
COLLEGE OF DEVELOPMENT STUDIES

CENTER FOR FOOD SECURITY STUDIES

# EFFECT OF LAND USE LAND COVER CHANGES ON RIVER WATER QUALITY AND HOUSEHOLD FOOD PRODUCTION IN LITTLE AKAKI RIVER CATCHMENT, CENTRAL, ETHIOPIA

BY

BIRUK WOLDE

SEPTEMBER, 2023

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BY

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A THESIS SUBMITTED TO CENTER FOR FOOD SECURITY STUDIES, COLLEGE OF DEVELOPMENT STUDIES, ADDIS ABABA UNIVERSITY, FOR PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOOD SECURITY AND DEVELOPMENT STUDY

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## Declaration

This thesis is my original work and has not been presented for MA/MSc degree in any other University and that all the sources and materials used for the thesis have been properly acknowledged.

Declared by: Biruk Wolde Gonfa

Signature: _____

Date: _____

Place: Addis Ababa University College of Development Studies, Center for Food Security Studies

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge as an advisor.

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As advisor of the thesis, I certify that I have read and evaluated the thesis prepared by Biruk Wolde Gonfa under my guidance, entitled "***Effect of land use land cover changes on river water quality and household food production in little Akaki river catchment Central, Ethiopia***" and I recommend that for open defense as fulfilling the requirements for the degree of Master of Science in Food Security and Development.

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Samuel Assefa(PhD) _____ _____

Co- advisor Date Signature

As a member of examining board of this thesis open defense, we certify that we have read and evaluate the thesis prepared by Biruk Wolde Gonfa under my guidance, entitled "Effect of land use land cover changes on river water quality and household food production in little Akaki river catchment Central, Ethiopia "recommend that it is acceptable as thesis required for the degree of Master of Science in Food Security and Development.

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Chairperson of the Center or Graduate Program Coordinator

## Dedication

I dedicated this thesis to my beloved father Wolde Gonfa Gurmessa (Abako) who had real heart to his family and others. Dear Abako we your family do understand and love you!

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First and foremost, I would like to express my sincere gratitude to Jesus, the Son of the Lord, for guiding my path and being with me every step of the way.

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BIRUK WOLDE GONFA

SEPTEMBER, 2023

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## Abbreviation

| | |
|---|---|
| ANOVA | Analysis of Variance |
| Cd | Cadmium |
| Cr | Chromium |
| CSA | Central Statistics Agency |
| DO | Dissolved Oxygen |
| EPA | Environmental Protection Authority |
| ETM | Enhanced Thematic Mapper |
| FAO | Food and Agriculture Organization |
| GCP | Ground Control Point |
| Ha | Hectare |
| ILRI | International Livestock Research Institute |
| IWMI | International Water Management Institute |
| Kg | Kilogram |
| KII | Key Informant Interview |
| HH | Household |
| LULC | Land Use Land Cover |
| Mg/L | Milligram per Liter |
| MLC | Maximum Likelihood Classification |
| OLI | Operational Land Imager |
| OWNP | One Wash National Program |
| Pb | Lead |
| PCC | Post Classification Comparison |
| pH | Power of Hydrogen |
| PLI | Pollution Load Index |
| RI | Ecological Risk |
| S | Sampling site |
| $Km^2$ | Square Kilometer |
| TDS | Total Dissolved Solids |
| TM | Thematic Mapper |
| UN | United Nation |
| UNFPA | United Nation Food Program Aid |
| USGS | United State Geological Survey |
| UTM | Universal Transverse Mercator |
| WFP | World Food Program |
| WGS | World Geodetic System |
| Zn | Zinc |

## Abstract

*The study area is located where urban and peri-urban agriculture practiced, urbanization expanded and land use changes observed. The overall objective of this research is to investigate the effect of land use land cover changes on river water quality and household food production in Little Akaki river catchment, central Ethiopia. To classify land use classes, supervised Maximum Likelihood Classification were used. Ten water sampling sites were selected using a purposive sampling procedure to assess water quality parameters. Additionally, eight key informants were interviewed for valuable insights. Data were gathered from USGS satellite imagery, field observations, secondary sources, and key informant interviews. Change detection were used to analyze the land use land cover change. Time series plot were used to see the water quality trend. Multiple linear regression and Pearson correlation were used to examine the land use classes that affect river water quality and household food production. Furthermore, paired t-test were used to examine the significance of water quality parameters. The maximum likelihood classification and change detection revealed that seven land use classes for the last three decades were identified using Arc GIS 10.7.1. The overall accuracy was 96% (1994) and 94.56% (2023). The settlement and buildup area faced the most significant change, in 1994-2023 with 27.25% (109.86km2) and 7.43% (29.97km2) during 2019-2023 showing increase of urbanization and industrialization process which has a significant effect. The time series plot revealed that there is significant change in river water quality parameters. The physio-chemicals decreased, Temperature by $0.0955^0c$, Power of Hydrogen=0.054, Dissolved Oxygen=0.0964, Total Dissolved Solids=163.77, Salinity=537.048, Chromium=0.0569, Cadmium=0.00476, whereas Turbidity=518.6, Lead=0.1671 and Zinc=0.09534 has increased. The multiple linear regression revealed that all land use classes have strong positive significant correlation with water quality indicators, whereas water body has strong negative correlation with dissolved oxygen. Furthermore, results revealed that decrease in crop land affected their household food production and livelihood. The study conclude that land use land cover change has outstanding effect on river water quality and Household food production. Finally, the research recommended enhancing regulation and enforcement, improving public awareness, prioritizing low impact development strategies, promoting agricultural initiatives, implementing water harvesting system and conservation, developing comprehensive land use plan,*



**Keywords: Change detection, Land use land cover change, Multiple linear regression, River water quality.**

# CHAPTER ONE: INTRODUCTION

## 1.1 Background of the study

Land use is the way in which land has been used by human actions and their habitats such as agriculture, settlements, industry while Land cover refers to biophysical characteristics of the Earth's surface such as vegetation and water body. The expansion of urban land usage results in a rise in metal levels and their fluctuation over time in storm water runoff, as reported by Taka et al. (2022). Studies have shown that natural and human activities have resulted in Land Use and Land Cover Changes (LULCC) which affects the services provided by the riparian ecosystem services (Chu et al., 2013; Wagner et al., 2013; Khan et al., 2017). These changes also affect the ability of biological systems to support human needs and determine, in part, the vulnerability of places and people to climatic, economic and socio-political perturbations (Lambin and Geist, 2006). Anthropogenic activities such as agriculture, deforestation and urbanization have been identified as the main drivers LULCC which affects the quality of water bodies and food production (Khan et al., 2015). These activities singularly or jointly impact the quality of water resources.

About three-fourth of the Earth’s land surface has been altered by humans within the last millennium. Successfully tackling global sustainability challenges such as climate change, biodiversity loss and food security depends on land use change, since it strongly affects carbon sources and sinks, causes habitat loss and underpins food production (Martinez et al., 2014). Surface water resources around the world are under increasing threats of pollution especially rivers (Mul et al., 2015). River water quality deterioration is one of the critical challenges facing many countries across the globe (Biswas., 2019; Boretti et al, 2019). Estimates show that about 40% of the river systems in the world have been polluted (Bi et al., 2018). River water pollution is one of the several critical issues facing the world in both developed and developing countries(Chaudhry and Malik, 2017).

The LULCC within a watershed has a great impact on the water quality and quantity of rivers which can reduce food production (Li et al., 2014). Therefore, the knowledge of the relationship between LULCC, river water quality and food production helps in identifying threats to water quality and food production. Identifying this relationship is relevant for effective and sustainable

river water quality management and food production especially in minimizing the pollution loads in the water body (Ding et al., 2015). Over the years the natural resources and ecosystems of Sub-Saharan countries have been modified through a broad array of land uses. Consequently, land use intensification will continue to support the growing population, affecting some of the most environmentally important ecosystems such as rivers.

Like many other developing countries, significant land cover changes have occurred in Ethiopia since the last century mainly in connection with the population increase and due to land use changes, including deforestation, over grazing, and improper cultivation of agricultural land which led to accelerated soil erosion and associate soil nutrient deterioration (Eleni et al., 2013). Furthermore, according to the UN human settlement program, urban population is expected to grow by 3.98% per year on average (UN-HABITAT, 2007). In Ethiopia, almost 90% of the country's medium and large scale industries are established in Addis Ababa city along with Akaki river basin (Africa Enterprise Survey, 2011; Ethiopian Science and Technology Minister, 2008).

Addis Ababa has experienced urban agglomeration due to rapid population growth (Terfa et al., 2019). Due to rapid population growth, industrialization, and other natural and human activities, LULCC of the city is changing (Feyissa et al., 2014). Expansion of built-up area and decline of vegetation cover land, surface temperature and urban heat island were increased from time to time in the city (Teferi and Abraha, 2017). Transformation of agricultural lands into urban areas has greatly affected the food production and river as a result of inappropriate practices of dumping domestic and industrial wastes (Terfa et al., 2019).

Little Akaki river catchment, where this study is conducted, is one of the prominent places experiencing with rapid land use changes which is originated from the Entoto Mountain chains and flow down to the man-made Lake, the Aba Samuel water reservoir, at the lower end of the City (Gebre and Rooijen, 2009; Beyene et al., 2009). The coverage status of forest land decreased by 0.62% since 1985-2011 this is because of very intense and high deforestation. According to Worako (2016) Land absorption coefficient increased from 0.002-0.009 showing expansion of town in the basin and urban population pressured due to industrial, urbanization and commercial center expansion. The land use land cover change of agricultural areas had

reduced from 64.27% in 1985 to 56.28% in 2015 due to the conversion of the land mass into the urban areas (Worako, 2016). This study focuses on LULCC effects on river water quality and household food production in little Akaki river catchment.

## 1.2 Statement of the Problem

Expansion of industries along river side and wastes from domestic and industries are polluting the quality of the river. According to Samuel et al. (2004) societies in the Akaki catchment areas are seriously vulnerable to family health since they use the polluted river water for smallholder farming, drinking, and other domestic activities. Because of poor quality wastewater cause disruption in crop growing, leave traces of foodborne diseases or residues of toxic substances, which cause animal diseases for livestock, fish and sea-life in the short and/or long run, and affect human health (Woldetsadik et al., 2018), which has a negative impact on food security. According to Abdulshikur (2007) the river is highly polluted under low water flow.

The rapidly growing population size increased urbanization and industrialization have led to inappropriate use of land and degradation of natural resources. In Little Akaki river catchment the coverage status of forest land decreased by 0.62% since 1985-2011 this is because of very intense and high deforestation. According to Workato (2015) land absorption coefficient increased from 0.002-0.009 showing expansion of town in the basin and urban population pressured due to industrial, urbanization and commercial center expansion.

Lack of proper enforcement of urban land use policies, largely due to institutional capacity constraints, is responsible for the expansion of informal settlements, urban sprawl and land use fragmentation (Cobbinah et al., 2015). The main drivers of land fragmentation are regulatory and institutional which means that without a strong institutional framework, urban and peri-urban land use integration or boundary delineation can be difficult (Hommann and Lall, 2019). Institutional capacity and coordination are also vital. The ability to respond to most efficient land utilization challenges depends on capable institutions (Page et al., 2020).

The Little Akaki river receives organic and inorganic pollutants from various anthropogenic sources where most of inorganic pollutants such as toxic heavy metals released into the river are eventually adsorbed and settle in the sediment. As heavy metals cannot be degraded, they are

continuously being deposited and incorporated in water, thus causing heavy metal pollution. Based on evidence from researches on selected heavy metals (Zn, Cr, Cd and Pb) using various indices, the little Akaki river has registered highest concentrations of heavy metals Zn (78.96 mg/kg); Cr (2.19mg/kg); Cd (2.09mg/kg) and Pb (30.92mg/ kg) and contamination factor values indicated that the sediments were moderate to very highly contaminated with toxic Cd and Pb (Mekuria et al., 2021).

There are a number of previous studies conducted on little Akaki river catchment. A research conducted to determine the existing LULCC in various years by using remote sensing data of Akaki river catchment (Woldesenbet, 2015), sediment enrichment with heavy metals, pollution load and potential ecological risks in downstream (Mekuria et al., 2020), sediments were limited to the assessment of the concentrations and distribution of some selected heavy metals (Gizaw, 2018; Nigussie et al., 2013) and distribution and ecological risk in the sediments of Akaki catchment areas (Berhanu et al., 2018) and towards improving food security in urban and peri-urban areas to identify the food provisioning capacity of the agricultural lands, to locate suitable areas for urban, peri-urban and food provisioning to assist future land-use planning decisions (S. Nigussie et al., 2020).

However, there is a research gap that correlate the LULCC with river water quality and food production. The contribution of institutional/policy factors to LULCC are not well addressed. Particularly effect of land use and land cover changes on river water quality and household food production had not been studied. Therefore, this research aimed to fill the gap through investigating the effects of LULCC on water quality and food production.

## 1.3 Objectives of the study

### 1.3.1 General objective

The general objective of the study is to investigate the effect of land use and land cover changes on river water quality and household food crop production in little Akaki river catchment, central, Ethiopia.

### 1.3.2 Specific objectives

The specific objectives of the study are to:

1. Assess the dynamics of land use and land cover changes
2. Examine the effect of land use and land cover changes on river water quality
3. Analyze the effect of LULCC on household food crop production

## 1.4 Research Question

1. What are the dynamics of LULCC in the study area?
2. Is the LULCC affect the river water quality of study area?
3. How did land use and land cover changes affect household food production in the study area?

## 1.5 Scope and Limitation of the study

This study is limited to Little Akaki river catchment, and it only focuses on analyzing the effect of land use and land cover change on river water quality and household food production. Since there is lack of empirical data of river water quality in physical, chemical and biological river water quality analysis parameters it is restricted to only on effect of few physiochemical and heavy metal parameters. The food crop production data for all of those land use changes years are not available for the specific catchment, so it is restricted to stories of key informant. The number of key informant interview institutions was restricted to small size because of limitation of resources.

## 1.6 Significance of the Study

The findings of this study can contribute to the strengthening of the existing knowledge regarding the topic and helps to conduct further interventions and also be used in the guiding of policy makers, local government staff, industries, local communities, researchers and educators at various regional, national and international levels. For policy makers and local government staff, the result of this research will help to design, and promote alternative water management systems such as rainwater harvesting and recycled wastewater and thereby reducing pollution in

the study area (Blinco et al., 2017). Increasing the food production on limited farmland size by small scale irrigation using the harvested rainwater and recycled wastewater for urban and peri-urban agriculture. For the local communities it will involve their participation and the policy and other intervention approaches that may undergo can directly help make sustainable ecosystem services for future generations using integrated approaches in river water quality and food crop production.

## 1.7 Ethical consideration

Studies are guided by ethical consideration in order to protect the rights of participants in the study area, safeguard against immoral research activities (e.g. personal gain of researchers at the expense of the participants) and conduct a proper scientific investigation. In case of data collection, ethical considerations were seriously taken into account to ensure the protection, integrity, anonymity, confidentiality, honesty, continuity and consents and other human elements of the informant. The respondents were not identified by names and their consent were required during interview. Initially, the researcher had taken ethical clearance certificate from College of Development Studies that fulfill Addis Ababa University ethical procedure. Secondly, study prepared consent that fully inform the participants about the purpose and objective of the study so as to avoid erroneous perception of the study based on the University ethical procedure. The procedure and the total duration of the interview were also clearly explained. The consent had encouraged participants to positively cooperate and give honest and unbiased answers. Therefore, the researcher believes that the information gathered through the key informant interviews are correct and relevant.

## 1.8 Organization of the study

This study has five chapters. Chapter one presents the background of the study, statement of the problem, objectives of the study, research questions, significance and limitation of the study. Chapter two deals with theoretical, empirical and conceptual literature reviews related to land use and land cover changes, river water quality and household food production as well as conceptual frame work for the study. Chapter three describes the study area, research design, sampling method, method of data collection and analysis. Chapter four presents the results of the

study and discusses the main findings. Finally, chapter five presents conclusion and recommendations.

# CHAPTER TWO: LITERATURE REVIEW

This section focuses on review of literature on LULCC, river water quality and household food production. The chapter also reviews the conceptual framework for this study, which is studied from the theoretical and empirical literatures perspectives that are used in investigating the effect of LULCC on river water quality and household food production.

## 2.1. Conceptual literature reviews

The theoretical framework for this study is based on the Land Change Science (LCS) theory. The LCS theory provides a conceptual framework for understanding the dynamics of land use and land cover changes, their drivers, and their environmental and socio-economic consequences. It emphasizes the interconnectedness between land use changes, river water quality and household food production. By adopting the LCS theory, this study aims to investigate the relationships between land use and land cover changes, river water quality and household food production.

The LCS theory offers a comprehensive framework to analyze the complex interactions among land use and land cover changes, river water quality, and household food production. It allows for a systematic exploration of change and their implications for both natural ecosystems and human livelihoods. By utilizing the LCS theory, this research seeks to uncover the factors that contribute to change in land use patterns and assess their impacts on river water quality and household food production.

### 2.1.1 Land use land cover change

Land use is the term used to describe the human use of land. Land use by humans has a long history, first emerging more than 10,000years ago as archaeological assessment reveals earths early transformation through land use (Ellis et al., 2016). Land cover change denotes a change in certain continuous characteristics of the land such as vegetation type, soil properties, and so on, whereas this involves the transformation in the natural landscape due to urban growth. Land use change is alteration in the way certain area of land is being used or managed by humans (Patel et al., 2019). It is mainly driven by urban growth and is particularly important now for developing and underdeveloped countries. However, natural causes may result in land cover change, but

land use change requires human intervention (Joshi et al., 2016). It is interesting to note that this change is responsible for a number of local and global effects, including biodiversity loss and its associated effects on human health, and the loss of habitat and ecosystem services (Crossley et al., 2019).

LULCC is a term used for the modification of the earth terrestrial surface by humans, mostly the results of an interaction between natural and anthropogenic processes (Rawat, Kumar 2015; Dinka, 2012). Particularly, the anthropogenic processes are the major driving force in shaping LULCC Rawat, Kumar (2015) and are significantly changing the Earth surface, resulting into an observable changing pattern in the LULC over time (Barlow et al., 2018; Dinka, 2012).

### 2.1.2 Concept of river water quality

River water quality refers to the physical, chemical and biological characteristics of water found in rivers. It is an important aspect of environmental assessment and management, as it directly impacts the health of aquatic ecosystems, human population and various water uses as drinking water supply, agriculture and recreational activities. The physical characteristics are temperature, turbidity, color, flow rate and depth. The chemical characteristics are pH, DO, heavy metals, TDS, Salinity, pesticides, nutrients and organic pollutants, while the biologicals are algae, insects, worms and fish where their presence and absence of determine the river quality. River water can be polluted by addition of substances or energy forms that directly or indirectly alter the nature of the water body in such a manner that negatively affects its legitimate uses (Marcos von Sperling, 2007). River pollution can occur through natural processes (e.g. from sedimentation by natural erosion). It can also be defined as the contamination of water sources by substances which make the water unusable for drinking, cooking, cleaning, swimming, and other activities. The release of substances into subsurface groundwater, lakes, streams, rivers, estuaries and oceans to the point where the substances interfere with beneficial use of the water or with the natural functioning of ecosystems.

River water pollutants come from either point sources or dispersed sources. A point source is a pipe or channel, such as those used for discharge from an industrial facility or a city sewerage system (Nesaratnam, 2014). Point sources of water pollution are easier to control than dispersed

sources, because the contaminated water has been collected and conveyed to one single point where it can be treated. A dispersed (or nonpoint) source is a very broad unconfined area from which a variety of pollutants enter the water body, such as the runoff from an agricultural area. It can destroy important food sources and contaminate drinking water with chemicals that can cause immediate and long-term harm to human health. Water pollution also often severely damages aquatic ecosystems. Rivers, lakes, and oceans are used as open sewers for industrial and residential waste. Pesticides, herbicides, oil products, heavy metals (such as mercury, lead, and zinc), detergents, and industrial wastes can kill aquatic organisms outright or make the environment so inhospitable that species can no longer thrive. River water pollution can be linked to the type of wastewater produced by urban, industrial, and agricultural activities that flows into surface and subsurface waters (Vittori et al., 2010).

### 2.1.3 Concept of food security and production

Food security is the availability of food in a country and the ability of individuals within that country (geography) to access, afford, and source adequate foodstuffs. According to the world food summit held in 1996, ‘’Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preference for an active and healthy life” (FAO, 1996). Similarly, Household food security is considered to exist when all members, at all times, have access to enough food for an active, healthy life US Department of Agriculture (2008). In addition, as the 1996 world food summit was subsequently reconfirmed in 2002, food security consists of four essential pillars: food availability, food access, food utilization and stability. Among those pillars food availability is the first pillar of food security, which is defined as the presence of food in a country or at household level through all forms of domestic production, food aid, and commercialization import and purchase (WFP, 2012). At micro level (household), food availability is the extent of which food is within reach of households through production and market (Pieters et al., 2013).

Food production is the cultivation of food crops with special regard to maximization of the total yield gained per acre in one planting season which can increase food availability. The tremendous increasing human population threatens the future food production in urban cities like Addis Ababa. Expansion of industries, Construction of houses and other nonfood uses of

agricultural lands have reduced food supply as the area under food crops has reduced. The global population is increasing and food demand in urban areas in particular is highly increasing because of population pressure. Despite the protection of biological and cultural diversities, agricultural land has provisioning services to maintain food security (Bommarco et al., 2013).

Food insecurity and chronic under nutrition persists mainly in countries with own production in urban areas like Addis Ababa. To tackle the problem, the limited land in the urban areas of the city should be given special attention for its contribution for food security and its river water contribution for small-scale irrigation. The urban and peri-urban agriculture should be given special attention. Rapid population growth has resulted in the scarcity of the most natural resource, soil and water on which agriculture depends.

**Food availability:** Is the first pillar of food security, which is defined as the presence of food in a country or at household level through all form of domestic production, food aid, and commercialization import and purchase (WFP, 2012). Human Population growth resulted in the shrinking of the farmland sizes. Urban food production and consumption is undermined by rapid population growth, decreasing landholdings and widespread land degradation. At micro level (household), food availability is the extent of which food is within reach of households through production and market (Pieters *et al*., 2013).

## 2.2 Empirical literature reviews

### 2.2.1 Effect of LULCC on river water quality

River water quality degradation is becoming a serious problem in Ethiopia. Particularly in urban cities like Addis Ababa which is among the first cities severely affected by the problem of water pollution because of its socio-political and industrial corner of the country and as a consequence of expanding industrialization and extensive population growth. Almost all the tributaries and major rivers draining the city are exposed to different pollution sources. Many industrial processes produce polluting waste substances that are discharged to the environment (Aregawi, 2014). Among the most polluting industries are textiles, tanneries, and beverage & food processing industries with processing plants and factories that produce liquid effluents which are discharged into rivers, often without treatment. In Addis Ababa, rivers frequently receive

polluting discharges from many different sources all at the same time Eshetu (2012) as cited in Amare (2019).

Most empirical studies on the subject confirmed that the change in land use and land cover has an effect on the water quality of the river. The quality of surface water is important for various purposes such as domestic, industrial, agriculture uses (Nabeela et al., 2014). The quality of water resources is affected by natural and anthropogenic activities (Matshakeni. 2016) which may render it less valuable for human use. Industrial effluents, decomposition of organic compounds, and fertilizers are the major nitrate sources on the earth's surface. Identifying the relationship between land use and water quality of rivers helps for effective and sustainable surface water quality management especially in minimizing the pollutant loads in the water body (Ding et al., 2015).

A study conducted in Peshawar district Pakistan showed that the minimum water nitrate value had raised in 2012 from 0.09 to 1.25mg/L in 2019 and the maximum to be from 41.72 in 2012 to 113.mg/L in 2019 showing the reason is due to rapid urbanization and increased agricultural activities and farmers use pesticides and large amounts of fertilizers to produce a high yield from small agricultural fields (Waqas et al., 2021).

A study conducted in the Offin river basin in Ghana showed due to land use and cover change, there exists degradation of land and deterioration of water resources sharply increased by 95.71 % and 78.60 % respectively (Bismark et al., 2017). Research conducted on Big Sioux River in South Dakota revealed that; technologies such as crop rotation, tillage conservation practices, and irrigation also minimized nitrogen leaching and conserved fertile topsoil, increased production, and supported higher yields per acre (Reitsma et al., 2015 as cited by (Dinesh, 2019).

A similar study conducted in little Akaki river Addis Ababa, Ethiopia revealed that pollution load of heavy metals (Zn, Cr, Cd and Pb) on river at the downstream is very high as compared to other sites located in the mid and upper courses of the river Zn (78.96 ± 0.021–235.2 ± 0.001 mg/kg); Cr (2.19 ± 0.014–440.8 ± 0.003 mg/kg); Cd (2.09 ± 0.001–4.16 ± 0.0001 mg/kg) and Pb (30.92 ± 0.018–596.4 ± 0.066 mg/ kg) (Mekuria et al., 2020). This implied that high metal inputs mainly from the municipal wastewater treatment plant, Kaliti industrial site and agro-chemicals from surrounding irrigated vegetable farms.

### 2.2.2 Effect of LULCC on household food production

Research conducted in Tana basin, Ethiopia using change detection shows that there exists extreme change in LULC due to population growth and urban expansion. According to the research the water body size covering 2156.2km$^2$ in 1984 had declined to 2152.7km$^2$ in 2018. The agricultural land has highly increased with the expense of forest land. The cover of forest was 887.5km$^2$ in1984 and changed to 546.9km$^2$ in 2018. The size of farmland was 5654.7km$^2$ in1984 and changed to 7608.7km$^2$ in 2018. According to Tewabe et al., (2020), the study conducted in the Lake Tana Basin, Crop land has increased in the basin with the expense of forest land and land use.

A study conducted in Offin river basin Ghana showed that the land use and land cover change analysis of natural forest and secondary forest reduced by 54.03 % and 10.05 %. The study also shows decrease of smallholder farm number from 53.27 % - 70.10 % cropland size less than 1 hectare and farmlands less than 2 hectares and production level of maize and rice had decreased considerably by 50.55% and 88.45 % respectively (Mensah-Brako & Agyare, 2017). This shows that the majority of the farmers have small farmland for their food production at the same time exposed to extreme land degradation.

Similarly, a study conducted in Bahir Dar city revealed that due to tremendous land use, land cover change of crop land to settlement and other land use, the crop land size in 1984 which has been 12,151ha is declined in 2019 to 10,850 (Assefa et al., 2021). A study conducted in Peshawar district Pakistan showed that the agriculture land cover was 606.865 km2 (47.24%) in 2012 and 510.928 km2 (39.77%) in 2019 showing the increase of built up and range land areas with the expense of food crop production agricultural land (Waqas et al., 2021).

A study conducted in India, China and Vietnam on analysis on urban land use changes and its impacts on food security in different Asian cities of three developing countries shows that urban areas increased from 96.15 ha to 150.23 ha while agricultural areas decreased from 91.59 ha to 45.33 ha from 2000-2009 in Dehradun, overall amount and extent of change from 28,023 ha to 33,215 ha while agricultural areas decrease from 45,031 ha to 41,173 ha during 2002-2010 in

Zhangjiagang showing significant increase of urban area and reduction for agricultural land (Zhang et al., 2011).

### 2.2.3 Institutional factors for LULCC

Land is an engine of economic development. Particularly, in countries where land is under state ownership like Ethiopia. It has become a major driver of economic growth and a tool for macroeconomic stabilization (Lian et al., 2016; Rithmire, 2017). In Ethiopia the land has been used as a policy instrument to attract domestic and foreign direct investment (Lavers, 2012). Investment attraction is chiefly to stimulate economic growth and reduce poverty. Urban land has been used to generate municipal revenue to finance urban infrastructure building. Using land use policy tool in countries such as China (Zoomers, 2010; Du and Peiser, 2014).

However, economic and social benefits from the land can only be realized if the land is used in an efficient and productive manner. Urban land use can be affected by an institutional capacity to implement policies, rates of urbanization and economic growth. According to UN-Habitat (2020), well defined and established institutions are indispensable for sustainable urban development. Several cities do not have the institutional environment that is essential for sustainable urbanization. However, planning and managing urban areas requires institutional capacity (Bandauko et al., 2021).

Land institutions determine the rules of the game regarding land use and management, and they can create a framework for people-to-land relationships. Land institutions are also instrumental in sustainably guiding urban development. Effective and credible land institutions are indispensable in ensuring effective land use planning, land rights protection, urban sprawl and informal settlement control, and effective land market development. According to Dowall and Clark (1996), in Ethiopia, urban land policies are ineffective or responsible for some adverse effects on society and economic activity. For example, misguided or ineffective land policies can lead to land use fragmentation or land vacancy (Zhang and Xu, 2016).

Effective land use planning is essential to attain certain land use policy objectives. Effective spatial planning guides urban land towards efficient use, while limiting construction in hazardous and environmentally sensitive areas. In the absence of a strong institutional capacity, it is

difficult to put an effective land use planning in place. Furthermore, an ineffective institutional and regulatory environment leads to misallocation of land (Lall et al., 2017).

Perception on river water quality and food crop production is another factor of LULCC. In the presence of strong institutional land use policy and regulation the awareness level of community will be high to use land, river and urban agriculture in sustainable manner and will be the concern of everyone. This is due to the fact that every individual can contribute for the river water quality and food crop production. In the presence of strong institutional policy implementation and community perception awareness level of the community will be high to manage river water quality and urban agriculture.

## 2.3 Conceptual framework

The conceptual framework presented in Figure 2.1 shows linkages between study variables assumed as affecting river water quality and household food production in the study area.

The framework was developed based on literature review. As discussed above, river water quality and household food production are affected by different LULC Changes. These factors which affect river water qualities are categorized into settlement and buildup area, crop land, waterbody, forest land, bare land, grazing land, shrub land and institutional factors either positively or negatively related to river water quality and household food crop production.

The analytical framework shows the linkage between LULCC, river water quality and household food production in the study area. In this study, Institutional setup factors are contributor for LULCC, river water quality and food crop production are categorized. Institutions include Government institutions, Non-government institutions. According to Shahid et al. (2015), river water quality is associated with economic and technological factors that influence the river water quality and crop yield of a households were industrialization and agricultural intensification by contributing heavy metal beyond the prescribed standard in soil and resulted to poor seed emergence and seedling growth which cause reduction in yield. Urbanization has led to conversion of agriculture land into non agriculture purpose such as factories, buildings, residential or other commercial use (Malik and Ali, 2015).

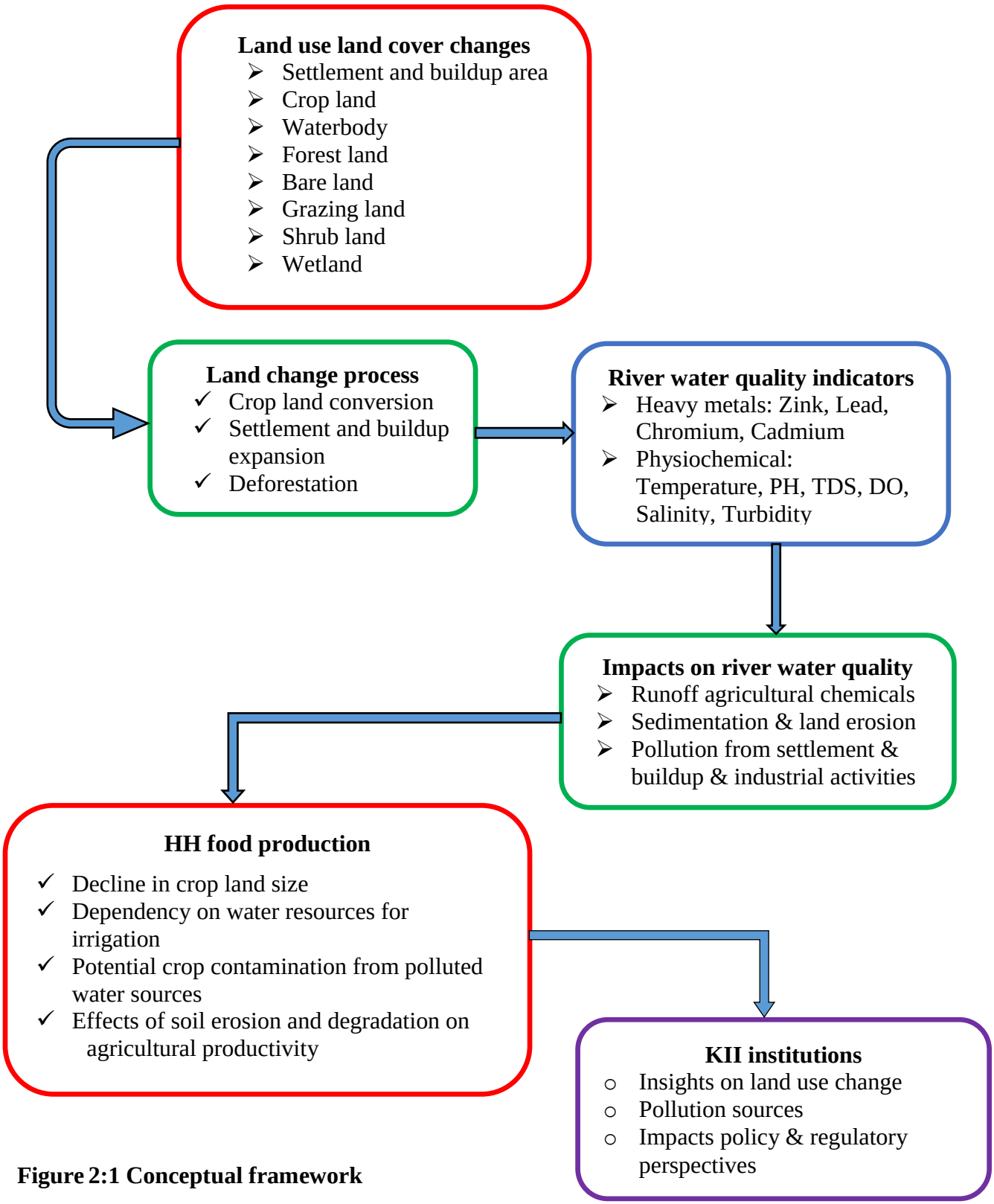


**Figure 2:1 Conceptual framework**

Source: Development based on literature review (2023)

According to Bufebo et al. (2021) farmland size are associated with various demographic and technological factors that influence farmland size of households. Rapid population growth and agricultural production intensification made almost impossible for farmers to practice the appropriate crop practice in the watershed. According to Wantzen et al. (2019), Illegal settlement through migration cause a serious threat to the environment which directly and indirectly cause reduction in yield and increase in the temperature of atmosphere with usage of modern equipment. Local Government is the decision maker to determine a local land use policy on housing provision. Van Assche and Djanibekov (2012) said that land use policy issues continue to integrate economic and environmental land use development, arguing that land use planning is used as a tool to find a good integration.

# CHAPTER THREE: RESEARCH METHODS AND MATERIALS

## 3.1 Study Area

This study was undertaken in Little Akaki river catchment, which is located in central Ethiopia and drains the western side of the city (Demlie et al., 2008). It is located at longitude from $38^0$ 34' 23" to $38^0$ 46' 26" and latitude from $8^0$ 50' 21" to $9^0$ 07' 57". The river is one of the main water source of the city and used by downstream communities for agriculture, livestock, drinking, and recreational purposes. Little Akaki river flows through varied altitudes that range from 2464 m.a.s.l at Geferssa Reservoir in the north to 2048 m.a.s.l. at Aba-Samuel Reservoir in the south.

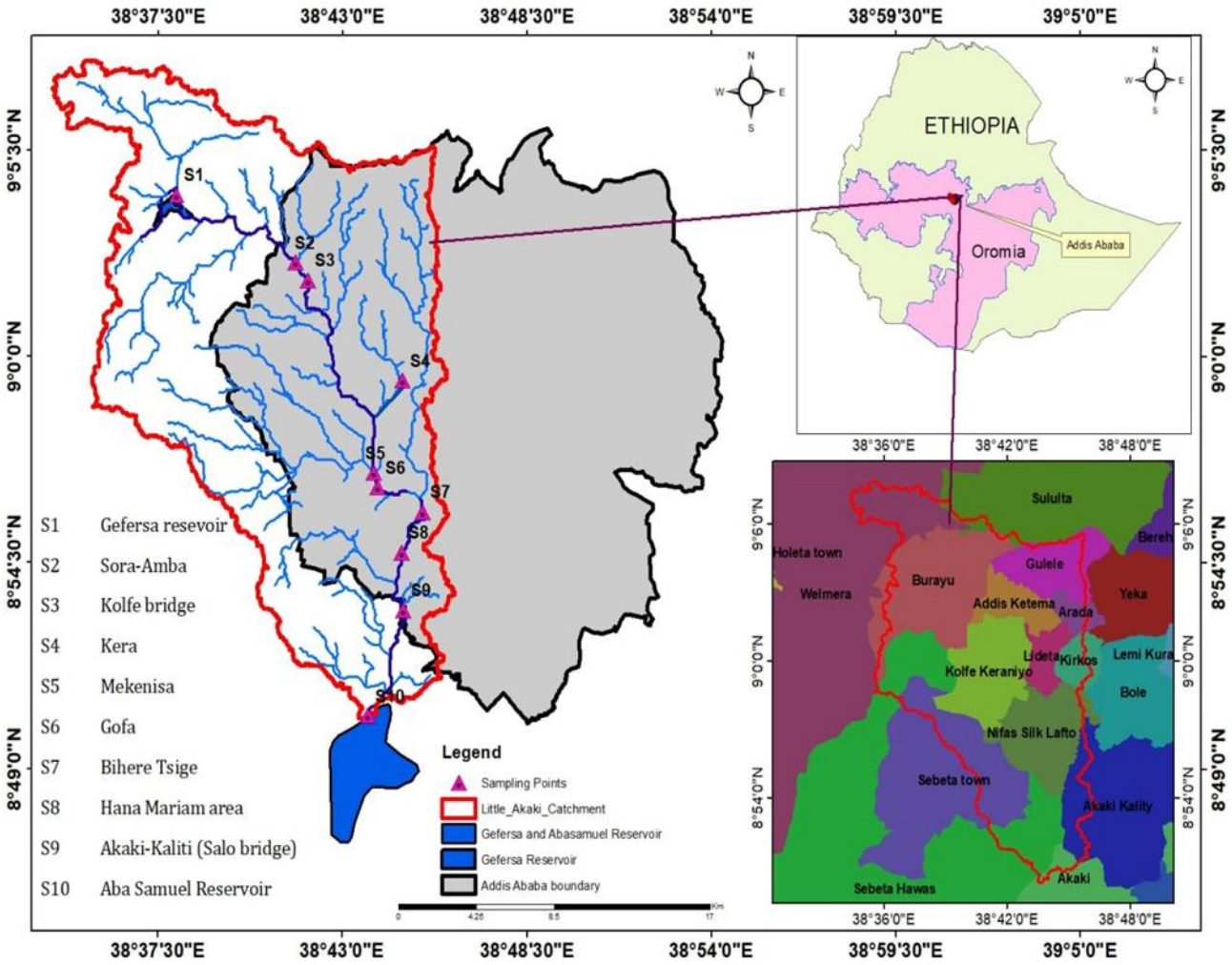


**Figure 3:1 Map of study area along with sampling sites**

Source: (CSA, Ethio-GIS 2015)

**Topography, Climate and Demographic characteristics**

The river is originated from Entoto mountain found in the northwest parts of Addis Ababa City as a small stream and merges with Geferssa reservoir, flows southwest and finally joins Aba-Samuel reservoir after traveling a total distance of 40km. The area of the catchment covers 403km$^2$. In the upper catchment, the river flows through a deep gorge, on a rocky bed with turbulences whereas in the lower catchment, it flows in a gentle slope landscape that is surrounded by irrigated vegetable farms and grazing lands. There are two types of soil predominantly found around little Akaki river: Vertisol which is commonly found on top of gentle slope lands and fluvisol at bottom of slope lands and on adjacent to the Akaki Riverbanks (Itanna et al., 2003).

Little Akaki river is one of the major rivers crossing through the city and largely used for socio-economic development activities. Almost all of the vegetable farmlands are along with river buffers in the city of Addis Ababa. However, evidence show that some field crop areas have been converted to settlements and industries as the urban areas expanded, resulting in a decrease in food production. Urban and peri-urban farmers downstream are using this river water with pollutants for the cultivation of vegetables around the riverbanks and supply the City with fresh vegetables. Moreover, peri-urban communities and farmers are largely dependent on the river water for cattle drinking, washing, recreational and even for domestic uses as well as sand mining during the dry season. Fishing is also undertaken in the lower parts of the river course and the Aba Samuel Reservoir. The catchment includes eight Addis Ababa Sub-cities; Gulele, Kolfe keranyo, Addis ketema, Arada, Lideta, Kirkos, Nefas silk Lafto and Akaki kality. The catchment also includes five Sheger City Administrative sub-cities; Sululta, Guje Gefersa, Furi sub-city, Gelan Guda, and Gelan sub-city.

**Table 3.1: Major land use and land cover classes in the study area and their description**

| Land use class | Description |
|---|---|
| Settlement and buildup area | Built-up areas, transportation networks, industrial sites, and other human-made surfaces. |
| Crop land and managed land | Land used for annual and perennial crops, agroforestry, and other managed agricultural practices. |
| Waterbodies | All types of water bodies, including rivers, lakes, reservoirs, and ponds. |
| Wetland | Areas with permanent or temporary water saturation, such as marshes, swamps, and wet meadows. |
| Forest and woodland | Natural forests, plantation forests, and other wooded areas. |
| Bare land | Bare soil and rocks used for source of raw material |
| Grazing land | Land covered with grass and animals feed |
| Shrub land | Area covered with small bushes |

Source: Developed based on FAO Land Use Land Cover Classification System (LCCS) with standard land use classes.

## 3.2 Research Design

This research has used a Mixed research design, and applied integrated or interdisciplinary research approaches where Ecological analysis conduct a quantitative analysis to assess the land use land cover changes using change detection analysis which analyze satellite imagery pattern over time, Water quality assessment which analyze water quality parameters and helps to determine the effect of LULCC on river water quality, household food production assessment where household food production data collected which helps to understand the effects of LULCC on household food production and institutional analysis which involve conducting interviews with KII of concerning institutions where how institutional factors influence LULCC decisions and their consequences on water quality and food production.

### 3.2.1 Data types and Sources

This study used both primary and secondary data sources. Primary data (qualitative and quantitative) was collected directly from each of selected land cover classes field survey using handheld Garmin GPS for ground truth. Qualitative method was used to develop true story from selected previous farmers and to see institutional setups and their contributions. This was done by using key informant interviews with the selected farmers and representatives from relevant institutions.

Secondary data were acquired from United State Geological Survey (USGS) from Earth Explorer website (https://earthexplorer.usgs.gov/) Therefore, for this study seven satellite images with (Landsat 4-5 TM for the year 1994 and 1999, Landsat-7 ETM+ (Enhanced Thematic Mapper) for the year 2004 and 2009, Landsat-8 Operational Land Imager (OLI) for 2014 and 2019, Landsat 9 for the year 2023 with five-year time interval and 30m spatial resolution was used. Secondary data of Little Akaki river water quality data of 2023 thematic research and 2019 study of Addis Ababa University, Center for Environmental Science were also used. Specifically, data of a study on assessing pollution profiles along little Akaki river receiving municipal and industrial wastewaters, Central Ethiopia: implications for environmental and public health safety data of 2019 which were relevant to the study are used.

### 3.2.2 Sampling technique and procedure

The study applied non-probability sampling design procedure to see river water quality of the study area. The study catchment was purposely selected based on river water pollution load and proximity to the center of the city. The water sample sites of the year 2019 and 2023 were selected to see the trend. The ten water sample areas are selected from the same places of the previous study plots based on access to transportation to see the trend using one of the Non-probability sampling design which is purposive sampling.

### 3.2.3 Sample determination

There is no universally accepted single benchmark of sample size for reference data points. A maximum of 50 samples for each land cover classes and fewer than 12 classes should be collected for maps with area size of 4,046.9km$^2$ (Lillesand et al., 2008). Accordingly, the study area with area coverage of 403km$^2$ the land use cover classification which consists of seven major classes were identified for each time period. Likewise, 30 samples for each LULC category were collected from google earth images.

**Table 3.2: Number of training samples from each land cover classes**

| Land use and land cover classes | Number of training samples | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1994 | 1999 | 2004 | 2009 | 2014 | 2019 | 2023 | Total samples |
| Settlement and build up | 43 | 46 | 49 | 51 | 51 | 53 | 55 | 348 |
| Crop land | 40 | 32 | 34 | 31 | 32 | 31 | 38 | 238 |
| Water body | 24 | 21 | 21 | 24 | 22 | 20 | 23 | 155 |
| Forest land | 19 | 21 | 23 | 22 | 23 | 20 | 20 | 148 |
| Bare land | 33 | 29 | 32 | 26 | 23 | 24 | 25 | 192 |
| Grazing land | 38 | 36 | 34 | 33 | 33 | 31 | 28 | 233 |
| Shrub land | 24 | 21 | 26 | 20 | 20 | 23 | 22 | 156 |
| Total samples | 221 | 206 | 219 | 207 | 204 | 202 | 211 | 1,470 |

Source: Computed based on data collected from each LULC training samples of Little Akaki river

catchment, 2023

Therefore, in this study a total of 1,470 training samples were collected, of which 1260 and 210 were used for classification and accuracy assessments, respectively. Classification is not complete until satisfactory level of accuracy is achieved (Lillesand et al., 2008); thus, error matrix was performed to assess classification accuracy. Therefore, Classified LULC classes were compared to ground truth to evaluate the degree of accuracy of the output. For this study, ten (10) water sample sites are selected deliberately based on the same water quality research sites of previous study (Mekuria et al., 2020). For institutional setups Seven (7) direct concerning institutions are selected purposely.

### 3.2.4 Tools and technique of data collection

The researcher employed field observation and KIIs to collect the primary data. These are explained as follows;

**Field observation**

The LULC classes and imagery data taken from the Landsat using ground truth of those georeferenced areas of the catchment were cross checked. To avoid errors that can arise in image classification and existing land use and land cover classes a total of 210 ground truth points were taken randomly for accuracy assessment.

**Key Informant Interviews (KII)**

To generate qualitative information for institutional setups towards river water quality which helps to examine and analyze the effect of LULCC on river water quality and household food crop production, a total of eight key informant interview were conducted. Six from governmental, one from industries and one from community. The KII was selected purposively to participate in the interview. Six governmental institutions are, Addis Ababa Urban Planning Institution, Addis Ababa City Land Administration Authority, Addis Ababa Environment Protection Authority, Addis Ababa City Administration Farmers and urban agriculture development commission, Addis Ababa City Administration Urban Beautification and Green Development Bureau, City Government of Addis Ababa Labor, Enterprise & Industry Development Bureau**.** One industry is Awash Wine Factory which is located near Little Akaki river in the catchment were purposively selected, one historical KII from the community that has practice farming where river catchment is located in the lower part is conducted. Key informants are selected based on their knowledge, involvement in urban planning, river side planning and management expertise, pollution load contributor industries and from community based on their previous and current urban and peri urban agriculture experience. Semi-structured interviews were conducted to collect information on efforts conducted for river water quality and food production.

Key informants were asked questions pertaining to their respective institutional assignment and planning strategies related to river water quality and food production efforts. The objectives, goals and their outcomes were also interviewed. In order to maintain the quality of data, scientific principles and guidelines during questionnaire designing, data collection, data filling, encoding, data entry and processing were applied. The questionnaire was first prepared in English and later translated into and Afaan Oromoo, so that the respondents has easily understand the questions.

**Secondary data**

Data for this study was also obtained by reviewing secondary sources information or archived data. Both published and unpublished research thesis/dissertation, journals, articles and reports were reviewed and used for this study. Similarly, government documents obtained from various official websites such as Ministry of Agriculture and Natural Resource (MoANR), Ethiopia Institute of Agriculture Research (EIAR), Central Statistics Agency (CSA) were reviewed and used for this study.

**Remote Sensing and ArcGIS**

Google Earth Explorer was uses to explore and download satellite image of each study years with 30m spatial resolution. Google Earth pro had employed to collect the training samples and to taste sample points for land use and cover classification and validation.

### 3.2.5 Method of data analysis

Both qualitative and quantitative method of data analysis was employed in this study. The quantitative data obtained from secondary data sources were analyzed using descriptive statistics and econometric analysis. Moreover, LULCC of the study area is analyzed using change detection. After data collection from archive, data was edited, coded and completed. The Satellite image was analyzed using ArcGIS Map 10.7.1. Finally, land use Map of the study area were produced. All data were entered into computer using package for social science (SPSS) version 24.0 software. Similarly, the qualitative data obtained through key informant interview and field observation were analyzed qualitatively through narrative and framework analysis.

#### 3.2.5.1 Descriptive statistics

Descriptive statistics such as, minimum, maximum, mean and standard deviation were applied to describe river water quality parameters. Variability of mean values of river water quality parameter analysis of variance(ANOVA) for 2019 and 2023 were calculated. In addition, land use class area coverage among all sample sites were also described. correlation coefficient check was done to identify the correlation between dependent variables and independent variables. Furthermore, to compare mean difference between the two years across the study paired –test was applied. In addition, a Pearson correlation coefficient was conducted to quantify the strength and direction of the linear relationship between land use class and river water quality parameters.

#### 3.2.5.2 Analysis of Land use and land cover change

The primary focus of this study was to employ satellite imagery for change detection of land use and land cover (LULC). The researcher utilized a well-established method known as supervised classification, which aids in categorizing the remote sensed LULC data from satellite images. This method involves the guidance of an image analyst who uses a specific algorithm to supervise the pixels and assign numerical values to different land cover types present in the scene. To accomplish this, representative samples from each land cover class were selected as training sites. These training sites were then utilized to create a reference key that assigns numerical values to different land cover types based on their spectral attributes. The widely used Maximum Likelihood algorithm was applied to classify the images Bayarsaikhan, et al., (2009). This algorithm relies on a probability function that assumes the training data for each class in each band follows a normal distribution.

The analysis and classification of satellite images were carried out using ArcMap 10.7.1 software. Thematic maps an area calculations were also performed using this software. Microsoft Excel was utilized for creating tables and conducting calculations related to LULCC. Graphs, such as clustered bar charts depicting area distribution, a comparison chart, and an area change diagram, presented as Figure 2.1, was included to provide a visual representation of the study's conceptual framework. The subsequent section provides detailed explanations of the components depicted in the flow diagram.

**Acquisition of data**

In this study both Primary and secondary data sources has been used. Primary data were acquired from ground trothing points and key informant interview which were used to get the primary data, while Google Earth data were used to gather the secondary data. Landsat imagery was chosen for the year of 1994, 1999, 2004, 2009, 2014, 2019 and 2023 from the USGS Earth Explorer online portal (path: 168, row: 054), to improve the likelihood of cloud-free image availability, the months of December, January and February were chosen. The year 1994 was chosen as the baseline year because, the government of Ethiopia has started to give attention to urban farmers lost their land because of development activities in Addis Ababa and stablished office. Landsat Level1T data was utilized to acquire all satellite images. It should be noted that the images had undergone prior adjustment and geometric correction. Subsequently, the selected satellite images were downloaded and suitably prepared for subsequent processing.

**Data preparation**

Landsat 4-5 TM for the year 1994 and 1999, Landsat-7 ETM+ (Enhanced Thematic Mapper) for the year 2004 and 2009, Landsat-8 Operational Land Imager (OLI) for 2014 and 2019, Landsat 9 for the year 2023 were used for the classification of land use and land cover. The research region was provided with satellite data from the Earth Explorer site, which is a plate form for accessing various satellite imagery. These datasets were then imported into ArcMap, a powerful geospatial processing software within the Esri ArcGIS site, specifically version 10.7.1, which is dedicated to satellite image processing. The USGS Erath Explorer offers a wide range of satellite imagery at no cost. However, finding cloud-free images can be challenging when relying on free data sources. To mitigate this issue, a search criteria was applied to select images with cloud cover below 10%. Fortunately, a satisfactory percentage of cloud cover ranging from 3% to 7% was obtained, ensuring minimal impacts on the final results. The downloaded datasets were in zipped format and were extracted to obtain the TIF files. To merge the individual bands and create a cohesive image, a layer stack tool was employed. The original raw images, with bands stored separately, can be found in Appendix 22.

**Image pre-processing**

The information accessible to public may not always be entirely accurate, requiring various modifications. In the context of satellite image analysis, preprocessing plays a vital role. It encompasses essential procedures like distortion correction and cloud removal, aiming to enhance visual interpretation capabilities and enable the differentiation of spectral characteristics of the Earth's surface (cited by Seyam, et al., (2023). Furthermore, preprocessing facilitates the provision of improved inputs for automated image processing algorithms, thereby advancing the overall quality of satellite image analysis.

**Layer stacking and sub-setting**

The Landsat 7 ETM sensor comprises 8 bands, while the Landsat 8 OLI/TIRS sensor consists of 11 bands. For this particular study, bands 1, 2, 3, and4 from Landsat 7 and bands 2, 3, 4, and 5 from Landsat 8 were combined into a single image using ArcMap 10.7.1. Each band was assigned to a specific color channel (Red, Green, and Blue), resulting in various combinations of true-color and false-color composites for the study area. To streamline image processing and analysis, the composite image was then subset to focus on the study area. Through this two-color composite, seven distinct classes were identified, which can be described as follows: a) areas of human settlement and infrastructure, b) Cultivated land for crops, c) bodies of water, d) forested area, e) barren land, f) grazing land, and g) shrub dominated areas.

**Image correction and enhancement**

Satellite image interpretation involves necessary corrections and enhancements to obtain a clearer and more comprehensive understanding of the image's properties. Two essential types of correction are applied: radiometric correction and geometric correction. Radiometric correction aims to improve the brightness levels of the satellite image, enhancing visibility and analysis. By adjusting bias and gain levels for each band, radiometric correction allows the conversion of Digital Numbers (DNs) into Top of Atmosphere (TOA) radiance measurements. These radiance measurements are further converted to TOA reflectance using sensor-specific irradiance values. For this investigation, all satellite images utilized were acquired at Level 1 (L1), which indicates

that no additional processing was required for geometric correction as the data were already orthorectified. Geometric correction ensures the spatial accuracy of the image. To further enhance the interpretability of the satellite imagery, image augmentation techniques are employed. These techniques include resolution enhancement, contrast enhancement, IHS (Intensity, Hue, and Saturation) transformation, density slicing, edge enhancement, digital mosaics, and synthetic stereo images. Augmentation techniques improve the visual impact of the interpreter and enhance the overall quality of the image analysis.

In this study, two techniques were employed to improve the image for visualization and analysis: contrast enhancement and intensity, hue, and saturation (IHS) transformation. Contrast enhancement is a crucial aspect of image processing, with the primary goal of maximizing the contrast within the image to effectively represent all the information present.

To tackle this challenge, various methods have been developed, including Decorrelation Stretching, Linear Contrast Stretching, Multi wavelets and singular value decomposition (SVD), Discrete Wavelet Transforms (DWT), DWT and SVD, Discrete Cosine Transform (DCT) and SVD, and Gamma correction. In this study, general histogram equalization, decorrelation stretching, and gamma correction techniques were employed to enhance the visual interpretation of land cover classes. The image color representation was transformed from RGB to the IHS system, and adjustments were made to improve the perception of differences during the enhancement process using the IHS transformation approach.

**Image classification**

To categorize satellite images in this study, an appropriate classification approach tailored to the study area was employed. A modified classification approach was utilized to classify various forms of land use and land cover (LULC). Per-pixel supervised classifiers were utilized, which assign class labels to pixels based on their spectral reflectance properties, aiming to identify pixels with similar or identical characteristics. The maximum likelihood algorithm, a well-known and widely used parametric classifier, was implemented in ArcMap version 10.7.1 to perform the supervised classification on Landsat images from 1994, 1999, 2004, 2009, 2014, 2019, and 2023.

The classification process involved three main steps: training sample selection, classification, and evaluation or accuracy assessment. Initially, a numerical "interpretation key" was created, representing the spectral characteristics of each land cover type of interest. This was achieved by selecting representative sample sites, or training regions, for recognized land cover types. Approximately 30 training samples were created for each class, resulting in a total of 210 training samples for each map. Subsequently, each pixel in the dataset was statistically compared to the interpretation key categories and labeled with the name of the category it most closely resembled.

The maximum likelihood technique, based on Bayes' theorem, is widely employed for land use and land cover change analysis. This technique determines the regular distribution of cells in each class sample within the multidimensional space. The weighted distance or probability (likelihood) D of an unknown measurement vector X belonging to a recognized class Mc is calculated using the Bayesian equation (1) as follows:

D = ln(ac) - [0.5ln(|covc|)] - [0.5(X-Mc) T(covc− 1) (X-Mc)] ... ... ... ... ... ... ... ... ... ... ..... (1)

In the equation, c represents a specific class, D denotes the weighted distance (likelihood), X represents the measurement vector of the candidate pixel, Mc represents the mean vector of the sample, ac signifies the likelihood (in percent) that the candidate pixel belongs to class C (defaulting to 1.0 or entered based on prior knowledge), Covc represents the covariance matrix for the class c pixels in the sample, |Covc| denotes its determinant in matrix algebra, Covc− 1 represents its inverse, ln denotes the natural logarithm function, and T signifies the transposition function in matrix algebra.

**Accuracy assessment**

After the generation of image classes, the accuracy of the classification was evaluated using the ArcGIS 10.7.1 application. Assessing the accuracy of the classification is crucial once the image classification is completed. For each of the identified images from 1994, 1999, 2004, 2009, 2014, 2019, and 2023, the accuracy evaluation tool of the supervised classifier randomly generated 210 reference points using stratified random sampling. Each reference point had a specific color and

pixel value, which the software automatically recognized. The initial classes from the categorized image were used as a starting point, and randomly generated points were identified for which the user manually assigned the appropriate class. A total of 210 random sites were selected for ground-trothing. The reference data for this study were obtained from field visits and high-resolution images from Google Earth Pro.

To assess the accuracy of the classification, an error matrix and kappa coefficient were manually created using Microsoft Excel for the seven classified images. The standard reference of kappa coefficient for accuracy assessment is $\leq 0$ kappa coefficient shows no agreement, 0.1 to 0.20 non to slight agreement, 0.21 to 0.40 fair, 0.41 to 0.60 moderate, 0.61 to 0.80 substantial and 0.81 to 1.00 shows as almost perfect agreement. The error matrix provides an indication of the accuracy of the categorization. The columns represent the classes described as "user value" from the reference data, while the rows correspond to the classes described as "producer value" derived from the classified image. The error matrix's cells along the diagonal indicate the total number of correctly detected points for each class in the classified and reference data. The off-diagonal cells represent pixels that were incorrectly assigned, indicating a mismatch between the reference and classified data.

During the classification process, two types of errors may occur: omission and commission errors. Commission errors occur when the classification algorithm assigns points to a class to which they do not belong. By counting the number of pixels mistakenly allocated to each class, one can identify commission errors in the cells above and below the main diagonal of the class. The producer's accuracy is also calculated to quantify the number of commission errors. Omission errors, on the other hand, occur when pixels from one class are included in other class pixels, resulting in missing pixels. The cells on the left and right of the main diagonal in the confusion matrix's rows are used to calculate the number of missing pixels. The user's accuracy is another measure that characterizes omission errors. Formulas are employed to determine both the user's and producer's accuracy, indicating the correctness of the classification.

$$Users\ Accuracy = \frac{Number\ of\ correctly\ classified\ pixels\ in\ each\ category}{Total\ number\ of\ classified\ pixels\ in\ that\ category\ (he\ row\ total)} X\ 100 \ldots\ldots\ldots\ldots (2)$$

$$Producer\ Accuracy = \frac{Number\ of\ correctly\ classified\ pixels\ in\ each\ category}{Total\ number\ of\ reference\ pixels\ in\ that\ category\ (the\ column\ total)} X\ 100 \ldots\ldots (3)$$

The following formula were used to determine the two data sets' overall accuracy and kappa coefficient.

$$Overall\ Accuracy = \frac{Total\ Number\ of\ Correctly\ classified\ pixels\ (Diagonal)}{Total\ Number\ of\ reference\ pixels} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$Kappa\ Coefficient\ (T) = \frac{(TS\ X\ TCS) - \sum(Column\ Total\ X\ Row\ Total)}{TS^2 - \sum(Column\ Total\ X\ Row\ Total)} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where in this formula, TS stands for Total Sample pixels and TCS stands for Total Correctly Classified Sample.

Seven land use and land cover classes were identified for the Little Akaki river Catchment after preliminary field survey and google earth satellite images. The categories of land use and cover classes and their descriptions are shown on table 3.1.

To classify and verify these major land use and cover types, training sample points were prepared. On the number of ground truth data sampling, there is no single ideal number of ground truth data for image analysis. Scientists are subjective on the number of points collected (Muke and Haile, 2018). However, what is recommended most is taking more coordinates for a single class of feature for creating signatures and accuracy assessment. The more points collected, the lower the standard error. A total of 210 ground truths were collected during field survey using Global Positioning System (GPS) for these land use and cover categories. After the LULCC analysis, Pearson correlation and multiple linear regression analyses were done to establish the relationship between river water quality and LULCC using Statistical Package for the Social Sciences (SPSS) version 24.

**Change detection**

Remote sensing and GIS-based change detection methods are commonly employed due to their cost-effectiveness and high temporal resolution. These methods utilize multi-temporal datasets from different dates to discriminate and detect changes. The post-classification comparison technique is utilized to identify areas of change by classifying images and comparing the relevant classes. In a comparative analysis of various techniques, the post-classification comparison approach demonstrated the highest classification accuracy.

In this study, a post-classification comparison method based on the Maximum Likelihood Classifier (MLC) algorithm was employed with Landsat data to validate land use changes in the Little Akaki river catchment. The post-classification comparison involved converting the classified raster images into vector layers for further analysis. To better understand the changes in land use and land cover (LULC), separate images were generated to represent the changes for each land cover type. The accuracy of the thematic maps produced through image classification plays a crucial role in determining the reliability of the results. The degree of change (C) for each class was calculated using the following equation:

$$Ci = Li - Bi \quad \ldots\ldots (6)$$

To determine the percentage change (C%) in each land-use class, a straightforward calculation method was employed. The change in class was divided by the area covered in the base year and multiplied by 100. This computation was performed for each land-use class individually, allowing for the assessment of the percentage change in each specific class.

$$Pi = \frac{Li - Bi}{Bi} x\ 100 \quad \ldots\ldots (7)$$

The image contains a total of I classes, representing different land cover categories. The extent of change in class I is denoted by Ci. Pi represents the percentage change specifically for class I. The reference image from 1994 is denoted as Li, while the most recent image from 2023 is represented as Bi.

### 3.2.5.3 Analysis of river water quality trends

To analyze the trend of water quality parameters, mean values, Time series plot was chosen since it involves plotting the water quality parameters mean values on the y-axis against the corresponding time points on the x-axis. This visualization allows us to observe any noticeable patterns or trends in the data. The formula is straight ward as below,

Y represents the values of the variable of interest.
X represents the time points at which the values of Y are recorded

Trend of the year (2019 and 2023) mean $\pm$ SD of water quality parameters were extracted from previous archive data and thematic research result into Microsoft Excel 2016 edition and the results presented using descriptive statistics. To test the variability between S1, S2, S3, S4, S5, S6, S7, S8, S9 and S10 mean values of river water quality parameters Cr, Cd, Pb and Zn, Temperature, PH, TDS, Dissolved Oxygen (DO), Salinity and Turbidity, analysis of variance (ANOVA) were conducted and tested at 95% confidence level and P value of 0.05.

To analyze the significance in water quality paired t-test is used. Paired t-test analysis is a statistical analysis that can be used to examine the significances in water quality parameters before and after land use and land cover changes is conducted. The paired t-test is typically used when the same sample location is measured at two different time points. Each measurement consists of observations, one before the land use change (2019) and one after change (2023). The hypothesis testing for paired t-test is used to analyze whether there is a statistically significant difference in water quality parameters between 2019 and 2023. The null hypothesis assumes that there are no significant differences, while the alternative hypothesis suggests there is a significant difference.

### 3.2.5.4 Analysis of LULC and river water quality

To analyze and understand the relationships and effects of multiple independent variables on one or more dependent variables, multiple linear regression and multivariate regression can be used. Both regression methods involve mathematical technique determining the best fitting regression

coefficient that minimize the discrepancy between the observed data and predicted values. Multiple linear regression allows to analyze the impact of multiple independent variables on a single dependent variable. However, Multivariate regression allows for analyzing the interrelationships among the dependent variables, capturing any shared or correlated effects of the independent variables on multiple outcomes simultaneously. Multiple linear regression involves analyzing the relationship between a single dependent variable and multiple independent variables. The focus is on understanding how the independent variables collectively influence the dependent variable. However, multivariate regression extends the concept of multiple linear regression by analyzing the relationships between multiple dependent variables and multiple independent variables simultaneously. It explores how the independent variables collectively affect each of the dependent variables.

Multiple linear regression was effective for assessment of land use change impacts on water quality where after used by different researcher in this field Tahiru, et al., (2020) was used for this study. Hence, the interest of the study with regard to this objective is to analyze the effect of land use and land cover change on river water quality and household food crop production. Therefore, multiple linear regression model is selected.

In multiple linear regression, the goal is to model the relationship between a dependent variable (Y) and multiple independent variables ($X_1$ , $X_2$ , ..., X□ ). The regression model is represented as:

$$Y = \beta o + \beta 1X1 + \beta 2X2 + \ldots + \beta pXp + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equation (8)}$$

where $\beta_0$ , $\beta_1$ , $\beta_2$ , ..., β□ are the regression coefficients associated with each independent variable, and ε represents the error term.

The regression coefficients (β) estimate the impact of each independent variable on the dependent variable. The estimation process involves minimizing the sum of squared errors (SSE) between the observed Y values and the predicted values based on the regression equation.

The Pearson correlation coefficient (r) is a measure of the strength and direction of the linear relationship between two variables. It is calculated using the following formula:

$$r = (\Sigma(X_i Y_i) - (\Sigma X_i)(\Sigma Y_i)/n) \,/\, sqrt((\Sigma X_i^2 - (\Sigma X_i)^2/n) * (\Sigma Y_i^2 - (\Sigma Y_i)^2/n)) \ldots\ldots (9)$$

Where:

$X_i$ and $Y_i$ represent individual data points (observations) of X and Y, respectively.

Σ indicating the sum of the calculations across all data points.

$\Sigma X_i$ represents the sum of all X values.

$\Sigma Y_i$ represents the sum of all Y values.

n represents the total number of data points.

The formula calculates the covariance between X and Y ($\Sigma(X_i Y_i) - (\Sigma X_i)(\Sigma Y_i)/n$) and normalizes it by dividing it by the product of the standard deviations of X and Y [$(\Sigma X_i^2 - (\Sigma X_i)^2/n) * (\Sigma Y_i^2 - (\Sigma Y_i)^2/n)$], taking the square root.

The Pearson correlation coefficient ranges between -1 and 1. A value of -1 indicates a perfect negative linear relationship, 1 indicates a perfect positive linear relationship, and 0 indicates no linear relationship between the variables. The guideline for correlation is (Very weak correlation = 0.00 - 0.19, Weak = 0.2 – 0.39, Moderate = 0.4 – 0.59, Strong = 0.6 – 0.79, Very strong = 0.8 – 1.0).

### 3.2.5.5 Analysis of LULCC and household food production

The total crop land size in the catchment during 2019 and 2023 were retrieved from land use classes. The variation in land use change patterns and trend is conducted including the magnitude and direction of change by identifying increase or decrease in specific land use class. The qualitative information from the institutional key informant interview and the farmer key informant interview story explored and organized in themes to facilitate the analysis. Change in crop yield, availability of agricultural land, access to resources for food production, soil fertility. The consistencies and discrepancies between qualitative insight and quantitative analysis is maintained. The qualitative and quantitative findings then integrated and interpreted by combining the result from correlation analysis and comparative key informant from key informant and interpreting the finding. The implication of the findings for the effect of land use land cover change on household food crop production was identified. The relationship between farm size, land use changes and implications for household food crop production was determined

by Pearson correlation analysis using, food crop production and LULCC of two data and the trend was identified.

### 3.2.6 Qualitative data analysis

The qualitative data refers to non- numeric information such as interview transcript, notes, and audio recordings, images and text documents (that will be obtained through key informant interview and field observation) will be analyzed through narrative and framework analysis focusing on proving meanings and explanation to the perceptions of the informants so as to dig out issues under investigation.

### 3.2.7 Description of variables and hypothesis

Based on the review of the literature, practical experiences and availability of data, explanatory variables which have logical and justifiable rational affecting river water quality and household food crop production are identified. These are presented as follows;

**Dependent variables**

**River water quality:** It was the first dependent variable. The main intention here is to identify the river water quality parameters that can affected by land use change.

**Household food production:** it was another dependent variable. The main intention here is to identify major land use change that affect household food crop production.

**Outcome**

Regarding river water quality is that refers various physical, chemical, and biological parameters that determine the suitability of water for different uses. Likewise, internationally EPA has set standard water quality as Clean Water Act and defined the river quality as standard that are acceptable in river and other water bodies to protect human health, aquatic life, and the environment. In addition, river water can be assessed and evaluated using seven common dimensions. These are physical parameters, chemical, biological, nutrient, microbiological,

toxicity and ecological. Therefore, toxicity (heavy metals) and physio chemicals are indicators used to measure river water quality.

Regarding household food production is that it refers to the practice of growing and producing food at household or individual level to obtain sufficient food on a day-to-day basis. Likewise, food security is defined as the ability of people to secure adequate food. Therefore, availability of large farmland size in hector is used to for food security interims of increasing household own food production potential. Moreover, food security has three dimensions namely food availability, food access and food use. Food availability in the definitions implies that a country must have sufficient quantities of available on consistent basis at both national and regional level. Food access the ability of a nation and households to acquire sufficient food on a sustainable basis. Through if there were large farm land size; there is a high food production and can increase to food security in the households.

**Independent variables**

The following potential explanatory variables, also called independent variables hypothesized to determine the river water quality and food crop production which are included for effect. These factors are related to the land use and land cover classes, demographic, social and institutional factors and these are explained as follows.

**Settlement and buildup (Settle)):** It is a continuous variable measured in "$km^2$" and it represent the total settlement and buildup covered land of the area. Human interference can affect river water quality through increasing housing development, industrial activities, vehicle emission increased use of chemical and improper waste disposal. Expansion of settlement and buildup areas with expense of crop land led to decrease in availability agricultural land for food production and loss of productive soil which can consequently limit capacity of households and communities to engage in agricultural activities. Moreover, based on previous studies, settlement and buildup land use showed most significant negative relationship with hydrological parameters. According to Yang et al. (2016); settlement and buildup was significant factor contributing to increased concentrations of pollutants, such as heavy metals and nutrients, in

river water. In the study area, settlement and buildup area was expected to have a negative effect on river water quality and household food production.

**Crop land (Crop):** It is a continuous variable measured in "$km^2$" and it presents to the total cultivated land of the area. A large size of cultivated land implies more production and availability of food grains. Food production can be increased extensively through expansion of area under cultivation (Haile et al., 2005; Babatunde et al.,2007). Crop land needs a continuous clearance of land surface for quality production. However, clearing activities of land for cropping can lead to increased salinity problems and the export of sediments and the decomposition of organic matter in streams which can lead to acidity problems (such as low pH and mobilization of dissolved heavy metals). Therefore, in this study it was hypothesized that crop land can increase agricultural activities consequently, affect the river water quality and household food crop production.

**Waterbody (Waterbody):** It is a continuous variable measured in "$km^2$" and it presents the total water cover area. Waterbodies such as pond, reservoir can trap sediments and prevent them from entering the river. However, if waterbodies are connected to river the sediments laden would be discharged into the river. This sedimentation process can increase the turbidity of river water. By acting as sediment traps, waterbodies may help improve water quality downstream, reducing the potential negative impacts on crop production and it contribute to the overall water availability in the catchment. It can also serve as water sources for irrigation, particularly during dry periods. Waterbodies are as ecosystem services providers in agricultural landscapes (Neus Rodríguez-Gasol et.al.,2020). Adequate water availability is crucial for crop growth and production, and the presence of waterbodies can help ensure a more reliable water supply for agricultural purposes and moderate temperature extremes, increase humidity, and create localized cooling effects. Therefore, in this study it was hypothesized that the increase in waterbody can affect river water quality and household food crop production.

**Forest land (Forest):** It is a continuous variable measured in "$km^2$" and it presents to the total land covered with forest. In this study forest land is another identified independent variable that can affect river water quality. In the absence of human intervention activities, natural forests would have no significant adverse effect on river water quality. According to Nainar et al. (2017), forest has some contribution to the preservation of water quality and reduce erosion. The

presence of forest land near rivers of has a positive impact on both water quality and of the river and production of food by a household through sediment control, biodiversity support, nutrient retention and agroforestry. Therefore, in this study it was hypothesized that forest land in the vicinity of rivers positively affects both river water quality and household food crop production.

**Barren land (Bare):** It is a continuous variable measured in "$km^2$" and it presents to the total land without vegetation cover. Lack of vegetation cover make the land susceptible to erosion by wind and water. Erosion can lead to the loss of topsoil, which contains essential nutrients for crop growth. Sediments eroded from barren land can enter rivers, increasing turbidity and degrading water quality. Excessive sedimentation can reduce the availability of clean water for irrigation. Barren land lacks organic matter, which is crucial for maintaining soil fertility and structure which can reduces the absorption and filtration capacity of the soil. The lack of vegetation on barren land can lead to significant climate changes which can affect crop growth by increasing water stress on plants, enhance evaporation rates, and create less favorable conditions for crop production. In areas with contaminated soils, barren land can contribute to the transport of heavy metals into rivers through erosion and runoff. Therefore, in this study it was hypothesized that increase in the bare land cover will negatively affect the river water quality and household food production.

**Grazing land (Grazing):** It is a continuous variable measured in "$km^2$" and it presents to the total land covered with grasses. Large grazing land would create expansion of livestock production which can lead to overgrazing or removal of vegetation along river side. This can lead to increased solar radiation exposure, resulting in higher water temperatures. Animal waste and overgrazing can increase nutrient concentration, leading to higher PH and TDS concentrations. Additionally, sediment erosion and intensive grazing on land can result in excessive nutrient inputs from animal waste and soil compaction which can increase turbidity of the water. Grazing land practices can influence soil erosion, potentially exposing underlying contaminated soils and transporting heavy metals into water bodies. Excessive nutrient runoff can also affect crop production if the nutrient levels become imbalanced or if the runoff carries away essential nutrients needed for crop growth. Therefore, in this study it was hypothesized that grazing land would have potential effect on river water quality and household food production.

**Shrub land (Shrub):** It is a continuous variable measured in "$km^2$" and it presents to the total land covered with sh. Shrub land can provide shade and regulate temperature in its immediate vicinity. The presence of shrubs can help reduce solar radiation exposure and thus lower water temperature in river near the shrub land. It can also indirectly influence dissolved oxygen levels in rivers through its impact on riparian vegetation and aquatic habitat by providing shade and organic matter inputs, which can help regulate water temperature and promote oxygen production by aquatic plants. This, in turn, can enhance dissolved oxygen concentrations, benefiting aquatic organisms and potentially supporting crop irrigation water quality. Shrub land can help reduce soil erosion and sediment runoff into rivers through vegetation and root systems of shrubs which can help to stabilize soils, reducing the amount of sediment carried by runoff. Consequently, it can contribute to lower turbidity levels in rivers, improving water clarity. The organic matter produced by shrubs can contribute to nutrient availability helping both agricultural land and natural vegetation. Therefore, in this study it was hypothesized that shrub land would positively affect both river water quality and household food production.

**Urban plan:** It is qualitative independent variable. A city should have urban plan which can be guided for its development. Urban plan can influence land use decisions, infrastructure development, and storm water management practices, which can have a substantial impact on river water quality. Planning that integrates sustainable practices, such as low-impact development techniques, green infrastructure and riparian buffer zones, can help mitigate storm water runoff and reduce water pollution. In addition, planning decisions that prioritize urban development without considering food production needs can lead to the loss of productive agricultural land and decreasing local food production. Urban planning would consider the livelihood and future development aspects of a city. The structure plan also forwarded a way of considering the slope of riversides and various ways of developing these sloped riversides as green buffer zone (AACPPO 2017). Therefore, in this study it was hypothesized that urban planning significantly affects both river water quality and household food production, with outcomes depending on the integration of sustainable practices, green infrastructure and land use pattern.

**Rivers and riversides development and climate change:** It is qualitative independent variable. Effective institutions ensure the integration of sustainable practices in river and river-side

development plans. This may involve the establishment of regulatory frameworks, guidelines, and standards that promote pollution control, proper waste management, and protection of riparian zones. Institutions that actively engage stakeholders and facilitate participatory decision-making processes are more likely to incorporate diverse perspectives and environmental considerations. Institutions can influence land use planning and zoning regulations to support and protect agricultural land, urban community garden and urban agriculture through designing suitable areas for food crop production, promoting sustainable farming practices, implementing land preservations can increase household food production. Therefore, it was hypothesized that river and river side development institutions significantly affect both river water quality and household food production, with outcomes depending on the effectiveness of governance structures, regulatory frameworks, and implementation of sustainable practices.

**Environmental protection institution:** It is qualitative independent variable. Environmental factors related to land use, such as deforestation, urban expansion and intensive agriculture can affect river water quality. Deforestation enhance soil erosion and sedimentation in rivers bringing to increase in turbidity and reduced water quality. Change in rainfall patter extremes can lead to crop failure, reduce yield and increase vulnerability to pests and diseases affecting household food production. It can also alter river ecosystems, increase sedimentation and impact nutrient level, dissolved oxygen and water temperature. Developing watershed planning is crucial to preventing urban river pollution, its contribution will be limited if not adequately integrated with urban plans to facilitate its implementation and ensure its sustainability (Bernhardt and Palmer 2007). Therefore, it is hypothesized that environmental protection authority significantly affect both river water quality and household food production, as they contribute to the implementation of effective regulations, sustainable practices, and conservation measures that promote environmental health and resilience.

**City administration beautification and cemetery development:** It is qualitative independent variable. adopt responsible pollution management practices, such as proper waste disposal, management of chemicals, and implementation of erosion control measures. By preventing contamination of nearby water bodies and minimizing the release of pollutants into the environment. The institution also Engage in community outreach to promote environmental awareness. Increased community understanding of the importance of water quality and

sustainable food production can lead to individual actions that contribute to improved environmental outcomes. The urban beautification efforts involve creation of green spaces, parks, and gardens within cities. These areas can be designed to incorporate urban agriculture practices, such as community gardens or rooftop farming. Urban agriculture initiatives can contribute to household food production by providing opportunities for local food production and reducing reliance on distant food sources. They can also prioritize the preservation of open spaces and natural landscapes. This can indirectly contribute to maintaining ecological balance, protecting watersheds, and minimizing soil erosion. Therefore, it is hypothesized that in city administration beautification and cemetery development institutions would have indirect impacts through potential influences on land use practices, pollution management, and community engagement.

**City land administration:** It is a qualitative independent variable. City land administration institution can develop land use plans that prioritize the protection of watersheds, riparian zones, and other ecologically sensitive areas. By designating buffer zones, preserving wetlands, and encouraging responsible land management practices, these institutions can help minimize soil erosion, reduce nonpoint source pollution, and maintain water quality in rivers. Effective land administration institution also recognizes the importance of preserving agricultural lands within the city's boundaries. Therefore, in this study it was hypothesized that Addis Ababa City Land Administration institution significantly affect river water quality and household food production through their influence on land use planning, zoning regulations, and sustainable development practices.

**City administration trade bureau urban agriculture sector:** It is a qualitative independent variable. The institution can promote proper waste management practices within urban agriculture systems, including composting and recycling. minimizing waste generation and ensuring responsible disposal of organic waste, the institution can prevent potential contamination of water bodies and reduce the release of pollutants into the environment. Urban agriculture sector institution can promote organic farming practices, which minimize the use of synthetic fertilizers, pesticides, and herbicides and promote local food production by supporting initiatives like community gardens, rooftop gardens, and urban farms. Conversion of land use from non-urban to urban uses, because it requires an increased need for space in (existing)

settlement areas Nuissl, H., Siedentop, S. (2021). Increased local food production helps enhance household food security and reduce pressure on natural resources used in conventional agriculture The institution can promote proper waste management practices within urban agriculture systems by minimizing waste generation and ensuring responsible disposal of organic waste preventing potential contamination of water bodies. Therefore, in this study it was hypothesized that City administration trade bureau's urban agriculture sector institution can have positive effects on river water quality and household food production through its influence on promoting sustainable agricultural practices, reducing reliance on external food sources, and implementing pollution management strategies.

**City administration urban job creation and food security agency:** It a qualitative independent variable. Facilitating access to land for urban agriculture, allocate community garden spaces, and provide necessary resources such as seeds, tools, and irrigation systems through supporting local food production will reduce the reliance on external food sources. Establishing connections between urban farmers and local markets, restaurants, and institutions, facilitating the sale and distribution of locally produced food. This support for local food systems encourages urban farmers, increases their income opportunities, and promotes sustainable agriculture practices within the city. Therefore, it was hypothesized that City administration urban job creation and food security agency may have limited direct effects on river water quality but can significantly impact household food production through its focus on promoting sustainable agriculture, supporting local food systems, and enhancing food security.

**Non-governmental institution:** It is qualitative independent variable. **I**ndustries are the main contributor of river water pollution through untreated wastes. Anthropogenic activities such as industry wastes have considerably influenced urban water quality (Alberti et al., 2003; Patra et al., 2018). Effective effluent management of industry reduces the release of pollutants, such as heavy metals, chemicals, and nutrients, into rivers, thereby positively influencing water quality. The institution can implement waste management strategies, including proper disposal and recycling of industrial waste, to prevent contamination of water bodies. The institution can facilitate the integration of urban agriculture within industrial areas, such as rooftop gardens or vertical farming. This integration not only enhances food production but also contributes to green spaces, reduces urban heat island effects, and improves overall environmental quality. Therefore,

in this study it was hypothesized that industry activities can have both positive and negative effects on river water quality and household food production. While industrial activities may contribute to pollution and environmental degradation, the institution's implementation of sustainable practices and pollution control measures can help mitigate these negative impacts and support sustainable food production.

# CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter presents the main results and discussion of the study. It is divided in to five sub sections. The first sub-section describes the pattern of land use and land cover, accuracy assessment and three decades change detection analysis of the LULC in the study area. The second sub section presents the trend of water quality for the two years. The third sub-section presents analysis of LULC change and river water quality and their indicators. The fourth sub-section shows that the finding from analysis that identifies the effect of LULCC on river water quality and household food crop production. Finally, the fourth sub-section discusses about institutional challenges that affect river water quality and household food production.

## 4.1 Land Use and Land Cover Dynamics of the study area

### 4.1.1 LULC Pattern of Little Akaki River Catchment in 1994

Figure 4.1 displays the layout of the land use and land cover (LULC) map created using Landsat 4-5TM data, accompanied by a bar chart illustrating the percentage distribution of different land use categories. Supplementary appendix 1, 2, and 3 provide information on the area distribution of land types in hectares, square kilometers, and percentages, along with metrics such as producer accuracy, user accuracy, overall accuracy, and kappa coefficient for the year 1994.

According to the findings of this study, the largest land use class is Crop land, covering an area of 112.15 square kilometers, which accounts for 27.81% of the total studied area. Settlement and build-up areas rank as the second-largest land use class, occupying 101.77 square kilometers or 25.24% of the total area. Barren land is the third-largest land use class, covering 59.67 square kilometers or 14.79% of the total area. Grazing land is identified as the fourth-largest land use class, spanning 49.57 square kilometers or 12.3% of the total area. Forest land encompasses 42.53 square kilometers or 10.54% of the total area, making it the fifth-largest land use class. Shrub land covers an area of 23.03 square kilometers (5.71%), while the waterbody represents 14.52 square kilometers (3.6%) of the total area.

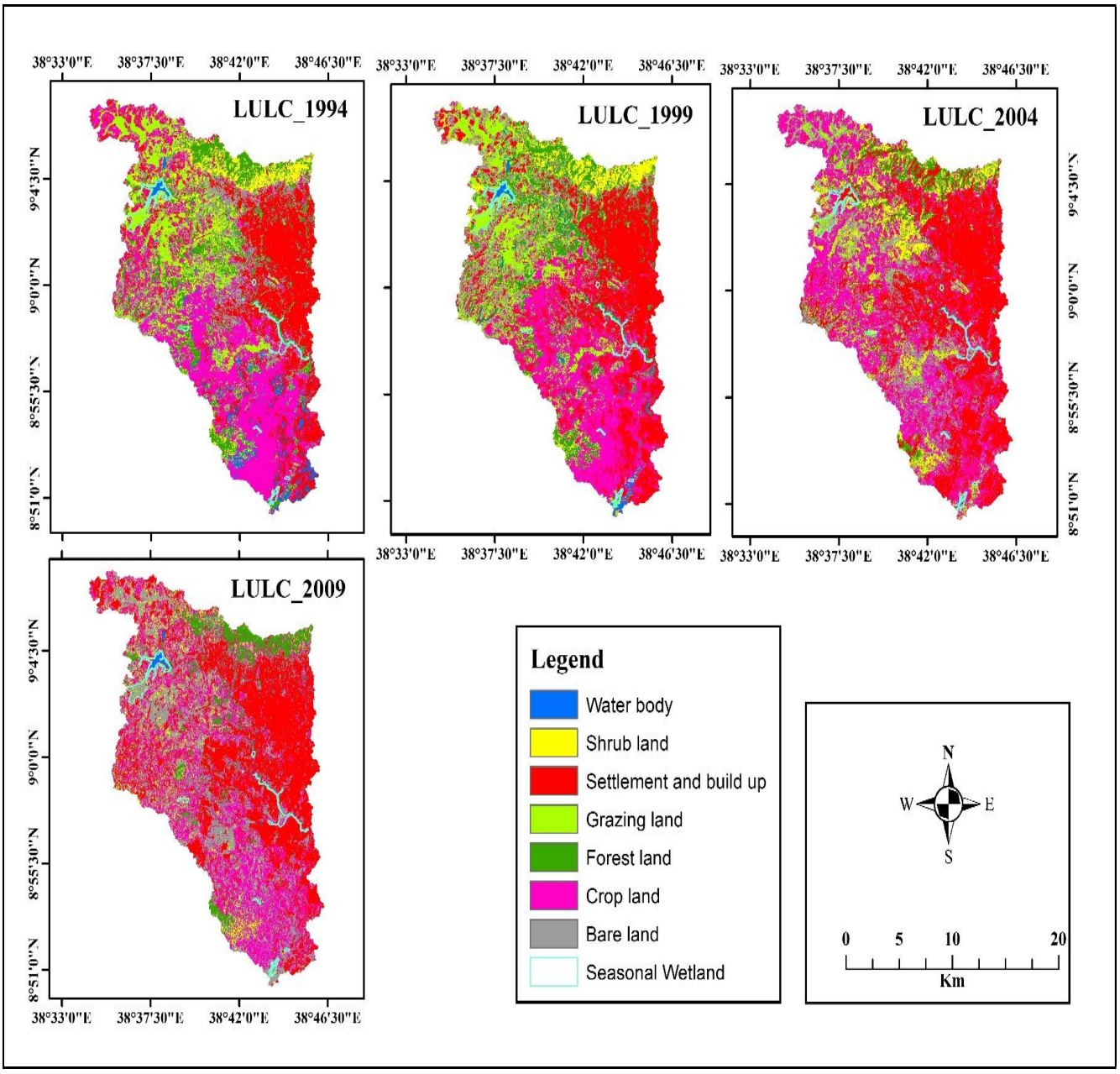


**Figure 4.1. Pattern of LULC of Little Akaki river catchment**

### 4.1.2 LULC pattern of Little Akaki river catchment in 1999

The land use classification for the year 1999 was carried out using Landsat 4-5TM data, as illustrated in Figure 4.1. The results of the study reveal that Settlement and build-up areas dominated the land area in 1999, covering 122.97 square kilometers or 30.5% of the total area. Crop land ranked as the second-largest land use class, encompassing 99.11 square kilometers or

24.58% of the total area. Grazing land followed with a coverage of 61.73 square kilometers, representing 15.31% of the total area. Forest land and Bare land were identified as significant land use classes, occupying 46.52 square kilometers (11.27% of the total area) and 45.92 square kilometers (11.39% of the total area), respectively. Shrub land and Water body were the remaining land use classes, accounting for 17.88 square kilometers (4.43%) and 9.10 square kilometers (2.26%) of the total area, respectively. Supplementary appendix 4, 5, and 6 provide detailed information on land use classes in terms of hectares, square kilometers, percentages, as well as metrics such as producer accuracy, user accuracy, overall accuracy, and kappa coefficient for the year 1999.

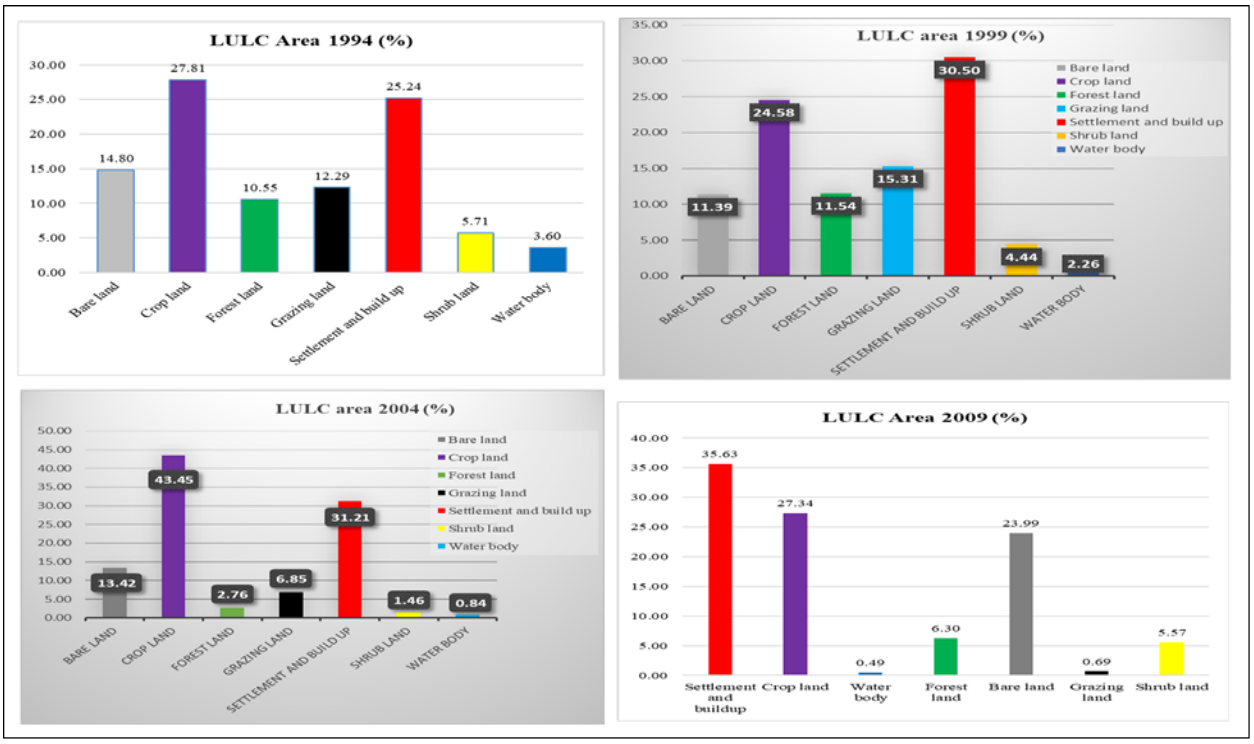


**Figure 4.2. Area distribution clustered bar chart of Little Akaki river catchment**

### 4.1.3 LULC pattern of Little Akaki river catchment in 2004

The land use classification for the year 2004 was created using Landsat 7ETM+ data. Figure 4.1 illustrates the distribution of different land use classes. The dominant land use classes in 2004 were settlement and build-up areas, covering 135.6 $km^2$ (33.61% of the total area), and crop land, covering 133.53 $km^2$ (33.1% of the total area). Other land use classes included bare land (53.09

$km^2$, 13.16% of the total area), shrub land (33.95 km2, 8.42% of the total area), forest land (25.20 $km^2$, 6.25% of the total area), grazing land (20.17 $km^2$, 5.00% of the total area), and water bodies (1.87 $km^2$, 0.46% of the total area). Supplementary appendix 7, 8, and 9 provide additional details such as land use class measurements in hectares and square kilometers, percentages, producer accuracy, user accuracy, overall accuracy, and kappa coefficient for the year 2004.

### 4.1.4 LULC pattern of Little Akaki river catchment in 2009

The layout of the land use and land cover (LULC) map created using Landsat 7ETM+ data is presented in Figure 4.2, accompanied by a bar chart illustrating the percentage distribution of different land use categories. Supplementary appendix 10, 11, and 12 provide detailed information on the area distribution of land types in hectares, square kilometers, and percentages, as well as metrics such as producer accuracy, user accuracy, overall accuracy, and kappa coefficient for the year 2009. According to the findings of this study, Settlement and build-up areas emerge as the largest land use class, covering an area of 143.74 square kilometers or 35.63% of the total studied area. Crop land follows as the second-largest land use class, occupying 110.31 square kilometers or 27.34% of the total area. Bare land is identified as the third-largest land use class, spanning 96.77 square kilometers or 23.99% of the total area. Forest land ranks as the fourth-largest land use class, covering 25.40 square kilometers or 6.3% of the total area. Shrub land covers an area of 22.46 square kilometers (5.57%), while Grazing land and Water body represent smaller land use classes, with coverages of 2.76 square kilometers (0.7%) and 1.96 square kilometers (0.49%) respectively, of the total area.

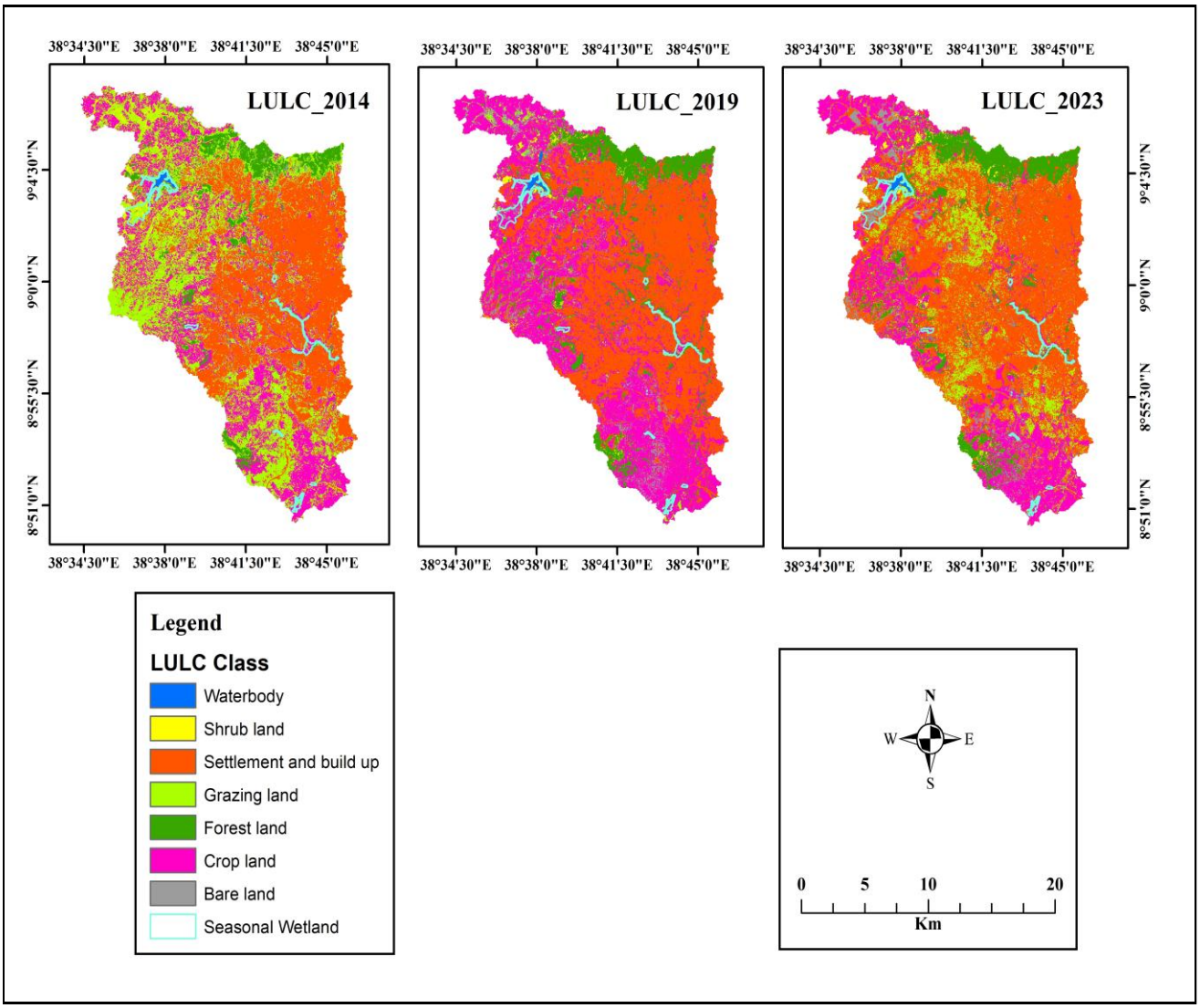


**Figure 4.3. Pattern of LULC of Little Akaki river catchment**

### 4.1.5 LULC pattern of Little Akaki river catchment in 2014

Figure 4.3 displays the layout of the land use and land cover (LULC) map created using Landsat 8-9 OLI/TIRS data, accompanied by a clustered bar chart illustrating the percentage distribution of different land use categories. Supplementary appendix 13, 14, and 15 provide detailed information on the area distribution of land types in hectares, square kilometers, and percentages, as well as metrics such as producer accuracy, user accuracy, overall accuracy, and kappa coefficient for the year 2014. According to the findings of this study, Settlement and build-up areas emerge as the largest land use class, covering an area of 136.48 square kilometers or 33.83% of the total studied area. Bare land follows as the second-largest land use class,

occupying 128.1 square kilometers or 31.8% of the total area. Crop land is identified as the third-largest land use class, spanning 106.5 square kilometers or 26.4% of the total area. Forest land ranks as the fourth-largest land use class, covering 24.1 square kilometers or 5.9% of the total area. Grazing land, Water body, and Shrub land represent smaller land use classes, with coverages of 6.3 square kilometers (1.6%), 1.25 square kilometers (0.31%), and 0.7 square kilometers (0.2%) respectively, of the total area

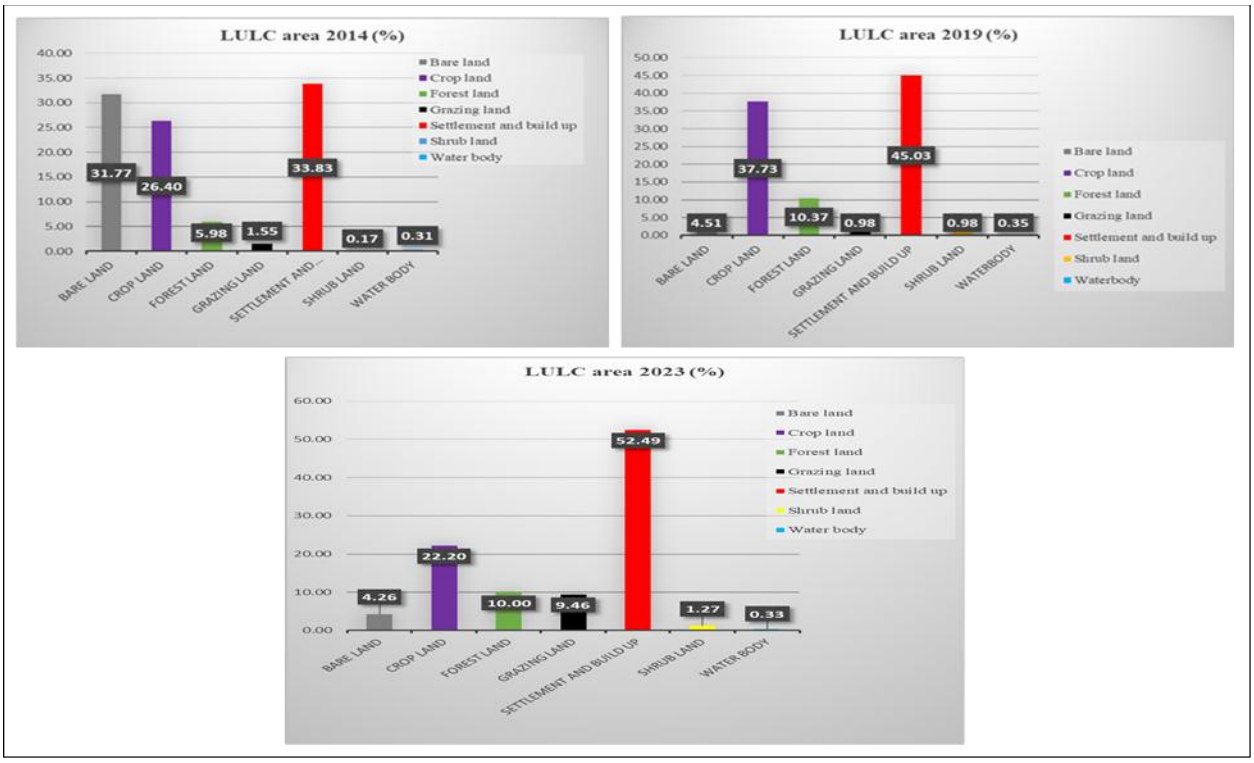


**Figure 4.4. Area distribution clustered bar chart of Little Akaki river catchment**

### 4.1.6 LULC pattern of Little Akaki river catchment in 2019

Figure 4.6 depicts the layout of the land use and land cover (LULC) map created using Landsat 8-9 OLI/TIRS data, accompanied by a clustered bar chart illustrating the percentage distribution of different land use categories. Supplementary appendix 16, 17, and 18 provide detailed information on the area distribution of land types in hectares, square kilometers, and percentages, as well as metrics such as producer accuracy, user accuracy, overall accuracy, and kappa coefficient for the year 2019. According to the findings of this study, Settlement and build-up areas emerge as the largest land use class, covering an area of 181.66 square kilometers or

45.03% of the total studied area. Crop land follows as the second-largest land use class, occupying 152.21 square kilometers or 37.73% of the total area. Forest land is identified as the third-largest land use class, spanning 41.83 square kilometers or 10.37% of the total area. Bare land ranks as the fourth-largest land use class, covering 18.21 square kilometers or 4.51% of the total area. Grazing land, Shrub land, and Water body represent smaller land use classes, with coverages of 3.97 square kilometers (0.98%), 3.93 square kilometers (0.97%), and 1.41 square kilometers (0.35%) respectively, of the total area.

### 4.1.7 LULC pattern of Little Akaki river catchment in 2023

Figure 4.7 presents the layout of the land use and land cover (LULC) map created using Landsat 8-9 OLI/TIRS data, along with a bar chart showcasing the percentage distribution of different land use categories. Supplementary appendix 19, 20, and 21 provide detailed information on the area distribution of land types in hectares, square kilometers, and percentages, as well as metrics such as producer accuracy, user accuracy, overall accuracy, and kappa coefficient for the year 2023. According to the findings of this study, Settlement and build-up areas are identified as the largest land use class, covering an area of 211.64 square kilometers or 52.49% of the total studied area. Crop land follows as the second-largest land use class, occupying 89.52 square kilometers or 22.2% of the total area. Forest land is identified as the third-largest land use class, spanning 40.3 square kilometers or 10.0% of the total area. Bare land ranks as the fourth-largest land use class, covering 17.19 square kilometers or 4.26% of the total area. Grazing land, Shrub land, and Water body represent smaller land use classes, with coverages of 38.14 square kilometers (9.46%), 5.13 square kilometers (1.27%), and 1.32 square kilometers (0.33%) respectively, of the total area.

**Table 4.1: Overall LULC class Area ($km^2$) and (%) from 1994-2023**

| LULC Class | Year | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1994 | | 1999 | | 2004 | | 2009 | | 2014 | | 2019 | | 2023 | |
| | Area | % | Area | % | Area | % | Area | % | Area | % | Area | % | Area | % |
| Settlement and buildup | 101.77 | 25.24 | 122.97 | 30.50 | 135.60 | 33.61 | 143.65 | 35.63 | 136.48 | 33.83 | 181.66 | 45.05 | 211.63 | 52.49 |
| Crop | 112.15 | 27.81 | 99.11 | 24.58 | 133.53 | 33.10 | 110.24 | 27.34 | 106.49 | 26.40 | 152.21 | 37.75 | 89.51 | 22.20 |
| Waterbody | 14.52 | 3.60 | 9.10 | 2.26 | 1.87 | 0.46 | 1.96 | 0.49 | 1.25 | 0.31 | 1.41 | 0.35 | 1.32 | 0.33 |
| Forest | 42.53 | 10.55 | 46.52 | 11.54 | 25.20 | 6.25 | 25.39 | 6.30 | 24.11 | 5.98 | 41.84 | 10.38 | 40.30 | 10.00 |
| Bare | 59.67 | 14.80 | 45.92 | 11.39 | 53.09 | 13.16 | 96.72 | 23.99 | 128.14 | 31.77 | 18.21 | 4.52 | 17.19 | 4.26 |
| Grazing | 49.57 | 12.29 | 61.73 | 15.31 | 20.17 | 5.00 | 2.76 | 0.69 | 6.26 | 1.55 | 3.97 | 0.98 | 38.14 | 9.46 |
| Shrub | 23.03 | 5.71 | 17.88 | 4.44 | 33.95 | 8.42 | 22.45 | 5.57 | 0.67 | 0.17 | 3.94 | 0.98 | 5.13 | 1.27 |
| Total Area | 403.24 | 100.00 | 403.25 | 100.00 | 403.41 | 100.00 | 403.17 | 100.00 | 403.40 | 100.00 | 403.23 | 100.00 | 403.21 | 100.00 |

Source: Own computation from the land use and land cover classification of the study area, 2023

From the above overall Table 4.1: it can be depicted that The LULC dynamics reveal a consistent and substantial increase in settlement and urban development areas over the analyzed period. The expansion of settlement areas, as evidenced by the rise from 101.77 $km^2$ (25.24%) in 1994 to 211.63 $km^2$ (52.49%) in 2023, signifies rapid urbanization and population growth. This trend aligns with global patterns of urbanization, driven by factors such as economic growth, rural-urban migration, and infrastructure development. Thus, the result of this research is consistent with previous research conducted by (Angel et al., 2011; Seto et al., 2013), where urban areas are expanding rapidly worldwide due to population growth, economic development, and migration from rural to urban areas.

The crop area demonstrates complex changes, characterized by both short-term fluctuations and long-term shifts. The initial decrease from 112.15 $km^2$ (27.81%) in 1994 to 99.11 $km^2$ (24.58%) in 1999 suggests potential agricultural land conversion or diversification of land uses. The subsequent increase to 133.53 $km^2$ (33.10%) in 2004 could be attributed to factors such as technological advancements, agricultural intensification, or changing market demands. However, the decline to 89.51 $km^2$ (22.20%) in 2023 implies possible land-use transitions, agricultural policies, or shifts in agricultural practices, such as land abandonment or the shift to non-agricultural uses. The result of this result aligns with a previous research finding by (Verburg et al., 2015; Lambin et al., 2001), where complex dynamics of agricultural land, influenced by factors such as changing market demands, technological advancements, and policy interventions. In addition, there is also a research finding where conversion of agricultural and natural land into built-up areas, leading to the loss of biodiversity, ecosystem services, and fragmentation of habitats (McDonald et al., 2011; Foley et al., 2005).

The relatively stable waterbody areas throughout the analyzed period indicate the preservation of natural hydrological features. Although minor fluctuations occurred, the overall percentage of waterbodies remained consistent. This suggests effective water resource management, conservation efforts, and the maintenance of ecological integrity within the study area. This result is consistent with the research finding conducted by (Wang et al., 2017; Carpenter et al., 2011), that preserving waterbodies for ecological integrity, water resource management, and flood control were important aspect. Moreover, there is also a study that highlighted the need for

maintaining riparian buffers, protecting the waterbody, and implementing sustainable land use practices to minimize water pollution and maintain its quality (Smart et al., 2017).

The forest area demonstrates a nuanced pattern of change over time, reflecting the interplay of multiple factors. The initial decline from 42.53 $km^2$ (10.55%) in 1994 to 25.20 $km^2$ (6.25%) in 2004 suggests potential deforestation or land-use conversions. The subsequent recovery to 40.30 $km^2$ (10.00%) in 2023 might indicate reforestation efforts, afforestation programs, or natural regeneration. However, the net change in forest cover remains relatively small, indicating the need for continued monitoring and conservation efforts to ensure sustainable forest management. According to the research finding by Hansen et al., (2013), deforestation as significant global environmental challenges, impacting biodiversity and climate regulation.

The significant fluctuations observed in the bare land areas signify complex land-use dynamics and potential land reclamation or rehabilitation processes. The notable increase from 53.09 $km^2$ (13.16%) in 2004 to 128.14 $km^2$ (31.77%) in 2014 suggests land-use changes such as urban sprawl, infrastructure development, or land degradation. The subsequent sharp decrease to 17.19 $km^2$ (4.26%) in 2023 implies potential land restoration, vegetation recovery, or land-use planning interventions. This result is consistent with previous studies conducted by Farley et al., (2020), where the potential for land reclamation and rehabilitation in bare areas, particularly in post-industrial or degraded landscapes. In addition, Palmer et al., (2016), explored that ecological restoration, soil remediation, and land-use planning to transform bare land into productive or ecologically valuable areas.

The grazing areas exhibit fluctuations that likely result from the interplay of socio-economic, environmental, and policy-related factors. The increase from 49.57 $km^2$ (12.29%) in 1994 to 61.73 $km^2$ (15.31%) in 1999 might reflect changes in livestock management practices, grazing policies, or agricultural land-use patterns. The subsequent decline to 38.14 $km^2$ (9.46%) in 2023 may indicate land-use conversions, agricultural intensification, or shifts in livestock production systems. Thus, finding gives insight with a research finding by Teague et al., (2013), that to balance livestock production with ecological conservation sustainable grazing practices, land use planning and rotational grazing should be maintained.

The shrub areas demonstrate complex changes influenced by a range of ecological and land management factors. The initial increase from 23.03 $km^2$ (5.71%) in 1994 to 33.95 $km^2$ (8.42%) in 2004 might be associated with ecological succession, natural regeneration, or land-use transitions. The subsequent decrease to 5.13 $km^2$ (1.27%) in 2023 could be a result of land-use conversions, vegetation management practices, or ecological disturbances.

4.1.8 Wetland

The area of seasonal wetland remains relatively stable with minor fluctuations over the years. In 1994, the wetland area occopies 5.02$km^2$, representing 1.25% of the total land area. From 1994 to 1999, there is a marginal decrease in wetland area by 0.01$km^2$ (0.01% of the total land area).

| **Year** | 1994 | 1999 | 2004 | 2009 | 2014 | 2019 | 2023 |
|---|---|---|---|---|---|---|---|
| **Area_km2** | 5.02 | 5.01 | 4.99 | 4.95 | 4.92 | 4.88 | 4.83 |
| **Change (km2)** | | 0.01 | 0.02 | 0.04 | 0.03 | 0.04 | 0.05 |
| **(%)** | 1.25 | 1.24 | 1.24 | 1.23 | 1.22 | 1.21 | 1.20 |

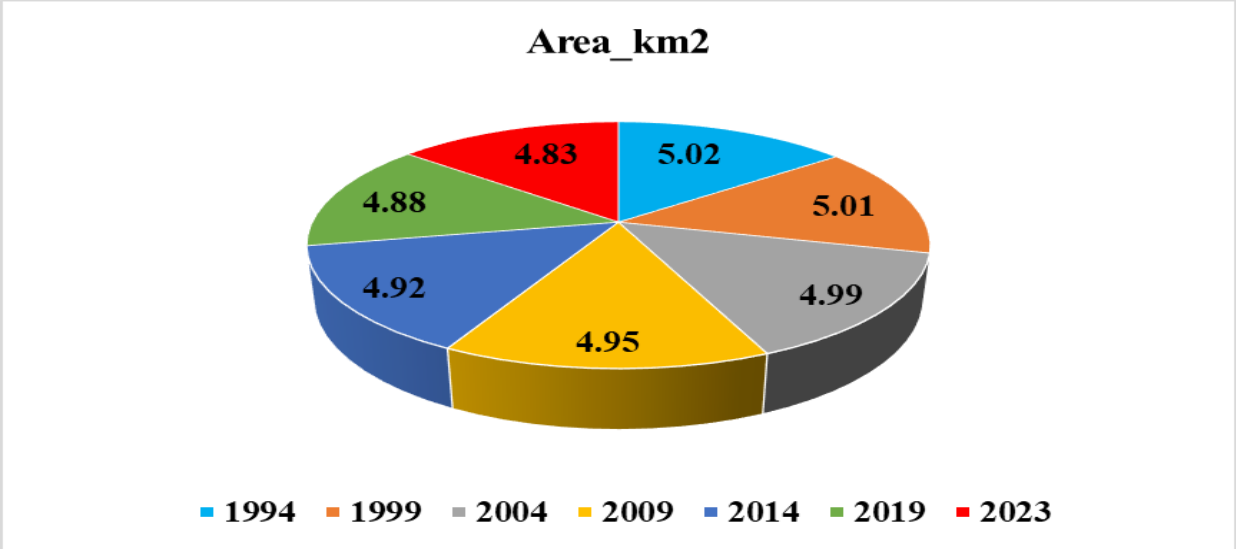


**Figure 4.8. Seasonal wetland area coverage comparison diagram from 1994 to 2023**

Between 1999 and 2004, there is a further decrease in wetland area by 0.02$km^2$ (0.01% of the total land area). This continued decline may indicate ongoing land use changes or environmental

factors affecting the wetland extent. The small absolute change suggests relatively stable conditions for the wetlands during this period.
From 2004 to 2009, the wetland are experiances a decline of 0.04km$^2$ (0.01% of the total land area). This decrese may indicate changes in land use, such as conversion to other land uses or the impact of human activities on wetland ecosystems. The cumulative effect of these chnages over time becomes more noticeable.

The trend of gradual decline in wetland area continues from 2009 to 2019, with a decrease of 0.03km$^2$ (0.01% of the total land area). This long term decline suggests ongoing land use transitions or environmental chnages that negatively affect wetland extent. The cumulative effect of these chnages becomes more apparent as the years' progress.

By 2023, the area of seasonal wetlands further decrease to 4.83km$^2$, representing 1.2% of the total land area. This decline of 0.05km$^2$ (0.01% of the total land arrea) indicates the continued loss of wetland area over time. The cummulative impact of land use chnages, agricultural practices, or policy interventions may be contributing to this reduction.

This shows consistent decline in th earea of seasonal welands over the years. While the absolute chnages in wetland area may seem small, the cumulative effect of these changes can have significant implications for biodiversity, ecosytem services, and overall landscape dynamics.

To address this decline, it essential to prioritize wetland conservation and management efforts. Implimenting measures such as wetland restoration, sustainable land use planning, and policy inteventions that protect and promote the value of wetland can help mitigate further loss and degradation, additionally, raising awarness about the importance of wetlands and promoting their conservation among policymakers, lan owners, and public is crucial for long tem preservation.

Generally, the analysis highlights the multi faceted nature of LULC changes over time. It underscores the need for a comprehensive understanding of the underlying drivers, including demographic trends, economic development, policy interventions, technological advancements, and environmental considerations.

## 4.2 Change detection analysis

### 4.2.1 LULC change detection from 1994-1999

The land use and land cover change detection analysis, as presented in Supplementary Appendix 23, reveals notable changes in different land use categories. In the year 1999, there was a decrease in the extent of Bare land and Crop land by approximately 13.75 square kilometers and 13.04 square kilometers respectively. Similarly, Water body decreased by 5.42 square kilometers and Shrub land by 5.15 square kilometers. Conversely, there was an increase in the area of Settlement and build-up, grazing land, and Forest land by 21.2 square kilometers, 12.16 square kilometers, and 3.99 square kilometers respectively. The highest percentage change was observed in the Settlement and build-up area, with an increase of 5.26%. Its coverage expanded from 25.24% in 1994 to 30.5% in 1999. Figure 4.8 provides a visual comparison of the land use areas for different classes and illustrates the change diagram. Table 4.2 presents a cross-tabulation of the land use data, offering a comprehensive overview of the distribution and changes in various land use categories.

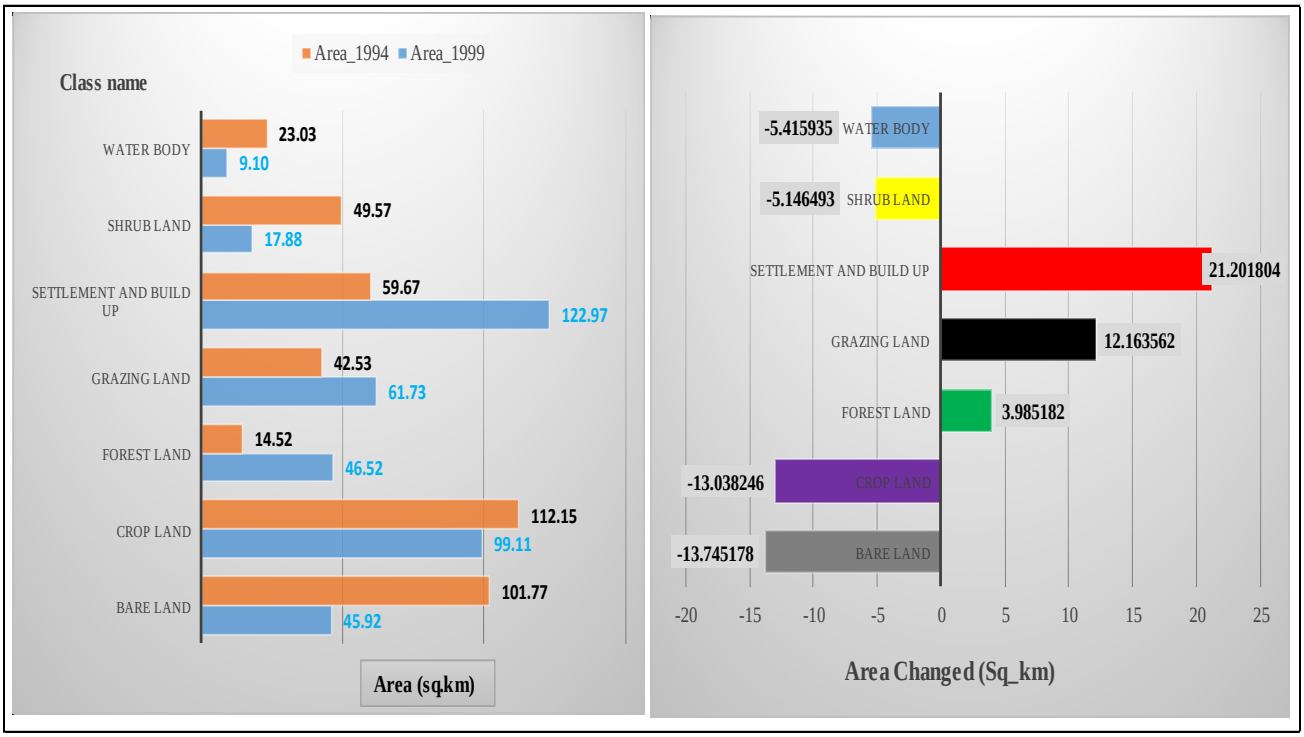


**Figure 4.8. Comparison and Area change diagram of the LULC Area in 1994 and 1999.**

#### 4.2.1.1 Change in Settlement and buildup Area

The primary transformation observed in the study area during the specified timeframe is the expansion of the buildup area. In 1994, the buildup area covered 101.77 square kilometers, and by 1999, it had increased to 122.97 square kilometers. This expansion is indicative of the development of new urban settlements. The unchanged area of 76.58 square kilometers represents the non-buildup regions adjacent to the settlement and buildup zone. Furthermore, there was a newly developed settlement and buildup area of approximately 46.32 square kilometers, as well as an expansion of the settlement and buildup area into other land use categories, totaling 25.14 square kilometers. The driving force behind this change is likely the rapid growth and improved transportation infrastructure in the capital city of Addis Ababa and the Sheger city areas, along with favorable conditions for industrial development within the catchment. The primary areas of development were along the Little Akaki river, while other regions may have lacked well-established road networks. The combination of industrialization, transportation development, and population migration led to human settlement and encroachment as people from various rural areas migrated to create new communities. To summarize, the significant change observed in the study area during the specified period is the expansion of the buildup area, which can be attributed to factors such as urbanization, improved transportation systems, industrial development, and population migration.

#### 4.2.1.2 Change in Crop land

The analysis of crop land change in the Little Akaki river catchment reveals that a significant portion of the crop land, approximately 59.91 $km^2$, remained unchanged throughout the period. However, around 52.17 $km^2$ of crop land transitioned into non-crop land categories such as forest, grazing land, settlement and buildup areas, shrub land, water bodies, and barren land. Conversely, there was an observed conversion of 39.17 $km^2$ from non-crop land to crop land. The cross-tabulation analysis confirms that a major portion of the crop land remained as crop land, while a substantial part converted into settlement and buildup areas between 1994 and 1999. This suggests a heavy dependence on crop production for farmers' livelihoods during that period. The total crop land decreased by approximately 13.04 $km^2$ over the five-year period, posing concerns for food security. The reasons behind this conversion include a shift towards

construction activities, decreased agricultural facilities, declining crop prices, increased demand for construction areas, industrial expansion, environmental changes, and technological factors.

Additionally, there have been instances where other land use classes have undergone conversion to crop land. This can be attributed to several factors, including the limited availability of suitable crop land, the growing demand for food due to population growth, and the decrease in agricultural land resulting from its conversion to settlement and buildup areas or bare land. Climate change effects and declining fertility of existing crop lands may also contribute to these conversions. The changes in land cover within the Little Akaki river catchment are primarily influenced by its geographical location and its connectivity with urban centers. The region has experienced an influx of migrants seeking increased economic opportunities and job availability. High levels of rural-to-urban migration driven by poverty and limited employment prospects in rural areas are also contributing factors. Moreover, the central location of the Little Akaki river within the city has attracted investments and stimulated development activities. As a result of rapid population growth, there is significant pressure to meet housing demands, which further impacts the farming sector and drives the need for change.

**Table 4.2: Cross-tabulation of LULC change from 1994-1999**

| Sum of Area change ($km^2$) | LULC, 1999 (Final) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC, 1994 (Initial) | Bare land | Crop land | Forest land | Grazing land | Settlement and build up | Shrub land | Water body | Grand Total |
| Bare land | 16.40 | 11.18 | 6.09 | 11.46 | 12.26 | 0.80 | 1.45 | 59.64 |
| Crop land | 11.68 | 59.91 | 2.21 | 11.81 | 25.05 | 0.41 | 1.02 | 112.08 |
| Forest land | 1.26 | 4.51 | 23.54 | 2.59 | 1.75 | 6.74 | 2.12 | 42.50 |
| Grazing land | 4.68 | 7.84 | 3.54 | 29.69 | 1.95 | 0.61 | 1.24 | 49.56 |
| Settlement and build up | 10.34 | 9.97 | 0.83 | 3.51 | 76.58 | 0.03 | 0.45 | 101.72 |
| Shrub land | 1.10 | 1.06 | 8.72 | 1.80 | 0.33 | 9.23 | 0.77 | 23.02 |
| Water body | 0.42 | 4.61 | 1.56 | 0.85 | 4.98 | 0.05 | 2.04 | 14.50 |
| Grand Total | 45.89 | 99.08 | 46.49 | 61.70 | 122.90 | 17.87 | 9.10 | 403.02 |

Source: Computed own using change detection analysis, 2023

#### 4.2.1.3 Change in Waterbody

The analysis of waterbody changes in the Little Akaki river catchment indicates a decrease of approximately 5.42 $km^2$. The unchanged waterbody area is estimated to be around 2.04 $km^2$, while newly emerged waterbodies cover approximately 7.06 $km^2$. Additionally, there has been a conversion of waterbodies to other land use types, totaling approximately 12.46 $km^2$. The decline in waterbodies can be attributed to human activities, such as the filling of wetlands and ponds to make space for housing and industrial areas. Climate change effects, including reduced rainfall and rising temperatures, may also contribute to this decrease. Furthermore, wetlands may be converted to other land types due to the increasing market value of the land.

#### 4.2.1.4 Change in Forest land

During the specified period, changes in forest land were observed in the Little Akaki river catchment. Approximately 23.54 $km^2$ of forest land remained unchanged, indicating the preservation of undisturbed forest areas. There was a conversion of 22.95 $km^2$ of non-forest land into forest land, while 18.96 $km^2$ of forest land transitioned into non-forest land. The cross-tabulation analysis confirms that a significant portion of the forest land remained intact and even exhibited some growth. This implies that a majority of the forested area has been effectively protected from disturbances. The incremental increase in forest land can be attributed to the plantation of new trees on previously non-forested land and the natural progression of shrub land towards becoming forested areas. Over the five-year period, the total forest land increased by approximately 3.99 $km^2$, which is a positive indication for sustainable ecosystem services. It is worth noting that the classification analysis revealed a smooth texture in satellite images for most of the harvested cropland, likely due to the timing of harvesting during the dry season. However, the forested areas showed an increase since 1994, and some shrub land has also been transformed into forested areas through local community-led afforestation efforts.

#### 4.2.1.5 Change in Barren Land

The analysis conducted in the Little Akaki river catchment revealed an unchanged area of approximately 16.4 $km^2$, along with the emergence of new barren land covering 29.49 $km^2$. Furthermore, there was a significant conversion of barren land into other land use classes,

amounting to 43.24 $km^2$. This transformation can be attributed to the growing population and their increasing need for space to meet basic requirements. To fulfill these needs, human encroachment occurred, resulting in the conversion of barren land into industrial areas, human settlements, crop fields, and other purposes. The study also observed a decrease in barren land, which can be attributed to the rising demand for settlements, industrialization, and urbanization. Additionally, barren land may have been transformed into grasslands or utilized as a source of raw materials for construction purposes. Over the five-year period, the barren land decreased by approximately 13.5 $km^2$.

#### 4.2.1.6 Change in Grazing land

The other major change that has occurred in this study area is grazing land. The grazing land in 1994 was 49.57 $km^2$ which has increased in 1999 to 61.73 $km^2$. The cross tabulation indicates the unchanged area of 29.69 $km^2$, non-grazing land to grazing land which means the newly developed grazing is about 32.01 $km^2$, and finally, grazing land to other land use which is about 19.87 $km^2$ was observed. The reason behind this change may be the crop land that has been used for crop production declined and changed to grazing land. It can also be the shrub land had cleared because of population increase and start for grazing purpose. Moreover, the waterbody has decreased in this period where river side area increased and start for to be used as grazing land.

#### 4.2.1.7 Change in Shrub land

The analysis conducted in the Little Akaki river catchment revealed an unchanged vegetation area of approximately 9.23 $km^2$. There was also a conversion of about 8.64 $km^2$ from other land use classes to shrub land, and a transition of approximately 13.79 $km^2$ from shrub land to non-shrub land. This transformation can be attributed to the plantation of new trees, which subsequently reached shrub height. The increased population migrating to the city center has resulted in a higher demand for energy sources. Consequently, forests have been utilized for charcoal production, as a source of home energy, and for tree cutting to sell in the market for various livelihood purposes. However, in some cases, the community may replant trees to ensure future use, while in other cases, tree replacement may not occur. As a result, newly planted trees

may reach the shrub level. Despite the increased population and the demand for food, the conversion of shrub land to crop land is not significant in the area.

### 4.2.2 LULC change detection from 1999-2004

The computed land use and land cover change detection is provided in Supplementary Appendix 23. During the studied period, there were notable changes in different land use classes. Crop land experienced a significant increase of approximately 34.42 $km^2$ (24.52%). Shrub land, settlement and build-up areas, and bare land also showed increases of 16.07 km2 (11.44%), 12.62 $km^2$ (8.99%), and 7.16 $km^2$ (5.1%) respectively. Conversely, grazing land and forest land exhibited substantial decreases of 41.56 $km^2$ (29.6%) and 21.32 $km^2$ (15.19%) respectively. Water bodies also decreased by 7.23 $km^2$ (5.15%). The highest percentage of change (-29.6%) was observed for grazing land, indicating a significant decrease. Figure 4.9 provides a comparison of the land use areas for different classes and a change diagram. Table 4.3 presents the cross-tabulation of the land use data.

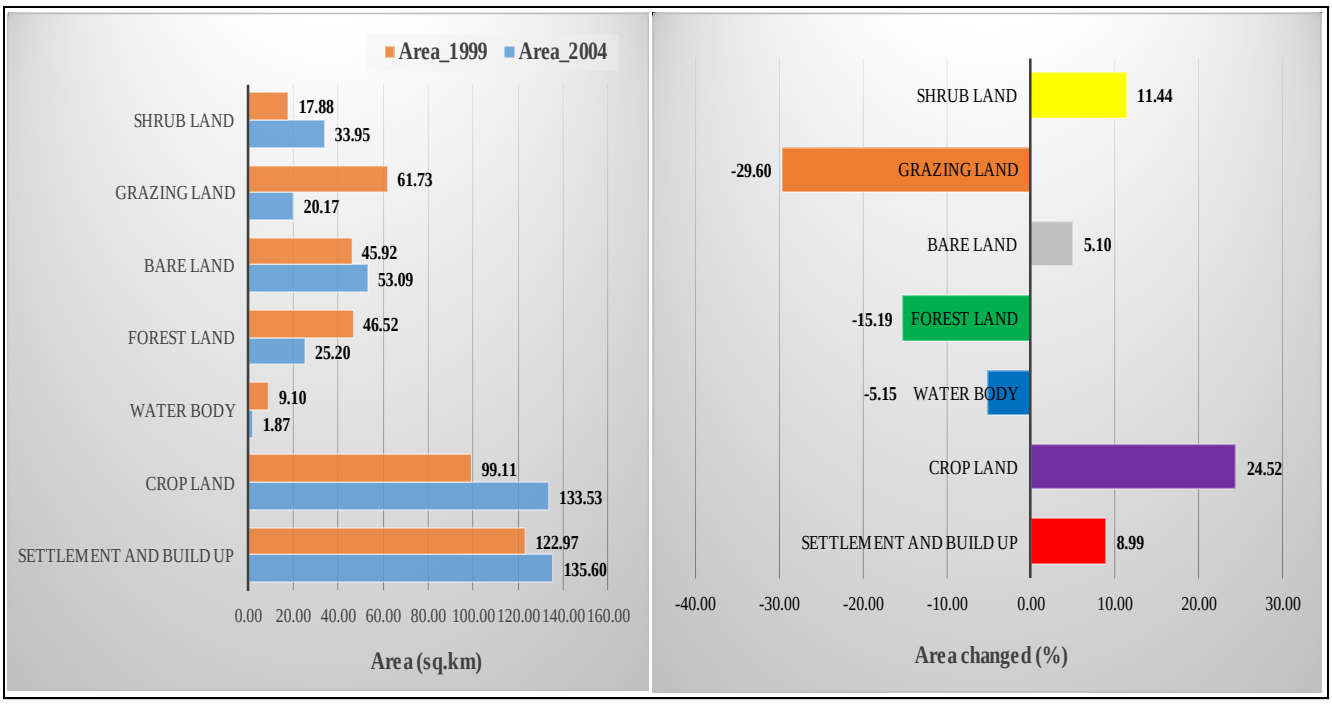


**Figure 4.9 Comparison and Area change diagram of the LULC Area in 1999 and 2004.**

#### 4.2.2.1 Change in Settlement and buildup Area

In 1999, the combined settlement and buildup area was 122.97 $km^2$, which expanded to 135.6 $km^2$ by 2004. The analysis revealed an unchanged area of 87.39 $km^2$, the conversion of other land cover areas into settlement and buildup areas totaling 48.06 $km^2$, and a transition of 35.39 $km^2$ from settlement and buildup areas into other land uses. The settlement and buildup area increased by 12.62 $km^2$, representing an 8.99% growth rate during this period. The primary reasons behind this change can be attributed to the improved transportation system in the capital city of Addis Ababa and the Sheger city areas. The expansion of industries along the river's edge has also played a significant role, as it necessitates intensive development, housing, and infrastructure within the catchment area. This finding aligns with a previous research study by Ogechi, et al., (2014) in the Keumbu region of Kisii Country, Kenya, which observed that population growth at an average rate of 20.5% resulted in the conversion of more agricultural land into settlement use, increasing by 0.658%. The emergence of new service sectors has likely contributed to the impact as well. Industrialization and improved access to transportation systems have led to high levels of migration, with people from various rural areas establishing new settlements. Although the size of cropland is increasing, the rapidly growing population requires greater food crop production to improve food security. Some informal settlement areas have taken measures to revert to their previous land uses.

#### 4.2.2.2 Change in Crop land

During the specified period, changes in crop land were observed in the Little Akaki river catchment. An area of approximately 45.2 $km^2$ remained unchanged as crop land, while significant conversions took place, including 53.86 $km^2$ of crop land transitioning into non-crop land (such as forest, grazing, settlement and buildup areas, shrub land, water bodies, and barren land), and 88.17 $km^2$ of other land use classes being converted into crop land. The cross-tabulation analysis indicates that a substantial portion of crop land remained consistent. However, a significant portion of the area was transformed into settlement and buildup areas between 1999 and 2004, highlighting the dependence of farmers on crop production for their livelihoods. Over the five-year period, the total crop land increased by approximately 34.42 $km^2$, which has positive implications for food security.

The driving factors behind this change can be attributed to government attention given to crop production in the study area. Additionally, the conversion of grazing land into crop land was pursued to increase crop production, driven by the growing demand for crops in the market and for self-consumption, resulting from population growth. The livelihood activities in the area have also contributed to increased crop production. Furthermore, limited availability of crop land, increased demand for food due to population growth, climate change effects, and decreased fertility of existing crop land have likely led to the conversion of other land use classes into crop land. The geographical location and connectivity of the Little Akaki river catchment with urban centers have significantly influenced land cover changes. The area has experienced increased human migration due to economic opportunities and job availability, while high rural-to-urban migration resulting from poverty and lack of employment opportunities may also be contributing factors.

#### 4.2.2.3 Change in Waterbody

During the study period, the waterbody in the Little Akaki river catchment experienced a decrease of 7.23 $km^2$. In 1999, the waterbody coverage was 9.1 $km^2$, which decreased to 1.87 $km^2$ by 2004. An area of approximately 0.22 $km^2$ remained unchanged as waterbody, while 1.65 $km^2$ of newly emerged waterbody was observed. Additionally, 8.88 $km^2$ of waterbody underwent conversion into other land use classes. The reduction in water bodies can be attributed to human encroachment patterns. Human activities, such as filling wetlands and ponds for housing and industrial areas, have led to the depletion of waterbodies. Improper utilization of river water has also contributed to the decline. The areas that were already depleted of water have become covered with grass and have started to remain bare. The decrease in forest coverage has further contributed to climate change, which, in turn, has affected the waterbody levels through reduced rainfall. Furthermore, wetlands have been converted to other land types due to the increasing land prices for sale.

**Table 4.3: Cross-tabulation of LULC change from 1999-2004**

| Sum of area change ($km^2$) | | LULC_2004 (Final) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC_1999 (Initial) | Settlement and build up | Crop land | Water body | Forest land | Bare land | Grazing land | Shrub land | **Grand Total** |
| Settlement and build up | 87.39 | 29.75 | 0.07 | 0.38 | 4.58 | 0.41 | 0.33 | **122.93** |
| Crop land | 24.31 | 45.20 | 0.19 | 0.86 | 19.65 | 6.04 | 2.80 | **99.06** |
| Water body | 2.43 | 2.35 | 0.22 | 1.02 | 0.43 | 1.09 | 1.56 | **9.10** |
| Forest land | 9.75 | 9.23 | 1.00 | 12.64 | 0.91 | 0.79 | 12.17 | **46.49** |
| Bare land | 7.54 | 26.34 | 0.13 | 0.82 | 6.63 | 1.66 | 2.74 | **45.87** |
| Grazing land | 2.40 | 18.83 | 0.12 | 1.61 | 20.74 | 10.04 | 7.94 | **61.72** |
| Shrub land | 1.62 | 1.67 | 0.14 | 7.82 | 0.10 | 0.13 | 6.39 | **17.87** |
| **Grand Total** | **135.45** | **133.37** | **1.87** | **25.15** | **53.04** | **20.16** | **33.92** | **403.04** |

Source: Computed own using change detection analysis, 2023

#### 4.2.2.4 Change in Forest land

The change in forest land has been described unchanged forest land which is about 12.64 $km^2$, other land use to forest land with 12.51 $km^2$ and forest land to non-forest land of about 33.85 $km^2$ was observed. The cross-tabulation shows us that a major portion of forest land continuous as forest land and showing some decrement. This may be majority of the forest land area has been protection. There has also shown some decrement which may be because of cutting trees. The total forest land is decreased by about 21.32 $km^2$ with in those five years and the decreasing rate of this land has negative effect on climate change and sustainable ecosystem services since its change is 15.19%. This finding is consistent with the previous study of Yonas et al. (2013) that a decline in forest land cover in northern Afar region over the past decades. Where the main reason for the decline found to be population growth, requiring land for farming and residential use resulting conversion of forest land. No matter how there is some shrub cover increment the level of deforestation was very high by local people during this period.

#### 4.2.2.5 Change in Barren Land

During the study period, an area of approximately 16.4 $km^2$ remained unchanged as barren land, while 6.63 $km^2$ of newly emerged barren land and 39.24 $km^2$ of barren land converted into other land use classes were observed in the Little Akaki river catchment. The population growth in the area has led to an increased demand for space to meet basic needs. Consequently, human encroachment has occurred, resulting in the conversion of barren land into industrialized areas, human settlements, crop areas, and other purposes. The increment in barren land is also noticeable, possibly due to the rising demands for settlement, industrialization, and urbanization. Additionally, the barren land may be transformed into grassland and utilized as a source of raw material for construction purposes. The barren land has experienced a growth of 7.16 $km^2$, representing a 5.1% increase within the five-year period.

#### 4.2.2.6 Change in Grazing land

The other major change that has occurred in this study area during this period is grazing land. The grazing land in 1999 was 61.73 $km^2$ which has decreased in 2004 to 20.17 $km^2$. The unchanged area of 10.04 $km^2$, the non-grazing land to grazing land which means the newly developed grazing is about 10.12 $km^2$, and grazing land to other land use is about 51.68 $km^2$. Grazing land during this period has highly decreased by 41.56$km^2$ which is by 29.6%. The main reason behind this change is majority of the land has changed into crop land and settlement and buildup areas. The reason for the reduction in grass land could be due to the conversion of grass land to crop land (Muluneh and Arnalds 2011). The land that has been utilized for grazing has started to use for farming purpose using agronomic inputs such as fertilizer and variety seeds. This could be mainly the level of awareness to the community has started to grow and extension services might be improved. To meet high level of food demand for the growing population the greater conversion of grazing land to crop land during this period. Moreover, grazing land has changed during this time into Settlement and build up area.

#### 4.2.2.7 Change in Shrub land

During the study period, the shrub land in the Little Akaki river catchment exhibited changes characterized by an unchanged shrub cover area of approximately 6.39 $km^2$, a conversion of other land use classes into shrub land covering 27.53 $km^2$, and a transition of shrub land into non-shrub land totaling 11.48 $km^2$. As a result, the shrub land increased by 16.07 $km^2$, representing an 11.44% growth rate. The increase in shrub land can be attributed to the plantation of new trees to replace highly deforested areas. The growing population migrating to the city center has increased the demand for energy sources, leading to the utilization of forests for charcoal, construction, and timber harvesting for livelihood and personal use. This has prompted communities to replant trees and allow them to reach the shrub level for future use. Although there is a lack of crop land and increased demand for food due to population growth, the conversion of shrub land into crop land is not significant. Despite a decrease in forest land during the period, a majority of shrub land has transitioned towards a forested state.

### 4.2.3 LULC change detection from 2004-2009

The computed land use and land cover change detection can be found in Supplementary Appendix 23. Over the course of five years, barren land experienced the highest increase, expanding by approximately 43.68 $km^2$. Settlement and buildup areas also increased by 8.14 $km^2$. Forest land and water bodies showed slight increases of 0.21 $km^2$ and 0.09 $km^2$ respectively. However, crop land, grazing land, and shrub land experienced significant decreases of 23.23 $km^2$, 17.41 $km^2$, and 11.49 $km^2$ respectively during the study period. The highest percentage of change (10.83%) was observed for barren land, followed by crop land (5.76%) and grazing land (4.32%). Settlement and buildup areas and shrub land had similar percentages of change (2.85% and 2.02% respectively), while water bodies had the lowest change percentage. Figure 4.10 provides a visual comparison of the land use areas for different classes and a change diagram, while Table 4.4 presents the cross-tabulation of the land use data.

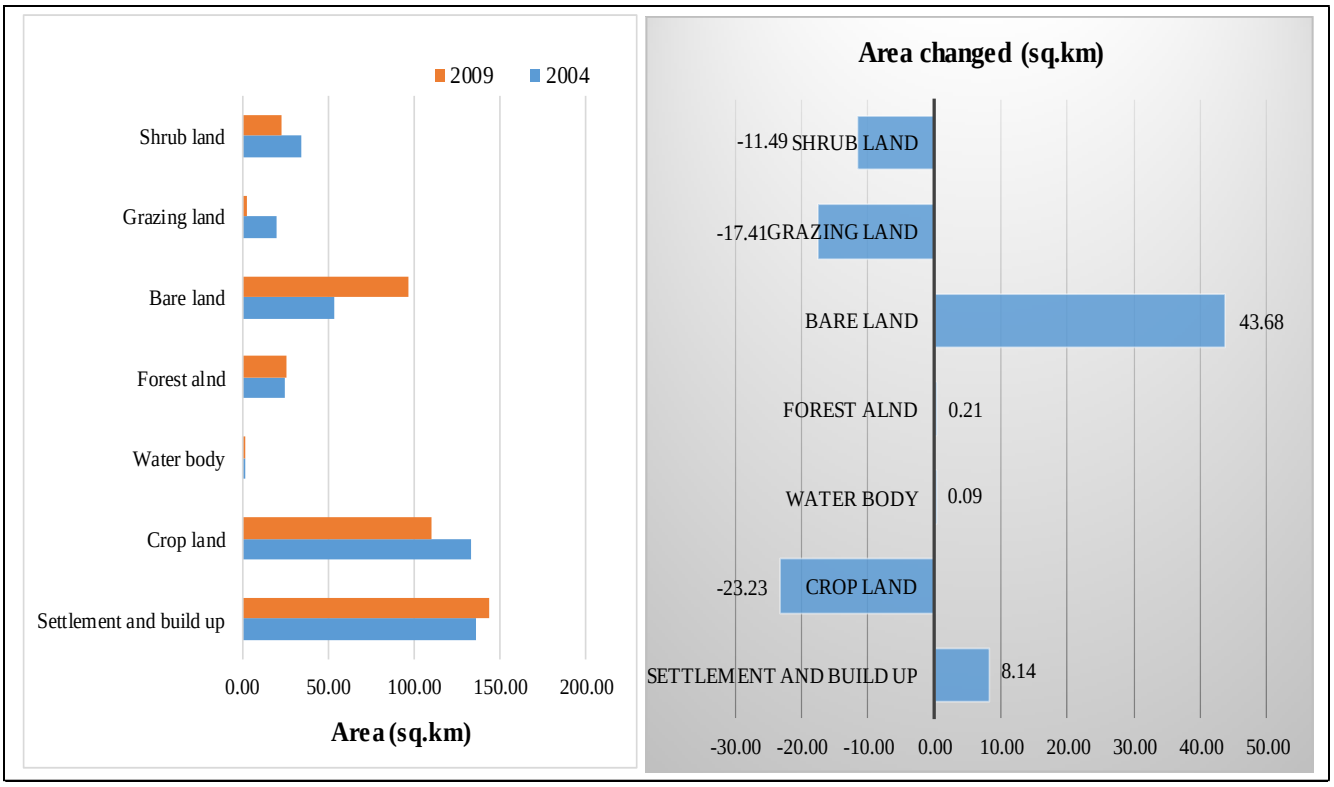


**Figure 4.10 Comparison and Area change diagram of the LULC Area in 2004 and 2009.**

### 4.2.3.1 Change in Settlement and buildup Area

A significant change observed in the study area is the expansion of the settlement and buildup area. In 2004, the area occupied by settlements and built-up structures was 135.53 $km^2$, which increased to 143.65 $km^2$ in 2009. This indicates an unchanged area of 88.53 $km^2$, with approximately 8.12 $km^2$ of newly developed settlement and buildup areas and 55.12 $km^2$ of conversion from non-settlement areas. The increase in the settlement and buildup area can be attributed to several factors. Firstly, the rapid population growth in the area has driven the demand for basic necessities and housing for newly migrated people. Additionally, improved transportation facilities and the availability of job opportunities have attracted individuals to settle in the region. These findings align with a previous study conducted in Keumbu region, Kisii Country, Kenya, which reported that a 20.5% average population growth rate resulted in the conversion of agricultural land into settlement areas at a rate of 0.658%. The expansion of development activities, private sector enterprises, service sectors, and the presence of

international organizations have further contributed to the migration of people towards the city, particularly along the banks of the Little Akaki river.

#### 4.2.3.2 Change in Crop land

The Crop land in the Little Akaki river catchment has undergone changes during the study period. The unchanged area of Crop land was approximately 50.46 $km^2$, while there was a conversion of 82.97 $km^2$ of Crop land to various non-crop land types such as forest, grazing land, settlement and build-up areas, shrub land, water bodies, and barren land. Conversely, there was a conversion of 59.78 $km^2$ of non-crop land into Crop land. From the cross-tabulation, it can be observed that a significant portion of Crop land remained unchanged. However, a considerable part of it was converted into Settlement and Barren land between 2004 and 2009. Overall, there was a decrease of approximately 23.19 $km^2$ in the total Crop land area during the five-year period, which has negative implications for food security as the production of food crops is reduced. In 2004, the size of Crop land was 133.43 $km^2$, accounting for 33.1% of the catchment's total area. By 2009, it had decreased to 110.24 $km^2$, covering 27.34% of the study area. The main reason behind this conversion can be attributed to the expansion of settlements and infrastructure at the expense of Crop land.

#### 4.2.3.3 Change in Waterbody

During the study period, there was a slight increase in water bodies by approximately 0.09 $km^2$. The unchanged water body area was around 0.03 $km^2$, while newly emerged water bodies covered approximately 1.93 $km^2$, and there was a conversion of 1.84 $km^2$ of water bodies to other land use classes. The increase in water bodies can be attributed to factors such as increased rainfall, improvements in water harvesting technologies, and the expansion of forest and shrub land, which have contributed to environmental improvements and a slight amelioration of climate change effects. There is also a growing awareness of the importance of preserving wetlands and ponds, discouraging their conversion for housing and industrial purposes.

However, it is important to note that there have been conversions from other land use classes to crop land as well. This can be attributed to the shortage of available crop land and the increased demand for food due to population growth. The previous agricultural land has decreased due to

conversion into settlement and built-up areas, as well as barren land. Additionally, inflation in food prices has incentivized farmers to cultivate previously grazed land. Farmers located near the city center have higher purchasing power for raw materials and goods, prompting them to expand their land into crop cultivation to maximize revenue, ensure sustainable livelihoods, and improve household security. Nevertheless, the overall decrease in farm land size has negative implications for farmers' livelihoods.

**Table 4.4: Cross-tabulation of LULC change from 2004 to 2009**

| Sum of Area change (km2) | LULC, 2009 (Final) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC, 2004 (Initial) | Settlement and buildup | Crop | Waterbody | Forest | Bare | Grazing | Shrub | **Grand total** |
| Settlement and buildup | 88.53 | 24.24 | 1.48 | 5.08 | 14.74 | 0.08 | 1.38 | **135.53** |
| Crop | 35.03 | 50.46 | 0.20 | 3.36 | 35.02 | 0.87 | 8.50 | **133.43** |
| Waterbody | 0.39 | 0.55 | 0.03 | 0.37 | 0.47 | 0.00 | 0.05 | **1.87** |
| Forest | 2.56 | 6.26 | 0.11 | 9.55 | 4.67 | 0.05 | 1.98 | **25.18** |
| Bare | 11.99 | 15.17 | 0.10 | 0.40 | 20.63 | 1.00 | 3.77 | **53.06** |
| Grazing | 2.18 | 4.22 | 0.01 | 0.33 | 10.59 | 0.53 | 2.30 | **20.16** |
| Shrub | 2.96 | 9.36 | 0.03 | 6.30 | 10.60 | 0.23 | 4.46 | **33.94** |
| **Grand total** | **143.65** | **110.24** | **1.96** | **25.39** | **96.72** | **2.76** | **22.45** | **403.17** |

Source: Computed own using change detection analysis, 2023

#### 4.2.3.4 Change in Forest land

The forest land in the study area exhibited changes during the analyzed period. The unchanged forest land covered approximately 9.55 $km^2$, while there was a conversion of 15.84 $km^2$ of non-forest land into forested areas, and 15.63 $km^2$ of forest land into non-forest land. The cross-tabulation reveals that a significant portion of the forest land remained unchanged and even showed some increment. This suggests that a majority of the forested areas have been protected from disturbances. The forest coverage in 2004 was 25.18 $km^2$, and by 2009, it had increased slightly to 25.39 $km^2$. This increment could be attributed to the plantation of new trees in other land areas and the transition of shrub land to forested areas. The overall increase of 0.21 $km^2$ in forest land over the five-year period is positive for maintaining sustainable ecosystem services.

#### 4.2.3.5 Change in Barren Land

The study area experienced changes in barren land during the analyzed period. The unchanged barren land area was approximately 20.63 $km^2$, while there was a significant emergence of new barren land covering 76.1 $km^2$, and a conversion of 32.43 $km^2$ of barren land into other land use classes. The increase in barren land can be attributed to the growing population, which requires more space to meet their basic needs. By 2009, the barren land had expanded from 53.06 $km^2$ in 2004 to 96.72 $km^2$, making it the third largest land use class with a total coverage of 24.0% in the study area. This significant increase of 43.66 $km^2$ in barren land coverage can be attributed to the demand for construction spaces, raw material sources, and waste disposal areas associated with settlement expansion, industrialization, and urbanization. Barren land has been converted into various uses such as industrial areas, human settlements, crop areas, and other purposes during this period.

#### 4.2.3.6 Change in Grazing land

During the analyzed period, a notable change occurred in the grazing land. In 2004, the grazing land covered an area of 20.16 $km^2$, accounting for 5.0% of the total area. However, by 2009, it had significantly decreased to 2.76 $km^2$, covering only 0.7% of the area. The unchanged grazing land area was about 0.53 $km^2$, while there was a conversion of non-grazing land into grazing land, resulting in approximately 2.23 $km^2$ of newly developed grazing land. On the other hand, there was a substantial conversion of grazing land into other land use classes, accounting for 17.4 $km^2$. This indicates a significant decrease and change of 17.4 $km^2$ in the grazing land. The primary reasons for this change include the expansion of crop land, the establishment of informal settlements, and the conversion of grazing land for these purposes. Additionally, the increase in barren land may have also contributed to the reduction of grazing land, as it encroached upon the available grazing areas.

#### 4.2.3.7 Change in Shrub land

During the studied period, there was an unchanged shrub land area of 4.46 $km^2$. There was a conversion of 17.99 $km^2$ of other land use classes into shrub land, while 29.48 $km^2$ of shrub land converted into non-shrub land. The main reason behind this change can be attributed to the

clearance of existing shrubs for various purposes such as energy sources and housing development. As a result, there was a decrease in shrub land by 11.48 $km^2$. The coverage of shrub land in 2004 was 33.94 $km^2$, accounting for 8.42% of the total area, which decreased to 22.46 $km^2$ by 2009, covering 5.5% of the area. The decrease and emergence of new shrub land can be attributed to the growth of newly planted trees and the conversion of other land covers, such as grazing land and bare land, which started to grow shrubs and undergo rehabilitation.

### 4.2.4 LULC change detection from 2009-2014

The computed land use and land cover change detection can be found in Supplementary Appendix 23. Over the span of five years, the most significant increase was observed in bare land, with an expansion of approximately 31.33 $km^2$. Grazing land also experienced an increase of 3.5 $km^2$. On the other hand, shrub land, settlement and build-up areas, and crop land showed decreases of 21.78 $km^2$, 7.22 $km^2$, and 3.82 $km^2$ respectively. Forest land and water bodies also decreased by 1.29 $km^2$ and 0.72 $km^2$ respectively. The highest percentage of change (-31.3%) was recorded for bare land, indicating a substantial increase. Figure 4.11 provides a visual comparison of the land use areas for different classes and a change diagram, while Table 4.5 presents the cross-tabulation of the land use data.

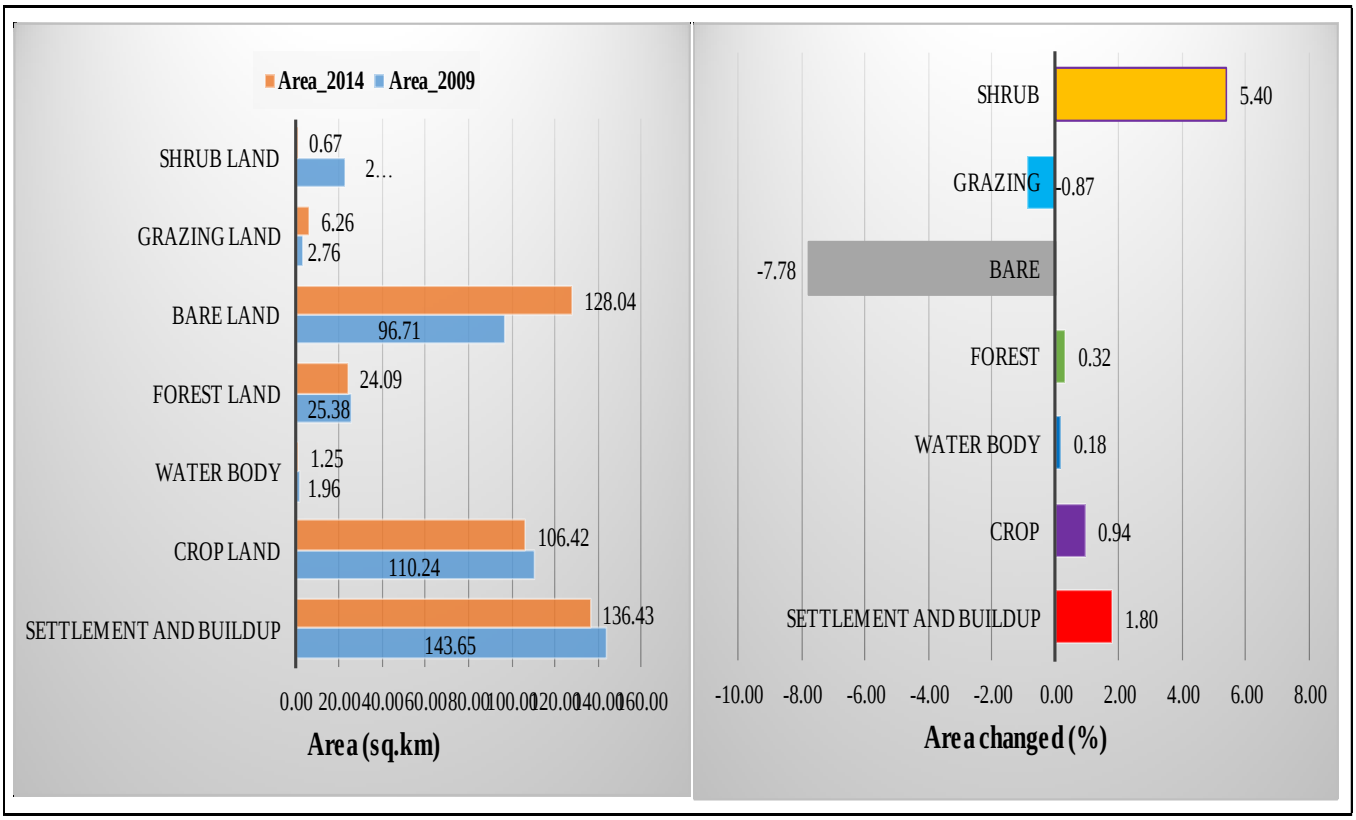


**Figure 4.11 Comparison and Area change diagram of the LULC Area in 2009 and 2014.**

### 4.2.4.1 Change in Settlement and buildup Area

During the analyzed period, a significant change occurred in the settlement and buildup area of the study area. In 2009, the settlement and buildup area covered 143.65 $km^2$, which decreased to 136.43 $km^2$ by 2014. The unchanged settlement and buildup area accounted for 96.28 $km^2$, while there was a conversion of non-buildup area into settlement and buildup area, resulting in approximately 40.15 $km^2$ of newly developed settlement and buildup area. On the other hand, there was a conversion of buildup area into non-buildup area, accounting for 47.37 $km^2$. This indicates a decrease of 7.2 $km^2$ in the settlement and buildup area during this period. The main reason behind this change may be the government's measures to clear unauthorized homes and informal settlements. The rapid population growth, improved transportation facilities, and increased demand for basic needs due to migration and job opportunities have contributed to the expansion of informal settlements and buildup areas. The availability of job opportunities in sectors like private enterprises, services, and the presence of international organizations has attracted people to settle in the city, particularly along riverbanks where rental housing and

informal settlements are more affordable. This influx of people has led to an increase in informal settlements and buildup areas.

#### 4.2.4.2 Change in Crop land

During the studied period, the crop land area remained relatively unchanged at 41.51 $km^2$. There was a significant conversion of crop land into non-crop land, mainly consisting of forest, grazing land, settlement and buildup areas, shrub land, water bodies, and barren land, covering approximately 68.73 $km^2$. Conversely, there was a conversion of non-crop land into crop land, totaling 64.91 $km^2$. The cross-tabulation indicates that a major portion of the crop land remained as crop land, although a significant portion was converted into barren land from 2009 to 2014. Overall, there was a decrease of 3.82 $km^2$ in crop land over the five-year period, which has negative implications for food security as food crop production is minimized. In 2009, the crop land covered 110.24 $km^2$, representing 27.34% of the total catchment area, which decreased to 106.42 $km^2$ in 2014. The main reason behind this conversion can be attributed to the low level of community awareness and involvement. Additionally, increased population migration and demand for new food resources have led landowners to focus on maximizing their income by converting crop land. Other land use classes have also been converted to crop land due to the scarcity of agricultural land, increased food demand, and the conversion of previous agricultural land into settlement and buildup areas or barren land. Inflation in food prices may have also incentivized the cultivation of previously unused land. The proximity of farmers to urban centers has increased their purchasing power for raw materials and goods, making crop land a primary target for conversion into settlement and buildup areas in the study area.

#### 4.2.4.3 Change in Waterbody

During the analyzed period, there was a decrease of approximately 0.71 $km^2$ in the waterbody area. The unchanged waterbody area accounted for about 1.11 $km^2$, while there was a newly emerged waterbody area of approximately 0.14 $km^2$. Additionally, 0.85 $km^2$ of waterbody was converted into other land use classes. The decrease in water bodies can be attributed to factors such as reduced rainfall, limited advancements in water harvesting technologies, and a decline in ecosystem services, leading to environmental degradation. These findings align with a study by

Worako, A. W. (2016), which reported a 0.06% reduction in water bodies during the years 2011-2015. One of the major reasons for this decline could be the impact of El Niño, which affected the country and resulted in decreased water levels, particularly in small river tributaries.

**Table 4.5: Cross-tabulation of LULC change from 2009 to 2014**

| Sum of Area change (km2) | LULC, 2014 (Final) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC, 2009 (Initial) | Settlement and buildup | Crop | Waterbody | Forest | Bare | Grazing | Shrub | Total |
| Settlement and buildup | 96.28 | 21.27 | 0.10 | 0.75 | 24.78 | 0.45 | 0.02 | 143.65 |
| Crop land | 16.05 | 41.51 | 0.02 | 5.19 | 45.93 | 1.39 | 0.15 | 110.24 |
| Waterbody | 0.33 | 0.14 | 1.11 | 0.01 | 0.37 | 0.00 | 0.00 | 1.96 |
| Forest land | 2.20 | 3.30 | 0.00 | 13.05 | 6.32 | 0.08 | 0.41 | 25.38 |
| Bare land | 20.14 | 31.12 | 0.01 | 3.27 | 38.71 | 3.42 | 0.04 | 96.71 |
| Grazing land | 0.13 | 0.62 | 0.00 | 0.02 | 1.69 | 0.31 | 0.00 | 2.76 |
| Shrub land | 1.30 | 8.46 | 0.00 | 1.80 | 10.24 | 0.61 | 0.04 | 22.45 |
| **Grand total** | **136.43** | **106.42** | **1.25** | **24.09** | **128.04** | **6.26** | **0.67** | **403** |

Source: Computed own using change detection analysis, 2023

#### 4.2.4.4 Change in Forest land

During the studied period, there was a conversion of approximately 11.04 $km^2$ of non-forest land into forest land, while 12.33 $km^2$ of forest land converted into non-forest land. The cross-tabulation reveals that a major portion of the forest land remained as forest land, with some decrement observed. This suggests that a significant area of the forest land has remained undisturbed due to protective measures. However, there has been a decrease in forest land, which can be attributed to activities such as deforestation for energy sources and livelihood activities, despite reforestation efforts on other land. The total forest land decreased by approximately 1.29 $km^2$ over the five-year period. Although there has been some decline, the rate of decrease in forest land is relatively favorable for maintaining sustainable ecosystem services compared to other land covers.

#### 4.2.3.5 Change in Barren Land

During the analyzed period, there was an unchanged barren land area of 38.71 $km^2$, along with the emergence of approximately 31.33 $km^2$ of new barren land and a conversion of 58.0 km2 into other land use classes. The rapid population growth has led to an increased demand for space to meet basic needs. In 2009, barren land covered 96.71 $km^2$, making it the third largest land use class, accounting for 24.0% of the total coverage. To fulfill the needs of the growing population, intensive human encroachment has occurred. By 2014, the coverage of barren land significantly increased to 128.04 $km^2$, representing 31.76% of the study area. During this period, barren land was converted into industrialized areas, human settlements, crop areas, and other purposes. The conversion of barren land has experienced a significant increase. The main reason behind this can be attributed to the increasing demand for settlement and buildup areas. Barren land decreased by 31.33 $km^2$, which accounts for a 24.47% decrease within the five-year period.

#### 4.2.4.6 Change in Grazing land

One of the significant changes observed during this period is in the grazing land. In 2009, the grazing land covered an area of 2.76 $km^2$, accounting for 0.7% of the total area. By 2014, it had increased to 6.26 $km^2$, representing 1.55% of the total area. The unchanged grazing land area was 0.31 $km^2$, while there was a conversion of non-grazing land into grazing land, resulting in approximately 5.95 $km^2$ of newly developed grazing land. Additionally, 2.45 $km^2$ of grazing land was converted into other land use classes. Overall, there was an increase of 3.5 $km^2$ in grazing land during this period. The reason behind this change could be a decrease in crop production or a decline in soil fertility, which led to a shift towards grazing activities. Furthermore, other land covers that were previously used for grazing may have been converted into settlements or transformed into crop land due to the expansion of agricultural activities.

#### 4.2.4.7 Change in Shrub land

During the analyzed period, there was a minimal unchanged shrub land area of about 0.04 $km^2$. The land that was initially covered with shrubs in 2009 has largely been converted into other land uses by 2014, with a total area of 22.41 $km^2$. Additionally, there was a conversion of non-shrub land into shrub land, resulting in approximately 0.63 $km^2$ of newly emerged shrub land. The primary reason for this change is the clearance of existing shrubs for various purposes such as energy sources and housing. In 2009, the coverage of shrub land was 22.45 $km^2$, accounting for 5.57% of the total area, but by 2014, it decreased to 0.67 $km^2$, representing 0.2% coverage. The decrease in shrub land and the emergence of new shrub land stems from the intensive clearance of shrub land for agricultural use. Additionally, there have been efforts to plant new trees and convert other land covers, such as grazing land and bare land, into shrub land.

### 4.2.5 LULC change detection from 2014-2019

The computed land use and land cover change detection can be found in Supplementary Appendix 23. Over the span of five years, the highest decrease was observed in bare land, with a reduction of approximately 109.9 $km^2$. Grazing land also experienced a decrease of 2.3 $km^2$. On the other hand, crop land and settlement and build-up areas showed increases of 45.7 $km^2$ and 45.2 $km^2$ respectively. Forest land, shrub land, and water bodies also increased by 17.7 km2, 3.3 $km^2$, and 0.2 $km^2$ respectively. The highest percentage of change (27.29%) was recorded for bare land, indicating a significant decrease. Figure 4.12 provides a visual comparison of the land use areas for different classes and a change diagram, while Table 4.6 presents the cross-tabulation of the land use data.

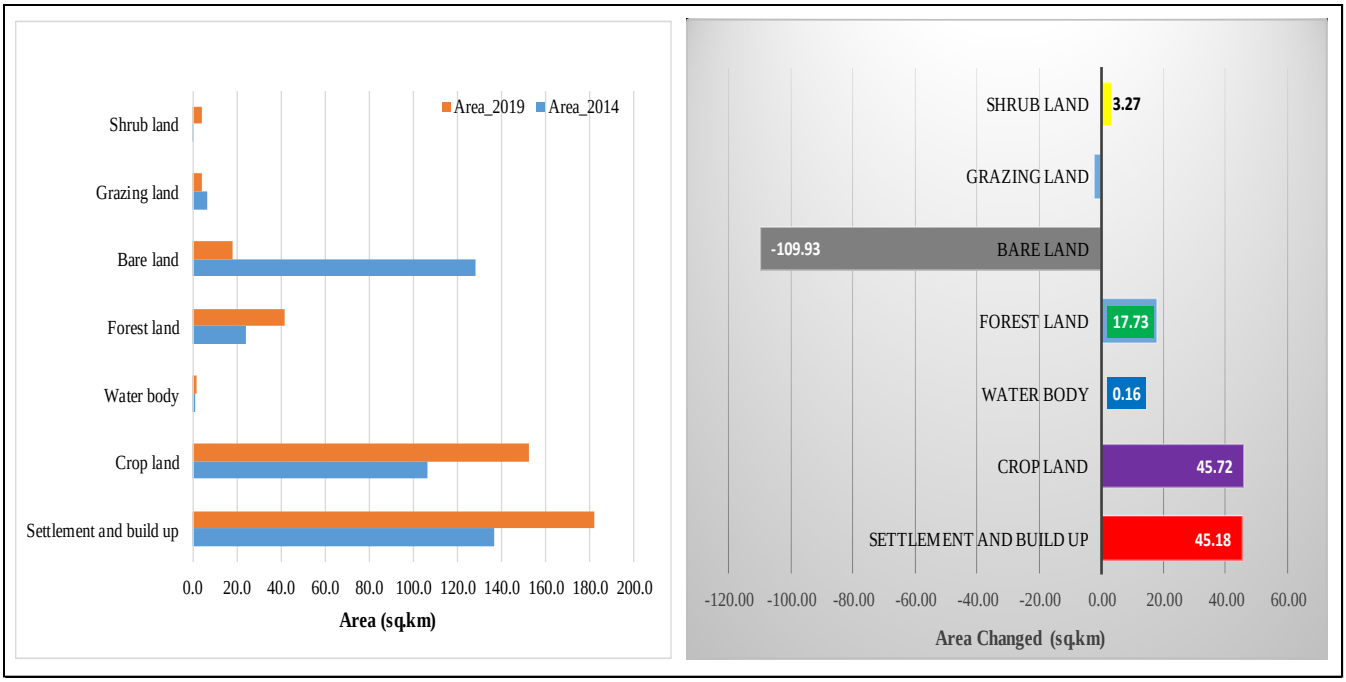


**Figure 4.12 Comparison and Area change diagram of the LULC Area in 2014 and 2019.**

### 4.2.5.1 Change in Settlement and buildup Area

A significant change observed in the study area is the expansion of the settlement and buildup area. In 2014, the settlement and buildup area covered 136.48 $km^2$, which increased to 181.66 $km^2$ by 2019. There was an unchanged area of 121.25 $km^2$, while approximately 60.35 $km^2$ of non-buildup area transformed into the settlement and buildup area. Conversely, there was a conversion of approximately 15.12 $km^2$ of the settlement and buildup area into non-buildup areas. This finding aligns with the research conducted by Worako, A. W. (2016), which reported a significant increase in urbanization and expansion during the period of 2011-2015. Lueliseged et al. (2011) also noted that the economic growth of the country and the construction of high-density condominiums, real estate houses, and cooperative-based housing developments in the city contributed to this increase. The expansion of the settlement and buildup area by 45 $km^2$ during this period can be attributed to alarming population growth, improved transportation facilities, the demand for basic needs by newly migrated people, and increased job opportunities. The availability of job opportunities due to development activities, private sector growth, service sectors, and the presence of international organizations has attracted people to migrate to the city, particularly in areas near riversides where rental houses and informal settlements are more

affordable. Furthermore, development activities have mainly concentrated along the banks of the Little Akaki river.

#### 4.2.5.2 Change in Crop land

During the analyzed period, there was an unchanged area of 69.33 $km^2$ designated as crop land. There was a conversion of approximately 37.04 $km^2$ of crop land into non-crop land categories such as forest, grazing land, settlement and buildup areas, shrub land, water bodies, and barren land. Conversely, there was a conversion of non-crop land covering 82.72 $km^2$ into crop land. Based on the cross-tabulation, it can be observed that a significant portion of crop land remained unchanged, while a substantial portion was converted into barren land between 2014 and 2019. Overall, there was an increase of approximately 45.7 $km^2$ in crop land during the five-year period, which positively contributes to food security by maximizing food crop production. In 2014, the size of crop land was 106.5 $km^2$, accounting for 26.4% of the total catchment area. By 2019, it had increased to 152.21 $km^2$, covering 37.73 $km^2$ of the study area.

**Table 4.6: Cross-tabulation of LULC change from 2014 to 2019**

| Sum of area change ($km^2$) | | LULC_2019 (Final) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC_2014 (Initial) | Settlement and build up | Crop land | Water body | Forest land | Bare land | Grazing land | Shrub land | **Grand Total** |
| Settlement and build up | 121.25 | 12.03 | 0.11 | 1.33 | 1.58 | 0.03 | 0.03 | **136.37** |
| Crop land | 20.95 | 69.33 | 0.05 | 9.57 | 4.24 | 0.75 | 1.47 | **106.37** |
| Water body | 0.12 | 0.01 | 1.10 | 0.00 | 0.00 | 0.00 | 0.00 | **1.25** |
| Forest land | 1.68 | 2.68 | 0.00 | 18.24 | 0.18 | 0.03 | 1.26 | **24.07** |
| Bare land | 36.88 | 64.36 | 0.14 | 11.88 | 11.15 | 2.48 | 1.08 | **127.97** |
| Grazing land | 0.67 | 3.63 | 0.17 | 1.04 | 0.67 | 0.08 | 0.00 | **6.26** |
| Shrub land | 0.04 | 0.01 | 0.60 | 0.00 | 0.01 | 0.00 | 0.00 | **0.67** |
| **Grand Total** | **181.60** | **152.05** | **2.18** | **42.07** | **17.83** | **3.38** | **3.84** | **402.9** |

Source: Computed own using change detection analysis, 2023

The main reason behind this conversion can be attributed to an improved awareness level among the community, increased migration of population demanding new food supplies, and

landowners focusing on maximizing their income. Additionally, other land use classes have also been converted into crop land, possibly due to a shortage of available crop land, increased food demand resulting from population growth, and the conversion of agricultural land into settlement and buildup areas or barren land. Inflation in food prices may have also played a role, prompting the cultivation of previously unused land. Farmers located near the city center may have benefited from higher purchasing power for raw materials and goods, leading them to expand their bare land or grazing land into crop land to maximize their revenue.

#### 4.2.5.3 Change in Waterbody

There has been an increase of approximately 0.2 $km^2$ in the waterbody within the study area during the analyzed period. The unchanged waterbody area accounts for about 1.1 $km^2$, while there is approximately 1.08 $km^2$ of newly emerged waterbody. Additionally, there has been a conversion of approximately 0.15 $km^2$ of waterbody into other land use categories. The increase in water bodies can be attributed to factors such as an increase in rainfall amounts, improvements in water harvesting technologies, and the expansion of forest and shrub land. These environmental improvements have contributed to a slight improvement in climate change conditions. Moreover, there is growing awareness about the need to reduce human interference in wetlands and ponds, particularly for the construction of housing and industrial areas, which further supports the preservation and expansion of waterbody areas.

#### 4.2.5.4 Change in Forest land

During the analyzed period, changes in forest land have been observed. There is an unchanged forest land area of approximately 23.54 $km^2$, while approximately 22.95 $km^2$ of non-forest land has been converted into forest land. Conversely, there has been a conversion of approximately 18.96 $km^2$ of forest land into non-forest land. The cross-tabulation reveals that a significant portion of the forest land has remained unchanged and shows some increment, indicating that a majority of the forested areas have been protected from disturbances. Additionally, there has been an increase in forest land, which can be attributed to the plantation of new trees on other land areas and the expansion of shrub land into forested areas. In total, there has been an increase of approximately 3.99 $km^2$ in forest land during the five-year period, which is significant for

ensuring sustainable ecosystem services. These findings align with the research by Worako, A. W. (2016), which reported an increase in forest land coverage from 9.7% to 11.9% in the Akaki basin between 1985 and 2015. The improvement in forest coverage can be attributed to the government's focus on green-based economic development and the rehabilitation efforts undertaken by stakeholders to restore degraded areas.

#### 4.2.5.5 Change in Barren Land

The unchanged area of barren land is approximately 16.4 $km^2$, while there is approximately 11.15 $km^2$ of newly emerged barren land. There has been a significant conversion of approximately 116.82 km2 of barren land into other land use classes. This conversion can be attributed to the growing population and their increasing need for space to fulfill their basic requirements. In 2014, barren land covered an area of 128.1 $km^2$, making it the second-largest land use class with a total coverage of 31.8%. However, by 2019, the coverage significantly decreased to 18.21 $km^2$, representing 4.51% of the study area. This decline is primarily due to intensive human encroachment as barren land has been converted into industrial areas, human settlements, crop fields, and other purposes. The decrease in barren land can be attributed to the rising demand for settlement, industrialization, and urbanization. Over the five-year period, barren land decreased by 109.89 $km^2$, representing a decline of 27.29%.

#### 4.2.5.6 Change in Grazing land

One significant change observed during this period is the decrease in grazing land. In 2014, the grazing land covered an area of 6.3 $km^2$, accounting for 1.6% of the total area. However, by 2019, it had decreased to 3.97 $km^2$, covering only 0.98% of the total area. There is an unchanged area of 0.08 $km^2$, approximately 3.3 $km^2$ of non-grazing land has been converted into grazing land, and approximately 6.18 $km^2$ of grazing land has been converted into other land use categories. The decrease in grazing land can be attributed to factors such as the expansion of crop land, the encroachment of informal settlements, and the coverage of grazing land by water bodies. Land that was previously used for grazing has been converted into settlements, and due to the expansion of crop land, those areas have been transformed into agricultural fields.

Additionally, the increase in water bodies during this period has led to the grazing land near rivers being covered by water.

#### 4.2.5.7 Change in Shrub land

The coverage of shrub land in 2014 has undergone complete transformation into other land uses by 2019, with no unchanged shrub land observed during this period. There has been a conversion of approximately 3.84 $km^2$ from other land uses to shrub land, while approximately 0.67 $km^2$ of shrub land has been converted into non-shrub land. The primary reason for this change is the clearance of existing shrubs for various purposes such as energy sources and housing development. However, there has been an overall increase in shrub land by approximately 3.3 $km^2$. In 2014, the coverage was 0.7 $km^2$, accounting for 0.2% of the total area, while in 2019, it had increased to 3.93 $km^2$, covering 0.97% of the total area. The increase and emergence of new shrub land can be attributed to the growth of newly planted trees and the conversion of other land covers, such as grazing land and bare land, which have started to grow shrubs and undergone rehabilitation efforts.

### 4.2.6 LULC change detection from 2019-2023

The computed land use and land cover change detection can be found in Supplementary Appendix 23. The results indicate a significant decrease in crop land between 2019 and 2023, with a reduction of approximately 62.7 $km^2$. Forest land, bare land, and water bodies also experienced decreases of 1.53 $km^2$, 1.01 $km^2$, and 0.09 $km^2$ respectively. On the other hand, there was an increase in settlement and buildup areas by 29.98 $km^2$ and grazing land by 34.17 $km^2$ during those years. Shrub land also showed a slight increase of 1.19 $km^2$. The highest percentage of change (41.2%) was observed for crop land, which is a concerning trend. Figure 4.13 provides a visual comparison of the land use areas for different classes and a change diagram, while Table 4.7 presents the cross-tabulation of the land use data.

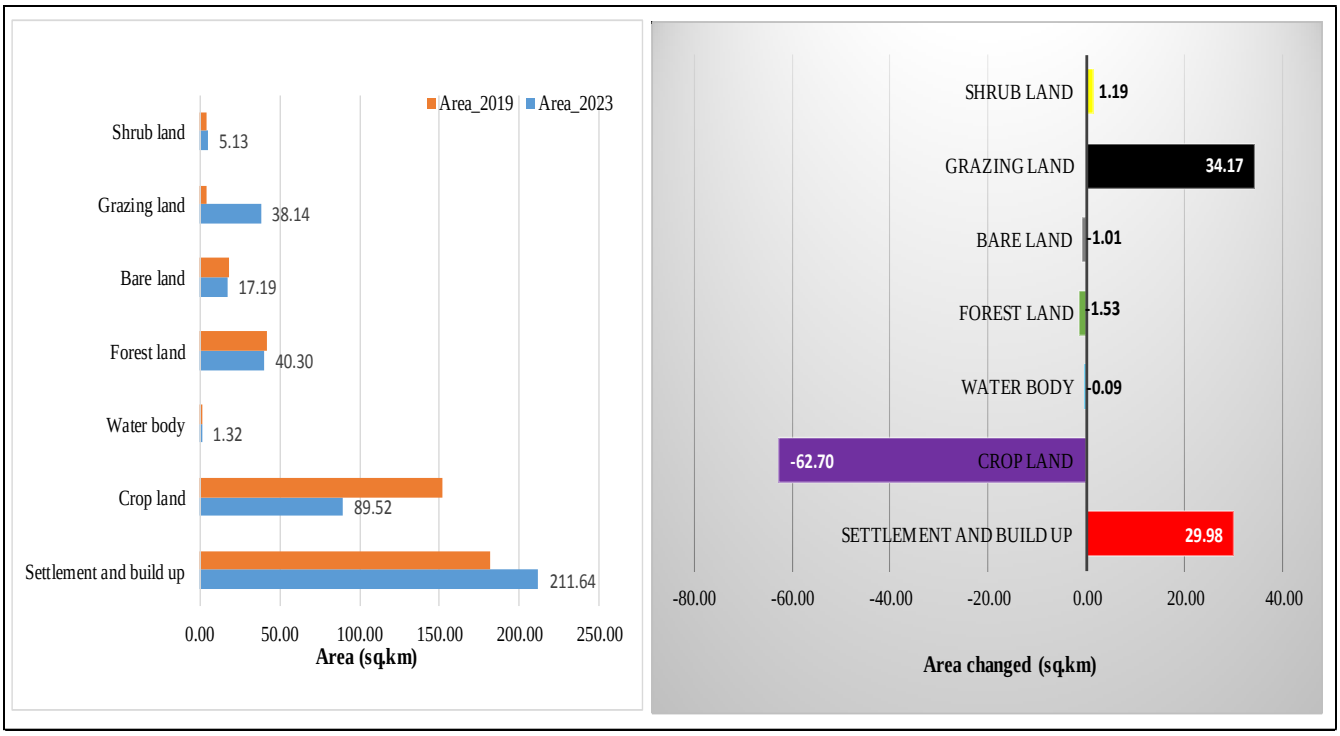


**Figure 4.13 Comparison and Area change diagram of the LULC Area in 2019 and 2023.**

### 4.2.6.1 Change in Settlement and buildup Area

The most prominent change observed in the study area is the significant increase in the settlement and buildup area. In 2019, this area covered 181.66 km$^2$, which has further expanded to 211.64 km2 in 2023. There is an unchanged area of 140.73 km$^2$, approximately 70.91 km$^2$ of non-buildup area has been converted into the settlement and buildup area, and approximately 40.87 km$^2$ of the buildup area has been transformed into non-buildup land. This indicates an overall increase of 29.98 km$^2$ in the settlement and buildup area. These findings align with a previous study conducted by Worako, A. W. (2016), which reported an increase in the urban or built-up area in the Akaki Catchment from 414 km$^2$ to 507 km$^2$ between 1984 and 2015. The reasons behind this change can be attributed to the expansion of housing, improved transportation systems, the growth of service sectors and institutions, particularly in the capital city of Addis Ababa and Sheger city in the Little Akaki river catchment. Additionally, the establishment of industries along the riverbanks has played a significant role, as it requires intensive development, housing, and infrastructure within the catchment. The opening of new

service sectors has also contributed to this transformation. The process of industrialization and improved access to transportation systems has led to high migration rates, with people from rural areas settling in the study area. While the size of cropland is increasing, the growing population requires higher food crop production to improve food security. Some informal settlement areas have taken measures to revert back to their previous land uses, indicating a dynamic transformation process.

### 4.2.6.2 Change in Crop land

Figure 4.14 illustrates the changes in crop land within the Little Akaki river catchment. There is an unchanged area of approximately 71.06 $km^2$ that remained as crop land throughout the study period. Around 80.94 $km^2$ of crop land has been converted into non-crop land, including forest, grazing areas, settlements, buildup areas, shrub land, water bodies, and barren land. Conversely, approximately 18.38 $km^2$ of non-crop land has been converted into crop land. The cross-tabulation reveals that a significant portion of crop land has remained as crop land, while a substantial portion has been converted into settlement and buildup areas from 2019 to 2023, indicating that the livelihood activities of farmers heavily relied on crop production.

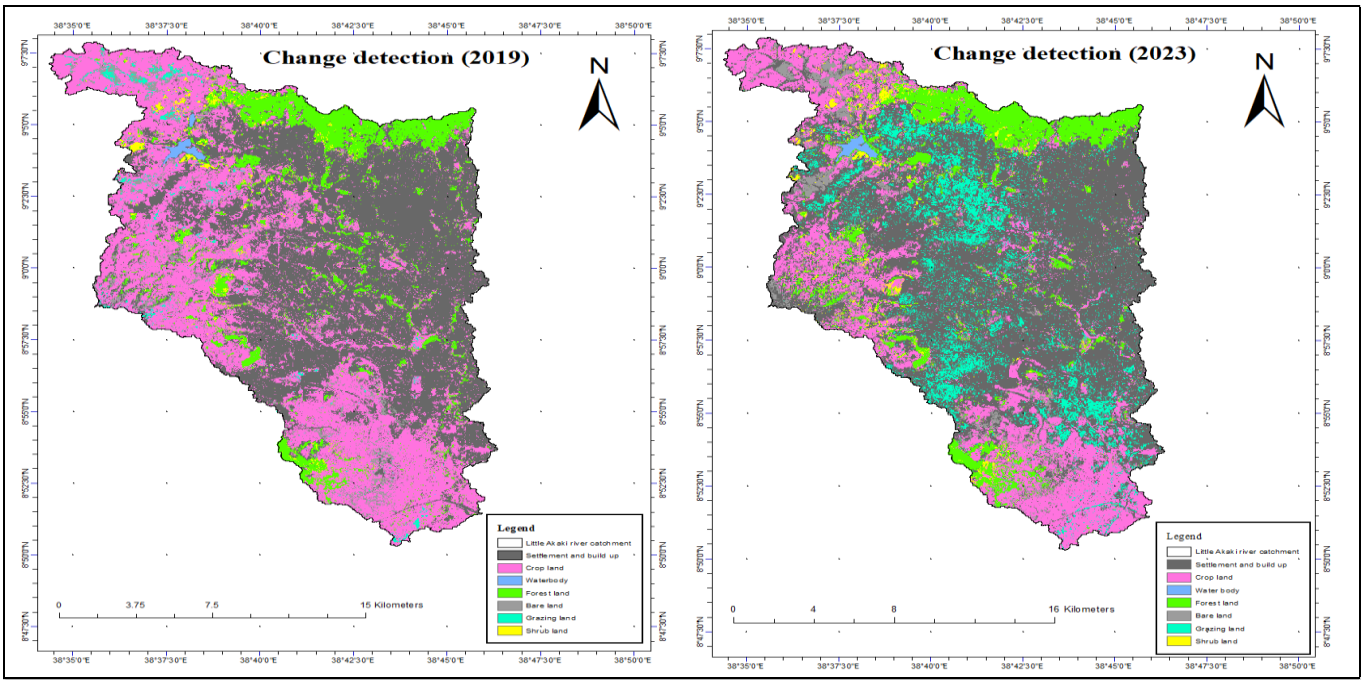


**Figure 4.14: Change detection comparison of Little Akaki river catchment (2019-2023)**

The total coverage of crop land in 2019 was 152.21 $km^2$, which decreased by approximately 62.7 $km^2$ to 89.51 $km^2$ in 2023. This finding aligns with a previous study conducted by Workato, A. W. (2016), which showed an increase in urban area coverage in the study area at the expense of a reduction in agricultural land, decreasing from 64% to 56.28%. Consequently, the high rate of crop land decrease observed over the four-year period has negative implications for food security.

The reason behind this change could be described as improper land use and high rate of informal settlement and build up area. The change of government and instability in the country may also contribute for the increase of informal settlement and rate of migration become high. Since that change the country has also faced war with opposing party which has make the administrative body busy with other issues. This also created informal settlers to use administrative gaps that arise from lack of attention to informal settlers. Moreover, the change of livelihood activities in the catchment has changed leaving the agriculture sector and focusing on service sector.

The expansion of service sectors has primarily occurred at the expense of crop land area. Many individuals have chosen to sell or rent their crop land to informal settlers, real estate developers, and others, while also engaging in different business ventures. This shift has resulted in significant changes in the livelihood activities of the area. Additionally, there have been conversions of other land use classes into crop land, possibly due to measures taken against informal settlers who had built compounds for housing purposes, thereby affecting the climate. The changes in land cover within the Little Akaki river catchment are largely influenced by its geographical location and its connectivity to urban centers. Increased economic activity and job opportunities have led to a rise in human migration to the area. Furthermore, high levels of rural migration to urban centers can be attributed to poverty and limited employment opportunities.

#### 4.2.6.3 Change in Waterbody

According to the calculations, there has been a decrease of approximately 0.09 $km^2$ in the waterbody area during the study period in the study area. In 2019, the waterbody coverage was 1.41 $km^2$, which decreased to 1.32 $km^2$ in 2023. There is an unchanged waterbody area of approximately 1.13 $km^2$, while a newly emerged waterbody covers around 1.71 $km^2$.

Additionally, approximately 0.28 $km^2$ of waterbody has been converted into other land uses. The decline in water bodies can be attributed to human encroachment patterns, where wetlands and ponds are filled for the construction of housing and industrial areas. Mismanagement of river water resources has also contributed to the depletion of waterbodies. Areas that were already depleted of water have become covered with grass or have turned bare. The reduction in forest coverage has further exacerbated climate change, which has led to decreased rainfall levels and directly impacted the waterbody levels in the study area. Furthermore, wetlands have been converted to other land types due to increasing land prices.

**Table 4.7: Cross-tabulation of LULC change from 2019 to 2023**

| Sum of area change ($km^2$) | LULC_2023 (Final) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LULC_2019 (Initial) | Settlement and build up | Crop land | Water body | Forest land | Bare land | Grazing land | Shrub land | **Grand Total** |
| Settlement and build up | 140.73 | 6.23 | 0.16 | 3.39 | 1.67 | 29.10 | 0.30 | **181.59** |
| Crop land | 55.37 | 71.06 | 0.01 | 6.43 | 10.04 | 7.60 | 1.58 | **152.10** |
| Water body | 0.21 | 0.05 | 1.13 | 0.01 | 0.01 | 0.00 | 0.00 | **1.41** |
| Forest land | 5.81 | 5.34 | 0.02 | 28.22 | 0.24 | 0.40 | 1.78 | **41.82** |
| Bare land | 7.32 | 5.46 | 0.00 | 0.71 | 3.65 | 0.88 | 0.18 | **18.20** |
| Grazing land | 1.45 | 0.71 | 0.16 | 1.43 | 0.08 | 0.14 | 0.00 | **3.97** |
| Shrub land | 0.63 | 0.59 | 1.36 | 0.14 | 0.07 | 1.14 | 0.00 | **3.93** |
| **Grand Total** | **211.54** | **89.44** | **2.84** | **40.33** | **15.76** | **39.26** | **3.85** | **403.01** |

Source: Computed own using change detection analysis, 2023

#### 4.2.6.4 Change in Forest land

The forest land in the study area remained unchanged at approximately 28.22 $km^2$. Around 12.11 $km^2$ of non-forest land has been converted into forest land, while approximately 13.6 $km^2$ of forest land has been transformed into non-forest land. The cross-tabulation reveals that a significant portion of the forest land has remained as forest land, possibly due to its protected status. However, there has been a slight decrease in the overall forest land coverage. To address this, special attention has been given to afforestation efforts, particularly through programs like

the green legacy program, which has made significant strides in combating climate change by protecting existing forest cover and aggressively planting new trees. Despite these efforts, the total forest land has decreased by approximately 1.53 $km^2$ over the four-year period, which has negative implications for climate change and the provision of sustainable ecosystem services. The decrease in forest land can be attributed to activities such as tree cutting for personal use as an energy source and the clearing of old trees to make way for various development activities. However, the newly planted trees are expected to contribute to an increase in forest coverage in the coming years. It is worth noting that although there has been some increment in shrub cover, the level of deforestation by local communities during this period has been high.

#### 4.2.6.5 Change in Barren Land

In 2019, the total coverage of barren land in the study area was 18.21 $km^2$, accounting for 4.51% of the land. By 2023, the coverage had decreased to 17.19 $km^2$, representing a reduction of 1.01 km2 over the four-year period. The primary factors driving this change are the increasing demand for settlement areas, industrialization, and urbanization. Barren land may also be converted into grassland or utilized as a source of raw material for construction purposes. Among the barren land, approximately 3.65 $km^2$ remained unchanged, indicating stable conditions. Around 12.11 $km^2$ of newly emerged barren land has appeared, while 14.55 $km^2$ of barren land has been converted into other land use classes. The population growth in the area has led to a greater need for space to meet basic needs, resulting in human encroachment on barren land. This encroachment has led to the conversion of barren land into industrial areas, human settlements, crop areas, and other purposes. Consequently, a decrease in barren land has been observed during the study period in the study area.

#### 4.2.6.6 Change in Grazing land

One significant change observed in the study area during the study period is the expansion of grazing land, as depicted in Figure 4.14. In 2019, the grazing land covered an area of 3.97 $km^2$, which increased to 38.14 $km^2$ by 2023. There is an unchanged grazing land area of approximately 0.14 $km^2$, while approximately 39.12 $km^2$ of non-grazing land has been converted into grazing land. Additionally, around 3.83 $km^2$ of grazing land has been transformed into other

land use classes. The grazing land has experienced a substantial increase of 34.7 $km^2$ over the four-year period. The primary cause of this change is the conversion of a significant portion of land into informal settlements with large sizes. However, government measures have resulted in the reclamation of these informal settlements, returning the land to the land bank. Another reason for the increase in grazing land could be the conversion of land previously used for crop production. Factors such as reduced crop production and declining soil fertility may have led to the transformation of such lands into grazing areas. Additionally, to improve livestock feeding, some shrub land has also been converted into grazing land. The expansion of livestock production in the area may also be driving the increased demand for grazing land, as it requires ample space and grass resources for feeding purposes.

#### 4.2.6.7 Change in Shrub land

According to Figure 4.14, there has been a notable change in shrub land within the study area. A significant portion of the land previously covered by shrubs has been converted to other land use categories. The conversion from other land use types to shrub land is approximately 3.85 $km^2$, while the transformation from shrub land to other land uses is about 3.93 $km^2$. Consequently, the overall area of shrub land has increased by 1.19 $km^2$ during the study period. This growth can be attributed to the natural regeneration of shrubs and the planting of new trees to replace deforested areas.

The increased population migrating to urban centers has resulted in a higher demand for energy sources. As a consequence, forests have been utilized for charcoal production, as a source of energy for homes, and for construction purposes. Additionally, trees are being cut and sold in the market for various livelihood purposes and personal use. However, communities are aware of the importance of trees for future use, and it is expected that they will replace the trees they have cut and make efforts to sustain their resources for future needs.

**Table 4.8: Overall LULC change Area ($km^2$) and (%) from 1994-2023**

| LULC Class | Year | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1994-1999 | | 1999-2004 | | 2004-2009 | | 2009-2014 | | 2014-2019 | | 2019-2023 | | 1994-2023 | |
| | Area | % | Area | % | Area | % | Area | % | Area | % | Area | % | Area | % |
| Settlement and buildup | 21.20 | 5.26 | 12.62 | 3.12 | 8.05 | 2.02 | -7.17 | 1.80 | 45.18 | 11.22 | 29.97 | 7.43 | 109.86 | 27.25 |
| Crop | -13.04 | 3.23 | 34.42 | 8.52 | -23.29 | 5.76 | -3.75 | 0.95 | 45.72 | 11.35 | -62.70 | 15.55 | -22.64 | 5.61 |
| Waterbody | -5.42 | 1.34 | -7.23 | 1.79 | 0.09 | 0.02 | -0.72 | 0.18 | 0.16 | 0.04 | -0.09 | 0.02 | -13.20 | 3.27 |
| Forest | 3.99 | 0.99 | -21.32 | 5.29 | 0.19 | 0.05 | -1.28 | 0.32 | 17.73 | 4.40 | -1.53 | 0.38 | -2.23 | 0.55 |
| Bare | -13.75 | 3.41 | 7.16 | 1.77 | 43.63 | 10.83 | 31.42 | 7.78 | -109.93 | 27.25 | -1.02 | 0.25 | -42.48 | 10.53 |
| Grazing | 12.16 | 3.02 | -41.56 | 10.31 | -17.41 | 4.32 | 3.50 | 0.87 | -2.29 | 0.57 | 34.17 | 8.47 | -11.43 | 2.83 |
| Shrub | -5.15 | 1.28 | 16.07 | 3.98 | -11.50 | 2.85 | -21.78 | 5.40 | 3.27 | 0.81 | 1.19 | 0.30 | -17.90 | 4.44 |

Source: Own computation from the land use and land cover change detection of the study area, 2023

The above Table 4.8 presents the overall land use and land cover (LULC) changes in terms of area (in $km^2$) and percentage (%) for the period from 1994 to 2023. From 1994 to 2023, the settlement and buildup areas increased by 109.86 $km^2$ (27.25%), indicating significant urbanization and population growth. The growth rate varied across different time intervals, with the highest increase observed from 2019 to 2023 (29.97%). However, during the period from 2009 to 2014, there was a slight decrease (-7.17%), possibly due to land-use planning interventions or shifts in development patterns. This result is consistent with previous research conducted by Seto et al. (2013), that urban areas are expanding rapidly worldwide due to population growth, economic development, and migration from rural to urban areas.

The crop areas experienced a net decrease of 22.64 $km^2$ (5.61%) from 1994 to 2023. The changes in crop area varied across different time intervals, with the highest increase observed from 1999 to 2004 (34.42%) and the highest decrease observed from 2014 to 2019 (-62.70%). These changes may be attributed to factors such as changes in agricultural practices, land-use policies, or market demands. This result aligns with the previous research finding that complex dynamics of agricultural land, influenced by factors such as changing market demands, technological advancements, and policy interventions Verburg et al., 2015.

The waterbody areas experienced a slight net decrease of 13.20 $km^2$ (3.27%) from 1994 to 2023. The changes in waterbody area were relatively small compared to other LULC classes, indicating overall preservation and management of natural hydrological features. However, there were minor fluctuations observed in different time intervals, suggesting localized changes due to natural processes or human activities. According to Allan (2004), river ecosystems and highlighted the impacts of land-use changes, such as urbanization and agriculture, on water quality, hydrology, and species composition.

The forest areas showed a net decrease of 2.23 $km^2$ (0.55%) from 1994 to 2023. The changes in forest cover varied across different time intervals, with the highest decrease observed from 1999 to 2004 (-21.32%). However, there was a slight recovery in forest area from 2014 to 2019 (17.73%), indicating potential reforestation efforts or natural regeneration. Deforestation and forest degradation as significant global environmental challenges, impacting biodiversity, carbon sequestration, and climate regulation (Hansen et al., 2013; Gibbs et al., 2010).

The bare land areas experienced a significant net decrease of 42.48 $km^2$ (10.53%) from 1994 to 2023. The changes in bare land area showed fluctuations across different time intervals, with the highest increase observed from 2004 to 2009 (43.63%) and the highest decrease observed from 2019 to 2023 (-1.02%). These changes may be attributed to land reclamation or rehabilitation efforts, land-use planning interventions, or natural vegetation recovery. According to Palmer et al. (2016), restoring degraded lands can have positive impacts on biodiversity conservation, carbon sequestration, and ecosystem services.

The grazing areas showed a net decrease of 11.43 $km^2$ (2.83%) from 1994 to 2023. The changes in grazing area varied across different time intervals, with the highest decrease observed from 1999 to 2004 (-41.56%). However, there was an overall increase in grazing area from 2014 to 2019 (34.17%), suggesting potential shifts in livestock management practices or land-use transitions. Thus, the finding is consitent with the finding of van der Meer et al. (2017) investigated the use of soil remediation techniques in reclaiming contaminated lands and highlighted the importance of sustainable land use planning.

The shrub areas experienced a net decrease of 17.90 $km^2$ (4.44%) from 1994 to 2023. The changes in shrub area showed fluctuations across different time intervals, with the highest increase observed from 1999 to 2004 (16.07%) and the highest decrease observed from 2004 to 2009 (-11.50%). These changes may be influenced by ecological succession, land-use transitions, or vegetation management practices.

### 4.3 Water quality in the Little Akaki river catchment

The mean values of water quality for both 2019 and 2023 are shown in Table 4.9 and Table 4.10. For river water quality, heavy metals and physiochemical are shown below. Paired t-test is applied to assess whether there is a significant difference between the means of paired samples. It will tell as that if there is a statistically significant change in water quality between the two years.

**Table 4.9 Heavy metals and physio-chemical water quality parameters (Mean ± SD) in 2019**

| Parameters | | Cr | Cd | Pb | Zn | Temp. ($^0$c) | PH | DO (mg/L) | TDS (mg/L) | Sal. (PSU) | Turb. (NTU) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Sites | S1 | 0.013 | 0.017 | 0.031 | 0.082 | 21.85 | 7.32 | 7.17 | 48 | 48.12 | 38.57 |
| | S2 | 0.138 | 0.014 | 0.089 | 0.174 | 21.25 | 7.07 | 4.67 | 391.93 | 381.75 | 59.83 |
| | S3 | 0.203 | 0.003 | 0.078 | 0.048 | 20.8 | 7 | 4.55 | 523.83 | 513.13 | 140.33 |
| | S4 | 0.124 | 0.006 | 0.124 | 0.193 | 19.85 | 7.34 | 3.254 | 915.57 | 918.1 | 126.6 |
| | S5 | 0.024 | 0.02 | 0.091 | 0.253 | 19.6 | 7.26 | 4.32 | 893.3 | 901.23 | 138.87 |
| | S6 | 0.012 | 0.01 | 0.036 | 0.138 | 20.4 | 7.2 | 4.89 | 714.3 | 748.8 | 102.53 |
| | S7 | 0.014 | 0.007 | 0.034 | 0.091 | 20.25 | 7.48 | 5.6 | 713.53 | 707.6 | 112.47 |
| | S8 | 0.119 | 0.009 | 0.043 | 0.08 | 22.25 | 8.09 | 4.25 | 731.53 | 730.2 | 138.6 |
| | S9 | 0.127 | 0.008 | 0.033 | 0.051 | 22 | 8.05 | 5.15 | 763.87 | 767.35 | 128.3 |
| | S10 | 0.078 | 0.016 | 0.048 | 0.318 | 21.7 | 8.04 | 6.4 | 706.83 | 684.2 | 76.3 |
| Total Mean | | 0.852 | 0.11 | 0.607 | 1.428 | 209.95 | 74.85 | 50.254 | 6402.69 | 6400.48 | 1062.4 |
| Mean average | | 0.085 | 0.011 | 0.0607 | 0.1428 | 20.995 | 7.485 | 5.0254 | 640.269 | 640.048 | 106.24 |

Source: Center for Environmental Science, Addis Ababa University, *D.M* Mekuria et al., 2019.

**Table 4.10 Heavy metals and physio-chemical water quality (Mean + SD) in 2023**

| **Parameters** | | **Cr** | **Cd** | **Pb** | **Zn** | **Temp. ($^0$c)** | **PH** | **DO (mg/L)** | **TDS (mg/L)** | **Sal. (PSU)** | **Turb. (NTU)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Sites | S1 | 0.015 | 0.003 | 0.152 | 0.073 | 22 | 7.61 | 5.39 | 82 | 46 | 82 |
| | S2 | 0.025 | 0.008 | 0.293 | 0.094 | 19 | 6.91 | 6.22 | 195 | 67 | 660 |
| | S3 | 0.034 | 0.005 | 0.22 | 0.118 | 23 | 7.5 | 4.83 | 488 | 89 | 414 |
| | S4 | 0.05 | 0.0091 | 0.15 | 0.24 | 19.6 | 7.29 | 6.06 | 515 | 139 | 379 |
| | S5 | 0.031 | 0.005 | 0.246 | 0.221 | 19 | 7.21 | 6.46 | 588 | 127 | 914 |
| | S6 | 0.009 | 0.007 | 0.09 | 0.0324 | 16.7 | 7.23 | 4.27 | 568 | 126 | 910 |
| | S7 | 0.038 | 0.008 | 0.293 | 0.116 | 20.8 | 7.21 | 3.84 | 566 | 131 | 735 |
| | S8 | 0.025 | 0.0042 | 0.262 | 0.029 | 22.7 | 8.48 | 4.32 | 642 | 125 | 722 |
| | S9 | 0.041 | 0.0091 | 0.31 | 0.518 | 19.6 | 7.43 | 3.44 | 552 | 97 | 811 |
| | S10 | 0.015 | 0.004 | 0.262 | 0.94 | 18 | 7.44 | 4.46 | 569 | 83 | 621 |
| **Total Mean** | | **0.852** | **0.283** | **0.0624** | **2.278** | **2.3814** | **2.3814** | **200.4** | **74.31** | **49.29** | **4765** |
| **Mean average** | | **0.085** | **0.0283** | **0.00624** | **0.2278** | **0.23814** | **0.23814** | **20.04** | **7.431** | **4.929** | **476.5** |

Source: College of Veterinary Medicine and Agriculture, Addis Ababa University, Teketel et al., 2023.

**Table 4.11 Change of heavy metals and physio-chemical water quality (Mean ± SD) 2019-2023**

| Parameters | | Cr | Cd | Pb | Zn | Temp. ($^0$c) | PH | DO (mg/L) | TDS (mg/L) | Sal. (PSU) | Turb. (NTU) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Sites | S1 | 0.002 | -0.014 | 0.121 | -0.009 | 0.15 | 0.29 | -1.78 | 34 | -2.12 | 43.43 |
| | S2 | -0.113 | -0.006 | 0.204 | -0.08 | -2.25 | -0.16 | 1.55 | -196.93 | -314.75 | 600.17 |
| | S3 | -0.169 | 0.002 | 0.142 | 0.07 | 2.2 | 0.5 | 0.28 | -35.83 | -424.13 | 273.67 |
| | S4 | -0.074 | 0.0031 | 0.026 | 0.047 | -0.25 | -0.05 | 2.806 | -400.57 | -779.1 | 252.4 |
| | S5 | 0.007 | -0.015 | 0.155 | -0.032 | -0.6 | -0.05 | 2.14 | -305.3 | -774.23 | 775.13 |
| | S6 | -0.003 | -0.003 | 0.054 | -0.1056 | -3.7 | 0.03 | -0.62 | -146.3 | -622.8 | 807.47 |
| | S7 | 0.024 | 0.001 | 0.259 | 0.025 | 0.55 | -0.27 | -1.76 | -147.53 | -576.6 | 622.53 |
| | S8 | -0.094 | -0.0048 | 0.219 | -0.051 | 0.45 | 0.39 | 0.07 | -89.53 | -605.2 | 583.4 |
| | S9 | -0.086 | 0.0011 | 0.277 | 0.467 | -2.4 | -0.62 | -1.71 | -211.87 | -670.35 | 682.7 |
| | S10 | -0.063 | -0.012 | 0.214 | 0.622 | -3.7 | -0.6 | -1.94 | -137.83 | -601.2 | 544.7 |
| Total Mean | | 0.852 | -0.569 | -0.0476 | 1.671 | 0.9534 | -9.55 | -0.54 | -0.964 | -1637.69 | -5370.48 |
| Mean average | | 0.085 | -0.0569 | -0.00476 | 0.1671 | 0.09534 | -0.955 | -0.054 | -0.0964 | -163.769 | -537.048 |

Source: Own computation change in mean value of river water quality, 2023

### 4.3.1 Trends of water quality parameters

The following table shows the change of river water quality parameters mean values for the year of 2019 and 2023.

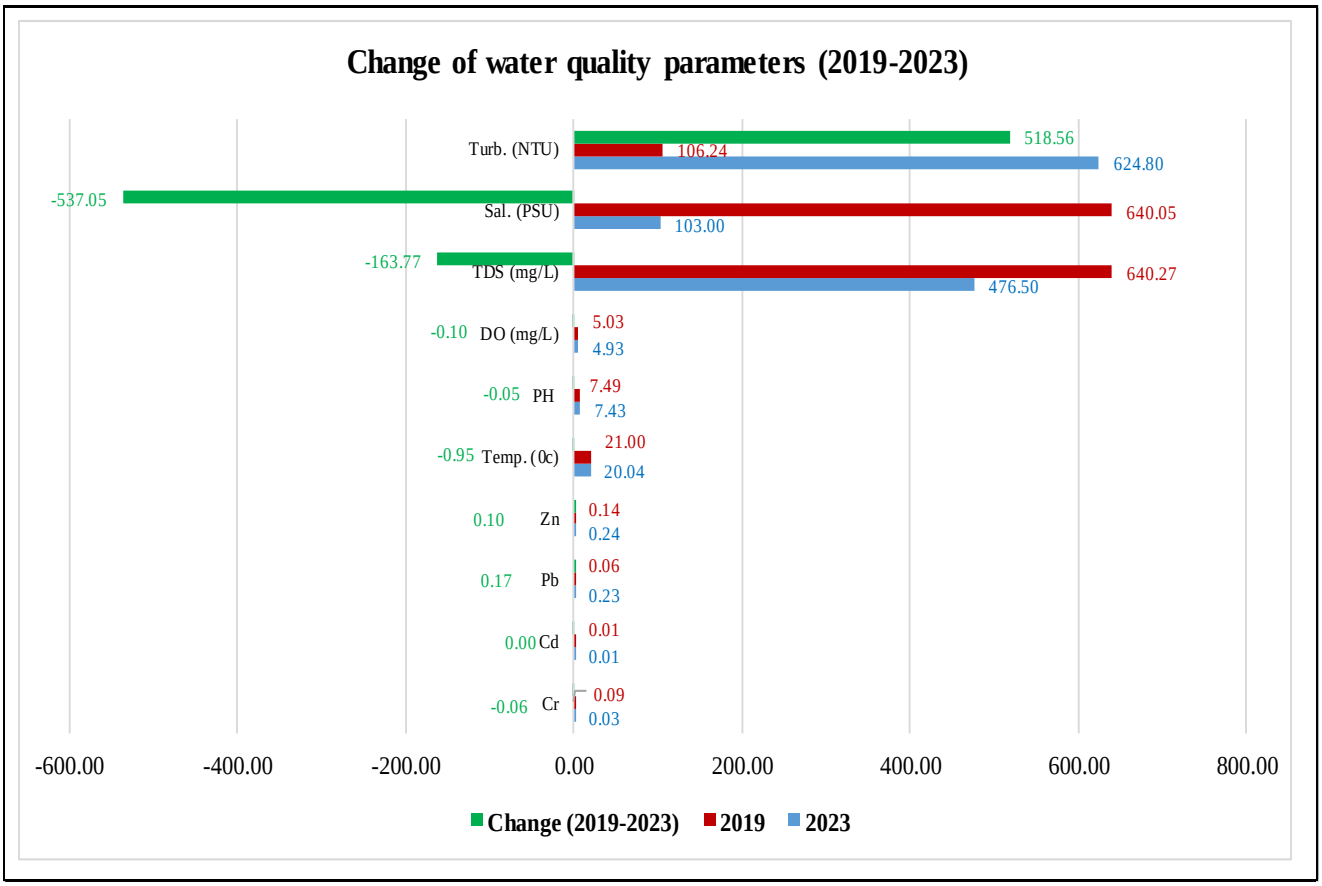


**Figure 4.15: Overall change of water quality parameters (2019-2023) clustered bar chart**

### 4.3.1.1 Chromium

The mean Chromium concentration of water in the Little Akaki river catchment showed slight variations over the last four years' period as shown in (Fig. 4.16). In 2019 the highest mean Chromium was recorded which is (0.203) at sample site (S3) and the least mean Chromium concentration was recorded (0.009) during the year of 2023 at sample site (S6). Moreover, average Chromium of 0.085 was recorded for 2019 and 0.028 in 2023. The study finding indicated that the concentration of Chromium in the water changed during a 4-year period, with the highest value (0.203mg/l) in 2019 has decreased to lowest value of (0.009mg/l) in 2023. Throughout each sampling sites, the measured Chromium concentration levels were decreased to < 0.1mg/L indicated by USEPA and WHO criteria for safe drinking water.

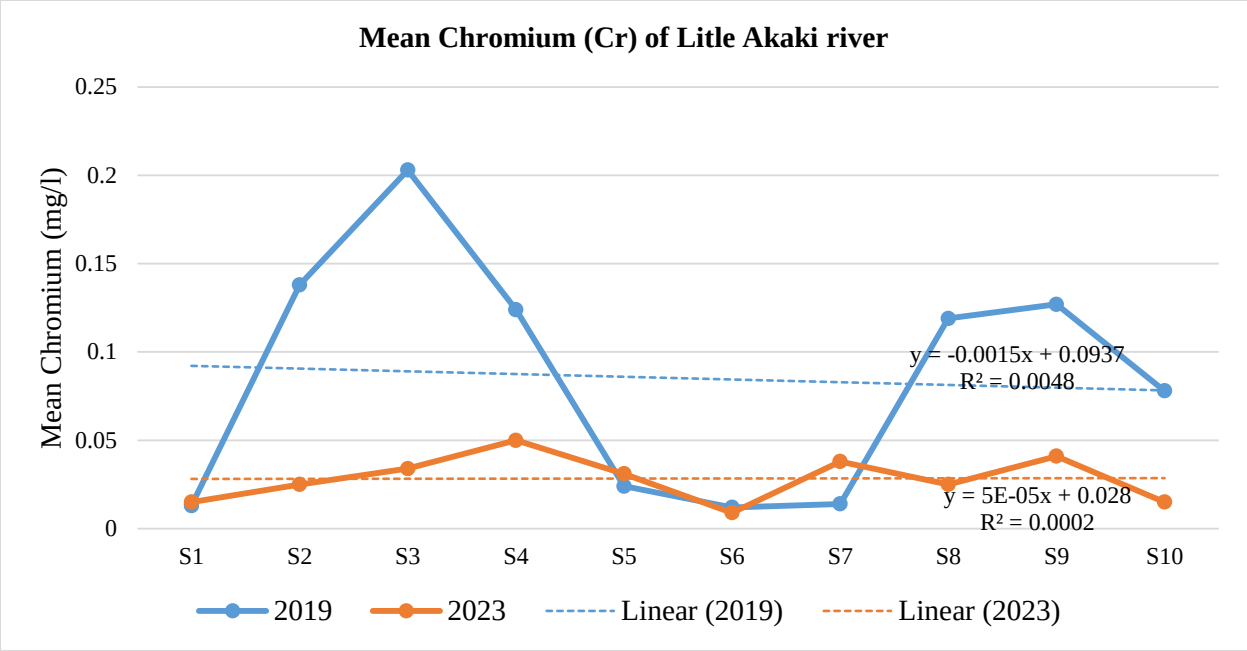


**Figure 4.16: Mean values Chromium time series plot graph**

| Mean Chromium | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | 0.013 | 0.138 | 0.203 | 0.124 | 0.024 | 0.012 | 0.014 | 0.119 | 0.127 | 0.078 |
| 2023 | 0.015 | 0.025 | 0.034 | 0.05 | 0.031 | 0.009 | 0.038 | 0.025 | 0.041 | 0.015 |

The mean Chromium showed a rising and falling pattern among sampling sites of study. In addition, there is variation within sampling years. Moreover, the variation has decreased for each sampling sites in 2023. Based on the chromium solubility, environmental receiver or human intake, and toxicity consequences, the United States Environmental Protection Agency (USEPA) has proposed water quality criteria with the maximum permitted concentration of total chromium in drinking water at 0.1 mg/L. The mean value of current research data of Chromium content in Little Akaki river is within the USEPA drinking surface water quality standard of 0.1mg/L. The main reason for the reduction in Chromium content for the year of 2023 from that of 2019 could be application of conventional wastewater treatment on physio chemical parameters by nearby industries.

### 4.3.1.2 Cadmium

The mean Cadmium concentration of water in the Little Akaki river catchment showed variations over the last four years' period as shown in (Fig. 4.17). In 2019 the maximum mean Chromium was recorded which is (0.02mg/L) at sample site (S5) and the least mean Chromium concentration was recorded (0.003) during the year of 2019 and 2023 at sample site S3 and S1 respectively. Moreover, average Chromium of 0.011 was recorded for 2019 and 0.006 in 2023. The study finding indicated that the concentration of Cadmium in the water's changed during a 4-year period, with the highest value (0.02mg/l) in 2019 has decreased to lowest value of (0.003mg/l) in 2023. Throughout each sampling sites, the measured Cadmium concentration levels were decreased. However, the World Health Organization (WHO) standard maximum level of Cadmium in drinking water were not meet which is (<0.003).

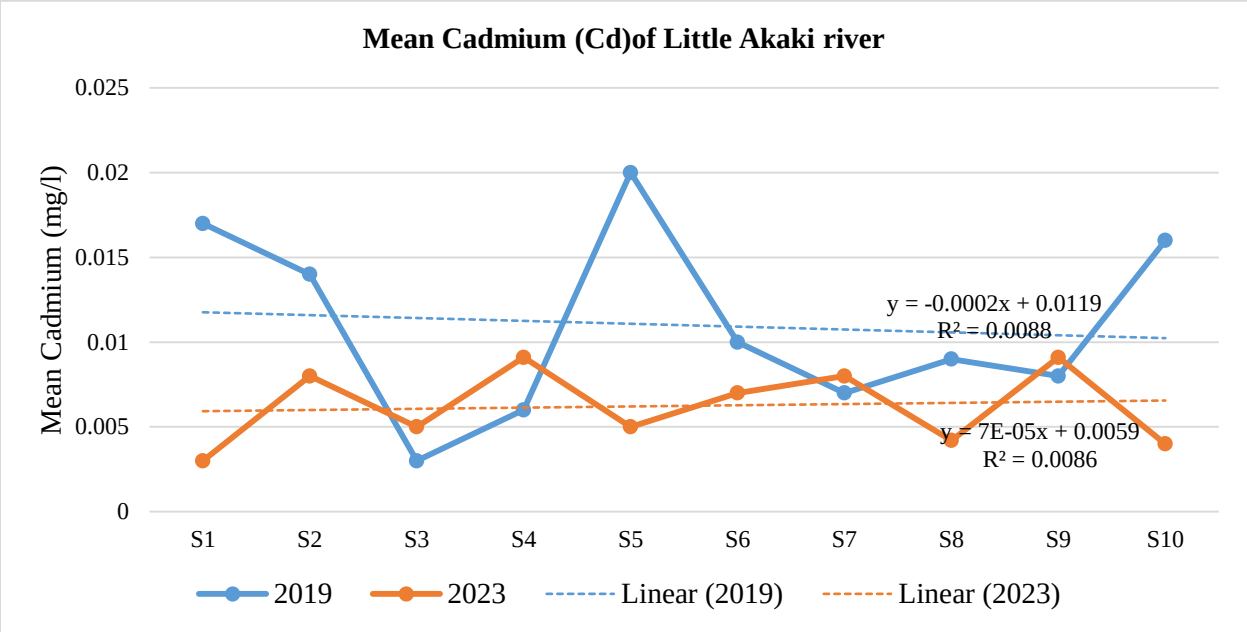


**Figure 4.17: Mean value Cadmium time series plot graph**

| Mean Cadmium | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | 0.017 | 0.014 | 0.003 | 0.006 | 0.02 | 0.01 | 0.007 | 0.009 | 0.008 | 0.016 |
| 2023 | 0.003 | 0.008 | 0.005 | 0.0091 | 0.005 | 0.007 | 0.008 | 0.0042 | 0.0091 | 0.004 |

The mean Cadmium content showed a rising and falling pattern among sampling sites of study. However, there is high variation within sampling years. Even though the Cadmium concentration was decreased, the values, however, were above the 2011 World Health Organization (WHO)-recommended limit of 0.003mg/l. The reason could be environmental exposure of the river water to fumes and dusts during the electroplating, melting, or mining process along river side. Moreover, contamination of a water source through natural erosion of cadmium-containing rocks, industrial wastes, wastes from crop land around riverside by fertilizer (contaminant in phosphate rock), pigment production, mine tailings or spoils, smelting, and plasticizers production.

#### 4.3.1.3 Lead (Pb)

The mean Lead (Pb) content of water in the Little Akaki river catchment showed variations over the last four years' period (Fig. 4.18). In 2023 the highest mean Pb was recorded which is (0.31mg/l)) at sample site (S9) and the least mean Pb was recorded (0.031) during the year of 2019 at sample site (S1). Moreover, mean average Pb of 0.06 was recorded for 2019 and 0.227mg/l in 2023. The study finding indicated that the water's lead changed from 2019 to 2023, with the lowest value (0.031mg/l) in 2019 has increased to greatest value ( 0.31mg/l) in 2023. Throughout each sampling sites, the measured Pb content were significantly greater than the 0.01mg/l indicated by 2008 WHO criteria for safe drinking water.

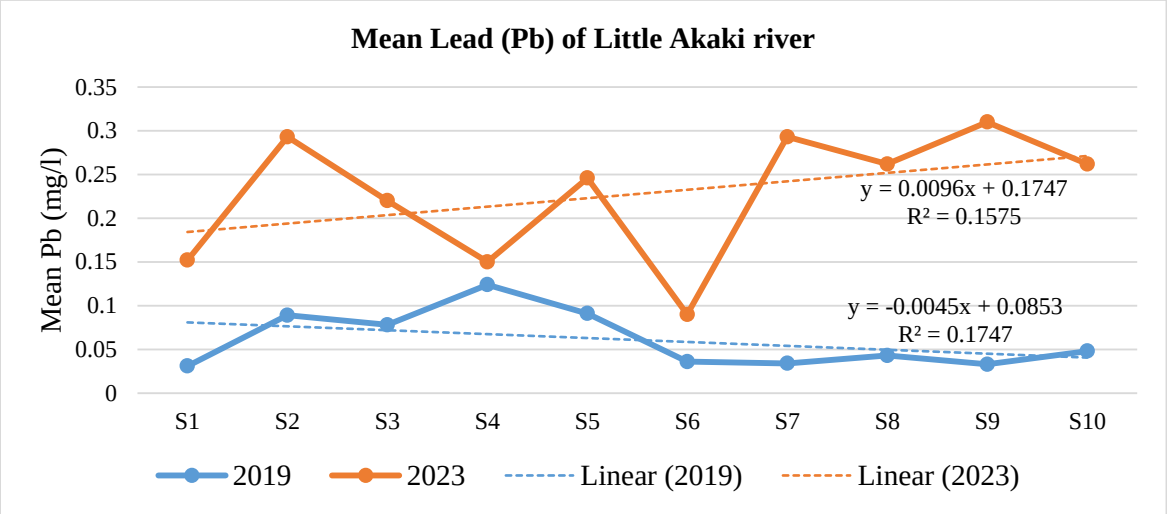


**Figure 4.18: Mean value Lead time series plot graph**

| Mean Lead (Pb) | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | 0.031 | 0.089 | 0.078 | 0.124 | 0.091 | 0.036 | 0.034 | 0.043 | 0.033 | 0.048 |
| 2023 | 0.152 | 0.293 | 0.22 | 0.15 | 0.246 | 0.09 | 0.293 | 0.262 | 0.31 | 0.262 |

The mean Pb showed a rising and falling pattern among sampling sites. However, there is high variation within sampling years. Moreover, the concentration of Pb is beyond the normal surface water quality standard of 0.01m/l. In addition, the variation of increase has doubled for each sampling sites. The main reason for the increase in Pb content could be expansion of industrial wastewater sources.

#### 4.3.1.4 Zink (Zn)

The mean Zink content of river water in the Little Akaki showed variations over the last four years' period (Fig. 4.19). The highest mean ZN was recorded in 2023 which is (0.94mg/l)) at sample site (S10) and the least mean Pb was recorded (0.029) during the same year of 2023 at sample site (S8). Moreover, mean average Zink of 0.142 and 0.238 mg/l was recorded for 2019 and in 2023 respectively.

The study finding indicated that the water Zink level changed from 2019 to 2023. However, both the lowest value (0.029mg/l) and greatest value (0.31mg/l) is registered in 2023. In most of the sampling sites, the measured Zn level were on the range of < 0.2mg/l indicated by 2008 WHO criteria for safe drinking water except S4, S5, S9 and S10. The mean Zn showed a rising and falling pattern among sampling sites. However, there is slight variation within sampling years. Moreover, the concentration of Zn is beyond the normal surface water quality standard of 0.2mg/l. In addition, the variation of increase is slight for each sampling sites. The main reason for the increase in Zn content could be natural inputs of metals from catchment or from specific industrial discharges.

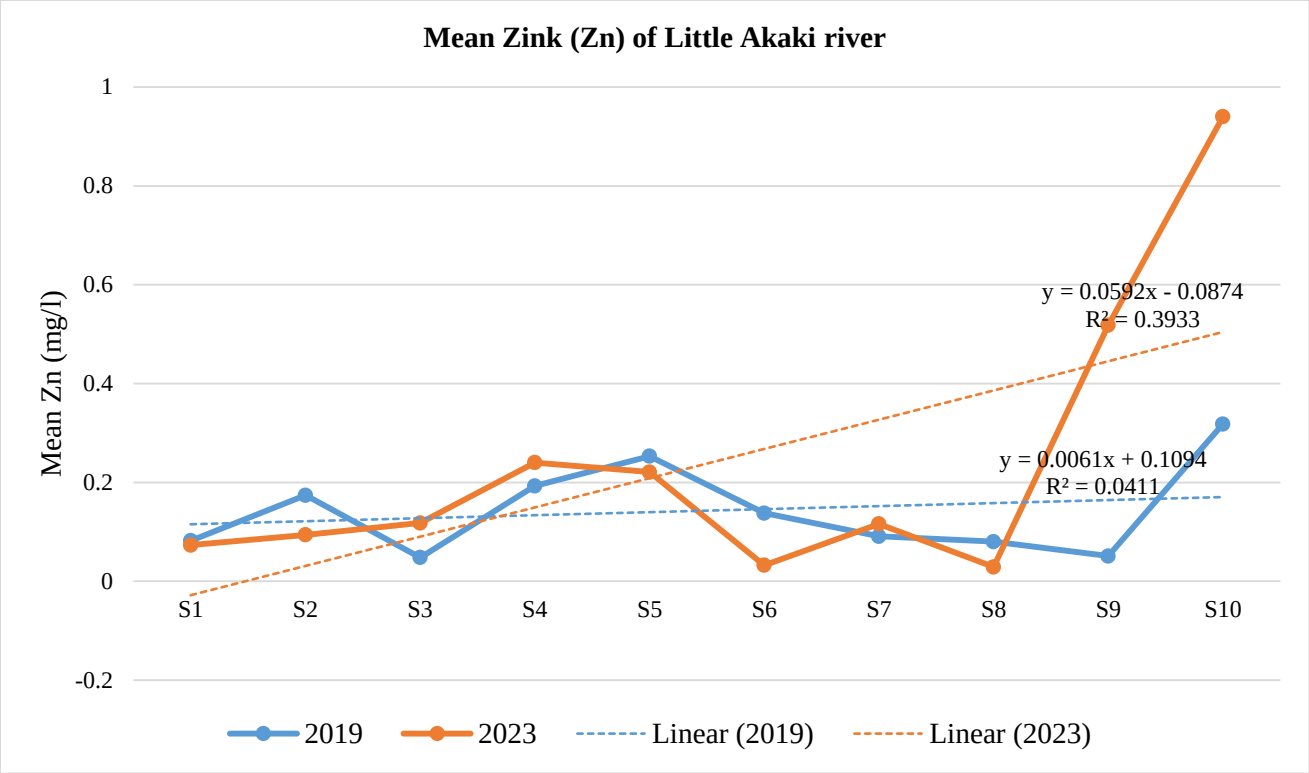


**Figure 4.19: Mean value Zink time series plot graph**

| Mean Zink (Zn) | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | 0.082 | 0.174 | 0.048 | 0.193 | 0.253 | 0.138 | 0.091 | 0.08 | 0.051 | 0.318 |
| 2023 | 0.073 | 0.094 | 0.118 | 0.24 | 0.221 | 0.0324 | 0.116 | 0.029 | 0.518 | 0.94 |

### 4.3.1.5 Mean Temperature (Temp.)

The mean Temperature of river water in the Little Akaki showed variations over the last four years' period (Fig. 4.20). The highest mean Temp. was recorded in 2023 which is ($23^0$c)) at sample site (S3) and the least mean Temp. was recorded ($16.7^0$c) during the same year of 2023 at sample site (S6). Moreover, mean average Temperature of 21 $^0$c and 20.04 $^0$c was recorded for 2019 and 2023 respectively. The study finding indicated that the water Temp. level changed from 2019 to 2023. However, both the lowest value ($16.7^0$c) and greatest value ($23^0$c) is registered in 2023. In most of the sampling sites, the measured Temp. level were on between the range of < $20^0$c - $50^0$c indicated by WHO criteria for safe drinking water. The mean Temperature showed a rising and falling pattern among sampling sites. However, there is slight variation

within sampling years. Moreover, the level of Temp. is within the range of WHO normal surface water quality standard of $20^0$c -$50^0$c. In addition, the variation of increase is slight for each sampling sites. The main reason for the increase in Temp. level could be stream discharges, which is the inflows and outflows of a river has an effect on the heating capacity.

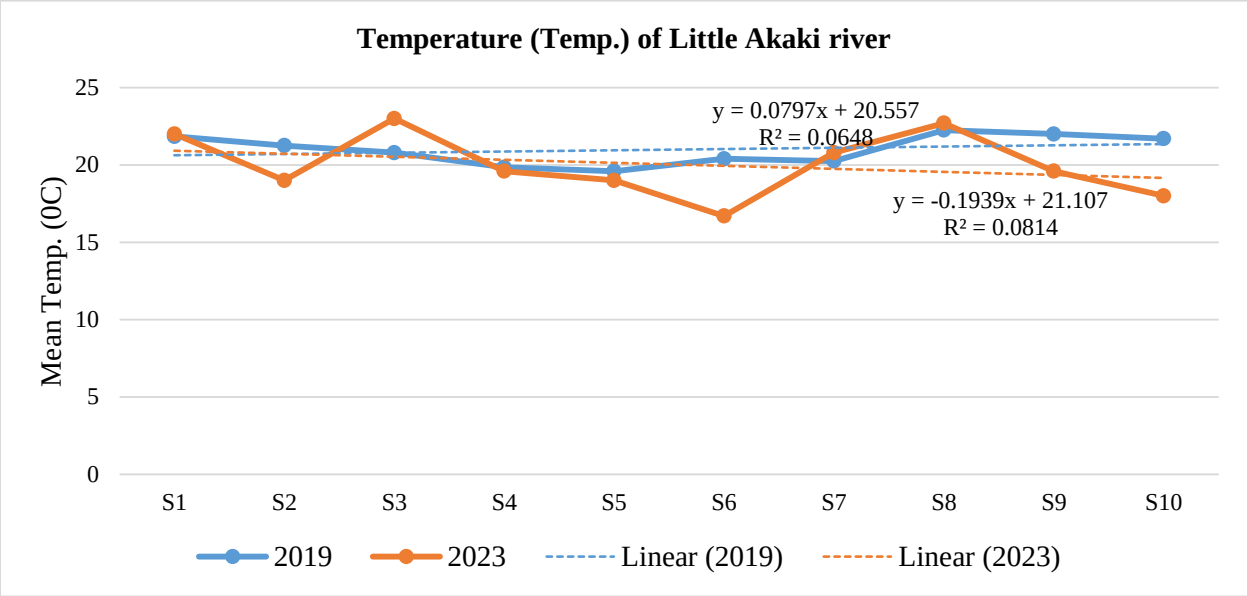


**Figure 4.:20: Mean value Temperature time series plot graph**

| Mean Temperature | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **2019** | 21.85 | 21.25 | 20.8 | 19.85 | 19.6 | 20.4 | 20.25 | 22.25 | 22 | 21.7 |
| **2023** | 22 | 19 | 23 | 19.6 | 19 | 16.7 | 20.8 | 22.7 | 19.6 | 18 |

### 4.3.1.6 Power of Hydrogen (pH)

The mean pH of water in the Little Akaki river catchment showed variations over the last four years' period (Fig. 4.21). The highest mean PH was recorded in 2023 which is (8.48) at S8 and the least mean pH was recorded (6.91) during the same year of 2023 at S2. Moreover, average mean pH of 7.48 was recorded for 2019 and 7.43 in 2023. Throughout each sampling sites, the measured pH value was within 6.5-9.0 indicated by USEPA criteria for safe water.

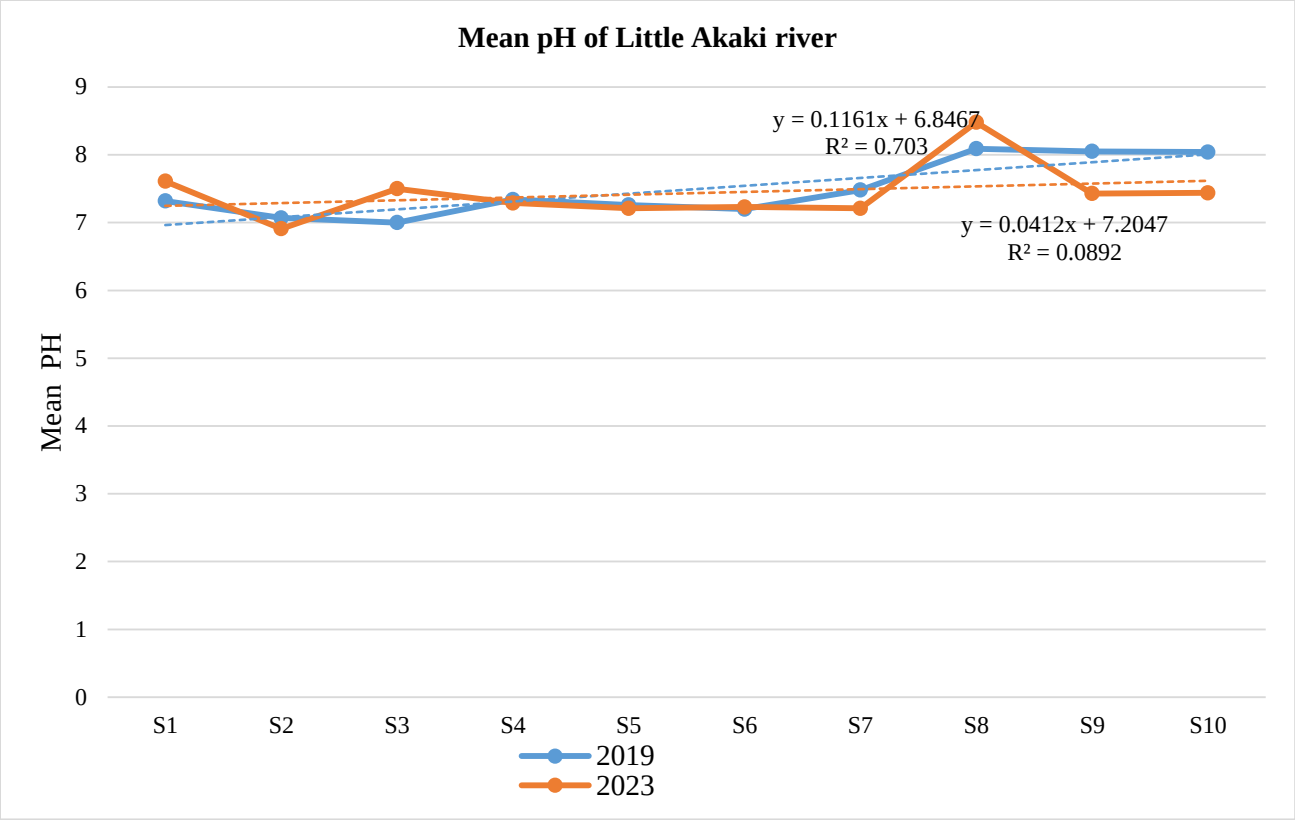


**Figure 4.21: Mean value PH time series plot graph**

| Mean PH | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | 7.32 | 7.07 | 7 | 7.34 | 7.26 | 7.2 | 7.48 | 8.09 | 8.05 | 8.04 |
| 2023 | 7.61 | 6.91 | 7.5 | 7.29 | 7.21 | 7.23 | 7.21 | 8.48 | 7.43 | 7.44 |

In 2019, the measured mean value of PH amongst water sample sites varied between 7.0 and 8.09, indicating neutral to alkaline water conditions. While in the 2023, pH level varied between 6.91 and 8.48. The average pH was slightly acidic to alkaline.

### 4.3.1.7 Dissolved Oxygen (DO)

The mean Dissolved Oxygen content of river water in the Little Akaki showed variations over the last four years' period (Fig. 4.22). The highest and least mean DO was recorded in 2019 which is (7.19mg/l) at sample site S1 and (3.25mg/l) at sample site (S4) respectively. Moreover, mean average DO of 4.30 and 4.39 was recorded for 2019 and 2023 respectively. The finding indicated that the water DO of Little Akaki river level changed from 2019 to 2023. Never the

less, both the lowest and the greatest value of Do is registered in 2019. In most of the sampling sites, the measured DO level were between the range of 6.5-8mg/L which is less than the indicated WHO criteria for safe drinking water.

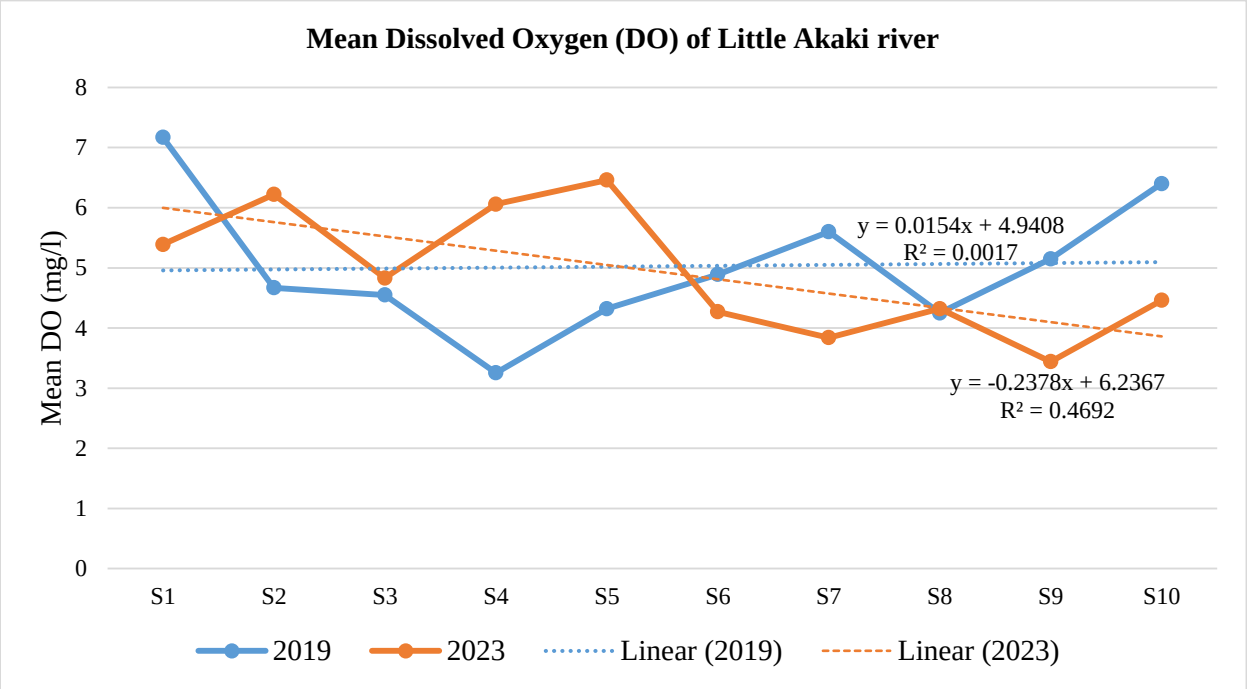


**Figure 4.22: Mean value Dissolved Oxygen time series plot graph**

| Mean DO | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | 7.17 | 4.67 | 4.55 | 3.254 | 4.32 | 4.89 | 5.6 | 4.25 | 5.15 | 6.4 |
| 2023 | 5.39 | 6.22 | 4.83 | 6.06 | 6.46 | 4.27 | 3.84 | 4.32 | 3.44 | 4.46 |

In 2019, the measured mean value of DO amongst water sample sites varied between 3.25 and 7.17, indicating below the level of standard DO. While in the 2023, DO level varied between 3.44 and 6.46. The average value of DO in Little Akaki river water was slightly increased during 2023. The main reason could be due to relative large surface area and ground discharge which meant that their dissolved oxygen concentrations will depend on the water temperature.

### 4.3.1.8 Total Dissolved Solids (TDS)

The mean Total Dissolved Solids content of river water in the Little Akaki showed variations over the last four years' period (Fig. 4.23). The highest and least mean TDS was recorded in 2019 which is (915.57) at sample site S4 and (48) at sample site (S1) respectively. Moreover, mean average TDS of 640.27 and 476.5 was recorded for 2019 and 2023 respectively. The finding indicated that the water TDS of Little Akaki river level changed from 2019 to 2023. Never the less, both the lowest and the highest value of TDS is registered in 2019. In most of the sampling sites, the measured average mean TDS level were within the range of maximum concentration level set by EPA which is 500mg/L.

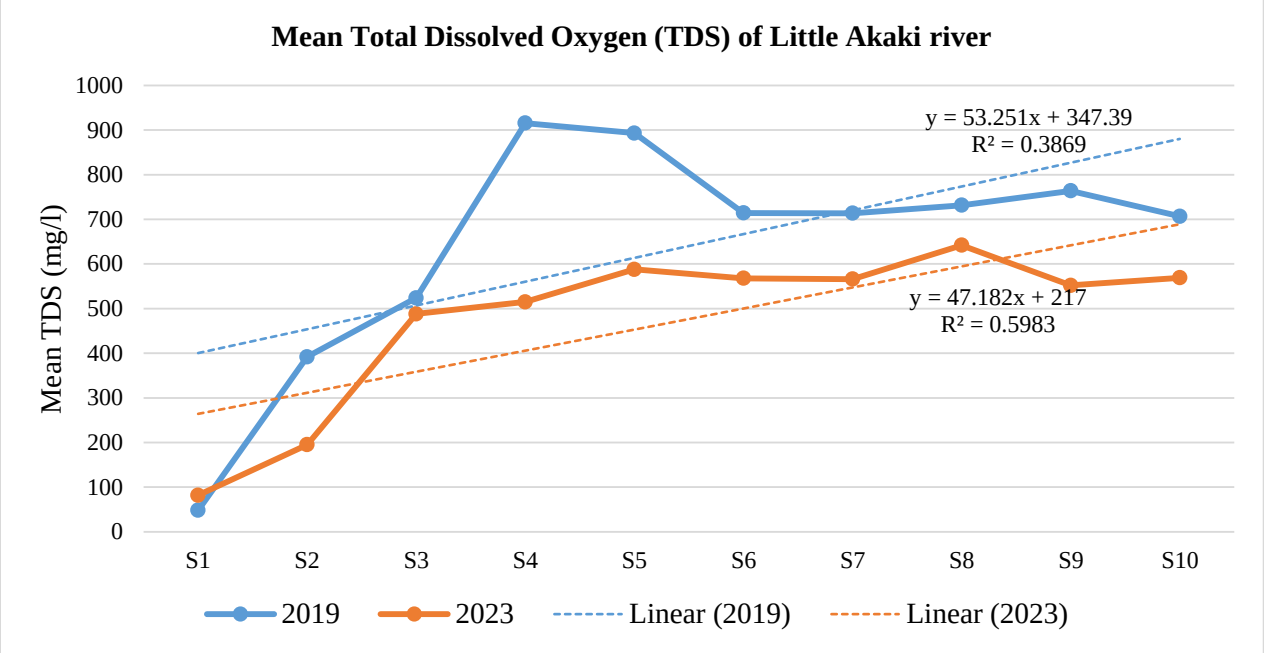


**Figure 4.23: Mean value Total Dissolved Solids time series plot graph**

| Mean TDS | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | 48 | 391.93 | 523.83 | 915.57 | 893.3 | 714.3 | 713.53 | 731.53 | 763.87 | 706.83 |
| 2023 | 82 | 195 | 488 | 515 | 588 | 568 | 566 | 642 | 552 | 569 |

In 2019, the measured mean value of TDS amongst water sample sites varied between 48mg/L and 915.57mg/L, indicating below and above the level of standard TDS. While in the 2023, TDS level varied between 82mg/L and 642mg/L. The average value of TDS in Little Akaki river

water was decreased during 2023. The main reason could be due to the flow rate of a waterbody. Fast running water can have large sized and more sediment and heavy rain can pick the clay, sand, silt, leaves and soil. However, the study water samples have been taken during dry season. Therefore, this could be the reason for water TDS level decrement.

#### 4.3.1.9 Salinity

The mean Salinity content of river water in the Little Akaki showed variations over the last four years' period (Fig. 4.24). The highest mean Salinity was recorded in 2019 which is (918.1mg/L) at sample site S4 and least (46mg/L) at sample site (S1). Moreover, mean average Salinity of 640.05 and 103 was recorded for 2019 and 2023 respectively. The finding indicated that the water Salinity at S4 had been very high in 2019 and decreased to 139mg/L in 2023. The same minimum mean Salinity concentration was recorded at S1 for both years of the study. In most of the sampling sites, based on taste threshold not on health consideration set by WHO guideline; the measured average mean Salinity level were above the range of maximum concentration level which is 250mg/L for chloride (Cl) and 200mg/L for Sodium (Na) during the year 2019 and below during 2023.

In 2019, the measured mean value of Salinity amongst water sample sites varied between 48.12mg/L and 918.1mg/L, indicating below and above the level of standard. While in the 2023, Salinity level varied between 46mg/L and 139mg/L. The average value of Salinity in Little Akaki river water was significantly decreased during 2023. The main reason could be due to in the long term, trees soak more water. Therefore, there is less saline ground water entering the river. Moreover, salinity increase is continuously counterbalanced by input of fresh water from rainfall, precipitation and other streams.

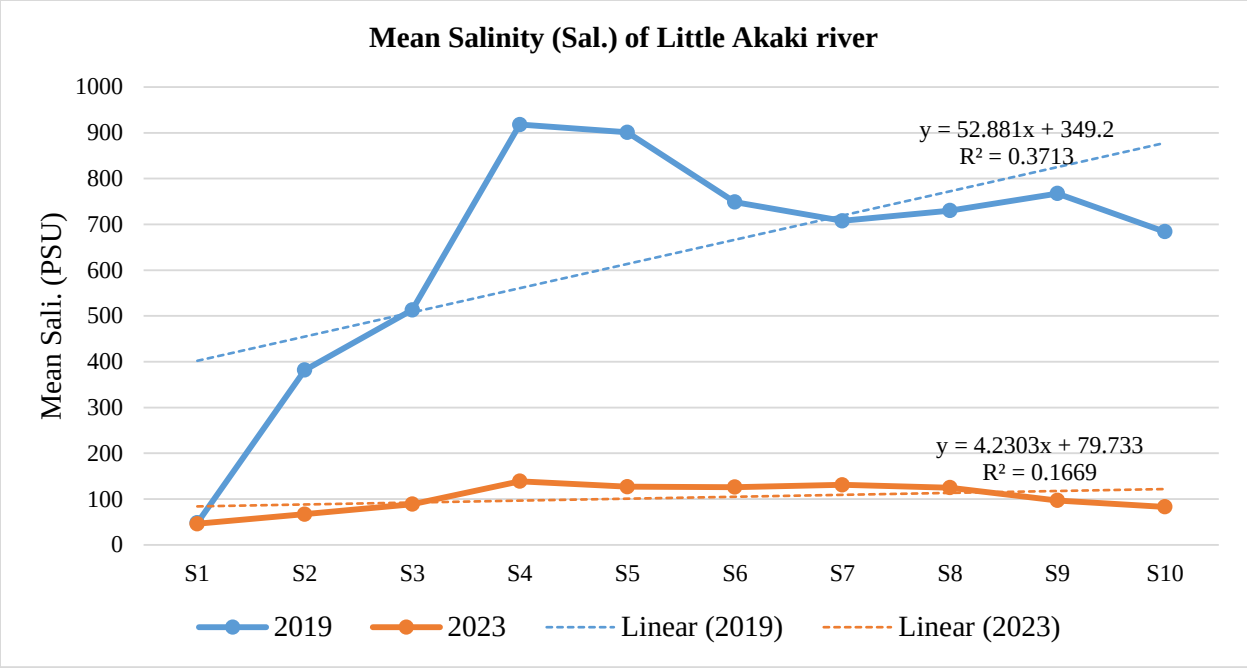


**Figure 4.24: Mean value Salinity time series plot graph**

| Mean Salinity | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | 48.12 | 381.75 | 513.13 | 918.1 | 901.23 | 748.8 | 707.6 | 730.2 | 767.35 | 684.2 |
| 2023 | 46 | 67 | 89 | 139 | 127 | 126 | 131 | 125 | 97 | 83 |

### 4.3.1.10 Turbidity

The mean turbidity of water in the Little Akaki river catchment showed variations over the last four years' period (Fig. 4.25). In 2023 the highest mean turbidity was recorded which is (914 NTU) at sample site (S5) and the least mean turbidity was recorded (38.57 NTU) during the year of 2019 at sample site (S1). Moreover, average turbidity of 106.24 was recorded for 2019 and 624.8 NTU in 2023. The study finding indicated that the water's turbidity changed during a 4-year period, with the lowest value (38.57 NTU) in 2019 has increased to greatest value ( 914 NTU) in 2023. Throughout each sampling sites, the measured turbidity levels were significantly greater than the 0.2 NTU indicated by WHO criteria for safe water.

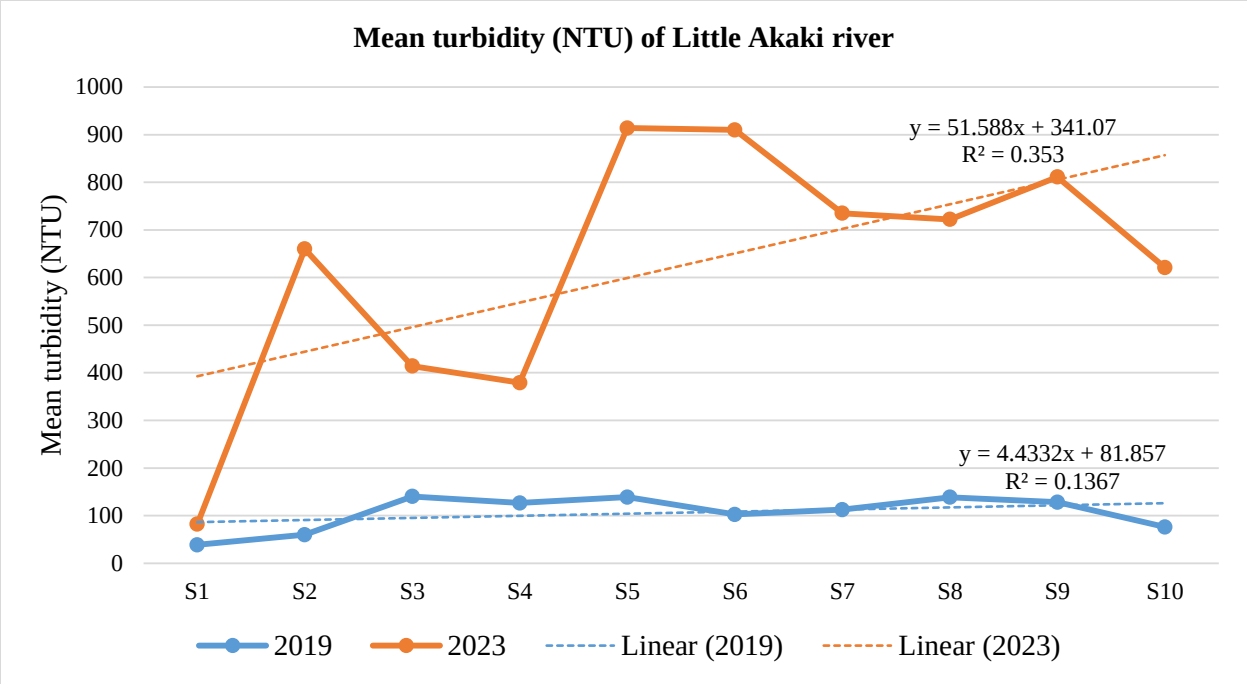


**Figure 4.25: Mean value Turbidity time series plot graph**

| Mean | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | 38.57 | 59.83 | 140.33 | 126.6 | 138.87 | 102.53 | 112.47 | 138.6 | 128.3 | 76.3 |
| 2023 | 82 | 660 | 414 | 379 | 914 | 910 | 735 | 722 | 811 | 621 |

The mean turbidity showed a rising and falling pattern among sampling sites of study. However, there is high variation within sampling years. Even though the turbidity concentration was within the normal surface water quality standard of 1-1000 NTU, the values, however, were above the World Health Organization (WHO)-recommended limit of 5 NTU and above EDWQ standard limit which is 7NTU for portability. Moreover, the variation has significantly increased by more than double for each sampling sites. The reason for the high turbidity level could be attributed to the annual foods. Moreover, farming along the river sides and activities like sand mining in the lower part of the catchment were prevalent and could have contributed to the high turbidity due to surface run off. It is evident that high turbidity limits the amount of sunlight and oxygen available for the survival of aquatic life and hence biological productivity in the area.

### 4.3.2 Paired t-test

The result of the paired t-test revealed a significant difference in Chromium concentration during 2019 and 2023 (t (9) = 2.874, p = .018). This finding supports our hypothesis that land use change would lead to increase chromium level of water. This result is consistent with previous research by Saran et al. (2018), who also reported significant increase in chromium content of water due to agricultural land use impact. The current study further strengthens the existing evidence and underscores the land use land cover change would increase the chromium content of river water. The mean difference in Chromium was .0569 Unit (SD = .0626), indicating an increase of river water Chromium level with land use land cover changes.

The result of the paired t-test revealed a significant difference in Lead concentration during 2019 and 2023 (t (9) = -6.347, p = .001). This finding supports our hypothesis that land use land cover change would lead to increase Lead level of water. This result is consistent previous research by Emenike, P. C., Tenebe, I T., Neris, J. B., Omole, D. O., Afolayan, O., Okeke, C. U., & Emenike, I K. (2020), who reported that urban land use had the highest lead concentration in river water, followed by agricultural land use. The current study further strengthens the existing evidence and underscores the land use land cover change would increase the lead content of river water. The mean difference in lead was -.1671 Unit (SD = .0825), indicating an increase of river water lead level with land use land cover changes.

The result of the paired t-test revealed a significant difference in Total Dissolved Solids (TDS) concentration during 2019 and 2023 (t (9) = 4.127, p = .003). This finding supports our hypothesis that land use change would lead to increase Total Dissolved Solids (TDS) level of water. This result is consistent with previous research by Sharma, C.M., Kang. S., Tripathee. L. et al. (2021), who reported significantly higher TDS concentrations in rivers affected by urban land use and wastewater discharges. The current study further strengthens the existing evidence and underscores the land use land cover change would increase the Total Dissolved Solids (TDS) content of river water. The mean difference in Total Dissolved Solids (TDS) was 163.769 Unit (SD = 125.500), indicating an increase of river water Total Dissolved Solids (TDS) level with land use land cover changes.

**Table 4.12: Paired t-test river water quality parameters for 2019 and 2023**

| Paired Samples Test | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Paired Differences | | | | | | | |
| | | | | | 95% Confidence Interval of the Difference | | | | |
| Site | Parameters | Mean | Std. Deviation | Std. Error Mean | Lower | Upper | t | df | p |
| S 1 | Cr_2019 - Cr_2023 | .05690 | .06260 | .01980 | .01212 | .10168 | 2.874 | 9 | .018 |
| S 2 | Cd_2019 - Cd_2023 | .00476 | .00685 | .00217 | -.00014 | .00966 | 2.197 | 9 | .056 |
| S 3 | Pb_2019 - Pb_2023 | -.16710 | .08325 | .02633 | -.22666 | -.10754 | -6.347 | 9 | .000 |
| S 4 | Zn_2019 - Zn_2023 | -.09534 | .24564 | .07768 | -.27106 | .08038 | -1.227 | 9 | .251 |
| S 5 | Temp_2019 - Temp_2023 | .95500 | 1.96842 | .62247 | -.45313 | 2.36313 | 1.534 | 9 | .159 |
| S 6 | PH_2019 - PH_2023 | .05400 | .38091 | .12045 | -.21849 | .32649 | .448 | 9 | .665 |
| S 7 | DO_2019 - DO_2023 | .09640 | 1.76963 | .55961 | -1.16951 | 1.36231 | .172 | 9 | .867 |
| S 8 | TDS_2019 - TDS_2023 | 163.76900 | 125.50042 | 39.68672 | 73.99141 | 253.54659 | 4.127 | 9 | .003 |
| S 9 | Sal_2019 - Sal_2023 | 537.04800 | 235.37362 | 74.43167 | 368.67185 | 705.42415 | 7.215 | 9 | .000 |
| S 10 | Turb_2019 - Turb_2023 | -518.56000 | 248.36294 | 78.53926 | -696.22814 | -340.89186 | -6.603 | 9 | .000 |

Notes: *** P<0.01 and ** P<0.05

Source: Computed own, 2023

The result of the paired t-test revealed a significant difference in Salinity concentration during 2019 and 2023 (t (9) = 7.215, p = .001). This finding supports our hypothesis that land use change would lead to increase Salinity level of water. This result is consistent with previous research by Kharazmi, R., Tavili, A., Rahdari, M.R., Chaban, L., Pnidi, E., & Rodrigo-Comino, J. (2018), who also reported a significant increase in Salinity content of river water in Iran. The current study further strengthens the existing evidence and underscores the land use land cover

change would increase the Salinity content of river water. The mean difference in Salinity was 537.048 Unit (SD = 235.373), indicating an increase of river water Salinity level with land use land cover changes.

The result of the paired t-test revealed a significant difference in Turbidity concentration during 2019 and 2023 (t (9) = -6.603, p = .001). This finding supports our hypothesis that land use change would lead to increase Turbidity level of water. This result is consistent with previous research by Camara. M., Jamil, N.R. & Abdullah., A.F.B. (2019), who also reported that land use changes associated with urbanization and agriculture had a significant impact on turbidity levels in river water. The current study further strengthens the existing evidence and underscores the land use land cover change would increase the Turbidity content of river water. The mean difference in Turbidity was -518.56 Unit (SD = 248.362), indicating an increase of river water Turbidity level with land use land cover changes.

### 4.4. Land use land cover change and river water quality parameters

#### 4.4.1 Settlement and buildup

The hypothesis is that settlement and buildup activities have a significant effect on water quality indicators such as PH, Total Dissolved Solids (TDS), Salinity, and Turbidity. Urban areas generate significant amount of wastewater, including domestic sewage and industrial effluents. These effluents can contain acidic components like detergents, organic acids and industrial chemicals that can lower the PH of the receiving river if inadequately treated and discharged directly. In 2019, a strong positive correlation is observed between settlement buildup and pH (r = 0.764, p = 0.010). This correlation is statistically significant at the 0.05 level, indicating that as settlement and buildup increases, there is a tendency for the pH levels to increase as well. This finding suggests that settlement and buildup have an impact on the acidity or alkalinity of the water. Thus, the outcome is consistent with a research finding by Bhattarai et al. (2019), that urbanization significantly influenced water quality, resulting in lower pH levels in urban streams compared to rural streams. There is also a strong positive correlation between settlement buildup and TDS (r = 0.677, p = 0.031). This correlation is statistically significant at the 0.05 level, indicating that settlement and buildup is associated with higher concentrations of dissolved solids

in the water. The presence of settlement and buildup may contribute to increased TDS levels, which can impact water quality and potentially affect various aquatic organisms. A strong positive correlation is also observed between settlement and buildup and salinity ($r = 0.671$, $p = 0.034$). This correlation is statistically significant at the 0.05 level, suggesting that settlement and buildup is associated with higher salinity levels. The research result is consistent with the research findings by Cui et al. (2017), that influence of urban development on river water salinity, showing urbanization lead to higher salinity levels. The increase in settlement and buildup contributed to an accumulation of salts in the water, leading to elevated salinity levels.

In 2023, there is a very strong positive correlation between settlement buildup and total dissolved solids (TDS) ($r = 0.814$, $p = 0.004$). The correlation is statistically significant at the 0.01 level, suggesting a robust association between settlement buildup and higher TDS levels. Settlement buildup activities likely contribute to the increased presence of dissolved solids in the water. There is also a strong positive correlation between settlement buildup and turbidity ($r = 0.736$, $p = 0.015$). The correlation is statistically significant at the 0.05 level, indicating a robust association between settlement buildup and increased turbidity. Settlement buildup activities likely contribute to higher levels of suspended particles, leading to greater water turbidity. Thus, the result is consistent with the research finding by Woldesenbet et al. (2017) and Woldesenbet et al. (2018) in the upper Blue Nile Basin, Ethiopia, expansion of settlement and buildup area with expense of forest land increase surface runoff which will turn enhance TDS and Turbidity of river water quality.

According to Addis Ababa City Land Administration Authority key informant interview, the emergence of informal settlements and various development activities, particularly industrial undertakings as the primary factors contributing to land cover change around Little Akaki river. The interview mentions that the contamination of river water is attributed to waste generated by industries and households, indicating potential sources of pollution that can impact water quality indicators. Thus, the key informant interview had aligned with the research finding. Settlement and buildup areas, if not properly managed, can contribute to increased pollution through inadequate waste disposal, improper sewage system and release of pollutants into the water. To address the contamination and improve water quality, the authority proposes establishing a strong sense of ownership across sectors, implementing local methodologies at the individual

level to prevent contamination, and involving the community in river-side management. These proposed strategies align with the hypothesis that settlement and buildup land can have a significant effect on water quality indicators since addressing pollution sources and involving the community are crucial steps to mitigate water pollution.

According to Urban planning institution of Addis Ababa City key informant interview, land use changes and the construction of illegal buildings as the main causes of land use and land cover changes in the catchment area. These changes negatively affect the river buffer areas, originally planned for water treatment purposes, and contribute to surface and groundwater contamination. Improper waste disposal resulting from land use changes also contaminates the river, further affecting water quality indicators. The key informant also addressed the importance of implementing protective laws and regulations regarding water quality standards, as well as developing safe and accessible riverbanks and buffers to reduce the need for costly water purification. Thus the key informant insight is aligned with research finding and hypothesis.

**Table 4.13: Pearson Correlation coefficient LULCC and water quality parameters of 2019**

| Variables | | 2019 Correlation coefficient | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cr | Cd | Pb | Zn | Temp | PH | DO | TDS | Sal | Turb |
| Settlement _build | r | -0.215 | -0.031 | -0.42 | 0.188 | 0.12 | .764* | -0.015 | .677* | .671* | 0.432 |
| | p | 0.552 | 0.933 | 0.227 | 0.603 | 0.74 | 0.01 | 0.967 | 0.031 | 0.034 | 0.213 |
| Crop land | r | -0.133 | 0.061 | -0.321 | 0.399 | 0.113 | .715* | 0.033 | .655* | .642* | 0.325 |
| | p | 0.713 | 0.867 | 0.366 | 0.254 | 0.755 | 0.02 | 0.927 | 0.04 | 0.045 | 0.36 |
| Waterbody | r | 0.27 | -0.35 | 0.264 | 0.27 | -0.324 | 0.236 | -.645* | .877** | .868** | .679* |
| | p | 0.45 | 0.322 | 0.462 | 0.451 | 0.361 | 0.512 | 0.044 | 0.001 | 0.001 | 0.031 |
| Forest | r | -0.075 | -0.157 | -0.269 | 0.231 | 0.025 | .713* | -0.144 | .778** | .768** | 0.538 |
| | p | 0.838 | 0.665 | 0.452 | 0.52 | 0.945 | 0.021 | 0.691 | 0.008 | 0.01 | 0.109 |
| Bare | r | -0.085 | 0.01 | -0.25 | 0.408 | 0.054 | .674* | -0.05 | .708* | .695* | 0.378 |
| | p | 0.815 | 0.978 | 0.486 | 0.242 | 0.882 | 0.032 | 0.891 | 0.022 | 0.026 | 0.281 |
| Grazing | r | -0.108 | 0.011 | -0.261 | 0.385 | 0.025 | 0.628 | -0.074 | .702* | .689* | 0.4 |
| | p | 0.766 | 0.976 | 0.466 | 0.272 | 0.946 | 0.052 | 0.839 | 0.024 | 0.027 | 0.252 |
| Shrub | r | 0.004 | -0.172 | -0.092 | 0.302 | -0.152 | 0.513 | -0.323 | .855** | .848** | 0.618 |
| | p | 0.991 | 0.634 | 0.801 | 0.396 | 0.676 | 0.13 | 0.363 | 0.002 | 0.002 | 0.057 |

Note: *. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

Source: Own computation

### 4.4.2 Crop land

The hypothesis is that crop land have a significant effect on water quality indicators such as PH, Zink, Total Dissolved Solids (TDS), and Salinity. In 2019, there is a strong positive correlation (Pearson correlation = 0.715*) between Crop and PH observed. This correlation is statistically significant ($p = 0.020 < 0.05$) at the 0.05 level. This outcome is consistent with the research finding by Wutich et al. (2016), where researcher analyzed water samples from urban crop land sites and found that irrigation practice and fertilizer use in urban crop cultivation increased river water pH. Soil pH plays a critical role in nutrient availability, microbial activity, and soil chemical reactions. Scientific studies have demonstrated the importance of pH in crop growth and yield.

There is a strong positive correlation (Pearson correlation = 0.655*) between Crop land and Total Dissolved Solids. This correlation is statistically significant ($p = 0.040 < 0.05$) at the 0.05 level. The significant correlation suggests a meaningful relationship between Crop land and Total Dissolved Solids in 2019. This research outcome is consistent with a research finding conducted by Gupta, S., & Gupta, R. D. (2016), that water with high TDS content for irrigation increased the TDS of soil subsequently affected TDS concentration in river water through runoff and percolation. Total Dissolved Solids represent the concentration of various dissolved substances, including minerals and salts, in water. The influence of TDS on crops depends on the specific crop species and their tolerance to different salts. Several scientific studies have highlighted the importance of maintaining appropriate TDS levels for optimal crop growth

There is a strong positive correlation (Pearson correlation = 0.642*) between Crop and Salinity. This correlation is statistically significant ($p = 0.045 < 0.05$) at the 0.05 level, indicating a meaningful relationship between Crop and Salinity in 2019. Thus, the outcome of this result is consistent with the research finding by Pradhan, P., et al. (2020), which is conducted in Mahanadi River Basin, India, shows strong correlation of crop land and river water salinity. Higher salinity levels may correspond to better crop growth. Salinity refers to the concentration of salts in soil or water, which can affect crop growth and development. Scientific research has demonstrated that appropriate levels of salinity can enhance nutrient uptake, osmotic regulation, and water-use efficiency in salt-tolerant crops, leading to improved growth and yield.

In 2023, there is a strong positive correlation between Crop and Total Dissolved Solids (r = 0.686, p = 0.029). This indicates that as crop yield increases, the concentration of dissolved solids in the water tends to increase as well. The significance level of 0.029 suggests that this correlation is statistically significant at the 0.05 level. There is a strong positive correlation between Crop and Zinc levels (r = 0.774, p = 0.009). This indicates that as the crop yield increases, the Zinc levels in the soil or plants tend to increase as well. This research outcome is consistent with a research finding by Mawere et al. (2020), conducted in Zimbabwe revealed that agricultural practices, use of waste water and fertilizers increased Zink concentration of waterbody. Zinc is an essential micronutrient for plant growth and plays a vital role in various physiological processes. Several studies have shown that adequate Zinc levels in soil and plants positively influence crop yield and quality. For instance, a study conducted on wheat crops found that Zinc application improved grain yield and nutrient uptake.

According to Addis Ababa City Administration Farmers and Urban Agriculture Development Commission key informant interview, they promote practices such as rooftop farming, pot gardening, and hydroponics, which can potentially have an impact on water quality indicators if they involve the use of irrigation and nutrient solutions. The interview mentions challenges faced by urban agriculture, like water scarcity and river water pollution where water scarcity can affect water quality indicators by altering the concentration of dissolved solids and potentially impacting pH and also Zink levels. To address water scarcity, the commission has taken measures such as creating water holes and distributing pumps to farmers, also encourages water harvesting during the summer season. These interventions can potentially influence water quality indicators by ensuring better access to water for irrigation.

### 4.4.3 Waterbody

The hypothesis is that waterbody have a significant effect on water quality indicators such as Total Dissolved Solids (TDS), Salinity, Turbidity and Dissolved Oxygen (DO). In 2019, the correlation coefficient between Waterbody and Total Dissolved Solids (TDS) is 0.877, indicating a very strong positive correlation. The p-value of 0.001 suggests that this correlation is highly statistically significant ($p < 0.01$). The data suggests a significant positive relationship between Waterbody and Total Dissolved Solids, indicating that as Waterbody increases, TDS levels also tend to increase. Thus, this research outcome is consistent with research finding by Kibria, G., et al. (2020, in Sangu River, Bangladesh, that waterbody have positive effect on TDS of river water. The correlation coefficient between Waterbody and Salinity is 0.868, indicating a very strong positive correlation. The p-value of 0.001 suggests that this correlation is highly statistically significant ($p < 0.01$). The data implies a significant positive relationship between Waterbody and Salinity, suggesting that as Waterbody increases, Salinity levels also tend to increase. This finding aligns with previous research that has reported similar positive associations between waterbody characteristics, such as connectivity to saline sources or hydrological conditions, can contribute to increased salinity levels (Peterson, B.J., et al., 2017).

The correlation coefficient between Waterbody and Turbidity is 0.679, indicating a strong positive correlation. The p-value of 0.031 suggests that this correlation is statistically significant ($p < 0.05$). The data suggests a significant positive relationship between Waterbody and Turbidity, indicating that as Waterbody increases, Turbidity levels tend to increase. The correlation coefficient between Waterbody and Dissolved Oxygen (DO) is -0.645, indicating a strong negative correlation. The p-value of 0.044 suggests that this correlation is statistically significant ($p < 0.05$). The data implies a significant negative relationship between Waterbody and Dissolved Oxygen (DO) levels, indicating that as Waterbody increases, Dissolved Oxygen tends to decrease. This finding aligns with previous research that has reported similar negative associations between waterbody characteristics and dissolved oxygen. Factors such as nutrient loading, organic matter content, and water temperature can influence dissolved oxygen levels in water bodies (Zhang, Y., et al., 2018).

In 2023, the correlation coefficient between Waterbody and Total Dissolved Solids is 0.826, indicating a very strong positive correlation. The p-value of 0.003 suggests that this correlation is statistically significant ($p < 0.01$). The data indicates a significant positive relationship between Waterbody and Total Dissolved Solids, suggesting that as Waterbody increases, TDS levels also tend to increase for the year 2023. Factors such as geological composition, weathering processes, and anthropogenic activities can influence TDS levels in water bodies (Wu, F., et al., 2020). The strong positive correlation in this dataset for the year 2023 indicates that as Waterbody increases, the concentration of dissolved solids tends to increase, potentially indicating higher levels of pollutants or minerals.

The correlation coefficient between Waterbody and Salinity is 0.719, indicating a strong positive correlation. The p-value of 0.019 suggests that this correlation is statistically significant ($p < 0.05$). The data implies a significant positive relationship between Waterbody and Salinity, indicating that as Waterbody increases, Salinity levels also tend to increase. This finding aligns with previous research that has reported similar positive associations between waterbody characteristics, such as connectivity to saline sources or hydrological conditions, can contribute to increased salinity levels (Peterson, B.J., et al., 2017). The correlation coefficient between Waterbody and Turbidity is 0.766, indicating a strong positive correlation. The p-value of 0.010 suggests that this correlation is statistically significant ($p < 0.05$). The data suggests a significant positive relationship between Waterbody and Turbidity, indicating that as Waterbody increases, Turbidity levels tend to increase for the year 2023. This finding align with previous research that has reported similar positive association between waterbody and turbidity by Wang, Z., et al. (2018), Yarlung Tsangpo River Basin, where waterbody and turbidity have significant association.

### 4.4.4 Forest land

The hypothesis is that Forest land have a significant effect on water quality indicators such as PH, Total Dissolved Solids (TDS), Salinity and Turbidity. In 2019, there is a strong positive correlation between forest land and PH ($r = 0.713$), and it is statistically significant at the 0.05 level. This indicates that increased forest land is associated with higher pH values in water. Forests can have a buffering effect on water pH by releasing organic acids and reducing the

acidity caused by other sources. This finding aligns with previous research that has reported forest can affect pH through leaf litter decomposition releases organic acids, which can neutralize acidity and increase pH (Likens et al., 2017). Additionally, the finding is supported with previous research where the presence of vegetation in forests can intercept rainfall, reducing the amount of acidic inputs reaching the water and potentially leading to higher pH values (Bishop et al., 2018). There is a strong positive correlation between forest land and total dissolved solids (TDS) ($r = 0.778$), and it is statistically significant at the 0.01 level. This indicates that increased forest land is associated with higher TDS levels in water. Forests can contribute to TDS through natural processes like leaf litter decomposition and soil erosion. This finding aligns with previous research that has reported leaf litter decomposition releases organic matter and dissolved substances into the water, increasing TDS (Creed et al., 2017).

There is a strong positive correlation between forest land and salinity ($r = 0.768$), and it is statistically significant at the 0.01 level. This suggests that increased forest land is associated with higher salinity levels in water. Forests can indirectly affect salinity by altering water balance, groundwater levels, and influencing the movement of salts through soil. This finding aligns with previous research that forests can impact salinity primarily through their effect on the water balance. Forest vegetation intercepts rainfall, reducing the amount of water reaching the ground and potentially leading to increased salt concentration (Wang et al., 2020). In addition, this finding also aligns with a research that forests can influence groundwater levels, and changes in groundwater dynamics can affect the movement of salts through the soil and into water bodies (O'Connor et al., 2019).

In 2023, there is a very strong positive correlation between forest land and total dissolved solids (TDS) ($r = 0.894$), and it is statistically significant at the 0.01 level. This indicates that increased forest land is strongly associated with higher TDS levels in water. Forests can contribute to TDS through processes like leaf litter decomposition and soil erosion, which release organic matter and minerals into the water. This finding aligns with previous research that soil erosion from forested areas can transport mineral particles and dissolved constituents, further elevating TDS levels in nearby water bodies (Zhang et al., 2020).

The presence of forests can also influence hydrological patterns, affecting water flow and the concentration of dissolved solids. Increased groundwater discharge from forested areas can

contribute to higher TDS levels in streams and rivers. There is a strong positive correlation between forest land and turbidity (r = 0.699), and it is statistically significant at the 0.05 level. This indicates that increased forest land is associated with higher turbidity levels in water. This finding aligns with previous research that forests can contribute to turbidity through sedimentation processes, erosion control, and the presence of organic matter. presence of vegetation reduces the velocity of surface runoff, promoting sedimentation and leading to increased turbidity in nearby water bodies (Croke et al., 2019). In addition, this finding also align with previous research that forested areas can also serve as sediment sources due to erosion processes, particularly during intense rainfall events or land disturbance activities (Allan, 2004). Furthermore, the accumulation of organic matter in forested watersheds can contribute to turbidity, as suspended particles and dissolved substances can increase light scattering and reduce water.

**Table 4.14: Pearson Correlation coefficient LULCC and water quality parameters of 2023**

| | 2023 Correlation coefficient | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | | Cr | Cd | Pb | Zn | Temp | PH | DO | TDS | Sal | Turb |
| Settlement and buildup | r | 0.019 | 0.127 | 0.404 | 0.482 | -0.323 | 0.24 | -0.627 | .814** | 0.53 | .736* |
| | p | 0.958 | 0.726 | 0.247 | 0.159 | 0.363 | 0.505 | 0.052 | 0.004 | 0.115 | 0.015 |
| Crop land | r | -0.133 | -0.011 | 0.377 | .774** | -0.457 | 0.109 | -0.509 | .686* | 0.279 | 0.584 |
| | p | 0.715 | 0.976 | 0.282 | 0.009 | 0.185 | 0.765 | 0.133 | 0.029 | 0.434 | 0.076 |
| Waterbody | r | 0.357 | 0.501 | 0.332 | 0.247 | -0.381 | -0.105 | -0.207 | .826** | .719* | .766** |
| | p | 0.311 | 0.14 | 0.348 | 0.491 | 0.277 | 0.774 | 0.566 | 0.003 | 0.019 | 0.01 |
| Forest | r | 0.141 | 0.192 | 0.389 | 0.542 | -0.314 | 0.196 | -0.587 | .894** | 0.593 | .699* |
| | p | 0.698 | 0.596 | 0.267 | 0.105 | 0.377 | 0.587 | 0.074 | 0 | 0.071 | 0.025 |
| Bare | r | -0.087 | 0.04 | 0.412 | .780** | -0.439 | 0.116 | -0.551 | .684* | 0.269 | 0.588 |
| | p | 0.812 | 0.912 | 0.237 | 0.008 | 0.204 | 0.75 | 0.099 | 0.029 | 0.452 | 0.074 |
| Grazing | r | 0.065 | 0.189 | 0.385 | 0.524 | -0.391 | 0.175 | -0.569 | .855** | 0.567 | .766** |
| | p | 0.857 | 0.601 | 0.271 | 0.12 | 0.264 | 0.629 | 0.086 | 0.002 | 0.088 | 0.01 |
| Shrub | r | 0.047 | 0.164 | 0.351 | 0.471 | -0.397 | 0.13 | -0.526 | .898** | 0.614 | .806** |
| | p | 0.898 | 0.651 | 0.321 | 0.17 | 0.256 | 0.72 | 0.119 | 0 | 0.059 | 0.005 |

Note: *. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

Source: Own computation

According to Addis Ababa Administration Environmental Protection key informant interview, industries located along the river sides are major contributors to pollution, releasing waste directly into the water. It mentions that some industries have been identified as major sources of heavy metal pollution, and measures have been taken against them. This information suggests that industrial activities, rather than forest land or shrub land, are the primary focus when discussing pollution in the Little Akaki river. The authority also employs standard measurement tools and conducts inspections to monitor and address pollution from industries. It emphasizes the importance of raising awareness among industries and communities about environmental protection. The interview also acknowledges challenges in integrating different sectors and ensuring compliance with regulations, as well as the need for better collaboration and awareness creation.

### 4.4.5 Barren land

The hypothesis is that Barren land have a significant effect on water quality indicators such as PH, Total Dissolved Solids (TDS), Salinity and Zink. During 2019, there is significant strong positive correlation between barren land and PH. The correlation coefficient is 0.674 and statistically significant at the 0.05 level ($p < 0.05$). This outcome is consistent with previous research finding by Paudel, et al. (2019), that conversion of forest land areas into bare land affects river water pH significantly in Chitwan National Park Nepal. There are also significant strong positive correlation coefficients between bare land and TDS. The correlation coefficient for TDS is 0.708 and reaches a high level of significance ($p < 0.01$), indicating a strong direct relationship. Bare land can contribute to increased sedimentation and runoff, which can carry dissolved solids into water bodies, resulting in higher TDS levels. This finding highlights the importance of erosion control measures and land management practices to minimize sedimentation and maintain water quality. This outcome is consistent with previous research findings by Burguet, et al., (2010), that investigated the effect of bare land on soil properties on flash floods and subsequent transport of sediment and slats into the river increased salinity of river water. The statistical significance of correlation supports the idea that Bare land can affect salinity of river water.

In 2023, the correlation coefficient of 0.684* between bare land and TDS concentrations is statistically significant at the 0.05 level ($p < 0.05$). This implies a significant positive relationship between bare land and TDS levels in the water. The correlation coefficient of 0.780** between bare land and zinc concentrations is statistically significant at the 0.01 level ($p < 0.01$). This indicates a significant positive relationship between bare land and zinc levels in the water. Thus, the outcome is consistent with previous research finding by Birch, et al., (2008), Australia, where TDS and Zink have significant positive relationship. Heavy metals can enter water bodies through various industrial activities, mining and runoff. Increased surface runoff can transport heavy metals from contaminated soils and urban area wastes into river and stream. Bare land can contribute to zinc contamination through erosion and runoff processes. The transportation of zinc-rich particles from bare land to water bodies can lead to elevated zinc concentrations.

### 4.4.6 Grazing land

The hypothesis is that Grazing land have a significant effect on water quality indicators such as Total Dissolved Solids (TDS), Salinity and Turbidity. In 2019, here is a strong positive correlation between Grazing and TDS ($r = 0.702$, $p = 0.024$). The correlation is statistically significant at the 0.05 level. This indicates that grazing activities may contribute to higher levels of total dissolved solids in the water. Further research is needed to examine the specific mechanisms through which grazing affects TDS. Grazing shows a strong positive correlation with Salinity ($r = 0.689$, $p = 0.027$). The correlation is statistically significant at the 0.05 level. The strong positive correlation between Grazing and Salinity ($r = 0.689$, $p = 0.027$) suggests that grazing activities may be associated with increased salinity levels in the water. This finding is consistent with previous research that has documented similar positive relationships between grazing land salinity by Mullen et al. (2012). The statistical significance of this correlation supports the idea that grazing practices can influence water salinity.

In 2023, there is a strong positive correlation between Grazing and Total Dissolved Solids (TDS) ($r = 0.855$, $p = 0.002$). The correlation is statistically significant at the 0.01 level, indicating that grazing activities may contribute to higher TDS levels in the water. This finding aligns with previous research that has reported similar positive association between grazing land and TDS of river water by Liu, et al., (2019). The statistical significance of this correlation supports the idea

that grazing land can affect TDS of river water. There is a strong positive correlation between Grazing land and Turbidity (r = 0.766, p = 0.010). The correlation is statistically significant at the 0.01 level, indicating that grazing activities may contribute to higher turbidity levels in the water. This finding is consistent with previous research that has reported positive association between grazing land and turbidity of river water by Stewart, R. E., & Hill, D.E. (2016). The statistical significance of this correlation supports the idea that grazing land can influence turbidity of river water quality.

**4.4.7 Shrub land**

The hypothesis is that Shrub land have a significant effect on water quality indicators such as Total Dissolved Solids (TDS), Salinity, and Turbidity. In 2019, the correlation between shrub land and both TDS and salinity for 2019 is very strongly positive (Pearson correlation coefficients of 0.855** and 0.848** respectively, both Sig. < 0.01). This finding is consistent with previous research that has reported positive association between shrub land and TDS of river water by Van Stan II, J. T., & Gordon, G. J. (2018). The statistical significance of this correlation supports the idea that shrub land can influence TDS of river water quality.

In 2023, the correlation between shrub land and TDS remains strongly positive (Pearson correlation coefficient = 0.898**, Sig. < 0.01). This indicates that areas with more shrub land continue to be associated with higher TDS levels in the water. Shrub land areas are often associated with increased soil erosion, which can lead to sediment and dissolved minerals being transported into nearby water bodies. Shrub land areas often have shallow root systems, which can lead to increased soil erosion. This erosion can transport sediments and dissolved minerals into streams, rivers, or other water bodies, subsequently increasing TDS and salinity levels.

The correlation between shrub land and turbidity for 2023 remains positive and statistically significant (Pearson correlation coefficient = 0.618, Sig. < 0.05). This indicates that areas with more shrub land are associated with higher turbidity levels in the water. This finding is consistent with previous research that has reported positive association between shrub land and Turbidity of river water by Huang, et al., (2017), riparian zones of Dongting Lake in China. The statistical significance of this correlation supports the idea that shrub land can influence Turbidity of river water quality. The presence of shrub land can contribute to increased turbidity through sediment

inputs, vegetation debris, or other factors related to land runoff or erosion. Shrubs can mitigate soil erosion by reducing the impact of raindrops on bare soil surfaces, thus decreasing sediment transport and subsequent turbidity levels. However, shrub land can also introduce plant debris and organic matter to water bodies, which can contribute to increased turbidity. The presence of suspended particles, such as organic particles and sediment, can scatter and absorb light, resulting in higher turbidity levels.

### 4.5. Land use land and cover change and household food production

To gain insight into the effects of land use and land cover changes on household food production, a key informant interview story was conducted with one of a farmer and long-time resident in lower part of the study area. His experience and observation provide valuable first and information on the challenge faced by rural communities in relation to changing landscapes and their impact on food security and livelihoods.

#### 4.5.1 Effect of land use and land cover change

According to the key informant the study area has undergone significant LULCC over the past few decades. He noted a decrease in crop land and forest coverage due to the expansion of urban and informal settlements. Many farmers, including key informant himself, have been forced to sell their agricultural lands for residential construction, resulting in a loss of productive farming areas. According to a research finding by Agidew, et al., (2017), the conversion of land use with the expense of grass lands, shrub lands, marginal lands and forest lands due to population growth, shortage of farm lands exacerbated the food security problems through crop yield reduction and soil erosion are identified.

##### 4.5.1.1 Decline in agricultural land and forest land coverage

The key informant observed that the study areas have undergone substantial land use and land cover change over the past few decades. The rapid expansion of urban areas and informal settlements has resulted in decline in agricultural land and forest coverage. This transformation has led to the conversion of fertile land, previously use for farming, into residential and commercial areas, reducing the availability of agricultural land.

#### 4.5.1.2 Encroachment of settlement

The settlements onto agricultural land has been a significant consequences of land use land cover changes. As urban areas expand, farmers are often compelled to sell their land for residential construction, leading to a loss of productive farming areas. This encroachment limits the space available for farming activities and can have long term implications for food production and livelihoods.

#### 4.5.1.3 Loss of grazing land

Land use land cover change has also resulted in the loss of grazing land for livestock farmers. The conversion of land for non-crop production purposes reduces the availability of open grazing areas, impacting livestock-rearing practices. The loss of grazing land can affect the productivity and sustainability of livestock systems, which are crucial for food security and livelihoods in rural areas.

#### 4.5.1.4 Environmental impacts

The interview highlighted the detrimental effects of land use and land cover changes on the environment, particularly the deterioration of water quality. Indiscriminate waste dumping, including domestic waste and industrial activities, has led to the pollution of local rivers. This pollution degrades water quality, impacting its suitability for farming and domestic use. Such environmental impacts can have cascading effects on agricultural productivity and overall ecosystem health. This insight is supported by previous research finding by Godebo, et al., (2021), that water sufficiency is a major concern for farmers that leads to frequent crop failures, especially due to erratic and insufficient rainfall. An important adaptation mechanism for farmers is the use of improved crop varieties, but major barriers to adaptation include a lack of access to irrigation water, credit or savings, appropriate seeds, and knowledge or information on weather and climate conditions.

#### 4.5.1.5 Implication for livelihoods and food security

The change in land use land cover changes have had direct implications for rural livelihoods and food security. The decline in agricultural land, loss of grazing land areas, and environmental degradation can limit farmers' ability to sustain their livelihoods and produce sufficient food crops. The encroachment of settlement and reduced access to agricultural land can also affect availability and accessibility of food, potentially compromising food security in the study area. These observations from the key informant interview emphasize the profound impacts of land use and land cover changes on the study area. The conversion of agricultural land, loss of grazing areas, and environmental degradation pose challenges for farmers, affecting their livelihoods and food security. This gives insight and aligns with previous research conducted by Fikadu, et al., (2023), in Nashe watershed, a ten-year period showed that cultivated land and forest land were reduced from 73% to 62% and 18%–14%, respectively, and swampy areas fully converted to Water Bodies, alternately increasing Water Bodies and grazing land also converted from 43.9% to 54.5% and 0.04%–17.96% respectively. The reason for this change was the construction of dams, human encroachment, and expansion of cultivated land which were bringing LULCC and the livelihoods were suffered by Dam construction, hindering environmental sustainability. Addressing these issue requires sustainable land management practices, land-use planning that balance urban development and agricultural needs, and measures to mitigate environmental impacts and support urban rural communities in adapting to change.

**A. Food security and well being**

The decline in farm size and crop production has directly impacted household food security and overall well-being Mr. Kena explained that the reduction in crop land availability has forced them to rely more on external sources for food. This has resulted in a decrease in dietary diversity and decline in overall well-being for his family. In addition, the loss of income generating opportunities from farming activities has further affected their quality of life. The challenges resulting from these changes have impacted the availability, accessibility, and utilization of food crops, thereby affecting the overall food security of households.

B. **Reduction in farm size and crop production**

Land use and land cover changes, including the conversion of agricultural land for residential purposes, have led to a decline in farm size. As a result, farmers like Mr. Kena have experienced a reduction in their crop production capacity. The loss of productive farming areas has limited their ability to cultivate sufficient quantities of food crops for household consumption and sale. However, according to the interviewee there are also other farmers who have changed their livelihood through diversifying their income sources with the money earned from sale. In addition, even if they sold their farm land there are also people who are living better life and completely changed their life style. Therefore, the finding of the key informant supports that farm land size decrease will affect household food production. Thus, the overall finding regrading to this is consistent with research conducted by Takyi, et al. (2023), in Ga West and Juaben Municipalities in Ghana, shows suggest that land use land cover change and diversification of livelihood activities from farm based activities to other non-farm based, concluding it will have both negative (adverse environmental effects) and positive (livelihood diversifications) effects.

**C. Limited availability of food crops**

**T**he decline in crop land resulting from land use change has reduced the availability of food crops. With less land devoted to farming, farmers face challenge in producing an adequate quantity of crops to meet their household food needs. This can lead a decreased availability of diverse food crops, affecting dietary diversity and nutritional adequacy. This finding is aligns with research finding conducted by Agidew, et al., (2018), in Teleyayen sub-water shed, South Wollo, that 79.1% of the sample households are food insecure where majority of the food insecure households were who own less than 1 ha of farmlands.

D. **Decreased access to food crops**

The encroachment of settlement and urban areas on agricultural land has limited farmers access to food crops. As farmers are forced to sell their land, they may lose direct access to the crops they used to cultivate. This can lead to increased reliance on external sources for food, potentially affecting the accessibility of food crops for rural households. Thus, it also aligns with

Khandoker, et al., (2022), showed strong positive association among farm production diversity, income and dietary diversity due to agricultural diversity give farmers greater access to produce diverse food and livestock animal in their farm.

### E. Impacts on dietary diversity and utilization

The diminishing availability and access to food crops can have implication for dietary diversity and utilization. Limited crop production may result a narrower range of available food options, potentially leading to a less diverse diet. This, in turn, can affect the utilization of essential nutrients and contribute to malnutrition and other health issues within the household. A research conducted by Khandoker, et al., (2022), showed strong positive association among farm production diversity, income and dietary diversity due to agricultural diversity give farmers greater access to produce diverse food and livestock animal in their farm. This can give insight to the result finding.

### F. Income generation challenges

**T**he reduction in income generating opportunities from farming activities due to land use land cover change can further impact household food crop production. Farmers like the key informant have had to explore alternative income sources, such as engaging in non-agricultural employment or diversifying their production practices. While these strategies can help offset some of the limitation, they may compensate for the loss of income and productivity from crop farming.

Overall, the interview highlights that land use land cover changes have posed significant challenges to household food crop production. The decline in available land, limited access to food crops, and associated income generation difficulties have impacted that availability, accessibility, and utilization of food crops, there by affecting the overall food security of rural households. Addressing these challenge requires sustainable land management practices, policies that prioritize local communities well-being, and measures to support and enhance agricultural productivity in the face of urban river side agriculture.

### 4.6.2 Deterioration of water quality

The key informant spoke about the degradation of river water quality due to waste dumping, which has further exacerbated the difficulties faced by farmers. Pollution from domestic waste and industrial activities has led to a decline in water quality in the rivers. Consequently, access to water for farming and domestic use has become limited. In the past, when irrigation water from the river was available, it contributed to higher crop production and improved livelihoods. The finding is supported by other scholar. According a previous research conducted by Kannan, et al., (2021), in Dindingul, Tanneries affected the livestock population, reduced agricultural production, polluted irrigation, polluted soil and made it infertile, deteriorated the quality of agricultural produce. Compared to economic benefits from tanneries the damage is exorbitant.

### 4.6.3 Adaptation strategies

To cope with the challenge posed by land use and land cover changes, Mr. Kena and his family have pursued alternative income sources. He sought employment as a security guard, while his daughters took up domestic work in other households. They also participate in limited poultry farming and cultivate vegetables on the remaining land they have. However, these alternative income source are insufficient to fully overcome the limitation imposed by the changes in the landscape. The research finding aligns with the previous study finding by Woleba, et al., (2023), Kedida Gamela district, Southern Ethiopia, that sale of livestock and hens, sell of productive assets, participation in small trade used as a coping strategies for household food security among small scale farmers.

Therefore, key informant interview provides valuable insights into the effects of land use and land cover changes on household food production and livelihoods. His experiences align with the research findings, highlighting the significant impact of diminishing crop land, forest coverage, and grazing land on food security and well-being. The interview underscores the need for sustainable land management practices and policies that prioritize the well-being of local communities, aiming to mitigate the adverse effects of LULCC.

# CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

This study aimed to analyze the effects of land use and land cover changes on river water quality and household food production in the Little Akaki river catchment, Central Ethiopia. Through the application of change detection, descriptive and econometric data analysis models, significant findings were obtained. The study utilized a Maximum Likelihood classification algorithm for land use classification and identified seven land use classes: Settlement and buildup, Crop land, Waterbody, Forest land, Barren land, Grazing land, and Shrub land. The results indicated substantial changes in land use and land cover over the study period. Settlement and buildup areas exhibited a significant increase, while Crop land and Waterbody areas decreased. Forest land, Barren land, grazing land, and Shrub land also experienced reductions in their coverage. These changes underscore the expansion of settlements at the expense of other land use categories, resulting in decreased waterbody, crop land, forest, barren, grazing, and shrub land areas in the catchment.

The significant growth in settlement and buildup areas indicates rapid urbanization and population expansion, which exert increasing pressure on natural resources and raise concerns about environmental sustainability. The decline in crop land and grazing land raises concerns about potential impacts on agricultural productivity, food production, and the livelihoods of local communities. The relatively minor decrease in waterbody areas underscores the need for conservation efforts to protect and preserve water resources. Water scarcity and water quality issues may arise if proper measures are not implemented to sustainably manage waterbodies in the catchment. The minimal change in forested areas suggests the importance of forest conservation measures to safeguard biodiversity, maintain carbon sequestration capacity, and preserve ecosystem services. Even slight declines in forest cover can have significant ecological impacts, emphasizing the need for proactive conservation strategies. The reduction in bare land signifies changes in land use practices and indicates potential improvements in land management approaches, such as afforestation and sustainable agriculture. However, the implications of this change on soil erosion, land degradation, and ecosystem stability should be carefully monitored and addressed.

The concentrations of heavy metals, including Chromium (Cr), Cadmium (Cd), Lead (Pb), and Zinc (Zn), exhibited varying changes across the different sample sites. Overall, there was a positive change in the concentration of Chromium (0.852) and Zinc (1.671), indicating an increase in their levels. Conversely, Cadmium (-0.569) and Lead (-0.0476) showed negative changes, suggesting a decrease in their concentrations. These changes in heavy metal levels may have implications for water quality and ecosystem health. The physio-chemical parameters, including temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), salinity, and turbidity, also displayed varying changes. Temperature, pH, and turbidity exhibited both positive and negative changes across the sample sites. Dissolved oxygen (DO) showed a negative change (-9.55), indicating a decrease in its levels, which could impact aquatic organisms. Total dissolved solids (TDS) and salinity displayed significant negative changes (-1637.69 and -5370.48, respectively), suggesting a notable decrease in their concentrations. The mean average change values for heavy metals and physio-chemical parameters were generally small, indicating relatively subtle changes in water quality over the study period. However, negative mean average values were observed for most parameters, suggesting a decreasing trend in their concentrations.

Moreover, the study identified changes in river water quality indicators between 2019 and 2023, which were attributed to LULCC. The Pearson correlation analysis revealed strong positive correlations between certain land use classes and river water quality parameters. Settlement and buildup areas exhibited strong positive correlations with PH, TDS, Salinity, and Turbidity. Crop land showed strong positive correlations with Zn, PH, TDS, DO, Salinity, and Turbidity. Forest land and Barren land also exhibited strong positive correlations with certain water quality parameters. Notably, Waterbody displayed a strong negative correlation with Dissolved Oxygen. Furthermore, the study highlighted the adverse impact of LULCC on household food production. The reduction in crop land negatively affected food production and consequently impacted household food security. Livestock production was also affected due to the decrease in grazing land availability. The findings emphasized the need to address the consequences of land use changes on agricultural practices and food security in the study area.

The research also revealed significant land use and land cover changes, including the expansion of informal settlements, river-side industries, and the conversion of land for settlement purposes. Challenges related to peri-urban agriculture, insufficient attention to river water quality,

institutional gaps, lack of accountability, and limited integration among institutions and local communities were identified. In light of these findings, it is crucial to adopt holistic and integrated approaches to land use management, water quality protection, and sustainable agricultural practices in the Little Akaki river catchment. This entails implementing sustainable land use planning, promoting responsible agricultural practices, and protecting waterbodies through effective conservation measures. Integrated planning, stakeholder engagement, environmental education, and awareness programs are also essential for preserving ecosystems, ensuring food security, and promoting the well-being of communities.

The conclusions drawn from this study provide valuable insights for policymakers, researchers, and stakeholders involved in land use planning, water resource management, and agricultural development in the Little Akaki river catchment and similar regions. By addressing the identified challenges and implementing appropriate interventions, it is possible to mitigate the negative impacts of land use changes and foster sustainable development in the study area.

## 5.2 Recommendations

The following recommendations were suggested for consideration in light of the findings draw herein before and conclude the above. The recommendation should be assumed to give insight for future policy formulation regarding to effect of land use and land cover changes on river water quality and household food production and also helps to inputs for further investigation in the country. Thus, these policy recommendation possibilities to mitigate issue related to demographic and socioeconomic problems of people living, Little Akaki river catchment and the people who live the same characteristics in other areas of the country.

- The research finding shows that there is dynamic land use land cover change and expansion of informal settlement in the study area. This implies that developing a comprehensive land use plan that considers the ecological, social, and economic aspects of the river catchment. The plan should involve stakeholders from various sectors and aim to balance development needs with environmental conservation.
- The research finding also show that the reason for the change to be limitation in regulation and integration among institutions. This implies that enhancing land use

regulation and enforce compliance to prevent unauthorized land conversion, illegal logging and other detrimental activities through establishing continuous penalties for non-compliance and incentivize sustainable land management practices by supporting policies and programs and improving collaboration among institutions, NGOs and local communities.

- Based on the study, land use land cover change was positively and significantly related with river water quality parameters TDS, PH, Salinity, Turbidity, Zink and DO. Hence, the experts in the woredas, sub-cities in the catchment as well as concerning actors should give attention in conducting public awareness campaign and educational programs to inform residents about the importance of sustainable land use practices, water conservation, and the impact of land use change on river water quality.

- The research finding also shows that river water quality, forest, crop land highly depleted. This implies that undertaking river restoration projects to restore natural habitats, and improving water flow will enhance ecosystem services by removing barriers, restoring riparian vegetation and reducing erosion. In addition, encouraging urban planning that prioritize low impact development strategies, such as preserving natural areas and promoting mixed land which can reduce pollution runoff, improve soil fertility and preserve crop land for food production.

- The finding revealed that land use and land cover is positively and negatively significantly affecting river water quality. This implies that enhancing biodiversity and habitats for wildlife through implementing green infrastructure practices such as constructing wetland, riparian buffers and filtering pollutants through green roofs and reducing runoff to improve river water quality of the study area. In addition, implementing best practices such as rainwater harvesting system, rain garden, and permeable pavement where it can treat runoff, introduction of pollutants and preserving river water quality.

- Based on the study, land use and land cover change was significantly decreased crop land and affected household food production in the river side. This implies that

promoting urban and peri- urban agriculture initiatives such as community garden, vertical farming and rooftop gardens will reduce long distance transportation of food, enhance sustainability of urban areas and most importantly increase household food security. In addition, land tenure security of river side community which can incentivize investment in sustainable land use practices and enabling long term planning for improved river water quality and household food production. Moreover, engaging local communities, landowners, agricultural producer and other concerning stakeholders in discussion and awareness campaign on sustainable land use and providing information on benefit of preserving the river water.

- The study also revealed that there is limited integration among institution and limitation in taking accountability for the Little Akaki river. This implies that institutional integration at all level will be required in order to improve river water quality and household food production.

- Finally, in order to restore the ecosystem services of the study area, improve river water quality and enhance urban and peri urban agriculture food production in the catchment should be given special attention and needs support from NGOs and governmental development programs such as International Livestock Research Institute (ILRI), International Water Management Institute (IWMI), Ministry of Agriculture Natural Resources, One Wash National Program (OWNP) others.

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# Appendix

Appendix 1: Area distribution of land use class in hectors, square kilometers, and percentages for the year 1994.

| LULC Classes_1994 | Area (ha) | Area (sq.km) | Area (%) |
|---|---|---|---|
| Settlement and build up | 10177.03 | 101.77 | 25.24 |
| Crop land | 11214.98 | 112.15 | 27.81 |
| Water body | 1451.9 | 14.52 | 3.6 |
| Forest land | 4253.31 | 42.53 | 10.55 |
| Bare land | 5966.96 | 59.67 | 14.8 |
| Grazing land | 4956.79 | 49.57 | 12.29 |
| Shrub land | 2303.08 | 23.03 | 5.71 |
| **Grand Total** | **40324.05** | **403.24** | **100** |

**Appendix 2: Accuracy Assessment of 1994 LULC**

| LULC Class | Settlement and build up | Crop land | Water body | Forest land | Bare land | Grazing land | Shrub land | **Total (User)** |
|---|---|---|---|---|---|---|---|---|
| Settlement and build up | 20 | 1 | 0 | 0 | 0 | 0 | 0 | **21** |
| Crop land | 0 | 20 | 0 | 0 | 0 | 0 | 0 | **20** |
| Water body | 1 | 0 | 12 | 0 | 0 | 0 | 0 | **13** |
| Forest land | 0 | 0 | 0 | 16 | 0 | 0 | 0 | **16** |
| Bare land | 0 | 0 | 0 | 1 | 4 | 0 | 0 | **5** |
| Grazing land | 0 | 0 | 0 | 0 | 0 | 16 | 0 | **16** |
| Shrub land | 0 | 0 | 0 | 0 | 0 | 1 | 8 | **9** |
| **Total (Producer's)** | **21** | **21** | **12** | **17** | **4** | **17** | **8** | **100** |

**Appendix 3: Accuracy assessment and Kappa Coefficient 1994**

| LULC Class | Users Accuracy | Producer Accuracy |
|---|---|---|
| Settlement and build up | 20/21*100=95 | 20/21*100=95 |
| Crop land | 20/20*100= 100 | 20/21*100=95 |
| Water body | 12/13*100= 92 | 12/12*100=100 |
| Forest land | 16/16*100= 100 | 16/17*100=94 |
| Bare land | 4/5*100= 80 | 4/4*100=100 |
| Grazing land | 16/16*100= 100 | 16/17*100=94 |
| Shrub land | 8/9*100= 88.8 | 8/8*100=100 |

**Overall Accuracy=** 96/100*100= **96%**

$$\boldsymbol{Kappa\ Coefficient}\ (\boldsymbol{T}) = \frac{(100x96) - \sum(21x21) + (21x20) + (12x13) + (17x16) + (4x5) + (17x16) + (8x9)}{100^2 - \sum(21x21) + (21x20) + (12x13) + (17x16) + (4x5) + (17x16) + (8x9)} X\ 100$$

$$= \frac{9{,}600 - 1{,}653}{10{,}000 - 1{,}653} X\ 100$$

$$= \mathbf{95\%} = \mathbf{0.95}$$

**Appendix.4: Area distribution of land use class in hectors, square kilometers, and percentages for the year 1999.**

| LULC Classes_1999 | Area (ha) | Area (sq.km) | Area (%) |
|---|---|---|---|
| Settlement and build up | 4592.44 | 45.92 | 11.39 |
| Crop land | 9911.16 | 99.11 | 24.58 |
| Water body | 4651.83 | 46.52 | 11.54 |
| Forest land | 6173.15 | 61.73 | 15.31 |
| Bare land | 12297.2 | 122.97 | 30.5 |
| Grazing land | 1788.43 | 17.88 | 4.44 |
| Shrub land | 910.31 | 9.1 | 2.26 |
| **Grand Total** | **40324.52** | **403.25** | **100** |

**Appendix 5: Accuracy Assessment of 1999 LULC**

| **LULC Class** | Settlement and build up | Crop land | Water body | Forest land | Bare land | Grazing land | Shrub land | **Total (User)** |
|---|---|---|---|---|---|---|---|---|
| Settlement and build up | 19 | 1 | 0 | 0 | 1 | 0 | 0 | **21** |
| Crop land | 0 | 19 | 0 | 0 | 0 | 1 | 0 | **20** |
| Water body | 0 | 0 | 12 | 0 | 0 | 1 | 0 | **13** |
| Forest land | 1 | 0 | 0 | 14 | 0 | 0 | 1 | **16** |
| Bare land | 0 | 1 | 0 | 0 | 4 | 0 | 0 | **5** |
| Grazing land | 1 | 1 | 0 | 0 | 0 | 14 | 0 | **16** |
| Shrub land | 0 | 0 | 0 | 1 | 0 | | 8 | **9** |
| **Total (Producer's)** | **21** | **22** | **12** | **15** | **5** | **16** | **9** | **100** |

**Appendix 6: Accuracy assessment and Kappa Coefficient 1999**

| **LULC Class** | **Users Accuracy** | **Producer Accuracy** |
|---|---|---|
| Settlement and build up | 19/21*100=90.47 | 19/21*100=90.47 |
| Crop land | 19/20*100= 95 | 19/22*100=86.36 |
| Water body | 12/13*100= 92.3 | 12/12*100=100 |
| Forest land | 14/16*100=87.5 | 14/15*100=93.3 |
| Bare land | 4/5*100= 80 | 4/5*100=80 |
| Grazing land | 14/16*100= 87.5 | 14/16*100=87.5 |
| Shrub land | 8/9*100= 88.8 | 8/9*100=88.8 |

**Overall Accuracy=** 90/100*100= **90%**

$\boldsymbol{Kappa\ Coefficient}\ (\boldsymbol{T})$

$$= \frac{(100x90) - \sum(21x21) + (22x20) + (12x13) + (15x16) + (5x5) + (16x16) + (9x9)}{100^2 - \sum(21x21) + (22x20) + (12x13) + (15x16) + (5x5) + (16x16) + (9x9)} X\ 100$$

$$= \frac{9{,}000 - 1{,}639}{10{,}000 - 1{,}639} X\ 100$$

$$= \mathbf{88.04}\% =$$

**Appendix 7: Area distribution of land use class in hectors, square kilometers, and percentages for the year 2004.**

| LULC Classes_2004 | Area (ha) | Area (sq.km) | Area (%) |
|---|---|---|---|
| Settlement and build up | 13559.67 | 135.6 | 33.61 |
| Crop land | 13353.42 | 133.53 | 33.1 |
| Water body | 187.08 | 1.87 | 0.46 |
| Forest land | 2519.69 | 25.2 | 6.25 |
| Bare land | 5308.84 | 53.09 | 13.16 |
| Grazing land | 2017.14 | 20.17 | 5 |
| Shrub land | 3394.99 | 33.95 | 8.42 |
| **Grand Total** | **40340.82** | **403.41** | **100** |

**Appendix 8: Accuracy Assessment of 2004 LULC**

| **LULC Class** | Settlement and build up | Crop land | Water body | Forest land | Bare land | Grazing land | Shrub land | **Total (User)** |
|---|---|---|---|---|---|---|---|---|
| Settlement and build up | 15 | 1 | 0 | 0 | 0 | 0 | 0 | **16** |
| Crop land | 0 | 13 | 0 | 0 | 0 | 1 | 0 | **14** |
| Water body | 0 | 0 | 13 | 0 | 0 | 0 | 0 | **13** |
| Forest land | 0 | 0 | 0 | 9 | 0 | 0 | 1 | **10** |
| Bare land | 0 | 0 | 0 |  | 8 | 1 | 1 | **10** |
| Grazing land | 1 | 1 | 0 | 0 | 0 | 12 | 0 | **14** |
| Shrub land | 0 | 0 | 0 | 1 | 0 | 0 | 12 | **13** |
| **Total (Producer's)** | **16** | **14** | **13** | **10** | **8** | **14** | **14** | **90** |

**Appendix 9: Accuracy assessment and Kappa Coefficient of 2004**

| LULC Class | Users Accuracy | Producer Accuracy |
|---|---|---|
| Settlement and build up | 15/16*100=93.75 | 15/16*100=93.75 |
| Crop land | 13/14*100=92.86 | 13/14*100=92.86 |
| Water body | 13/13*100= 100 | 13/13*100=100 |
| Forest land | 9/10*100=90 | 9/10*100=90 |
| Bare land | 8/10*100=80 | 8/8*100=100 |
| Grazing land | 12/14*100= 85.7 | 12/14*100=85.7 |
| Shrub land | 12/13*100= 92.3 | 12/14*100=85.7 |

**Overall Accuracy=** 82/90*100= **91.1%**

$\boldsymbol{Kappa\ Coefficient}$ $(\boldsymbol{T})$

$$= \frac{(90x82) - \sum(16x16) + (14x14) + (13x13) + (10x10) + (8x10) + (14x14) + (14x13)}{90^2 - \sum(16x16) + (14x14) + (13x13) + (10x10) + (8x10) + (14x14) + (14x13)} X\ 100$$

$$= \frac{7{,}380 - 1{,}063}{8{,}100 - 1{,}063} X\ 100$$

$$= \mathbf{89.77}\%$$

**Appendix 10: Area distribution of land use class in hectors, square kilometers, and percentages for the year 2009.**

| LULC Classes_2009 | Area (ha) | Area (sq.km) | Area (%) |
|---|---|---|---|
| Settlement and build up | 14373.97 | 143.74 | 35.63 |
| Crop land | 11030.65 | 110.31 | 27.34 |
| Water body | 196.48 | 1.96 | 0.49 |
| Forest land | 2540.37 | 25.4 | 6.3 |
| Bare land | 9676.73 | 96.77 | 23.99 |
| Grazing land | 276.34 | 2.76 | 0.69 |
| Shrub land | 2246.36 | 22.46 | 5.57 |
| **Grand Total** | **40340.9** | **403.41** | **100** |

**Appendix 11: Accuracy Assessment of 2009 LULC**

| **LULC Class** | Settlement and build up | Crop land | Water body | Forest land | Bare land | Grazing land | Shrub land | **Total (User)** |
|---|---|---|---|---|---|---|---|---|
| Settlement and build up | 20 | 1 | 0 | 0 | 0 | 0 | 0 | **21** |
| Crop land | 0 | 18 | 0 | 0 | 1 | 1 | 0 | **20** |
| Water body | 1 | 0 | 12 | 0 | 0 | 0 | 0 | **13** |
| Forest land | 0 | 0 | 0 | 15 | 0 | 0 | 1 | **16** |
| Bare land | 0 | 0 | 0 | 1 | 4 | 0 | 0 | **5** |
| Grazing land | 0 | 2 | 0 | 0 | 1 | 13 | 0 | **16** |
| Shrub land | 0 | 0 | 0 | 1 | 0 | 1 | 7 | **9** |
| **Total (Producer's)** | **21** | **21** | **12** | **17** | **4** | **17** | **8** | **100** |

**Appendix 12: Accuracy assessment and Kappa Coefficient of 2009**

| **LULC Class** | **Users Accuracy** | **Producer Accuracy** |
|---|---|---|
| Settlement and build up | 20/21*100=95 | 20/21*100=95.2 |
| Crop land | 18/20*100= 90 | 18/21*100=85.7 |
| Water body | 12/13*100= 92 | 12/12*100=100 |
| Forest land | 15/16*100= 93.75 | 15/17*100=88.2 |
| Bare land | 4/5*100= 80 | 4/6*100=66.7 |
| Grazing land | 13/16*100= 81.25 | 13/15*100=86.7 |
| Shrub land | 7/9*100= 77.8 | 7/8*100=87.5 |

**Overall Accuracy=** 89/100*100= **89%**

$$\boldsymbol{Kappa\ Coefficient}\ (\boldsymbol{T})$$

$$= \frac{(100x89) - \sum(21x21) + (21x20) + (12x13) + (17x16) + (6x5) + (15x16) + (8x9)}{100^2 - \sum(21x21) + (21x20) + (12x13) + (17x16) + (6x5) + (15x16) + (8x9)} X\ 100$$

$$= \frac{8900 - 1{,}631}{10{,}000 - 1{,}631} X\ 100$$

$$= \mathbf{86.85}\%$$

**Appendix 13: Area distribution of land use class in hectors, square kilometers, and percentages for the year 2014.**

| LULC Classes_2014 | Area (ha) | Area (sq.km) | Area (%) |
|---|---|---|---|
| Settlement and build up | 13647.95 | 136.48 | 33.83 |
| Crop land | 10649.26 | 106.49 | 26.4 |
| Water body | 124.9 | 1.25 | 0.31 |
| Forest land | 2410.68 | 24.11 | 5.98 |
| Bare land | 12814.08 | 128.14 | 31.77 |
| Grazing land | 626.15 | 6.26 | 1.55 |
| Shrub land | 66.66 | 0.67 | 0.17 |
| **Grand Total** | **40339.69** | **403.4** | **100** |

**Appendix 14: Accuracy Assessment of 2014 LULC**

| **LULC Class** | Settlement and build up | Crop land | Water body | Forest land | Bare land | Grazing land | Shrub land | **Total (User)** |
|---|---|---|---|---|---|---|---|---|
| Settlement and build up | 14 | 2 | 0 | 0 | 0 | 0 | 0 | **16** |
| Crop land | 0 | 17 | 0 | 0 | 1 | 1 | 0 | **19** |
| Water body | 0 | 0 | 11 | 0 | 0 | 0 | 0 | **11** |
| Forest land | 0 | 0 | 0 | 13 | 0 | 0 | 1 | **14** |
| Bare land | 0 | 0 | 0 | 1 | 7 | 0 | 0 | **8** |
| Grazing land | 0 | 2 | 0 | 0 | 0 | 14 | 0 | **16** |
| Shrub land | 0 | 0 | 0 | 0 | 0 | 1 | 8 | **9** |
| **Total (Producer's)** | **14** | **21** | **11** | **14** | **8** | **16** | **9** | **89** |

**Appendix 15: Accuracy assessment and Kappa Coefficient of 2014**

| LULC Class | Users Accuracy | Producer Accuracy |
|---|---|---|
| Settlement and build up | 14/16*100=87.5 | 14/14*100=100 |
| Crop land | 17/19*100= 89.5 | 17/21*100= 80.95 |
| Water body | 11/11*100= 100 | 11/11*100=100 |
| Forest land | 13/14*100= 92.8 | 13/14*100=92.85 |
| Bare land | 14/16*100= 87.5 | 7/8*100=87.5 |
| Grazing land | 8/9*100= 88.9 | 14/16*100=87.5 |
| Shrub land | 8/9*100= 88.8 | 8/9*100=88.9 |

**Overall Accuracy=** 84/89*100= **94.4%**

$$\boldsymbol{Kappa\ Coefficient}\ (\boldsymbol{T}) = \frac{(89x84) - \sum(14x16) + (17x19) + (11x11) + (13x14) + (7x8) + (14x16) + (8x9)}{89^2 - \sum(14x14) + (17x21) + (11x11) + (13x14) + (7x8) + (14x16) + (8x9)} X\ 100$$

$$= \frac{7{,}476 - 1{,}202}{7{,}921 - 1{,}208} X\ 100$$

$$= \mathbf{93.5}\%$$

**Appendix 16: Area distribution of land use class in hectors, square kilometers, and percentages for the year 2019.**

| LULC Classes_2019 | Area (ha) | Area (sq.km) | Area (%) |
|---|---|---|---|
| Settlement and build up | 18167.2 | 181.7 | 45 |
| Crop land | 15222.4 | 152.2 | 37.7 |
| Water body | 140.8 | 1.4 | 0.3 |
| Forest land | 4183.9 | 41.8 | 10.4 |
| Bare land | 1820.9 | 18.2 | 4.5 |
| Grazing land | 397.1 | 4 | 1 |
| Shrub land | 393.6 | 3.9 | 1 |
| **Grand Total** | **40325.8** | **403.2** | **100** |

Appendix 17: Accuracy Assessment of 2019 LULC

| **LULC Class** | Settlement and build up | Crop land | Water body | Forest land | Bare land | Grazing land | Shrub land | **Total (User)** |
|---|---|---|---|---|---|---|---|---|
| Settlement and build up | 19 | 1 | 0 | 1 | 0 | 0 | 0 | **21** |
| Crop land | 0 | 20 | 0 | 0 | 0 | 0 | 0 | **20** |
| Water body | 1 | 0 | 12 | 0 | 0 | 0 | 0 | **13** |
| Forest land | 0 | 0 | 0 | 14 | 0 | 0 | 2 | **16** |
| Bare land | 0 | 0 | 0 | 1 | 4 | 0 | 0 | **5** |
| Grazing land | 0 | 0 | 0 | 0 | 0 | 16 | 0 | **16** |
| Shrub land | 0 | 0 | 0 | 1 | 0 | 1 | 7 | **9** |
| **Total (Producer's)** | **20** | **21** | **12** | **17** | **4** | **17** | **9** | **100** |

**Appendix 18: Accuracy assessment and Kappa Coefficient of 2019**

| **LULC Class** | **Users Accuracy** | **Producer Accuracy** |
|---|---|---|
| Settlement and build up | 19/21*100=90.47 | 19/20*100=95 |
| Crop land | 20/20*100= 100 | 20/21*100=95 |
| Water body | 12/13*100= 92 | 12/12*100=100 |
| Forest land | 14/16*100= 87.5 | 14/17*100=82.35 |
| Bare land | 4/5*100= 80 | 4/4*100=100 |
| Grazing land | 16/16*100= 100 | 16/17*100=94 |
| Shrub land | 8/9*100= 88.8 | 7/9*100=77.8 |

**Overall Accuracy=** 92/100*100= **92%**

$$\boldsymbol{Kappa\ Coefficient}\ (\boldsymbol{T})$$

$$= \frac{(100x92) - \sum(20x21) + (21x20) + (12x13) + (17x16) + (4x5) + (17x16) + (9x9)}{100^2 - \sum(20x21) + (21x20) + (12x13) + (17x16) + (4x5) + (17x16) + (9x9)} X\ 100$$

$$= \frac{9{,}200 - 1{,}641}{10{,}000 - 1{,}641} X\ 100$$

$$= \mathbf{90.4}\%$$

**Appendix 19: Area distribution of land use class in hectors, square kilometers, and percentages for the year 2023.**

| LULC Classes_2023 | Area (ha) | Area (sq.km) | Area (%) |
|---|---|---|---|
| Settlement and build up | 21164.2 | 211.64 | 52.49 |
| Crop land | 8951.85 | 89.52 | 22.2 |
| Water body | 131.69 | 1.32 | 0.33 |
| Forest land | 4030.46 | 40.3 | 10 |
| Bare land | 1719.32 | 17.19 | 4.26 |
| Grazing land | 3814.01 | 38.14 | 9.46 |
| Shrub land | 512.61 | 5.13 | 1.27 |
| **Grand Total** | **40324.15** | **403.24** | **100** |

**Appendix 20: Accuracy Assessment of 2023 LULC**

| **LULC Class** | Settlement and build up | Crop land | Water body | Forest land | Bare land | Grazing land | Shrub land | **Total (User)** |
|---|---|---|---|---|---|---|---|---|
| Settlement and build up | 20 | 0 | 0 | 0 | 0 | 0 | 0 | **20** |
| Crop land | 0 | 17 | 0 | 0 | 0 | 1 | 0 | **18** |
| Water body | 1 | 0 | 11 | 0 | 0 | 0 | 0 | **12** |
| Forest land | 0 | 0 | 0 | 13 | 0 | 0 | 1 | **14** |
| Bare land | 0 | 0 | 0 | 0 | 5 | 0 | 0 | **5** |
| Grazing land | 0 | 0 | 0 | 0 | 1 | 14 | 1 | **15** |
| Shrub land | 0 | 0 | 0 | 1 | 0 | 0 | 6 | **8** |
| **Total (Producer's)** | **21** | **17** | **11** | **14** | **6** | **15** | **8** | **92** |

**Appendix 21: Accuracy assessment and Kappa Coefficient of 2023**

| LULC Class | Users Accuracy | Producer Accuracy |
|---|---|---|
| Settlement and build up | 20/20*100=100 | 21/21*100=95.2 |
| Crop land | 17/18*100=94.4 | 17/17*100=100 |
| Water body | 11/12*100=91.7 | 11/11*100=100 |
| Forest land | 13/14*100=92.85 | 13/14*100=92.85 |
| Bare land | 5/5*100=100 | 5/6*100=83.3 |
| Grazing land | 14/15*100=93.3 | 14/15*100=93.3 |
| Shrub land | 7/8*100=87.5 | 7/8*100=87.5 |

**Overall Accuracy=** 87/92*100= **94.56%**

$$\boldsymbol{Kappa\ Coefficient}\ (\boldsymbol{T})$$

$$= \frac{(92x87) - \sum(21x20) + (17x18) + (11x12) + (14x14) + (6x5) + (15x15) + (8x8)}{92^2 - \sum(21x20) + (17x18) + (11x12) + (14x14) + (6x5) + (15x15) + (8x8)} X\ 100$$

$$= \frac{8{,}004 - 1{,}373}{8{,}464 - 1{,}373} X\ 100$$

$$= \mathbf{93.5}\%$$

**Appendix 22: Remote sensing data base information**

| Image type | File date | Date acquired | Row | Path | Cloud |
|---|---|---|---|---|---|
| Landsat 4-5 TM $C_2L_1$ | 1994 | 27/01/1994 | 168 | 54 | Excluded |
| Landsat 4-5 TM $C_2L_1$ | 1999 | 24/12/1998 | 168 | 54 | Excluded |
| Landsat 7 TM | 2004 | 1/12/2003 | 168 | 54 | Excluded |
| Landsat 7 TM | 2009 | 29/12/2008 | 168 | 54 | Excluded |
| Landsat 7 TM | 2014 | 10/1/2014 | 168 | 54 | Excluded |
| Landsat 8-9 OLI/TIRS | 2019 | 16/01/2019 | 168 | 54 | Excluded |
| Landsat 9 OLI/TIRS | 2023 | 19/01/2023 | 168 | 54 | Excluded |

**Appendix 23: Computed land use and land cover change detection**

| Change-detection | 1994- 1999 | 1999-2004 | 2004-2009 | 2009-2014 | 2014-2019 | 2019-2023 |
|---|---|---|---|---|---|---|
| Settlement and build up - Settlement and build up | 76.58 | 87.39 | 88.53 | 96.28 | 121.25 | 140.73 |
| Settlement and build up - Crop land | 9.97 | 29.75 | 35.03 | 21.27 | 12.03 | 6.23 |
| Settlement and build up - Water body | 0.45 | 0.07 | 0.39 | 0.10 | 0.11 | 0.16 |
| Settlement and build up - Forest land | 0.83 | 0.38 | 2.56 | 0.75 | 1.33 | 3.39 |
| Settlement and build up - Bare land | 10.34 | 4.58 | 11.99 | 24.78 | 1.58 | 1.67 |
| Settlement and build up - Grazing land | 3.51 | 0.41 | 2.18 | 0.45 | 0.03 | 29.10 |
| Settlement and build up - Shrub land | 0.03 | 0.31 | 2.96 | 0.02 | 0.03 | 0.30 |
| Crop land - Settlement and build up | 25.05 | 24.31 | 24.24 | 16.05 | 20.95 | 55.37 |
| Crop land - Crop land | 59.91 | 45.20 | 50.46 | 41.51 | 69.33 | 71.06 |
| Crop land - Water body | 1.02 | 0.19 | 0.55 | 0.02 | 0.05 | 0.01 |
| Crop land - Forest land | 2.21 | 0.86 | 6.26 | 5.19 | 9.57 | 6.43 |
| Crop land - Bare land | 11.68 | 19.65 | 15.17 | 45.93 | 4.24 | 10.04 |
| Crop land - Grazing land | 11.81 | 6.04 | 4.22 | 1.39 | 0.75 | 7.60 |
| Crop land - Shrub land | 0.41 | 2.80 | 9.36 | 0.15 | 1.47 | 1.58 |
| Water body - Settlement and build up | 4.98 | 2.43 | 1.48 | 0.33 | 0.12 | 0.21 |
| Water body - Crop land | 4.61 | 2.35 | 0.20 | 0.14 | 0.01 | 0.05 |
| Water body - Water body | 2.04 | 0.22 | 0.03 | 1.11 | 1.10 | 1.13 |
| Water body - Forest land | 1.56 | 1.02 | 0.11 | 0.01 | 0.00 | 0.01 |
| Water body - Bare land | 0.42 | 0.43 | 0.10 | 0.37 | 0.00 | 0.01 |
| Water body - Grazing land | 0.85 | 1.09 | 0.01 | 0.00 | 0.00 | 0.00 |
| Water body - Shrub land | 0.05 | 1.56 | 0.03 | 0.00 | 0.00 | 0.00 |
| Forest land - Settlement and build up | 1.75 | 9.75 | 5.08 | 2.20 | 1.68 | 5.81 |
| Forest land - Crop land | 4.51 | 9.23 | 3.36 | 3.30 | 2.68 | 5.34 |
| Forest land - Water body | 2.12 | 1.00 | 0.37 | 13.05 | 0.00 | 0.02 |
| Forest land - Forest land | 23.54 | 12.64 | 9.55 | 6.32 | 18.24 | 28.22 |

| Change-detection | 1994- 1999 | 1999-2004 | 2004-2009 | 2009-2014 | 2014-2019 | 2019-2023 |
|---|---|---|---|---|---|---|
| Forest land - Bare land | 1.26 | 0.91 | 0.40 | 0.08 | 0.18 | 0.24 |
| Forest land - Grazing land | 2.59 | 0.79 | 0.33 | 0.00 | 0.03 | 0.40 |
| Forest land - Shrub land | 6.74 | 12.17 | 6.30 | 0.41 | 1.26 | 1.78 |
| Bare land - Settlement and build up | 12.26 | 7.54 | 14.74 | 20.14 | 36.88 | 7.32 |
| Bare land - Crop land | 11.18 | 26.34 | 35.02 | 31.12 | 64.36 | 5.46 |
| Bare land - Water body | 1.45 | 0.13 | 0.47 | 0.01 | 0.14 | 0.00 |
| Bare land - Forest land | 6.09 | 0.82 | 4.67 | 3.27 | 11.88 | 0.71 |
| Bare land - Bare land | 16.40 | 6.63 | 20.63 | 38.71 | 11.15 | 3.65 |
| Bare land - Grazing land | 11.46 | 1.66 | 10.59 | 3.42 | 2.48 | 0.88 |
| Bare land - Shrub land | 0.80 | 2.74 | 10.60 | 0.04 | 1.08 | 0.18 |
| Grazing land - Settlement and build up | 1.95 | 2.40 | 0.08 | 0.13 | 0.67 | 1.45 |
| Grazing land - Crop land | 7.84 | 18.83 | 0.87 | 0.62 | 3.63 | 0.71 |
| Grazing land - Water body | 1.24 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 |
| Grazing land - Forest land | 3.54 | 1.61 | 0.05 | 0.02 | 0.17 | 0.16 |
| Grazing land - Bare land | 4.68 | 20.74 | 1.00 | 1.69 | 1.04 | 1.43 |
| Grazing land - Grazing land | 29.69 | 10.04 | 0.53 | 0.31 | 0.67 | 0.08 |
| Grazing land - Shrub land | 0.61 | 7.94 | 0.23 | 0.00 | 0.08 | 0.14 |
| Shrub land - Settlement and build up | 0.33 | 1.62 | 1.38 | 1.30 | 0.04 | 0.63 |
| Shrub land - Crop land | 1.06 | 1.67 | 8.50 | 8.46 | 0.01 | 0.59 |
| Shrub land - Water body | 0.77 | 0.14 | 0.05 | 0.00 | 0.00 | 0.00 |
| Shrub land - Forest land | 8.72 | 7.82 | 1.98 | 1.80 | 0.60 | 1.36 |
| Shrub land - Bare land | 1.10 | 0.10 | 3.77 | 10.24 | 0.00 | 0.14 |
| Shrub land - Grazing land | 1.80 | 0.13 | 2.30 | 0.61 | 0.00 | 0.07 |
| Shrub land - Shrub land | 9.23 | 6.39 | 4.46 | 0.04 | 0.01 | 1.14 |

**Appendix 24: Key Informant Interview Questioner**

Dear respondent,

My name is Biruk Wolde, I am a postgraduate student at Center for Food Security Studies, College of Development Studies, Addis Ababa University. Currently, I am doing my MSc thesis entitled Effect of Land Use and Land Cover Changes on River Water Quality and Household Food Production in Little Akaki River Catchment, Central Ethiopia. The main objective of this questionnaire is to collect primary data to undertake assessment for land use and land cover changes, river water quality and household food production. Your responses to the questions are valuable and will be held in utmost confidentiality to be used only for the analysis of this research. You will not be identified by name in any case. You have been selected purposely based on your farming experience, social involvement and participation in different livelihood activities that will have experience regrading river water quality and household production in this research, you will be doing so voluntarily and there will not be any monetary returns. You are also free to refuse to respond to any questions, you do not feel comfortable answering or to withdraw from the research all together. This interview will take about an hour of your time to respond to the questions.

| | |
|---|---|
| Date of the interview: | …… . |
| Name of the key informant: | …… . |
| Gender of informant: | …… . |
| Age of informant: | …… . |
| Sub-city: | …… . |
| Woreda: | …… . |
| Kebele: | …… . |
| Name of the Interviewer: | …… . |

1. Can you provide some information about your experience living in the area and your familiarity with land use and land cover changes?
2. How long have you been residing in this area, and how have you observed changes in land use and land cover over time?
3. What are your perceptions of the relationship between land use changes, river water quality, and household food crop production?
4. How would you describe the changes in land use and land cover in this area, particularly with regards to forest cover, crop lands, and settlement areas?
5. In your opinion, what are the main drivers or reasons for these changes?
6. How do you think these changes have impacted the river water quality and household food crop production?
7. How would you characterize the current state of the river water quality in this area?
8. Have you noticed any specific changes or deterioration in the quality of the river water over time?
9. What do you believe are the main factors contributing to the decline in water quality?
10. How has your household's food crop production been affected by the changes in land use and land cover?
11. Have you experienced any challenges or difficulties in maintaining or increasing crop production?
12. How do you perceive the relationship between land use changes, water quality, and your ability to grow food crops for household consumption?
13. Have you adopted any specific strategies or measures to cope with the changes in land use, water quality, and food crop production?
14. How have these changes affected your livelihood and food security?
15. Are there any alternative income or food sources you have explored as a result of these changes?
16. What do you think could be done to address the issues related to land use, water quality, and food crop production in this area?
17. Are there any existing initiatives, policies, or interventions that you believe have been effective or ineffective in addressing these challenges?

18. What kind of support or resources would you consider helpful in mitigating the impacts of land use changes on river water quality and food crop production?

## Thank you so much for your time!!!

Dear respondent,

My name is Biruk Wolde, I am a postgraduate student at Center for Food Security Studies, College of Development Studies, Addis Ababa University. Currently, I am doing my MSc thesis entitled Effect of Land Use and Land Cover Changes on River Water Quality and Household Food Production in Little Akaki River Catchment, Central Ethiopia. The main objective of this questionnaire is to collect primary data to undertake and identify institutional setups towards river water quality and household food production. Your responses to the questions are valuable and will be held in utmost confidentiality to be used only for the analysis of this research. You will not be identified by name in any case. Your institution has been selected purposely depending on its assignment and establishment regrading river water quality and household production in this research, you will be doing so voluntarily and there will not be any monetary returns. You are also free to refuse to respond to any questions, you do not feel comfortable answering or to withdraw from the research all together. This interview will take about an hour of your time to respond to the questions.

| | |
|---|---|
| Name of institution: | …… |
| Name of the key informant: | …… |
| Gender of informant: | …… |
| Position in the organization: | ……. |
| Date of the interview: | …….. |
| Name of the Interviewer | ……. |

1. Can you provide an overview of your institution's role and responsibilities in land management, water quality, and agricultural issues in the Little Akaki river catchment?

2. How long has your institution been involved in this area, and what projects or initiatives have you undertaken related to land use and land cover changes in the catchment?
3. What are the main goals and objectives of your institution regarding land use management, water quality preservation, and support for agricultural activities in the Little Akaki river catchment?
4. How does your institution define and monitor land use and land cover changes in the Little Akaki river catchment?
5. What are the primary drivers or factors contributing to these changes, according to your institution's assessments or studies?
6. How do you evaluate the impacts of land use changes on river water quality and household food crop production in the catchment?
7. What monitoring and assessment methods does your institution use to evaluate river water quality in the Little Akaki river catchment?
8. How often are water quality assessments conducted, and what parameters or indicators are measured?
9. Have you observed any specific trends or changes in water quality associated with land use and land cover changes in the catchment?
10. What interventions or strategies has your institution implemented to address the impacts of land use changes on water quality and agricultural production in the Little Akaki river catchment?
11. How do these interventions align with broader land use management plans or policies?
12. What are the main challenges or limitations your institution faces in implementing these interventions in the catchment?
13. Does your institution collaborate with other stakeholders, such as government agencies, NGOs, or local communities, to address land use and water quality issues in the Little Akaki river catchment?
14. What are the key partnerships or networks your institution engages with in this context?
15. How do these collaborations contribute to the overall approach in managing land use changes and water quality in the catchment?

16. Based on your institution's expertise and experiences, what are the potential long-term consequences of continued land use and land cover changes on water quality and agricultural production in the Little Akaki river catchment?
17. What recommendations or policy changes would your institution suggest to address these issues effectively in the catchment?
18. Are there any specific research needs or gaps that your institution believes should be addressed to better understand the relationship between land use changes, water quality, and food crop production in the Little Akaki river catchment?

**Thank you so much for your time!!!**