark
Crops (maize, Teff)		
Vegetables (potatoes, onions…)		
Fruits (Ficus sp., Phoenix reclinata…)		
Fish		
Honey		
Drinking water for animals		
Water for domestic use (bathing, washing, cleaning)		
Drinking water for humans		
Water for irrigation		
Firewood		
Fodder and grazing services		
Craft materials (for mattress etc)		
Seedling raising		
Sand		
Medicinal plants		
Regulation services		
Microclimate regulation		
Runoff and erosion regulation		

Water regulation (flow)		
Water purification		
Sediment retention		
Carbon sequestration		
Pollination		
Disease control		
Cultural services		
Recreational services		
Spiritual services		
Educational and research services		
Supporting services		
Biotic conservation (nursery and refugium) services		
Nutrient cycling		
Soil formation (accumulation of organic matter)		

✓ indicates the presence of an ES; blank indicates the absence