



Impacts of land use and land cover types on water quality and benthic macroinvertebrates in Great Akaki River Catchment

**By
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A thesis submitted to the Joint MSc. Program of Addis Ababa University and Bahir-Dar University in partial fulfilment of the requirements for the Degree of Master of Science in Aquatic Ecosystems and Environmental Management (AEEM)

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This thesis is my original work and has not been presented for any degree examination in any other institution or university.

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ABBREVIATIONS

AACPPO - Addis Ababa City Plan Preparation Program Office

AAEPA - Addis Ababa Environmental Protection Authority

ANOSIM - Analysis of Similarity

APHA - American Public Health Association

CCA - Canonical Correspondence Analysis

CSA - Central Statistical Agency

DCA - Detrended Correspondence Analysis

DO - Dissolved Oxygen

DWAF - Department of Water Affairs and Forestry

EC - Electrical conductivity

EOT - Ephemeroptera, Odonata, Trichoptera

EPT - Ephemeroptera, Plecoptera, Trichoptera

EPA - Environmental Protection Agency

GF/F - Glass Fibre Filters

GIS - Geographic Information System

GPS - Global Position System

LULC - Land Use Land Cover

NTU - Nephelometric Turbidity Unit

PAST - Paleontological Statistics

RDA - Redundancy Analysis

SASS - South African Scoring System

SRP - Soluble Reactive Phosphorus

TDS - Total Dissolved Solids

TP - Total Phosphorus

TSS - Total Suspended Solids

UNEP - United Nations Environmental Programme

USGS - United States Geological Survey

USEPA - United States Environmental Protection Agency

WHO - World Health Organization

ABSTRACT

Limited access to clean water, exacerbated by urbanization, industrialization, and agricultural practices, brings significant challenges to human and ecosystem health. A decline in surface water quality is linked to land use/land cover changes worldwide, necessitating the use of such bio-indicators as macroinvertebrates for biomonitoring. However, efforts made to detect and understand land cover/land use changes and link them to changes in water quality parameters and macroinvertebrate communities structure are limited in Great Akaki River. As to address this limitation, this study aimed to assess the impact of land use land cover changes in the Great Akaki River catchment on water quality and macroinvertebrate community structures. This study was conducted in June and November 2023 at six sampling sites. Temperature, pH, dissolved oxygen, electrical conductivity, total dissolved solids, and turbidity were measured in-situ, while nutrients were analyzed in the Laboratory. Macroinvertebrates were collected from 4 representative biotopes using a square frame hand net and identified to family level. Habitat quality assessment was conducted using the Rapid Bioassessment Protocol. River water quality was classified using SASS 5 and ETHbios methods. Land use land cover was assessed using GIS tools for the years 2008, 2016, 2023. Considering the fact that data were not normally distributed, non-parametric tests, Kruskal-Wallis and Mann-Whitney U tests, were used to assess spatial and temporal variation of water quality parameters, respectively. SPSS and XLSTAT were used for data analysis and filling missing data values, respectively. Principal component analysis was conducted to explore the relationship between land use types and water quality parameters and Redundancy analysis was used to evaluate the relationship between water quality and macroinvertebrates community structure. ANOSIM and SIMPER were used to assess the influence of land use type on macroinvertebrates. Results of the study showed that the main land use types in the catchment area were agriculture, urban land, bare land, vegetation and water body. Agricultural land was the dominant LULC types covering approximately 61.37% in 2008, 60.68% in 2016, and 41.78% in 2023. The analysis of land use change between 2008 and 2023 showed a significant rise in urban area (29.91%), while other land use types decreased. Urban area was strongly and positively correlated with SRP, pH, temperature and TDS indicating the deterioration of water quality with the expansion of urbanization. Agriculture was strongly and positively correlated with SRP while Bare land was strongly and positively correlated with EC and TDS. Examination of the influence of different land use types on macroinvertebrates assemblages revealed that urban area had the highest impact and Order Ephemeroptera contributed the highest variability between land use types. Analysis of water quality-macroinvertebrates relationship revealed positive correlation between several sensitive and moderately sensitive macroinvertebrates families with DO and habitat assessment. The downstream study sites that demonstrated severe ecological impairment since highly tolerant taxa were abundant and had strong correlations with TDS, SRP; and TP, NO₃, turbidity levels. The results of the present study will provide valuable information for environmentalists and policy makers in their endeavours directed to sustainable river management.

Key word: Akaki River, Benthic Macroinvertebrates, Bioindicator, Land use/Land Cover, Water Quality

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በከተሞች መስፋፋት፣ በኢንዱስትሪ መስፋፋትና በግብርና ልማት ምክንያት የሚባባሰው የንጹህ ውሃ አቅርቦት ውስን መሆኑ በሰው ልጅና ሥነ ምህዳራዊ ጤንነት ላይ ከፍተኛ ችግር ያስከትላል። የውሃ ጥራት እየቀነሰ መምጣቱ የመሬት አጠቃቀም/መሬት ሽፋን ለውጦች በመላው ዓለም እንዲከሰት ምክንያት ሆኗል። ለዚህም ደግሞ ለባዮሞኒተሪንግ በማክሮይን የጀርባ አጥንት የሌላቸው የመሳሰሉ ባዮ-ጠቅሚዎች መጠቀም የግድ ነው። ይሁን እንጂ የመሬት ሽፋን/መሬት አጠቃቀም ለውጦችን ለማወቅና ለመረዳት እንዲሁም በውሃ ጥራት መለኪያ እና በማክሮይን የጀርባ አጥንት የሌላቸው ማህበረሰብ መዋቅር ላይ ከሚደረጉ ለውጦች ጋር ለማያያዝ የተደረጉ ጥረቶች በታላቁ አቃቂ ወንዝ ላይ ውስን ናቸው። ይህን የአቅም ገደብ ለማስወገድ ይህ ጥናት በታላቁ አቃቂ ወንዝ ላይ በመሬት አጠቃቀም ላይ የተደረጉ ለውጦች በውኃ ጥራትና በማክሮይን የጀርባ አጥንት የሌላቸው ማህበረሰባዊ መዋቅሮች ላይ የሚያሳድሩትን ተጽዕኖ ለመገምገም ታሰቦ የተደረገ ነው ። ይህ ጥናት የተካሄደው በሰኔ እና በግዳር 2023 በሲድስት የናሙና ቦታዎች ነበር። የሙቀት መጠን፣ የሃይድሮጅን አቅም፣ የሚሚ አክሲድን፣ የኤሌክትሪክ አስተላላፊነት፣ ጠቅላላ የሚሚ ጠጠር እና ድፍርስነት በቦታው ሲለኩ፣ በላቦራቶሪ ውስጥ ደግሞ ንጥረ ነገሮች ተመርምረዋል። ማክሮይን የጀርባ አጥንት የሌላቸው፣ አራት ማዕዘን የሌላ መረብ ተጠቅመው ከ 4 ተወካይ ባዮቶፖች ተሰብስበው ወደ ቤተሰብ ደረጃ ተለይተዋል። የመኖሪያቸው ጥራት ግምገማ በፈጣን ባዮአሰመንት ፕሮቶኮል ተመርቷል። የወንዝ ውሃ ጥራት፣ ሳሰ-5 እና ኢትባዮስ ዘይታችን በመጠቀም ተገምግሟል። የመሬት አጠቃቀም የመሬት ሽፋን በጂኦሎጂ መሳሪያዎች በመጠቀም በ2008፣ 2016፣ 2023 ተገምግሟል። መረጃዎች በተለምዶ ያልተሰራጨ መሆናቸውን ግምት ውስጥ ማስገባት፣ ፓራሜትሪክ ያልሆኑ ምርመራዎች፣ ክሩስካል-ዋሊስ እና ማን ዊትኒይ ዩ ምርመራዎች፣ የውሃ ጥራት መለኪያዎችን የቦታ እና የጊዜ ልዩነት ለመገምገም ጥቅም ላይ ውሏል። ኤስፒኤስኤሥ እና ኤክሴልስታት ለመረጃ ትንታኔ እና የጎደሉትን የመረጃ እሴት ለመመላት ጥቅም ላይ ውለዋል። በመሬት አጠቃቀም ዓይነቶች እና በውሃ ጥራት መለኪያ እና ድግግሞሽ ትንተና በውሃ ጥራት እና በማክሮይን የጀርባ አጥንት የሌላቸው ማህበረሰብ መዋቅር መካከል ያለውን ግንኙነት ለመገምገም ዋና ዋና የንጥረ ነገሮች ትንተና ተካሂዷል። አኖዝም እና ሲምፐር የመሬት አጠቃቀም ዓይነት በማክሮይን የጀርባ አጥንት የሌላቸው ላይ የሚያሳድረውን ተጽዕኖ ለመገምገም ጥቅም ላይ ውሏል። በአካባቢውም ዋነኞቹ የመሬት አጠቃቀም ዓይነቶች ግብርና፣ የከተማ መሬት፣ ባዶ መሬት፣ ዕፅዋትና የውሃ አካላት መሆናቸውን በጥናቱ ውጤት አመለካከቷል። የእርሻ መሬት በ 2008 በግምት 61.37%፣ 60.68% በ2016፣ እንዲሁም በ 2023 ውስጥ 41.78% የሚሸፍን ዋነኛ የመሬት አጠቃቀም/መሬት ሽፋን አይነት ነበር። በ2008 እና በ2023 መካከል በተደረገው የመሬት አጠቃቀም ለውጥ ላይ የተደረገ ጥናት በከተሞች አካባቢ (29.91%) ከፍተኛ ጭማሪ አሳይቷል፤ ሌሎች የመሬት አጠቃቀም ዓይነቶች ግን ቀንሰዋል። የከተማ አካባቢ ከከተሞች መስፋፋት ጋር የውሃ ጥራት እየሸቀለቀለ መሄዱን ከሶሊዩብል ሪአቸቲቭ ፎሰፈረስ፣ የሃይድሮጅን አቅም፣ የሙቀት እና ጠቅላላ የሚሚ ጠጠር ጋር ጠንካራ እና አዎንታዊ ተዛማጅነት ነበረው። የባዶ መሬት ከኤሌክትሮኒክ አስተላላፊነት እና ጠቅላላ የሚሚ ጠጠር ጋር ጠንካራ እና አዎንታዊ ተዛማጅነት ሲኖራቸው ግብርና ከከሶሊዩብል ሪአቸቲቭ ፎሰፈረስ ጋር ጠንካራ እና አዎንታዊ ተዛማጅነት ነበረው። የተለያዩ የመሬት አጠቃቀም ዓይነቶች በማክሮይን የጀርባ አጥንት ያላቸው ስብስቦች ላይ የሚያሳድሩትን ተጽዕኖ መመርመራችን በከተሞች አካባቢ ከፍተኛ ተጽዕኖ እንዳሳደረገና ኤጌሜርፕቴራ ደግሞ በመሬት አጠቃቀም ዓይነቶች መካከል ከፍተኛ ልዩነት እንዲኖር አስተዋጽኦ እንዳደረገ አመልክቷል። በውሃ ጥራት-ማክሮይን የጀርባ አጥንት የሌላቸው ግንኙነቶች ላይ የተደረገ ጥናት እንደሚሳየው የሚሚ አክሲድን እና የመኖሪያ አካባቢ ግምገማ ያላቸው በርካታ በቀላሉ የሚጎዱ እና መጠነኛ ብክለትን መቋቋም የሚችሉ ማይክሮን የጀርባ አጥንት የሌላቸው ቤተሰቦች መካከል አዎንታዊ የሆነ ዝምድና አለ። የታችኛው ተፋሰስ የናሙና ስፍራዎች ከባድ ሥነ ምህዳራዊ እክል መኖሩን ከፍተኛ ብክለትን መቋቋም የሚችሉ ምድቦች አሳይተዋል በተጨማሪም ጠቅላላ የሚሚ ጠጠር፣ ከሶሊዩብል ሪአቸቲቭ ፎሰፈረስ ጋር ጠንካራ ግንኙነት የነበራቸው የጥናት ቦታዎች፣ እና ጠቅላላ ፎሰፈረስ፣ ናይትሬት፣ ድፍርስነት የአሁኑ ጥናት ውጤት ለአካባቢ ጥበቃ ባለሙያዎች እና ፖሊሲ አውጪዎች ዘላቂ ለሆነ የወንዝ አስተዳደር በሚሰጡት ጥረት ጠቃሚ መረጃ ይሰጣል።

1. INTRODUCTION

1.1. Background

Humans and all other forms of life on Earth depend on water as a vital and life-sustaining resource. For humans and other aquatic animals to survive, there must be an adequate supply of high-quality water (Khwakaram *et al.*, 2012). Yet, investigations have revealed that just 1% of the freshwater on the planet is accessible to humans and is found in streams and lakes (UN-Habitat, 2010). In fact, the need for water is increasing rapidly, and this is true not just for domestic needs but also for industrial and agricultural expansion. Due to these factors, its pollution and scarcity are becoming a challenge to economic and social development (Narasimhan, 2008) as well as a potential source of transboundary conflict (Rahman, 2013).

Rivers are essential natural resources that enable socioeconomic development. Although they are major sources of fresh water, rivers are contaminated due to improper waste management, particularly in developing nations where 90% of sewage and 70% of industrial wastes are dumped untreated straight into surface water bodies (UN-Water, 2009). The majority of rivers and streams have been used for drinking, aquaculture, irrigation, industry, transportation, recreation, and other purposes (Barakat *et al.*, 2016). Surface water quality has been declining all around the world as a result of anthropogenic activities such as land use change, discharge of sewage, municipal and residential garbage, urbanization, industrial expansion, and application of pesticides on agricultural lands (Mustapha *et al.*, 2013; Oketola *et al.*, 2013).

There is a clear link between land use and water quality, either positive or negative. Urbanization, industries, and intensive agricultural practices, for instance, may increase erosion and sediment accumulation (Beasley and Kneale, 2002; Goss *et al.*, 2014; Smucker and Detenbeck, 2014; Da Silva *et al.*, 2015), and input of chemicals like nitrogen and phosphorus (Beasley and Kneale, 2002; Goss *et al.*, 2014; Raper *et al.*, 2015; Colin *et al.*, 2016). Biodiversity and ecosystem services are also being more threatened by changes in land and water usage (Elmhagen *et al.*, 2015; Selemani *et al.*, 2018). The abundance and richness of aquatic organisms, such as fish (Hook *et al.*, 2017; Wright *et al.*, 2017), macroinvertebrates (Baillie and Neary, 2015; Gerth *et al.*, 2017), and plants, will be impacted by the changes in the physico-chemical and hydro morphological characteristics of the impacted river or its catchment (Liu *et al.*, 2015; Rääpysjärvi *et al.*, 2016). Regarding the physical, chemical, and biological aspects of its environment, each aquatic organism has

specific requirements. As a result, changes in these conditions may lead to a decline in the number of species, and a shift in the dominance of species, or the extinction of sensitive species (Worku Legesse *et al.*, 2000).

Physical and chemical methods used to monitor water quality allow only instantaneous measurements that provide information on water quality at the time of measurement, while biological methods enable us to detect long-term environmental effects on biota since they have the capacity to reflect the conditions, which were not present at the time of sampling and analysis. Physical and chemical water quality parameters are, therefore, a snapshot reflection of the state of the ecological health of the aquatic system. The most direct and effective measure of the integrity of a water body is, thus, the status of its living system. That is why river/stream ecologists including Mangadze *et al.* (2019) recommended the use of biological indicators like macroinvertebrates to address this issue. Macroinvertebrates have continued to be the subject of research of stream ecologists worldwide (Tornwall *et al.*, 2015). Their community has a wide variety of species with varying tolerances to water contamination, making them ideal bio-indicators for assessing the health of freshwater ecosystems (Seid Tiku *et al.*, 2013). According to Balderas *et al.* (2016), macroinvertebrates have many advantages over other aquatic indicators, including sensitivity to stream disturbance, brief life cycles, restricted mobility, ease of collection and identification, and high variability in terms of environmental tolerance and habitat preference (Arenas-Sánchez *et al.*, 2021; Dalu *et al.*, 2021; Wasserman and Dalu, 2022).

Water pollution caused by human activity nowadays is a major issue on a worldwide scale. Ethiopia also has the problem of deteriorating water quality, with the extent and severity of the water quality problem becoming more visible in big cities like Addis Ababa, where the issue is now at its worst. Rivers and riverbanks are among the natural resources of Addis Ababa that are adversely impacted by the city's fast watershed urbanization, leading to high river water pollution from land use change, which threatens human health and native biodiversity through habitat loss and fragmentation. (Tamiru Alemayehu, 2001; Getaneh Gebre and Van Rooijen, 2009; Mazhindu *et al.*, 2012; AACPPO, 2017; Hamere Yohannes and Eyasu Elias, 2017; Yared Worku and Mekonnen Giweta, 2018). The Great Akaki River, the subject of the present study, has a catchment that has experienced considerable land cover/land use changes, which seem to have impacted its water quality and hence local biodiversity. The majority of Addis Ababa's big and medium-sized companies, with the exception of a few extremely old industries, are located in the Akaki industrial zones across

which the Great Akaki River flows (CSA, 2010). This indicates that industrial effluents entering the river may have had a considerable detrimental influence on the water quality and hence on macroinvertebrates community structure of the river. To gather information useable in efforts geared towards its watershed management, an investigation on the impacts of land cover/land use changes on its water quality and hence macroinvertebrates community structure is mandatory.

1.2. Statement of the problem

Anthropogenic activities affect water flow and quality of rivers, and their impacts can be felt miles away downstream. According to UNESCO (2017) report, 80% of the wastewater produced by industries flows into river ecosystems without being treated. Like many developing nations, Ethiopia faces a significant environmental issue of managing the quality of its rivers' water. As the socio-political and industrial hub of the nation, Addis Ababa suffers greatly from the issue of water pollution and as one of the major rivers, the Great Akaki River, which collect household and industrial wastewater, is no exception.

Agriculture, urban, bare land, vegetation and water body are among the land use types in and around the city. Most parts of the riverbank and surrounding areas have settlers that use the rivers for both sanitation and as sites for the disposal of waste. Household trash is discharged into the river system without being properly treated, and pipelines from various sources discharge their wastes straight into rivers (Hamere Yohannes and Eyasu Elias, 2017). Over the past three decades, the Akaki Kality sub city has seen dramatic changes in land use and land cover (Abdrhman Berga, 2011). This resulted in increased competition for land, which impacted the river water quality and aquatic biodiversity negatively.

The Great Akaki River passes primarily through residential and commercial areas of Addis Ababa. It is subjected to industrial effluents in its lower catchments when it passes through Akaki, the largest industrial town (AAEPA, 2005). The upper catchment is dominated by residential settings as is the middle catchment although the latter is sparsely populated. The lower catchment largely harbours large- and medium-size industries, workshops, big garages, small lands for cultivation and livestock- holding activities by residents, sites for irrigation domestic use and so on (EPA, 2002). There have been different studies on the quality of water in Great Akaki River using chemical criteria, and bioassessment techniques (EPA, 2002; AAEPA, 2005; Tamiru Alemayehu *et al.*, 2006; Solomon Akalu *et al.*, 2011). However, studies linking the impact of land use land cover change on water quality and

macroinvertebrates assemblages in the Great Akaki River are lacking. Therefore, undertaking such studies can provide scientific information on macroinvertebrates abundance, distribution, and diversity, and status of water quality in the Great Akaki River thereby enabling to determine the effects of anthropogenic activities and the possible sources of pollution in the river's catchments. The data that emanated from this study will be useful in informing governmental bodies responsible for the management of rivers and their catchments for improved water quality and aquatic biodiversity.

1.3. Research Questions

- What are the existing land use and land cover patterns in the Great Akaki River catchment between 2008 and 2023?
- How do changes in water quality of Great Akaki River influence benthic macroinvertebrates community structures?
- How do land use and land cover changes impact the water quality of Great Akaki River?
- How do land use and land cover changes impact the macroinvertebrates community structures in the Great Akaki River?

1.4. Objectives

1.4.1. General objective

The general objective of this study is to assess the impacts of land use and land cover types on water quality, and benthic macroinvertebrates in Great Akaki River catchment, Addis Ababa.

1.4.2. Specific objectives

- i. To analyze the land use and land cover change along Great Akaki River catchment over the years between 2008-2023.
- ii. To determine the relationship between water quality and benthic macroinvertebrates composition.
- iii. To assess the impacts of land use and land cover changes on physico-chemical water quality parameters of Great Akaki River.
- iv. To assess the relationship between land use and land cover types and the benthic macroinvertebrates community in the Great Akaki River.

1.5. Significance of the study

The Great Akaki River is one of the polluted river that drains in the city, and keeping it clean is the key to the protection of human health. The development of strategies of protection and restoration of polluted rivers necessitates the generation of water quality data. Thus, scientific information that has emanated from the study reported here will assist environmentalists and policy makers in their efforts to be made to take management measures geared to the impact of pollution on aquatic habitats and human health. If policy makers and other relevant governmental and non-governmental bodies happen to make the best use of the information that this study has come up with, the local communities will have their vital resource protected and sustained for livelihood. Furthermore, the present data will serve as baseline information for future studies. The results of this study have unravelled the abundance, distribution, diversity, and conditions of macroinvertebrate life in the river as well as the impact of land use land cover changes and the potential sources of pollution in the watershed. By incorporating macroinvertebrates in water quality monitoring, the government, interested groups, and local communities can work together in water resources monitoring.

2. LITERATURE REVIEW

2.1. Land use and land cover types along rivers

According to de Sherbinin (2002) the term “*Land use*” is viewed as the total of all arrangements, activities and inputs that people undertake in a certain land cover type. In contrast, *Land cover* is the observed physical and biological cover of the earth’s land including vegetation, rocks, water body or man-made features. The changes in land use and land cover are the consequence of complex interactions between a number of biophysical and socioeconomic factors that can take place over a wide range of temporal and spatial dimensions (Reid *et al.*, 2000). Watershed patterns are primarily altered by changes in land use and land cover, which also affect runoff behavior and the equilibrium between evaporation, groundwater recharge, and stream discharge in particular locations and across entire watersheds. These changes have a significant impact on all water users (Sahin and Hall, 1996; DeFries and Eshleman, 2004; Huang Juan *et al.*, 2013). Hence, improved management of watersheds requires an understanding of how changes in land use and land cover affect the health of rivers.

The biogeochemical cycle has been significantly impacted in the past 40 years by changes in land use and land cover, which have altered surface atmospheric energy exchanges, the carbon and water cycles, soil quality, biodiversity, the capacity of biological systems to support human needs, and ultimately influence climate at all scales. This has resulted in significant pollution of water bodies and other undesirable effects on aquatic ecosystems (Overmars and Verburg, 2005; Van Rompaey *et al.*, 2007). Many studies have been done on how different watersheds' land usage and land cover have changed.

For instance, in Liaoning province of China, Wang *et al.* (2014) studied the influence of land use patterns on water quality in the Daliao River basin. In this basin, land use was constituted primarily by forests (64%), agriculture (28%), and urban areas (5%), with water, grassland, and bare land making up the remaining 3% of the total area, while the other land uses were situated in the midstream and downstream regions of the basin, the forest land was situated in the upper zones of the catchment. The land use and land cover change study in the Sukinda valley in India showed that mining increased by 1.3 % between 1975 and 1992, and also by 1.6 % between 1992 and 2005. But, dense forest area decreased in both periods by 6.2 % and 2.3 % respectively. Water bodies decreased during the first period and increased during

the second period. There was a continuous increase in non-forest areas which may be attributed to an increase in settlement areas, barren land, and deforestation activities (Majumder, 2011).

Maitima *et al.* (2009) reported that land use changes in East Africa have replaced natural vegetation with farmlands, grazing fields, human settlements, and urban centres. Deforestation, biodiversity loss, and land degradation were the results of these changes. Land resources in Kenya confront significant issues, primarily due to population increase. This puts stress on the land's resources and encourages inefficient land use methods including intensifying farming, expanding farmland, overgrazing, and cutting down trees for fuel. As a result, environmental degradation would eventually lead to decreasing natural resource productivity (Agustina, 2008). For example, the main land use types in the Bdarugu and Ruiru river basins were, forests (14.93%, 16.25%), small-scale agriculture (54.02%, 60.93%), large-scale agriculture (11.93%, 15.54%), urban areas (14.69%, 5.8%), grassland (4.18%, 1.29%), and water (1%). Through temporal analysis, the forested land was shown to be on a decreasing trend, while agriculture and urban areas were on an increasing trend. According to Wambugu (2018), this is linked to population expansion and urbanization.

Most of Ethiopia's land is farmed by smallholders for subsistence. Smallholders need additional land to grow crops and make a living due to the rapid population expansion and lack of agricultural intensification, which causes deforestation and the conversion of other types of land use to farmland (Asmamaw Adamu, 2013). Hurni *et al.* (2010) further stated that whereas more than 90% of the Ethiopian highlands were originally forested, only 20% of this area is now forested, and the percentage of forest cover is less than 4%. This demonstrates that there was a high incidence of degradation of vegetated land in the past and that it is still occurring today. The overall area of the Kebena River watershed is 5,247.60 ha. The predominant land use, making up 39.14% of the total land area, is forested land, which comprises natural forests, *Eucalyptus globulus* plantations, and vegetation along rivers. The second largest land use, estimated at 32.51% of the total area, is settlement, with cultivated land making up the remaining 27.1%. Only 1.1% of the surface area is made up of bare rock and soil (Kalkidan Asnake *et al.*, 2021).

Five main LULC types (agricultural land, bushland, woodland, grassland, and settlements) were utilized to classify Landsat photos in the Birr River basin (1986, 2001, and 2018) (Demelash Ademe *et al.*, 2023). Agriculture constituted 56.39%, while bush land accounted

for 26.18% of the territory. Forest, grassland, and towns made up the remaining 4.94%, 11.27%, and 0.73%, respectively, of the study area in 1986. Similarly, in 2001, bush land and agricultural land accounted for 61.99% and 23.80%, respectively, of all LULC classes. The percentages of forest, grassland, and populated areas were, respectively, 1.77%, 11.25%, and 1.19%. Additionally, according to the 2018 LULC classification types, agriculture and bush land make up the largest percentages of all LULC classes, occupying 70.19% and 19.30% of the total, respectively. In contrast, forest, grassland, and settlements occupied 1.92%, 7.16%, and 1.42% of the total, respectively. Similarly, Mitiku Badasa *et al.* (2022) reported that from 1990 to 2020, agricultural land coverage in the Geba watershed, western Ethiopia, was higher than those of other LULC types. Owing to the rapid rise in population in the Geba watershed, woodland was being converted to cultivated land and settlement areas (Temesgen Mekuriaw, 2019). Throughout most of Ethiopia, human activity has diminished the amount of forest cover (Wuletawu Abera *et al.*, 2020).

In the years 2001, 2010, and 2015, Lemlem Tadesse *et al.* (2017) looked into changes in land use and land cover in the Yezat watershed in northwest Ethiopia. Between 2001 and 2010, grassland and woodland fell, but from 2010 to 2015, they rose. On the other hand, the amount of cultivated land increased in the first period and declined in the second one. During these times, the number of homesteads increased while shrub/bushland decreased.

2.2. Relationship between land use and land cover types and water quality

Water quality and land use land cover have been proven to be inextricably related in a given watershed (Sutherland *et al.*, 2002). When natural and human activity in the watershed are taken into account, these connections can, however, be complicated (Wang *et al.*, 2014). Some land uses, including agriculture, forestry, urban, and industrial regions, can influence the water quality of rivers that pass through them.

2.2.1. Agriculture

Water quality within an agricultural land is impacted negatively by planting, input application (fertilizers, agro-chemicals), and irrigation (Stoate *et al.*, 2009). Numerous studies have demonstrated that row crops (typically spaced to allow for easy cultivation and harvesting) and other forms of intensive planting have a significant impact on river conditions as agricultural land area increases and water quality declines (Dillon and Kirchner, 1975; Wang *et al.*, 2019). According to previous studies in numerous nations, watersheds with a high

percentage of cropland can emit more nitrogen and phosphorus (Neill, 1989; Gu *et al.*, 2015). Hence, the portions of fertilizers that are not absorbed by crops enter the water through runoff. The rise in these nutrients speeds up eutrophication, which causes shift in microbial composition and decline in aquatic plants, and numerous invertebrates and vertebrates due to oxygen depletion (Yang *et al.*, 2020). Moreover, sewage from livestock barns that may be dumped straight into rivers, lakes, and other bodies of water, pollute them with enormous amounts of nitrogen, phosphorous, and other fertilizer components (Samways, 2022).

The same is true in Ethiopia, where one of the main human activities contributing to nonpoint sources of pollution in streams and rivers is agriculture (Aschalew Lakew and Moog, 2015a). For instance, a study in southwest Ethiopia's Gilgel Gibe Reservoir watershed found that agriculture was the primary land use that had the greatest impact on the water quality (Bizuneh Woldeab *et al.*, 2019). According to this study, agriculture dominated areas had lower DO while, conductivity and TDS were lower at vegetation-covered areas. These results concur with the findings reported in other nations like Kenya and Uganda by Kasangaki *et al.* (2008) and Wambugu (2018), respectively.

2.2.2. Urbanization and Industry

Degradation of water quality is most common in regions with more pronounced human activity and rapid land use change, particularly in regions that are rapidly urbanizing. According to Bu *et al.* (2014), industrial and urban areas are the primary sources of pollution with heavy metals including lead, organics including raw sewage, and nutrients including phosphorus and nitrogen. The effluents from these sources can negatively impact the physical, chemical, and biological makeup of the receiving water body. An estimated 300-400 million tons of heavy metals, solvents, toxic sludge, and other trash are dumped into waters globally each year by industry (UNEP, 1991).

Another issue is related to the construction of houses and roads, as well as the rise in impermeable surfaces, which may expose toxins in the soil and hasten erosion while clogging the city's drainage system with sediments and fills. In terms of many features including slope, size, shape, roughness, and degree of imperviousness, the urban drainage system is very uneven (Shrivastava, 2016).

Even though Ethiopia has relatively few developed urban areas and business centres, water bodies close to cities like Addis Ababa have a serious pollution problem (Baye Sitotaw, 2006). For instance, the data documented by Ferezer Tegegn (2012) study on the physico-

chemical pollution pattern in the Akaki River basin showed that as industrialization and urbanization increased, there was an increase in the concentration and variations of EC, NO₃, PO₄⁻³ phosphate parameters both inside and outside the city of Addis Ababa. A comparison also revealed that the Little Akaki River was far more polluted than the Great Akaki River (Ferezer Tegegn, 2012). Huluka River in west Showa zone is also losing its pristine nature due to the direct dumping of domestic and municipal sewage into its catchment area, which has a severe impact on its water quality thereby causing significant harm to aquatic life and downstream users (Ferezer Tegegn, 2012). Similarly, the water quality of Keha River exhibited a decreasing trend from upstream to downstream due to land use change into urban area (Amsalu Alemu, 2018). Efreem Benito and Pandey (2016) also reported that the growing urbanization of Addis Ababa city had caused bacteriological contamination, the extent of which at downstream exceeded those of upstream and midstream. Water pollution as a result of discharge of municipal wastes and urban runoff have been reported for Kebena stream (Tesfaye Berhe, 1988), Great and Little Akaki rivers (Tamiru Alemayehu *et al.*, 2006), Modjo River (Seyoum Leta *et al.*, 2003), and Awetu River (Dereje Hailu, 1997).

2.3. Water quality assessment using benthic macroinvertebrates

Benthic macroinvertebrates are the most often utilized bioindicators as they provide a more accurate representation of changing aquatic conditions than physico-chemical and microbiological data, which only reveal short-term changes (Raven *et al.*, 2000; Ikomi *et al.*, 2005). Water samples analysed for their chemicals actually reflect only a snapshot of the water at that precise moment. The water can change quickly, but analysis using macroinvertebrates reflects the present situation. Either recurrent periods of poor water quality or ongoing bad water quality will have an impact on their make-up. The other explanation is that they are less mobile and typically located at the bottom of streams, making it tough for them to relocate away from environmental stress (Ghosh and Biswas, 2015). Additionally, a number of recent studies have suggested that because macroinvertebrates have relatively short life cycles, they can quickly reflect environmental changes through changes in community composition in response to water column and sediment pollutants, helping to provide a record of environmental conditions (Santonja *et al.*, 2018). Also, their richness and spread make them useful markers for determining if aquatic systems are trustworthy, appropriate, and highly praised globally (Dalu and Froneman, 2016).

For instance, in Lithuania, Europe, different sized rivers were studied, and benthic macroinvertebrates were employed to determine the most suitable macroinvertebrate families

for river water quality (Višinskienė and Bernotienė, 2012). This study demonstrates that while certain families like the Caenidae cannot be relied upon as markers of clean water, groups such as Oligochaeta, Sphaeriidae, and Erpobdellidae are reliable indicators of organic pollution. It is well known that oligochaeta worms can endure challenging conditions like low DO and high concentration of pollutants (Karrouch *et al.*, 2017). In Kenya, the west region's sugarcane and molasses processing factories' pollution management procedures have been studied using benthic macroinvertebrates (Raburu *et al.*, 2017). The authors developed biotic index based on tolerance values of different macroinvertebrates (0-3 for intolerant taxa, 4-6 for moderately tolerant and 7-10 for most tolerant taxa). The effluent flow ponds were dominated by tolerant taxa like Syrphidae, while subsequent ponds located towards the outflow were dominated by more sensitive taxa like EPT.

In Ethiopia, there are studies that aimed at assessing the ecological health of the lotic environments using macroinvertebrates. For instance, Harrison and Hynes (1988) were pioneers in the study of benthic macroinvertebrates in Ethiopia, especially the benthic fauna of highland streams, while Tesfaye Berhe (1988) studied degradation of the Kebena River using macroinvertebrate community structures. Baye Sitotaw (2006) studied some benthic macroinvertebrate community structures in relation to environmental degradation in some rivers. Birenesh Abay (2007) assessed pollution of downstream effluent along the Tikur Wuha River using macroinvertebrates as indicators. The Jimma wetlands' water quality parameters and macroinvertebrate index of biotic integrity were explored by Hayal Desta and Seyoum Mengistou (2009), and Lake Kuriftu's macroinvertebrate abundance and community structure were investigated by (Tujuba Ayele and Seyoum Mengistou, 2013). It has been well-known in theory and practice for many years that a study on fauna can be used to assess the state of water quality and impact of climate change (Davis, 1995). Benthic macroinvertebrates can help assess the general health of flowing water systems and their water quality. They are impacted by modifications to a stream's physical and/or chemical features (Karr and Kerans, 1991). However, these studies are simply at their infancy as development of a national bioassessment program and studies at lower taxonomic levels will be ultimately mandatory.

2.4. Relationship between land use and land cover types and Benthic macroinvertebrates

Land use land cover has been shown to have an influence on both water quality and biotic components (Ometo *et al.*, 2000). For instance, changes in land use types can significantly alter community composition within a region by altering the physico-chemical characteristics of the aquatic ecosystem (Fierro *et al.*, 2017). The taxonomic diversity of macroinvertebrates significantly decreases along land use intensity and urbanization gradients (Liu *et al.*, 2021). In Africa, the main reasons of declining water quality and ecological degradation include fast population growth and the associated increase in household and community waste, agricultural development, and industrialization. Africa is home to 30% of the world's tropical forests, making it one of the major carbon sinks (Kasangaki *et al.*, 2008). However, since nearly everyone in this region (90%) uses wood as a fuel source, the vegetation is under threat since trees are frequently removed. On the other hand, the use of previously forested land for agricultural purposes by farmers may have a similar impact on forest resources as the collection of fuel wood. Thus, erosion and biodiversity loss are on the rise. Comparatively, forested streams have a higher taxon richness of macroinvertebrates compared to adjacent streams associated with other types, such as agricultural or pasture lands (Kasangaki *et al.*, 2008; Aura *et al.*, 2011; Minaya *et al.*, 2013).

In Ethiopia, the water quality of rivers and streams in the Oromia region near Sebeta town were studied using macroinvertebrate species to evaluate the impact of anthropogenic activities on river water quality (Amare Mezgebu *et al.*, 2019). The results of this study, have revealed that the total number of macroinvertebrate families was highest in the less polluted upstream sites, while the lowest was recorded for sites with point-source contamination. In contrast to urban land uses, agricultural land uses were associated with much higher levels of diversity and richness in the sensitive EPT group, according to a study by Moore and Palmer (2005).

2.5. Application of benthic macroinvertebrates in assessing water quality

The variance in the distribution pattern of biological diversity among taxonomic groupings in rivers and streams is linked to changes in physical habitat qualities, water quality (physico-chemical variables), and the frequency and degree of disturbances (Payakka and Prommi, 2014; McGarvey and Terra, 2016). A drop in diversity is caused by stressors in an aquatic environment, such as physical, chemical, or habitat degradation. A similar decline in the

diversity of macroinvertebrates also has a significant potential to change the taxonomic composition of the ecosystem (Gaskill, 2014). Hershey *et al.* (2010) identified a number of physico-chemical factors, such as water temperature, total dissolved solids, electrical conductivity, turbidity, pH, dissolved oxygen, and nitrates, that affect the organization of the macroinvertebrate community.

The movement and quality of food and water, as well as the interstitial spacing with the sediment regime, are all thought to have been changed by pollution and sedimentation, which are also key causes of the reduction of macroinvertebrates (Akaahan *et al.*, 2014). According to Kithiia (2012) and UNEP (2012), water quality degradation has an impact on the ecological balance, regular operation, and population dynamics of the aquatic environment along the river's course. According to various researchers, macroinvertebrates have varying degrees of tolerance to changes in environmental conditions brought on by human activity, which could result in changes to macroinvertebrate assemblages and biodiversity (Akaahan *et al.*, 2014; Bere *et al.*, 2014). Some species are very sensitive to particular changes, while others can resist a wide range of contamination. These differences provide information about the species' suitability for use as water quality indicators (Odume *et al.*, 2012; Adu *et al.*, 2016).

Trichoptera and Coleoptera taxa are more sensitive to human disturbance or pollution than others and hence good indicators of degraded habitat and important for taxa biomonitoring in many types of freshwater habitats (Olomukoro and Dirisu, 2014; Houghton, 2015). Some groups such as Baetidae and Caenidae are tolerant of human disturbances (Aschalew Lakew and Moog, 2015a). More specifically, Oligochaeta, Sphaeriidae, Erpobdellidae Naucoridae, Veliidae, Pleidae, Caenidae, Dytiscidae are tolerant to water temperature while Hydraenidae, Goeridae, Limnephilidae, Perlidae are sensitive to water temperature (Kasangaki *et al.*, 2008; Višinskienė and Bernotienė, 2012). According to Amare Mezgebu *et al.* (2019), Thiaridae and Syrphidae were dominant in areas with high turbidity. Chironomidae and Oligochaeta were tolerant of high turbidity while, Elmidae and Leptoceridae were sensitive to turbidity (Masese *et al.*, 2014).

Hershey *et al.* (2010), noted that extreme values of pH have a significant effect on macroinvertebrate communities. Streams with higher acidity had lower abundance of macroinvertebrates. Macroinvertebrates have different DO level requirement due to their diverse behaviour and morphological features. For example, Chironomidae have a

haemoglobin-like pigment in their body that stores oxygen and allows them to be tolerant to anoxic condition (Merritt and Cummins, 1996). Other than Chironomidae, Gastropoda and Thiaridae are known to be tolerant to low DO levels in water. As for nitrogen, order Trichoptera Triplectides, Neurochorema and Oeconesus, order Odonata Coenagrionidae were found in lower nitrate level while order Perlidae were sensitive to nitrates (Gichana *et al.*, 2015).

In general, a healthy aquatic environment is dependent on water's physico-chemical and biological features, which give important information about the ecosystem's available resources for supporting life (Thirupathaiah *et al.*, 2012). Macroinvertebrates are the most abundant and diverse species in stream and river ecosystems, and they are also the most vulnerable to poor water quality, as evidenced by their composition, variety, and quantity (Adeogun and Fafione, 2011). So, if today's environment is not properly managed it will lead to unsustainability of the resources.

2.6. GIS and Remote sensing

Planners and resource managers require a reliable method for promptly and accurately identifying, monitoring, and assessing changes in land use in order to assess the effects of the stress placed on natural resources. Delivering the required information in a timely and cost-effective manner is difficult using the traditional methods of environmental data collection and analysis. So, it has become necessary to examine Earth from space in order to fully understand the cumulative impact of human actions on its natural resource base. Yet, compared to other approaches, remote sensing technology can play a crucial role in providing precise and reliable information in a more time and cost-effective manner. Through the analysis of data collected by a device that is not in direct contact with the object or feature being studied, a technique known as remote sensing can be used to learn more about an object or feature (Lillesand *et al.*, 2015). Developed to deal with data referenced by spatial and geographical coordinates, GIS is a computer-based, geographically related information system (Maantay *et al.*, 2006).

GIS and remote sensing technologies are applied in water resource-related studies and are recognized as powerful technologies that have been employed as essential tools for modelling and analyzing hydrology (Khairy *et al.*, 2001). Satellite data imagery, topographical maps, land use/land cover, weather, and topography are some of the sources of information used in GIS projects. Integration of both technologies is highly respected in land use watershed

management because to remote sensing's power to acquire current satellite information for broad ground areas and GIS's capacity to store, alter, and manage data from diverse sources (Tattao, 2010).

Numerous studies have used GIS to aid in the interpretation of spatial data while examining land use-water quality connections at various management scales. Several studies have demonstrated that the use of GIS in combination with ecology and water quality modelling helps in the development of decision-making for effective land use management, long-term water quality evaluation, and enhanced non-point source pollution control at the watershed level (Zhang and Wang, 2012).

3. MATERIALS AND METHODS

3.1. Study sites description

3.1.1. Location and topography

Akaki River is located in the central part of Ethiopia covering the latitude range from 8° 46' to 9° 14' N, and the longitude range from 38° 34' to 39° 04' and the river basin covers the western part and drains the city from north to south (Abdrhman Berga, 2011). Great Akaki River has a catchment area of about 900 km², while Little Akaki River has a catchment area of about 540 km². Little Akaki River originates from the Northwest direction through Gefersa Reservoir down to the center of the city and passes through the industrial area and ending up in the Aba-Samuel. Great Akaki River emanates from Legedadi Reservoir in the Northeast of the city and passes through the industrial areas, finally entering Aba-Samuel Reservoir. Both rivers are discharging in to the Aba-Samuel Reservoir after 53 km flow (Yared Worku and Mekonnen Giweta, 2018). The topography of the Great Akaki River basin is rugged and steep mostly between Entoto and Filwoha, while it is gentle and flat-lying in the south and southwest parts of the basin (Feyera Asfaw, 2007).

3.1.2. Climate

The study area is characterized by bimodal rainfall regime. The major rainy period, which spans from mid-June to end of September is responsible for 70% of the annual average rainfall of 1400 mm and the minor rainy season covers the period from February to April. The remaining months of the year (Dry period) are generally characterized by having little or no rainfall. Annual average temperature varies from 9.9 to 24.6° C (EPA, 2002). The mean annual discharge of the Great Akaki River is 8.86 m³ /s (Tamiru Alemayehu *et al.*, 2006).

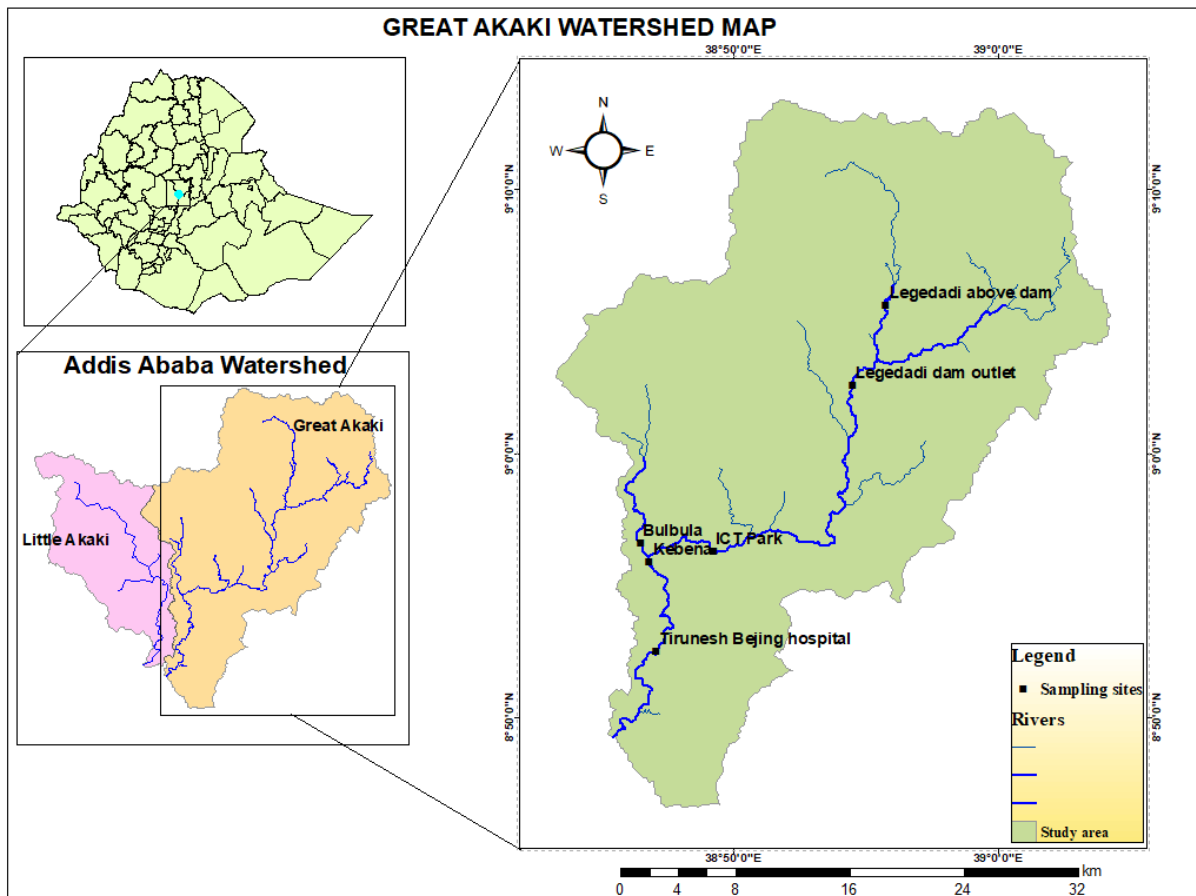


Figure 3.1: Map of the Great Akaki River and its catchment showing sampling sites

3.1.3. Hydrology

The surface water reservoirs found in this catchment are Legadadi and Dere, the major water supply sources for Addis Ababa. The presence of massive, fractured and porous units at different depths produces a multi-layer aquifer system in the Great Akaki catchment. Due to this, hand-dug wells and boreholes located in most parts of this catchment, tap groundwater from different aquifers and it is common to use springs in this catchment for human consumption especially when there is shortage of municipal water supply. The distinctive characteristic of the Great Akaki sub- catchment is the occurrence of thermal water in Filwoha and its surrounding. The boreholes drilled at Hilton, Filwoha, Ghion, National palace and St. Joseph school tap thermal groundwater that occur in phreatic and confined conditions (Abdrhman Berga, 2011).

3.1.4. Socioeconomic activities

i. Population

According to the 2007 census, the total population of Akaki Kaliti Sub city is 181, 048 which is 6.62% of the entire population of the city. Of the total population, 88,526 are male and 92,522 are female (CSA, 2007)

ii. Economic activities

Around the Great Akaki River in the Akaki Kaliti sub-city, there are several well-established industries. They either directly or indirectly discharge wastes into the river. More than 160 hectares of land are utilized for agricultural fields, mostly to the south of Addis Ababa, where vegetables are grown for the city markets. Vegetables are typically produced on plots adjacent to rivers, where irrigation water is available. Either a motor pump directly pumps up the water or canals are used to divert it (Minbale Aschale *et al.*, 2016; Minbale Aschale *et al.*, 2017). There are several large and medium-sized factories, workshops, and huge garages located below the middle catchment. On the banks of the Little Akaki and Great Akaki rivers, several industries are found, including tanneries, slaughterhouses, oil refineries, and beverage manufacturers. A short distance from the river is where you may also find more industries. Horticultural crops are also irrigated in this catchment. Moreover, the irrigation system reaches the farming area of Akaki in the lower catchment (Ferezer Tegegn, 2012). The lower part of the catchment eventually joins the Aba-Samuel reservoir after passing through suburban areas of the city. Wastes from Kaliti's sewage treatment facility are released at a point source in this area of the watershed.

3.2. Study site selection

For this study, totally 6 sampling sites were selected on the basis of differing habitat conditions, land uses and human activities. The study sites include one reference site that is found above the Legedadi Dam and five impacted sites starting from Legedadi Dam outlet (Table 3.1). The reference site selected based on the criteria recommended by Aschalew Lakew and Moog (2015b).

Table 3.1: Description of sampling sites

Sampling site	Sampling site code	Description of sampling sites	Altitude (m a.s.l.)	Geographic coordinates
Above Legedadi Dam	S1	Riffles with boulders and stones, pools with some silt, stable bank, well protected riparian vegetation, no human disturbance.	2416	9°5'34.2"N, 38°55'44.76"E
Legedadi Dam outlet	S2	Few settlements, riffle mostly of boulders, pools with mainly silt and mud, watering of cattle, and cattle excreta present.	2337	9°2'33.8"N, 38°54'29.7"E
ICT park	S3	Riffle with bedrocks and run with stones and cobble, urban settlements, cattle grazing and cattle excreta present, quarrying, industrial parks about 5 km away from the site.	2170	8°56'17.1"N, 38°49'13.3"E
Bulbula	S4	Riffle with mainly cobbles and run with stones and gravel, high urban settlement.	2141	8°56'36.7"N, 38°46'27.3"E
Kebena	S5	Confluence of Bulbula and Kebena rivers, run stones and gravel, pool with sand and silt, gravel grinding machines present nearby.	2117	8°55'52.8"N, 38°46'48.4"E
Tirunesh Bejing Hospital	S6	Pool with high silt, cattle market, industries nearby, Tirunesh Bejing Hospital, sand mining from inside the river, <i>Eucalyptus</i> vegetation in the East, high urban irrigated agricultural activities, urban settlements.	2072	8°52'30.2"N, 38°47'4.1"E

3.3. Spatial land use land cover pattern

3.3.1. Sources and types of data

To meet the objectives of this research, different kinds of data were collected from both primary and secondary data sources. Primary data include: satellite imagery, Google earth. Satellite images were collected from United States Geological Survey (USGS) Earth Explorer (<https://earthexplorer.usgs.gov/>). Secondary data such as the findings of previous research works were used as supportive secondary data sources.

3.3.2. Data Acquisition

Satellite Image and GIS Data Collection

Time series land-sat images of 2008, 2016, and 2023 were used to analyze LULC change of the study area. All data were collected from USGS-EROS, which comprised of the, Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) (Table 3.2). All images used in this study had 30 m spatial resolution and below 10% cloud cover. To reduce the effect of cloud cover and its seasonal variation on the classification results, Landsat images of the same season were considered (December to February). All the images were projected to the Universal Transverse Mercator (UTM) zone 37 N and georeferenced to the data for which Ethiopia has been selected by the WGS (World Geodetic System) (zone 84) for consistency and compatibility.

Table 3.2: Summary of spatial data sets used in this study

Dataset type	Year	Resolution	Path/Row	Source
Landsat ETM+	2008	30m	168/ 054	USGS
Landsat OLI/TIRS	2016	30m	168/ 054	USGS
Landsat OLI/TIRS	2023	30m	168/ 054	USGS

3.3.3. Image pre-processing

Radiometric corrections and image enhancement were conducted on ERDAS IMAGINE 2015 software prior to the image classification. The aim of this process was to bring satellite images to the spectral standard and to enhance the quality of the image and readability of the features. Radiometric corrections such as haze reduction and scan line error correction were executed as well. The prime objective of radiometric correction was to manage the spectral differences originating from detector discrepancy and variations in radiation incidence angle. To increase the visual interpretability of an image and assist image analysis, enhancement of

classification and interpretation of image were conducted using histogram equalization. Moreover, spatial enhancement of convolution of Kernel 5 by 5 of high pass filtering has been done on the images of the respective years. Finally, after passing the aforementioned processes each image was clipped using the boundary of the watershed.

Table 3.3: Software used in the course of the study

Software	Application
ARCGIS 10.8	Image processing and map preparation
ERDAS EMAGINE 2015	Image processing
MS EXCEL	Chart, graphs

3.3.4. Land use and land cover classification

This study used a hybrid classification method involving both unsupervised and supervised image classification techniques. First unsupervised classification was carried out before field work to understand the general LULC classes of the study area and to select sample training sites for data collection during field work. This is because unsupervised classification is automatic and requires little knowledge of the study area. After the field work supervised classification was carried out with maximum likelihood algorithm to categorize the images using training sites. Training sites were defined by using original images, the results of unsupervised classification, field study knowledge and ancillary data (Google Earth). Image classification was performed using ERDAS IMAGINE 2015 software. For the LULC classification 180 ground control points (GCPs) (40 from agriculture, 40 from forest, 20 from water body, 40 from urban land, and 40 from bare land) were collected from the field using hand held global positioning system GPS and from high resolution Google Earth. Of the total GCPs collected during the field work and from Google Earth 40% GCPs from each LULC types were used as ground truth to assist image classification, while the remaining 60% were used for image classification accuracy assessment.

3.3.5. Accuracy assessment

Accuracy assessment is an important step in the image classification process. Land use/cover classification is not free from errors. Errors may appear from the method of image capturing to the classification technique implemented. So as to verify to what extent the produced classification is compatible with what actually exists on the ground, it is important to evaluate the accuracy of classification results. Accordingly, error matrix was produced for all images

in this study. An error matrix is a square array of rows and columns and presents the relationship between the classes in the classified and reference data. The reference data used for accuracy assessment were obtained from GPS points during field work and from high resolution Google Earth. The GPS points used in classification accuracy assessment were independent of the ground truths used in the classification.

3.3.6. Land use land cover change detection

After checking the classification accuracy, the next important task was land-use land-cover change detection. Using the classified image, the first change was for the year 2008 and 2016, the second was for the year 2016 and 2023 and the last was for year 2008 and 2023. In order to show the clear change between the two periods, the difference between two period images was calculated. Accordingly, the recent point of time minus the earlier point of time gives the change. This result indicates increasing (positive or gain) or decreasing (negative or loss) of each category of land-use/land-cover types.

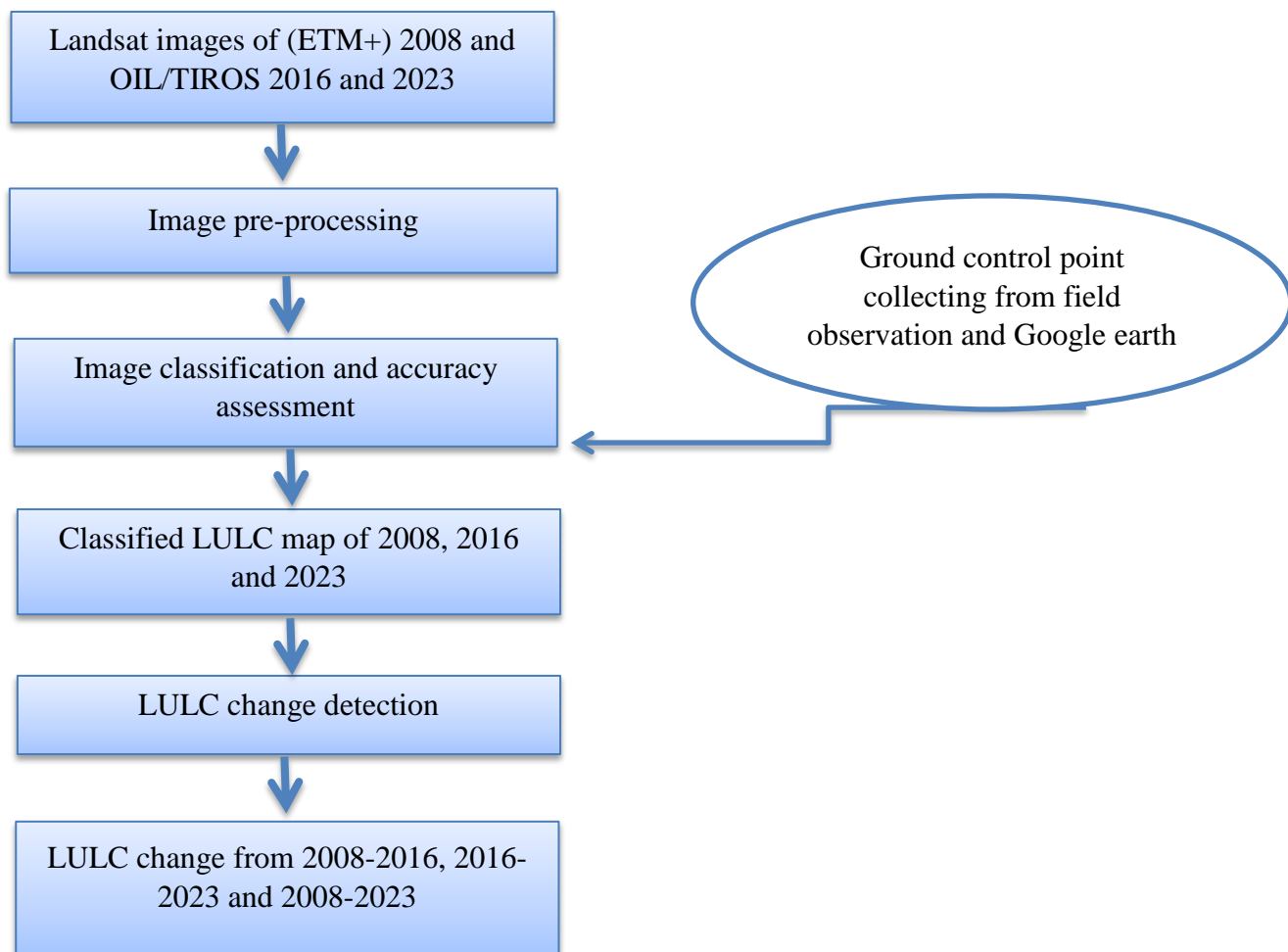


Figure 3.2: Flow chart that shows the general methodology of LULC change assessment

Source: Researcher (2024)

3.4. Methods of data collection

3.4.1. Physico-chemical parameters

Sample collection was carried out in June and November 2023. Physico-chemical parameters, which are deemed to be significant indicators of water pollution caused by anthropogenic activities, such as temperature, pH, DO, and conductivity were measured *in-situ* using a multi-probe meter (HQ40d HATCH), Turbidity was measured using a turbidometer (OAKTON T-100), while TDS was recorded using Pocket Pro TDS meter (MSIP-REM-HAH-140321539). Three replicate water samples from different sampling points with in a sampling site were collected from the water surface of the river in 1L polyethylene bottles and were taken to the Seyoum Mengistou Limnology laboratory, AAU for nutrient analysis.

Secondary data on water quality for the years 2008 and 2016 was collected from published and unpublished reports. Data started from the year of 2008 due to the limitation of historical water quality data of Great Akaki River.

Table 3.4: Mean of water quality parameters of Great Akaki River obtained from previous and present studies

Years	Temp (°C)	pH	EC ($\mu\text{S cm}^{-1}$)	TDS (mg L^{-1})	NH ₃ (mg L^{-1})	SRP(mg L^{-1})
2008	18.62	6.95	849.67	542.67	9.90	3.90
2016	20.86	6.35	545.25	308.98	3.27	4.50
2023	21.05	8.05	645.70	290.28	10.15	6.64

(Taffere Addis, 2008; Tesfamarkos Atsbha, 2016)

3.4.2. Benthic macroinvertebrates

Benthic macroinvertebrate samples were collected from four representative biotopes; pools, riffles, runs, marginal vegetation to obtain representative data using square frame hand net with frame width of 25*25 cm and mesh size of 500 μm . During sampling, multi habitat sampling scheme (MHS) was implemented to include micro-habitat types within sampling reach following Moog (2007) by disturbing the substrate. A single composite sample was collected from 20 kicks from all habitat types. Then the sample was poured into a container and preserved with 95% ethanol (Barbour, 1999), which was labelled accordingly with site name, sampling site code, and date of collection.

3.5. Habitat quality assessment

The habitat features were scored using a multi-habitat approach called Rapid Bioassessment Protocol (RBP) (Barbour, 1999). However, specific habitat parameters were added, which are

considered relevant in the Ethiopian river context, to provide more comprehensive evaluation. The parameters are manure/human waste presence, water appearance, bank grass cover, canopy cover. Therefore, rapid habitat scores were provided based on visual evaluation of 14 habitat parameters, with values ranging from 0 to 20 for each parameter, and habitat quality data was collected at each site using the RBP habitat assessment technique (Appendix 1). The river reach was evaluated as having good, fair, or poor management based on the final score of the habitat characteristics.

3.6. Laboratory analysis

3.6.1. Nutrients

Water samples were filtered via GF/F (Glass Fiber Filters papers) and the inorganic nutrients nitrate, nitrite, ammonia, and soluble reactive phosphate-phosphorus (SRP) were determined using UV/visible spectrophotometer following the standard methods described in APHA (2005).

Table 3.5: Methods of analysis for nutrients

Parameters	Analysis methods
SRP and TP	Ascorbic Acid method
NH ₃ -N	Phenate method
NO ₂ ⁻ -N	Colorimetric method
NO ₃ ⁻ -N	Sodium salicylate method
TSS	Gravimetric method

3.6.2. Benthic macroinvertebrates

Macroinvertebrate sample analysis was done in the Seyoum Mengistou Limnology laboratory at AAU. The collected samples were washed through a sieve, using tap water and sorted in a white plastic tray and then poured into vials. After sorting identification was made under dissecting microscope to mainly family level for all taxa with the help of identification keys (Gerber and Gabriel, 2002; Bouchard, 2004).

3.6.3. Water quality class

The classification of river water quality was conducted using two methods: SASS 5 and ETHbios. The SASS 5 score represents the “quality” scores assigned to each taxon irrespective of its abundance, while Average Score Per Taxon (ASPT) is obtained by dividing

SASS5 score by number of taxa present (Dickens and Graham, 2002). The quality scores range from 1 to 15 (least sensitive-most sensitive). These scores along with ASPT were used to categorize the river water quality into 5 classes, with water quality class 1 indicating “natural water quality, high habitat diversity”, while water quality class 5 indicates “major deterioration in water quality”.

ETHbios is a modified version of SASS, which was developed as a tool for rapid biomonitoring assessment of different human impacts on highland streams and rivers of Ethiopia by Aschalew Lakew and Moog (2015a). Based on threshold values, 5 river quality classes are defined, ranging from class 1 showing “high water quality with low level of degradation” to class 5 indicating “bad water quality with heavy degradation”.

3.7. Data analysis

3.7.1. Relationship between land use change and water quality

In the analysis of the relationship between land use types and water quality, the raw data of replicate samples of water taken from each site was first organized in MS Excel. Then the water quality data was subjected to normality test using Shapiro-Wilk test. The result indicated that the environmental parameters were not distributed normally. Therefore, the data was subjected to non-parametric Kruskal-Wallis test to determine the extent of the spatial variations and pair-wise post-hoc test was conducted using Mann-Whitney *U* test for the temporal comparison. IBM SPSS version 23 was used to perform Kruskal-Wallis and Mann-Whitney *U* test, and determination of means and standard deviations.

Pearson correlation analysis was used to explore the relationship between water quality and land use in Great Akaki River catchment using IBM SPSS version 23. Missing water quality data was filled using XLSTAT 2018 model in MS Excel. For the years 2008, 2016, 2023 pooled mean concentration of available water quality measure was examined from the closest years in the 8 years' interval. Only water quality parameters measured in all sites and available years were included and this has resulted in reduction of parameters.

3.7.2. Relationship of land use types and benthic macroinvertebrate community

The counts of individuals belonging to each macroinvertebrate family were recorded and then organized in MS Excel. Shapiro-Wilk test revealed that the macroinvertebrate data did not distributed normally. Therefore, both spatial and temporal variations were assessed using Kruskal-Wallis and Mann-Whitney *U* test, respectively. The macroinvertebrate metrics were calculated using MS Excel, while the diversity indices were determined using Past 4.03

software. The relative abundance of macroinvertebrates community at different sites was plotted using Sigma plot 15.0 software. Boxplots were used to display macroinvertebrate metrics and indices data distribution as well as outliers.

Site clustering was done using selected macroinvertebrate taxa by Euclidean index of similarity using Ward's method in PAST 4.03 software. The significance of variation and the taxa contributing to similarity or dissimilarity among clustered groups (land use types) was assessed using Analysis of Similarity (ANOSIM) with 999 permutations and Similarity Percentage (SIMPER) in PAST software. R value generated in ANOSIM ranges from -1 to +1, where values close to +1 indicates complete dissimilarity between groups, values close to 0 indicates no difference between groups and values close to -1 indicates complete similarity between groups. Therefore, ANOSIM was used to test the spatial difference in macroinvertebrates assemblage between land use types and SIMPER used to test which macroinvertebrate taxa contributed the most to the dissimilarity between land use types.

3.7.3. Relationship between water quality and benthic macroinvertebrates

To evaluate the relationship between macroinvertebrate community structure and water quality parameters, Detrended correspondence analysis (DCA) was performed using CANOCO 5 program. Before conducting the analysis, macroinvertebrates count data were Hellinger-transformed, while physico-chemical data were $\log(\text{Log}_{10}(x+1))$ -transformed. The gradient length in DCA was 2.1 standard deviation (SD) (< 3) suggesting that the species response follows a linear model. Redundancy analysis (RDA), a linear model, was, therefore, employed for the analysis. The benthic macroinvertebrates data relationship with variations in thirteen water quality parameters (temperature, pH, DO, EC, turbidity, TDS, TSS, alkalinity, NH_3 , NO_2 , NO_3 , SRP, TP) and habitat quality assessment data was performed. The RDA output was two dimensional tri-plot, in which physico-chemical parameters and macroinvertebrate families were plotted as arrows and sampling sites as points. The Monte Carlo test with 999 permutations was used in order to test the significance of the relationships between the environmental variables and macroinvertebrate taxa at $p < 0.05$.

4. RESULTS

4.1. Land use land cover map of the study area

Spatial LULC analysis was carried out to describe the pattern and changes over time. Five land cover classes were represented on maps for the years 2008, 2016, and 2023 (Fig 4.1, 4.2, and 4.3). The overall accuracy indicated a significant classification. 91.48%, 90.24% and 94.45% were achieved for the years 2008, 2016, 2023, respectively with high user and producer accuracy ranging from 66.67%-100%.

Table 4.1: Description of the land cover classes in this study

Class	Class description
Water body	Reservoirs and rivers
Vegetation	Trees, shrubs, grasses
Bare land	Clear /bare ground including bed rocks
Agricultural land	Terrestrial cultivated areas
Urban area	Built-up, roads, and settlement areas

4.1.1. LULC map of 2008

Fig 4.1 indicates that agricultural land covered about 61.37% while urban, bare land, vegetation and water body covered 16.40%, 12.71%, 8.55% and 0.97%, respectively. During this period most of the catchment area was dominated by agricultural lands followed by settlement in the western part of the catchment, and only a little forest cover remained in the northern and north-western part of the catchment.

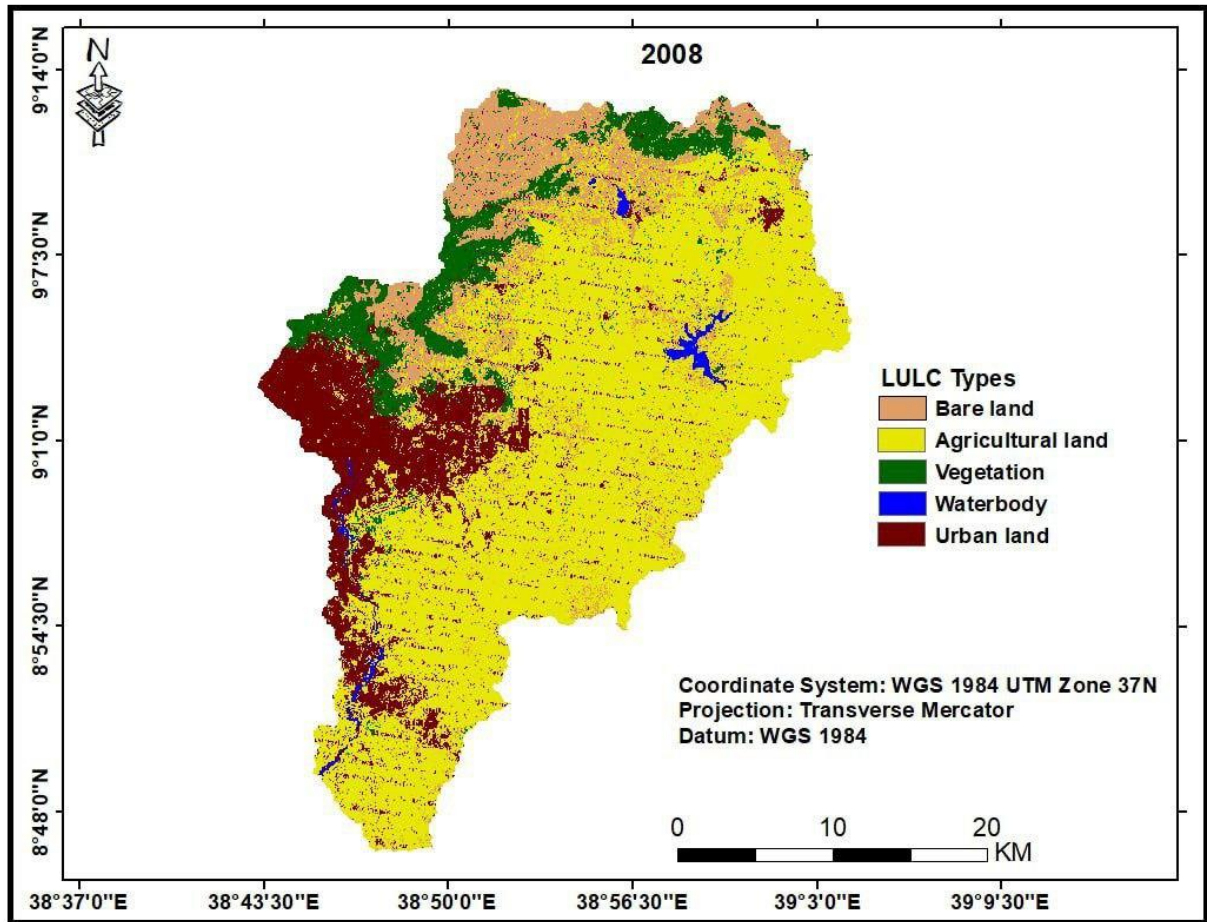


Figure 4.1: Land use land cover map of the year 2008

4.1.2. LULC map of 2016

The land use/land cover map of 2016 (Fig. 4.2) shows that the Great Akaki River's catchment was covered by 60.68% agricultural land, 23.19% urban land, 8.48% vegetation, 6.72% bare land, with the least percentage cover of water body ($\approx 0.93\%$). During this period, mainly the vegetated land in the northern part and the water body of the catchment were reduced. On the contrast, the urban land expanded in most parts of the catchment.

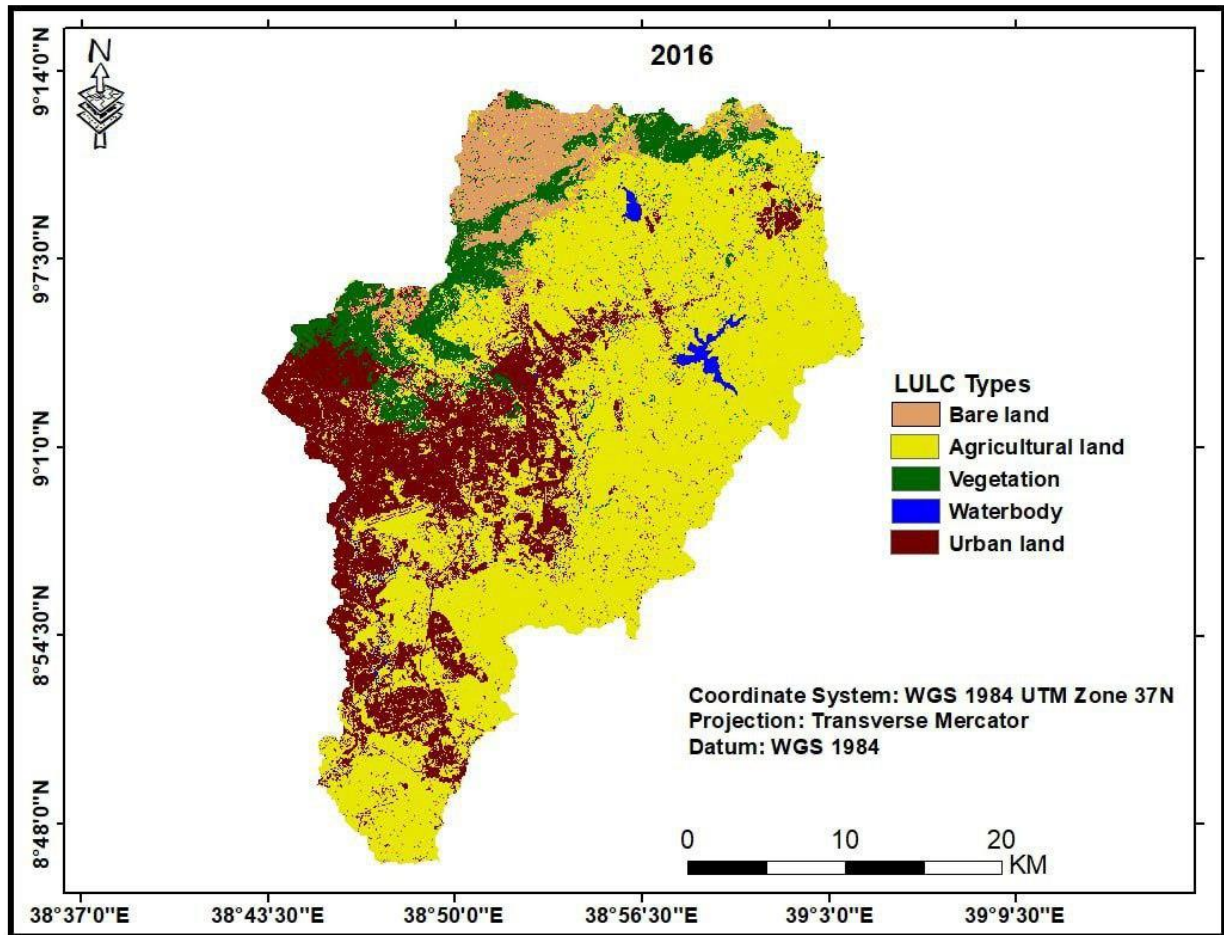


Figure 4.2: Land use land cover map of the year 2016

4.1.3. LULC map of 2023

Based on the 2023 LULC map, agricultural and urban land uses accounted for large percentage covers of the catchment, 41.78% and 41.31%, respectively. While, bare land, vegetation and water bodies accounted for 8.24%, 7.97%, and 0.69%, respectively (Fig 4.3). In this year, urban area expanded, while agricultural land shrank.

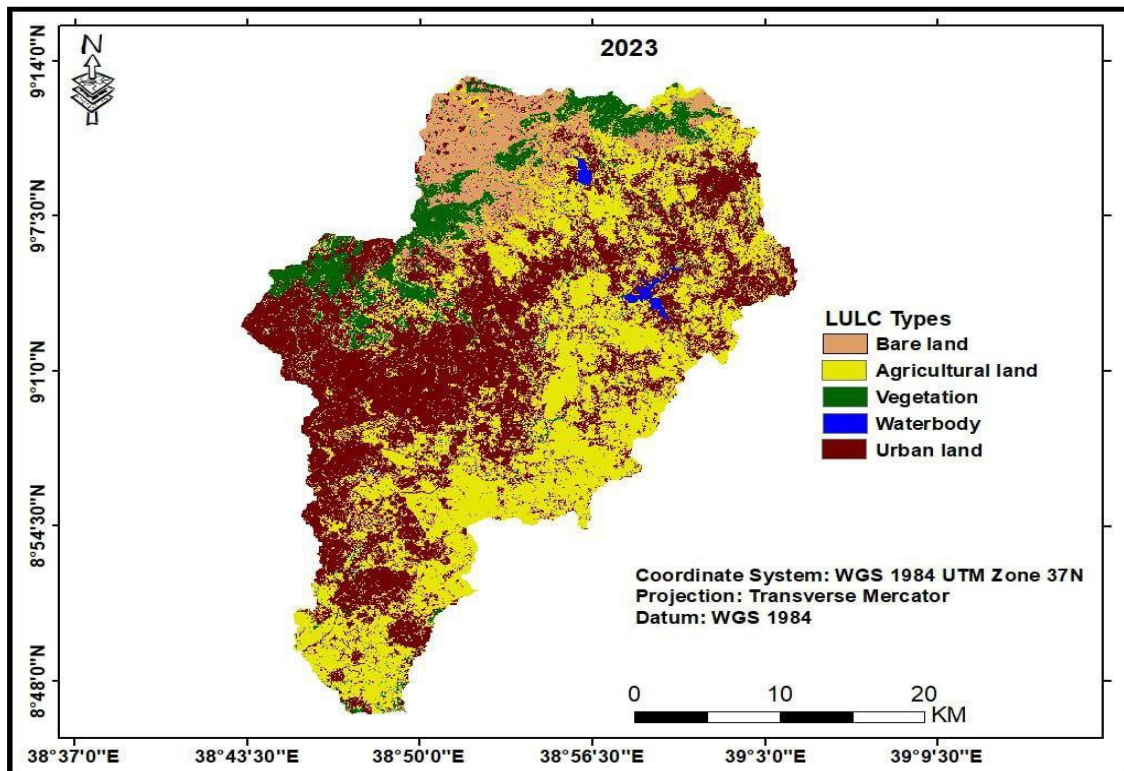


Figure 4.3: Land use land cover map of the year 2023

4.1.4. Land use change between 2008 and 2023

Change was calculated as percentage, by dividing the total land use area of a specific land use class by total land use area of the catchment and multiplying by 100, to give the proportion of total land use area for each land use class. The analysis of change detection of 2008-2023 showed that there was a significant change in urban area, which increased from 162.98 km² to 410.71 km², an increase of about 24.91%, meanwhile, other land use types water body - 0.58% (-5.78 km²), bare land -4.48% (-44.51 km²), vegetation -0.28% (-2.73 km²), and agriculture -19.59% (-194.71 km²) significantly decreased in the study period (Fig 4.4).

Table 4.2: Area coverage of each LULC types of the year 2008, 2016, and 2023

LULC Classes	2008		2016		2023	
	Area_km ²	Area%	Area_km ²	Area%	Area_km ²	Area%
Vegetation	85.0383	8.55	84.28	8.48	79.2585	7.97
Waterbody	9.624	0.97	9.26	0.93	6.8967	0.69
Bare land	126.375	12.71	66.84	6.72	81.8658	8.24
Urban land	162.977	16.40	230.55	23.19	410.707	41.31
Agricultural land	610.093	61.37	603.18	60.68	415.38	41.78
Total	994.108		994.108		994.108	

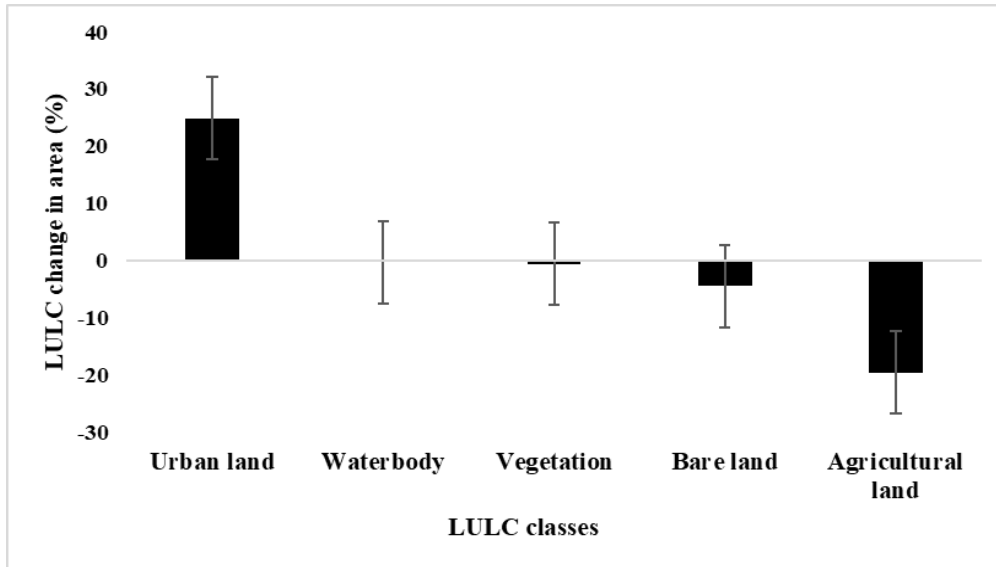


Figure 4.4: Land use land cover net changes that occurred from 2008 to 2023

4.2. Habitat quality assessment

Based on rapid bioassessment protocol (RBP), 14 habitat parameters were measured and values ranging from 0-20 for each site (Table 4.3). Most parameters had their maximum at S1, followed by S2. Minimum channel alteration and even mix of large-shallow, large-deep, small-shallow, small-deep pools were present in all sampling sites. In general, the highest habitat score (79.3) was found for S1, with the score declining sharply to those of downstream sites.

Table 4.3: Habitat quality assessment scores for each sampling site in the Great Akaki River

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
1. Epifaunal Substrate/ Available Cover	18	17	10	15	5	5
2. Pool Substrate Characterization	16	15	14	16	10	10
3. Pool Variability	17	16	16	18	18	16
4. Sediment Deposition	18	13	15	17	10	5
5. Channel Flow Status	15	15	15	15	14	17
6. Channel Alteration	18	18	18	16	10	14
7. Channel Sinuosity	10	15	15	10	6	10
8. Manure presence / human waste	17	11	15	3	15	11
9. Water appearance	14	6	2	3	5	5
10. Bank grass cover (graze)	18	3	18	2	3	5
11. Canopy cover Left/Right Bank	15	3	3	10	2	1
12. Bank Stability	18	14	18	10	3	2
13. Vegetative Protection	10	8	4	8	8	8
14. Riparian Vegetative Zone Width	18	8	16	10	10	8
Total score	222	162	179	153	119	117
Scores from 100%	79.3	57.9	63.9	54.6	42.5	41.8

4.3. Physico-chemical parameters

The mean values of physico-chemical parameters are presented in (Table 4.4). The mean values for water temperature, turbidity, TDS, and EC increased consistently from upstream to downstream, with statistically significant differences in all except turbidity between sampling sites. Mean water temperature ranged from 16.97 ± 1.34 at S1 to 21.48 ± 1.03 at S6. The mean values for turbidity varied between 59.86 ± 61.88 and 511.83 ± 292.82 NTU, with the lowest and highest levels occurring at S1 and S2, respectively, although turbidity did not differ significantly among sites. The mean values of total dissolved solids (TDS) ranged from 71.67 ± 7.53 mg L⁻¹ at S1 to 255.00 ± 84.56 mg L⁻¹ at S4. Likewise, Electrical conductivity (EC) ranged from 230.20 ± 14.08 μ S/cm at S1 to 860.17 ± 115.59 μ S/cm at S4.

Mean DO values generally decreased as the water flows from upstream to downstream, ranging from 7.63 ± 0.25 mg L⁻¹ at upstream site (S1) to 3.61 ± 0.84 mg L⁻¹ at a downstream site (S6). Mean pH values varied from 8.65 ± 0.32 at S3 to 9.30 ± 0.15 at S4. Both DO and pH values varied significantly among sites. The observed mean total suspended solids (TSS) concentrations varied from 665.37 ± 683.57 mg L⁻¹ at S1 to 995.57 ± 662.95 mg L⁻¹ at S5.

SRP and ammonia had their high concentrations at S6, 1.34 ± 0.37 mg L⁻¹ and 2.61 ± 0.34 mg L⁻¹, respectively, while their lowest values recorded at S1 were 0.16 ± 0.08 mg L⁻¹ and 0.09 ± 0.03 mg L⁻¹ in S1, respectively. The mean concentration of NO₃⁻ (nitrate) varied from 0.19 ± 0.03 to 0.29 ± 0.05 mg L⁻¹, with the highest and lowest values occurring at S2 and S1, respectively. The highest mean NO₂⁻ (nitrite) level (0.06 ± 0.04 mg L⁻¹) was recorded at S3, S4, S5, and S6, while the lowest (0.03 ± 0.00 mg L⁻¹) was observed at S1. The highest concentration of TP (2.27 ± 1.20 mg L⁻¹) was recorded at S3, while the lowest (0.27 ± 0.05 mg L⁻¹) was recorded at S1. Among the inorganic nutrients, SRP, NH₃, and TP varied significantly among sites.

Table 4.4: Mean \pm standard deviation of physico-chemical parameters recorded for the six sampling sites. and their spatial (based on Kruskal-Wallis test) and temporal (based on Mann–Whitney U test) variations

Parameters	Sampling site						<i>P</i> value (Spatial)	<i>P</i> value (Seasonal)
	S1	S2	S3	S4	S5	S6		
	Mean \pm SD							
T (°C)	16.97 \pm 1.34	20.57 \pm 0.90	20.22 \pm 3.13	20.07 \pm 0.60	19.53 \pm 1.36	21.48 \pm 1.03	0.012	0.091
pH	8.74 \pm 0.08	8.88 \pm 0.06	8.65 \pm 0.32	9.30 \pm 0.15	8.97 \pm 0.10	8.82 \pm 0.14	0.000	0.355
Turbidity (NTU)	59.86 \pm 56.47	511.83 \pm 266.16	458.10 \pm 398.9	106.62 \pm 35.7	476.00 \pm 341.33	458.87 \pm 400.1	0.089	0.000
DO (mg L ⁻¹)	7.63 \pm 0.25	6.94 \pm 0.10	4.63 \pm 2.84	5.16 \pm 1.42	6.09 \pm 1.19	3.61 \pm 0.84	0.001	0.008
TDS (mg L ⁻¹)	71.67 \pm 7.53	108.33 \pm 27.87	213.33 \pm 91.58	255.00 \pm 84.56	235.00 \pm 67.75	251.67 \pm 104.20	0.000	0.006
EC (μ S cm ⁻¹)	230.20 \pm 14.08	338.67 \pm 16.08	613.50 \pm 238.63	860.17 \pm 115.59	689.17 \pm 138.60	684.33 \pm 179.29	0.000	0.010
TP (mg L ⁻¹)	0.27 \pm 0.05	1.11 \pm 0.61	2.27 \pm 1.20	1.27 \pm 0.16	1.85 \pm 0.57	2.09 \pm 0.9	0.003	0.406
SRP (mg L ⁻¹)	0.16 \pm 0.08	0.25 \pm 0.06	0.83 \pm 0.37	0.92 \pm 0.24	1.23 \pm 0.37	1.34 \pm 0.37	0.000	0.791
NH ₃ (mg L ⁻¹)	0.09 \pm 0.03	0.27 \pm 0.10	2.42 \pm 0.27	2.45 \pm 0.28	2.42 \pm 0.13	2.61 \pm 0.34	0.000	0.226
NO ₂ (mg L ⁻¹)	0.03 \pm 0.00	0.05 \pm 0.00	0.06 \pm 0.02	0.06 \pm 0.04	0.06 \pm 0.04	0.06 \pm 0.04	0.119	0.000
NO ₃ (mg L ⁻¹)	0.19 \pm 0.03	0.29 \pm 0.05	0.26 \pm 0.05	0.23 \pm 0.05	0.27 \pm 0.06	0.25 \pm 0.07	0.063	0.022
TSS (mg L ⁻¹)	665.37 \pm 154.00	725.23 \pm 176.36	807.9 \pm 97.98	943.60 \pm 170.65	995.57 \pm 118.31	778.97 \pm 165.42	0.259	0.000

4.4. Macroinvertebrates community composition

During this study a total of 11,847 macroinvertebrate individuals belonging to 11 orders and 37 families were identified and counted (Table 4.5). In the wet and dry seasons, respectively, the total number of individuals ranged from 155 at S3 to 2347 at S2, and from 251 at S4 to 1479 at S1. Overall, the benthic macroinvertebrate communities of the river were dominated numerically by Oligochaeta (33.29%), although the relative dominance differed among particular sites (S1=0.46% to S6=80.61%). The second dominant taxon was Caenidae (27.44%), although at the two upstream sites, S1 and S2, its percentage contributions were 62.47% and 54.22%, respectively, with its contributions at the four downstream sites varying between 0% and 0.65%. Chironomidae was the third in overall dominance (17.24%). Three families, Chironomidae, Culicidae, and Psychodidae, were recorded at all sampling sites.

Table 4.5: Abundance of taxa identified from the six sampling sites of Great Akaki River

Order/ Phylum	Family/ Class	Site1	Site 2	Site 3	Site 4	Site 5	Site 6
Ephemeroptera	Betidae	408	416	0	3	10	1
	Caenidae	1365	1874	6	0	4	2
	Heptageniidae	57	30	0	0	0	0
Trichoptera	Hydropsychidae	96	175	0	0	0	0
	Leptoceridae	4	0	0	0	0	0
Coleoptera	Dytiscidae	10	37	0	0	1	0
	Elmidae	7	6	0	1	0	0
	Hydrophilidae	6	99	0	0	0	0
	Gyrinidae	0	1	0	0	0	0
Hemiptera	Belostomatidae	1	6	0	0	0	0
	Corixidae	30	13	0	0	0	0
	Nepidae	0	1	0	1	0	0
	Notonectidae	0	9	0	2	0	0
	Veliidae	1	9	0	0	0	0
	Naucoridae	0	1	0	0	0	0
Odonata	Aeshnidae	2	3	0	0	0	0
	Coenagrionidae	15	105	0	0	0	0
	Libellulidae	0	1	0	0	0	0
Diptera	Athericidae	0	0	0	1	0	0
	Ceratopogonidae	0	8	2	0	0	0
	Chironomidae	117	271	589	152	324	589
	Culicidae	6	7	100	82	24	60
	Ephydriidae	0	1	0	5	3	0
	Muscidae	2	0	2	10	0	0
	Psychodidae	2	6	5	387	60	13

	Simulidae	4	6	3	0	0	1
	Tabanidae	0	65	1	0	1	0
	Syrphidae	0	0	0	5	0	2
	Tipulidae	0	1	0	0	0	0
Lepidoptera	Pyrilidae	0	0	0	0	0	1
Platyhelminthes	Turbellaria	9	11	0	0	0	0
Annelida	Hirudinae	11	13	0	0	0	1
	Oligochaeta	10	188	219	68	670	2789
Mollusca/ Gastropoda	Physidae	2	78	3	0	1	0
	Planorbidae	5	1	0	0	0	0
Mollusca/ Pelecypoda	Sphaeriidae	14	14	0	0	0	0
	Unionidae	1	0	0	0	0	1
Total		2185	3456	930	717	1098	3460

The main taxonomic groups were Diptera (11 families, 2,917 individuals= 24.62%), followed by the Ephemeroptera (3 families, 4176 individuals= 35.25%), and Annelida (2 families, and 3969 individuals= 33.5%). Spatially, the highest relative abundance of Diptera (89.54%) was found at S4 and the lowest (6%) at S1, followed by Ephemeroptera, with the highest (83.75%) at S1 and lowest (0.09%) at S6. Temporally, the highest relative abundance in the wet season was that of Annelida (40.33%), followed by that of Diptera (28.11%). While in the dry season the highest relative abundance was that of Diptera (57.79%), followed by that of Ephemeroptera (20.62%) (Fig 4.5).

The taxonomic richness varied from 5 at S6 to 22 at S2, and from 6 at S5 to 26 at S2, during the wet and dry seasons, respectively. The sensitive taxa Ephemeroptera (Baetidae, Caenidae, and Heptageniidae) and Trichoptera (Hydropsychidae) were abundantly found at the reference site (S1). However, the macroinvertebrate Orders Trichoptera and Odonata were not encountered at the degraded sites (S3, S4, S5, and S6). The proportion of macroinvertebrate families of the order Diptera and classes of phylum Annelida were notably high at the stressed sites.

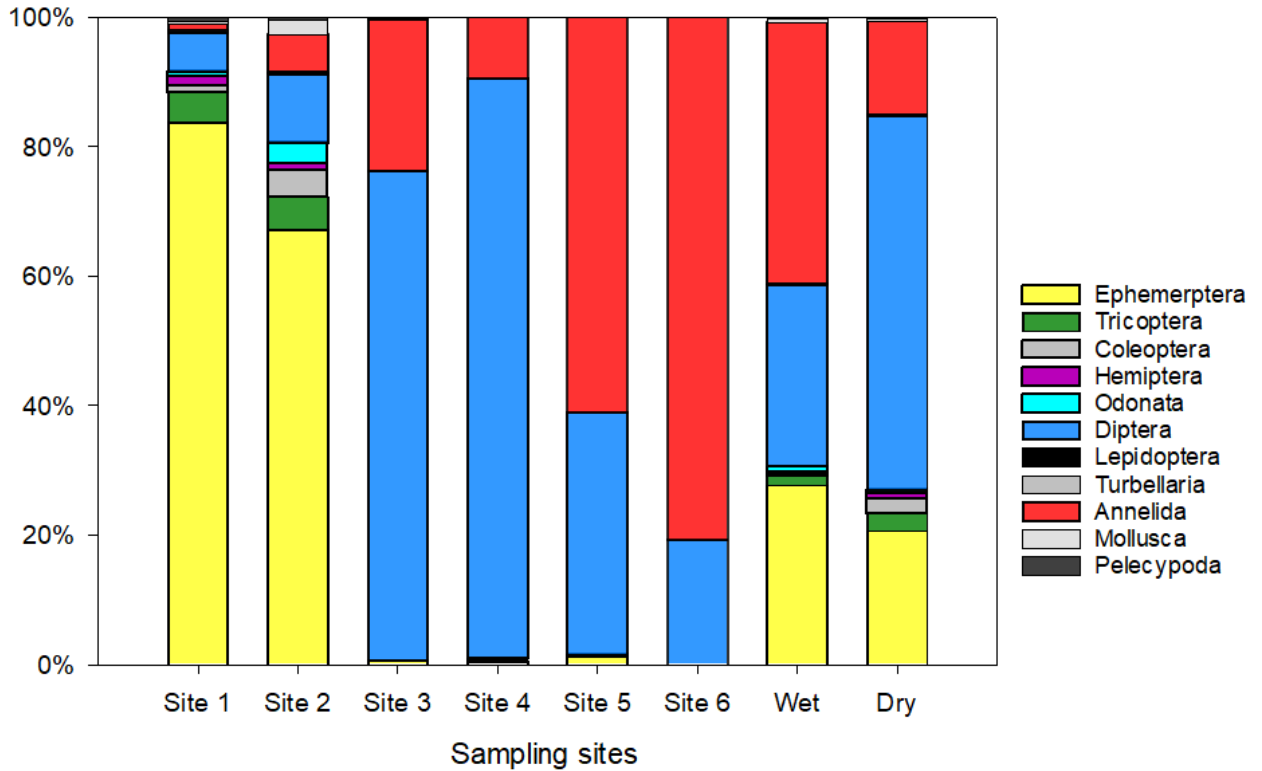


Figure 4.5: The relative abundance of macroinvertebrate taxonomic groups at each sampling sites

4.5. Macroinvertebrate community indices and metrics

Shannon-Wiener diversity index values were higher for the upstream sites. The highest diversity index value was recorded for S2 (1.76), which was followed by that for the reference site, S1, (1.34), while the lowest was found for S6 (0.59). The sensitive macroinvertebrate metrics such as %ET and %EOT were incomparably lower for the impacted sites S3 to S6 than those recorded for S2 and the reference site. The recorded values of %ET ranged from 0.09 to 88.49%, with the noticeably high values being associated with S1 and S2 (88.49% and 72.21%, respectively). Similarly, recorded values of %EOT ranged from 0.09 to 89.27%, with the first and second highest values characterizing S1 and S2

(89.27% and 75.37%, respectively).

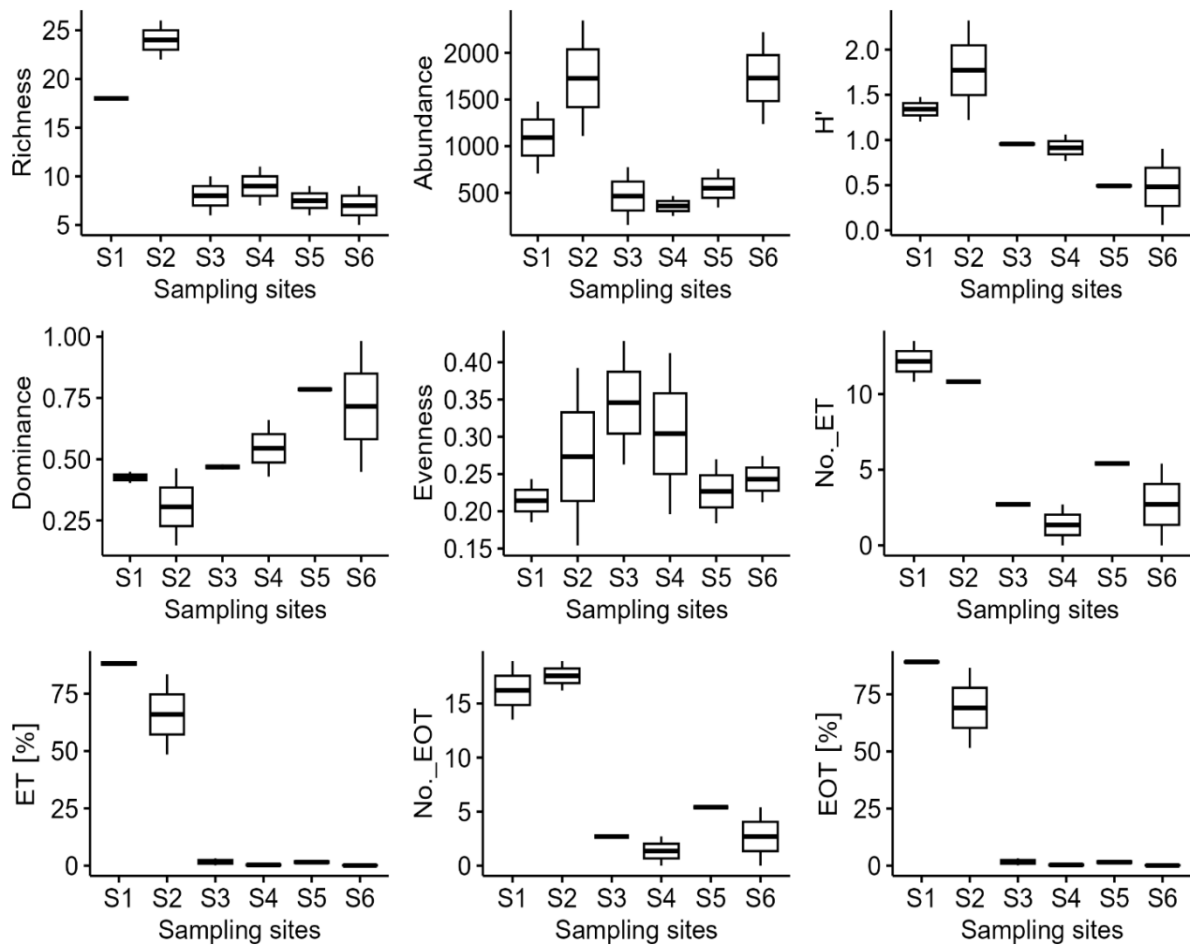


Figure 4.6a: Box plots of selected macroinvertebrate metrics and indices

Macroinvertebrate metrics, particularly the percentages of Diptera, Chironomidae, and Oligochaeta were considerably higher at the impacted sites in comparison to the reference site: %Diptera ranged from 6.01 to 89.54%, %Chironomidae from 5.36 to 63.33%, and %Oligochaeta from 0.46 to 80.6%, with the lowest values of all occurring at the reference site, while the highest percentage contribution of Diptera was found at S4, %Chironomidae at S3, and %Oligochaeta at S6.

In comparison to the impaired sites, the least impacted sites were associated with high SASS5 (67.5-98) and ETHbios scores (83.5-109.5). However, the lowest score of SASS5 was recorded for S3 (23), while the lowest score of ETHbios was observed for S6 (15.5). Similarly, the values of ASPT of SASS5 and ETHbios were also lower at the downstream sites. The highest SASS5 and ETHbios ASPT values recorded at the least-impacted sites, (S1 and S2), ranged from 4.64 to 4.48 and from 4.21 to 4.23, respectively.

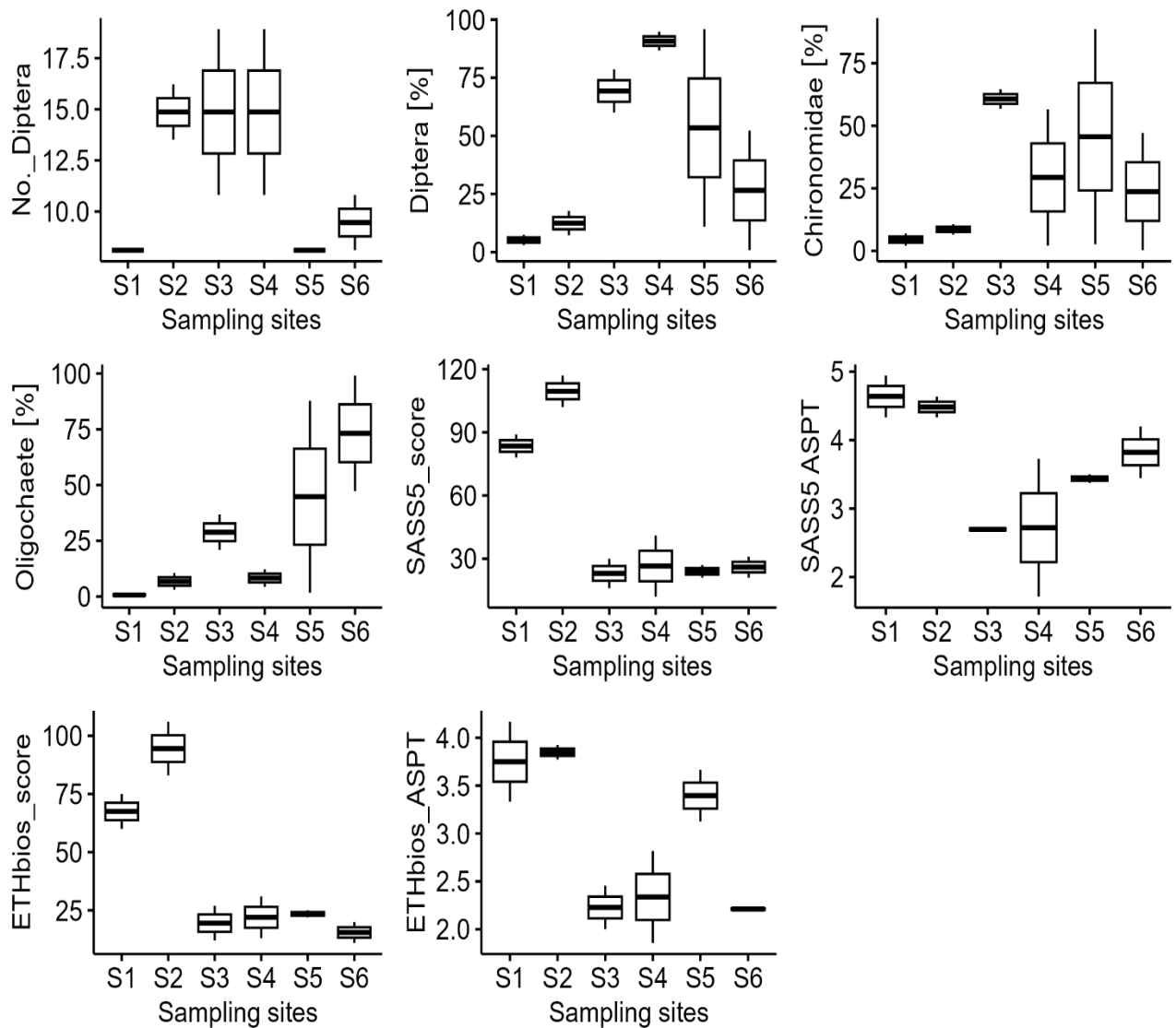


Figure 4.7b: Box plots of selected macroinvertebrate metrics and indices

4.6. Impacts of Land use land cover change on water quality

As the results of this study (Table 4.5), show, urban area is strongly and positively correlated with temperature (0.760), pH (0.810), SRP (0.998), and TDS (0.756). implicating that these water quality parameters become high as the urban area expands. SRP, TDS, and ammonia (NH₃) of the water increased as agricultural land increased, with a positive correlation of 0.984, 0.582, and 0.501, respectively. In addition, it was found that vegetation cover was strongly but negatively correlated with SRP (-0.997), pH (-0.881), TDS (-0.661), and temperature (-0.666).

Table 4.6: Pearson correlation for water quality parameters change and LULCC

Water quality parameters	Water body	Vegetation	Bare land	Agriculture	Urban
Temperature(°C)	-0.666	-0.650	-0.949	-0.587	0.760
pH	-0.881	-0.891	0.083	-0.925	0.810
EC(µS/cm)	-0.321	0.300	0.997	0.223	0.445
TDS(mg/l)	-0.661	0.645	0.951	0.582	0.756
NH3(mg/l)	-0.411	-0.431	-0.673	0.501	0.285
SRP(mg/l)	-0.997*	-0.995	-0.467	0.984	0.998*

* Correlation is significant at the 0.05 level.

4.7. Relationship between land use types and benthic macroinvertebrate community

The results of the study indicate that there are discernible differences in the distribution of macroinvertebrate taxa across different land use types within the study area. Macroinvertebrate taxa distribution from the six sampling sites was clustered in to three major land use types to detect how macroinvertebrate varied along the gradient of increasing anthropogenic impact. The choice of clustering based on land use types allowed for a clearer understanding of how human activities and associated land use practices influence macroinvertebrate taxa distribution. Specifically, Site 1, characterized by vegetation cover, was considered the least impacted area, while Sites 2 and 3 represented agricultural land and Sites 4, 5, and 6 represented urbanized areas, reflecting increasing levels of anthropogenic disturbance.

The family richness varied across the three land use types. In forested and agricultural areas, there was evidence of the presence of sensitive orders such as Ephemeroptera and Trichoptera. However, Trichoptera declined in agricultural areas compared to forest area. Conversely, urban-dominated areas were primarily represented by Ephemeroptera, particularly families such as Baetidae and Caenidae. Additionally, the order Diptera was observed across all land use types, but it was more abundant in agricultural-dominated areas, with a total of eight families (Fig 4.9).

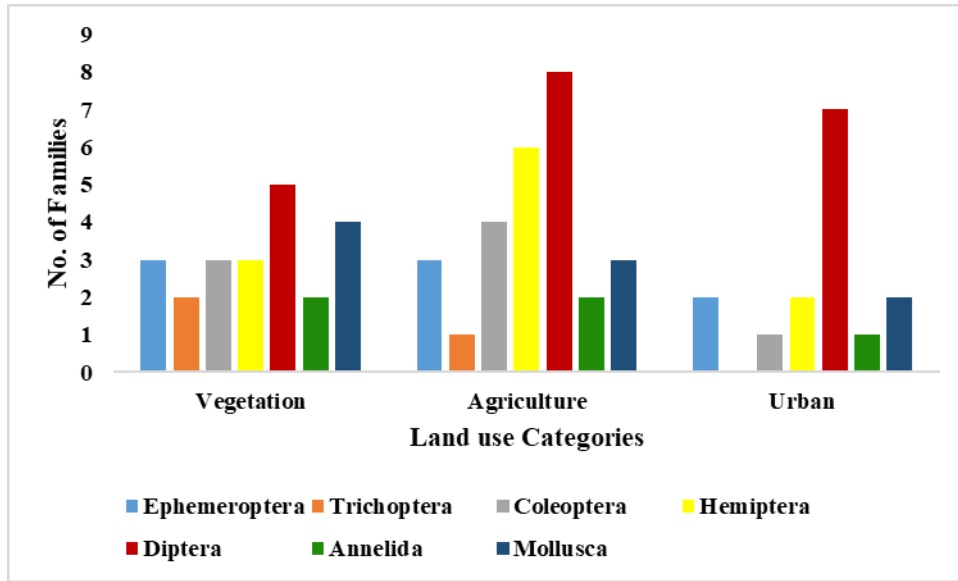


Figure 4.8: Macroinvertebrate family richness among the land use types

The ANOSIM test results showed that the distribution of macroinvertebrate taxa among the three clustered land use types exhibited a significant spatial difference (ANOSIM $R = 0.312$, $p = 0.034$). Moreover, the p -value of 0.034, being less than the conventional significance threshold of 0.05, indicates similarity between groups is less than similarity within a group or the observed dissimilarity is statistically significant.

Table 4.7: ANOSIM pairwise test results for land use land cover types

	Vegetation	Agriculture	Urban
Vegetation	1.000	0.263	0.037
Agriculture	0.263	1.000	0.187
Urban	0.037	0.187	1.000

Pairwise comparison test revealed a statistically significant difference in macroinvertebrate assemblage between vegetation and urban areas ($p = 0.037$), indicating that these two land use types harbor distinct macroinvertebrate communities. However, no significant differences were found between urban and agriculture ($p = 0.19$) or between vegetation and agriculture ($p = 0.26$). The result from SIMPER analysis showed the overall average dissimilarity between vegetation and agriculture, vegetation and urban, agriculture and urban were 67.24, 92.38, and 69.51, respectively. Additionally, the SIMPER analysis identified key taxa contributing to the observed dissimilarities. For instance, Ephemeroptera contributed the highest variability between vegetation-agriculture (63.49%) and vegetation-urban (53.17%), suggesting that these particular taxa are sensitive to differences in habitat conditions in these

land use types. Conversely, Annelida taxa contributed substantially to the dissimilarity between agriculture and urban (35.56%), followed by that of Ephemeroptera (30.23%).

Table 4.8: Macroinvertebrate taxa contributing to the similarity/dissimilarity among land use types

Taxa	Vegetation-Agriculture		Vegetation-Urban		Agriculture-Urban	
	Contrib.	Cumulative	Contrib.	Cumulative	Contrib. %	Cumulative
	%	%	%	%	%	%
Ephemeroptera	63.49	63.49	53.17	53.17	30.23	30.23
Diptera	16.84	80.33	16.17	69.34	24.18	54.41
Annelida	7.231	87.57	24.16	93.5	35.56	89.97
Trichoptera	4.765	92.33	3.316	96.82	3.268	93.23
Coleoptera	2.855	95.19	0.5931	97.41	2.841	96.08
Odonata	1.665	96.85	0.5984	98.00	1.546	97.62
Mollusca	1.079	97.93	0.2371	98.24	1.187	98.81
Hemiptera	0.9787	98.91	0.8807	99.12	0.6796	99.49
Pelecypoda	0.6811	99.59	0.5713	99.69	0.2851	99.77
Turbellaria	0.4108	100	0.2965	99.99	0.219	99.99
Lepidoptera	0	100	0.0055	100	0.007631	100

4.8. The relationship between water quality and benthic macroinvertebrates

The relationships between the physico-chemical parameters and macroinvertebrates communities, based on redundancy analysis (RDA), are shown in (Fig 4.10). The variations in the macroinvertebrates data explained by the first and second canonical axes, were 68.39% and 21.35%, respectively. The CANOCO 5 program's forward selection technique identified ammonia, pH, SRP, turbidity, and EC as environmental variables that influenced macroinvertebrate variation, with contributions of (68.3%), (15.2%), (12.5%), (3.2%), and (0.9%), respectively. The Monte Carlo permutation test revealed significant correlation ($p < 0.05$) between ammonia and SRP and macroinvertebrate community variation.

In the first axis, DO and habitat assessment (HA) were positively correlated with Baetidae, Planorbidae, Heptagenidae, Corixidae, Turbellaria, Coenagrionidae, Vellidae, Sphaeridae, Caenidae, Hydropsychidae, Aeshnidae, Hydrophilidae at S1 and S2. Similarly, pH was positively correlated with Muscidae, Nepidae, Psychodidae, Syrphidae, and Ephydriidae at

S4. In contrast, Ceratopogonidae, Unionidae, Simulidae, Tabanidae, Physidae, Dytiscidae, and Hirudinae had negative correlation with nitrate, total phosphorus (TP), turbidity, and soluble reactive phosphate-phosphorus (SRP). On the other hand, Chironomidae was strongly and positively correlated with SRP and TDS, while Oligochaeta was positively correlated with TP, nitrate and turbidity. The second axis is strongly associated with the downstream site (S4) and significantly correlated with pH, alkalinity, water temperature, EC, ammonia, NO₂, and TSS.

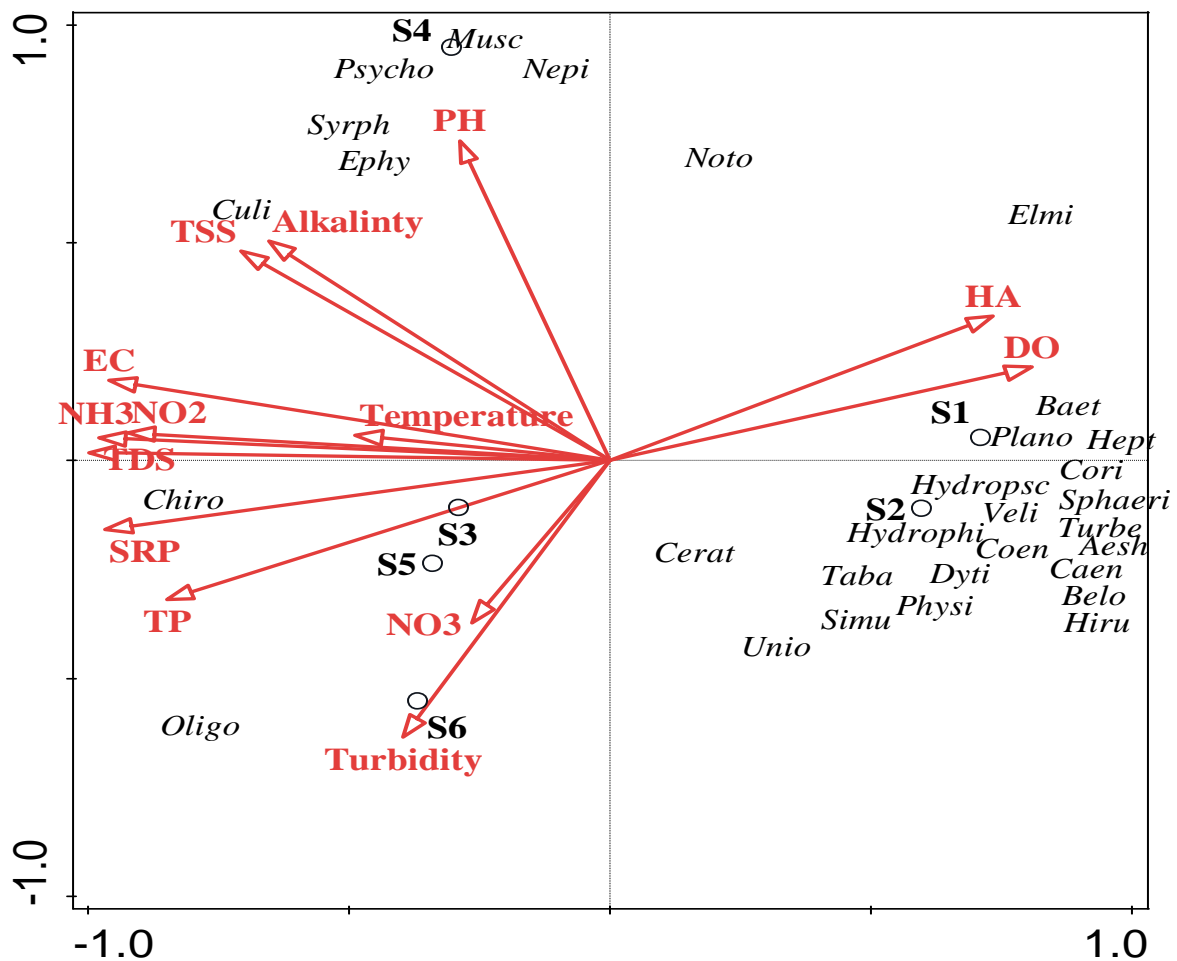


Figure 4.9: Redundancy analysis (RDA) tri-plot of the macroinvertebrate community in relation to the physico-chemical parameters at all sampling sites

(Baet-Baetidae, Hydrophi- Hydrophilidae, Plano- Planorbidae, Elmi- Elmidae, Turbe-Turbilaria, Chiro-Chironomidae, Oligo-Oligochaeta, Cori-Corixidae, Hept-Heptagnidae, Sphaeri- Sphaeridae, Simu-Simulidae, Caen- Caenidae , Tabo-Tabanidae, Syrph-Syrphidae, Culi-Culicidae; Musc-Muscidae, Psycho-Psychodidae, Nepi-Nepidae, Ephy-Ephydridae, Noto-Notonectidae, Hydrops- Hydropsychidae, Veli-Vellidae, Cerat-Ceratopogonidae, Unio-Unionidae, Physi-Physidae, Dyti-Dyticidae, Coen-Coenagrionidae, Aesh-Aeshnidae, Belo-Belostomatidae, Hiru-Hirudinae)

5. DISCUSSION

5.1. Land use Land cover change distribution

The results of the present study revealed a decline in vegetation, water body, agriculture and bare land, and significant expansion of urban land in the catchment as it covers a major portion of the Akaki River catchment, which is a highly populated area. Therefore, the main cause for the large reduction in areas of vegetation, bare land, and agriculture is conversion to urban area, which resulted from population growth and improved economic development. There was a similar evidence for Addis Ababa city watershed documented by Gule *et al.* (2023) that showed the increase in built up area from 72.6 km² to 318.5 km² between 1991 and 2021, while the size of other land use types was reduced. Similarly, in the Upper Awash Basin, an increasing trend in urban land by 606.2% was reported (Alemayehu Shawul and Sumedha Chakma, 2019). This expansion of urban land use has profound detrimental effect on hydrology, water quality, biodiversity and overall aquatic ecosystem health (Aduah *et al.*, 2015; Su *et al.*, 2015; Namugize *et al.*, 2018) as it includes the residential areas, industrial zones, different infrastructures, and formation of impervious surfaces.

5.2. Physico-chemical parameters

The presented findings on the physico-chemical parameters of the Great Akaki River provide valuable insights into the water quality dynamics across different sampling sites. Water temperature exhibited a clear downstream trend, ranging from 16.97±1.34 °C to 21.48±1.03 °C. This is in line with the results of the study made in Awash River by Temesgen Eliku and Seyoum Leta (2018), even though the mean water temperature value reported for Awash River was higher than that found in the present study. The lowest temperature was observed at S1, the upstream site, which may be attributed to the shading effect of riparian vegetation, shallow depth, higher altitude, and limited human disturbance, while the highest was recorded at S6. This pattern could be attributed to various factors, including urban settlement, agricultural runoff, or industrial discharges, influencing the thermal dynamics of the river. According to WHO (2008) and USEPA (1994), temperatures of river water generally range from 5 to 30°C and should be <32°C for the protection of the aquatic species, respectively. Therefore, the temperatures of the Great Akaki River were within the limits regarded suitable for aquatic species.

pH values showed variations, ranging from 8.65 ± 0.32 to 9.30 ± 0.15 , with the highest at S4 and lowest at S3. The observed pH values in those specific sites could be influenced by various anthropogenic activities such as discharge of industrial wastes as well as natural processes including decomposition of organic material, and weathering of rocks. The average pH value (8.89) of the present study is higher than those reported for the Great Akaki River (Solomon Akalu *et al.*, 2011), for Upper Awash River (Fasil Degefu *et al.*, 2013), and for Guder River, (Bizualem Wakuma, 2017). However, this value of pH is outside the permissible limits set by both the Canadian Council of Ministers of the Environment (CCME, 2008) for livestock watering and irrigation water (6.5-8) and World Health Organization's (WHO, 2008) for both drinking and irrigation water (6.5–8.5). This unusually high pH level might create hazardous circumstances for aquatic life thereby affecting their growth and may even have lethal effects on organisms threatening survival of some species and altering community structure. Therefore, the Great Akaki River may not be suitable for some species as regards pH.

The levels of DO ranged from $7.63 \pm 0.25 \text{ mg L}^{-1}$ at S1 to $3.61 \pm 0.84 \text{ mg L}^{-1}$ at S6. Similar results were also reported by Gichana *et al.* (2015) and Temesgen Eliku and Seyoum Leta (2018) who recorded high DO values in the headstreams of Nyangores River and Awash River, respectively. In order to support aquatic life, the concentration of DO should be greater than 5 mg L^{-1} (CCME, 2008). The values recorded at S1, S2, S4, and S5 are consistent with the limit set by CCME (2008) for aquatic life. However, DO concentration at S3 and S6 were found to be less than 5 mg L^{-1} , which was considerably below the standard limit. The possible reason for DO to be high in the reference site might be due to algal photosynthesis, cooler water temperature as DO level is temperature dependant, minimum organic pollution (Masresha Birara, 2021). Specifically, ammonia concentration which had a negative relation with DO, showed an increasing trend while DO decreased downstream (S3 and S6) in this study. This could be due to the oxygen in the river being consumed by the organic wastes, causing an increase in ammonia level in the water. On the other hand, DO concentration at S5 was within the standard limits. This seems to be associated with the turbulent flow after the confluence of Bulbula and Kebena rivers, where S5 was located, which may have resulted in high DO concentration by aeration.

Electrical Conductivity (EC) showed an increasing trend towards downstream, which seems to follow the human disturbance gradient. EC ranged from $230.20 \pm 14.08 \text{ } \mu\text{S cm}^{-1}$ to $860.17 \pm 115.59 \text{ } \mu\text{S cm}^{-1}$, with the highest value observed at S4. This may have resulted from

the high salt content of domestic and industrial wastewaters discharged into this site. During sampling, we have witnessed high level of discharge of domestic waste directly into this specific site of the river and there were a lot of settlements near the river bank. However, none of the EC values of the sampling sites exceeded the WHO standard limit ($1000 \mu\text{S cm}^{-1}$).

Turbidity exhibited variability across sampling sites (59.86 ± 61.88 to 511.83 ± 292.82 NTU), with the lowest values occurring at S1 (least impacted area) and the highest at S2 (outlet of Legedadi dam). The high turbidity at S2 could be attributed to the turbulence caused by the release of water from the dam, which can re-suspend sediment particles, leading to increased turbidity. The low turbidity at S1 might be due to the limited sediment input in this part of the watershed which is associated with the well vegetated riparian zones, relatively stable riverbanks, and low human disturbance. The average turbidity value (345.21 NTU) recorded in the present study is substantially higher than the average value of turbidity (63.3 NTU) reported for Tyume River, South Africa (Sibanda *et al.*, 2014), and (86.57 NTU) for Awash River, Ethiopia (Temesgen Eliku and Seyoum Leta, 2018).

Total Suspended Solids (TSS) concentrations varied across sites, with the highest mean value recorded for S5 and the lowest for S1. This suggests localized sources of sediment input or resuspension, influencing TSS levels. Similarly, the highest concentrations of total dissolved solid (TDS) was found in S4 ($255.00 \pm 84.56 \text{ mg L}^{-1}$) and lowest in S1 ($71.67 \pm 7.53 \text{ mg L}^{-1}$) the upstream of the river. Higher values of TDS can be mainly due to household sewage discharge and other human activities like irrigation practices, and constructions. While, the minimum values could be due to the riparian vegetation acting as a natural filter, minimal urban development and industrial activities, low-intensity agriculture, low mineral content of the watershed. However, the boundary values of the range of mean TDS levels of the present study are lower than those of GudBahri River (326 to 770 mg L^{-1} ; Mehari Muuz (2013)), while they are still higher than those of Tyume River (26.4 ± 3.2 to $182.25 \pm 11.9 \text{ mg L}^{-1}$; Sibanda *et al.* (2014)). According to DWAF (1996), TDS of river water intended for domestic uses should lie at 0 – 450 mg L^{-1} . Therefore, TDS values of this study fell within the range of guidelines values.

Ammonia (NH_3 , $\text{NH}_4^+\text{-N}$) concentrations varied between a minimum of $0.09 \pm 0.03 \text{ mgL}^{-1}$ at S1 and a maximum of $2.61 \pm 0.34 \text{ mgL}^{-1}$ at S6. The high value recorded at the downstream site of the river might be due to agricultural runoff, sewage discharge (domestic activities) and the biological degradation of manure. Except those of the two upstream sites, S1 and S2,

concentrations of ammonia do not comply with the guideline values recommended by DWAF (1996) for domestic use ($0\text{-}1\text{mg L}^{-1}$). However, the concentration of ammonia of the present study is lower than those previously reported for the same river, Great Akaki River, (0.14 ± 0.08 to $21.35\pm 2.97\text{ mg L}^{-1}$; Solomon Akalu *et al.* (2011)).

The nitrate (NO_3) concentrations ranged from 0.19 ± 0.03 to $0.29\pm 0.05\text{ mg L}^{-1}$, with the highest and lowest concentrations corresponding to S2 and S1, respectively. The highest concentration might have been due to agricultural runoff, animal wastes, sewage from the watershed. The present nitrate levels are within the acceptable limits (50 mg L^{-1} ; WHO (2008)). Nitrite (NO_2) concentrations ranged from 0.03 ± 0.00 in S1 to $0.06 \pm 0.04\text{ mg L}^{-1}$ in S3, S4, S5, and S6. The source for nitrite in the study area could be fertilizers, wastes from animal and human sewage with associated untreated municipal wastes. Over all NO_3 and NO_2 concentrations observed in this study were low compared to those reported by other studies conducted on Awash River 0.24 ± 0.04 to 0.9 ± 0.31 and 0.022 ± 0.00 to 0.024 ± 0.00 , respectively (Tesfaye Muluye *et al.*, 2023), and Tyume River 0.25 ± 0.1 to 3.91 ± 0.3 and 0.02 ± 0.0 to 2.35 ± 0.1 , respectively (Sibanda *et al.*, 2014).

The concentration of soluble reactive phosphorus (SRP) showed a clear increasing trend downstream, ranging from 0.16 ± 0.08 to $1.34\pm 0.37\text{ mg L}^{-1}$. This might be due to discharges from industrial facilities, runoff from agricultural fields, decomposition of organic matter. However, concentrations of SRP recorded in this study are lower than those reported in previously conducted studies (Solomon Akalu *et al.*, 2011; Sisay Derso *et al.*, 2017). A similar increasing trend was observed in TP concentration except that its concentration at S3 exceeded those of other sites. This might be due to quarry activities, often involve the removal of large amounts of rock and soil, which can lead to erosion. During rainfall, phosphorus bound to rock and soil particles can be washed in to the river.

5.3. Macroinvertebrate community composition

Comprehensive assessment of macroinvertebrate communities in Great Akaki River watershed provides valuable insights into the health and ecological dynamics of the aquatic ecosystem. The results of the present study revealed the significant variations in the composition and abundance of macroinvertebrates community. The dominance of tolerant and moderately tolerant taxa at the impacted sites, specifically S6, was notably higher than the reference site, while the diversity and richness of these macroinvertebrate taxa were the reverse. This could be due to oxygen depletion, sedimentation, various anthropogenic

activities such as urban, and agricultural activities. Moreover, high dominance of tolerant taxa at impaired sites might be due to the presence of species with specific physiological or behavioural adaptation to pollution. For instance, it is known that Red-Chironomidae are good indicators of stressed sites and have been dominant and abundant in these areas (Buss *et al.*, 2002; Buckup *et al.*, 2007). This is because Chironomids are able to tolerate low DO using high affinity haemoglobin (Thorp and Covich, 2009; Getachew Beneberu *et al.*, 2014).

In addition, the upstream site supported high proportion of sensitive taxa such as Ephemeroptera (Baetidae, Caenidae, Heptageniidae), and Trichoptera (Hydropsychidae), which exhibited remarkable reduction starting from S3 mainly due to the inability to withstand the low DO level in the downstream sites (Welch *et al.*, 1992). A similar trend was reported by several studies in Ethiopia (Baye Sitotaw, 2006; Solomon Akalu *et al.*, 2011; Misgana Dabessa *et al.*, 2021; Tesfaye Muluye *et al.*, 2023). The Odonata family of Coenagrionidae had high abundance in S1 and S2. However, there were no Odonata taxa at S3, S4, S5, and S6. This could be due to the unstable and disturbed downstream sites, short life cycle, lack of suitable riparian vegetation which serves as their ovipositional site and refuge from predators (Osborn, 2005; Iwata and Watanabe, 2009; Narender *et al.*, 2016).

The tolerant taxa Chironomidae, Culicidae, Psychodidae, and Oligochaeta accounted for 56.9% of the macroinvertebrate abundance in the Great Akaki River. According to Riens *et al.* (2013) most Diptera families tolerate disturbed water by utilizing atmospheric oxygen. Even though, Chironomidae larvae were found in all sites with different abundance. Oligochaeta was the most abundant and dominant at S5 and S6. In agreement with the present results, the high dominance of Chironomidae and Oligochaeta in water with severe pollution was previously reported for Tikurwuha River (Birenesh Abay, 2007), Great Akaki River (Solomon Akalu *et al.*, 2011), Tamirabarani River Basin (Mophin-Kani and Murugesan, 2014), Streams and Rivers in Central and Southeast highlands of Ethiopia (Aschalew Lakew and Moog, 2015a), Sebeta Rivers (Amare Mezgebu *et al.*, 2019), Theta River (Gituanja, 2020), and Upper and Middle Awash River (Tefaye Muluye *et al.*, 2023).

5.4. Macroinvertebrate metrics

The pattern of macroinvertebrate metrics observed in the present study suggests that less disturbed or least impacted areas exhibit higher diversity of macroinvertebrate taxa. The present results are consistent with findings of Birenesh Abay (2007), Assefa Wosnie and Ayalew Wondie (2014), and Masresha Birara (2021). The main reason for this trend could be

the availability of nutrients and the level of ecosystem disturbance. Generally, diversity index and dominance were inversely related. Similar trends were observed in different studies made in Ethiopia (Fasil Degefu et al., 2013; Aschonitis et al., 2016; Tarekegn Wondmagegn, 2019; Masresha Birara, 2021).

Moreover, the present results indicated a decline in the abundance of intolerant taxa % ET and % EOT as the disturbance level increased downstream. Order Odonata was regarded as one of the sensitive taxa since Plecoptera was not found in all sampling sites (Seid Tiku *et al.*, 2013; Liu *et al.*, 2017; Tesfaye Muluye *et al.*, 2023). This decline in sensitive taxa suggests the prevalence of poor water quality in downstream sites (Patrick *et al.*, 2015; Liu *et al.*, 2017), low oxygen water as Ephemeropteras prefer fast flowing water that gets oxygenated (Jun *et al.*, 2016). Furthermore, % Diptera, % Chironomidae, and % Oligochaeta had an inverse relationship with % ET and % EOT in the present study, a trend, which was also reported by previous studies (Baye Sitotaw, 2006; Raburu *et al.*, 2009; Misgana Dabessa *et al.*, 2021).

According to ETHbios and SASS 5 scores, the headwaters of Great Akaki River, presumably those with less anthropogenic disturbance, are classified as “good water quality river” and the stressed sites as “poor water quality with major deterioration”. However, it’s noteworthy that low SASS score was recorded for S3, which seem to indicate that this particular site was facing more severe disturbance. The lowest ETHbios score was also observed for S3 and S6. Additionally, ETHbios and SASS ASPT suggested moderate water quality with major deterioration. Similar results were reported for streams and rivers in Central and Southeast highlands of Ethiopia (Aschalew Lakew and Moog, 2015a), Addis Ababa rivers (Solomon Desalegne, 2018), and Upper Awash River (Misgana Dabessa *et al.*, 2021).

5.5. Impacts of land use land cover change on water quality

The complex interplay between land use types and water quality parameters in Great Akaki River catchment was revealed by results of the present study. The observed correlation between urban land, agricultural land, vegetation cover and various physico-chemical parameters offer valuable insights into the impact of human activity on river ecosystem.

Accordingly, the results revealed strong positive relationship between urban area and temperature, pH, SRP, TDS and a moderate positive correlation with NH₃. This could be ascribed to the fact that the increase in urban area was associated with water quality degradation. The elevated temperature and EC levels observed with increasing urbanization

could be attributed to the reduction or elimination of vegetation cover, or the conversion of natural vegetation to urban land, leading to an increase in impervious surfaces (Yu *et al.*, 2013). Urbanization includes construction of impervious surfaces like roads, pavements and buildings that reduce water infiltration into the ground and increase surface runoff, which carry point and non-point source pollutants including SRP and TDS into the river system. The development of lands for settlement and expansion of urbanization in the proximity of downstream sites may have also contributed to the high level of river water pollution. Inorganic nitrogen concentration increases as urban area increases (Foley *et al.*, 2005; Namugize *et al.*, 2018). The present finding is consistent with those reported for surface waters in Ohio state (Tong and Chen (2002)), Mngeni river catchment (Namugize *et al.* (2018), Theta river catchment (Gituanja (2020), Lake Kyoga (Obubu *et al.* (2021), and surface waters in Addis Ababa city (Gule *et al.*, 2023).

Vegetation cover land use type showed negative correlation with some of the water quality parameters such as temperature, pH, SRP (with strong negative relationship), and NH₃. This illustrates that vegetation covered areas tend to be associated with decreasing levels of those parameters. This agrees with the findings of Faiilagi (2015); Gituanja (2020); Kalkidan Asnake *et al.* (2021); Obubu *et al.* (2021). However, positive correlation was observed between EC and vegetation land use type, which is consistent with findings reported by Kalkidan Asnake *et al.* (2021); Obubu *et al.* (2021). This indicates the significance of natural vegetation in maintaining the water quality as it plays a vital role in stabilizing the soil thereby reducing soil erosion. Moreover, natural vegetation acts as a buffer zone, effectively filtering pollutants emanating from the surrounding environment.

Conversely, agricultural land use type exhibited positive correlation with SRP, TDS, and NH₃. This observation could be attributed to the use of chemical fertilizers, and pesticides close to the river system. Intense cultivation could lead to soil instability and subsequent erosion, which increases sedimentation (Faiilagi, 2015). Similar observations were reported in the studies made by Namugize *et al.* (2018); Obubu *et al.* (2021). Elsewhere, some studies reported contrasting results such as those of Gule *et al.* (2023) who stated that agricultural land negatively influenced NH₃, PO₄³⁻, and TDS, while Faiilagi (2015) argued that agriculture positively influence temperature, pH, and EC.

5.6. Relationship between land use land cover types and macroinvertebrate community

This study's findings show significant differences in family richness of macroinvertebrates across various land use types. Forested area exhibited higher Ephemeroptera and Trichoptera richness, which clearly decreased in agricultural and urban sites. Some families of mayfly were collected from these areas, albeit in small numbers, suggesting a facultative presence, as noted by Baye Sitotaw (2006). As suggested by Baye Sitotaw (2006) as regard to this unclear disturbance of these macroinvertebrate taxa, further study at lower taxonomic level is necessary. However, the total loss of sensitive Ephemeroptera taxa (family Heptagenidae) and Trichoptera at the urban site could be due to the high industrial pollution, habitat quality alteration, poor water and habitat quality. Similar studies have been conducted by Hall *et al.* (2001); Walsh *et al.* (2001); Baye Sitotaw (2006); Hepp *et al.* (2010).

In addition, Order Diptera was abundant at urban sites. The possible explanation is their ability to tolerate high level of pollution. This result is corroborated by the findings of several previous studies, including those of Bartlett-Healy *et al.* (2012); Couceiro *et al.* (2012); Riens *et al.* (2013); Masresha Birara (2021), which indicate that Diptera are commonly found in wide range of water qualities, especially in disturbed areas due to their high tolerance levels.

ANOSIM analysis confirmed that there are notable dissimilarities in the composition of macroinvertebrates across different land use categories. The statistically significant difference between vegetation and urban areas land use types revealed by the results of the pair wise comparison test suggests that these two land use types host distinct macroinvertebrate communities. This indicates that urbanization has a notable impact on macroinvertebrate composition compared to areas with natural vegetation (Suárez *et al.*, 2022). However, no significant differences were found between urban and agricultural areas or between vegetation and agriculture. This suggests that macroinvertebrate communities in agricultural areas may share more similarities with urban areas than with natural vegetation. This could be due to similarities in disturbances or environmental stressors present in both agricultural and urban landscapes, such as nutrient put through runoff, sedimentation, and altered hydrology.

The higher dissimilarity values resulting from SIMPER analysis suggest greater differences in community composition. In the present study, urban land was associated with the highest dissimilarity value. The identification of key taxa contributing to these dissimilarities shows

specific groups of macroinvertebrates that are sensitive to variations in habitat conditions associated with different land use types. Notably, Ephemeroptera taxa made the highest contribution to the differences between vegetation-urban (63.49%) and vegetation-agriculture (53.17%) pairs. This suggests that Ephemeroptera species are particularly sensitive to differences in habitat characteristics between natural vegetation areas and areas affected by agriculture or urbanization. Conversely, Annelida taxa, which include various types of worms and leeches, are sensitive to differences in habitat conditions between agricultural and urban areas.

5.7. Relation between water quality and macroinvertebrate community

The results of RDA conducted in this study revealed a substantial relationship between physico-chemical parameters and macroinvertebrate communities of the river ecosystem. Through the forward selection technique, NH_3 and SRP were identified as environmental parameters with notable importance in shaping macroinvertebrate communities. Examining the correlation along the first axis revealed intriguing patterns of association between physico-chemical parameters and macroinvertebrates taxa at different sampling sites.

For instance, DO was positively correlated with diverse macroinvertebrate families such as Baetidae, Caenidae, Heptagenidae, Hydropsychidae, Corixidae, Coenagrionidae, Aeshnidae, Hydrophilidae, Elmidae, Vellidae, Sphaeridae, Planorbidae, Turbellaria at upstream sites. This suggests that these families prefer high oxygen levels. Similar results of strong correlation between DO and specific families such as Heptagenidae, Baetidae, Caenidae, and Hydropsychidae by Tesfaye Muluye *et al.* (2023), Hydrophilidae by Kaboré *et al.* (2016); Tarekegn Wondmagegn (2019), Heptagenidae, Sphaeridae, and Hydrophilidae by Gezahegn Degefe *et al.* (2017), most Ephemeroptera genera by Shelly *et al.* (2011); Masresha Birara (2021), and Baetidae and Caenidae by Osimen *et al.* (2021).

Conversely, several sensitive and moderately sensitive macroinvertebrate families exhibited negative correlations with NO_2 , TP, turbidity, SRP. This might indicate that chronic toxicity is at play in the river, in addition to the effects of eutrophication as noted by Solomon Akalu *et al.* (2011). Few tolerant families such as Chironomidae and Oligochaetas were positively correlated with TDS, SRP; and TP, NO_3 , turbidity, respectively, as the ecological impairment becomes sever. These families are known to utilize available organic matter as a food source, as discussed by Amare Mezgebu *et al.* (2019).

CONCLUSION

The study assessed the relation between land use land cover changes over a 15-year period and water quality as well as macroinvertebrate communities in the Great Akaki River catchment. From the findings of the present study, it is evident that land use has greatly changed across the catchment, as a result of clearing natural vegetation and expansion of urbanization. From 2008 to 2023, urban area increased by 24.9% coincident with the decline in other types of land uses. The observed increase in urban area was correlated with high levels of pH, SRP, temperature, and TDS, indicating the impact of urbanization on water quality. Vegetation cover had negative relationship with temperature, pH, SRP, NH₃ as it improves water quality. Agricultural land was associated with high levels of SRP, TDS, and NH₃, indicating the fact that agricultural practices lead to degradation of water quality. Furthermore, ecological consequence of land use change was largely variations in the spatial distribution of macroinvertebrate community across different land use types. Higher macroinvertebrate diversity and richness characterized the site with vegetation cover, while in the urban land use sites being depauperate in community composition was observed. Significant dissimilarity in macroinvertebrate assemblages between land use types, with taxa responding differently to habitat alteration was also revealed by the present results. The redundancy analysis identified EC, pH, NH₃, SRP, and turbidity as key drivers of the variations in macroinvertebrate assemblages.

6. RECOMMENDATIONS

Based on the results of the study reported here, the following measures/activities are recommended:

- ❖ Establishment of buffer zone and wastewater treatment plants to reduce pollutants entering from agricultural runoff and urban effluents.
- ❖ Implementation of solid and liquid waste management policies by municipalities to prevent community discharge into the river system, as such actions adversely affect public health and the environment.
- ❖ Establishment of a long term monitoring program for the river ecosystem through collaborative efforts of local environmental organizations and research institutions to set up a mechanism of regular data collection to ensure continuous and comprehensive data acquisition.
- ❖ Identification of macroinvertebrates to the genus or species level as it may provide a better insight into the ecological impacts of land cover land use changes.
- ❖ Inclusion of such other water quality parameters as microbial, BOD, COD, and heavy metals as this is likely to provide a more complete picture of the impacts of land use land cover changes on water quality.

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7. PLATES



Plate 1: Pictures of above Legedadi dam site (Site-1)





Plate 2: Pictures of Legedadi dam outlet site (Site-2)



Plate 3: Pictures of around ICT park site (Site-3)



Plate 4: Pictures of Bulbula site (Site-4)



Plate 5: Pictures of Kebena site (Site-5)





Plate 6: Pictures of Tirunesh Bejing Hospital (Site-6)



Plate 7: *In-situ* water quality assessment using multi-probe meter



Plate 8: Macroinvertebrate sampling using square frame hand net



Plate 9: Macroinvertebrate sorting in the field



Plate 10: Laboratory activities

8. APPENDICES

Appendix 1: Habitat assessment data sheet to obtain habitat score for all sampling sites

Habitat Parameter	Condition Category																				
	Optimal					Suboptimal					Marginal					Poor					
SCORE	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1. Epifaunal Substrate/ Available Cover Score	Greater than 50% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are <u>not</u> new fall and <u>not</u> transient).					30-50% mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of new fall, but not yet prepared for colonization (may rate at high end of scale).					10-30% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.					Less than 10% stable habitat; lack of habitat is obvious; substrate unstable or lacking.					
2. Pool Substrate Characterization Score	Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common.					Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present.					All mud or clay or sand bottom; little or no root mat; no submerged vegetation.					Hard-pan clay or bedrock; no root mat or vegetation.					
3. Pool Variability Score	Even mix of large-shallow, large-deep, small-shallow, small-deep pools present.					Majority of pools large-deep; very few shallow.					Shallow pools much more prevalent than deep pools.					Majority of pools small-shallow or pools absent.					
4. Sediment Deposition Score	Little or no enlargement of islands or point bars and <20% of the bottom affected by sediment deposition.					Some new increase in bar formation, mostly from gravel, sand or fine sediment; 20-50% of the bottom affected; slight deposition in pools.					Moderate deposition of new gravel, sand or fine sediment on old and new bars; 50-80% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.					Heavy deposits of fine material, increased bar development; 80% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.					
5. Channel Flow Status Score	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.					Water fills >75% of the available channel; or <25% of channel substrate is exposed.					Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.					Very little water in channel and mostly present as standing pools.					
6. Channel Alteration Score	Channelization or dredging absent or minimal; stream with normal pattern.					Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr.) may be present, but recent channelization is not present.					Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.					Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.					
7. Channel Sinuosity Score	The bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line. (Note- channel braiding is considered normal in coastal plains and other low-lying areas. This parameter is not easily rated in these areas.)					The bends in the stream increase the stream length 2 to 3 times longer than if it was in a straight line.					The bends in the stream increase the stream length 2 to 1 times longer than if it was in a straight line.					Channel straight; waterway has been channelized for long distance.					
8. Manure Presence/ Human Waste Score	Small presence of manure or human waste.					Moderate presence of manure or human waste.					High presence of manure or human waste.					Very high presence of manure or human waste.					
9. Water Appearance Score	Very high water clarity					High water clarity					Moderate water clarity					Small water clarity					
10. Bank Grass Cover/ Graze Score	Very high grass cover					High grass cover					Moderate grass cover					Small grass cover					
11. Canopy Cover	Very high canopy cover					High canopy cover					Moderate canopy cover					Small canopy cover					

Score											
Left/Right Bank	10	9	8	7	6	5	4	3	2	1	0
12. Bank Stability LB RB	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.							
13. Vegetative Protection LB RB	More than 90% of the stream bank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the stream bank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the stream bank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the stream bank surfaces covered by vegetation; disruption of stream bank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.							
14. Riparian Vegetative Zone Width LB RB	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters; little or no riparian vegetation due to human activities.							

Appendix 2: Error matrix for years 2008, 2016, and 2023

LULC classes	Urban land	Agricultural	Bare land	Waterbody	Vegetation	Total	User's accuracy
Urban land	13	0	0	0	0	13	100.00
Agricultural land	0	10	0	0	1	11	90.91
Bare land	2	0	5	0	0	7	71.43
Waterbody	0	0	0	4	0	4	100.00
Vegetation	0	1	0	0	11	12	91.67
Total	15	11	5	4	12	43	
Producer's accuracy	86.67	90.91	100.00	100.00	91.67		

2008 overall accuracy= 91.48%

LULC classes	Urban land	Agricultural	Bare land	Waterbody	Vegetation	Total	User's accuracy
Urban land	12	0	1	0	0	13	92.31
Agricultural land	1	11	0	0	0	12	91.67
Bare land	0	1	4	0	1	6	66.67
Waterbody	0	0	0	3	0	3	100.00
Vegetation	0	0	0	0	7	7	100.00
Total	13	12	5	3	8	37	
Producer's accuracy	92.31	91.67	80.00	100.00	87.50		

2016 overall accuracy=90.24%

LULC classes	Urban land	Agricultural	Bare land	Waterbody	Vegetation	Total	User's accuracy
Urban land	17	1	0	0	0	18	94.44
Agricultural land	1	16	1	0	0	18	88.89
Bare land	0	0	7	0	0	7	100.00
Waterbody	0	0	0	5	0	5	100.00
Vegetation	0	0	0	0	7	7	100.00
Total	18	17	8	5	7	52	
Producer's accuracy	94.44	94.12	87.50	100.00	100.00		

2023 overall accuracy=94.45%

Appendix 3: Macroinvertebrate metrics and indices

Sampling sites	Taxa richness	Abundance	Dominance	Shannon	No. ET	% ET	No. EOT	%EOT	No. Diptera	%Diptera	% Oligochaet ^a	% Chironomidae	SASS5 score	SASS5 ASPT	ETHbios score	ETHbios ASPT
Site 1	25	2185	0.431	1.344	13.51	88.49	18.92	89.27	13.51	6.01	0.46	5.36	110	4.40	88	3.52
Site 2	31	3456	0.3231	1.761	10.81	72.21	18.92	75.37	21.62	10.56	5.44	7.84	137.00	4.41	119.00	3.84
Site 3	10	930	0.4682	1.001	2.70	0.65	2.70	0.65	18.92	75.48	23.55	63.33	30.00	3.00	27.00	2.70
Site 4	12	717	0.3587	1.329	2.70	0.42	2.70	0.42	18.92	89.54	9.48	21.20	44.00	3.67	34.00	2.83
Site 5	10	1098	0.463	1.002	5.41	1.27	5.41	1.27	13.51	37.49	60.96	29.48	33.00	3.30	32.00	3.20
Site 6	11	3460	0.679	0.5869	5.41	0.09	5.41	0.09	13.51	19.22	80.61	18.39	42.00	3.82	27.00	2.46

Appendix 4: Pearson Correlations among environmental parameters and macroinvertebrate metrics

	SRP	NH₃	EC	pH	Turbidity	Taxa richness	Abundance	Dominance	Shannon
% ET	-0.92319	-0.99567	-0.94158	-0.30424	-0.30814	0.94104	0.473687	-0.44316	0.693974
%EOT	-0.92406	-0.99703	-0.94081	-0.30091	-0.29443	0.947568	0.481535	-0.44979	0.702382
%Diptera	0.382334	0.664774	0.748926	0.461124	-0.15898	-0.64703	-0.81033	-0.19552	-0.12639
% Oligochaeta	0.86711	0.667133	0.493822	-0.08807	0.542148	-0.63101	0.18302	0.846293	-0.85472
% Chironomidae	0.40853	0.622528	0.43403	-0.28439	0.362505	-0.66467	-0.5931	0.16412	-0.41529
SASS5 score	-0.87614	-0.95969	-0.84889	-0.1645	-0.14111	0.998586	0.603394	-0.5068	0.784889
SASS5 ASPT	-0.69051	-0.83925	-0.6958	0.005306	-0.32875	0.875952	0.695864	-0.26021	0.569827
ETHbios score	-0.87899	-0.95305	-0.84349	-0.16283	-0.07703	0.996116	0.551046	-0.57339	0.828112
ETHbios ASPT	-0.79612	-0.87691	-0.76246	-0.05498	-0.06891	0.875504	0.274313	-0.70232	0.848821

Appendix 5:Forward Selection results

Name	Explains %	Contribution %	pseudo-F	P-value
NH3(mg/l)	68.2	68.2	8.6	0.004
Ph	15.2	15.2	2.7	0.126
PO4 (mg/l)	12.5	12.5	6.1	0.034
Turbidity	3.2	3.2	3.7	0.199
EC	0.9	0.9	<0.1	1.

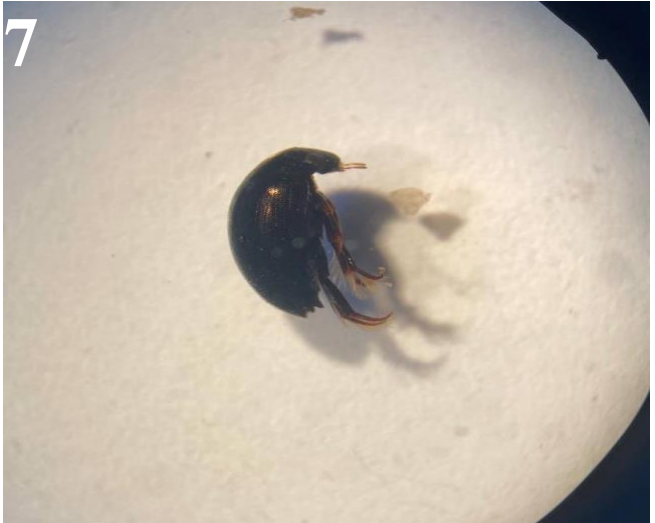
Appendix 6: SIMPER results indicating the average contribution of the taxa responsible for the dissimilarities between land use types

Order	Vegetation-Agriculture		Vegetation-Urban		Agriculture-Urban	
	Contrib. %	Cumulative %	Contrib. %	Cumulative %	Contrib. %	Cumulative %
Ephemeroptera	63.49	63.49	53.17	53.17	30.23	30.23
Diptera	16.84	80.33	16.17	69.34	24.18	54.41
Annelida	7.231	87.57	24.16	93.5	35.56	89.97
Trichoptera	4.765	92.33	3.316	96.82	3.268	93.23
Coleoptera	2.855	95.19	0.5931	97.41	2.841	96.08
Odonata	1.665	96.85	0.5984	98.00	1.546	97.62
Mollusca	1.079	97.93	0.2371	98.24	1.187	98.81
Hemiptera	0.9787	98.91	0.8807	99.12	0.6796	99.49
Pelecypoda	0.6811	99.59	0.5713	99.69	0.2851	99.77
Turbellaria	0.4108	100	0.2965	99.99	0.219	99.99
Lepidoptera	0	100	0.0055	100	0.007631	100

Appendix 7: Some of the identified macroinvertebrate families in Great Akaki River



Ephemeroptera: 1. Baetidae, 2. Caenidae, 3. Heptagenidae



Trichoptera: 4. Hydropsychidae

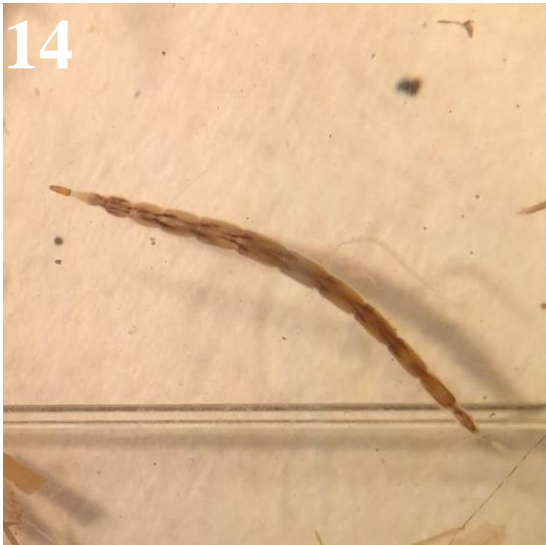
Coleoptera: 5. Dytiscidae, 6. Elmidae, 7. Hydrophilidae

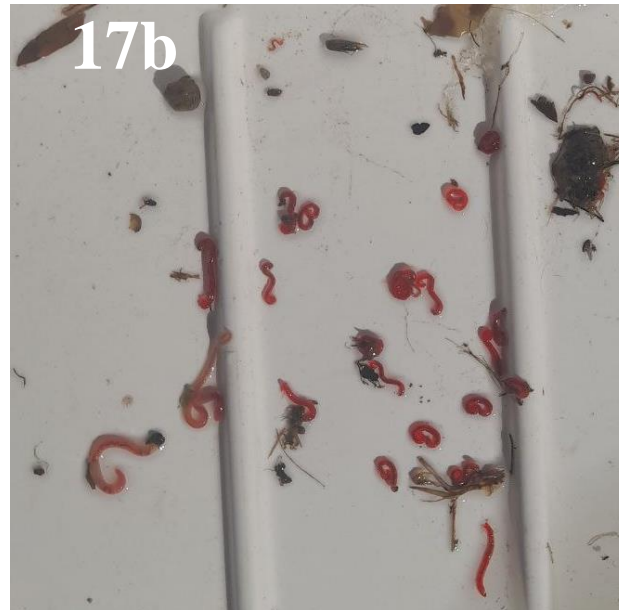


Hemiptera: 8. Belostomatidae, 9. Notonectidae, 10. Nepidae, 11. Corixidae



Odonata: 12. Aeshnidae, 13, Coenagrionidae





Diptera: 14. Ceratopogonidae, 15. Psychodidae, 16. Culicidae, 17. Chironomidae, 18. Syrphidae, 19. Ephydriidae, 20. Muscidae

Annelida: 21. Oligochaeta, 22. Hirudiinae

