

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING



ENVIRONMENTAL IMPLICATION OF URBAN RIVER
REACH MORPHOLOGY
(THE CASE OF BIG AKAKI RIVER IN ADDIS ABABA)

MSc Thesis in Civil and Environmental Engineering
Stream: Water Supply and Environmental Engineering

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A Thesis Submitted to Addis Ababa institute of Technology, School of Graduate Studies,
Addis Ababa University

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In Partial Fulfillment of the Requirements for the Degree of Master of Science Degree in Civil and
Environmental Engineering.

Water Supply and Environmental Engineering

By

Mihretab Gebretsadik

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Declaration

I, the undersigned, declare that the Thesis is my original work performed under the supervision of research advisor Dr Fiseha Behulu and has not been presented as a thesis for a degree at any University and that all sources of materials used for the thesis have been acknowledged.

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ABSTRACT

Environmental degradation in urban rivers are becoming common problems, even worsening due to the increased anthropogenic causes led by urbanization. Urban river reach's morphology is highly sensitive for alteration by the human settlement and municipal demands. Flooding during the rainy seasons and zero environmental flows with poor water quality are the current guise of small rivers at residential areas. This study is conducted on the environmental implication of river morphology on the big Akaki and Kebena Rivers with combined application of quantifying the land use/cover and morphological characteristics change with remote sensing and GIS techniques and with selected water quality nutrient loads parameters estimated using stream flow simulation. The land use/cover and morphological assessment was analyzed from high resolution satellite images of SPOT and the Google earth using the Arc-GIS 10.4 for the study period. The stream flow has been simulated by employing the HEC-HMS hydrologic model. The water quality parameters collected by various researchers and organizations were compiled to understand the changes for certain physico-chemical parameters. The nutrient loads of phosphate and nitrate simulated with LOADEST model using the flow output of the hydrologic model. The result shows the land use/cover has undergone a dynamic change, in particular the crop land reduced by 11 % and the urban area shows 7.33 % increase. The morphometric characteristics of sinuosity (SI) and River Network Change Index (RCIM) shows slight change over the decade with -0.008 and +0.039 values for Kebena respectively. While the big Akaki morphometric characteristics of SI and RNCI has been found to be +0.027 and 0.00 respectively over the decade. On the other hand, the water quality parameters show complex and undefined pattern of the pollution status. However, all the assessed parameters were below the water quality standards of both the international and national organizations. The sedimentation problem observed to be higher especially when the slope becomes gentle and the velocity decrease. Moreover, the average Nitrate and phosphate loads where larger than the standard limits with high level of seasonal variation for both Kebena and Akaki Rivers between 2006-2016 year. The link between the percent of urban area and the two morphometric parameters were found to be significant with a p-value of 9.08×10^{-8} . From this study, high level of correlation between the morphometric characteristics, the water quality parameters were perceived. The linkage between RNCI and the nine physico-chemical and nutrient water quality parameters where highly correlated. While the SI found to be insignificant on the pH and nutrient parameters determination. Based on the results obtained, the recommended Nature Based and contextualized channel rehabilitation measures for the two river reaches can be a best management practice to mitigate the environmental pollution.

Keywords: Big Akaki, Satellite image, Morphology, Nutrients, HEC-HMS, LOADEST,

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LIST OF ABBREVIATION

AAEPA	Addis Ababa Environmental Protection Agency
ADCP	Acoustic Doppler Current Profiler
AMLE	Approximate Maximum Likelihood Estimation
ANOVA	Analysis of Variance
BDA	Basin Development Authority
CN	Curve Number
DEM	Digital Elevation Model
GII	Geospatial Information Institute
GIS	Geographical Information System
HEC-HMS	Hydrologic Engineering Center
HWQD	Hydrological Prediction for the Environment
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
LAD	Least Absolute Estimation
LWRC	Land and Water Resource Center
MLE	Maximum Likelihood Estimation
MoWIE	Ministry of Water Irrigation and Energy
MODIS	Moderate Resolution Imaging Spectro-radiometer
NASA	National Aeronautics and Space Administration
NMA	National Meteorological Agency
SCS	Soil Conservation Service
SPOT	Satellite Pour l'Observation de la Terre
SRTM	Shuttle Radar Topographic Mission
UMT	Urban Morphometric Types
WRF	Weather Research and Forecasting

CHAPTER 1 INTRODUCTION

1.1. Background

Surface water is one of the most vulnerable natural resources and its alterations have led to extensive environmental degradation and decline in water quality and quantity. Anthropogenic activities, such as land use, waste disposal and other activities have caused degradation of surface water quality throughout the world. The surface water system is highly exposed to alterations compared to the ground water which has lower exposure to the environment and diminishes its use for agriculture, drinking, industry, recreation and other purposes. Discharges of untreated domestic and industrial wastes bullying ecosystems and human health in many locations around the world (Sasakova et al. 2018).

Addis Ababa is located at the foothill of Entoto Mountain with several small streams originating from the mountain range. Torrential rains are common during the rainy season in the city. Heavy rain causes a sudden rise in outflow of these streams which bring about flood damages to settlements along the bank of these streams. Such damages have often caused losses of property (Achamyeleh 2003). The foundation and expansion of Addis Ababa have been associated with the rapid conversion of rural land to an urban area. For the last one hundred twenty-three years, it has been noticed that an intensive conversion of rural land to urban development like buildings, transportation networks and facilities (airports and highways), recreation areas, reservoirs and other manmade structures, where most of them are impermeable structures (Adugna 2016; Dagnachew 2012).

The rapid rates of urbanization in many countries create major challenges for main cities to surface water quality deterioration. In developing urban areas, the growth of population and movement towards the riverside has posed a big impact on the agricultural land conversion to building homes and other infrastructure. As a result, the demands for river water for different purposes are highly endangered in many urban areas like Addis Ababa. Hydrological investigations show that from the total amount of water supplied to the city, 70% returns as sewage with high organic pollution. About 35% of the solid waste generated in Addis Ababa is

dumped on open sites, drainage channels and rivers (Weldesilassie et al. 2011). City of Addis Ababa generates a solid waste of 0.5 kg per capita per day (Desta et al. 2014). Thus, this could be the source of environmental problems like erosion, pollution, overtopping, a barrier to traffic and other related problems.

Manmade and natural structures constructed around river systems have changed the hydro-morphological characteristic of the river system over time. Naturally, the channel network in the runoff process is increased with the increase of the watershed area, so as in urban areas with artificial channels. The final receiving system for all run-offs is a waterway such as stream or river. The influence of urbanization on river systems was the most significant, and 60% of river systems in the world were changed greatly because of urbanization (Deng and Ma 2015). The artificial storm water runoff drainage system takes sewages from the vicinity in its way to the final receiving system. Depending on local conditions, these changes can contribute to flooding, soil erosion, channel modification, and siltation of streams. These effects are often felt well beyond the immediate vicinity of the river courses (Tafete 2013).

Water quality criteria are developed by scientists and provide basic scientific information about the effects of water pollutants on specific water use. They also describe water quality requirements for protecting and maintaining individual use. Water quality criteria are based on variables that characterize the quality of water and/or the quality of the suspended particulate matter, the bottom sediment and the biota. Many water quality criteria set a maximum level for the concentration of a substance in a particular medium (i.e. water, sediment or biota). The prevention of pollution at source, with prior licensing of wastewater discharges by competent authorities, have become key elements of successful policies for preventing, controlling and reducing inputs of hazardous substances, nutrients and other water pollutants from point sources into aquatic ecosystems (Enderlein et al. 2006)

Streams and rivers contribute to regulating the material such as nutrients exported downstream by means of transformation, storage, and removal of nutrients. It has been recently suggested that the efficiency of stream network process rates relative to available nutrient concentration in streams eventually declines, following an efficiency loss (EL) dynamics. However, most of these predictions are based at the reach scale in pristine streams, failing to describe the role of entire

river networks (Aguilera et al. 2013). The impacts of excess nutrients are found in all types of water bodies. Pollutants often enter upstream waters like creeks and streams and then flow into larger water bodies like lakes, rivers and bays. Excess nitrogen and phosphorus can also travel thousands of miles to coastal areas where the effects of the pollution are felt in the form of massive dead zones. In addition, nutrients can soak into ground water and urban areas giving hazy skies and air quality problem related to airborne nitrogen pollution (EPA 2020).

Currently, Addis Ababa is undergoing improvement of existing roads and constructing new roads which will highly influence the runoff volume of the city. So mitigation measures should be considered to accommodate the incoming surface runoff (Habtamu 2011). The city is also undergoing one of its highly anticipated riverside development projects this year. The project has just completed around the National Palace area at the upstream of Kebena river. Although many researches have been conducted on the pollution of rivers in Ethiopia, very few of them were in relation with morphological changes impacts. This research is aimed to address the above-mentioned challenges. The study particularly intended to find impact of river reach morphological change, caused by anthropogenic and nature, on environment in general. This study output could be used for the future development of the river and the watershed.

1.2. Statement of problem

Most of the river courses in Addis Ababa city become full and flood their surroundings during the three main rainy months of June, July and August (Getahun and Gebre 2015). Heavy rains followed by high runoff coming from the nearby mountains cause flooding in several streams which damaged houses and structures close to river banks (Tafete 2013). This phenomenon causes the loss of life or injury, property damage, infrastructure, environmental degradation, social and economic disruption. Systematic assessments of the hazards posed are useful for the environment, the river health, future river-side development, disaster planning, emergency response, and flood warnings (Michaud et al. 2005).

On the other hand, the pollution status of the rivers in urban areas are highly affected by urbanization. Nutrient and chemical pollutants generated from the point and non-point sources are heavily impacting the livelihood of rivers in developing urban areas like the Akaki

watershed. The water quality in the Akaki rivers found to be deteriorated and not meeting the river water quality standard (Mersha 2012). The Akaki river is one of the most polluted river system in the country. Such deterioration are derived from different sources of pollutants both from point (factories discharge, urban wastewater discharges, garage wastes, hospital wastes, etc.) and non-point sources (e.g. different sewages runoff, agricultural runoff) (Yohannes and Elias 2017).

The big Akaki River is the significant proportion of the Addis Ababa watershed. The river is exposed to flooding during the rainy season, which forms a problem of overtopping the river water into the residential, government and private business areas. During the dry season, the river mostly carries sediments, sewage and other wastes which cause environmental pollution as well as bad smell and unwelcoming environment. The water quality of the river is highly degraded due to the domestic, industrial and other effluents discharged directly into the river. The rivers morphology is highly shifting due to the change in the flow pattern, settlement, construction and dumping of waste and excavated materials near the river banks. Lack of consistency and highly unstable river channel morphology makes the river exposed to pollution and environmental degradation.



Figure 1-0-1: Big Akaki and Kebena river current conditions at (a) below Akaki bridge (b) below st Joseph bridge (c) around maselteгна (d) Bole bridge

1.3. Research Questions

This research will answer the following research questions:

- How is the dynamics of land-use in the watershed?
- What is the river flow quantity and seasonal variability?
- What are the river water quality major pollutants and how is their status?
- Are the river channel and the adjacent buffer area morphology stable or ever-changing?
- Is the settlement expansion and riparian vegetation affecting the river flow and water quality?
- What are the impacts of the river reach morphology on the spatial and temporal pattern of the water quality and nutrient loads?
- What should future river development look like, in the context of the rivers environment?

1.4. Objectives

1.4.1. General objective

The general objective of the study is to evaluate the implication of urban river reach morphology on the environment.

1.4.2. Specific objectives

- To analyze the land use dynamics using historical satellite imageries.
- To investigate the river channel morphology, with morphometric characteristics from remotely sensed and in-situ datasets.
- To analyze the streams inflow characteristics and seasonal flow pattern in the sub-catchments.
- To investigate the water quality status and dynamics with Physico-chemical and nutrient parameters.
- To investigate the environmental implication, propose mitigation measures and provide structural recommendation for future development on river development projects.

1.5. Significance of the study

These study will help us to understand the relationship between the land-use, hydro-morphology, water quality and their impact on the environment. Particularly, this study will have significance in giving an insight on the following points:

- To understand the land use change extent and its impact on the river environment.
- To understand the water quality and quantity in relation with river morphology.
- To indicate the river's situation for river planning, development and management works.

1.6. Limitation

This study is limited to the Kebena and big Akaki rivers within the vicinity of Addis Ababa. The research was aimed to conduct for many parameters of water quality and pollutants constituent and loads. However, due to the availability of data only Nitrate and phosphate nutrient loads estimation was conducted.

The lack of water quality time series data of different parameters is a serious challenge for examining rivers trends and conditions in developing countries. Also, the absence of stream flow gauging station on Kebena river was a big challenge to this study.

1.7. Thesis outline

This thesis has five chapters. Chapter 1 (this chapter) presents the general introduction, statement of the problem; objectives and significance of the study. Chapter 2 gives a brief literature review related to the scope and objective of this thesis works. This chapter explains previous similar studies and the software capability in relation to this study plan. The study area description, data collection and analysis and the methodology for analysis are presented in chapter 3. This chapter also explains in detail the steps used for simulation. In chapter 4 results and discussions are presented and mitigation measures are proposed. The conclusion and recommendation are given in chapter 5. Some suggestions for future work are also included in the last chapter.

CHAPTER 2. LITERATURE REVIEW

2.1. Land use change analysis

Mapping the earth's surface, resources and ecosystems is an invaluable source of knowledge about the past and present state of our planet. Mapping is termed as "Land literacy" and a source of information for "Traditional use studies" and "Hazards management" (McCall, 2003). There are different ways of image processing and analysis methods depending on the purpose of the application. Among this the fuzzy object extraction method produces files of training sites for all tracks of the image. In order to minimize redundant differences in homogeneous areas of the image, a segmentation function by software applied on the image tracks. After segmentation, training sites could be used to define object classes (Sohrabinia et al. 2008).

Change analysis of features of Earth's surface is essential for better understanding of interactions and relationships between human activities and natural phenomena. Remote Sensing (RS) has been used to classify and map land cover and land use changes with different techniques and data sets. Analysis of detected change is the measure of the distinct data framework and thematic change information that can lead to more tangible discernment to underlying process involved in upbringing of land cover and land use changes (Ahmad 2012).

Recently several change detection techniques have been developed that make use of remotely sensed images. A variety of change detection techniques and algorithms have been developed and reviewed for their advantages and disadvantages. Among these Unsupervised classifications or clustering, Supervised classification, Principal Component Analysis (PCA), Hybrid classification and Fuzzy classification are the most commonly applied techniques used in classification (Lu et al. 2004). Among these, post-classification comparison was found to be the most accurate procedure by variety of studies as it offered an advantage of representation of nature of occurring changes. It compares classifications of images from different dates, which are independently produced in order to detect land cover changes (Ding et al. 1999).

Supervised and unsupervised image classification methods have been applied by using Multi-spectral (MS) and pan-sharpened images. For the supervised method, training samples could be

selected through interactive visual on-screen inspection. Training sites should be selected for each track of the image and for each of the MS and pan-sharpened images. Digital maps and aerial photographs also used for better recognition of training sites (Sohrabiniaa et al. 2008). A satisfactory spectral signature is the one ensuring that there is ‘minimal confusion’ among the land covers to be mapped (Gao and Liu 2010). After that maximum likelihood algorithm was used for supervised classification of the images. It is the type of image classification which is mainly controlled by the analyst as the analyst selects the pixels that are representative of the desired classes (Butt et al. 2015).

Changes in the land use in a watershed can affect water quality and supply. For instance, land use patterns change due to watershed development frequently resulting in increased surface runoff, reduced groundwater recharge and transfer of pollutants (Turner et al. 2001). Watershed management is necessary because a watershed is not merely a hydrological unit (but also socio-ecological being which plays a vital role in determining economical, food and social security and provision of life support services to local residents (Butt et al. 2015).

Changes in land cover/land use in watershed area including urbanization and deforestation continuously affect the water availability as well as the nature and extent of surface and subsurface water interactions thus influencing watershed ecosystems and the services provided by them. With proper understanding of the spatial and temporal variations occurring in a watershed over time and the interaction of the hydrological components of a watershed with each other, better water conservation strategies can be formulated (Ashraf 2013).

According to the fourth assessment report of Intergovernmental Panel on Climate Change (IPCC) in 2007, human activities, such as urbanization and agriculture, accounted for 90% of global warming (Pachauri and Reisinger 2008). Many experiments have been conducted to understand that there is close relationship between urbanization and climate change (Singh and Shi 2014). (Zhang et al. 2010) simulated the influence of urbanization on climate in the Yangtze River Delta by the application of weather research and forecasting (WRF) model and found out that the conversion of rural land (mostly irrigated cropland) to urban land cover results in significant changes to the near-surface temperature, humidity, wind speed, and precipitation.

Observations by (Liao et al. 2014) revealed that, by utilizing WRF model and MODIS data, intensive building clusters in mega cities in the Yangtze River Delta form the urban canopy layers and modify the surface energy budgets and surface roughness, which change thermal and dynamic characteristics of the surface layer. Both simulative and numerical analysis suggest that urban growth-driven land-use change significantly influences the surface heat balance, exchange of water vapor, and momentum between the atmosphere and the surface layer and consequently results in the changes of regional weather, especially the rainfalls (Pathirana et al. 2014) (Memon and Leung 2010) Global surface temperature trends, based on land and marine data, show warming of about 0.8°C over the last 100 years. This rate of warming is sometimes questioned because of the existence of well-known Urban Heat Islands (UHIs) (Böhm 1998). Arguments on the effects of urban development on large-scale warming climate still exist (Parker et al. 2006).

In Addis Ababa Urban Morphology Types (UMTs) based surface cover assessment showed that there is a considerable vegetation growth over many of the UMTs considered as non-green and impervious. Of course availability of vegetation is not evenly distributed across all the UMTs; rather it is strongly influenced by UMT types. As an example, high proportion of green is observed on the forest, crop fields and vegetable farms but low on the peripheries of impervious surfaces (Woldegerima et al. 2017).

2.2. The river system in Addis Ababa

In Ethiopian context, where watersheds of many urban centers receive significant amount of annual rainfall and where rainfall intensity is generally high, control of runoff at the source, flood protection, and safe disposal of the excess water/runoff through proper drainage facilities become essential (Adugna et al. 2019). Ethiopian urban centers posed a serious drainage problems including flooding, deterioration of roads, land degradation, sedimentation, water logging, blockage of drainage facilities and the like.

The technologies in handling the environmental problems of urban storm water drainage in Ethiopia, which have been practiced, are not in a position to utilize the flood/runoff for various uses, like the treatment/sedimentation of runoff water, construction of detention ponds and other perforated structures for the water to be infiltrated in to the soil, rather the primary aim of urban

storm water drainage system in the country is to safely discharge the storm/run-off out of the urban centers (Belete 2011).

City of Addis Ababa is situated at altitude varying from 2350 to 2700 meters. Undulating and flat topography of the city spreads to the southern slopes of Entoto Ridge. The urban land includes valleys formed by five river systems flowing towards south. Flat topography gradually slopes to the south easterly direction (JICA 1998). The following table shows the principal features of the river system flowing in Addis Ababa.

Table 2-1: Channel characteristics of Addis Ababa rivers (JICA 1998)

River System	Average slope	Channel Width (m)		Carrying Capacity (m ³ /s)
		Minimum	Average	
West Akaki	1/100	15	40	400-800
Little Akaki	1/50	5	20	50-300
Kebena	1/50	5	25	150-800
Bantyketu	1/120	10	20	30-150
Kechene	1/30	8	15	50-250
Kurtume	1/35	8	10	30-150
Hanku	1/160	5	10	20-150

The river channel characteristic of the city has been computed based on the river survey and the hydraulic analysis made by Nippon Koei and JICA. Channel width and the river carrying capacity were among the important information compiled. A study by Adugna et al showed that 14% of the drains in in the Addis Ababa new city parts and 28% in old city parts were in conditions inadequate for removal of storm water, resulting in flash flooding and infrastructure degradation in the associated watersheds. Further, more than 72% of the surveyed drains were oversized, storm water overtopping reoccurs as a season-to-season problem, ascribed to illegal dumping of waste into drains, reducing their hydraulic capacity (Adugna et al. 2019).

Flooding during rainy season is also affecting the lives and livelihood of residents specially, in the downtown of the city where houses and shelters situated closer to the rivers. The picture below shows the flooding extents and the lack of flood prone areas buffer zone. Recently the frequency of the disasters happening to the residents living near by the rivers is escalating due to the anthropogenic causes and climate extreme events frequently happening to our world.



Figure 2-1 Flooding in big Akaki and Kebena rivers (a) Kebena river (Tafete 2013) (b) settlement near the river (Yohannes and Elias 2017)

2.3. Pollutants and Waste management in Addis Ababa city

A study made on the Addis Ababa rivers of Little and Big Akaki for various physical and trace metal parameters shows that the Little Akaki is more polluted than the Big Akaki. The water quality and sediment quality of both rivers is also linked to anthropogenic sources with the intensity of human pressure associated with industrial effluent, domestic waste and agricultural activities (Tolla 2006). The low oxygen level and the high level of metals and other toxic compounds in both the Big and Little Akaki rivers are manifestations of this situation. In fact, these rivers do not contain higher aquatic species, such as fish. The only species to be found are worms (i.e. *Tubifex tubifex*) that can survive under low oxygen conditions (Teklehaimanot 2003). In Addis Ababa both point and non-point source of pollution observed in the river water. The major pollutants are listed below:

2.3.1. Solid waste and Domestic swage

In most developing countries city, the rate of urbanization and availability of both solid and liquid waste removal facility are not balanced to the development rate. According AACC (2004), the daily waste generation is estimated about 0.252 kg/capita/day, 65 % of municipal waste is collected in the city, surface water bodies receive the major parts of waste produced by the residents and various factories (Negash 2009).

Despite generating large amounts of solid waste from domestic activities, Addis Ababa does not have adequate waste management facilities. As a result, solid waste is often piled on available open grounds, stream banks and near bridges, where it is washed off into rivers (Yohannes and Elias 2017). In some small tributaries of the city, toilets are built right on top of the rivers, they don't even have cesspool to store and connect to the rivers.



Figure 2-2: Solid and liquid pollutants discharged into the river system (Source: (Yohannes and Elias 2017))

2.3.2. Industrial Waste:

Most of the medium and large scale industries in Ethiopia (more than 65%) are located in Addis Ababa and the nearby town of Akaki (South western part of the city) (CSA 1999) and the majority of this industries discharge their untreated waste directly into the Akaki Rivers. The predominant industries in Addis Ababa and the surroundings can be categorized into the following namely; food and beverages, leather and footwear, wood, paper and printing, textiles, tobacco, chemicals, non-metals and metals (CSA 1998).

A study by Leta et al revealed as much as 90% of these industries do not have any kind of treatment plant and discharge their solid, liquid and gaseous wastes untreated into the environment (Leta et al. 2004). Similarly study by Desta et al in 1990 only 6% of the industries in the city of Addis Ababa and the surroundings had treatment plants. This figure did not rise significantly by 2000, i.e. 20% had treatment plants (Desta 2000). Currently a lot of initiatives exist particularly in the Awash basin to monitor the industries waste discharge into the rivers and

give a permit for the industries who have the waste treatment system functioning based on the polluter pay principle.

2.3.3. Agricultural waste

In the peripheral parts of Addis Ababa, crop production and animal husbandry is carried out extensively on an individual or cooperative basis. Cattle in the city reared in the compounds of the individual owner or in the open spaces and along the river banks. It is to be expected that a substantial amount of organic waste is generated from cattle raising. In the rural areas the predominant agricultural activity is crop production using small plots of land (ESTC 2005).

One of the major pollutants with regard to agriculture is associated to erosion of the soil in the upper catchments of the river as a result chemical fertilizers supplemented to increase productivity also enter the streams. This in turn contributes to the eutrophication of the streams in and around Addis Ababa. One of the main components of chemical fertilizer in Ethiopia, i.e. urea, is a major polluter of groundwater systems. This is mainly a result of the associated nitrate which is mobile in subsurface flow system (Tamiru et al. 2004).

2.3.4. Garage and petrol station

Petrol Stations in Addis Ababa are built at random locations. The main petroleum depots including the ones for NOC, Oil Libya and Total are all situated in the southern part of the city, in close proximity to the main industrial region at Kaliti. Also, services like the washing and greasing of cars, oil, washing solvents and other related contaminants enter surface water bodies. This in particular may be a major source of pollution since the high-jet pressure water, used during the cleaning process, generates a high amount of liquid waste which ultimately joins the surface water body in the proximity (ESTC 2005).

In Addis Ababa around 400 garages, excluding those built for nonprofit purposes in governmental and non-governmental organizations exist. Untreated wastes generated from this sources pose ecological and human health implications are to be expected. For instance, damages to plants were observed in streams having a high level of used black oil (Tamiru et al. 2004).

2.3.5. Health facility

Health facilities are among the important sources for the waste generated in the city of Addis Ababa. Among the types of wastes generated by such sources are pathogenic substances and hazardous wastes that include chemicals, solvents, disposable syringes and needles. As the number of health facilities has increased dramatically in the last two decades, solid waste generated from this facility will increase (ESTC 2005).

Most health facilities have incinerators to dispose of the toxic and pathogenic waste they generate. However, some health facilities have also been observed to utilize the garbage containers that provide services to all residents (Tamiru et al. 2004). Although obligatory to have incinerators and other specialized waste disposal facilities in such health delivery centers, the limited follow-up and lack of proper mechanism for enforcement is a serious concern (ESTC 2005).

In addition, atmospheric pollution particulate emissions by vehicles and motors, by product of open air burning of municipal and industrial solid waste and garbage; all of these will eventually transported to the inner and central Akaki River by precipitation and drainage (Negash 2009).

2.4. Morphological change and morphometric characteristics

Drainage morphometry is defined as a measurement of linear, areal and relief characteristics of any drainage basin (Clarke 1966). Drainage morphometry was first initiated by (Horton 1932). The drainage morphometric characteristics are important to understanding the underlain structure, geomorphological formations and hydrological characteristics of any basin (Oberlander and Morisawa 1985). The geomorphological stages of evolution with its erosional characteristics can also be best understood through the various drainage morphometric parameters (Strahler 1952). It provides huge idea to identify the morphological, hydrological problems and helps with related management procedures.

An assessment made to study the hydro morphology of the Danube River in Europe shows people change the natural course of the river for hydropower generation, flood defense and

navigation. These changes affected the ecological quality of the rivers and reduced their naturalness. The study shows 40 % of the investigated course of the river is still in healthy ecological condition. Although some part of the river is strongly altered by the human activity, the overall river course shows positive status and additional restoration activity is necessary. The holistic view of rivers and lakes is that as well as physico-chemical conditions, type-specific hydrological, morphological and river continuity (hydro-morphological) aspects of the Danube are crucial for the good functioning of the aquatic environment. The specific hydro morphological components that are relevant to ecological status and support the biology of a water body are listed in the table below (Mandl 2015)

Table 2-2 hydro-morphological components for water body (Mandl 2015)

Morphology	Hydrological regime	River continuity
River depth and width variations	Quantity and dynamics of flow	for aquatic organisms
Structure and substrate of river bed	Connection to groundwater bodies	for sediment transport
Structure and conditions of riparian zone		
Flow velocities		

Maidment (Maidment 1993) have established some of the relationships between hydrologic and geomorphologic variables using statistical methods. The morphological and climate characteristic of a basin govern its hydrological response to a considerable extent. Linking of the morphologic parameters with the hydrologic characteristics of the basin can lead to a simple and useful procedure to simulate the hydrologic various bases particularly the un gauged ones (Singh et al. 2003).

(Ansari et al. 2012) found remote sensing and GIS as an efficient tool to understand the morphometric behavior of any plain topographical area. The anomalies in drainage morphometric parameters are an important indicator of active tectonics. Remote sensing and GIS have proved as efficient tools to understand this phenomenon (Bali et al. 2012; Pareta and Pareta 2012). (Parveen et al. 2012) have found remote sensing and GIS as a very helpful tool to understand the topographical and drainage morphometric characteristics in plateau regions of the

world. The results of morphometric analysis from remote sensing and GIS techniques are useful for hydrological implication of river basin and artificial recharging structure (Golekar et al. 2013). The remote sensing and GIS-induced morphometric parameters are proved to be immense utility in natural resource management, water conservation and river basin evaluation (Singh et al. 2013).

Only very few studies were done so far in Ethiopia on drainage morphometric analysis and characterization. Analysis of morphometric parameters in Dire-Dawa indicated that pattern of stream networks is less controlled by structural condition though the area is situated in the rim of the great east African rift valley; and its geomorphic development is at late youth stage (Moges and Bhole 2015). Similarly, Study on lake Hawassa shows the Ethiopian Rift Valley lakes have been subjected to environmental and ecological changes due to recent development endeavors and natural phenomena, which are visible in the alterations to the quality and quantity of the water resources (Abebe et al. 2018).

In the lake Tana catchment a study to investigate the Gumera river planform and cross-section change contribution to the flooding and vice-versa shows the flood caring capacity has diminished in recent time due to anthropogenic impacts (irrigation and construction of dykes) (Abate et al. 2015). Another study on the same sub-basin investigated the effect of land use and land cover change on increasing the suspended sediment loads and fine sediment settling in areas with low flow velocity, such as flood plains and low-gradient reaches of the Ribb river (Mulatu et al. 2018).

2.5. River water quality assessment and Models

Many urban rivers are stressed by various loads such as nutrients, heavy metal, personal care products or drugs resulting from combined sewer overflow, highly polluted surface runoff after heavy rainfall or their functioning as receiving waters. The biodiversity and ecological state of many urban rivers is considerably impoverished compared to natural freshwater bodies (Walsh et al. 2005).

In rapidly expanding urban area with high level of human activities, there have some serious problems in urban rivers such as consume a lot of water resource, decline in biodiversity, emit

large amounts of pollutants, and so on. Urban river natural and economic functions have seriously decreased and social and economic sustainable development has restricted (Zhang Yuhua 2016).

High biodiversity of aquatic species and the presence of sensitive species are good signs of a healthy stream. Nature of the river as a collection point for water flowing from every corner reflects the health of the surrounding area. Therefore, any changes or modification on riparian vegetation and surrounding landscape may subsequently alter the composition and functional structure of aquatic life inhabiting it. Healthy water body shows ecological integrity, which represents the natural or undisturbed area (Salmiati and Salim 2017).

The ecological status and resilience in the major rivers in Addis Ababa with macroinvertebrates and diatoms as indicator organism's assessment showed little presences of both organisms in the sampling sites in Akaki river, which indicates a low ecological status. The protection of water resources and natural resources received inadequate attention at all levels in Ethiopia. This has been manifested in the gross pollution of many rivers as a result of rapidly increasing urban population and intensified agricultural and industrial activities (Beyene et al. 2012).

In Akaki river, vegetables are irrigated either from the river water which is contaminated with toxic substances dumped into it from nearby industries and/or through industrial liquid wastes directly applied on the farmlands. The vegetables have been growing in this manner for the last three decades (Itanna 1998). A study also assessed the impacts of human activities on the Big Akaki River using physicochemical parameters and macro-invertebrate metrics. In the Big Akaki River the upper reaches were characterized by greater number and diversity of taxa while the middle and lower reaches were dominated by fewer tolerant taxa (Akalu et al. 2011).

2.6. Nutrient pollution on rivers

There are several previous studies on river water quality in Ethiopia and Addis Ababa. (Awoke et al. 2016), focused on ecological status of major river systems in Ethiopia, by evaluating physio-chemical parameters and bio indicators. The physio-chemical parameters showed a deterioration of water quality in surface water in the rivers compared to non-impacted sites, and the study determined that the river water pollution in Ethiopia is increasing. (Eriksson and Sigvant 2019).

Anthropogenic source of phosphorous and nitrogen is untreated or insufficiently treated wastewater. The average nitrogen and phosphorous content in excreta from adults in the Ethiopian Village Bolo Selassie (located 75 km east of Addis Ababa) is 3.9 kg per person per year and 0.85 kg per person per year respectively (Järnberg et al. 2018). This amount highly depends on the diet. In addition, washing clothes in lakes and rivers is a common practice in many developing countries like Ethiopia and such activities directly add phosphorous through usage of soaps and detergents that contains high amount of phosphates.

High phosphorous loads are usually the main cause since it is normally the limiting nutrient in surface waters. Phosphorous in water exists in soluble and particulate form and is transferred from soil to surface water through erosion and runoff. The usage of fertilizers in agriculture may cause an increased leaching of phosphorous as well as nitrogen. Phosphorous and nitrogen are also transferred from animal excreta disposed close to the river by riverside grazing (Mekonnen and Hoekstra 2018).

Water-quality degradation associated with high phosphorus concentrations are key water-quality concern in many of US rivers and streams (USGS 2020a). Bank erosion during floods can transport a lot of phosphorous from the river banks and adjacent land into a stream, lake, or other water body (USGS 2020b). Moreover, Phosphorus (P) fertilizer has contributed to the eutrophication of freshwater ecosystems. Watershed-based conservation programs aiming to reduce external P loading to surface waters have not resulted in significant water-quality improvements (Stackpoole et al. 2019).

2.7. River rehabilitation Experience

Polluted rivers in urban areas began to draw public attention in the 1980s and 1990s and variety of efforts have been made to restore urban river streams in many counties, particularly in Europe and the united states (Lee and Choi 2012). River and floodplain rehabilitation and restoration embraces a great variety of measures having in common the emphasis on natural functions of rivers, which may have been lost or degraded by human interventions (e.g. damming, construction of levees and embankments, sediment dredging, changing of natural forms of rivers, construction of infrastructure on the floodplain, etc.). Several European rivers have been significantly modified in the past decades to serve only one dominant function (e.g. navigation)

or few more. However, one-sided use is no longer optimal and is being replaced by an integrated approach. River and floodplain restoration is done to mitigate the negative effects of human modifications, which does not only produce benefits for the ecological functioning of the river but also for the human society (Climate-adapt 2019)

The diversity of a river's ecology, the presence of habitats, and a river's potential for recreational purposes highly depends on the quality of the water. Fluvial and ecological processes happening in the river stream sustain habitats including animal and plant life. Rivers serve human beings by supplying water, mitigating floods, and receiving waste water and these activities have led to the biological death of many rivers in the world, thus attracting the attention of scientists (Paul and Meyer 2001).

South Korea has various experience in river restoration works including the very controversial four rivers restoration project on the Han River, Nakdong River, Geum River and Yeongsan River. The five key objectives of the project was securing abundant water resources to combat water scarcity; implementing comprehensive flood control measures; improving water quality and restoring river ecosystems, creating multipurpose spaces for local residents; and regional development centered on the rivers.

The challenge on the rivers before restoration includes flood damage have been about £600 million a year in the areas surrounding the major rivers; riverbed levels have become elevated and flow sections and capacity have been considerably reduced; water quality in some parts of the rivers is also not potable due to run-off from adjacent agricultural and industrial activities; insufficient water volume, which may cause drought and in addition to the above, the effects of global climate change are likely to make the situation more critical (Shin and Chung 2011). Additionally the waterfront parks can reduce the healthcare expenditure of residents in surrounding areas significantly compared to general land parks (Rosenberger et al. 2005).

Like many other river development projects, the project faces some opposition from environmental organizations. Environmental activists demand that the present river systems be kept intact. Environmental assessment of the project revealed that temporary damage to the river ecosystems cannot be fully avoided during the dredging work. However, it also revealed that the river environment will become healthier and diverse within a few years (Shin and Chung 2011).

The opposing political party utilized environmental groups and NGOs to voice opposition to the project. A dispute started to arise when environmental societies asserted that the rare wild plant ‘Danyang aster helophyllus’ only found around the Southern Han River was threatened with extinction because of project constructions. (Cha et al. 2011).

The other most praised project in Korea is the Cheong Gye Cheon community-driven scheme to demolish a 6 km long, 10-lane stretch of concrete highway in the middle of Seoul city to bring the old Cheong Gye Cheon river underneath it back to life. It has created a much-needed green corridor in the post-industrial center of one of the world's largest cities (Shin and Lee 2006).

Similarly, in USA rivers rehabilitation efforts were launched with a view to improve riparian zones, ameliorating water quality, improving stream habitats, stabilizing banks, etc. Essentially analysis on how much the rivers benefit from rehabilitation efforts and the authorities need to gather proper information regarding the strength of their strategies. To this end, a huge program, the National River Restoration Science Synthesis (NRRSS), has been launched by the USA incorporating freshwater scientists and their river rehabilitation experiences (Madsen et al. 2006).

According to the US National Research Council, in the twentieth century, the mighty Missouri river was altered by the construction of dams, reservoirs, and navigation channels for commercial purposes, all to produce many social benefits. Unfortunately, the toll for this was paid by the loss of habitats and extinction of many fish species (Council 2002). In contrary, Australian river rehabilitation projects are well-judged before the initiation of the projects based on the experiences of the USA, Spain, and other developed countries (Madsen et al. 2006).

Ethiopia has also launched the rivers side development project with the purpose of making the river water shade clean; to create public space along the rivers which will be suitable for several activities and to increase the green space of the city. This project stretch in two rivers and it will widen the river up to 20m and create an average green space of 50m.

CHAPTER 3. MATERIALS AND METHODS

3.1. Study area

To study the morphologic change and the related environmental impact in Addis Ababa city between the years of 2006 and 2016 two river reaches has been selected. The Kebena river from the confluence of Kebena and Bantiketū Rivers at Peacock Park up to the ring road bridge around St. Joseph church which bounds between geographic coordinate of 8°59'52'' N and 38°47'33'' E and 8°59'31'' N 38°46'57 E and the big Akaki river course starting at the confluence of big Akaki and Kebena rivers up to the Akaki Bridge bound between geographic coordinate of 8°56'07'' N and 38°46'48'' E and 8°52'27'' N 38°47'46'' E. In the study area, old settlement sites of the city, major infrastructures, commercial areas, airport, huge new settlement areas and other industrial and sub-rural settlements are located. Both river reach possesses unique features that tell the cities characteristics. The criteria for the selection mainly is with the consideration to topographical, accessibility, settlement density, land use variation, data availability as well as purpose of the study to signify diverse characteristics.

3.1.1. Location and Topography

The study area is located in the Big Akaki river, at the upstream of the Awash river basin. The river network within Addis Ababa can be divided into two catchments, the big Akaki catchment (900 km²) and the little Akaki catchment (540 km²) (Aschale et al. 2017). Hence, Addis Ababa city's more than half of its area is laid in the big Akaki sub-basin. Two water supply reservoirs namely Legedadi and Dire are also located in the upstream of this watershed just outside the city's boundary. Addis Ababa is Ethiopia's largest city and it is administrative and communications Centre. It is the main Centre for trade and the nation's service and finance sectors. Also, the major industries producing food, beverages, processed tobacco, plastics, chemical products, textiles, cement and leather are located in the city. In addition, The African Union and the UN Economic Commission for Africa are headquartered in Addis Ababa, which turned into a hub for the large tourist industry and hosts numerous international conferences.

There is a high topographic variability particularly the elevation and slope decrease between the northern and the southern part of the Big Akaki watershed. The northern part is part of Entoto

Mountain and Sendafa area characterized by steep slopes and flat-topped plateaus while the southern part has a gentle slope to flat.

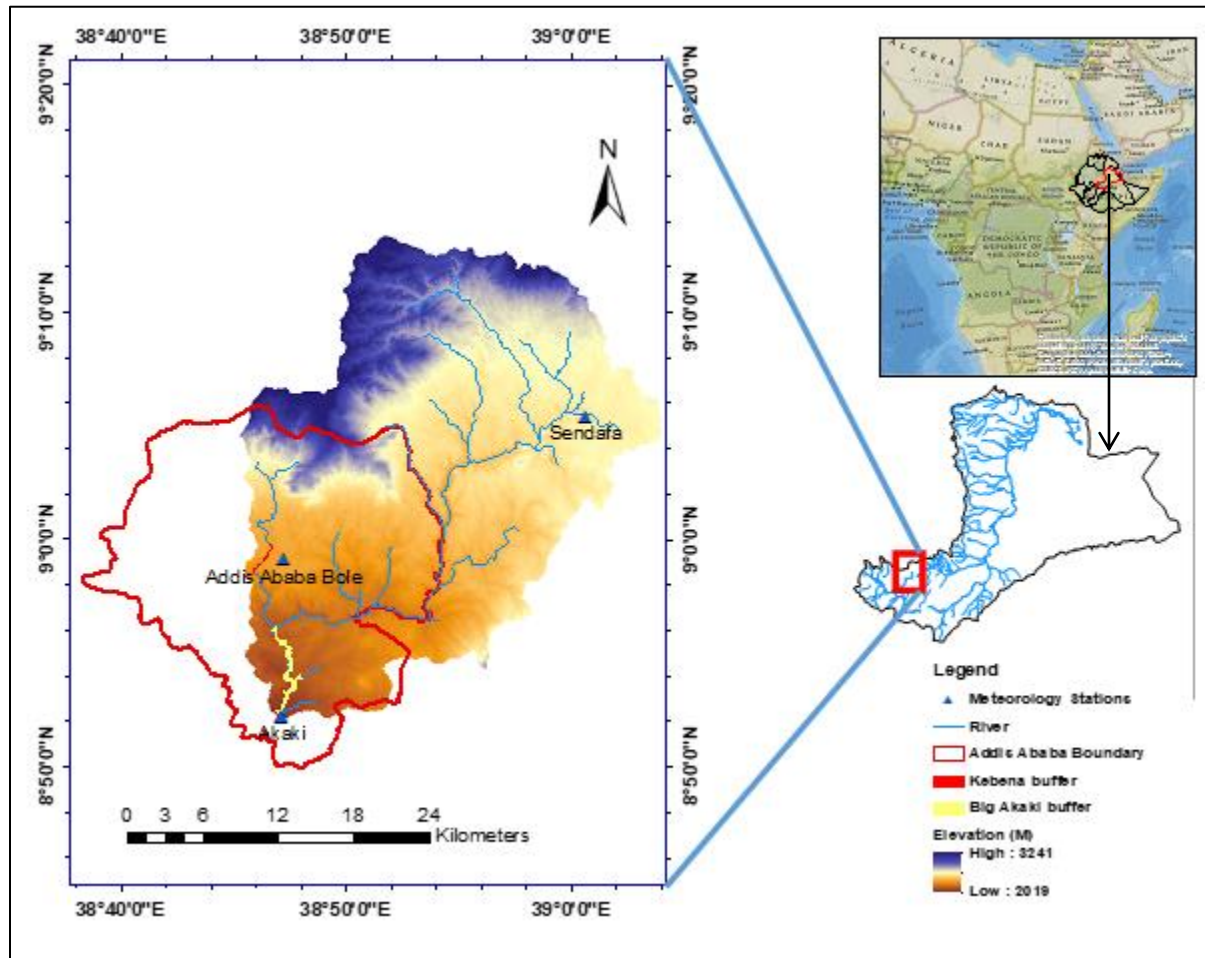


Figure 3-1: Location of the study area in Africa

3.1.2. Climate

High annual rainfalls in the region of Addis Ababa occur when the moist wind is forced to rise in order to pass over mountains; such conditions prevail especially along with the mountain ranges that extend early at right angles to the prevailing storm movements. The highest and lowest mean maximum temperature over record periods is 25°C in dry season and 20°C in the wet season, while the variation of mean monthly temperature values falls in the range of 7°C to 12°C throughout the year, the entire study area shares the same climatic condition as that off Addis Ababa, therefore the rainfall patterns of the catchment area has a bimodal profile with strong peaks in the summer months and minor rainfalls in the months of March and April. The main

rainy season, which is characterized by intense rainfall of short duration, is responsible for 70% of the annual average rainfall of 1400 mm (Girmay 1985).

3.1.3. Geology and soil type

Geologically, Addis Ababa lies on volcano rocks with basaltic lava flows and welded tuffs found at different localities and ages with minor amounts of fluvial sediments (Girmay 1985). It is rambled with across many wooden hillsides and gullies cut through with fast-flowing streams. The situated hill chain (Entoto) in the northern part of the city is composed of Termaber basalts. The urban area is composed of younger basalts called Addis Ababa basalts which are also covered with volcanic topsoil materials. The western part belongs to younger age stratum; The northern part is mainly composed of Trachy basalts. In the Bole area, a kind of volcanic rock called Ignimbrite is partly found. The topsoil materials in the western part are thick and soft compared to those of the northern and eastern parts (JICA 1998).

The soil of the Big Akaki watershed mostly constitutes with vertisol followed by luvisol, and the least soil type available in the area is Nitisol. Two soil types namely the cambisol and leptisol also exist in the area. The figure below shows the soil map of the study area.

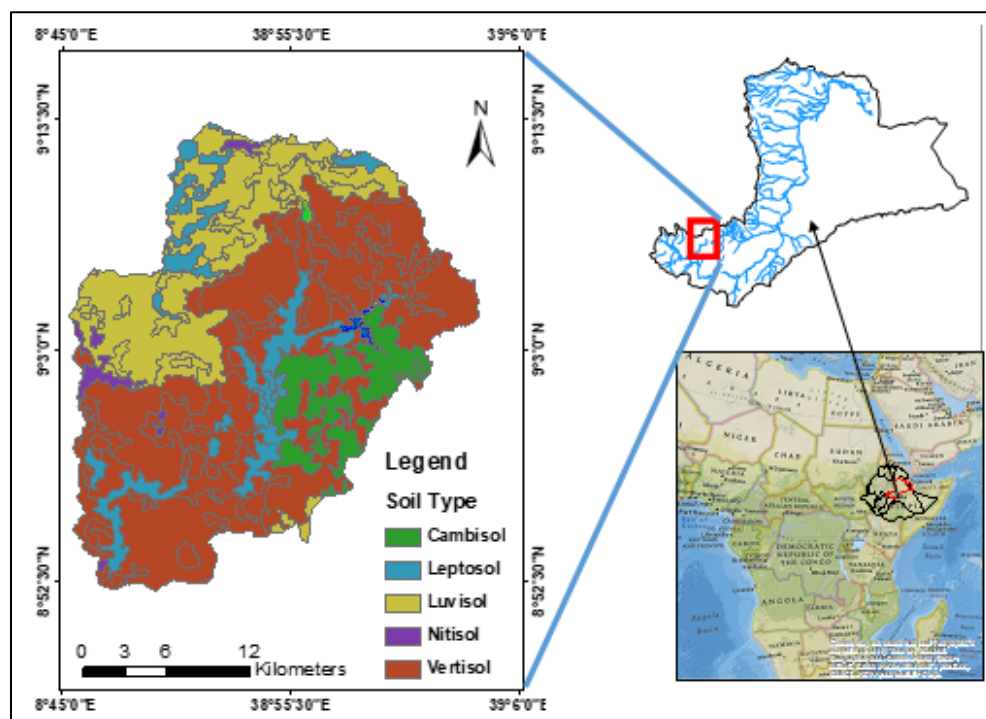


Figure 3-2: Soil map of the study area

3.1.4. Drainage and Reservoirs

The big Akaki river has many tributaries among which Ginfile, Kebena, Kechene, Kurtume Bantyeketu and Yeka are all found within the eastern part of the city boundaries. During the rainy season, the city appears cleaner from wastes. Even though rivers and streams represent self-renewing resources, continuous input of wastes may change them into natural sewerage lines. In the upstream part of the river two reservoirs exist namely the Legedadi and Dire. The main purpose of both dams is for water supply to the Addis Ababa city. The big Akaki river eventually flows to the Aba-Samuel reservoir to join the Little Akaki river.

The Legedadi reservoir is situated about 30 km northeast of Addis Ababa (Figure 3.3). It is built for a single-purpose to provide drinking and household water supply for the city of Addis Ababa since 1971. The reservoir is located around $9^{\circ} 20' N$ and $38^{\circ} 45' E$ at an altitude of 2450 (m.a.s.l.), paved close to the main road to northern part of the country. The reservoir is extremely irregular shaped constructed with a maximum depth 34 m close to the dam and minimum depth of 4m at the periphery and the reservoir covers an area of 200 km^2 . The live storage has a level range between 2446 and 2466 (m.a.s.l.). The theoretical residence time of the water is 200 days, at full supply level. The second reservoir existing in the watershed is the Dire dam. The reservoir storage volume is 19 Mm^3 for water supply purpose to Addis Ababa and to Dire-Legedadi aqueduct. The dam is an earth-fill dam with impermeable core with 45.96m high, 1980m crest length, 2.67 Mm^3 volume and possess a spillway to discharge excess water.



Figure 3-3 Areal view of reservoirs in the study area upstream of Addis Ababa city (a) Legedadi and (b) Dire Dam

3.1.5. Socioeconomic development and governance

The big Akaki watershed includes both urban and rural areas. The watershed lies both in the Addis Ababa city administration and the Finfine Zuria Zone of the Oromia region. The Addis Ababa city founded in 1887, is the Centre of legislative, executive and judicial power to the federal government. The city has Ten sub-cities in total, among this the Gulele, Yeka, Arada, Bole, Kirkos, Nifas silki laphto and Akaki Kaliti lay on the big Akaki Watershed. In addition, towns from the Finfine zuria zone such as Sendafa, Kara and so many small villages are located in the study area. The main source of economy to the rural area is agricultural practices. While the urban community have different sources of income as the city is under development.

3.2. Materials

3.2.1. Topographic and Satellite image

Digital Elevation Model (DEM) 30*30m from the SRTM has been used to delineate the watershed and extract the stream network by considering 1% of the watershed area. Other related shape files, to process the DEM, has been collected from the Ministry of Water Irrigation and Energy (MoWIE). Spot image of 2006 and 2016 with 5m and 1.5m resolution respectively bought from the Geospatial Information Institute (GII) as shown in Fig 3.4. SPOT is a commercial high-resolution optical imaging Earth observation satellite system operating from space. The images are converted to a similar resolution for analysis purpose. It has been used for the assessment of land-use change for the study period. In addition, historical Google earth images were utilized for identification of the vegetation area and the river course for the Kebena and big Akaki rivers. Moreover, the future land use plan of the 10 years' master plan was collected from the Addis Ababa city plan commission to understand the future plan on the city's river reaches and buffer zone delineations. The primary investigation of the river reach condition has been conducted with consecutive field visits at the river courses and the watershed.

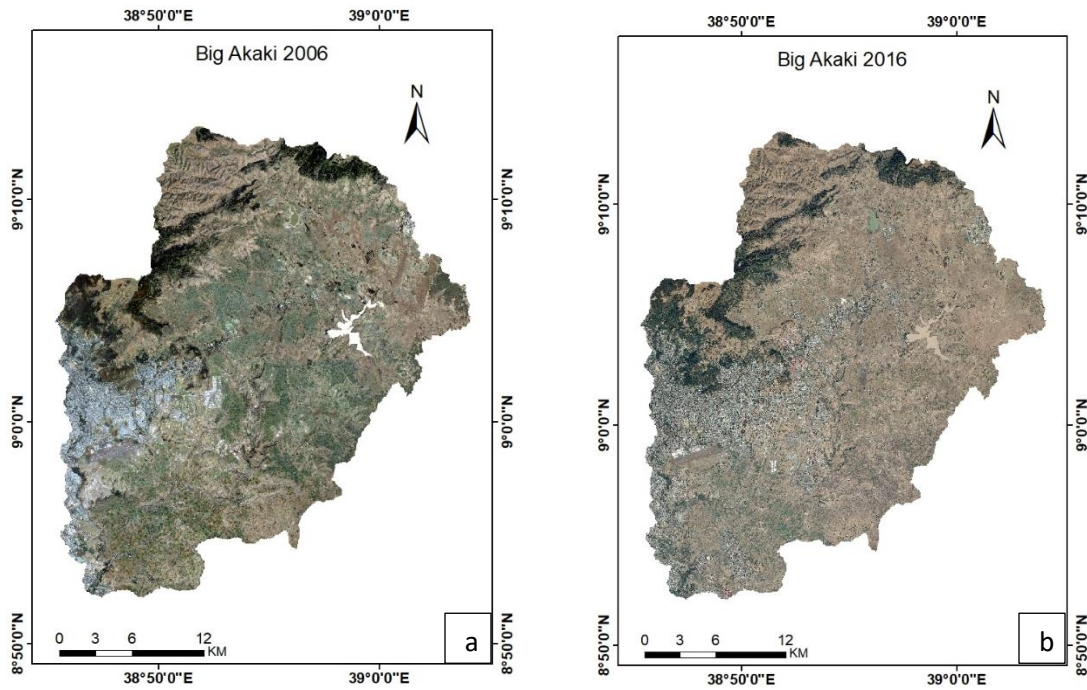


Figure 3-4 Spot satellite image of Big Akaki watershed (a) 2006 and (b) 2016

3.2.2. Meteorological and Hydrological data

Rainfall data has been collected from the National Meteorological Agency (NMA) mainly from three meteorological observation stations in the big Akaki sub-basin. Additional meteorological station has been used for data gap filling on the three selected stations.

Corresponding to the precipitation data, stream flow data for calibration and validation of the hydrologic model has been collected for the time period between 2000 and 2016. In this watershed, only one stream gauging station is available at Akaki near Akaki (Tirunesh-bejing bridge). The stream flow data is collected from the Hydrology and Water Quality Directorate of the Basin Development Authority (BDA/ MoWIE).

Table 3-1 List of selected Meteorological and Hydrological gauging stations used for this study

Type	Name	Latitude	Longitude	Period
Precipitation	Addis Ababa (Bole)	9°02'00''	38°45'00''	2000-2016
Precipitation	Akaki	8°52'11''	38°47'10''	2000-2016
Precipitation	Sendafa	9°09'08''	39°01'17''	2000-2016
Hydrologic	Akaki @ Akaki	8°53'00''	38°47'00''	2000-2016

Primary flow measurement data for the water quality model calibration has been collected. The need for flow data that corresponds to the nutrient loads is crucial for better estimation of nutrient loads with the model calibration and validation. Standard techniques and measurement with the HWQD/BDA have been used to measure the flow by wadding (with price AA current meter) and floating for the low flow period and ADCP measurement using instruments for high flow measurements by applying standard procedures. The figure below shows the data collection both at Kebena and Big Akaki rivers.



Figure 3-5 Flow measurement (a) Kebena river at st joseph church (b) Akaki at Akaki bridge

3.2.3. Water quality sampling

The use of secondary water quality physico-chemical parameters has been a significant input to understand the water quality characteristics of the river over the study period. A different source of data has been compiled. The Oromia water mineral and energy bureau with EU-WFF project and the basins development authority have some data on the river. Previous environmental, water quality, ecological, river health and their implication studies have been incorporated into this study as a source of data and as an indicator. In addition, environmental impact assessment and evaluation documents and reports from the governmental agencies that have been conducted in different time and scales were collected as well. The use of secondary data of nutrient concentration collected by different organizations and researchers used as a crucial input for the nutrient load model calibration and validation specially for historical periods.

Moreover, primary data collection has been done in both the Akaki and Kebena rivers together with flow measurement after an intensive preliminary survey to decide the sampling location. Both the physico-chemical and nutrient concentration were tested at the field and in laboratory. The figure below shows instrument calibration and water quality data collection.



Figure 3-6 Physical parameter measurement at the field (a) & (b) instrument calibration (c) & (d) water sampling

3.3. Methodology

On both big Akaki and kebona rivers, data for the morphological, hydrological and water quality has been collected inline to the scope y and availability of resources to the study. The two river reaches are a distinct section which represent a different type of land use, urbanization and

settlement as well as different socio-economic activities. To understand the linkage between urbanization and climate change, detailed land use change analysis using supervised classification with ground truth signature files has been done for a period between 2006 and 2016. In addition, the morphometric characteristics of the two river reach has been analyzed using the satellite images of 2006 and 2016 dry season.

Water quality results analysis of the Physico-chemical parameters were compared for temporal variation over the specified time period. Next, the stream flow, using HEC-HMS, simulated for the same period of time. Following the nutrient loads estimation with the validated model has been run by using the flow hydrograph acquired from the stream flow model. Finally, a mitigation measure and Best Management Practice (BMP) has been suggested to combat the current environmental implication.

3.3.1. Analysis of Land cover change

The land cover change detection is done using GIS and remote sensing techniques. The satellite images acquired from the SPOT missions have been delineated for the watershed. This study uses the 2006 and 2016 satellite data to evaluate the typical landscape change over the decade. Both the pre-classification and post-classification change detection analysis approaches were implemented to assess the changing scenario. The image classification has been done using maximum likelihood supervised classification technique. Signature classes of the significant land cover category have been assigned. Broadly it is categorized into five land cover types namely cropland, built-up, bare land, forest and water.

This classification is established based on quantifying the major environment implication of the change as well as the land use change characteristics of the watershed. It has also been validated from ground truth data collected by different institutions such as the Awash basin development office. After ensuring satisfactory accuracy values for each classified image, various statistical calculation of the classified land cover types and change dynamics, the changes were quantified with percentage to evaluate the conversion rates.

3.3.2. Hydro-morphology change detection and analysis

Historical images over the study period, from Google Earth various missions have been utilized for identification of river morphology change. In ArcGIS 10.4, the channel vegetated area, the

active channel area and the water surface have been considered for the same months of dry season. The buffer area is calculated from the free settlement areas on the riverside and the built-up area. While the active channel has been derived from both the area of the river water body as well as from vegetated bars near to the water.

Morphometric characteristics were calculated for the two river reaches both in 2006 and 2016. As an indicator of the morphology changes including channel width (W), water flow length (S), section length (L), erosion area (EA), Sediment area (DA), and alluvial bar length (BL) were calculated for the study period. The erosion area (EA) is the area created by channel variation process during a period where channel turned to be part of the active channel at one time. DA is the area of the active channel that has been changed to other land cover types (Grenfell et al. 2014; Yousefi et al. 2019). In addition, the morphological indices such as the sinuosity index (SI) (Eq. 1) and the River Network Change Index (RNCI) (Eq. 2) were calculated using Google earth and ArcGIS10.4.

$$SI = \frac{S}{L} \quad (1)$$

$$RNCI = \left(\frac{\sum EA - \sum DA}{L} \right) / Y \quad (2)$$

Where, Y is the number of years between start and the end of a period.

3.3.3. Hydrological model simulation

The HEC-HMS model has been used to simulate the big Akaki river watershed. The model is capable of simulating historical hydrologic time series and predicts future scenario. The model has been used for sub-basins of the watershed after calibration and validation with the existing hydrological gauging station at big Akaki River. The calibration process is done for three years discharge data followed by the model validation process for another three years of datasets. As a result, the developed time series hydrograph will be used as an output for the flow estimation.

In this study, HEC-HMS rainfall-runoff model (CEIWR-HEC 2000) was used to simulate the water in the main Akaki and 10 sub-basins. HEC-HMS is capable of simulating runoff based on hourly to daily rainfall (CEIWR-HEC 2017). The DEM and other important components were analyzed using ArcGIS and HEC-GeoHMS (version 10.4). All the necessary processes that are

used to produce HEC-HMS project have been prepared using ArcHydro (Maidment and Morehouse 2002) and HEC-GeoHMS (CEIWR-HEC 2013) tools with input files of a stream network, sub-basin boundaries, and connectivity of various hydrologic elements. The HEC-GeoHMS in ArcGIS environment can create HEC-HMS project by terrain pre-processing and basin processing tools (Cho 2020). The ArcHydro is a geospatial and temporal data model for water resources that operate within ArcGIS. The attribute tables of the terrain were enriched with consecutive calculations on basin slope, river length, river slope, basin centroid, centroid elevation, and centroid longest flow path under “Characteristics” tool.

The land use and soil map were combined to generate the CN grid map through the HEC-GeoHMS tool “Generate CN grid”. A curve number grid was generated and with the “HMS” tool, the most common parameters in flood simulation were entered to develop the “HMS schematic” for importation into HEC-HMS. The Soil Conservation Service Curve Number (SCS CN) method for losses, the SCS unit hydrograph for transformation, monthly constant for base flow and Muskingum for channel routing methods have been chosen to simulate the runoff. After performing all the necessary process in the HEC-GeoHMS, the HMS model is exported for hydrologic simulation.

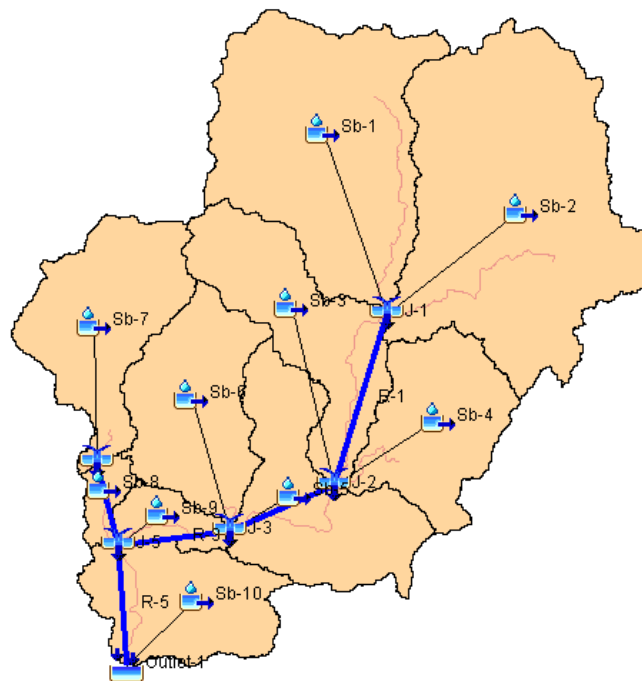


Figure 3-7 Sub basins for hydrologic simulation HEC-HMS (ver. 4.2.1)

A rainfall-runoff model parameter should be derived from calibration against one or more observed output variables (e.g. stream flow). The model parameters usually have some physical meaning and acceptable ranges for their values (Behailu 2004). Exact values for the parameters usually cannot be fixed in advance. Therefore, the HEC-HMS was set up by calibration and validation with six years storm between 2000 and 2005. The precipitation observed on three precipitation gauge and one hydrological gauge station were used to set up the model. The model estimates flow output and compares it with the observed flow at the Akaki gauge station. The statistical metrics are used to assess the model performance (i.e., the strengths and weaknesses of the model). This measures-oriented approach to model performance assessment focuses on several different aspects of the overall accuracy or skill of the stream flow model. The applied model is evaluated with a coefficient of statistics that intended to give a range of information (Kisi et al. 2013).

The coefficient of determination (R^2) used to describe the degree of correlation between simulated and measured data. It ranges from -1 to 1 and values close to 1 indicate least error. The statistical parameters and equations that were employed in this study are shown below:

$$R^2 = \left[\frac{\sum_{i=1}^n (O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^n (S_i - \bar{S})^2}} \right]^2 \quad (3)$$

$$PBIAS = \frac{\sum_{i=1}^n (O_i - S_i)}{\sum_{i=1}^n O_i} \times 100 \quad (4)$$

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \quad (5)$$

$$MAE = \frac{\sum_{i=1}^n |O_i - S_i|}{n} \quad (6)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (O_i - S_i)^2}{n}} \quad (7)$$

where, *PBIAS* is Percent Bias (%), *NSE* is Nash-Sutcliffe Efficiency, *MAE* is Mean Absolute Error (m^3/sec), *RMSE* is Root Mean Square Error (m^3/sec), O_i is measured flow (m^3/sec), S_i is

simulated flow (m^3/sec), and \bar{O} and \bar{S} are mean measured and simulated flow (m^3/sec), respectively.

3.3.4. Water quality sample analysis

Application of secondary water quality, data will be of great importance in the analysis as we are considering historical loads. Selected physico-chemical and nutrient parameters (T° , pH, NH_3N , PO_4^{3-} , NO_3 , COD, EC, TDS, salinity) are to be considered for this study. Similar to the morphology change the same catchments, one on the main Akaki River and the other on the tributary Kebena river has been selected for computation

In the primary water quality data collection, the instrument has been calibrated with buffer solutions before conducting the testing. This is done for the two sensors of pH and conductivity. The calibration is crucial in order to get the accurate results of the rivers water quality.



Figure 3-8 Water quality sampling in Akaki and Kebena rivers

For the nitrate and phosphate concentration test, a sample taken from the river has been analyzed at BDA/MoWIE laboratory using standard reagents and laboratory testing instruments such as photometer appropriate for river water quality testing.

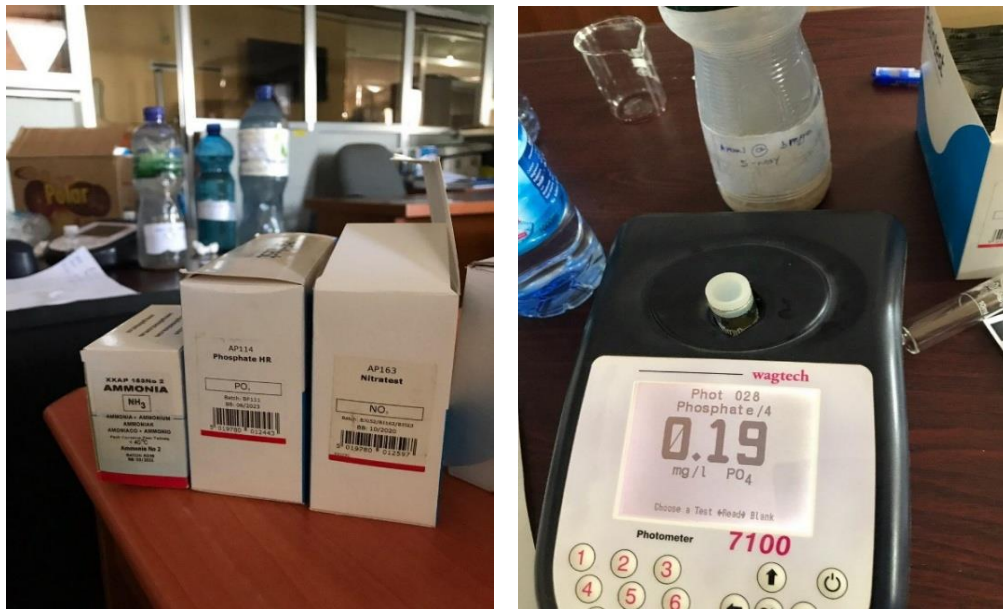


Figure 3-9 Lab testing and reagents for analysis

3.3.4.1 pH & Temperature

The pH was measured on the site using the portable Thermo Scientific instrument. The glass pH electrode is used with built-in temperature sensor after calibrating the meter with buffer solutions of pH=4, pH=7 & pH=10. Two approaches were applied, one is measuring directly on the water by inserting the sensor and the other by sampling the water at the site and conduct the measurement straightaway. The latter mainly applied in the big Akaki river due to inconvenience to do the measurement inside the river. The temperature is also measured in the same manner.

3.3.4.2 Electrical conductivity, TDS and Salinity

The portable Thermo Scientific instrument is equipped with two types of sensors. The sensor used to measure EC, TDS and salinity has been calibrated with the buffer solution of EC=1413 $\mu\text{S}/\text{cm}$. Similar to the pH measurement, the other physical parameters measurement was conducted both inside the river and taking the sample and test immediately.

3.3.4.3 Nutrient

The phosphate and nitrate concentration has been determined by using Wagtech Photometer 7100 instrument capable of measuring the full range of water quality parameters. The analysis is done at the HWQD laboratory of BDA/MoWIE. The test tube method has been used for the samples using appropriate reagents as per the procedures for each parameter.

3.3.5. Water quality load modeling (LOADEST)

For the nutrient load estimation LOADEST software package from the USGS has been used. LOADEST has an explanatory variable within the regression model consist of various functions of stream flow, decimal time, and additional user-specified data variables. The formulated regression model then is used to estimate loads over a user-specified time interval (estimation). Mean load estimates, standard errors, and 95 percent confidence intervals are developed on a monthly and (or) seasonal basis (Runkel et al. 2004).

Recent concentration data for the parameters have been collected for the model calibration together with the specified discharge data. Nitrate and phosphate indicators have been simulated in the model to calculate the general loads of nutrients. The result of the simulated concentration with the flow gives a hydrograph of concentration to see the extent of pollution and environmental challenges in predefined time period.

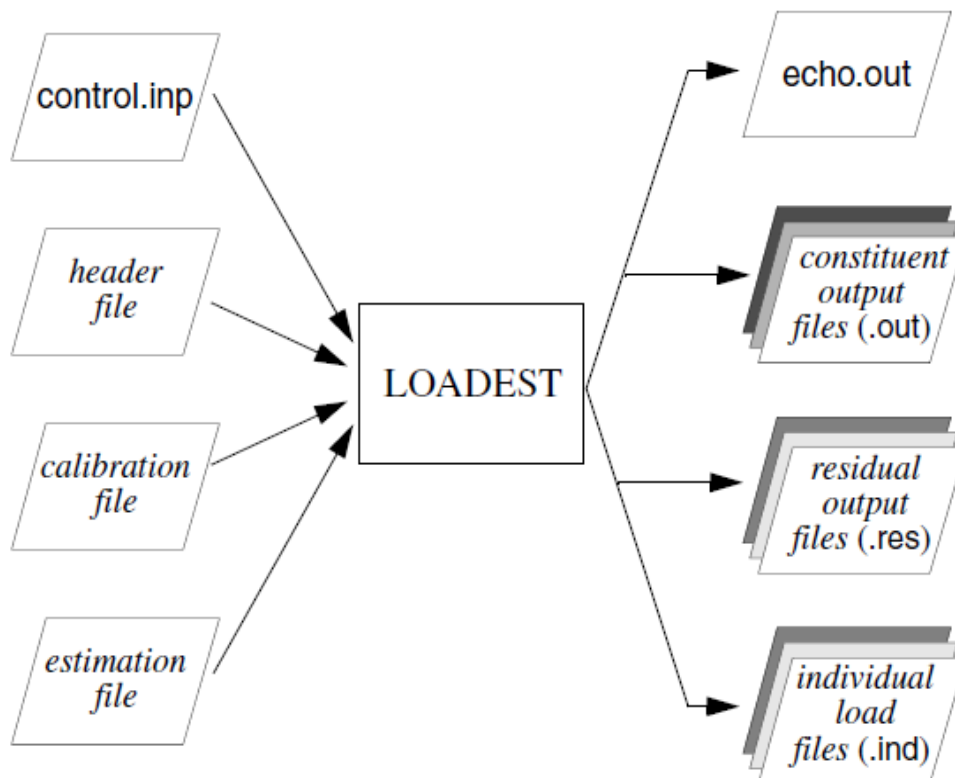


Figure 3-10 LOADEST model input/output program

Statistical considerations show that the pollutant load of a river is likely to be underestimated by methods in which unmeasured concentrations estimates of instantaneous load are biased; estimates may underestimate the true load by as much as 50 percent (Ferguson 1986). This retransformation bias is addressed by introducing bias correction factors for the calculation of instantaneous load. Data censoring occurs when one or more observations used in the calibration step have constituent concentrations that are less than the laboratory detection limit (Gilbert 1987). A more rigorous treatment of censored data is therefore required. That is why in this study the measurement of concentration loads together with the flow is needed. Intensive measurements of loads and flows have increased the regression equations efficiency. As described by Cohn 1995, several techniques are available for estimating total load, Lt. Loadest uses the linear regression based on the eqn. below.

$$\ln(L) = [a_0 + \sum_{i=1}^{NV} a_i X_i] \quad (8)$$

Where a_0 and a_i are model coefficients, NV is number of explanatory variables, and X_i is an explanatory variable.

The assumption of ordinary least square (OLS) regression model residuals as a normally distributed creates complications. Alternate methods for estimating model coefficients are applicable when model residuals do not follow a normal distribution. Because of these complications, LOADEST provides three methods for load estimation; each method is described below (Runkel et al. 2004).

3.3.5.1 Maximum Likelihood Estimation (MLE)

Maximum likelihood estimation (MLE) is one of the widely used method of estimating the parameters of a model. The method selects the set of values of the parameters that maximizes the likelihood function. As an alternative to OLS regression, model coefficients (a_0 and a_i , eqn. 8) may be calculated using the method of maximum likelihood (MLE). When the calibration data set includes censored data, implementation of MLE also is known as tobit regression (Helsel and Hirsch 2002). As with OLS, tobit regression assumes that model residuals are normally distributed with constant variance. Given the model coefficients provided by regression, estimates of instantaneous load may be obtained by retransforming equation 9.

$$L^{MVUE} = \exp[ao + \sum_{i=1}^M a_i X_i] g_m(m, s^2, V) \quad (9)$$

where L^{MVUE} is the MLE estimate of instantaneous load, m is the number of degrees of freedom, s^2 is the residual variance, and V is a function of the explanatory variables (Cohn et al. 1989). The model coefficients in equation 8 (a_0 and a_i) are estimated by maximum likelihood; the bias correction factor [$g_m(m, s^2, V)$] is an approximation of the infinite series given in (Finney 1941). Under the MLE method, estimates of instantaneous load are developed for all of the observations in the estimation data set using equation 9.

3.3.5.2 Adjusted Maximum Likelihood Estimation (AMLE)

For the case of censored data, model coefficients estimated by censored regression model (tobit regression) (MLE) exhibit first-order bias. It is also known that the maximum likelihood methods do not provide explicit estimators for the mean and standard deviation of the normal distribution based on Type II censored samples (Balakrishnan 1989). In addition, the Bradu-Mundlak bias correction factor (g_m , equation 9) results in biased estimates of instantaneous load. A “nearly unbiased” (Cohn 1988) estimate of instantaneous load then is given by:

$$L^{AMLE} = \exp[ao + \sum_{i=1}^M a_i X_i] g_m(a, b, s^2 \alpha, \kappa) \quad (10)$$

Where L^{AMLE} is the AMLE estimate of instantaneous load, a and b are functions of the explanatory variables (Cohn et al. 1992), α and κ are parameters of the gamma distribution, and s^2 is the residual variance. The model coefficients in equation 10 (a_0 and a_i) are maximum likelihood estimates corrected for first-order bias; the bias correction factor [$H(a, b, s^2, \alpha, \kappa)$] is an approximation of the infinite series given in (Cohn et al. 1992). Under AMLE, estimates of instantaneous load are developed for all of the observations in the estimation data set using equation 10.

3.3.5.3 Least Absolute Deviation (LAD)

All of the regression methods discussed thus far (OLS, MLE, AMLE) assume the model residuals are normally distributed with constant variance. When model residuals do not conform to the assumption, alternate techniques may be appropriate. One such technique, the least absolute deviation (LAD) method, is implemented within LOADEST. Model coefficients for

LAD are developed using the regression method of (Powell 1984). Given the model coefficients, estimates of instantaneous load are developed using the “smearing” approach of (Duan 1983):

$$L^{LAD} = \exp[a_0 + \sum_{i=1}^M a_i X_i] g_m(a, b, s^2 \alpha, \kappa) \quad (11)$$

Where L^{LAD} is the LAD estimate of instantaneous load, a_0 and a_i are model coefficients developed by the LAD regression, e is the residual error, and n is the number of uncensored observations in the calibration data set. LAD estimates of instantaneous load are developed for all of the observations in the estimation data set using equation 11.

3.3.5.4 Summary of MLE, AMLE, and LAD for Load Estimation

The primary load estimation method used within LOADEST is AMLE. AMLE has been shown to have negligible bias when the calibration data set is censored (Cohn et al. 1992). For the special case where the calibration data set is uncensored, the AMLE method converges to MLE (Cohn et al. 1992), resulting in a minimum variance unbiased estimate of constituent loads. MLE estimates are provided as a check on AMLE results and as a means of comparing LOADEST results with standard statistical packages that implement MLE. AMLE. If the residuals do not adhere to the assumption of normality, AMLE (and MLE) results for censored data may not be optimal. Load estimates from the LAD method should therefore be considered in lieu of AMLE, as the LAD load estimates are not dependent on the normality (Runkel et al. 2004).

3.3.6. Overall methodological flow chart

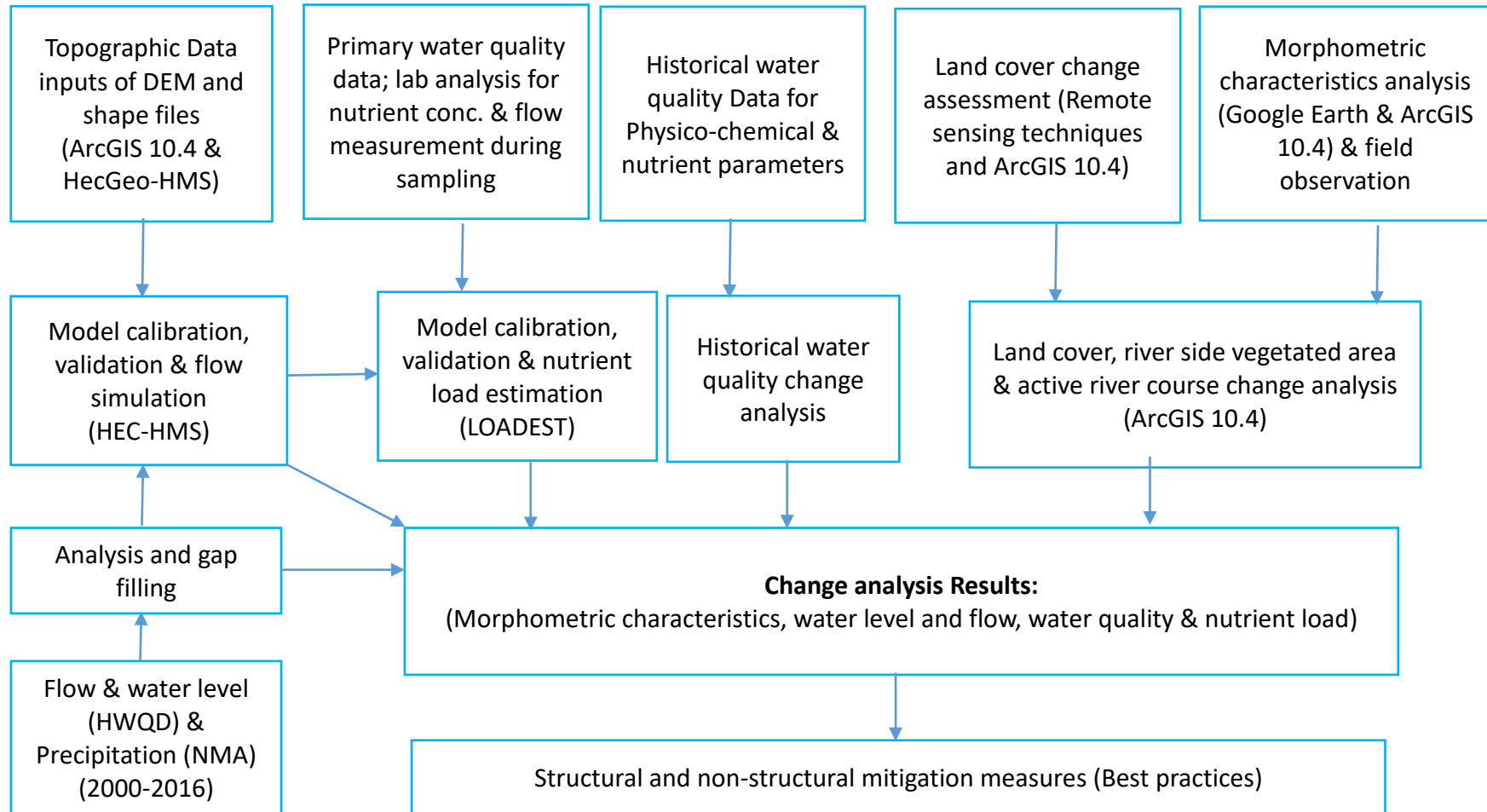


Figure 3-11: Methodological flow chart

CHAPTER 4. RESULTS AND DISCUSSION

4.1 Land cover Change

From the image analysis result it was found that the main land use that undergoes change over the study period was the cropland into built-up area. Urbanization and expansion of settlement areas are the main causing elements.

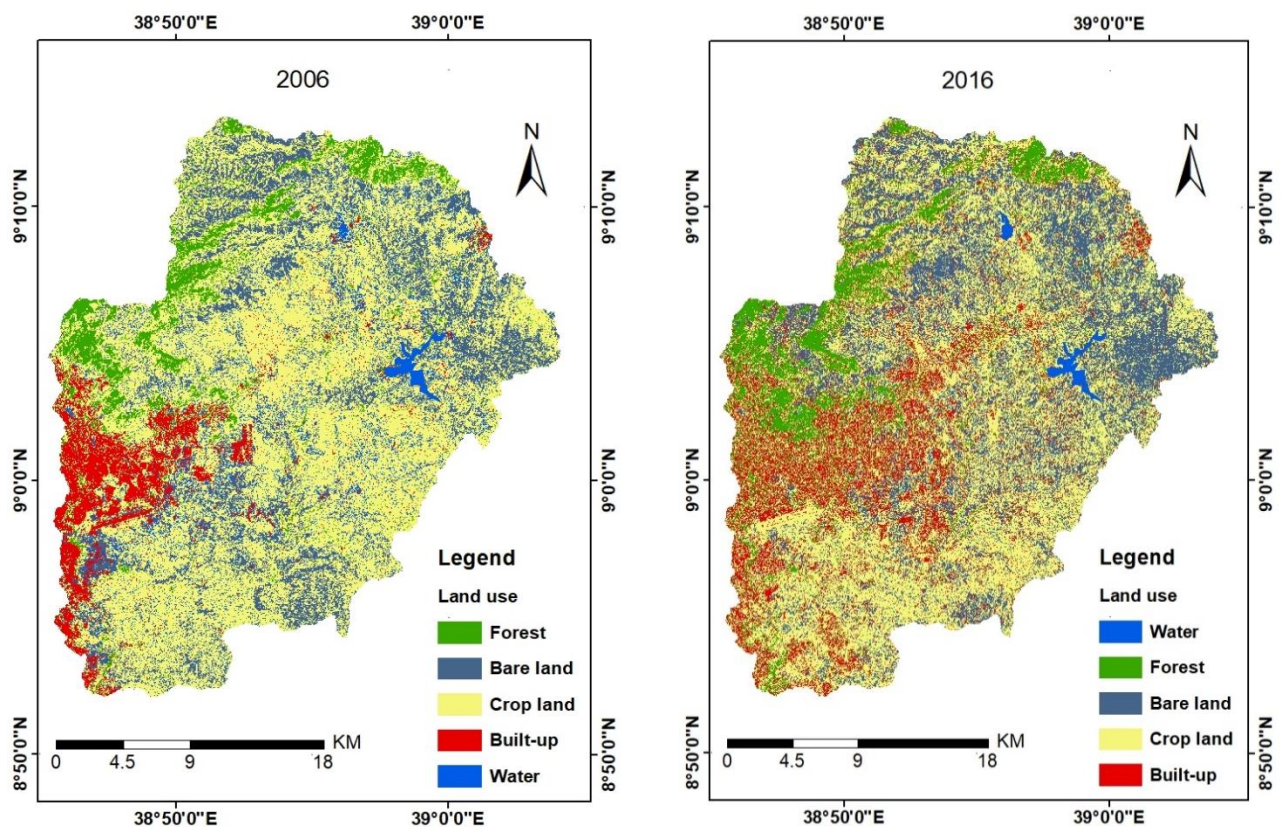


Figure 4-1 Land cover of big Akaki watershed (a) 2006 and (b) 2016

The rate of change from crop-land to built-up area over the study period is the weighty part of the land use change. Nonetheless, the change also shows a positive impact on the forest cover. The other land use constitutes such as the water and bare land seems to have remained the same. The figure below shows the land use type and their coverage area in November 2006 and November 2016. In 2006 the cropland shares about 60 % of the total area and bare land, forest,

built up and water contribute 19.07 %, 7.75 %, 7.25 % and 5.96 % respectively. While in 2016 the crop land still covers the largest area of 48.43% even after a significant reduction. The rest of classified land covers of bare land, built up, forest and water shares 19.62 %, 14.58%, 10.85 % and 6.54 % respectively.

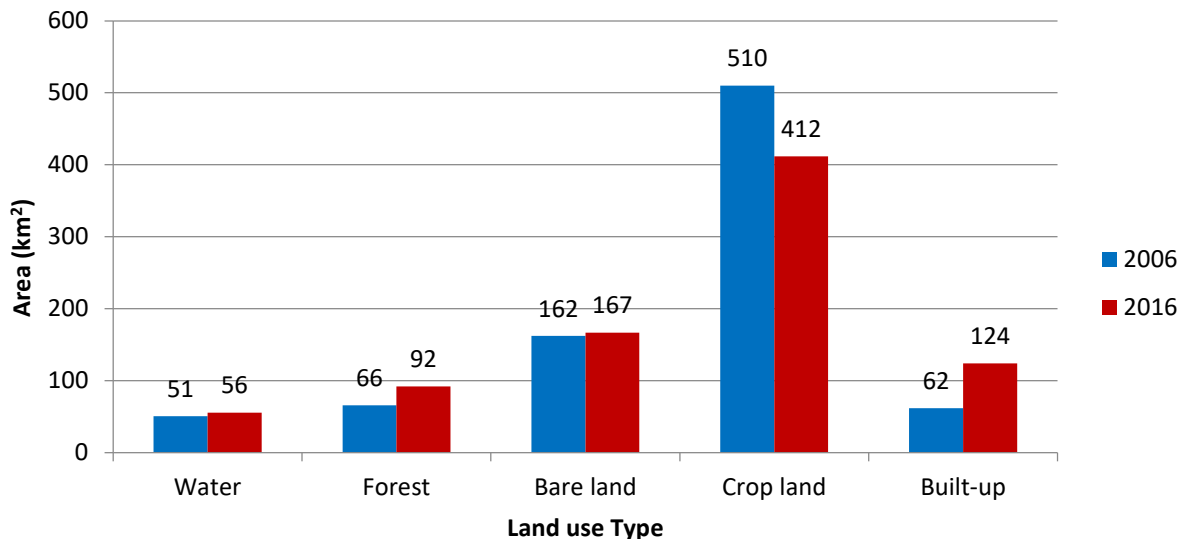


Figure 4-2 Land use of the big Akaki watershed (2006 & 2016)

The land use between the ten years is recorded to be; water shows +0.58%; forest shows +3.1%; bare land shows +0.55%; built-up area shows +7.33 % and the highest change recorded on the cropland with -11.54% decline. This has a direct impact on understanding the watershed’s hydrological and environmental characteristics.

4.2 Morphometric characteristics change

The vegetated area was analyzed by taking the settlement-free areas from the SPOT satellite and the Google Earth images. The active river course change is also calculated for both rivers by utilizing the high-resolution satellite imageries. The images were taken in the same dry season on the month of November, for better contrast results. The active river course is detected by identifying the river water surface and river course area. Also, new construction along the riverside such as housing, bridge, retaining walls and so on was detected for change indication.

In Kebena River vegetated area show significant reduction over the decade and the flow area shows shifting pattern from one side to the other and vice versa. The main reason for shifting could be the location of the area in city center where many residential and commercial areas are located and settlements around the river buffer area. Fig 4.3 shows the change over the decade.

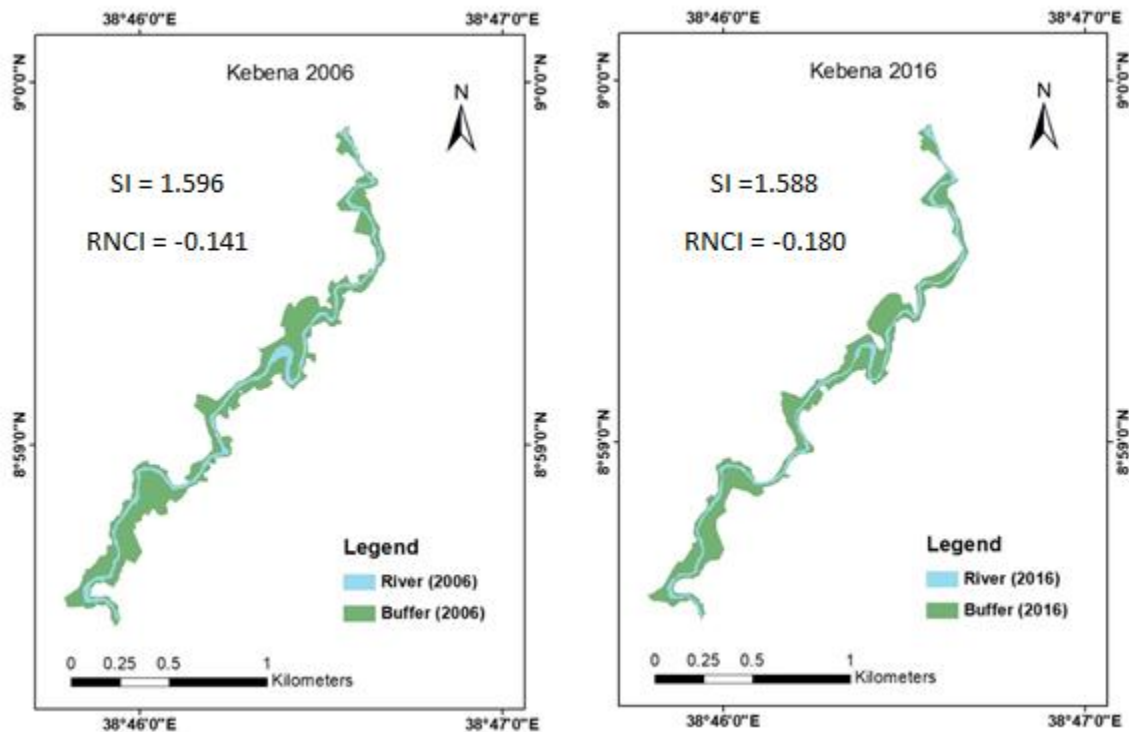


Figure 4-3 Kebena river course vegetated area and river course (a) 2006 and (b) 2016 years

The vegetated and settlement-free area (buffer zone) in 2006 was 0.31 km^2 while it reduced to 0.25 km^2 in just ten years constituting 19% reduction of the buffer area. Similarly, the active river course in 2006 was 0.075 km^2 and it reduced to 0.06 km^2 in 2016 constituting 20% reduction. This highly indicates the narrowing of the river course and buffer area. It is likely for a change in the water course and vegetated area to occur on the highly populated and economically important parts of the city. Mostly, residents in and around the buffer area show an expansion pattern to river course which eventually has a high risk of flooding and loss of lives and livelihood. In fact, other means should be considered for settlement instead of expansion to rivers. The table below shows some of the morphometric characteristics in Kebena river.

Table 4-1 Morphometric characteristics of the Kebena River

Year	S (km)	L (km)	EA (km ²)	DA (km ²)	SI	RNCI (m/yr)
2006	4.34	2.72	0.009	0.013	1.596	-0.141
2016	4.32	2.72	0.002	0.007	1.588	-0.180

From the calculated morphological indices for the study period, the Kebena river reach undergoes a significant evolution and channel narrowing process occurred. The RNCI value during the two study periods was about -0.18 m/year. The negative value of RNCI indicates that sedimentation or narrowing is the main process in the river (Yousefi et al. 2018). The sinuosity index had decreased by about 0.008 from a starting value of 1.596 in 2006.

Similarly, the big Akaki river vegetated area shows a major change during the study period. Even though most part of the big Akaki river is located in the sub urban and rather gorge area, the change in the buffer area and the river crossing area is still higher as shown below.

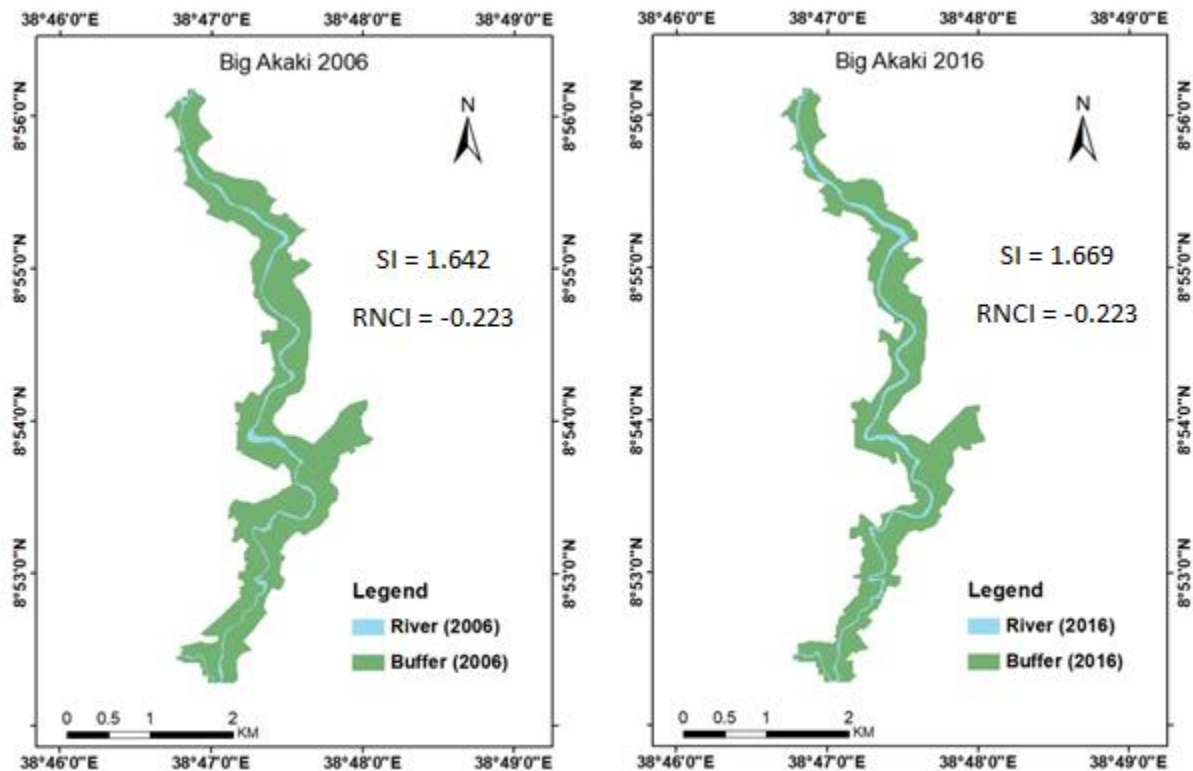


Figure 4-4 Big Akaki vegetated area and river course area (a) 2006 and (b) 2016

The settlement free area (buffer zone) in 2006 was 4.31 km² and it reduces to 3.64 km² in just ten years constituting 16% reduction of the buffer area. Similarly, the active river course in 2006 was 0.38 km² and it reduces to 0.31 km² in 2016 constituting 18% reduction. The total flow length has increased by 180m.

Like the Kebena river, the big Akaki river undergoes narrowing of the river course and buffer area over the decade. The change has been observed to be slower than the Kebena river reach. In the big Akaki case urbanization process into agricultural and river boundary are the major contributor to the river morphology change. The morphometric characteristics are shown below:

Table 4-2 Morphometric characteristics of the big Akaki river

Year	S (km)	L (km)	EA (km ²)	DA (km ²)	SI (S/L)	RNCI (m/yr)
2006	11.07	6.74	0.033	0.048	1.642	-0.223
2016	11.25	6.74	0.036	0.051	1.669	-0.223

The morphological indices showed that during the study period, the big Akaki reach undergoes a significant evolution and channel narrowing process occurred. The RNCI value during the two study periods was about -0.22 m year⁻¹. Braided index (BI) reached the highest value of 1.9 in 1966 and dropped to 0.4 by 2013. The sinuosity index had increased by about 0.029 from a starting value of 1.642 in 2006.

Furthermore, the high rate of sedimentation problem observed in the downstream part of big Akaki river is additional factor for morphological change. The risk of flooding due to channel overtopping is higher when the river channels are filled with sediments. In such cases the need for dredging to increase the channel capacity is needed.

On the other hand, during the field visit, people have been observed extracting sand manually from the river bed. A study on Ribb river shows, prolonged sand mining activity in the Middle and Lower River reaches has clearly affected the natural riverbed topography. Sand miners extract sand from bar tops during low flow conditions, altering the shape and height of sand bars, as well as the sediment balance of the river (Mulatu et al. 2018). The Fig 4.5 below shows the manual sand extraction at the big Akaki River.



Figure 4-5 sand extraction below the new bridge at Tirunesh Beijing

The river channel near to the big Akaki bridge is found to be occupied by sedimentation. As the slope near to the bridge is gentle, most of the suspended materials fell around this area. The pictures below show the accumulated sediments near Tirunesh Beijing bridge.



Figure 4-6 Sediment accumulation around Tirunesh Beijing bridge

Correspondingly, the water level at Akaki Bridge hydrological gauging station shows a sharp rise due to the high sediment accumulation on the river bed. As a result, high water level rise recorded as shown on figure 4.6. To conclude, the sum of the bed, the active water surface and

vegetated area changes are the major contributors to the morphological change of the big Akaki River and the tributaries on the watershed.

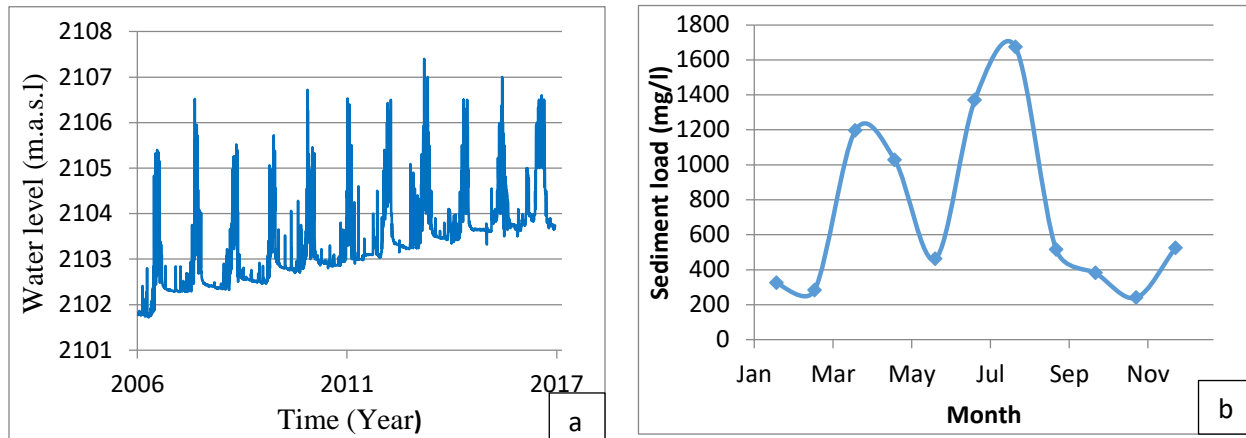


Figure 4-7 Sediment accumulation at Akaki Bridge (a) Daily observed water level at Akaki bridge hydrology station (b) Monthly average observed sediment load

4.3 Flow Simulation (Hydrological analysis)

4.3.1 Model calibration and Validation

The HEC-HMS model calibrated and validated against the stream flow data of Akaki at Akaki bridge stream flow gauging station. The calibration is done for three years' daily flow data between 2000 and 2002. The calibration result shows good estimation as evaluated both graphically and with certain error metrics. The result for R^2 , PBIAS, NSE, MAE and RMSE statistical indices were within the acceptable range.

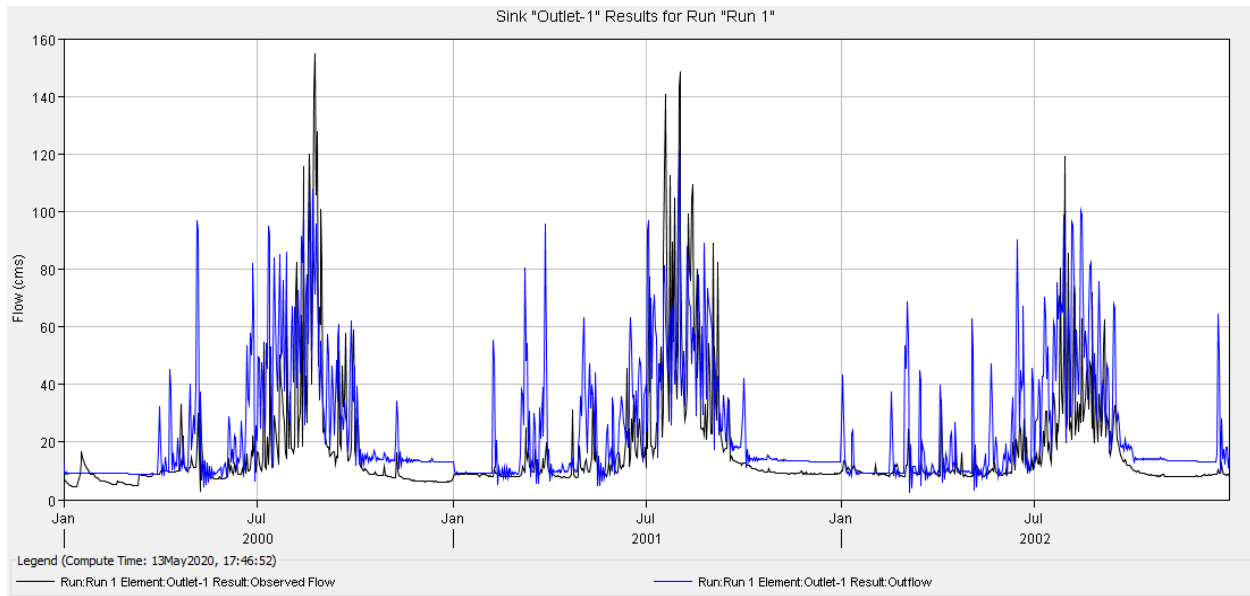


Figure 4-8 Calibration hydrograph

The model is also validated for another three independent consecutive years between 2003 and 2005. Similar to the calibration, the model shows acceptable ranges for the specified statistical indices during validation.

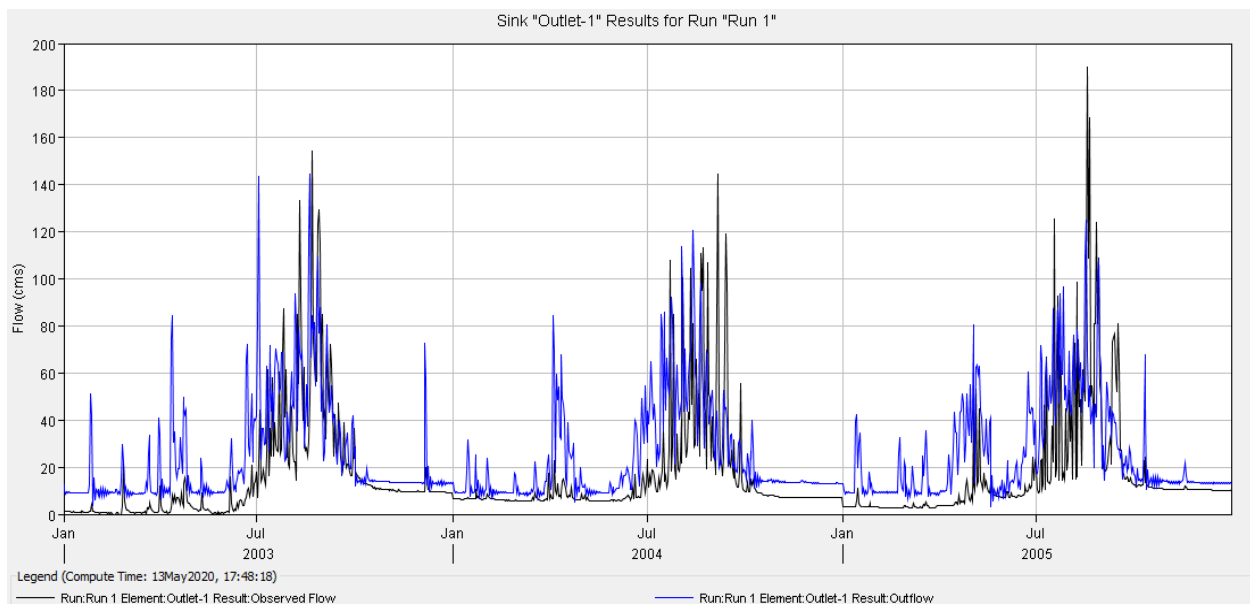


Figure 4-9 Validation hydrograph

The error metrics after calibration and validation for the metrics of R^2 is 0.41, PBIAS is -9.25 , NSE is 0.402, MAE is 14.0 and RMSE is 23.4 which is within the acceptable range for simulation.

4.3.2 Flow simulation

The calibrated and validated HEC-HMS model was set for simulation to generate flow hydrograph between 2006 and 2016 as shown in the figure below. The flow at the big Akaki at Akaki bridge has a total of 10 sub-basins.

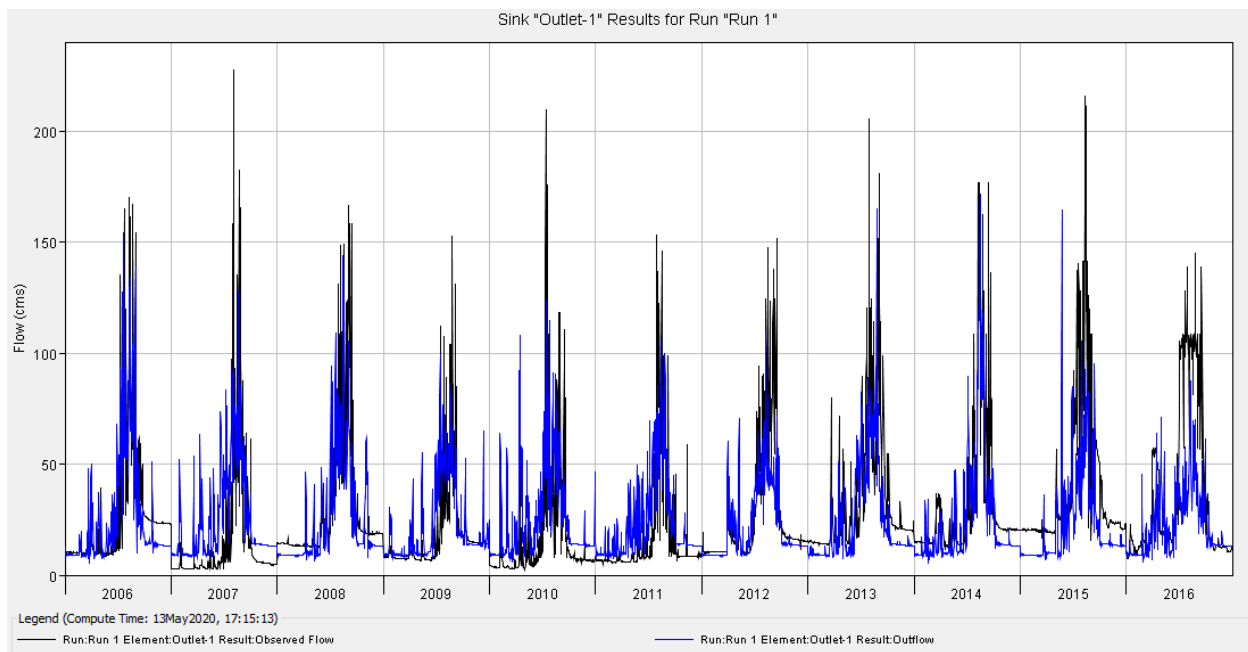


Figure 4-10 Flow hydrograph at the outlet and observed flow at Akaki station

Kebena is one of the ten sub-basins in the big Akaki watershed. The Kebena river reach watershed was delineated using the point at the St Joseph church. The discharge at the outlet of this sub-basin shows a high level of temporal variation for wet and dry seasons i.e. high level of seasonal variability as shown on Fig 4.11.

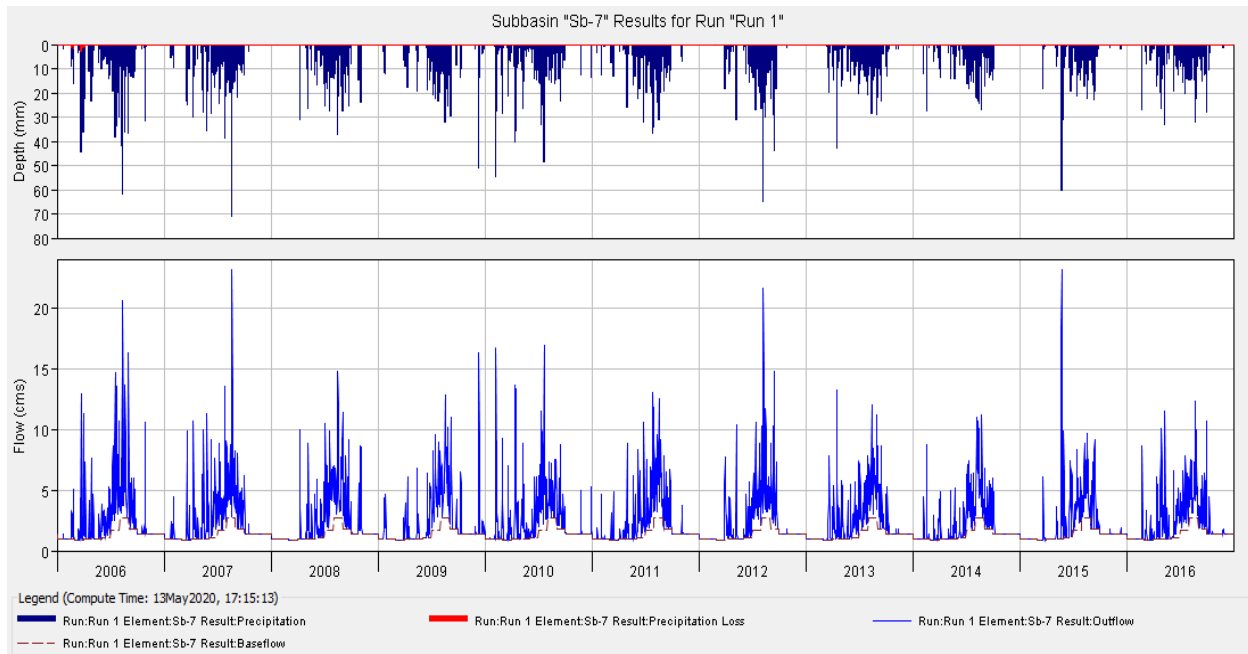


Figure 4-11 The hydrograph and rainfall hyetograph at the Kebena River at Yoseph Bridge

4.4 Water quality assessment

4.4.1 Historical water quality change for Physico-chemical parameters

Various water quality data and reports were collected from the Oromia water energy and mineral bureau through EU-WFF project; the Basin Development Authority (BDA) through Awash Basin Development Office (AwBDO); reports and researches conducted on the river. All the data was compiled to estimate the water quality change of the two river reaches. The result shows that there has been irregular pattern change for most of the water quality parameters assessed. Most of the results indicate the pollution was growing over the study period and it can be concluded that the water quality over the study period was deteriorating. Although some parameters are ever-changing, the comparison can give us a general signal.

Kebena river water quality has been publicized by various sources for physico-chemical parameters. The results collected from different years since 2006 compiled in the table below. The recorded parameters have shown an increase for physical parameters of T° , pH, COD, TDS and salinity.

Table 4-3 Water quality physico-chemical parameters of Kebena river at the study location

Parameters	2006 ^a	2006 ^b	2009 ^c	2019 ^d	2020 [*]
T ^o	16	19.7	23	20.6	21.2
pH	7.17	7.72	7.61	7.42	8.11
NH ₃ -N	21.35	-	54.07	-	nill
PO ₄ ³⁻	9.67	-	5.05	75.1 (reac P)	0.03
No ₃	-	-	11.11	0.86 (Nitrite)	8.28
COD	137.25	-	-	649	-
EC (μS/cm)	-	639	1096	935	690.4
TDS	-	307	-	-	336.5
Salinity	-	0.3	-	-	0.326

Sources: a-(Solomon, 2006), b-(Belachew T, 2006), c- (Temesgen N, 2009), d-(Zenash, 2019) & *- (this study, 2020)

Similarly, the water quality parameters for the big Akaki river has been assessed. Unlike the Kebena river, the big Akaki have more studies and monitoring results for the historical periods. The table below shows the water quality parameters results over the study period. The pH shows a decreasing pattern and the water temperature seen to be increasing.

Table 4-4 Water quality results of big Akaki at Akaki bridge

Parameters	2006 ^a	2006 ^b	2014 ^c	2015 ^d	2020 [*]
T ^o	21	19.5	19.2	23	23.2
pH	7.58	7.65	6.7	6.47	7.81
NH ₃ -N	10.95	-	6.66	5.26	nill
PO ₄ ³⁻	4.16	-	-	-	0.27
No ₃	-	-	-	-	17.1
COD	190	-	46	70	-
EC (μS/cm)	-	563	540	695	613.1
TDS	-	225	274	347	303.7
Salinity	-	0.2	-	-	0.287

Sources: a-(Solomon, 2006), b-(Belachew T, 2006), c- (EU-WFF) & *- (this study, 2020)

The water qualities measured parameters over the study period for both rivers were much below the standard river water quality of national and international organizations. Report by the AAEPa shows the pollution rate of the rivers in the Addis Ababa city is highly worrisome. The rivers are polluted by coliforms, heavy metals from industries, and human and other waste

released directly into the rivers. In addition, expansion of new industrial areas in the big Akaki watershed is exceedingly polluting the rivers with heavy metal and chemicals. The table below shows the standard water quality limits from different organizations.

Table 4-5 Recommended water quality criteria

Parameter	Desirable limit	Maximum permissible limit	Organization/ Body
T ^o		15	CCME
pH	7.0-8.5	6.5-9.2	WHO
NH ₃ -N	1.37-2.20, for aquatic life		CCME
PO ₄ ³⁻	0.35	6.1	EC
NO ₃	25	50	EC
COD	250		SCCL
EC (μS/cm)	750	2500	WHO
TDS	500	1500	ICMR
Salinity			

CCME: Canadian Council of Minister for the Environment; WHO: World Health Organization; ICMR: Indian Council of Medical Research; EC: European Community; EPA: Environmental Protection agency.

Level of pollution in the big Akaki river has been studied by various researchers for limited parameters and environmental matrices due to the expensiveness of the laboratory analysis. The pollutants of rivers by biological, chemical and metallic are generated both from point and non-point sources. When a variety of pollutants discharged into a river system, the combination of individual toxins yields synergetic effects which results in toxic effects much higher than the effects of the individual toxins.

Lack of stock assessment results hindered the research and other works planned for the river system. Government agencies such as the AAEPa have the responsibility in monitoring the pollution status of rivers. These organizations are expected to collect analyze and archive historical data not only from the industrial release for monitoring purpose but also from the river water at observational locations. Routine and seasonal measurements will also, complement the understanding of the pollution trend that will help evaluate the status of any interventions.

4.4.2 Nutrient load estimation

LOADEST has been used to estimate the nutrient contents of both rivers. The model has been calibrated with primary data of concentration and flow data collected at the sampling locations as

well as historically collected concentration data with corresponding flow. Due to their abundance in the watershed, only nitrate and phosphate has been selected for load estimation. LOADEST has different ways of estimating the constituents. Some of these are AMLE, MLE and LAD. Both the primary and secondary concentration data used in this study are collected on approximately similar locations.

Table 4-6 Loads concentration mg/l for all the sampling area

mg/l		25 th		75 th		90 th	95 th	99 th	Max.
		Min.	Pct	Med.	Pct	Pct	Pct	Pct	
Akaki PO ₄ ³⁻	AMLE	0.55	3.92	5	5.84	6.25	6.35	6.41	6.41
	MLE	0.55	3.97	5.07	5.93	6.34	6.42	6.48	6.48
	LAD	0.64	1.93	2.53	3.26	4.23	5.25	6.03	6.38
Akaki NO ₃ ⁻	AMLE	0.001	2.39	16.28	34.98	43.76	43.76	43.76	43.76
	MLE	0.001	2.45	16.65	35.65	44.53	44.53	44.53	44.53
	LAD	0.001	1.11	11.67	34.52	48.53	48.53	48.53	48.53
Kebena PO ₄ ³⁻	AMLE	4	16	24	34	57	68	76	84
	MLE	4	16	24	35	58	68	77	84
	LAD	11	20	24	30	45	53	62	75
Kebena NO ₃ ⁻	AMLE	8	9	13	27	41	48	57	62
	MLE	8	9	13	27	41	48	57	62
	LAD	5	6	9	19	36	48	79	174

4.4.2.1 Nitrate load estimate

In previous studies, nitrate levels in rivers ranged from 0.21 to 18.2 mg NO₃/l in the Kebena river catchment in dry season (Beyene et al. 2009) (Eriksson and Sigvant 2019). The figure below shows the load estimation with the corresponding flow discharge. As it is seen the flow is directly proportional for the LAD estimation method. From this study, the nitrate concentration load ranges up to 400 tons/day for Kebena river and it goes up to 2000 tons/day in the big Akaki river.

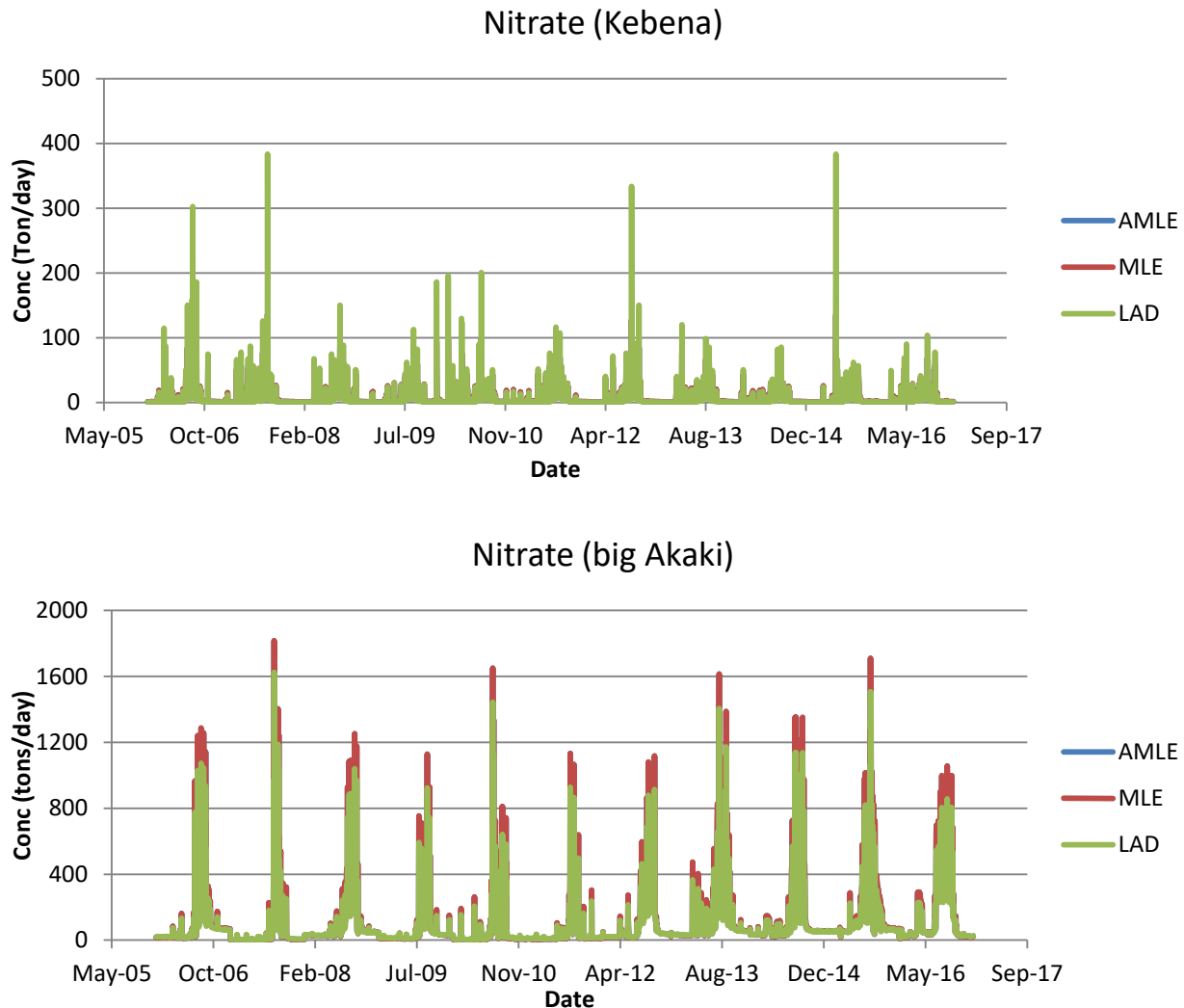


Figure 4-12 Nitrogen load time series (2006-2016) (a) Kebena (b) Akaki at Akaki bridge

The Kebena river nitrogen load time series shows a similar pattern throughout the simulation period. While the big Akaki river shows a little increment on the minimum loads for periods between 2012 to 2016 which is mainly associated with the flow pattern. The seasonal variability is still higher especially for the LAD estimation than the other two methods.

4.4.2.2. Phosphate

In previous studies conducted on the big and little Akaki rivers, the concentrations of phosphate were found to be in the range of 0–25 mg PO₄/l (Akalu et al. 2011; Weldesilassie et al. 2011). While the result of this study for phosphate load concentration ranges between 0 and 4 tons/day

for Kebena. For big Akaki river it the phosphate concentration reaches up to 14 tons/day. When comparing the phosphate concentration collected by secondary sources with the primary data collected with this research, the current condition seems to be less concentrated than the previous ones. As the main sources for phosphate in stream flow are runoff from fertilized agricultural land, the reduction in the agricultural land could have contributed to this reduction.

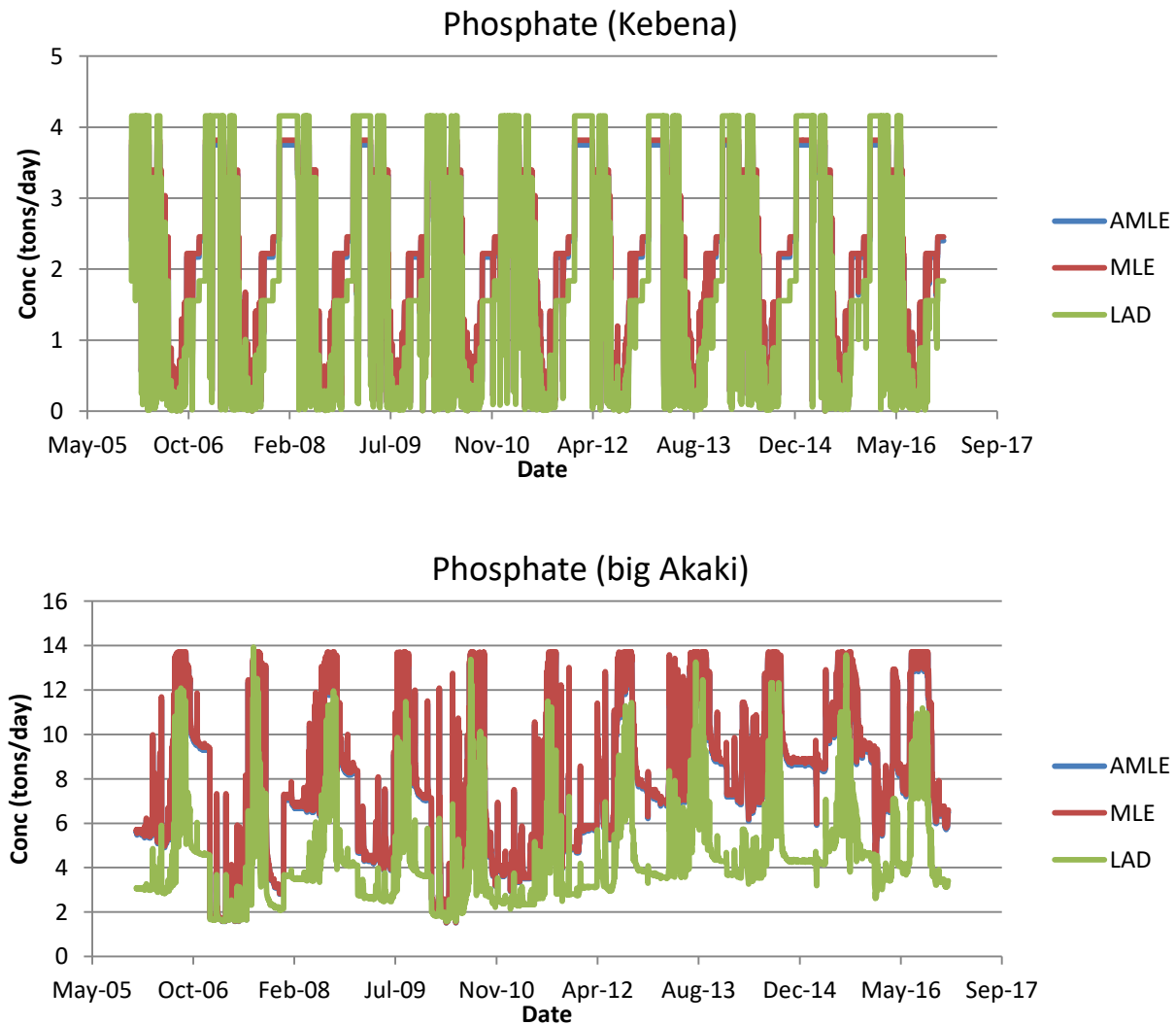


Figure 4-13 Phosphate load time series (2006-2016) (a) Kebena (b) Akaki at Akaki bridge

The nitrate load estimation has shown that the load is directly proportional to the river flow. Particularly, at the beginning of the rainfall, an event where soil and water matters enter the drainage stream, the nutrient load increases for all the AMLE, MLE and LAD estimation

methods. The capability of rivers to transport nutrients is very high that in drought year, less nitrate is transported on the rivers than the wet seasons. During dry years, nitrate tends to build in soils, largely as a result of reduced plant uptake and is washed into streams at larger rates during subsequent wet years (Goolsby et al. 1991).

For the case of phosphorous load, the simulation has shown that the phosphorous load is less than that of nitrate. Phosphorous concentration over time estimation is highly affected by the samples taken and the procedures and conditions. In general, concentration data collected typically for the load estimation purpose has an impact on the results. As stated in the limitations, the need to observed concentration and flow at regular interval is crucial to the accuracy of the load estimation.

4.5 Discussion

The impact of river morphology change on the environment has been studied with certain water quality and nutrient loads parameters. Clark and Wilcock studied North-Easter Puerto Rico between 1830-1950, changes in water or sediment supply can affect channel morphology, infiltration, runoff, and peak flows. Many studies have documented the negative impact of human disturbances on channel morphology, which include agricultural practices (Clark and Wilcock 2000). Study on Shiwuli River show that e-flows are significantly influenced by changes in river morphology. With an increase in siltation depth, the e-flow requirements will decrease Although siltation could reduce the e-flow requirements, which is positive in terms of sufficient e-flow, siltation is negative for flood control (Zhang et al. 2019).

As studied by many researchers, the impact of land-use or urbanization to the climate change is very high (Huong and Pathirana 2013; Pachauri and Reisinger 2008; Singh and Shi 2014; Zhang et al. 2019). However, Satterthwaite (Satterthwaite 2009) emphasized that it is not the growth in (urban or rural) populations that drives the growth in greenhouse gas (GHG) emissions but rather, the growth in consumers and in their levels of consumption. Nevertheless, the total sum of both urbanization, climate change and morphometric changes have a significant impact on the water quality as well as the environment of water bodies.

In addition to the satellite images, in-situ data has been used to determine the dynamics of the river morphology. The sediment load and siltation rate in the big Akaki River has been distinguished to be very high. As it has been observed in the problem statement, large amount of excavated soils for construction in the city are dumped on and near the rivers. In addition, solid wastes are dumped directly to the rivers. The effect of these activities is well observed in the downstream of the river where the river bed slope becomes gentle and low flow velocities exist.

In both the big Akaki and Kebena watershed, the highest recorded land-use change over the study period was, the increase in built-up area. While the morphology with the morphometric characteristics indicates a sharp change and evolution of the river channel morphology. ANOVA analysis was selected to evaluate the relationship between the landuse and the morphometric parameters. The land-use and morphometric characteristics dynamics showed a correlation on the ANOVA analysis as shown in table 4.7 below and the P-value of 7.09×10^{-8} from the ANOVA analysis shows a significant relationship between the landuse and the two morphometric change indicators of SI and RNCI.

Table 4-7 ANOVA output between percentage of urban area and the morphometric parameters.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	6.846	2	3.423	170.044	7.09E-08	4.256
Within Groups	0.181	9	0.02			
Total	7.027	11				

To the main objective of this thesis, the relationship between the morphometric characteristics and the water quality for physical, biological and nutrient parameters is demonstrated in Table 4-8 below. The result is interpreted as a cause and effect relationship for the deterioration of the water quality linked with the two morphometric characteristics. As a result, when RNCI value increases to the negative side; Ph, T^o, NH₃, COD, EC, TDS, Salinity as well as Nutrient parameters of the loadest model outputs (NO₃ and Po₄) shows an increasing pattern in Kebena. Whereas, when RNCI values remain constant T, BOD, EC, TDS and salinity values decreased in Akaki river, while pH, NH₃, PO₄³⁻, NO₃⁻ increased. The negative value of RNCI indicates high amount of sediment deposition than erosion in the upstream area which could be originated from damping of soil and solid waste excavated from other construction sites.

On the other hand, the correlation between the sinocity index (SI) and the water quality parameters has been found to show directly proportionating with most of the parameters. When the SI increase water quality parameters of T^o, EC, TDS and Salinity increased in both Kebena and big Akaki rivers. While other parameters shows uncertain relation which is considered as a non significant relationship between SI and pH, NH₃-N, PO₄³⁻ and NO₃⁻.

Table 4-8 Morphometric and water quality parameters change comparison

River year	SI	RNCI	T ^o	pH	NH ₃ -N	PO ₄ ³⁻	NO ₃ ⁻	BOD ₅	EC (μS/cm)	TDS	Salinity
Kebena 2006	1.596	-0.14	17.85	7.45	21.35	1.93	8.28	36.52	639	307	0.3
Kebena 2016	1.588	-0.18	21.6	7.71	54.07	8.22	117		907.13	336.5	0.33
Akaki 2006	1.642	-0.22	20.25	7.62	10.95	9.2	197.0	10.7	563	225	0.2
Akaki 2016	1.669	-0.22	21.8	6.99	5.96	1.95	6.65	20.17	616.03	308.23	0.29

As most of the river courses in Addis Ababa city become full and flood their surroundings during the three main rainy months (June–August) (Getahun and Gebre 2015), high seasonality of flow has been observed in the hydrographs of the two rivers. The e-flow for small rivers like the Kebena is very restricted, highly polluted and deteriorated both in quality and quantity. Release of waste and sewerages worsen the environmental situation of the urban rivers. Dumping of excavated soils in an uncontrolled way are also some of the problems to the quantity and seasonal variations of urban rivers.

On the other hand, water quality in the rivers have shown a deterioration pattern between 2006 and 2016. Although historically not much data were available related to nutrient constituent loads and other pollutant parameters, this research collected some sort of nutrient constituent loads together with flow to see the phosphate and nitrate loads over the study period. The result could have been enhanced by employing more data over different seasons for the model validation in order to utilize it in the actual load estimation with certain level of confidence.

This study due to the limiting factors of data and other resources, were done for a decade only. The extent and linkage between the landuse change, morphometric characteristics and the water quality could have been soundly drawn if longer periods of observations were applied. As morphology and flow condition of the rivers can affect the aeration and the river water flow distribution or consolidation, advanced river training and structures will have an important role. The BMP displayed in this work can contribute for the betterment of the river health together with future rivers side development works in both Kebena and big Akaki rivers.

CHAPTER 5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study has been investigating the relationship between the land-use change on the river morphology and the outcome on the environment in terms of the water quality and pollutant loads. The land use of the big Akaki river basin has shown major changes especially the built-up area shows about +7.33 % and the cropland area declined by -11.54%. This has a major impact in the watershed environment both in utilizing the available water resource and generating and releasing wastes without appropriate treatment and disposal way.

It has been evident from this research finding that the morphology of both Kebena and Akaki rivers has been changing due to anthropogenic and natural causes during the study period. The active river course decreased by -20% and 18 % and the riverside vegetated area decreased by -19% and -16% in a decade for the Kebena and Akaki Rivers respectively. The decline is also shown in many morphometric indices such as the SI and RNCI.

The water quality of both rivers shows changing pattern linked with the intensity of human pressure associated with industrial effluent, domestic wastes and agricultural activities. The assessment of nutrients load also reveals that the rivers are carrying a large amount of Phosphate and nitrates. The water quality assessment shows that both big Akaki and Kebena Rivers are highly polluted. As Kebena river is located in the downtown area, the pollution due to the fecal release to the river is very high. Also, the water quality parameters show that with human disturbance, poor governance and management of the natural ecosystem both Kebena and big Akaki streams are severely affected and it needs immediate restoration and rehabilitation tasks. The nutrient loads are also very high and vary seasonally. Both rivers show a high amount of nitrate loads compared to the phosphate. The sedimentation problem is also very high as observed during the field visits and the water level at the gauging station. Many causes can be raised to the siltation, the major ones are upstream activities include dumping of soils near to the riverside, solid waste dumping and lack of soil and water conservation in the agricultural lands.

5.2. Recommendation

This study tries to collect historical data from different sources including research papers. Historical record of water quality parameters has a significant role in the study of environmental changes particularly in dynamic urban watersheds. In this regard, organizations like the Addis Ababa City Environmental protection Agency better be engaged in such monitoring measures with many parameters. In addition the Federal organizations working on river basins deploy monitoring mechanisms in highly susceptible areas for environmental changes. The cause and effect relation of morphology in the environment as well as many other water related problems like hydraulic structure and water related planning would be future research topic with varies spatial and temporal scales in urban watersheds.

The Addis Ababa City Administration developed a 10-year master plan which has a big areas left for buffer zone and greenery in the city see Appendix C & D. According to this plan, the river will be converted to recreational area. Combining this research suggestion with the master plan of the city for construction of resilient structures could enhance the water quality, quantity, river health and the residents' day to day life. Nature based river rehabilitation works on river channel and buffer area as well as construction for pollution prevention could bring a positive impact to the environment including the nutrient loads, environmental flow, siltation, erosion and so on.

The best practices from different countries shown below with contextualizing to the situation of the rivers can contribute to future river rehabilitation projects in these rivers. Currently the Addis Ababa city administration is developing the riversides and recreation parks along the banks of the Kurtume and Kebena rivers. In particular, the Sheraton area Riverside Park Development Project is a major project which is currently in its final project phase. Such a project can thus give a lot of practical experiences, which would contribute to the success of the Kebena and big Akaki River future rehabilitation project.

5.2.1. Mitigation measures (Best Management Practice)

Nature-based solutions are highly preferred over artificial structural mitigation measures when dealing with the natural ecosystem restoration plans. River restoration assist the establishment of the improved hydrologic, geomorphic, and ecological process in a degraded watershed system

and replacing lost, damaged, or compromised elements of the natural system (Wohl et al. 2005). Upstream soil and water conservation works are highly recommended. The main reason for the morphological change is erosion and dumping of excavated materials into the river channel. This needs a high level of protection to protect the environment as well as flood mitigation downstream and reservoir of the Aba Samuel sustainability.

The result of this work has shown there has been a major challenge in the big Akaki and the tributary rivers. Interference for the betterment of the river environment is highly required. Currently, river restoration project is under construction, the commitment for this is highly appreciated. This section provides proposed mitigation measures to solve the problem of the river morphology on the big Akaki and Kebena rivers. Also, advises best management practices implemented for such level of a problem. urban stormwater drainage that has been hindering the drainage systems.

The hydrological analysis on the big Akaki basin shows there is a high level of seasonality in the flow pattern. Basically the flow can be classified into two seasons namely the wet and the dry. The dry season constitutes about eight months from October to May. Hence any mitigation measure better consider this variability at the planning stages. While, for the tributary rivers like the Kebena, combined channel is highly recommended. These channels are convenient as the river flows are highly varying seasonally. Such channels are good for the environmental flow and regulate the flow safe with a non-scouring and non-silting velocity on the channel. Also, the space left for high flows can be utilized for different purposes during the dry season. Keeping in mind that the spaces are flood zones and no structures should be built on them.

As the big Akaki river is located on the downstream of Dire and Legedadi reservoirs serving the water supply of the city, it is more regulated flow than the Kebena River. Therefore, constructing weirs across the river to maintain the flow is more realistic. The small dams at the upstream can be used to aggregate the river flow. Moreover, the water stored in the weirs can be used for multipurpose, one is to store water during the dry season and pump it back to the legedadi reservoir for water supply during a shortage of water. On the other hand, if consecutive weirs constructed over the river, they could be used for navigation over the river.

Furthermore, care should be placed in selecting the types of weir structure to be placed. This shall consider the water quality condition of the river. The figure below shows the proposed river cross section and the types of weirs that suits the water quality condition of the Kebena and big Akaki Rivers.

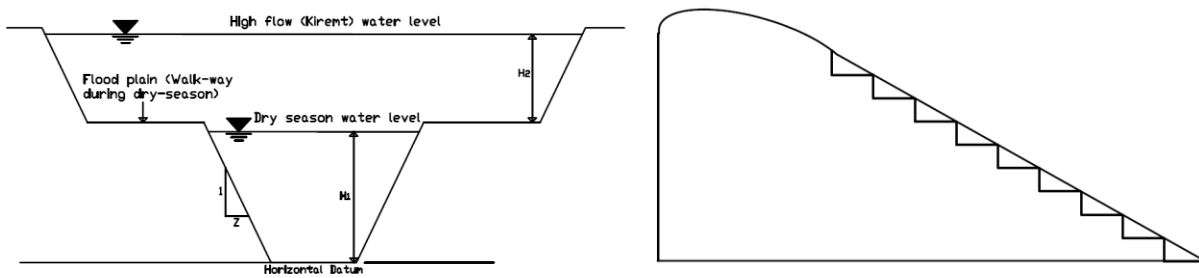


Figure 5-1 Proposed structural measures (a) cross section for Kebena River (b) aerated weir for big Akaki River

REFERENCE

- Abate, M., J. Nyssen, T. S. Steenhuis, M. M. Moges, S. A. Tilahun, T. Enku & E. Adgo, 2015. Morphological changes of Gumara River channel over 50 years, upper Blue Nile basin, Ethiopia. *Journal of Hydrology* 525:152-164.
- Abebe, Y., M. Bitew, T. Ayenew, C. Alo, A. Cherinet & M. Dadi, 2018. Morphometric Change Detection of Lake Hawassa in the Ethiopian Rift Valley. *Water* 10(5):625.
- Achamyeleh, K., 2003. Ethiopia: Integrated flood management. *Integrated Flood Management Case Study*:1-15.
- A dugna, D., 2016. Study of the Urban Drainage System in Addis Ababa, Yeka Sub-city. Addis Ababa University.
- A dugna, D., B. Lemma, M. B. Jensen & G. S. Gebrie, 2019. Evaluating the hydraulic capacity of existing drain systems and the management challenges of stormwater in Addis Ababa, Ethiopia. *Journal of Hydrology: Regional Studies* 25:100626.
- Aguilera, R., R. Marcé & S. Sabater, 2013. Modeling nutrient retention at the watershed scale: Does small stream research apply to the whole river network? *Journal of Geophysical Research: Biogeosciences* 118(2):728-740.
- Ahmad, F., 2012. Detection of change in vegetation cover using multi-spectral and multi-temporal information for District Sargodha, Pakistan. *Sociedade & Natureza* 24(3):557-571.
- Akalu, S., S. Mengistou & S. Leta, 2011. Assessing human impacts on the Greater Akaki River, Ethiopia using macroinvertebrates. *SINET: Ethiopian Journal of Science* 34(2):89-98.
- Ansari, Z. R., L. Rao & A. Yusuf, 2012. GIS based morphometric analysis of Yamuna drainage network in parts of Fatehabad area of Agra district, Uttar Pradesh. *Journal of the Geological Society of India* 79(5):505-514.
- Aschale, M., Y. Sileshi, M. Kelly-Quinn & D. Hailu, 2017. Pollution assessment of toxic and potentially toxic elements in agricultural soils of the city Addis Ababa, Ethiopia. *Bulletin of environmental contamination and toxicology* 98(2):234-243.
- Ashraf, A., 2013. Changing hydrology of the Himalayan watershed. Current perspectives in contaminant hydrology and water resources sustainability. Islamabad: Intech.
- Awoke, A., A. Beyene, H. Kloos, P. L. Goethals & L. Triest, 2016. River water pollution status and water policy scenario in Ethiopia: raising awareness for better implementation in developing countries. *Environmental management* 58(4):694-706.
- Balakrishnan, N., 1989. Approximate maximum likelihood estimation of the mean and standard deviation of the normal distribution based on type II censored samples. *Journal of Statistical Computation and Simulation* 32(3):137-148.
- Bali, R., K. Agarwal, S. N. Ali, S. Rastogi & K. Krishna, 2012. Drainage morphometry of Himalayan Glacio-fluvial basin, India: hydrologic and neotectonic implications. *Environmental Earth Sciences* 66(4):1163-1174.
- Behailu, S., 2004. Stream flow Simulation for The Upper Awash Basin. Addis Ababa University.
- Belete, D. A., 2011. Road and urban storm water drainage network integration in Addis Ababa: Addis Ketema Sub-city. *Journal of Engineering and technology research* 3(7):217-225.
- Beyene, A., T. Addis, D. Kifle, W. Legesse, H. Kloos & L. Triest, 2009. Comparative study of diatoms and macroinvertebrates as indicators of severe water pollution: case study of the Kebena and Akaki rivers in Addis Ababa, Ethiopia. *ecological indicators* 9(2):381-392.
- Beyene, A., Y. Kassahun, T. Addis, F. Assefa, A. Amsalu, W. Legesse, H. Kloos & L. Triest, 2012. The impact of traditional coffee processing on river water quality in Ethiopia and the urgency of

- adopting sound environmental practices. *Environmental monitoring and assessment* 184(11):7053-7063.
- Böhm, R., 1998. Urban bias in temperature time series—A case study for the city of Vienna, Austria. *Climatic Change* 38(1):113-128.
- Butt, A., R. Shabbir, S. S. Ahmad & N. Aziz, 2015. Land use change mapping and analysis using Remote Sensing and GIS: A case study of Simly watershed, Islamabad, Pakistan. *The Egyptian Journal of Remote Sensing and Space Science* 18(2):251-259.
- CEIWR-HEC, 2000. Hydrologic modeling system hec-hms technical reference manual. US Army Corps of Engineers Institute for Water Resources Hydrologic Engineering Center (HEC): Davis, CA, USA:1-148.
- CEIWR-HEC, 2013. HEC-GeoHMS Geospatial Hydrologic Modeling Extension User's Manual, Version 10.1. US Army Corps of Engineers Institute for Water Resources Hydrologic Engineering Center (HEC),:1-193.
- CEIWR-HEC, 2017. Hydrologic Modeling System HEC-HMS Applications Guide. US Army Corps of Engineers Institute for Water Resources Hydrologic Engineering Center (HEC):1-195.
- Cha, Y. J., M.-P. Shim, S. K. Kim & N. River, The four major rivers restoration project. In: UN-Water international conference, Zaragoza, 2011. p 3-5.
- Cho, Y., 2020. Application of NEXRAD Radar-Based Quantitative Precipitation Estimations for Hydrologic Simulation Using ArcPy and HEC Software. *Water* 12(1):273.
- Clark, J. J. & P. R. Wilcock, 2000. Effects of land-use change on channel morphology in northeastern Puerto Rico. *Geological Society of America Bulletin* 112(12):1763-1777.
- Clarke, J., 1966. Morphometry from maps. *Essays in geomorphology*. Heinmann, London:235-274.
- Climate-adapt, 2019. Rehabilitation and restoration of rivers and floodplains (2019). In: <https://climate-adapt.eea.europa.eu/metadata/adaptation-options/rehabilitation-and-restoration-of-rivers>.
- Cohn, T. A., 1988. Adjusted maximum likelihood estimation of the moments of lognormal populations from type 1 censored samples. US Geological Survey.
- Cohn, T. A., L. L. Delong, E. J. Gilroy, R. M. Hirsch & D. K. Wells, 1989. Estimating constituent loads. *Water resources research* 25(5):937-942.
- Cohn, T. A., E. J. Gilroy & W. G. Baier, 1992. Estimating fluvial transport of trace constituents using a regression model with data subject to censoring. *The Survey*.
- Council, N. R., 2002. The Missouri River ecosystem: exploring the prospects for recovery. National Academies Press.
- CSA, 1998. Report on the 1998 Health and Nutrition Survey. In: Agency, E. C. s. (ed).
- CSA, 1999. Statistical Abstracts. In: Agency, E. C. s. (ed).
- Dagnachew, A., 2012. Study of the Urban Drainage System in Addis Ababa Yeka Sub-city. Addis Ababa University.
- Deng, C. & J. Ma, 2015. Viewing urban decay from the sky: A multi-scale analysis of residential vacancy in a shrinking US city. *Landscape and Urban Planning* 141:88-99.
- Desta, 2000. National Project on Ecological Sustainable Industrial Development (ESID), . Industrial Environmental Policy and Strategy of Ethiopia, UNIDO, Addis Ababa 1.
- Desta, H., H. Worku & A. Fetene, 2014. Assessment of the contemporary municipal solid waste management in urban environment: The case of Addis Ababa, Ethiopia. *J Environ Sci Technol* 7:107-122.

- Ding, Y., C. Elvidge & R. Lunetta, 1999. Survey of Multispectral Methods for Landcover Change Analysis. Remote Sensing Change Detection: Environmental Monitoring and Applications Taylor & Francis, London.
- Duan, N., 1983. Smearing estimate: a nonparametric retransformation method. Journal of the American Statistical Association 78(383):605-610.
- Enderlein, S., R. E. Enderlein & W. Peter, 2006. *-Water Quality Requirements.
- EPA, 2020. Where nutrient pollution occurs. In. <https://www.epa.gov/nutrientpollution/where-nutrient-pollution-occurs>.
- Eriksson, M. & J. Sigvant, 2019. Causes and impact of surface water pollution in Addis Ababa, Ethiopia.
- ESTC, 2005. Program on sustainable consumption and production in the Akaki river basin, A situation analysis of Akaki river. Ethiopian Science and Technology (ESTC), United Nations Environment Programme (UNEP) and The Ethiopian cleaner production center (ECPC).
- Ferguson, R., 1986. River loads underestimated by rating curves. Water resources research 22(1):74-76.
- Finney, D., 1941. On the distribution of a variate whose logarithm is normally distributed. Supplement to the Journal of the Royal Statistical Society 7(2):155-161.
- Gao, J. & Y. Liu, 2010. Determination of land degradation causes in Tongyu County, Northeast China via land cover change detection. International Journal of Applied Earth Observation and Geoinformation 12(1):9-16.
- Getahun, Y. & S. Gebre, 2015. Flood hazard assessment and mapping of flood inundation area of the Awash River Basin in Ethiopia using GIS and HEC-GeoRAS/HEC-RAS model. Journal of Civil & Environmental Engineering 5(4):1.
- Gilbert, R., 1987. Statistical methods for environmental pollution monitoring New York Van Nostrand Reinhold Co. Gilbert Statistical Methods for Environmental Pollution Monitoring 1987.
- Girmay, H. S., 1985. Shallow resistivity investigation in the Filwoha fault. Unpublished MSc Thesis, Addis Ababa University, Ethiopia.
- Golekar, R., M. Baride & S. Patil, 2013. Morphometric analysis and hydrogeological implication: Anjani and Jhiri river basin, Maharashtra, India. Archives of Applied Science Research 5(2):33-41.
- Goolsby, D., R. Coupe & D. J. Markovchick, 1991. Distribution of selected herbicides and nitrate in the Mississippi River and its major tributaries, April through June 1991. US Department of the Interior, US Geological Survey.
- Grenfell, M. C., A. Nicholas & R. Aalto, 2014. Mediative adjustment of river dynamics: The role of chute channels in tropical sand-bed meandering rivers. Sedimentary Geology 301:93-106.
- Habtamu, G., 2011. Impact of built environment on hydrological regimes of Addis Ababa. School of Post Graduate Studies, Addis Ababa University.
- Helsel, D. R. & R. M. Hirsch, 2002. Statistical methods in water resources, vol 323. US Geological Survey Reston, VA.
- Horton, R. E., 1932. Drainage-basin characteristics. Eos, transactions american geophysical union 13(1):350-361.
- Huong, H. T. L. & A. Pathirana, 2013. Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. Hydrology and Earth System Sciences 17(1):379.
- Itanna, F., 1998. Metal concentrations of some vegetables irrigated with industrial liquid waste at Akaki, Ethiopia. SINET: Ethiopian Journal of Science 21(1):133-144.
- Järnberg, L., E. E. Kautsky, L. Dagerskog & P. Olsson, 2018. Green niche actors navigating an opaque opportunity context: Prospects for a sustainable transformation of Ethiopian agriculture. Land use policy 71:409-421.

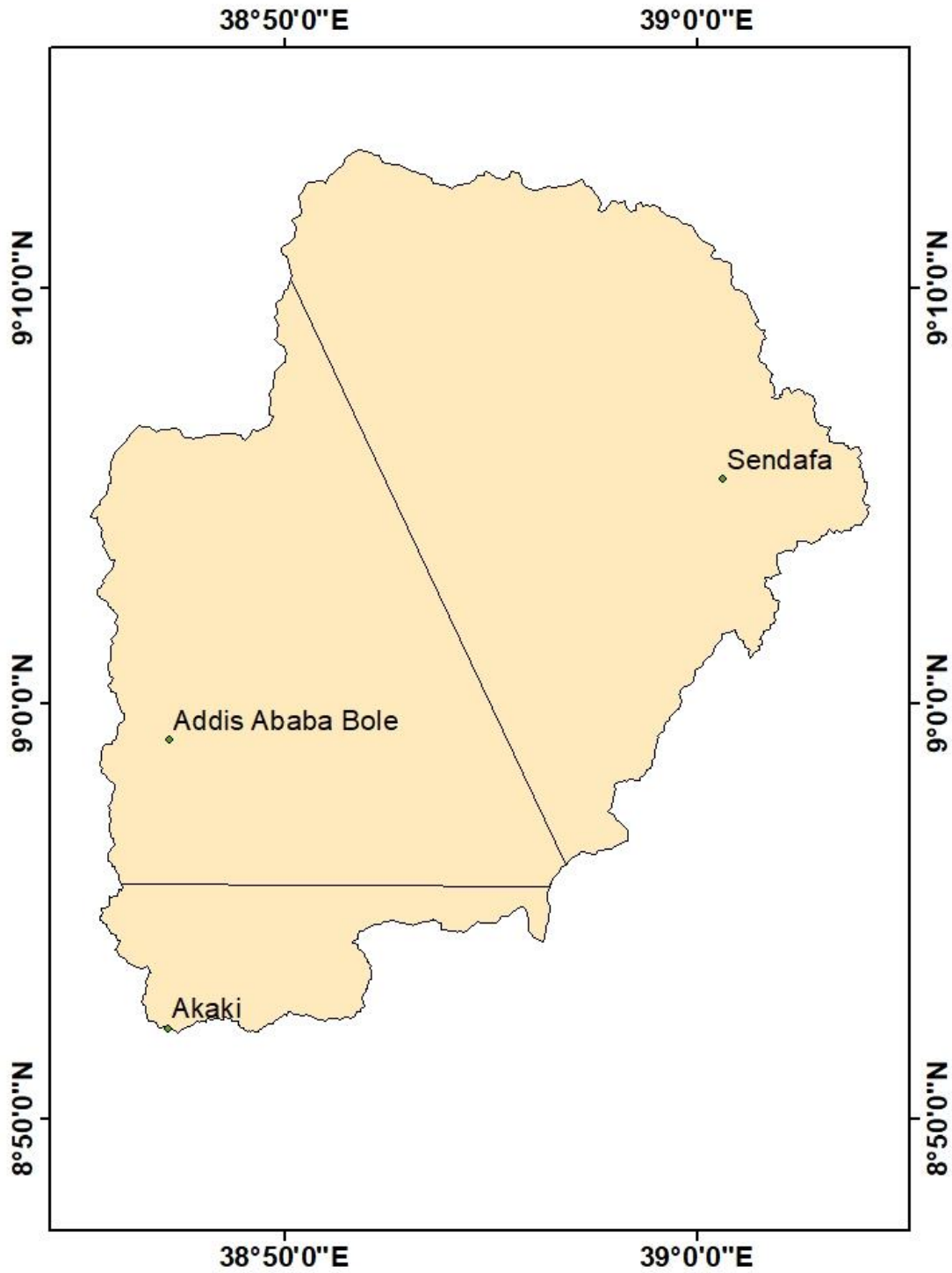
- JICA, 1998. *The Study on Addis Ababa Flood Control Project in the Federal Democratic Republic of Ethiopia-Volume II Main Report*”.
- Kisi, O., J. Shiri & M. Tombul, 2013. Modeling rainfall-runoff process using soft computing techniques. *Computers & Geosciences* 51:108-117.
- Lee, S. & G.-W. Choi, 2012. Governance in a river restoration project in South Korea: The case of Incheon. *Water resources management* 26(5):1165-1182.
- Leta, S., F. Assefa, L. Gumaelius & G. Dalhammar, 2004. Biological nitrogen and organic matter removal from tannery wastewater in pilot plant operations in Ethiopia. *Applied microbiology and biotechnology* 66(3):333-339.
- Liao, J., T. Wang, X. Wang, M. Xie, Z. Jiang, X. Huang & J. Zhu, 2014. Impacts of different urban canopy schemes in WRF/Chem on regional climate and air quality in Yangtze River Delta, China. *Atmospheric Research* 145:226-243.
- Lu, D., G. Li, G. S. Valladares & M. Batistella, 2004. Mapping soil erosion risk in Rondonia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. *Land degradation & development* 15(5):499-512.
- Madsen, B., P. J. Boon, P. S. Lake, S. E. Bunn, C. N. Dahm, T. E. Langford & M. Zalewski, 2006. Ecological principles and stream restoration. *Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen* 29(4):2045-2050.
- Maidment, D. R., 1993. *Handbook of hydrology*, vol 9780070. McGraw-Hill New York.
- Maidment, D. R. & S. Morehouse, 2002. *Arc Hydro: GIS for water resources*. ESRI, Inc.
- Mandl, B., 2015. *Danube watch*. International Commission for the Protection of the Danube River.
- Mekonnen, M. M. & A. Y. Hoekstra, 2018. Global anthropogenic phosphorus loads to freshwater and associated grey water footprints and water pollution levels: A high-resolution global study. *Water resources research* 54(1):345-358.
- Memon, R. A. & D. Y. Leung, 2010. Impacts of environmental factors on urban heating. *Journal of Environmental Sciences* 22(12):1903-1909.
- Mersha, Z., 2012. Determination of the pollution level of Great and Little Akaki rivers and trend of pollution. *Addis Ababa city Environmental Protection Authority*:45-56.
- Michaud, J., C. Johnson, J. Iokepa & J. Marohnic, 2005. *Methods for Estimating the Impact of Hypothetical Dam Break Floods Chemistry for the Protection of the Environment* 4. Springer, 195-199.
- Moges, G. & V. Bhole, 2015. Morphometric characteristics and the relation of stream orders to hydraulic parameters of river Goro: An Ephemeral River in Dire-Dawa, Ethiopia. *Universal Journal of Geoscience* 3(1):13-27.
- Mulatu, C. A., A. Crosato, M. M. Moges, E. J. Langendoen & M. McClain, 2018. Morphodynamic trends of the Ribb River, Ethiopia, prior to dam construction. *Geosciences* 8(7):255.
- Negash, T., 2009. *Assessment of the physico-chemical Parameters of selected rivers in the city of Addis Ababa*. Addis Ababa University.
- Oberlander, T. & M. Morisawa, 1985. Origin of drainage transverse to structures in orogens Tectonic geomorphology. vol 15. Allen and Unwin Boston, 155-182.
- Pachauri, R. & A. Reisinger, 2008. *Climate change 2007. Synthesis report. Contribution of Working Groups I, II and III to the fourth assessment report*. Cambridge University Press, Cambridge.
- Pareta, K. & U. Pareta, 2012. Quantitative geomorphological analysis of a watershed of Ravi River Basin, HP India. *International journal of remote sensing and GIS* 1(1):41-56.

- Parker, A. G., A. S. Goudie, S. Stokes, K. White, M. J. Hodson, M. Manning & D. Kennet, 2006. A record of Holocene climate change from lake geochemical analyses in southeastern Arabia. *Quaternary Research* 66(3):465-476.
- Parveen, R., U. Kumar & V. K. Singh, 2012. Geomorphometric characterization of upper South Koel basin, Jharkhand: a remote sensing & GIS approach. *Journal of Water Resource and Protection* 4(12):1042.
- Pathirana, A., H. B. Denekew, W. Veerbeek, C. Zevenbergen & A. T. Banda, 2014. Impact of urban growth-driven landuse change on microclimate and extreme precipitation—A sensitivity study. *Atmospheric Research* 138:59-72.
- Paul, M. J. & J. L. Meyer, 2001. Streams in the urban landscape. *Annual review of Ecology and Systematics* 32(1):333-365.
- Powell, J. L., 1984. Least absolute deviations estimation for the censored regression model. *Journal of Econometrics* 25(3):303-325.
- Rosenberger, R. S., Y. Sneh, T. T. Phipps & R. Gurvitch, 2005. A spatial analysis of linkages between health care expenditures, physical inactivity, obesity and recreation supply. *Journal of Leisure Research* 37(2):216-235.
- Runkel, R. L., C. G. Crawford & T. A. Cohn, 2004. Load Estimator (LOADEST): A FORTRAN program for estimating constituent loads in streams and rivers.
- Salmiati, N. Z. A. & M. R. Salim, 2017. Integrated approaches in water quality monitoring for river health assessment: scenario of Malaysian River. *Water Quality*:315.
- Sasakova, N., G. Gregova, D. Takacova, J. Mojzisova, I. Papajova, J. Venglovsky, T. Szaboova & S. Kovacova, 2018. Pollution of surface and ground water by sources related to agricultural activities. *Frontiers in Sustainable Food Systems* 2:42.
- Satterthwaite, D., 2009. The implications of population growth and urbanization for climate change. *Environment and urbanization* 21(2):545-567.
- Shin, J.-H. & J.-Y. Chung, The four major rivers restoration project in South Korea. In: *Proceedings of the Institution of Civil Engineers-Civil Engineering*, 2011. vol 164. Thomas Telford Ltd, p 19-26.
- Shin, J.-H. & I.-K. Lee, Cheong Gye Cheon restoration in Seoul, Korea. In: *Proceedings of the Institution of Civil Engineers-Civil Engineering*, 2006. vol 159. Thomas Telford Ltd, p 162-170.
- Singh, P., J. K. Thakur & U. Singh, 2013. Morphometric analysis of Morar River Basin, Madhya Pradesh, India, using remote sensing and GIS techniques. *Environmental Earth Sciences* 68(7):1967-1977.
- Singh, R., C. Bhatt & V. H. Prasad, 2003. Morphological study of a watershed using remote sensing and GIS techniques. *Hydrol J* 26(1-2):55-66.
- Singh, R. & C. Shi, 2014. Advances in observation and estimation of land use impacts on climate changes: improved data, upgraded models, and case studies. *Advances in Meteorology* 2014.
- Sohrabinia, M., S. Sadeghianb & D. Manavic, 2008. Application of image processing and image analysis methods for large scale map revision. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 37:1351-1354.
- Stackpoole, S. M., E. G. Stets & L. A. Sprague, 2019. Variable impacts of contemporary versus legacy agricultural phosphorus on US river water quality. *Proceedings of the National Academy of Sciences* 116(41):20562-20567.
- Strahler, A. N., 1952. Hypsometric (area-altitude) analysis of erosional topography. *Geological Society of America Bulletin* 63(11):1117-1142.
- Tafete, E., 2013. Evaluation of Drainage system in Kebena stream catchment, Addis Ababa. Addis Ababa University.

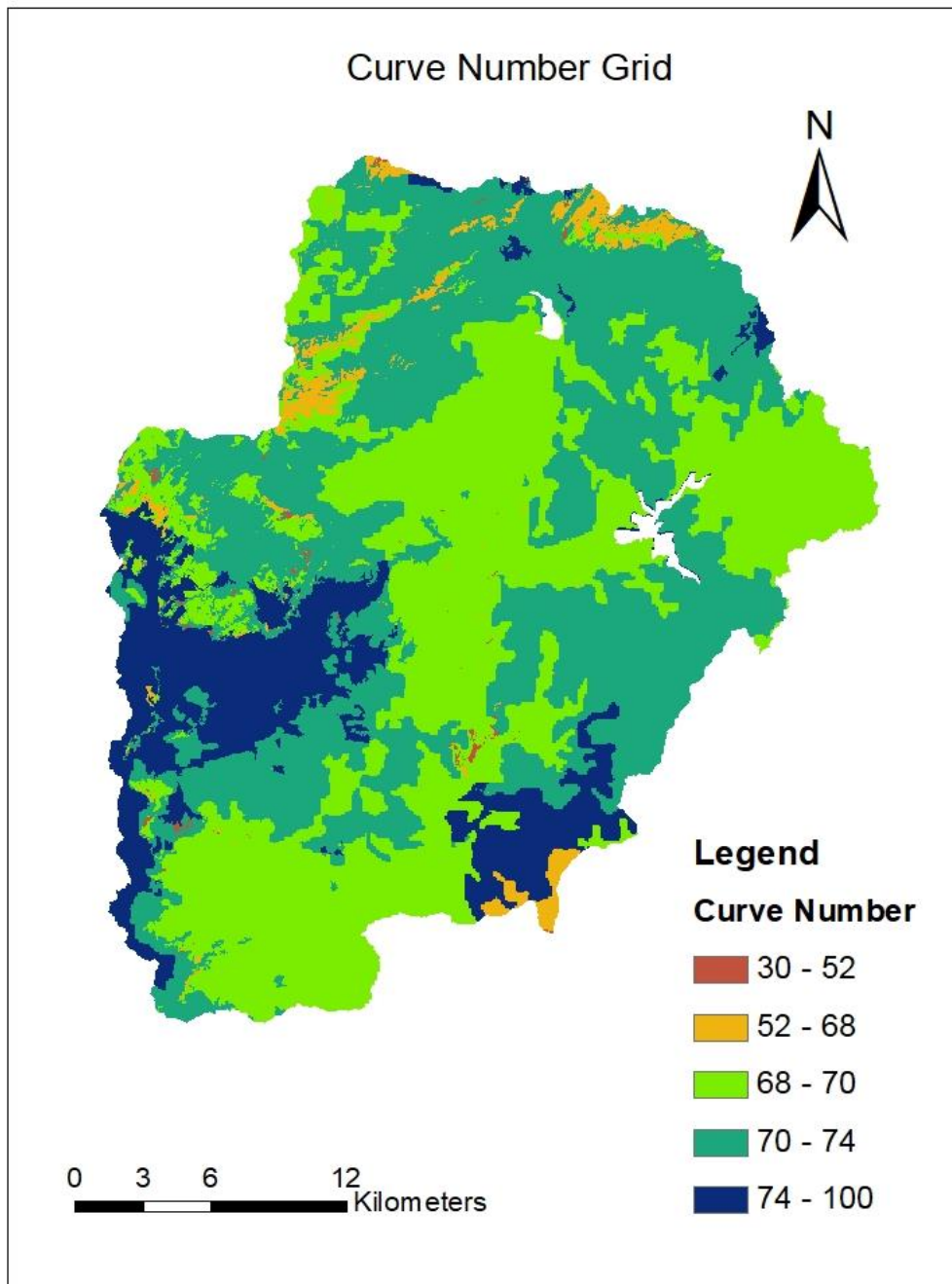
- Tamiru, A., L. Dagnachew, A. Tenalem, T. Yirga, W. Solomon & M. Nuri, 2004. Assessment of pollution status and groundwater vulnerability mapping of the Addis Ababa water supply aquifers. Ethiopia(available online at <http://www.unep.org/groundwater/project/Countries/Ethiopia/Report/Nov2004.pdf>)(unpublished).
- Teklehaimanot, R. R., 2003. Toxic Risk Evaluation of the Awash River Basin, Ethiopia. Wageningen University, Wageningen M.Sc Thesis in Environmental Sciences, .
- Tolla, B., 2006. Physico-chemical characteristics and pollution levels of trace metals in the Little Akaki and Big Akaki Rivers. Addis Ababa University.
- Turner, M. G., R. H. Gardner, R. V. O'Neill & R. V. O'Neill, 2001. Landscape ecology in theory and practice, vol 401. Springer.
- USGS, 2020a. Phosphorus and River Water Quality. In. <https://www.usgs.gov/news/phosphorus-and-river-water-quality>.
- USGS, 2020b. Phosphorus and Water.
- Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman & R. P. Morgan, 2005. The urban stream syndrome: current knowledge and the search for a cure. *Journal of the North American Benthological Society* 24(3):706-723.
- Weldesilassie, A. B., E. Boelee, P. Drechsel & S. Dabbert, 2011. Wastewater use in crop production in peri-urban areas of Addis Ababa: impacts on health in farm households. *Environment and Development Economics* 16(1):25-49.
- Wohl, E., P. L. Angermeier, B. Bledsoe, G. M. Kondolf, L. MacDonnell, D. M. Merritt, M. A. Palmer, N. L. Poff & D. Tarboton, 2005. River restoration. *Water Resources Research* 41(10).
- Woldegerima, T., K. Yeshitela & S. Lindley, 2017. Characterizing the urban environment through urban morphology types (UMTs) mapping and land surface cover analysis: The case of Addis Ababa, Ethiopia. *Urban ecosystems* 20(2):245-263.
- Yohannes, H. & E. Elias, 2017. Contamination of rivers and water reservoirs in and around Addis Ababa city and actions to combat it. *Environ Pollut Climate Change* 1(116):2.
- Yousefi, S., H. R. Moradi, S. Keesstra, H. R. Pourghasemi, O. Navratil & J. Hooke, 2019. Effects of urbanization on river morphology of the Talar River, Mazandarn Province, Iran. *Geocarto International* 34(3):276-292.
- Yousefi, S., H. R. Moradi, H. R. Pourghasemi & R. Khatami, 2018. Assessment of floodplain landuse and channel morphology within meandering reach of the Talar River in Iran using GIS and aerial photographs. *Geocarto international* 33(12):1367-1380.
- Zhang, L., B. Yuan, X. Yin & Y. Zhao, 2019. The Influence of Channel Morphological Changes on Environmental Flow Requirements in Urban Rivers. *Water* 11(9):1800.
- Zhang, N., Z. Gao, X. Wang & Y. Chen, 2010. Modeling the impact of urbanization on the local and regional climate in Yangtze River Delta, China. *Theoretical and applied climatology* 102(3-4):331-342.
- Zhang Yuhua, H. x., Jin Congcong, 2016. Research of Urban River Health Assessment Model. *Journal of Water Resources and Ocean Science* Vol. 5, No. 4, pp. 47-52. doi:10.11648/j.wros.20160504.11.

APPENDIX

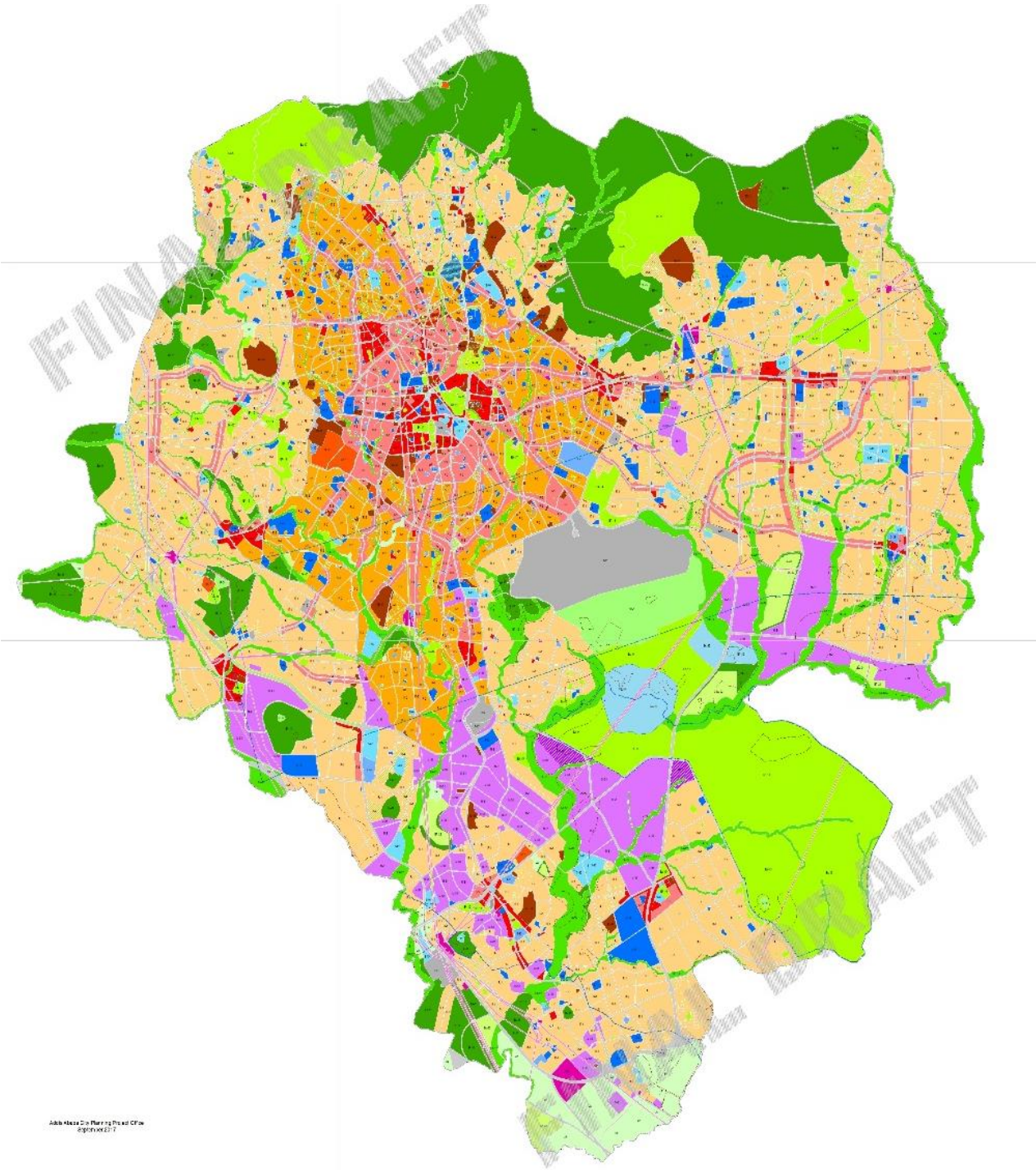
Appendix A: **Thiessen polygon**



Appendix B: Curve number grid



Appendix C: Addis Ababa Master Plan Final Draft (A)



Appendix D: Addis Ababa Master Plan Legend Final Draft (B)



በአዲስ አበባ ከተማ አስተዳደር የመሬት ፕላን ፕሮጀክት ጽ/ቤት
Addis Ababa City Planning Project Office



የአዲስ አበባ መሬት አጠቃቀም ፕላን - የመጨረሻ ሻ ረቂቅ

LAND USE PLAN OF ADDIS ABABA - FINAL DRAFT

