ADDIS ABABA RIVERS AND RIVERSIDES DEVELOPMENT PLAN PROJECT

ADDIS ABABA CITY RIVERS POLLUTION AND SANITATION STUDY

ADDIS ABABA RIVERS & RIVERSIDES DEVELOPMENT PLAN PROJECT

FINAL PROJECT. SEPTEMBER, 2017

City Pollution and Sanitation Study for Addis Ababa Rivers and Riversides

Client : Addis Ababa Rivers and Riversides Development and Climate Change Adaptation Project Office, Addis Ababa City Adminis tration

Consultancy Service Provider: Center for Environmental Science, Addis Ababa University

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URL: www.aau.edu.et and www.ces-aau.org

This publication can be cited as: Seyoum Leta, Andualem Mekonen, Eshetu Alemu, Tadesse Alemu, Zerihum Abate, Eyob Yilma, Gulelat Teshome, Hanna Habtemariam, Challa Ragassa and Mesfin Sahle, Teshome Soromessa, Ahmed Hussen and Dejene Tsegaye (2017). Pollution and Sanitation Study for Addis Ababa Rivers and Riversides Development Plan Project, Center for Environmental Science, Addis Ababa University, Addis Ababa.

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ACRONYMS

AAEPA	Addis Ababa Environmental Protection Authority
AOB	Ammonium Oxidizing Bacteria
AAU	Addis Ababa University
AAWSA	Addis Ababa Water and Sewerage Authority
AnAOB	Anaerobic ammonium oxidizing bacteria
APHA	American Public Health Association
ASS	Atomic Absorption Spectrophotometer
BA	Big Akaki
BKK+K	Banteyiketu-Kechene- Kurtume and Kebena
BOD	Biological Oxygen Demand
BY	Banteyiketu

CANON	Completely Autotrophic Nitrogen Removal Over Nitrite
CCME	Canadian Council of Ministers for Environment
CLLE	Continuous Liquid-Liquid Extraction
COD	Chemical Oxygen Demand
CSA	Central Statistics Agency
DMAL	Desirable Maximum Allowable Limit
DO	Dissolved Oxygen
EC	Electrical Conductivity
ECA	Economic Commission for Africa
EEC	European Economic Commission
EU	European Union
FEPA	Federal Environmental Protection Agency
FC	Feacal Coliform
FEDB	Finance and Economic Development Bureau of Addis Ababa City
FOG	Fats, Oils and Grease
GA	Great Akaki
GPS	Global Positioning System
GPC	Gel Permeation Chromatography
GTP	Growth and Transformation Plan
KA	Kebena
KC	Kechene
KU	Kurtume
LA	Little Akaki
m.a.s.l	meter above sea level
MAC	Maximum Allowable Concentration
MAL	Maximum Allowable Limit
MoWR	Ministry of Water Resources
NOB	Nitrite Oxidizing Bacteria
NTU	Nephelometric Turbidity Unit
SBPDA	Sanitation, Beautification &Parks Development Agency
SCBR	Suspended Carrier Biofilm Reactors
SSF	Slow Sand Filtration
SWG	Solid Waste Generation
TC	Total Coliforms
TDS	Total Dissolved Solids
TSS	Total suspended solids
TDS	Total Dissolved Solids
UK GQA	United Kingdom General Quality Assessment
UNESCO	United Nations Educational, Scientific and Cultural Organization
UDWW	Untreated Domestic Wastewater
USEPA	United States Environmental Protection Agency
USFEPA	United States Federal Environmental Protection Agency
USNAS	United States National Academy of Science
USPHS	United States Public Health Service
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

Acknowledgments

The study team would especially like to thank the Addis Ababa City Rivers and Riversides and Climate Change Adaptation Project Office for its financial support and full cooperation in undertaking such an intensive field and laboratory based studies on Addis Ababa City rivers pollution and sanitation. We wish to thank the Centre for Environmental Science, Addis Ababa University for the active engagement and closer follow-up as well as facilitation of the project field study from inception to finalization.

The responsibility for mistakes and misunderstandings remain fully with the study team.

EXECUTIVE SUMMARY

Introduction

Founded in 1886, Addis Ababa is the capital City of Ethiopia, and it is located at 9° 2' N; 38° 42' E with altitude ranging from 2,100 meters at Akaki in the south to 3,000 meters at Entoto hill in the North. At present media reports and studies showed that the population of Addis Ababa is estimated to be more than 4million with a growth rate of 2.9 percent per year; this will be more than double by the year 2030. Its geographic area has grown quickly over the last decade, expanding from 11,000 hectares in 1995 to the current built-up area of the City lying within the Big and little Akaki river basins which has a catchment area of about 540 square kilometers. The increasing trend in population growth, urbanization and industrialization puts an extreme pressure on City's urban environmental management. In order to assess the extent of pollution and identify management and technological options for the sustainable management of Addis Ababa City rivers and riversides, the study was commissioned by the Addis Ababa City Rivers and Riversides and Climate Change Adaptation Project office in March 2016.

Objectives of the Study

The objective of the Pollution and Sanitation Project is to identify existing rivers and their tributaries, map pollution loads from point and non-point sources; assess waste (solid and liquid) and waste management practices and point out both management and technological options for the treatment/clean-up of City rivers pollution including implementation strategies.

Approach and Methodology

The study covers identification of existing City rivers, river sides and its tributaries; and mapping pollution sources (solid and liquid wastes); biophysical (physic-chemical and biological) assessment of selected rivers and their tributaries; development of cleanup plans and implementation strategies for the selected rivers (Banteyiketu, Kebena, kechene and Kurtumie) including cost estimation of the proposed waste and waste management technologies and systems along these selected rivers. However, the pollution status assessment covers the two major rivers in Addis Ababa City, namely; Big Akaki river basin (Eastern sub catchment) and Little Akaki river basin (western sub catchment).

Overall pollution load assessment was conducted for Kechene-kutumie-Banteyeketu and Kebena rivers as well as for the Big and little Akaki rivers until they join Aba Samuel Lake. Detailed assessment and mapping of pollution sources from point sources such as hospitals, schools, hotels, garages, printing presses and condominium sites including solid and liquid waste management practices; generation rate and disposal mechanisms along Kechene-kurtumie-Banteyeketu and Kebena rivers were also made. Water and sediment samples collected from 32 sampling sites were analyzed for water quality parameters such as temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate, sulfate, sulfide, conductivity, Alkalinity, hardness, turbidity, total dissolved solids, chloride, total suspended solids (TSS), total coliform (TC), and fecal coliform (FC), heavy metals and pesticides. The field monitoring, sample collection and analyses were undertaken for two seasons dry (May 2nd week) and wet seasons (August 1st week). In this report rivers water quality parameters for dry and wet seasons covering BKK+K as well as Akaki rivers is presented. Pollution types and sources identified, characterized and mapped along the BKK +K by its source and type is also described. Finally, series of management and technological options are also described for City rivers pollution control and management.

Existing Situation of City Waste Management Practices

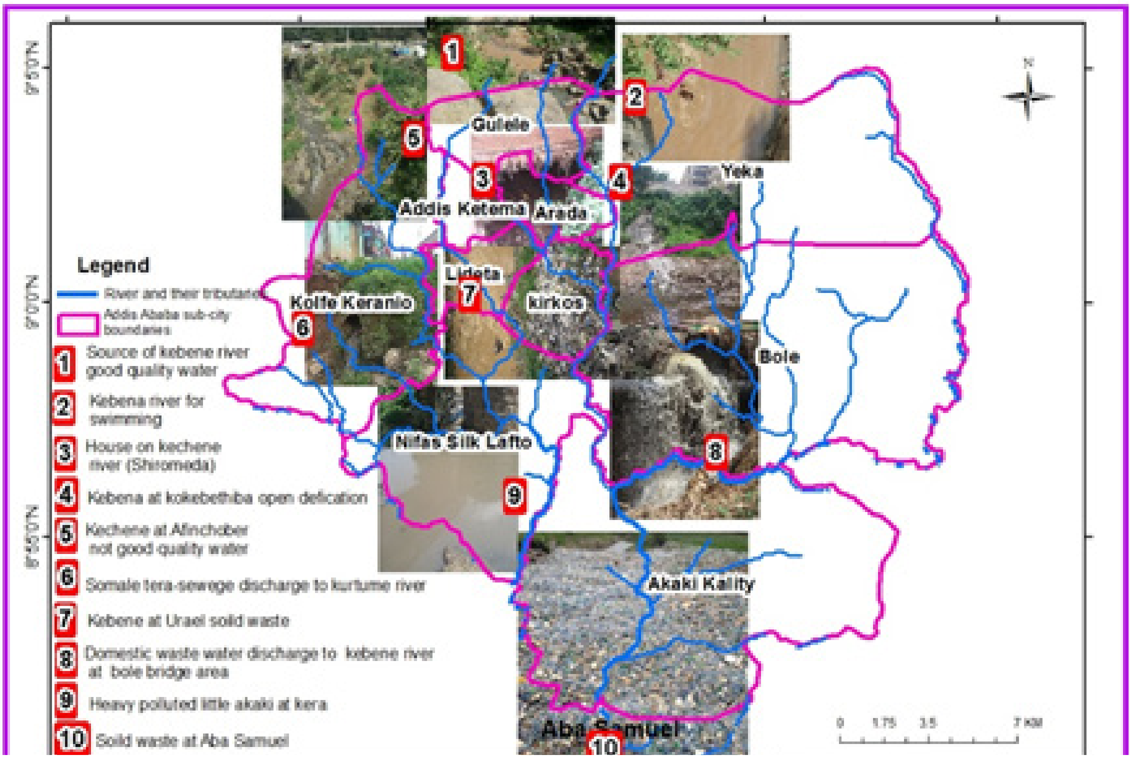
According to Addis Ababa solid waste management system report (2010), the daily waste generation rate in the City is estimated at 0.44kg/capita/day and 65 % of municipal solid waste is collected in the City, 10 % composted/recycled and the remaining 25% is dumped illegally into rivers and rivers sides and or open spaces. Solid waste disposed-off in open spaces and open defecation are washed by runoff during rains, and flows into rivers and seeps into shallow groundwater. Studies also showed that there are more than 2500 industries in Addis Ababa and more than 90% these industries discharge their wastewater directly into nearby stream courses without treatment. Downstream vegetable growing farmers use the polluted river water for irrigation to grow vegetables, which later are sold and consumed by inhabitants of the City.

The principal sources of wastewater in the City are the households, industrial, commercial, service and institutions. The municipal liquid waste consists of sewage, surface run off, human excreta and other domestic and industrial waste waters. The wastewater collection and disposal system in Addis Ababa is very poor and the sanitation coverage is also very low. According to the information from AAWSA, out of the total yearly wastewater generation (851 tonnes), only about 12% of the wastewater is collected, treated and disposed-off properly by sewerage system. Studies also showed that 22.1%of the City's population are using flash toilets, 64.8% are using pit latrines and 13.1% of the City's residents do not have any form of sanitation facilities. 98.64% of the housing units of Addis Ababa had access to safe drinking water, while 14.9% had flush toilets, 70.7% pit toilets (both ventilated and unventilated), and more than 14.3% had no toilet facilities (which might use open defecation).

In the City, streams and rivers receive the major part of the waste produced by the municipality. These rivers end up at Aba Samuel reservoir. The seasonal and perennial rivers of Addis Ababa are heavily polluted by industrial and municipal solid and liquid wastes.

From our field based survey the following were identified as the major pollution problems along the City rivers:

- Liquid waste discharge in to the river including sewer lines
- Municipal solid waste damping on the river banks.
- Almost all the drainage system opens their out let to the river system
- Hospital wastes discharge in to the river
- Open defecation on the banks of the rivers
- Surface run off from municipal, agricultural land and vegetable farming.
- Discharge of animal wastes from cattle sheds located along the river banks



Major -pollution problems along Addis Ababa City rivers

The inappropriate practices of dumping domestic and industrial wastes into the river catchments has resulted in turning the rivers in to sewer line services. Open green areas in general and rivers and riversides in particular, have been placed under extreme pressure, thus threatening their ability to maintain basic ecological, social and economic functions.

Current Status of City Rivers Pollution

Pollution load assessment results showed that the upper part of the river water quality parameters were within the allowable limits. However, in the middle and lower (downstream) sampling sites along BKK +K as well as little and big Akaki rivers, the water quality parameters exceeded the surface water quality standards set by various bodies. The findings revealed that the pollution level of the river is higher than not only the permissible limits used by various bodies for surface water quality parameters but also it is by far higher than the wastewater characteristics for typical untreated domestic wastewater. The findings clearly showed that there is a strong correlation between source of pollution, anthropogenic activities, and river water quality status along the BKK+ K rivers.

The solid wastes and wastewater loads from the various pollution sources show that generation of solid wastes from the various enterprises is estimated at 270.49 m3/day, whereas that of wastewater is 4,525.11 m3/day. Due to existing poor waste management technology, domestic, commercial and industrial waste disposal systems along the riverbanks, City rivers are seriously suffering from pollution and classified as badly polluted rivers. The main surface water system and the most impacted rivers in the City include Banteyiketu, Kechene, Qurtumie, Kebena, and little Akaki rivers.

Management and Technological Options for City Rivers Pollution Control

City Rivers Management Options

The findings from this study has clearly shown that industries, sewerage lines, hospitals, commercial centers, etc. were identified to be major sources of pollution for Addis Ababa City rivers. Most of the large and medium scale industries do not have their own effluent treatment plants. Moreover, there are no common effluent treatment systems to treat the effluent from these industries and as a result these industries contribute to the point source pollution of river water bodies, especially in the little and great Akaki rivers as well as Kurtumie-Kechene –Baneyiketu and Kebena rivers. In addition to industrial waste water, domestic wastewater is also directly discharged from slums, residential areas, and smaller drains into the sewerage network. In most cases sewage directly enters the rivers at various places all along these rivers.

Any sustainable approach to City rivers pollution control and management should include the following components: (1)Environmental Management: River ecosystems will remain degraded if solid and liquid wastes are untreated before entering the watercourse. The establishment of environmental management systems (EMS) geared to improve solid waste collection and management as well as sewage treatment will help address pollution problems. The EMS may include regulations on river easement in order to minimize or prevent solid waste dumping, and policies to abate pollution loading from untreated industrial wastewater and sewage. (2) Surface run-off control. City rivers are usually part of cities' drainage systems so that surface runoff especially during the rainy season are very likely. River rehabilitation programs therefore involve surface runoff management through the construction and/or improvement of revetment, parapet or river wall and soil embankment among other control operations like dredging, sanitation works and warning systems. The clearing of structures, dredging the river, and waterways that drain into the river are done to reduce frequency and degree of runoffs. (3) Housing and Resettlement: Many of the urban riverbanks are lined with informal settlements, so that the orderly and peaceful resettlement is relevant for the health of the river ecosystem and the safety of riverbank communities. A livelihood program can be provided to affected communities to maintain, restore and/or enhance their incomes that may have been disrupted due to relocation. Despite planned strategies, community people may still protest against many demolition and subsequent relocation projects for economic reasons. This can be addressed by opening avenues for their participation within the formal planning process

River restoration describes a wide range of activities aimed at restoring the natural state and functioning of rivers and the water environment. Restoring a river's natural conditions brings considerable benefits for people and the environment, from improving wellbeing by creating attractive landscapes to ensuring a healthy, thriving ecosystem. The main sources of pollution for selected rivers in Addis Ababa have been identified qualitatively and quantitatively. Accordingly, the following methods are proposed to be the restoration mechanisms:

(1) Sewage Management is considered to be long term solution for the piped and channeled sewages to the river. Sewage from the households, institutions, commercial centers, hospitals, industries and others must be collected, channeled and treated at the proposed zones of the central treatment plants by AAWSA. Sewage management is proposed to be compulsory condition for the rehabilitation of the river for two main reasons (i) the main stressors of the river such as population growth, hotels, commercial centers and the like are expected to grow dramatically, (ii) any proposed treatment methods along the river sides cannot withstand the volume and concentrations that will be discharged to the proposed treatment scheme to be established along these rivers.
(2) Wastewater management originating from industries, hotels, condominium and other point sources: Industries should be responsible and put in place wastewater treatment systems following existing regulations and policy provisions in order to treat their wastewater prior to discharge either to City sewer lines channeled to central effluent treatment or directly to the river systems.
(3) Construction of public toilet/common sanitation facilities: The municipality must play a key role in providing public toilets that are safe, accessible, clean and environmentally sustainable.
(4) Establishment of a solid waste management system: the City government should strictly enforce anti-dumping ordinance and introduce a refuse collection policy with the target of creating an effective solid waste management system, with a garbage collection efficiency rate of more than 98% with the aim of preventing direct or indirect dumping of solid wastes on waterways.
(5) Resettlement of residents along the City river sides/buffer zones for proper rivers and riversides management: Many of the urban riverbanks are lined with informal settlements, so that the orderly and peaceful relocation is relevant for the health of the river ecosystem and the safety of riverbank communities.
(6) Cleanup of river banks along BKK + K river water ways: Non-biodegradable solid wastes such as plastic wastes are observed scattered along the river banks. For proper management and restoration of the polluted rivers and river banks, there should be planned and organized cleanup process through involvement of communities dwelling along the riversides. Strategies and incentive mechanisms should be devised on how to involve the community particularly the youth in the massive cleanup processes of the rivers all along the selected segments.
(7) Enforcement of the environmental statutory of the City and the country at large: Any gaps to existing policy and regulatory framework should be identified and pertinent regulations be amended, if any, for a good marriage of policy and practice for bringing City rivers into its natural state and continue o render it ecological, economic and social services.
(8) Education and awareness creation: The improved natural rivers ecosystem can provide valu-

able opportunities for formal and informal learning, helping develop people's appreciation of their local environment and raising their awareness of the need to protect and live with rivers.

Technological Options for City rivers Pollution Abatement

Technological options that can are suitable for river pollution control and remediation systems can be physical, chemical and biological or combination of these. Recent developments, however, give more weight to bio-remediation technologies (i.e. remediation using aquatic plants, remediation using aquatic animals, and microbial remediation) as one of the effective ways to deal with the pollution of natural water systems.

Taking into consideration the suitability of the existing technologies for river pollution abatement as well as considering the existing situation of Addis Ababa City rivers, slow sand filtration (SSF) technology in combination with plant based systems (constructed wetland) along the river banks is considered to be appropriate in attaining water quality standards and feasible in terms of construction and operation. The currently, piped and channeled sewerages from the households will be collected and primarily treated in septic tank in two sides of the river bank (left and right) and finally treated with slow sand filtration followed by constructed wetland system. The location of treatment facilities will be along selected river segments of BKK-Kebena rivers. Selection and location of the treatment facilities along the rivers segments are based on the pollution load, watershed catchment characteristics; housing and settlement density; distance between the treatment facilities and existing structures and services along the each segment of the rivers.

Restoration of river banks with selected indigenous plants is pivotal for increasing nutrient retention capacity and self-purification ability of the river systems. This is very important for infiltration of the nutrients from solid and liquid wastes. Selection of indigenous plants that have the capacity to absorb nutrients and heavy metals should be selected and planted along the BKK-Kebena river banks.

Conclusion

The discharge of untreated effluent, solid wastes and wastewater from industries, households and institutions are the main sources of water pollution in Addis Ababa. The inappropriate practice of dumping domestic and industrial wastes into the river catchments has resulted in turning the rivers in to sewer line services. Open green areas in general and rivers and riversides in particular, have been placed under extreme pressure, thus threatening their ability to maintain basic ecological, social and economic functions. The pollution problem is exacerbated by the poor drainage systems. As a result Akaki river serves the City as drainage and sewer systems. According to UK General Quality Assessment (GQA) criteria for rivers, the findings from present study leads to the conclusion that the two rivers are classified as badly polluted river (except Tafo river). In wet season, the BOD and COD concentrations were shown to increase worsening the quality of river (very badly polluted) due to kirmet rainfall water containing all sorts of wastes including sewerage, solid organic waste, open defecation wastes, sediments and nutrients, all end up in the rivers. Microbial pathogens and heavy metal contamination not only affecting the water quality but also affects the general public health as well as downstream vegetable farming which in turn also becomes the major health issue of vegetable consumption.

Therefore, if proper wastewater treatment and solid waste management system will not be implemented at City wide level, the City rivers which can be called untreated domestic wastewater, continue to negatively affect urban environment, damage its aesthetic value, and threatens the livelihood of the society particularly downstream rural poor communities.

Recommendations

- Establishing regular water quality monitoring program for all the parameters to ensure the safety of the river waters, the health of the community and the integrity of the river ecosystems.
- Initiate cleanup of solid wastes already dumped into the City rivers on a case by case basis involving communities and the youth residing along the rivers.
- Establish environmental management systems (EMS) geared to improve solid waste collection and management as well as sewage treatment will help address pollution problems.
- City wide sewage management through connecting all sewer lines to the established and to be established wastewater treatment systems as a permanent and lasting solutions
- Enforce decentralized wastewater treatment systems for all small, medium and large scale industries including service giving institutions such as health centers, condominiums, hotels, etc.
- The proposed management and technological options should be combined with proper education, community awareness and participatory processes.
- Landscaping and beautification should give due attention to rivers physical restoration with proper restoration of river banks with selected indigenous plants for increasing nutrient retention capacity and self-purification ability of the river systems.
- For good river water recharge especially during dry seasons, proper watershed management at the upper catchment is desirable.

1 INTRODUCTION

1.1. Overview of the City of Addis Ababa

The urban area of Addis Ababa has expanded dramatically over the past decades. The built-up area of Addis Ababa - featuring ultra-modern buildings adjacent to slums - lies within the big Akaki and little Akaki river basins which has a catchment area of about 540 square kilometers (Figure 1). The big and little Akaki rivers, with their dendritic tributaries, drain the City from north to south. The inappropriate practice of dumping domestic and industrial wastes into the river catchments has resulted in turning the rivers in to sewer line services.

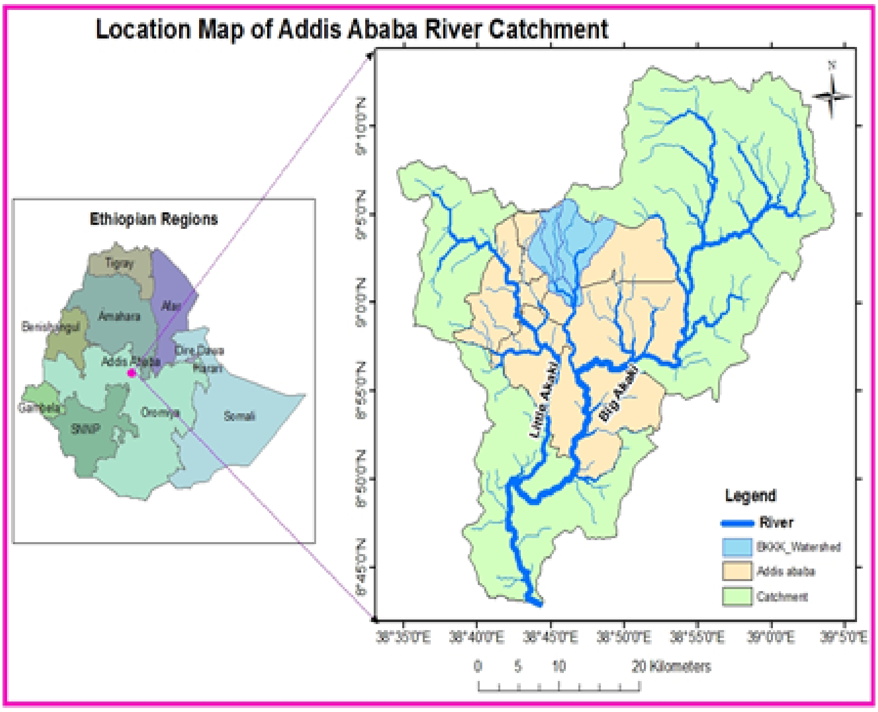


Figure 1: Geographic location of Addis Ababa City

At present media reports and studies showed that the population of Addis Ababa is estimated to be more than 4 million with a growth rate of 2.9 %per year; this will be more than double by the year 2030. The increasing trend in population growth, urbanization and industrialization puts an extreme pressure on City's urban environmental management.Addis Ababa is a typical example of developing countriescity where the rate of urbanization and availability of waste removal facilities are not in tandem. Solid waste that is generated is often disposed of in open spaces, where it is washed by runoff during rains, and flows into rivers and seeps into shallow groundwater.

Studies also showed that there are more than 2500 industries in Addis Ababa and majority of these industries discharge their wastewater directly into nearby stream courses. 90 per cent of these existing industries lack onsite treatment facilities (AAEPA 2007; Gebre and van Rooijen, 2009).The volume of wastewaters discharged from industries into the rivers is estimated at 4.8 million m3 / per year (CSA, 1999). Downstream vegetable growing farmers use the polluted river water for irrigation to grow vegetables, which later are sold and consumed by inhabitants of the City.

1.2. City Rivers Catchments, Tributaries and Riverside Management

There are two major rivers crossing the City, namely, little and big Akaki, which are used as open municipal waste disposal sites for the City of Addis Ababa. This river system is part of the larger Awashriver catchment, which drains to the central and eastern part of Oromiya and the confluence of which is at the Aba-Samuel reservoir (Figure 3). The downstream region, particularly the Akaki–Aba-Samuel wetlands, has an ecological importance for migratory birds (TadesseAnimaw, 2011).

Big Akaki: The eastern branch of the river, the big Akaki, rises north-east of Addis Ababa (Entoto, Kersa and Dire dam) and flows into Aba-Samuel reservoir after 53 km. bigAkaki river system crosses residential areas in the upper stream, particularly in Kebena area, and Minilik hospital where wastes directly dumped in to this river course from residential, commercial, services and industrial sectors, etc. The main tributaries of Big Akaki river are *Cheffe (Entoto), Kechene1, Kechene 2, Kurtumie, Banteyiketu (Kechene and Qurtumie), Kebena, Big kebena (Banteyiketu and Kebena), Tafo river (Tafo and Abado river), Beshale river (Legetafo and dire river) and Akaki river (Beshale river and gerji river) and big Akaki river (Akaki and Big kebena rivers).*

In the upper part of the City, the upstream river isthe area with minimum anthropogenic disturbance and pollution. Moving down the river course inside the City, the water has different chemistry. This change islikely induced by urbanization along with industrial and agricultural activities along the catchments. The lower course of big Akaki crosses rapidly expanding urban centers of Addis Ababa including proposed sites for future industrial expansion (TadesseAnimaw, 2011). In the lower course of the river, the long section of the river is intensively used for irrigated agriculture and finally joins Aba Samuel reservoir. According to Fissha Itanna (2002), arsenic (As) and zinc (Zn) are measurably higher in the soils irrigated by the Akai river. Akaki river is one of the tributaries draining Addis Ababa City to the Awashriver.

Little Akaki: The western branch of the river, little Akaki, originates North-West of Addis Ababa on the flanks of Wechacha Mountain and flows for 40 km before it reaches the reservoir. Most of the streams flowing from the North Western side meet little Akakiriver at Gullele area where some of the factories are located, i.e. Gulele Soap, Shirt and Marble factories. The river crosses densely populated residential and commercial centers around Merkatoand it also serves as dumping sites for Awash Winery effluents. Moreover, around Mekanisa the river receives effluents from National Alcohol and Liquor factory (Figure 2).

Figure 2: Wastewater discharge into Little Akaki River

Tributaries from North Western direction receive wastes of major sources like Addis Ababa abattoir, which hasdirect alteration of water quality. In the downstream section, the river crosses Akaki-Kality sub-city and flows into to Aba Samuel reservoir where it mixes with bigAkaki river. The river system is used as irrigation water source around Kolfe-Keranio, Lideta, Mekanisa and Akaki areas (TadesseAnimaw, 2011). The main tributaries of little Akakiriver are *Shegoleriver, 44 river, Bulchariver, Safari river, Mekanisa river, Akaki river.*

Aba Samuel Lake

The lake, located south of Addis Ababa, is an important site for avian ecology in Ethiopia; it is also noted as a tourist destination being so close to the capital. The lake was formed by the building of a hydro-electric dam that came 'on line' in 1939. It ceased electricity production in 1970 due to siltation problems and mechanical issues.The lake has become a reservoir of large area of highly polluted water with excessive algal growth (eutrophication) induced by excessive nutrient loading into the lake from incoming polluted rivers. Currently the lake is restored to continue to generate electricity and other ecological services.

At present, Addis Ababa City is seriously suffering from municipal and industrial wastes. This is due to the existing poor municipal waste management technology and industrial waste disposal system along the riverbanks, especially for industries established many years ago. Therefore identifying existing rivers and their tributaries, mapping pollution loads from point and non-point sources; assessing waste (solid and liquid) and waste management practices and developing a comprehensive treatment/clean-up strategies and implementation plan is timely.

1.3. Objective of the Study

The main objective of the City Rivers Pollution and Sanitation Study Project is toidentify existing rivers and their tributaries, map pollution loads from point and non-point sources; assess waste (solid and liquid) and waste management practices and point out both management and technological options for the treatment/clean-up of City rivers pollution including implementation strategies.

1.3.1 Specific Objectives

i. Identify and assess existing situation of the selected rivers and their tributaries and map diffused sources of pollution entering the rivers system; and determine pollution profiles (water quality);
ii. Assess solid waste and wastewater management practices in the City;
iii. Review, select and design of treatment/clean up technological options; formulation of a comprehensive development and management plan of selected rivers and river sides; and
iv. Pilot technologies and implementation strategies.

1.4. Scope of the Study

The study covers identification of existing City rivers, river sides and its tributaries; and mapping pollution sources (solid and liquid wastes); biophysical(physic-chemical and biological) assessment of selected rivers and their tributaries; development of cleanup plans and implementation strategies for the selected rivers: Kutumie, Kechne, Banteyiketu, and Kebena, rivers including cost estimation of the proposed waste and waste management technologies and systems along the selected rivers. However, the pollution status assessment covers the two major rivers in Addis Ababa City, namely; big Akaki river basin (eastern sub catchment) and littleAkaki river basin (western sub catchment).

1.5. Approach and Methodology

1.5.1 Study Area

The detailed pollution assessment was conducted in the two Akaki river catchments. bigAkaki is located in the eastern part of the City and collects water from its tributary rivers and streams in the region. Similarly, the little Akaki collects tributaries found in the western part of the City (Figure 3). The detailed study focuses on the big Akaki tributaries, namely: *Kurumie, Kechene, Banteyiketu, and Kebena (BKKK) rivers.*

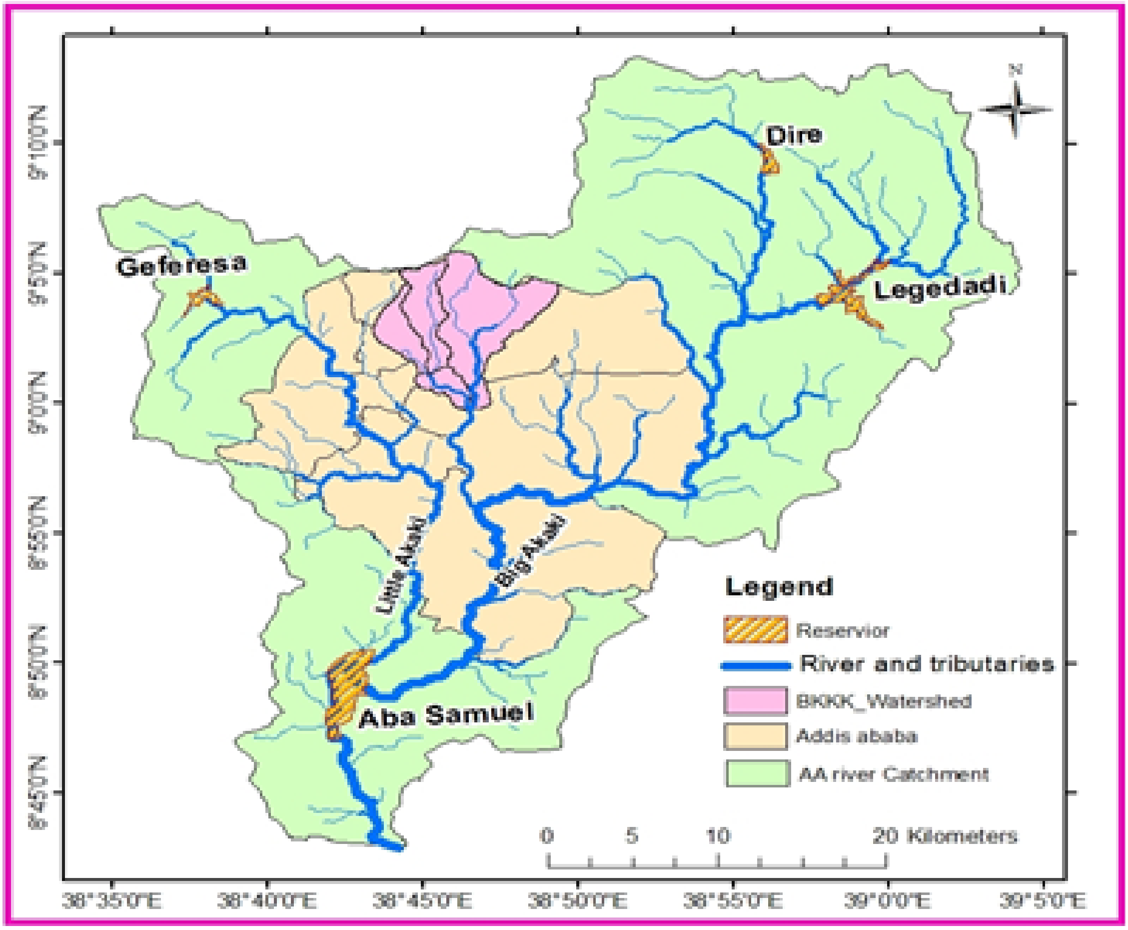


Figure 3: Map of Addis Ababa Rivers and Water reservoirs,

1.5.2 Approach

In order to generate a well-documented, synthesized and organized report on the pollution situations of selected Addis Ababa rivers; map sources of pollution loads from households, commercial centers, hospitals, garages, and industries; and develop a sound mitigation and treatment (management) interventions including implementation plans, the study adopted a three phased approaches (Figure 4), namely;

(a) Situation analysis: a robust review of existing documentations on waste (solid and liquid) management practices in the City of Addis Ababa, policies, regulations and institutional arrangement situations, as well as involvement of various stakeholders;

(b) Field survey: identification of rivers and its tributaries, mapping pollution loads of the rivers, sampling and analysis of pollution loads of the wastes from point and non-point sources and map pollution loads of the rivers, assess existing waste (solid and liquid) discharges and management practices along the rivers, etc.;

(c) Technology review: identification of series of technological options, selection and conceptualization of polluted rivers rehabilitation and design and developing a comprehensive treatment/ management/implementation plan with corresponding cost estimate.

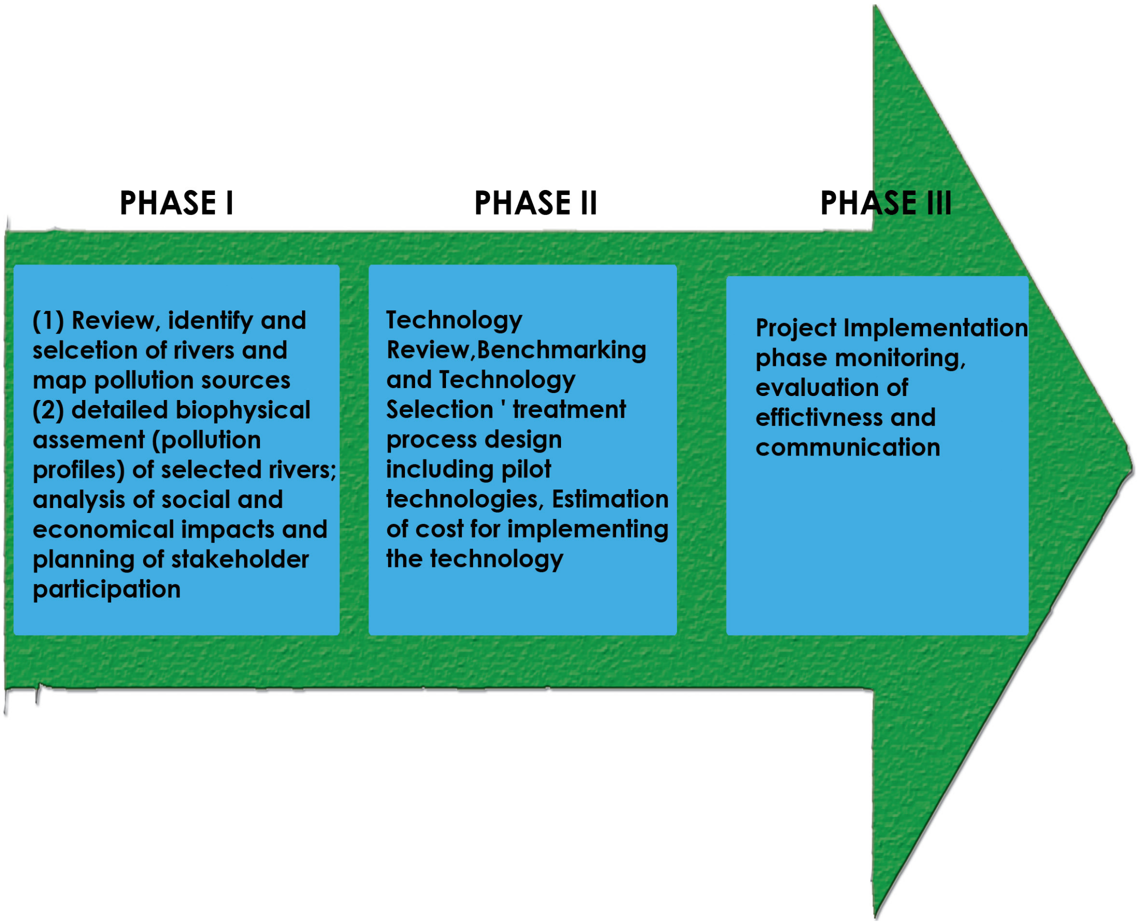


Figure 4: Project Phased Activities

Phase I: Existing Situational Analysis

• Document review: documents relevant to the Addis Ababa rivers and its tributaries were thoroughly reviewed in line with the project goals and objectives. Project working groups were categorized according to their respective profession and review literatures from legitimate and relevant sources. Document review, evaluation and analysis of existing studies, reports, research information and other relevant literatures pertaining to naturalization of the urban river and riverside were assessed.

• Field survey: preliminary field visits was made on existing selected rivers and tributaries of the City. The field survey was supported by capturing pictures using camera and taking GPS readings. The expected sources of pollution on these selected rivers such as households, industries, institutions, hospitals, garages and other activities will be identified and recorded. Identification of stream type, classification in terms of physical attributes of the river channel such as slope, physical, chemical and biological quality of the river and tributaries, width-to-depth ratio, particle size of sediments in bed and banks, stream entrenchment ratio, landform features by stability class and others. It offers a morphological tool for the classification of rivers by type. Evaluation of river section and landscape will be taken at this stage. Samples were taken for chemical, physical and biological analysis by using appropriate sampling technique at two seasons (May and August) of the year.

1.5.3 Criteria for Sampling Sites

Sampling and choice of sampling sites is a key step of pollution assessment along the selected rivers. The following were the criteria used for sample site selection for the study:

i. Upper river catchment sampling sites - for background data (bench marking) due to undisturbed (unpolluted) river source;
ii. Concentrations of residential, industrial, commercial and related activities upstream of the river;
iii. Upstream/downstream intensive land use such as urban agriculture and other socioeconomic activities;
iv. Accessibility of the site;
v. Junction point between rivers– to see the pollution load and pollution source of respective rivers; and
vi. Vegetable production sites – to see the pollution load of river water used for irrigation.

Other criteria used to select the sampling point werepurposive sampling sites were also chosen for one of the following reasons:

- If the site is exceptionally recreational area i.e., protected area by the government or private institutions /organizations;
- If the site is highly polluted and morphology of the river is different;
- The sampling point must provide a sample that is representative of the final effluent discharged into the receiving environment.

Accordingly, thirty two (32) sampling sites from the two respective river basins were selected to carry out a comprehensive pollution load assessment of the major rivers in the City of Addis Ababa (Figure 5).

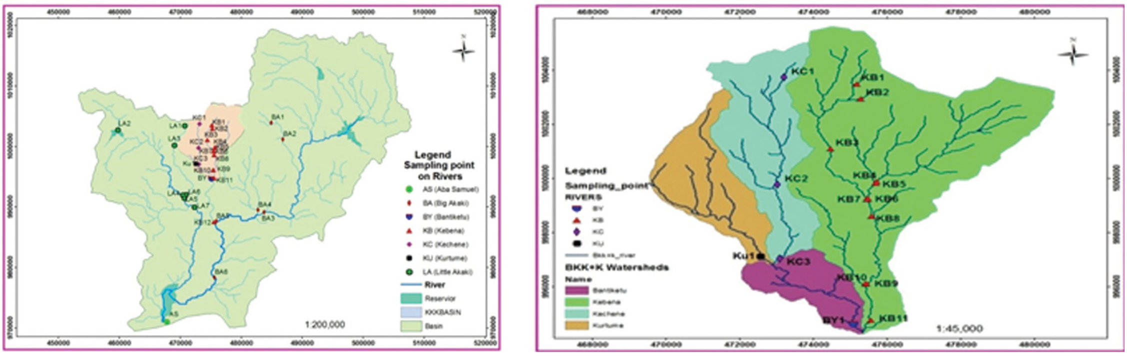


Figure 5: Sampling sites along the two river basins (a) including BKK plus kebena (b)

1.5.4 Sampling and Sampling Frequency

In order to establish City river pollution baseline for the Addis Ababa rivers, composite samples (water, soil, sediment and vegetables) were collected following standard sampling methods in dry (May) and wet seasons (July-August). The samples were analyzed in triplicates for phyico-chemical parameters (pH, Temperature ,EC, TDS, DO, COD, BOD, Ammonia, Nitrate, TN, TP, Phosphate, Sulphate, Sulfide, Chloride); heavy metals (Cd, Pb, Cr, Cu, Ni, Co, As), organic pollutants (oil and grease, pesticides); and biological parameters (pathogenic micro-organisms) as described below.

1.5.5 Sampling Techniques

Water, soil, sediment and vegetable samples were collected from selected rivers and river sides and different land use areas. Water and sediment samples were collected from 32sampling stations both in dry and wet seasons. Composite water samples from different river depth were collected using water sampler and Ekman grab. Soil, sediment and vegetation samples were collected from 3 sampling stations. Glass and polyethylene bottle were washed with 10% nitric acid and distill water prior to sample collection..

1.5.6 Laboratory Analysis

1.5.6.1. Water Samples Analysis

Water samples were taken for physical, chemical, and biological analyses as described above. pollutant parameters such as BOD, TN, TP, COD, ammonia, phosphate, hardness, TKN, TDS, TSS, chlorides, nitrates, sulphates, sulfide, pesticides, heavy metals as well as pathogen loads were analyzed according to standard methods (APHA, 1999) at the Center for Environmental Science Laboratory, Addis Ababa University. Turbidity, To, conductivity, alkalinity, pH and DO were measured onsite using portable devices. Microbial parameters (TC, FC, and E.coli) were analyzed using standard methods (APHA, 1999).

Oil and Grease was determined or extracted using two standard methods (1) 5520 B. Liquid-Liquid, Partition-Gravimetric Method(2) 5520 D.Soxhlet Extraction Method (EPA, 1998). Fat was extracted using dry weight measurement (APHA, 1998). Phenol was extracted using UV Vis spectrophotometer Genuine (Singleton and Rossi, 1965).

1.5.6.2 Sediment and Soil Samples Laboratory Analysis

Soil samples at the Kality, Gofa, peackok sampling stations were collected for analyses for the selected heavy metals and pesticide residue analyses. Finally, the solutions prepared were tested for their trace elements content at the Centre for Environmental Science laboratory using Atomic Absorption spectrophotometer (AAS). In addition, the water quality study is of importance in measuring the degree of pollution in the vicinity due to the presence of waste disposal from different factories and human activities in the area. During the project work since it was heavily raining in Addis Ababa City the farmers were not using the river water for irrigation. Hence, available data for heavy metal content in the vegetables irrigated with the polluted river were used for analysis.

1.5.6.3 Heavy Metal Analysis

Analyses for Cd, Pb, Cr, Cu, Ni and Cowere made for sedimentand water samples using standard methods. Water samples (50ml), 1 g soil/sediment sample weredigested with 5 ml of concentrated HNO3 and 2 ml of H2O2 using mixed nitric acid digestion method at 80 0C until the solution became transparent (APHA, 1999).The solution was filtered through Whatman No. 42 filter paper and the total volume was maintained to 50 ml with distilled water. The solution was analyzed using flame Atomic Absorption Spectrophotometer (model: analyticjena nova AA 400P, Germany).

1.5.6.4 Pesticides Compound Analysis

The pesticide extraction procedures from waste water, soil and sediment samples were adopted from Yanget al (2012), a dispersive liquid–liquid micro-extraction combined with gas chromatography-mass spectrometry, with some modifications. The applicability of the method was also validated in terms of recovery by spiking seven representative pesticides to the real samples. The recovery (99.28-111.83) obtained was in the acceptable ranges which indicate that the matrices of the real samples do not have significant effects on the extraction of pesticides.

Water sample analysis: Water samples were collected from Beheretsige, Gofe and Gerji stored in a brown glass bottle, in a refrigerator, at -4 oC in the dark prior to analysis, without any pretreatment. Water samples were then filtered using 0.45 cellulose acetate filter papers (0.45 μm, Micro-Science and 110 mm Smith F1/KA4, Germany) for further analysis. A 5 mL samples adjusted to pH 7 was spiked at 10 μg L-1. A mixture of 40 μL chloroform and 0.4 mL methanol was injected rapidly into the sample solution through the 5 mL syringe. An emulsion (water, extraction solvent and disperser solvent) was formed in the modified 5 mL micropipette tip. After 3 min, the mixture was centrifuged at 4000 rpm for 3 min. Finally, 1 μL of the sedimented phase was injected into GC-MS system for analysis.

Soil and sediment analysis: both soil and sediment samples were also collected from Pekok garden, Beheretsige, Gerji and Gofa. All samples were air-dried at room temperature, pulverized, and passed through 250 mm sieves. The extraction procedures were as follows: 1.0 g of the soil and sediment sample was accurately weighed and loaded into a 50-mL flask centrifuge tube, and then extracted with 5.0 mL methanol for 30 min at 250 rpm on a mechanical shaker, followed by centrifuging at 3500 rpm for 5 min. A mixture of 40 µL chloroform and 0.4 mL methanol extract was injected rapidly into the 5 mL deionized water adjusted to pH 7. An emulsion (water, extraction solvent and disperser solvent) was formed in the modified 5 mL micropipette tip. After 3 min, the mixture was centrifuged at 4000 rpm for 3 min. Finally, 1 µL of the sedimented phase was injected into GC-MS system for analysis.

1.5.7 Technology Review, Selection and Design of Treatment Technologies

Management and treatment technological options were assessed and selected on the on the basis of the following:

- The technological options and best available techniques and practices successfully adopted for such types of project by other developing and developed countries were assessed and two or three alternative technologies feasible for implementation in project area were short listed.
- The merits and demerits of the short listed technologies in the Ethiopian conditions (Viz: technically, financially, economically and socially) were analyzed and the most suitable technology mix for the project were recommended.
- The treatment process in accordance with the selected technology were designed or determined and described.
- The possible alternative treatment plant physical layouts, pointing out their respective advantages and disadvantages were prepared and described.
- The most feasible technology physical layout, stating reasons for choice, were selected; the plant layout was described in detail, showing of the proposed facilities, utility supplies and other infrastructure.
- Measures for a drainage basin and a river site need to be combined, in turn forming "treatment trains" of measures that supplement each other to meet planning targets. This requires conceptualization for a pre-design and a final design for construction by which measures are sized to meet the conditions of a site
- Reliable cost estimate for each selected rehabilitation mechanism were given as well as cost of spare parts and accessories were indicated for all projects.

The overall implementation schedule of the project showing major activities was prepared.

Pilot Technology and Implementation Strategy

Specific model sites suitable and easy for the implementation of the selected cleanup technologies along the BKK and Kebena were chosen.

i. These sites are preferred to be;

- o Areas with good vegetation coverage
- o Enough buffer zone at least (50-100m) from the settlement
- o Adjacent land use

ii. Important considerations in choosing pilot technologies.

The most appropriate technological solution is that which maximizes technical efficiency in the least expensive and simplest form possible; the technology that should make use of the human resources and materials available in the country.

The technical alternatives for solving any specific river restoration problem should be evaluated in terms of:
• The degree of complexity, which is linked with the capacity of the institutions and the people involved to build, maintain and operate a plant with the efficiency specified in the original design;
• The appropriate technological level, which ought to have a degree of reliability compatible with the other water supply components and should not result in costly solutions affordable only by a limited number of users;
• The necessary materials and equipment, seeking a technological level which makes maximum use of materials and equipment produced or available locally (it is possible to obtain high efficiency designs at low cost using almost exclusively local materials);
• The existing human and administrative resources, which takes into account the local technical and organizational capacity to supervise, construct, operate and maintain a design based on a particular technology, coupled with an adequate economic capacity to provide sufficient financial resources;
• The cost of a technological solution, including the costs of construction, installation, operation, maintenance and administration, and such factors as the cost of imported technology, direct and indirect benefits stemming from the use of a particular design, and the value of using short construction periods and simple construction processes;
• Its relationship with other development projects, taking into account the consequences of integrating a project with existing plans and political programs, the impact that it may have on government actions and on community acceptance, and indirect impacts such as the employment and/or technical upgrading of local manpower, indirect economic benefits, and direct and indirect repercussions on health.

1.5.8 Data Analysis

Data were recorded, organized and summarized in sample descriptive statistics methods with the latest software of GIS database, SPSS packages 21.00 to perform: Mean, Standard deviation and Analysis of Variance (ANOVA). Figures were organized using origion8 software. Results were analyzed using this statistical software, and these results were presented in a descriptive statistics such as correlations measures, ANOVAs, T-tests such as tables and graphs.

1.6. Project Deliverables

• Key City rivers selected, described based on agreed upon selection criteria;
• Pollution types and sources identified, characterized and mapped along the selected key rivers by its source and type;

• Pollution profiles of key selected rivers established and used for sensitization and awareness creation among stakeholders;

- Series of technological options reviewed and selected on basis of its feasibility and best practices;
- Waste management and treatment technological options for the sustainable management City river pollution control and management were described;
- Technology design and implementation strategies for the selected rivers with corresponding cost estimates formulated; and
- Implementation plan for pilot technologies developed.

2 EXISTING SITUATIONAL ANALYSIS

2.1 Desk Review on City Solid Waste and Waste Water Management

2.1.1 Municipal Solid Waste Management

According to Addis Ababa solid waste management system report (2010), the daily waste generation was estimated at 0.4 kg/capita/day with daily City waste production of 550 tons/day (200,000t/year) of which 65% is collected and disposed into a dump site. Another 5% of the waste is composted and 5% is recycled while the remaining 25% is dumped into open spaces, ditches, rivers and riverbanks (CGASBPDA, 2003; Chekole, 2006). Studies also showed that due to lack of adequate waste disposal management facilities, one quarter of the households in Addis use open defecation in free spaces, shrubs and river banks which can be transported by storm run-off in to Akaki rivers (Figure 6A)(Gebre& Van Rooijen, 2009).

The daily solid wastes generation in the city increases from time to time as waste generation goes with population and economic growth. The solid wastes are potential sources of contamination, such as pathogenic micro-organisms, oxygen demanding wastes, nutrients and solids which aggravates the pollution of rivers, affects user communities health and create overall environmental problems in the City. The cumulative effect of all these problems can be witnessed from overflowing of dumpsters and standing un-emptied for days which aggravate breeding cycle of disease causes vectors and flies (Figure 6).

Figure 6: A) Open defecation on Kechene river sides B)Solid waste dumping along river sides by the road

Physical Composition of Solid Waste in Addis Ababa

Studies on the City's solid waste composition analysis showed that from the total generated municipal solid waste, organic which is biodegradable (60%), vegetables (4.2%), paper (2.5%), rubber/plastic (2.9%), wood (2.3%), bone (1.1%), textiles (2.4%), metals (0.9%), glass (0.5%), combustible (15.1%), non-combustible stone (2.5%) and fine (5%) (Addis Ababa solid waste status report, 2003). As shown inTable1 the percentage composition of solid waste generated from hospitals, food waste takes the largest proportion by weight followed by paper, yard and plastic waste, consecutively. Figuratively, food waste share 88.4% of the total waste generated in commercial sectors and paper contributes about 3.8 %, yard is about 2.2 % and plastic is 1.7 % and the rest as a whole contributed to 3.8 % by weight (Samuel et al., 2006).

Table 1: Composition of Solid Waste Along BKK +K

Waste Categories	Percent by Weight		
	Schools	Hotels	Condominium
Food	5.5	88.4	59.17
Paper	84.86	3.78	5.01
Yard	3	2.19	12.02
Plastic	1.5	1.76	5.75
Metal	0.7	0.99	0.662
Glass/Ceramics	0.25	0.62	0.604
Textile	0.5	0.25	1.61
Rubber	0.24	0.03	0.015
Leather	-	-	0.168
Wood	2	0.23	1.51
Ash/dust	-	-	10.13
others	0.6	-	-

Similarly, highest proportion of food waste (59.17%) is generated from condominium followed by yard (12.02%), ash (10.13%), plastic (5.75%), paper (5.01%), textile (1.61%) and wood (1.51%). On the other hand, solid waste generated from schools, the highest portion is accounted by paper (84. 86%) followed by food waste (5.5%), yard waste (3.0%), plastics (1.5%) and inorganic (1%) (Girma Bizuneh, 2008). Two types of hospital wastesare generated, namely non-hazardous waste (median: 58.69%, range: 46.89–70.49%) and hazardous waste (median: 41.31%, range: 29.5 - 53.12%), the majority of which was infectious (median:13.29%, range:6.12-20.48%) and pathological waste (median:10.99%, range: 4.73-17.25%) and the rest sharps and pharmaceutical were (8.74%, range:6.41-11.07%) and (6.14%, range:3.54-8.73%), respectively. The average generation rate of infectious, pathological, pharmaceutical and sharps waste in each hospital were 25.50, 21.00, 12.00 and 15.13 kg/day, respectively (Mesfinet al., 2013). These cocktail of wastes are collected in the solid waste collection plates mostly on the shower of the rivers and ditches (Figure 7). Most of the time these plates did not removed on time, hence the waste overflow and ultimately enters in to the river system.

Figure 7: Municipal Solid Waste Collection Plates Within BKKK Watershed Catchments

2.1.2 Waste Water Management

The principal sources of wastewater in the City are the households, industrial, commercial, service and institutions. The municipal liquid waste consists of sewage, surface run off, human excreta and other domestic and industrial waste waters. The amount of wastewater generated is equivalent to 80 % of the daily water consumption/production. The current total amount of water consumption (production) is 599,000m3 per day in the City of Addis Ababa. Hence, the amount of wastewater generated in the City is estimated 479,200m3 per day. Temporal liquid waste discharge analysis showed that the amount of liquid waste discharge was increasing rapidly (Figure 8). Liquid waste generated from households such as washing of clothes, dishes, and floor, as well as left-over coffee is discharged in to either temporary collection points or to the rivers. Most wastewaters from industries is not being treated and instead is discharged directly into nearby rivers (EPA, 2005; Teku, 2006; Gebre, 2008).

Most of the AAWSA wastewater treatment plants are inefficient and overloaded. According to a study conducted by Water Works Design and Supervision Enterprise (2015), the Ayat, Gerji and Bole Homes wastewater treatment plants are not operating. Hence, the first two are overflowing to the environment. The Bole Homes wastewater drainage line to the stabilization pond was completely broken by Gerjiriver and the wastewater does not draint o the stabilization pond and directly entering into Gerjiriver without any treatment. Kaliti, Gelan and Bole Gerji plants are properly working. Kality treatment plant has a series of wastewater stabilization ponds and drying beds. Over capacity and under treatment are also expected for Kality stabilization pond. With an average treatment capacity of only 5,200m3/day, it runs under the design capacity of 7,600 m3/day (Alemayehu, 2008).The effluent flows out into the adjacent Akaki river. Eight drying pools are used for disposal of septic sludge from pit latrines and septic tanks. Therefore, the wastewater stabilization ponds are not working properly and currently releasing to the environment which can aggravate the health problems of the surrounding communities.

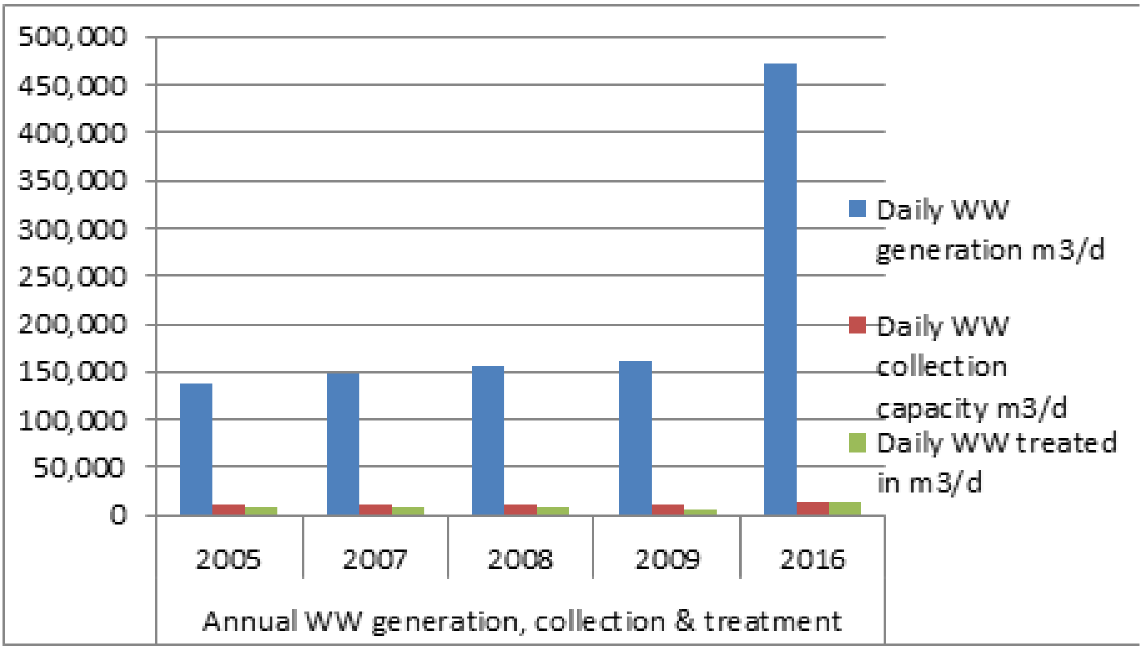


Figure 8: Temporal variations in liquid waste in the City

2.1.2.1 Sectoral Specific Waste Water Discharges in the City

2.1.2.1.1Waste Water from Industries

As shown above, there are more than 2,500 industries in Addis Ababa with an estimated wastewater generation of 4,877,362m3/year (CSA, 2010). These industries include food and beverages, textiles, tanneries, chemicals, rubber and plastics, paper and paper products, metallic and non-metallic mineral products and wood industries. The highest amount of wastewater discharge is from textile industries (40.9%), followed by food and beverage industries (36.8%). The amount of wastewater generated from leather and footwear industry is estimated at 11.2% (Table 2).The majority of these industries lack onsite treatment facilities and discharge their wastewaters to Akakiriver and its major tributaries (AAEPA, 2007). According to CSA report (2010), there were more than 105,832 manufacturing industries operating in Addis Ababa, of which 79 were state owned, 2674 were large and medium sized private enterprises, and the remaining 102,907 were micro to small-scale private enterprises. Most of the large and medium industries in Addis Ababa are located in industrial zones, such as the Akaki (old) Kality (new expansion) Industrial Zone.

Table 2: Volume of wastewater discharge from different industries in Addis Ababa

Type of Industry	Quantity of Wastewater (m3/ Year)	Percent from the total
Iron and steal	146,239	3.0
Non-ferrous metals	2,227	0.0
Food and beverages	1,795,252	36.8
Paper and printing	45,967	0.9
Petrochemicals	11,422	0.2
Rubber	205,746	4.2
Pharmaceuticals	50,089	1.0
Soap and detergents	1,089	0.0
Tobacco	31,080	0.6
Textiles	1,992,597	40.9
Leather and footwear	547,860	11.2
Wood	47,805	1.0
Total	4,877,362	100.0

Source: CSA 2010

2.1.2.1.2 Existing wastewater treatment practices

The Addis Ababa Water and Sewerage Authority (AAWSA) uses two methods of collecting liquid wastes, namely sewerage line and sucking truck. The proportion of housing units connected to a "modern" sewerage system is very small. According to AAWSA (2008), only 2,818 housing units are connected to the City sewer system. This accounts for only 0.75 percent of the total houses in Addis Ababa. The sewerage line was originally designed to serve for 200,000 residents or 38,462 houses. Hence, the City sewer lines collect about 7,500m3 liquid wastes per day. However, if all 38,462 houses were connected, the sewerage system would have a capacity to connect 10.26 % of the houses in Addis Ababa.

The other means of collecting the City liquid waste is using sucking trucks that have different holding capacity. The collection amount using the sucking trucks on average is 1,000m3 per day which is 0.74 percent of the total daily generated liquid waste. On the other hand, around 371, 924 from the total of 374,742 housing units do not have access to City sewer system. Moreover, the sucking trucks are not enough to cover these housing units. Hence, residents of the City have no ways to dispose the liquid waste generated. Instead, they connect wastewater drainage line either to the river system or to the drainage systems to dispose the sewage and other liquid wastes. Besides, it is also common for pit latrines or septic tanks to overflow in poor residential areas that have limited or no access to the roads for sucking trucks. The problem is worse in those septic tanks that fill up quite frequently in areas that are exposed to flood.

Addis Ababa has two secondary sewage treatment plants for the wastewater collected using both sewerage line and trucks. These are Kality and Kotebe treatment plants. The Kality treatment plant runs under its designed capacity of 7,600 m3/day. The sewer line is connected to Kality treatment plant while thesludge is transported to Kotebe treatment plant using vacuum trucks that empty septic tanks with an estimated annual volume of 85,000 m3 (NEDECO, 2002) as cited by (Van Rooijen et al., 2009). The treatment involves circulation of sewer in various ponds for about 30 days in order to make the level of BOD fall below 5mg/l (Mohammed, 2007).

2.1.3 Sanitation Situation in the City

2.1.3.1 Existing Water Supply Systems

The City of Addis Ababa obtains its water supply from both surface and ground water sources. There are three main dams used to collect run-off water to store in the dams to serve as surface water sources for water supply. The three dams are: Gefersa dam (situated 18-kms west of Addis Ababa), Legedadi Dam (situated 25-kms east of Addis Ababa), Dire dam (situated 10-km north of Legedadi dam) and Akaki groundwater (Akaki well field).

The Akaki groundwater (Akaki well field) is situated southeast of Akaki at about 22 km south of Addis Ababa; and the wells (boreholes) are located both within and nearby the City areas. In addition to the above water sources there are recently developed additional ground water wells. These are Akakai Phase II subsystem, Akaki Phase III-A subsystem, Akaki Phase III-B subsystem and Legedadi Phase I – subsystem located at about 30km from the City centre to the eastern part. Additional boreholes are being developed at strategic pocket areas within the City to produce additional ground water for the City of Addis Ababa (Table 3).

Table 3: Daily production capacity of each water sources

Name of Water Sources	Daily Production Capacity (M3/day)	Number of Boreholes/Dams
Legedadi Dam system	195,000	Legedadi and Dire dams
Gefersa dam system	30,000	Main Gefersa dam and Gefersa III dam
Akaki Phase I (Akaki and Fentawellfields)	40,000	Used to be 52,000 m3/day; thirty BHs
Akakai Phase II	73,000	Sixteen BHs
Akaki Phase IIIA	70,000	Twenty five BHs
Akaki Phase IIIB	70,000	Twenty four BHs
Legedadi Phase I	61,000	Nine (Ten) BHs
Pocket boreholes within the City Area	60,000	Over one hundred eighty BHs
Total	599,000	

Source: Compiled from GTP II, NRW report by Z&A and MCE Alternative power source for pumping stations at the reservoirs and wells existing assessment report 2015.

Currently, the total demand of potable water for the City of Addis Ababa is estimated to be above 700,000 m3/d while the coverage of the water supply of the capital is estimated to be 85.6 %.This coverage is actually dynamic as the population of the City increases from time to time. Consequently, domestic waste water discharge per capita per day increases.

2.1.3.2. Existing Sewerage and Sanitation Service System

The wastewater collection and disposal system in Addis Ababa is very poor and the sanitation coverage is also very low. Presently domestic wastewater from Addis Ababa City is collected and disposed in two ways.

1. Using vacuum trucks sewage from septic tanks and latrines (VIP and Pit) is transported to sewage drying lagoons located at Kaliti and the Eastern wastewater treatment plant sites.
2. Using a sewerage collection network wastewater from a portion of the City is transported for treatment at the Kaliti wastewater treatment plant site.

There is also a sector of the population which has no access to formal sanitation facilities as indicated in the 2007 population census. According to the information from AAWSA, out of the total yearly wastewater generation (851 tonnes), only about 12% of the wastewater is collected, treated and disposed-off properly by sewerage system. The AAWSA and private sludge vacuum trucks have capacity of 36% capacity to collect sludge from pit latrines and septic tanks making the total wastewater collected and treated to be 48% of the total annual wastewater generation.The study by Z&A consultants on the Decentralized Wastewater Management (2014), showed that 22.1%of the City's population are using flash toilets, 64.8% are using pit latrines and 13.1% of the City's residents do not have any form of sanitation facilities. A similar report on Urbanization and Water Pollution in Addis Ababa by Ayenew and Belliethathan (2011) indicated that Addis Ababa's sanitation coverage is low, with 13% of the City's population using flash toilets, 57% using pit latrines and 30% having no sanitation facilities at all.

The existing sewerage system and Kality wastewater treatment plant currently serve some parts of Kality catchment specifically Bole, Ledeta, old Airport, central part of the City, Mekanisa and Kera areas. The expansion of Kality wastewater treatment plant (a capacity of 100,000 m3/day) and rehabilitation of its associated main sewer lines (of length about 18 km) and secondary sewer lines are being constructed currently with a fund from the World Bank in order to solve the existing wastewater management problem of the southern part of Addis Ababa City.

2.1.3.3. Wastewater Catchment Areas of the City

According to the study conducted on decentralized waste water management in Addis Ababa by Z & AP Tropics Consulting Engineers (2014), the City of Addis is divided into three wastewater catchments (Figure9). These are Kality, Eastern and Akaki catchments:
• Kality Catchment - It is the North West part of the City having an area of 210Km2, covering the center of Addis Ababa. It includes Gulele, Arada, Addis Ketema, Lideta, KolfeKeranio, Kirkos, and some part of Nefas Silk Lafto.

• Akaki catchment - Covers the southern part of the City mainly AkakiKality Sub City and some part of Nefas silk Lafto, with an area of 150km2. It is proposed to be sub-divided into two main sub-catchments (South Akaki main catchment and Chefe main catchment) based on the topography of the area that allows gravity drainage systems to be developed.
• Eastern Catchment - encompasses mainly Yeka and Bole sub cities. It covers an area of 145 km2 and has eight sub catchments that are identified based on the topography of the area that controls gravity flow of the sewage with the area to the east, described as mixed development use, forming the ninth sub catchment.

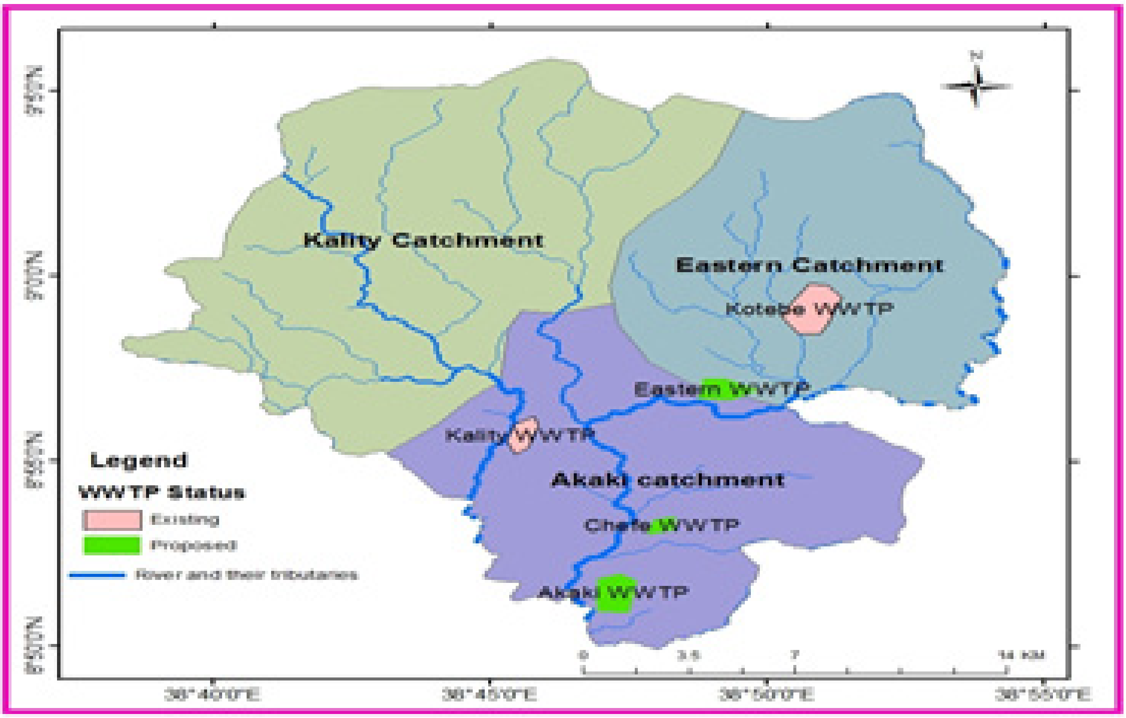


Figure 9: The three waste water catchments of the city of Addis Ababa

2.1.3.4. Wastewater Treatment

There are two waste water treatment plants that receive the inflow from the sewerage lines and wastes from vacuum trucks. These are Kality wastewater treatment plant with capacity to hold 10,000m3/day constructed in the year 1982 (Figure 10) and Kotebe wastewater treatment plant with holding capacity of 3,000m3/day constructed in the year 2001. There are also localized small bore sewers with independent treatment facilities (packaged decentralized treatment facilities) serving the Mikyleland (with treatment capacity of 750m3/d), Hayat Condo (1000m3/d), Gelan (3000 m3/d) and Gerji condominiums (1500m3/d).


Figure 10: Kality wastewater treatment plant

In general, the sewerage service for the City is currently estimated at 12% while the demand for vacuum truck service is also very high compared to the number of service provided by such system. All in all the current waste treatment capacity reaches 20,000m3/day, which needs to be improved in order to enhance the overall sanitation of the City.

2.1.3.5 Wastewater Collection by VacuumTrucks

As mentioned above, although there are more sewer lines that are under construction to increase the sewerage service coverage, the use of vacuum truck service is also very high compared to the number of service provided by such system. Currently, according to the information from AAWSA, there are about 104 (only a maximum of 58 are active on daily basis) government owned and over 69 privately operated vacuum trucks owned by different companies that are serving the population of the City. The AAWSA utility branch offices are giving service only for residential (domestic) houses but not for commercial and institutional entities.

The service of the vacuum trucks will continue as there are parts of the City which cannot be easily connected to sewer system and septic tanks in such areas will be emptied by the vacuum trucks. The private owned vacuum trucks collect about 35% while the government owned collect 65% of the wastewater from septic tanks and toilets in 2014.

2.1.3.6 Transfer Stations and Injection Point

The study and design of new transfer stations and sludge injection and rehabilitation of existing transfer station by Dongshin Engineering & Consultants Co. Ltd report (2014) showed that there are three existing transfer stations (Kechene, Sillassie and Kolfe transfer stations) and one injection point (Gofa injection point). These transfer stations are used as temporary disposal site for smaller vacuum trucks and then the wastewater (sludge) isremoved from the transfer stations to the treatment plants by bigger capacity vacuum trucks. The report indicated improvement of the existing transfer stations and proposed construction of new ones although the information from AAWSA indicated that the work has not yet taken place.

2.1.3.7 Challenges and Constraints in the Wastewater System

Some of the major observations and findings from AAWSA assessment report on the current problems associated with wastewater system in Addis Ababa City are:

• The City has now expanded in almost all directions of the City boundary with multipurpose high rise buildings being constructed and more under construction which requires the sanitation service in the form of sewerage system with treatment facilities or septic tanks with vacuum trucks for emptying. The current service is very limited compared to the size of the City and the existing demand for the service. To protect sewer over flow, AAWSA needs to expand the sewerage system and the septic tank emptying service to the population living in the newly developed areas and the booming complex buildings in the City.

• The capacity and size of the wastewater treatment plants are not sufficient to treat the waste generated and their locations are not at convenient places to receive more wastewater flow by gravity from each part of the City.

• In general the existing sanitation system has very limited service capacity in limited parts of the City and cannot satisfy the current service demand of the City.

• There are illegal connections of septic tanks to road side storm and to natural water ways like rivers.

• Discharge of untreated industrial wastewater to rivers, especially in the downstream part of the City.

• Condominiums are being constructed in so many places within the City without having constructed sufficient and efficient sewerage system to collect and treat the wastewater from these buildings.

• In most cases septic tanks become full so frequently that there are no sufficient vacuum trucks to empty the tanks on regular basis causing the wastewater to overflow to the streets and become nuisance and health risk to the residents.

• Currently there is no clear and defined rules and regulations for collection and disposal of wastewater from condominiums and real states.

• Lack of regular measuring and evaluating the wastewater treatment plants inflow and outflow wastewater quantitatively and qualitatively.

• Lack of regular monitoring, assessment and evaluation of the wastewater treatment plants opportunity of upgrading and expansion works.

• Limitation in the availability of data and information on the sanitation status.

2.1.4 Findings from the Field Based Reconnaissance Survey

The reconnaissance survey was mad on the big and little Akaki river as well as Kurtumie-Kechne-Banteyiketu and Kebera river catchments. The upper watershed of the Akaki river include the Mt. Entoto (3000m a.s.l) in the north, Mt. Wochacha in the west (3385m a.s.l.) and Mt. Yerer (3100 a.s.l.) in the southeast. While the highland part of the watershed becomes river valley and covered by forest, the central and lower Areas are used as a central residential, business and industrial districts. Akakiriver and four water reservoirs, namely legadadi, Gefersa, Dire and Aba-Samuel, represent the main surface water bodies within and in the vicinity of Addis Ababa.

In the City, streams and rivers receive the major part of the waste produced by the municipality. These rivers end up at AbaSamuel reservoir. The seasonal and perennial rivers of Addis Ababa are polluted by industrial and municipal solid and liquid wastes. The polluted Akaki river water is used by downstream residents to grow vegetables, which are sold and consumed by inhabitants of the City. The Akakirivers are contaminated with different organic and inorganic pollutants. During the field survey we found that the solid waste that is generated is often disposed of in open spaces, open defecation at the river banks, where it is washed by runoff, and flows into rivers (Figure 11).

Agricultural Practices Along Akaki River

Solid and Liquid Waste Discharge Along Akaki River

Figure 11: Waste disposal and agricultural activities along Akaki river

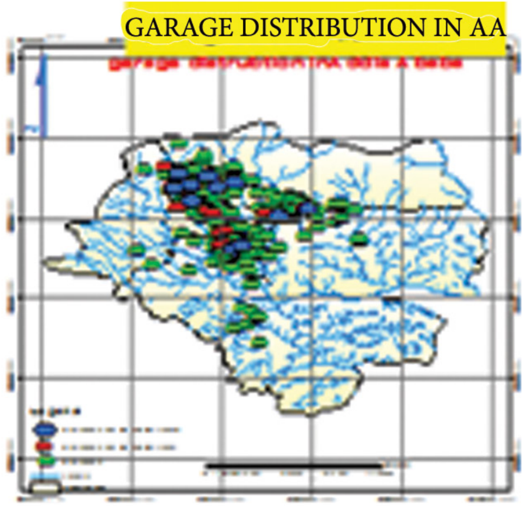
In the upper catchment,5 sampling points are selected (Chefe,, Intoto, Kersa, Gullele and Gefersa), which are relatively undisturbed (unpolluted) river water samples for control purposes. In the middle part of the river 12 sampling sites selected as representatives to determine the pollution loads, source and water quality. In the southern part of the City the same rivers serve for various purposes such as agriculture, drinking water for cattle, washing, and for other domestic activities. For this sub-project a total of 32sample sites are selected (for detail see Annex 1), of this 16sampling sites are from BKK + Kebena.

2.1.4.1 Big Akaki River

The eastern branch of the river, the Big Akaki, rises north-east of Addis Ababa and flows into Aba-Samuel reservoir after 53 km. BigAkaki river system crosses residential areas in the upper stream, particularly in Kechene, Kebena, and Minilik hospital, Zewditu hospital, garages etc. and where municipal wastes directly dumped in to this river course (Figure 12).Part of the big Akaki river system crosses the new Abado (where a potential recreational area is found), Ayat condominium, *Tafo* real estate in the upper catchment and *Bole Arabsa* settlement and Semit condominium in the middle stream. The lower course of big Akaki crosses rapidly expanding urban centers of Addis Ababa including proposed site for future industrial expansion (AkakiKality).

Big Akaki river tributaries and sampling points:-Big Akaki originates from Entoto, Kersa and Dire dam and flows to the southwest part of the City where it meets with a number of tributaries with different local names. The main tributaries of big Akaki river are *Cheffe (Entoto),Kechene 1, Kechene 2, Kurtumie, Banteyiketu (Kechene and Kurtumie), Kebena, Big Kebena (Banteyiketu + Kebena), Tafo river (Tafo + Abado river), Beshale river (Legetafo + Dire river) and Akakai river (Beshale river + Gergi river) and Big Akaki river(Akaki+ Big kebena river).* A total of 14 sample sites were selected from Big Akaki river tributaries for water quality analysis.


INDUSTRIAL WASTE


GARAGE DISTRIBUTION IN AA


DOMESTIC WASTE WATER


SOLID WASTE


Domestic Waste Discharge

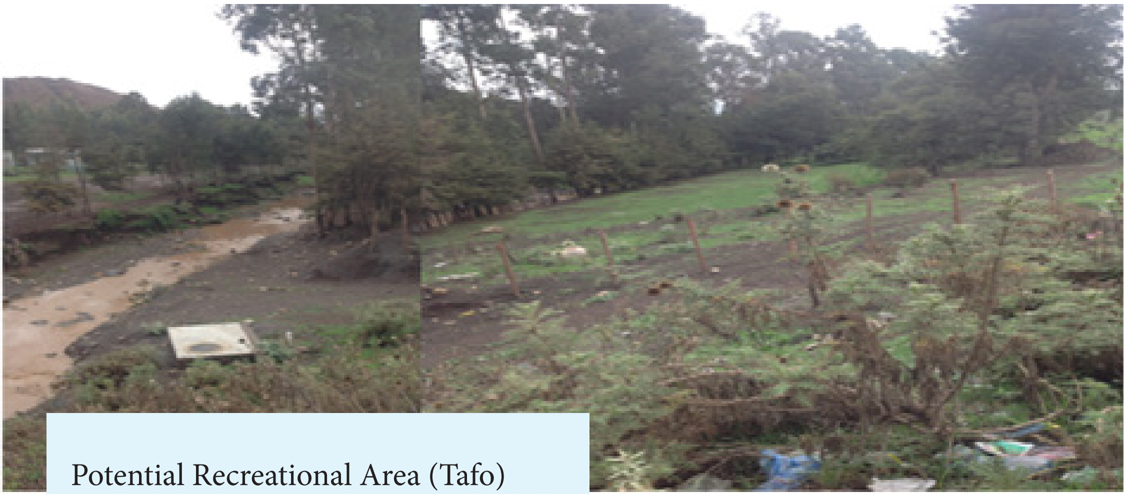


Figure 12: Source, Waste disposal and potential recreational area along Big Akaki river

2.1.4.2. Little Akaki River

The western branch of the Akaki River, Little Akaki, originates north-west of Addis Ababa on the flanks of Wechacha Mountain and flows for about 40 km before it reaches the Aba Samuel reservoir. Most of the streams flowing from the north western side meet Little Akaki river at Gullele area where some of the factories are located. Little Akaki river covers an area of about 950.562 km2, which covers 32.64% of the Akaki basin. The upper catchment, *gullele and gefersa*, is mostly dominated by forest area and the river is relatively undisturbed. The middle catchment is mostly dominated by residential settings. This catchment is also occupied by few medium and large industries. These are *Addis Ababa and Dire tanneries, Addis Ababa glass factory, Ethio-Marble Factory, TikurAbaby shoe Factory, Dil oil and Gulele soap factories*. Moreover, commercial activities are also dense in parts of the middle catchment, especially at Kolfe areas, and Eastern parts of the Merkato. Around Merkato area, the river crosses densely populated residential and commercial centers. Around Lideta area the river serves as dumping sites for Awash Winery effluents. Moreover, around Mekanisa the river receives effluents from *National Alcohol and Liquor Factory*. The middle catchment of Little Akaki (in the City) includes most of the pollution sources i.e. the full course of the river inside the City (Kolfie-Mekanisse –Kera, gofa to Akaki Kality). Tributaries from north western direction receive wastes of major sources such as A*ddis Ababa Abattoirs*, which has an impact on direct alteration of the river water quality. The upper tributaries and drainage from the *Addis Ababa Cement Factory* are joining the main river at a point near Behere Tsige Park. The river water is used as irrigation water source around *Kolfe Keranio, Lideta, Mekanisa and Akaki areas* (Figure 13). The downstream section of little Akaki river is crossing the lower parts of AkakiKality sub City and flows into the *Aba Samuel reservoir* where it mixes with big Akaki river.

Agricultural practice using little Akaki

Liquid and solid waste drainage in to Akaki

Figure 13: Waste disposal and agricultural practices along little Akaki river

Little Akaki River Tributaries and Sampling Points

Little Akaki originates from Gullele river and Gefersa dam and flows to the southern part of the City where it receives various tributaries with different local names. The main tributaries of little Akaki river are Shegole river, 44 river (Loliha), Bulcha river, Safari river, Mekanisa river, Akaki river. A total of 7 sample sites are selected from little Akaki river tributaries.

Major Pollution Sources Observed During Field Trips

- Liquid waste discharge in to the river including sewer lines
- Municipal solid waste damping on the river bank.
- Almost all the derange system opens their mouth to the river system
- Hospital wastes discharge in to the river
- Commercial wastes
- Open defecation on the banks of the river
- Surface run off (flood) from agricultural land and vegetable farming
- Surface runoff from which solid waste are dumped
- Dead bodies of animals
- Discharge of animal wastes from cattle sheds located along the river banks
- Garages wastes and Car washing wastes and Sediment.

3 CITY RIVERS POLLUTION PROFILE

3.1 Sources and Pollution Load Along BKK+ Kebena Rivers

3.1.1 Pollution Sources Along Kechene-Kutume-Bante Yiketu and Kebena Rivers

The Kechene-Kutume-Banteyeketu and Kebena (BKK + Kebena) rivers, as situated at the heart of the City of Addis Ababa, are receiving wastes (solid and liquid) from various types of pollution sources. The pollution sources are typically associated with a very compacted living conditions of citizens (slum areas), various hotels and restaurants mostly built at the edge of the rivers, presence of numerous schools (KGs, Primary and secondary schools and colleges), hospitals and health centers, printing enterprises, condominium apartments, car washes, fuel stations, etc.(Figure 15). Most of these sources do not have proper waste management systems and the wastes are being directly discharged into the rivers. The solid wastes and wastewater loads from the various pollution sources show that generation of solid wastes from the various enterprises is estimated at 270.49 m3/day, whereas that of wastewater is 4,525.11 m3/day (Tables 4 and 5). On the other hand the dry season river water quality parameters for the selected major pollutants such as BOD, COD, DO, ammonia N, coli forms and heavy metals (Pb and Cd)were found to range from 2.4 -27.9 mg/l, 0–378mg/l, 12.35 – 4.6mg/l, 0.12 – 31.9 mg/l, 0 – 107cfu/100 ml, 2.6 – 10.15mg/l, and 0.8 -1.8 mg/l, respectively (Annexes 1A, 1B, 2A and 2B). In wet season the concentration of DO in Kechene, TN, NH3-N, EC, Cl- and TDS showed a decreasing trend in their concentrations while turbidity, COD and BOD found to increase in its concentrations(Annexes 3A, 3B, 4A and 4). The findings clearly showed that there is a strong correlation between source of pollution, anthropogenic activities, and river water quality status along the BKK+ Kebena rivers.

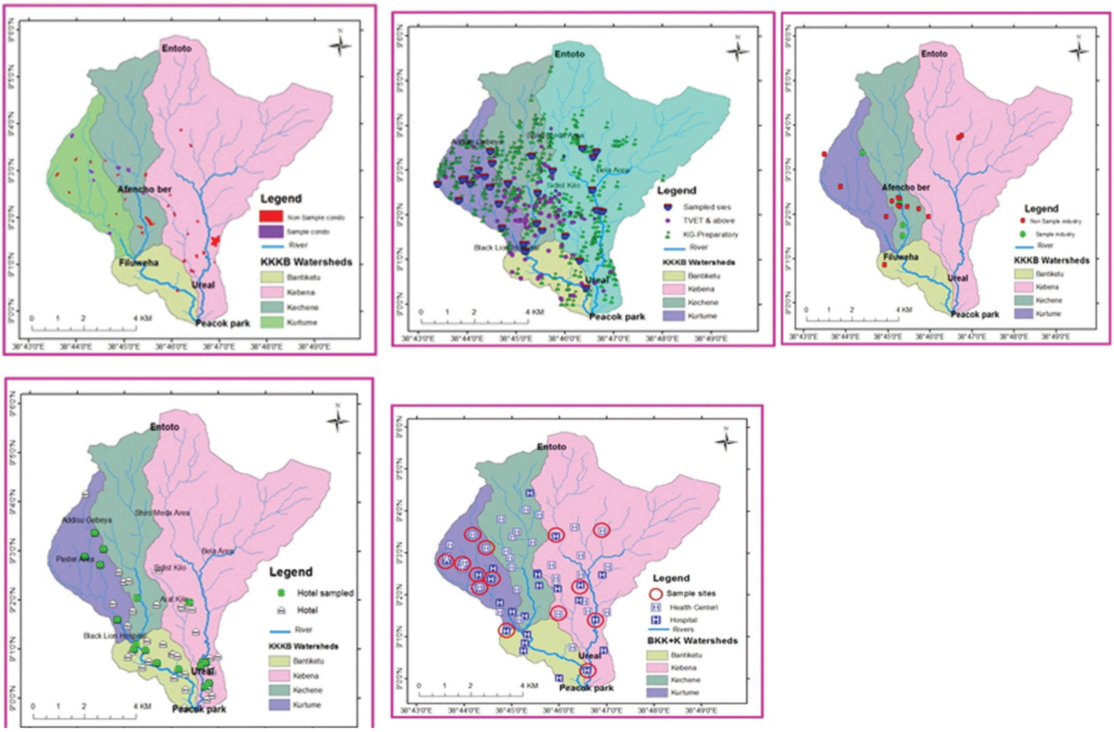


Figure 14: Map of pollution sources for different sectors

3.1.2 Solid Waste Generation and Management Practices Along BKK and Kebena Rivers

The major point sources of pollution in Kechene- Kurtumie-Bantiyketu and Kebenarivers tributaries, which flows within the City, are effluents from untreated sewage from urban centers; discharge from open drains carries sewage, hospitals, hotels, schools, commercial sites, discharge from car-wash, fuel stations and returned storm water from major tributaries. Pollution sources, 500m to 1 km away from the river were assessed. Solid waste generations from hospital and health centers were calculated for noninfectious wastes since the infectious and hazardous solid waste were burnt at hospitals and health centers and either buried or disposed into solid waste dumping sites (Pits). In order to calculate municipal noninfectious waste, approximate estimation on bags and containers were used.

Solid waste generations at schools, hotels and other sectors was calculated based on the interviewee of daily and/or weekly solid waste generation in terms of Kg, m3 or 'Madaberia'. All these units are converted in to m3. The conversion of Kg to m3 was done by conversion 1 m3equivalent of 102.2Kg (for municipal solid waste). For hospital and health centers non-infectious wastes measures was taken as it is and hazardous wastes was estimated as ash form.
A survey was conducted on 92 potential pollution sources found along Kechene- Kurtumie-Banteyiketu and Kebena rivers categorized in to 7 sectors (Table 4). Among the existing pollution sources; such as hospitals (11), Health Centers (both government and Private) (14), Schools (Kg, primary, secondary, TVET and Colleges) (34), Printing enterprises (3), hotels and restaurants (19),

fuel stations (4) and condominium houses (11); hotels and hospitals generate high solid per day, 140.53 m3//day and 32.25 m3/day, respectively. Their solid and liquid wastes generation and management practices regarding waste collection, segregation and final disposal was also assessed.

Pollution sources assessment in Kechene- Kurtumie-Bantiyketu and Kebenarivers showed that almost all the solid waste generated at each sector was collected by both private (25%) and Woreda small scale solid waste collection enterprises (75%) and disposed in to municipal solid waste (MSW) disposal sites.

Table 4: Solid waste sources, generation rates and management status along Kechene– Kurtumie–Bantiyeketu and Kebena rivers

No	Point Pollution Sources	Pollution sources (500- 1 km from the river)		Sectorial SWG Rate (m3/day)			Total amount of SWG (m3/day)	Onsite WW Management\ Status(%) and Final Disposal
			No of Sources Surveyed	Kechene-Bante-yike-tum3/day	Kurtume m3/day 19.5	Kebena m3/day		
1	Hospitals	27	11	7.97	19.5	4.78	32.25	•Segregation of plastic bottle, infectious and non-infectious wastes •25 % Incineration waste and ash was disposed in to MSW • plastic packs were given to other users
2	Health centers (Clinic)	153	14	3.26	15.7	ND	18.33	• Placental pit and ash from incineration of hazardous waste were buried. • Non-infectious were disposed in to MSW
3	Schools (1o ,2o, KG & TVET)	204	34	0.76	8.57	7.15	16.48	50% partial segregation Waste disposed in to MSW
4	Hotels	50	19	124.16	3.52	12.85	140.53	60 % segregation Waste disposed in to MSW
5	Fuel Station	23	4	1.25	ND	ND	1.25	
6	Printing press	12	3	4.34	ND	ND	4.34	100% segregation and 33.3% recycling of paper
7	Condo-minium	44	11		27.82		27.82	Goes to MSW
	Total		**34**	**141.74**	**80.48**	**48.71**	**270.19**	

In 8% of the sampling sectors, plastic bottles were segregated at source, and taken by solid waste collectors. I hospitals solid wastes are segregated in to infectious and noninfectious wastes; and 25 % the infectious wastes were incinerated and the ash was collected and disposed in to MSW collection pits. But in the newly constructed Woreda health centers, placenta and the ash from incineration is buried in its own premises. It has been observed also that there is periodic supervision of Health Centers in every 3 months, by the respective Sub-City Health Offices. Hence, concerning solid waste disposal, except ash disposal, no serious river pollution problem was observed. On the other hand, 60% of solid waste segregation, food waste and non-food waste, was made at source. In schools 50 % of segregation was made at source (plastic and non-plastic solid wastes) and collected by the Woreda small scale solid waste collection enterprises.

3.1.2.1. Solid Waste Management Along Kebena River

The solid waste and sludge management practices assessment at schools along Kebena river showed that the sampled schools collect solid waste properly. From the sampled schools, 16.7 % schools segregate solid waste at source, 8% uses it for composting and the remaining 75 % do not segregate at source and disposed to solid waste pits via solid waste collectors (Table 4). In many places alongKebena river, it was observed that the primary water pollutants are connecting sewerage linesdirectly to the river; dumping of solid wastes including domestic; open defecation at the shower of the river and drainage lines connected directly to the river water courses. Other pollution sources includes farm wastes, commercial wastes, washing of clothes and throwing unburnt animal dead bodies also adversely affect aesthetics, water quality and aquatic life. 50 % of hotel wastes are partially segregated at source in to two: food and other solid wastes, while 50% of hotel wastes are go to disposal systems without sorting. In all schools and hospitals, the solid waste collectors are from the Woreda solid waste collectors. However, 37.5 % of hotel solid waste collectors are using private track. Most of the hospital wastes are separated in to two; infectious and non-infections waste. Infectious wastes are collected and incinerated. The Infectious wastes in the ash form and non-infectious wastes are damped in to the solid waste pit, which has environmental and health concern. There is periodic supervision of Health Centers in every three months, by the respective sub City Health Office; however, the issue of infectious waste in the form of ash problem has not yet been solved.

3.1.2.2. Solid Waste Management Practices Along Kechene-Bante Yiketu River

As far as the management of expired and spoiled solid drugs /medicines in hospitals along the shore of Kechene – Banteyiketurivers are concerned, that these wastes are removed by an authorized committee organized by the Ministry of Health (MoH) as per the guideline of MoH , in consultation with FMHCA (Food ,Medicine & Health care control Authority). Zewditu Hospital has been practically using a model solid waste management directive produced by its own staffs, which can be used as a model for others. As the health centers assessed are newly built, there are no such issues of spoiled drugs at this stage. Similar trends of waste management practices like the hospitals in the future are expected, in collaboration with the Addis Ababa health bureau. In some clinics, there is a trend that all expired and spoiled solid drugs are burned in the presence of committee from Police and Health offices of the sub City. The solid waste sludge management practice from fuel station is subjected to bias since they use private track other than municipality to transport and dispose the solid waste sludge. The ultimate disposal site for this solid waste is unknown. In most of the enterprises assessed in this study, while there are some good practices, one can say that there is a better way to manage solid wastes on each stage from generation through segregation to final disposal. However, it was discovered from an interview with the hotel manager of National Hotel that this Enterprise is dumping its solid waste at the mouth of Bantiyiketuriver. It is worth mentioning that fuel station and Woreda 9 common living apartments (condominium) need to be closely looked up to minimized solid waste illegal damping to Kecheneriver and ultimately come up with objective solutions to manage Rivers and river sides at Kechene and Bantiketuriver routes .

Figure 15: Solid waste collection and mismanagement practices

Therefore, from the field survey, though solid waste generated from different sources may not be considered to have a profound effect on the Rivers water quality, it was observed that domestic solid wastes damped in to drainage system and Rivers banks from the overflow of solid waste collection pits and open defecation at the edge of the river are the main causes for river water pollution by solid waste. Only very few industrial activities are found, where no significant solid waste generation was observed and hence less contribution to the upper Rivers pollution.

3.1.2.3. Wastewater Generation and Disposal Practices Along BKK-Kebena Rivers

Identification of wastewater pollution sources and wastewater management practices were conducted on more than 100 institutions along the BKK plus kebenarivers catchments.Riversare used as receivers of all kinds of wastewaters. Pollution sources, 500 m to 1km away from the river was assessed. Most of the industries built along the rivers discharge their effluent directly into the rivers and their tributaries. The amount of wastewater generated from the domestic sources was calculated using water bills on the assumption that 80% of water consumed by the enterprises is generated as a wastewater.

Table 5: Wastewater Sources, Generation Rate and Management Practices Along BKK-Kebena Rivers

No	Point Pollution sources	Total Number of in stitutions within 1 km buffer	No of Sampled Institutions	Kechene-Banteyeketu (m3/day)	Kurtume River	Kebene River	Total waste water generated/ day/m3	Onsite wastewater management status (%) & final disposal
1	Hospital	27	11	169.2	1179.61	147.95	2096.76	72.72 % septic tank . 9% Directly connected to sewerage system 18.2% discharged to river
2	Health center	153	14	11.84	12.31	8.2	32.35	100% septic tank
3	Schools (1o ,2o, Kg & TVET)	204	34	28.77	34.45	95.5	158.72	70% septic tank 30% directly connected to the river
4	Hotels	50	19	1970.48	77.06	129.69	2177.23	63.16% septic tank , 21.1% sewer lines 15.79% directly connected to the river
5	Condominium	44	11	-	-	-	-	45.45% - septic tank 36.36% -connected to sewerage system; 18.2% - Direct discharge to river
6	Printing	12	3	13.37	-	-	13.37	66.6% - septic tank 33.4% discharged to the river
7	Car wash	3	3			30	30	100% river
8	Fuel Station	-	4	21.19			21.29	100% Septic tank
9	Park	1	1	-	2.7	-	2.7	100% river

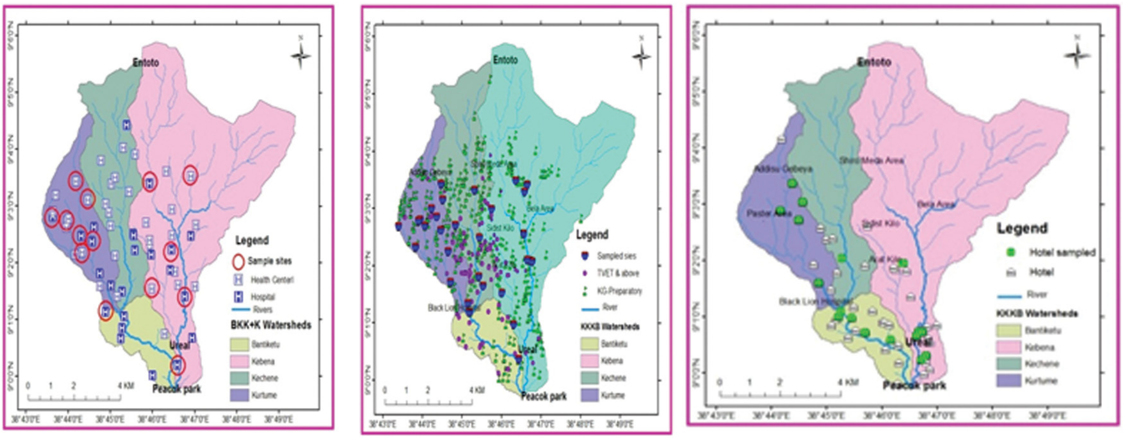
Accordingly, estimation of liquid waste generation per day from selected sectors was 1919.29 m3/ day along Kurtume river, 2201.45m3/day along Kechene-Banteyeketu rivers and 411.34m3/day along Kebena river. The overall volume of wastewater generated from the surveyed pollution was estimated at 4525.11m3/day. From the total wastewater generated, hospitals and hotels constitute about 97%(Table 5). Considering the on-site wastewater management status and final disposal systems; approximately 22% of the generated waste water from the sampled source of pollution is directly discharged to the river, 9% connected with the central sewer line system and the rest 69 % use septic tanks (Table 5). 30 % of schools wastewater is directly discharge in to the nearby rivers. However, it was very difficult to get information from the enterprises in relation to the water consumption of condominium houses and hence impossible to calculate liquid waste generation rates of the condominium apartments.

Liquid wastes discharged into BKK-Kebenarivers from different institutions like hotels, hospitals and health centers, schools, condominium, garages, car washing and printing press through different drainage lines, domestic liquid wastes from overflowing and seeping pit latrines, septic tanks, public and communal toilets, open ground excreta defection and gray water from kitchens and bathrooms flow through different drainage lines. The main sources of pollution for BKK-Kebena surface water bodies are hospitals, hotels, schools, municipal solid Waste and oily wastes from garages and fuel stations.

Hospitals, Health Centers, Schools and Hotels

Eleven major hospitals situated within 1km buffer zone of BKK-Kebenarivers were taken as sample representatives sources (Figure17). In most cases, these hospitals generate highest amount of liquid wastes (2096.76 m3/day) from laboratory cultures, isolation wounds, tissues, used dressings, human fetuses, blood, and other body fluids.

All eleven surveyed specialized general federal hospitals provide a clear indication of pollution problem for BKK- Kebena rivers as destiny of almost all hospital wastes. Most hospitals sampled for the study have no on-site wastewater treatment facilities and they directly or indirectly dispose waste waters into stream courses that are tributaries of either little or great Akaki rivers. Thus, the infectious clinical wastes, chemical residues and detergents used for cleaning purpose enter the river and result in serious environmental pollution problems that downstream dwellers are facing. In terms of number of pollutant management sectoral units, schools and health centers are dominating. It is also observed that from all BKK-Kebena rivers sampling points approximately 30% of schools discharge their waste waters (gray+ toilet) directly to the river without any treatment. Out of 204 total schools, 34 schools are selected for this study and wastewater from schools is the primary causes of BKK-Kebena rivers water pollution (more than 30% directly discharge wastewater to the nearby rivers).



A

B

C

Figure 16: Map of Pollution sources for different sectors (a) hospitals and health centers, (b) schools (c)Hotel

Figure 17: Discharge of wastewater from Kokobe Tsebah School to Kebena river

Figure 18: Direct discharge of waste water from Abebech Gobena Hospital to Kurtume river

Toilets

In the densely populated 500m width buffer zone of BKK-Kebenarivers the lack of space often forces large numbers of households to share the same latrine. Not surprisingly, residents of the Woredaslum compounds are facing problems of inadequate and poorly accessible sanitation facilities and services. The tenants' lack of ownership of such dwellings provides little or no incentive to keep them clean, make improvements in the existing facilities, or build new ones (Figure 19).

This also leads to the misuse of the shared latrine facilities, unhygienic and unsanitary conditions.

The shared latrines, sandwiched in between houses in collapsing superstructures, are overused and overflowing with raw sewage. Cleaning tankers cannot access them. Due to the lack of toilet facilities, roads often overflow with human excreta and garbage. The communal latrines provided are often blocked with all types of garbage and overflow into the streets or directly connected with the nearby rivers. Most of them are dreadfully grubby. Only few of these toilets are connected to a reticulated sewer system. Most of them have septic tanks that are connected to storm water drains and streams; the rest few have no septic outlet and are emptied about twice weekly by tankers.

Figure 19: Shared latrines, sandwiched in between houses in collapsing superstructures, are overused and overflowing with raw sewage around

Also most of the private toilets near along BKK-Kebena rivers directly connect the line to nearby river courses. The following picture (Figure 20) show the direct connection of toilets by Sheger Park, police station and Hagbes Company along Kurtume River.

Figure 20: Direct connection of toilets by Shager Park, police station and Hagbes company along Kurtume river

Fuel Stations, Garages and Car Washing

Sources of oil wastes in Addis Ababa City are fuel stations, private and government Garages. Car washing, Laviajo, are among the activities that cause oil seepage. The battery changing services also contribute to the low pH or acidic wastes from these centers

Figure 21: a. Garage discharges b. Car wash contaminating surface water

Condominium Sites

Out of 44 condominium sites in watershed of BKK- Kebenarivers, 11 sites were selected forthe survey(Figure22). From samples taken, 18.2% discharge their wastewater directly to river. Residents of a few condominium sites are trying to organize committees to deal with the issues including social behavioral problems by penalizing those who use green areas or parking lots as garbage disposal places.

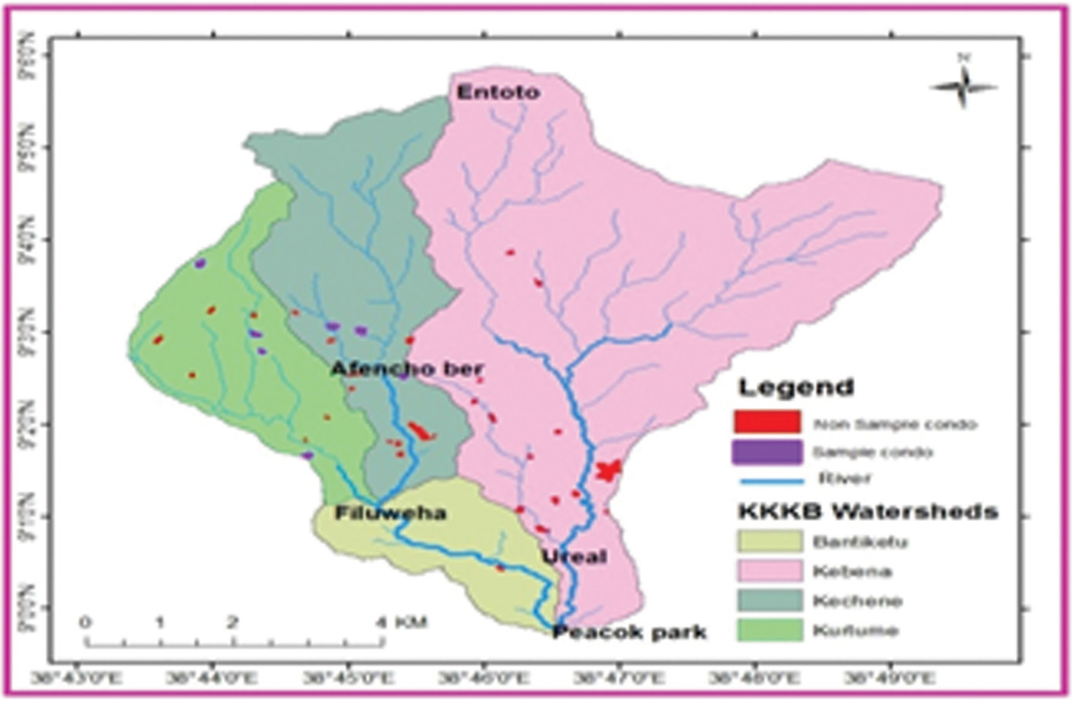


Figure 22: Map of Pollution Sources for Condominium Sites

Tsion Hotel site in Addisu Gebeya, in Northern Addis Ababa, and the other site in Western Addis Ababa are two sites to consider in this regard. But some of condominium sites like Police kibeb condominium discharges their wastewater directly to the rivers.

Figure 23: Discharge of wastewater to Kurtume river by police Kibeb condominium site

Generally, one can say that there is the gap between the volume of solid and liquid wastes generationand the existing disposal practices is very high. The problem is even severe with liquid waste generation and management.

3.2. River Pollution Status Along Kechene-Kurtumie-Bantiyketu and Kebena Rivers

3.2.1 Water quality status of BKK-Kebena rivers

Turbidity

Turbidity is used as a crude indicator of contamination. Lower turbidity was recorded at Upper Kebena (Entoto 1 and Entoto 2) and Fafatie river and Chefe, where no anthropogenic disturbance was observed. The dry season turbidity of water samples at the downstream locations of Wolamoriver, big Kebena 1 and big Kebena 2 rivers are exceptionally high (73.2 NTU, 37.8 NTU and 47.8 NTU, respectively) which indicates the presence of organic suspended material in these water samples. During the wet season,turbidity showed an increase in the downstream locations of particularly from Kurtume to big Kebena and from Kebeana at Germen embassy to Kokebetsebah.

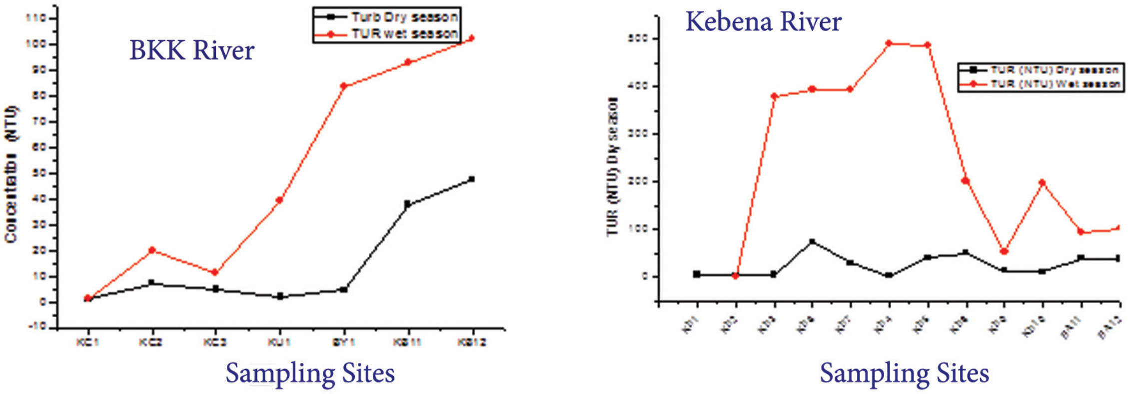


Figure 24: Turbidity status of BKK + Kebena river

pH and DO

The BKK-Kebena rivers water pH recorded in two seasons for all sampling point ranges from 6.5 to 8.63 (alkaline). As can be seen on the following Figure 26, the dry season PH values of Banteyiketu, Kebena 1, Denkakariver, Kokebetsebah, Uraeal were8.2, 8.2, 8.56, 8.46, 8.3 and 8.6, respectively). But still, all the water samples were within the permissible limit of WHO Standard (6-9) at all the sampling locations (Figure25).The maximum and minimum values were 8.5 and 6.53 log units detected at big Kebena and cheffee (Entoto) spring, respectively. Slightly higher pH values were observed in wet seasons. The possible reason for BKK+K river pH close to neutral water or within the recommended limits (6-9) may be due to the absence of industrial waste waters discharge in to the river.
DO in BKK and Kebenarivers varies 4.1 to 8.3 and 5.02 to12.35 mg/l, respectively in dry season. Similarly in wet season BKK and KebenariverDO values varies from 4.5 to 7.6 and 2.1 to 7.83 mg/l, respectively. A decreasing in DO values is observed moving from upper to lower course of BKK and Kebena rivers (Entoto Mountain to Akakiriver). During dry season DO values in the upper sites; Chefe, Entoto, Hamle 19, Denkaka and Wolamo rivers were 8.3, 10.1, 9.9, 10.6, 9.9 mg/l, respectively, and wet season values are 7.6, 10.08, 9.91, 9.97 and 10.58, respectively; which is above the cold water DO value and safe for natural life to exist.

On the contrary, the downstream site has the least Dissolved oxygen values. BKK river has lower Do Values than Kebena river in both seasons. Afinchober, Kechene and Kurtume, at Germen Embacy, Gnfile and Pekock sampling sites have lower DO values: 4.8, 4.6, 4.1, 5.3 and 5.02mg/l, in dry season and 5.6, 6.3, 5.9, 1.96, 2.57 and 4.5mg/l, respectably, showing that downstream rivers are heavily polluted by organic wastes. However, the DO values of the remaining sampling points are within the range of surface water quality (5.5-9.5).The existence of life will be compromised as the amount of DO in water samples is below 5.5 mg/l and this fact is in line with the trend of DO along the rivers as we go from upstream sites to downstream ones.

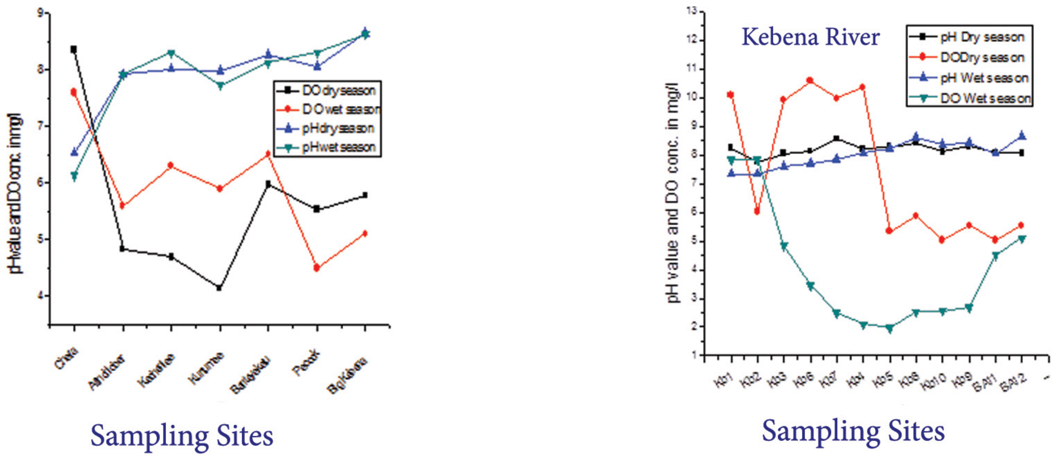


Figure 25: pH and DO status of BKK + Kebena River

Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

COD and BOD are among the most important biochemical parameters for water quality. Looking atBOD, COD values, ChefaandEntoto sites have the minimum values in both seasons for each parameter, as compared to the downstream sampling sites.

During dry season, a BOD and COD concentration in BKK river ranges from 11.3 - 52 mg/l and 16 – 378.7 mg/l, respectively. Similarly, BODconcentrations in Kebenariver ranges from 2.4 to 52 mg/l and COD concentration was in the range of ND (not detected)to 149.7 mg/l. In dry season maximum value of BOD and COD has been measured at Ginfle (52.3mg/l and 149.7mg/l respectively) and Kurtume (47.9 mg/l and 378.7mg/l, respectively) (Figure 26).
Due to high residential and commercial activities along the Kurtumeriver, the organic matter in terms of COD, TN and NH3-N have maximum values of 378.7 mg/l, 198 mg/l, 31 mg/l,respectively, compared to Kechene and Kebena rivers. In a similar trend, in the middle part of Kecheneriver sampling sites, such as Afenchober, Kechene at filwuha, and Banteyiketuriver has the highest COD value as compared to lower sampling sites (Big kebena). The pollution load decreases in the lower part of the rivers (Big Akaki) due to the natural purification capacity of the river. Moreover, this might also due to the dilution effect of the river water from excessive runoff due to the heavy rainy period.
BOD and COD also comply with the fresh water quality standard at most sampling sites. When compared to the sustainable water Group (SWG, 2010) river water quality criteria the middle and lower parts of BKK-Kebenarivers are classified as polluted water (COD>200 mg/l). During dry season higher level of BODand CODwas observed at Ginfle (52 mg/l and 149.7 mg/l), Kebena at Germen bridge (28.6 mg/l and 81mg/l) and Pekock (28.3mg/l, 68.97mg/l) respectively. However, the BOD concentration in Kecheneriverduring this season was below 30 mg/l.

During the wet season (Figure26) high BOD and COD was recorded in the middle Ginfle (86 and 200 mg/l, respectively) and lower part; Pekock (80 mg/l and 365 mg/l, respectively). In BKK river a radical increment BOD and COD was observed after Afinchober (74 and 84 mg/l)to Banteyiketu

(101 and 481 mg/l), respectively. This peak could directly be linked to lower DO values (Figure26). BOD and COD alongKebenariver showed an increase and decrease and again increase in its concentration moving down the river courses for the wet and dry seasons (Figure 26) due to the different tributaries coming from different pollution loads.

Positive relationships were established between BOD, COD and DO concentrations. An increase in BOD and COD; and an expected drop in DO levels are observed in the BKK+K rivers moving from Entoto to Big Kebena (Figure26). This suggests higher levels of decaying organic matter, in the form of municipal wastes, continuously entering in to the river. As a result the river water becoming partly anaerobic due to oxygen depletion in water bodies and continuous discharge of municipal wastewater in to the river which increases the BOD, COD, S2- and microbial concentration in the downstream; which was observed in laboratory results analysis and during field visit.

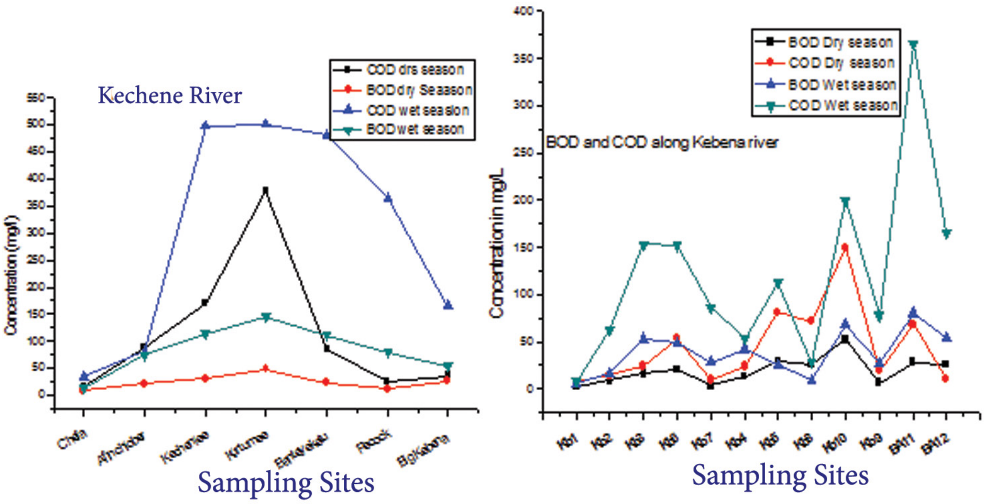


Figure 26: BOD and COD status along BKK + K River

Nutrient Loads Along BKK+K Rivers

BKK + Kebena river sample analysis for total nitrogen (TN) clearly showed that Chefe and Entoto 2, upper sampling sites showed the lowest values (0.85 mg/l). During dry season the concentrations of TN and NH3-N in BKK +K river water ranged from1.39mg/l (Chefe) to Kurtume (198 mg/l) and 0.85 mg/l (Entoto 2) to 133 mg/l (Ginfle). Similarly NH3- N ranged from 0.12 mg/l (Chefe) to 31.9 mg/l (Kurtume) and 0.6 mg/l (Entoto 2) to 133 mg/l (Ginfle). Therefore, the highest value of TN was recorded at Kurtume and Ginfle sampling sites, 198mg/l and 133 mg/l, respectively and the highest NH3-N values of 31.9 and 42.2 mg/l,are recorded in Kurtume and Ginfle, respectively. Except Chefe and Entoto 2 sampling sites, NH3- N concentrations in most sampling sites were found to be very high, exceeded the allowable limits. The high level of ammonia might be due to dead animal bodies and leaching of domestic organic matter into the river system. Comparing dry season with wet season data, the concentration of Total nitrogen (TN) in the wet seasons were lower than the dry seasons (Figure 27). This may be due to the dilution effect of rainfall.

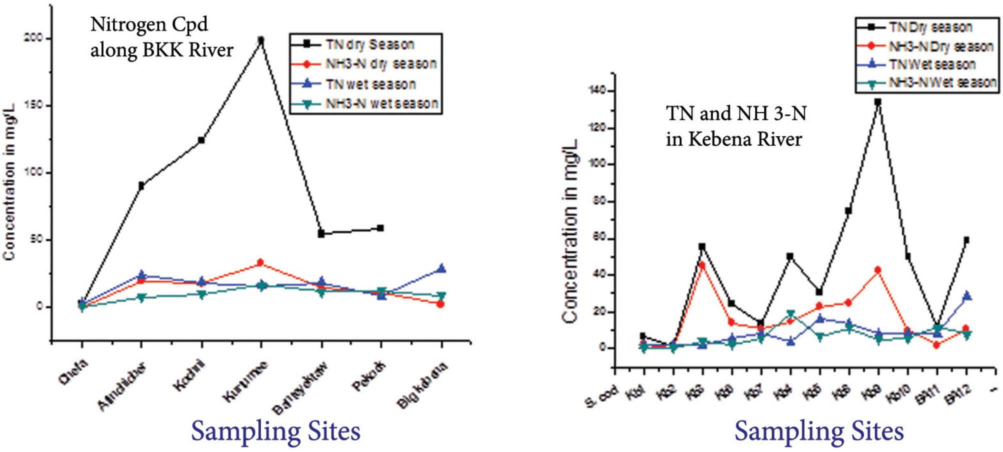


Figure 27: Nitrogen compound status along BKK + Kebena rivers

The concentration of SO42-and S2-along BKK + Kebenarivers during dry season ranged from 1.13 to 30.1 mg/l and 0.01 to 6 mg/l, respectively. The maximum value of SO42--has been measured from Denkakariver to Kokebetsebah (29-36.2 mg/l) and Afnchober, Kechene, Kurtume (29 - 31.2 mg/l), respectively. The maximum value of S2 was recorded at Kebena Germen Bridge (6mg/l). Sulfide concentrations in both seasons were very low. The SO42-concentration was higher in wet seasons in BKK and Kebenariver (Figure 28).

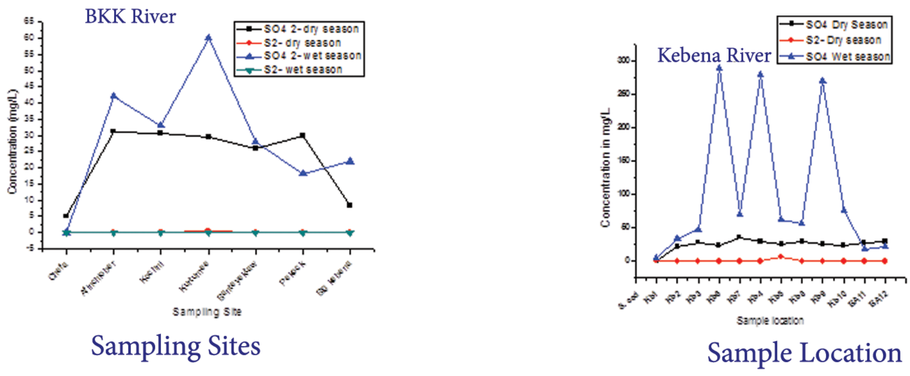


Figure 28: Sulfur compound status along BKK + Kebena rivers

During the wet season, the BKK river has shown lower level of nitrate (< 8mg/l) in all the sampling locations. One good reason could be mixing as a result of the wet season rainfall which eventually neutralizes the nitrate concentration. Higher peak was displayed only at Afinchober (7.8 mg/l) and then showed decreasing moving down the BKK river course (Figure 29). The wet season nitrate concentration along the Kebena river is higher than BKK river. The highest nitrate peak value was observed in Kebena at Germen Embassy (86 mg/l) which could probably be attributed to measurement error or undefined source.Studies also showed that the nitrate concentrations exceeds as high as 80 mg/l (Alemayehu et al., 2005).This is probably attributed to leaking septic tanks and discharge of pit latrine system directly in to the river in highly populated areas. According to the WHO (1984), for nitrate safe drinking water should not have nitrates exceeding 10 mg/l.Unlike the wet season nitrate load in the BKKriver, the Kebena river has shown a higher nitrate load along the river course.

The phosphate concentration in BKK and Kebenarivers during wet season was very high which could probably be attributed to an undefined source such as laundry and detergents from domestic sources. The concentration of phosphate in wet seasons (Figure 30) at Kebenariver showed a higher concentration than BKK rivers. And both rivers displayed a phosphate concentration above the maximum permissible EU limit (6.1 mg/l) in all sampling points except at sources. Comparison showed that the wet season concentration of phosphate along Kebena showed a higher peak than the BKK river.

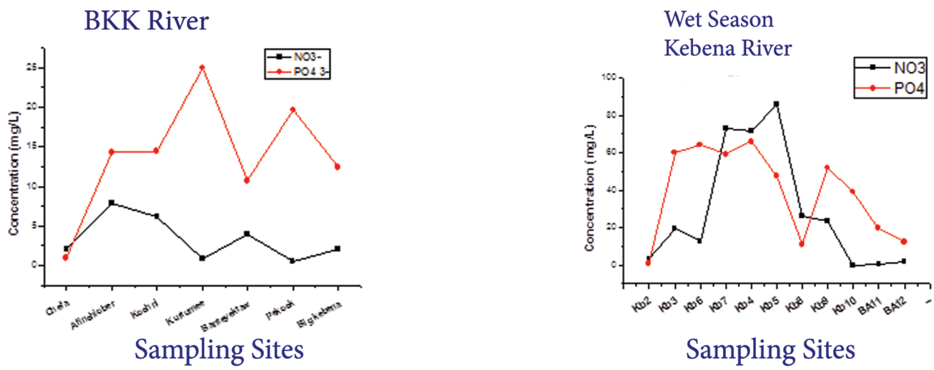


Figure 29: Nutrient Status Along BKK + Kebena Rivers

Salinity, Electrical Conductivity, Total Dissolved and Suspended Solids Along BKK+K Rivers

Salinity was determined by measuring its electrical conductivity (EC), total dissolved solids (TDS) and chlorides (Cl-). These parameters are the most important in determining the suitability of the water for irrigation in the downstream. The electrical conductivity (EC) is used as a replacement measure of TDS concentration. During dry seasonhigher values of EC was recorded in Denkaka (953.7Mic/s), Germen Embassy 1 (795.4Mic/s) and Kokebetsebah (754.5 Mic/s),Kurtumie at filwuha (1063 µS/cm) and Afinchober sites (923.3 µS/cm). In this area the EC concentration is higher than the standard limit (750µS/cm). In wet season higher values of EC was recorded in Kurtume (527.8µS/cm) (Figure 30).On the contrary, the smallest value is achieved by Chefa (53.07µS/cm) and Entoto 1 (52.98µS/cm) where the EC concentrations are Very low, below the standard and bottled drinking water EC values. Electrical conductivity values of all samples were within the WHO Standard, where the maximum permissible limit is 750µS/cm. This might be due to the presence of much dissolved cat-ions and anions due to pollution sources around Kurtumee and Afinchoberrivers. Logically, the pattern of total dissolved solids is proportional to electrical conductivity. Hence, Kurtumie and Afinchober sites have practically the highest values of TDS (total dissolved solid) whereas Chefa site has the smallest TDS value (Figure 31).

The higher EC and Cl-values within the middle part of the City may have resulted from different domestic wastes and sewerage leakage. Whereas, in the upper and lower part of the City rather showed lower conductivity values. However, comparing the seasonal variation along the BKK and Kebena river the dry season showed relatively higher concentration peaks which could be due to the absence of mixing and the higher evaporation rate that leaves salt behind. However, the concentration of EC in wet seasons do not crossed the threshold value of the World Health Organization (WHO), but in dry season EC concentration at Kurtume, Denkaka, Fafuatieriver and Kebena at Kokebetsibah exceeds 750μS/cm.

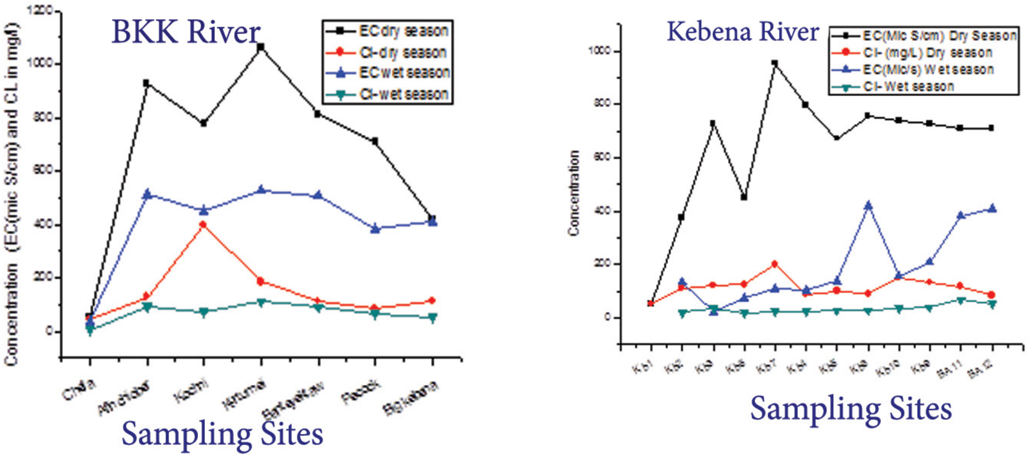


Figure 30: Electrical conductivity and chloride status along BKK and Kebena river

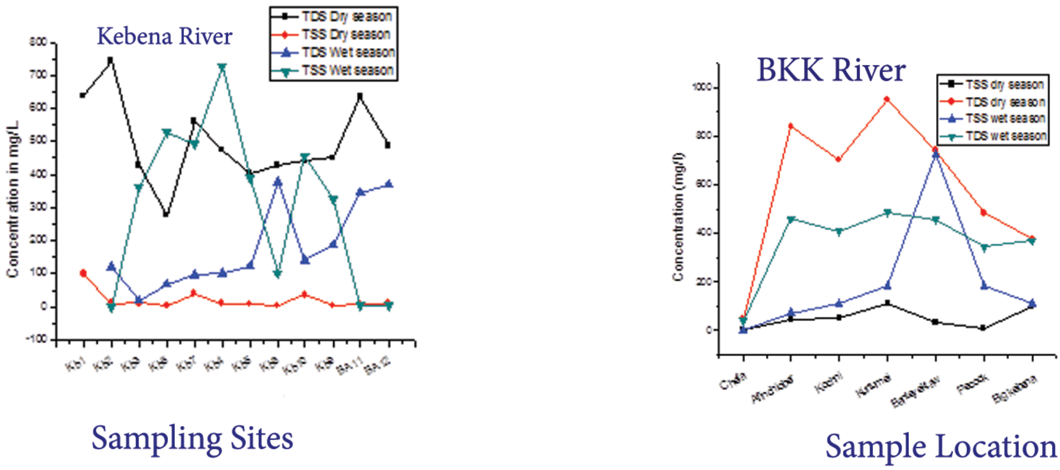


Figure 31: Total suspended solids and Total dissolved solids status along BKK andKebena river

3.2.2 Pollution Map Along BKK-Kebena Rivers

The mean concentrations of all parameters in Kechene and Kebenarivers were significantly lower in the headwaters than the lower sites. The head watersare characterized by upper sites (reference or background sites) especially Chefee and Entoto, where they are less polluted or undisturbed sites. Dissolved oxygen (DO) showed decreasing trend as we go down course of the river. Previous studies showed that the concentration of DO at the middle and lower parts of rivers reaches to zero. According to UK General Quality Assessment (GQA) criteria for rivers and pollution map analysis showed that in the middle and lower course the BKK-Kebena river in both seasons are classified aspoor quality. In wet season, the middle part of Kebena is classified as bad water quality (Figure 32).

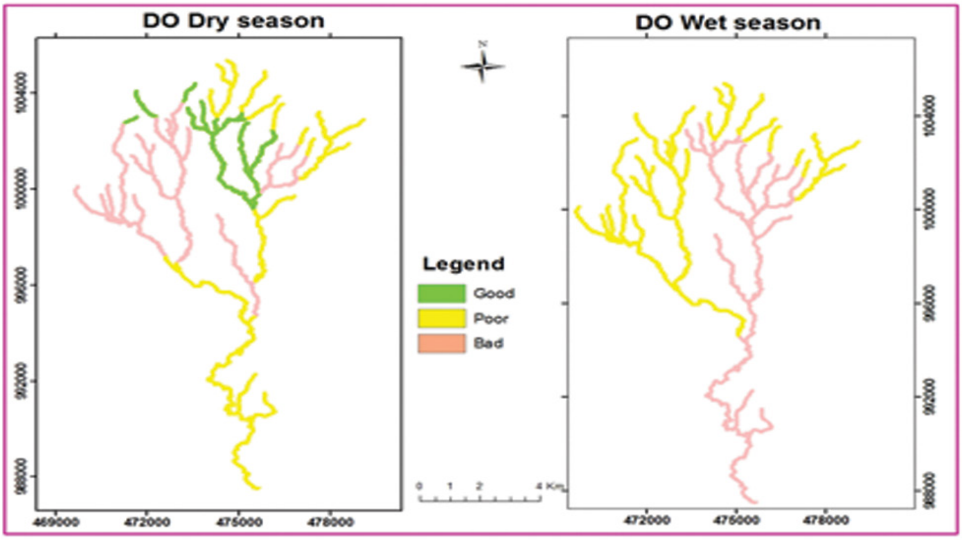


Figure 32: DO level along BKK +K in wet and dry seasons

The BOD and COD values in the upstream of both rivers are low and there is a high dissolved oxygen level. However, in the middle course of the rivers, Kurtume and Ginfle river sites has elevated organic matter and nutrient levels. Ginfle river don no have spring sources, but it carries wastes from eastern part of 6 Killo campus and Yekattit 66 hospital and passes through congested areas until it meets Kebena river at Ureal. In Kurtume river, much of their lengths pass through commercial centers at Merkato (Somalietera), TikurAnbessa Hospital and slum areas. These rivers crosses the densely populated and yet are poorly served with sanitation facilities and solid waste collection systems (UN-Habitat and CGAA, 2005), a possible explanation for the elevated levels of most nutrients, BOD and COD seen at downstream courses. BOD, COD pollution map (Figures33 and 34) showed increasing trend and dissolved oxygen showed a decreasing trend. According to UK General Quality Assessment (GQA) criteria for rivers, the present result leads to the conclusion that the two rivers are classified as badly polluted river. In wet season the BOD and COD concentrations are increased worsening the quality of the river (very badly polluted).This may be due to kirmet rainfall water containing all sorts of wastes including sewerage, solid organic waste, open defecation wastes, sediments and nutrients, all end up in the rivers.

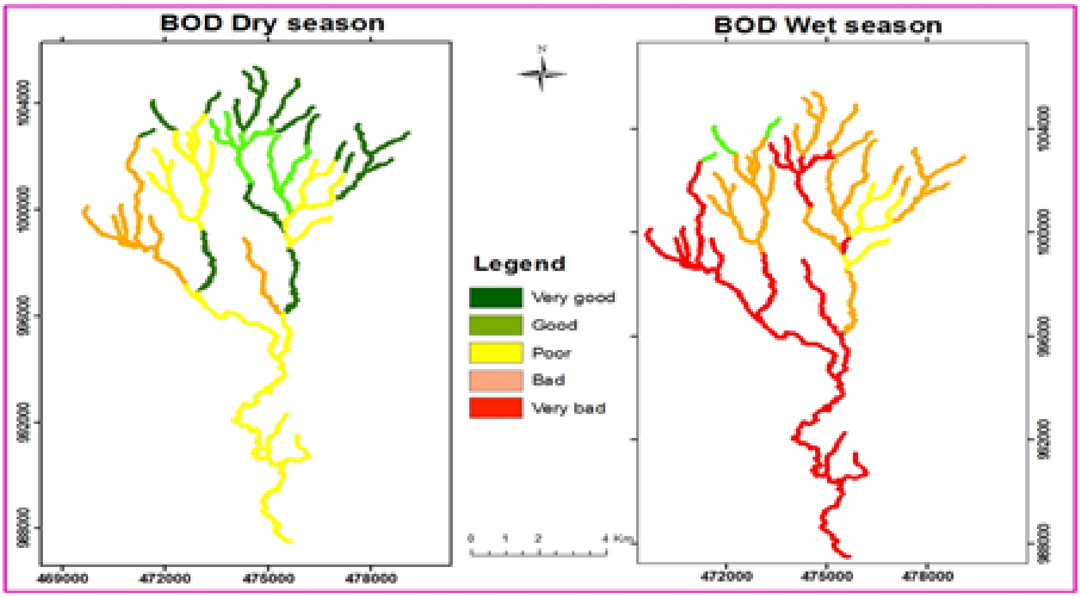


Figure 33: BOD pollution map along BKK +K in wet and dry seasons

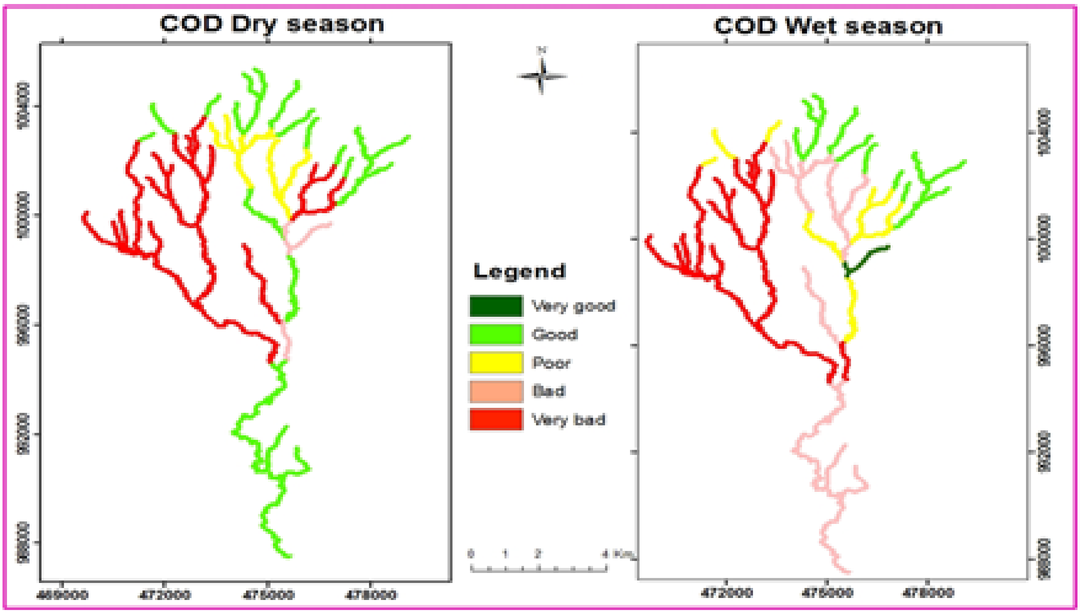


Figure 34: COD pollution map along BKK +K in wet and dry seasons

The concentration of nutrient pollutants in dry season is higher than wet seasons. In wet season the concentration of TN, NH3-N, and TDS showed a decreasing trend in their concentration along BKK river. The findings clearly showed that there is a strong correlation between source of pollution, anthropogenic activities, and river water quality status along the BK- Kebenarivers. For example, Kurtume river pollution is highly correlated with the pollution sources from hospitals, hotels, commercial centers (such as SumalieTera), schools, deranges from solid damping sites and open defecation.According to UK General Quality Assessment (GQA) criteria (Table 6&7) for rivers BKK + Kebena rivers are classified as bad and very bad in the middle and lower regions of the rivers, respectively (Figures35, 36 and 37).

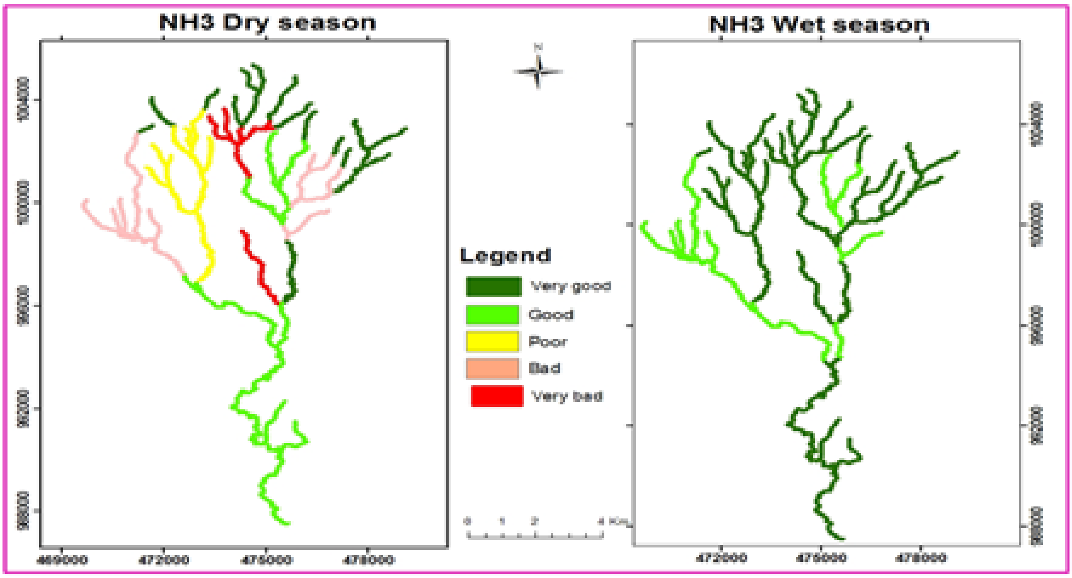


Figure 35: NH3 pollution map along BKK +K in wet and dry seasons

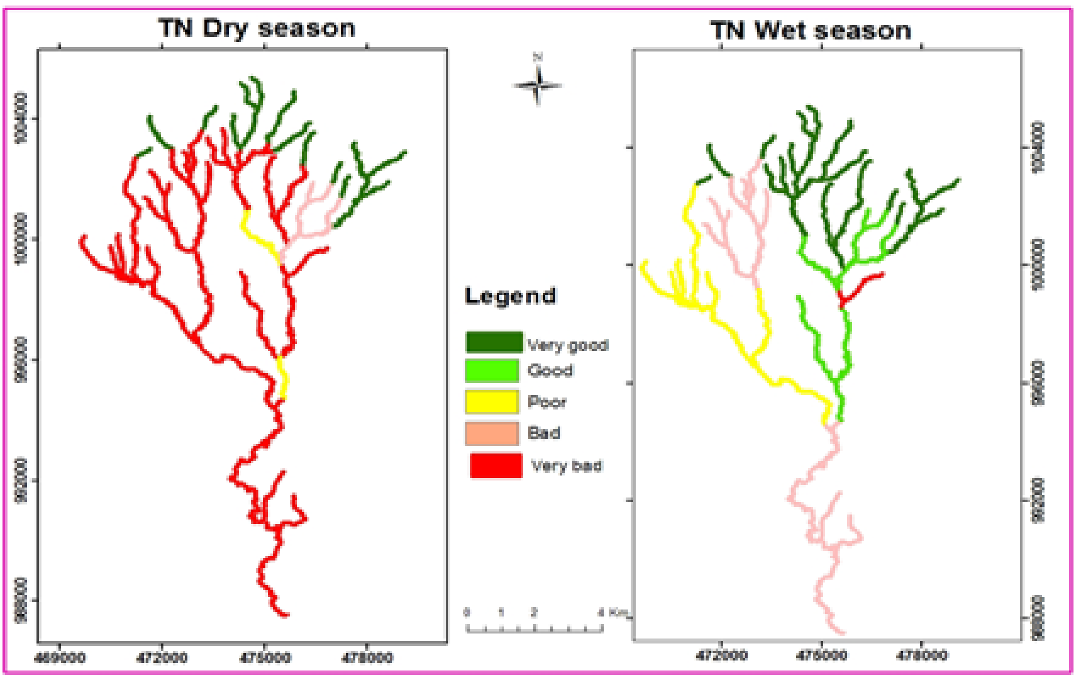


Figure 36: TN pollution map along BKK +K in wet and dry seasons

Increase in the proportion of impermeable surfaces in the City could also contribute to elevated levels of nutrients and BOD by increasing surface runoff (Roy et al., 2003). In Kechene and Kebena rivers, the pollution problem is exacerbated by the poor drainage system that serves the City (UN-Habitat and CGAA, 2005). Thus, most of the kirmet rainfall water containing all sorts of wastes including sewerage, solid organic waste, open defecation wastes, sediments and nutrients, all end up in the Rivers. The mean concentrations of NH3-N and COD increase in the middle and decreased in the lower reaches (Peacock) after their peak values at Kurtume and Ginfle, showing an improvement, although not significant. Tamiru Alemayehu et al. (2005) noted that the dominance of impervious surfaces, coupled with the altitude difference between upper and lower reaches, increased the discharge of rivers in Addis Ababa including the downstream of Big Akaki river. The average TDS, EC and TUR concentration is high in the middle sampling sites with a moderate decrease in the lower reaches, may be due to settling effects. Surface runoff from impervious surfaces and erosion from riparian areas contributed to the high TSS recorded in the study sites. During wet season the concentration of TDS showed higher than dry seasons as shown by pollution map (Figure 37)

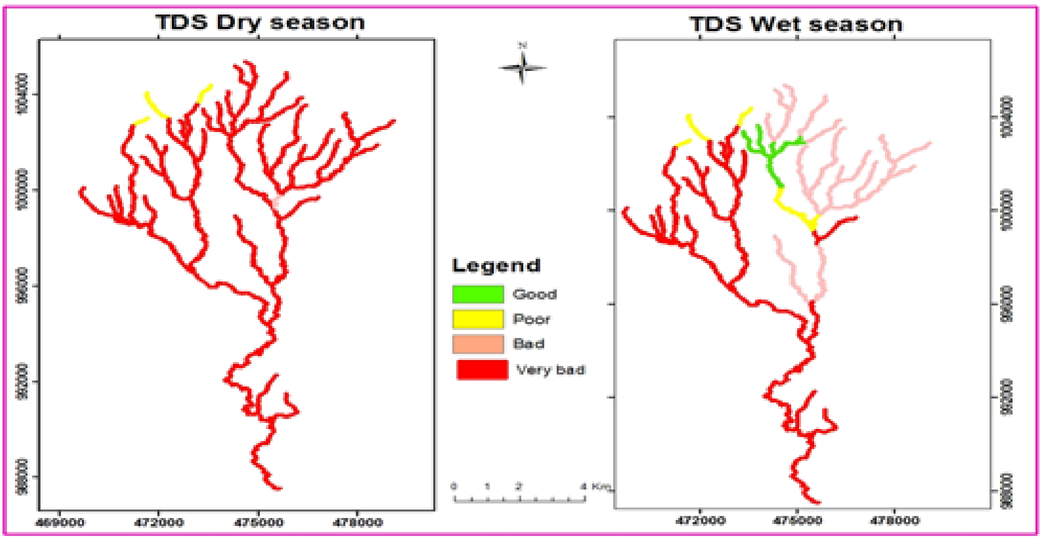


Figure 37: TDS pollution map along BKK +K in wet and dry seasons

Table 6: The UK General Quality Assessment (GQA) for rivers and hardness description used in the UK

GQA Grade	Description	BOD(mg/l)	NH3 (mg/l N)
A	Very good	2.5	0.25
B	Good	4.0	0.6
C	Fairly good	6	1.3
D	Fair	8	2.5
E	Poor	15	9
F	Bad	>15	<9

Table 7: Recommended water quality Criteria

Parameter	Desirable Limit	Maximum Permissible Limit	Organization/ Body
Temperature, Co		15	CCME
pH	7.0-8.5	6.5-9.2	WHO
DO, mg/l	5.5-9.5		CCME
Conductivity, us/cm	750	2500	WHO
TDS,mg/l500		1500	ICMR
Nitrate, mg/l	25	50, Drinking water	EC
	-	45	WHO
Chloride, mg/l	100-700	irrigation water	CCME
Phosphate, mg/l	0.35	6.1	CE
1			WHO
Calcium, mg/l	100, for livestock		CCME
Sulphate, mg/l<1000, for livestock			CCME
Nitrate, mg/l	0.06		CCME
		0.1	EC
NH3, mg/l	1.37-2.20 for protection of aquatic life		EC

Note: CCME = Canadian Council of Minister for Environment; WHO = World Health Organization; ICMR = Indian Council of Medical Research; EC = European Community; EPA = Environmental Protection Agency

Correlation Analysis of BKK + K River

Spearman correlation between physiochemical parameters along BKK + K river is shown in Table 8 and Table 9. DO concentration a negative relationship with BOD, COD, TN AND NH3-N for the two rivers. NH3-N strongly positively correlated with BOD, TN and COD in both seasons. The results from the analysis of variance (ANOVA) at α=0.05, showed that there is a significant difference in physiochemical parameter values between each sampling sites for most parameters.

Table 8: Pearson Correlation of mean concentration. of physiochemical parameters in BKK river

	pH-D	*DO-d*	*COD-d*	*BOD-d*	*TN-d*	*NH3-N-d*	*pH-w*	*DO-w*	*COD-w*	*BOD-w*	*TN-w*	*NH3-N-w*
pH-D	1											
DO-d	-0.823	1										
COD-d	0.345	-0.683	1									
BOD-d	0.366	-0.572	0.865	1								
TN-d	0.537	-0.873	0.946	0.781	1							
NH3-N-d	0.646	-0.896	0.898	0.865	0.957	1						
pH-w	0.964	-0.802	0.219	0.155	0.464	0.525	1					

DO-w	-0.673	0.632	-0.061	-0.135	-0.322	-0.371	-0.738	1				
COD-w	0.725	-0.603	0.575	0.404	0.603	0.565	0.679	-0.285	1			
BOD-w	0.817	-0.864	0.801	0.703	0.864	0.886	0.721	-0.381	0.875	1		
TN-w	0.719	-0.755	0.382	0.390	0.539	0.677	0.656	-0.268	0.294	0.615	1	
NH3-N-w	0.842	-0.825	0.690	0.687	0.777	0.818	0.753	-0.610	0.845	0.936	0.454	1

d= dry season and w = wet season

Table 9: Pearson Correlation of mean concentration. of physiochemical parameters in Kebena river

	pH-D	*DO-d*	*COD-d*	*BOD-d*	*TN-d*	*NH3-N-d*	*pH-w*	*DO-w*	*COD-w*	*BOD-w*	*TN-w*	*NH3-N-w*
pH-D	1											
DO-d	0.205	1.000										
COD-d	-0.012	-0.462	1.000									
BOD-d	-0.326	-0.147	0.419	1.000								
TN-d	0.074	-0.285	0.666	0.342	1.000							
NH3-N-d	0.071	-0.012	0.552	0.284	0.761	1.000						
pH-w	0.343	-0.537	0.399	0.239	0.636	0.248	1.000					
DO-w	-0.622	0.020	-0.454	-0.220	-0.481	-0.425	-0.650	1.000				
COD-w	-0.324	-0.376	0.427	0.902	0.105	0.089	0.181	-0.090	1.000			
BOD-w	-0.326	-0.147	0.419	1.000	0.342	0.284	0.239	-0.220	0.902	1.000		
TN-w	0.110	-0.437	0.003	0.209	0.321	-0.055	0.747	-0.152	0.189	0.209	1.000	
NH3-N-w	0.260	0.089	0.107	0.276	0.237	0.030	0.534	-0.555	0.143	0.276	0.234	1

d= dry season and w = wet season

3.2.3 Fats, Oils and Grease (FOG) and Phenols Along BKK River

Fats, Oils and Grease (FOG) and Phenols can cause serious problems in the drainage channel and swear system. From spills to clogged drainage system and pipes, these contaminants can debilitate any hydrological system through coagulation over time-cause manhole overflows, sewage spills and backups into public homes and businesses. FOG and phenols are primarily generated from Kitchens (food establishments) and abattoirs. They are a by-product of cooking;

either made from fried foods, cooked meat, cooking oils, or dairy products, garages, fuel stations etc. As these contaminants, together with solid waste, are poured down the drain, they can clog pipes, restricting the flow of water. As a result, drainage system blockage or back-ups and overflows, creating health hazards and harmful impacts on the environment, sometimes even entering storm water drains flowing into streams or Lakes. These contaminants can cause a depletion of oxygen residing within natural waterways causing harm to the aquatic life dependent on the oxygen.

These were and drainage system in Addis Ababa City discharge untreated wastewater,containing FOG, into along stream and Akaki river. FOG comes from different sources such as domestic wastes, car washing, restaurants, hotels, spillage oil over roads, oil refinery. Slaughterhouses, and dairy industries also producing effluents containing high amount of fat, oil and grease (El-Bestawyet al., 2005). Oil and grease in water come from petroleum derivatives and fats from vegetable oil and meat processing (Kiely, 1997), which comprise a wide variety of organic compounds having different physical, chemical and toxicological properties including fat, soaps, fatty acids, hydrocarbon, waxes and oils (Viessman and Hammer,1998), which have the greater solubility in an organic solvent than in water.

Phenols and petroleum hydrocarbons are toxic substances associated with fatty and oily wastewater which inhibitory growth of plant and animal, and causes carcinogenic to a human being (Lan et al., 2009). Also it causes ecology damages for aquatic organisms (Islam et al.,2013). On the other hands, vegetable oil classified as hazardous pollutants if it mixes with the aquatic ecosystem and become toxicity to the aquatic organisms (Mendiola et al., 1998). The use of untreated municipal wastewater, which content high amount of FOG, for irrigation, system may cause many problems for the quality of soil and crops(Travis et al., 2008). Traviset al. (2008) showed that the accumulation of oil and grease up to 200 mg/kg in the first 20 cm soil depth, when irrigated with domestic wastewater, consequently this led to a significant reduction in the soils ability to transmit water. Fat, oil and grease decreases dissolved oxygen levels and increases BOD (Sahuet al., 2007) in the water body due to formation of an oil layer on the water surface and prevent oxygen transfer from the atmosphere. This will lead to a reduction of the biological activity of treatment process where oil film formation around microbes in suspended matter and water (Facchinet al., 2013).

Along Kechene river, the concentrations of fat, oil and grease and phenols at Afinchober area were 0.625 mg/l , 2.476 mg/l, and 0.0618 mg/l, respectively. Similarly,fat, oil and grease concentration were 0.27 mg/l, 3mg/l and 0.589mg/l, respectively, along Kechene river at Filwuha area(Table 10). In the downstream courses of the river its concentration may be increased due to slaughter house and hotel wastewater discharges in to the river. The use of this water for irrigation might lead to the accumulation of fat, oil and grease and phenols in the soil and affect oxygen transfer and micro-organisms in the soil. This in turn might have an impact on the vegetable production and quality.

Table 10: Fats, Oils and Grease (FOG) and Phenol

Sampling Sites	Fats, Oils and Grease (FOG) and Phenols in mg/l		
	Fats	Oil and Grease	Phenols
Afinchober	0.625	2.476	0.0618
Kechene	0.27	3.00	0.589

3.2.4 Heavy Metal Status Along BKK and Kebena Rivers

The heavy metal concentration found in the water samples collected from BKK + Kebena rivers are shown in Figure39and 40. The concentration of cobalt in all the water samples collected in both dry and rainy seasons were below the detection limits of the equipment. Pb concentration is found to be the highest concentration in all the sampling sites of BKK-Kebena rivers. Pb concentration along BKK rivers ranged between 2.7 to 7.15 mg/l in the dry seasons and the level was in the range between 0.005 to 1.98µg/lin rainy seasons. In Kechene river the highest Pb value in BKK rivers was recorded in Kechene (1.82µg/lin wet season and 5.95mg/l in dry seasons); Kurtume (1.8µg/lin winter and 7.15µg/l in dry seasons) and Banteyiketu (1.7µg/l in winter and 6.13mg/l in dry seasons). The concentration of lead was significantly higher in the dry seasons than in the wet seasons (ANOVA, $p<0.05$). On the other hand, the concentration of lead was no significant different among sampling sites (ANOVA, $p=0.100$). The level in Kebena river was between 2.61 and 11.02mg/lin the dry seasons and it was between 0.87 and 3.17µg/l in the winter. The highest Pb was found at Hamlie 19 (10µg/l) and Peacock (7.55µg/l) in the dry seasons. The analysis of variation showed that the level of lead was significantly higher in the dry season than wet season(ANOVA, $p<0.05$). The concentration was not significantly different with the variation of sampling sites (ANOVA, $p=0.47$). The total 17 samples from BKK + K, 8 sampling sites have Pb concentrations above 5 µg/l.

Pb is one of the most significant toxins of the heavy metals. These high levels of Pb can pose serious threat to the public health given that the river is the major supplier of water to agricultural area in the downstream communities. Such elevated levels of human exposure through vegetable consumption may lead to damage of almost all organs, most importantly the CNS, kidneys and blood, culminating in death at excessive levels (Tong et al., 2000). It will be more interesting to determine the current Pb pollution in communities which currently consumes vegetable produced using this river water.

The possible sources of Pb may be the discharge of car wash and leaded gasoline from Garage wastes, tire wear, lubricating, oil and grease, old lead acid batteries, solder, rust inhibitors, paints and ceramics, vehicular emissions, runoff from contaminated land areas, sewage effluents and plastic stabilizers (WHO, 2011), into feeder streams and drainages of the Kebena river.

Cd concentration along all BKK- Kebena river sampling sites ranged between 0.8 and 1.8µg/lin the dry seasons. The concentration was below the detection limit of the equipment in the wet season. The analysis of variance showed that the concentration of Cd along all BKK + K rivers in the dry season was significantly higher than wet season (ANOVA, $p<0.05$). However, the concentration was not significantly different among sampling sites (ANOVA, $p=0.5$). Cd is well known to have some profound toxic effects to human body systems even at extremely low levels.

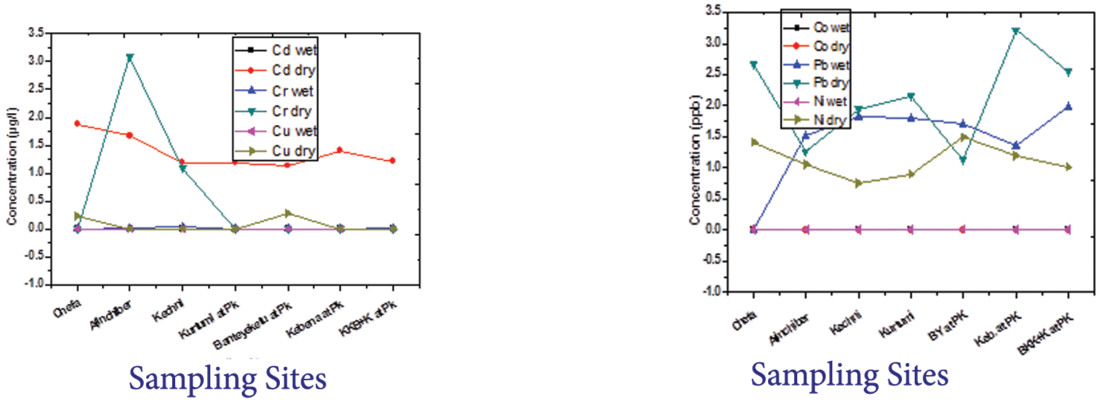


Figure 38: Heavy Metal Status Along K River (A) + BKK (B)

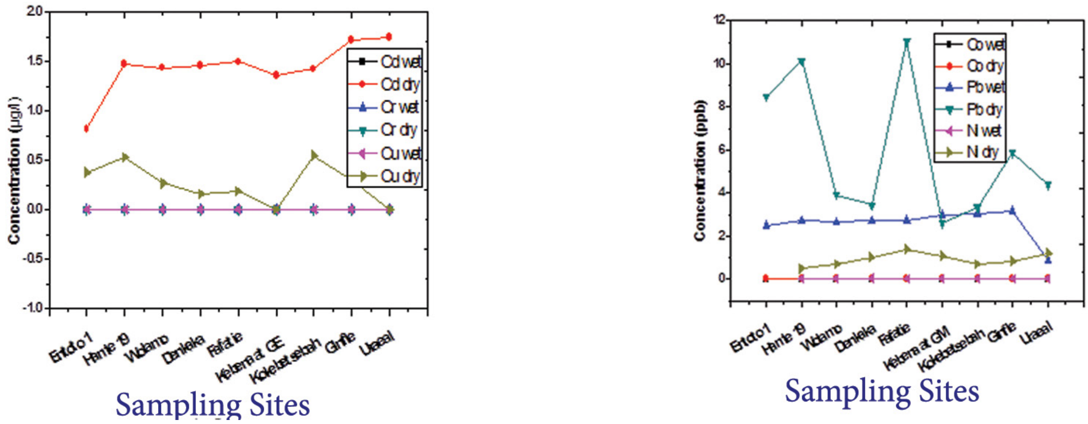


Figure 39: Heavy Metal Status Along K River (A)+ BKK (B)

The level of nickel was highest in Banteyeketu river (1.49µg/lin dry seasons and 0.0154µg/lin the wet season) and the minimum concentration was recorded at Kechene river (0.75µg/l) in the dry seasons. The level of Ni was significantly higher in the dry season than the winter season (ANOVA, $p<0.05$). The level of Ni was not significantly varied with variation of sampling sites (ANOVA, $p=0.47$). Similarly, along Kebena river, Ni concentrations were found to be lower in Hamle 19 (0.49 µg/l) and highest at Germen Embassy bridge (1.4 µg/l) in the dry seasons. In the wet season, highest Ni was recorded at Dankaka (0.045µg/l), Fuafatie (0.013µg/l) and Kokebetsebah (0.025µg/l). The level of Ni was below the detection limit of the equipment in all the remaining sampling sites. The analysis of variation showed that the level of nickel was significantly varied with variation of seasons (ANOVA, $p<0.05$).

The chromium levels were below the detection limits in all the water samples collected from Kebena rivers in both the dry and rainy seasons. The level along BKK river was also below the detection limits in Chefa, Kurtumee, Banteyeketuand Kebena at Pekock. However, highest value as recorded in Kechene river (1.09µg/l in dry and 0.031µg/l in wet season);Afenchober (3.09µg/lin dry and 0.012µg/lin wet season).The level of chromium along BKK river was not significantly varied with variation of seasons (ANOVA, P=0.23).

A Cu concentration along BKK was detected at Peacock (0.28µg/l) whereas it was detected along Kebena river ranging from 0.1 to 0.55µg/lat Entoto 2 and Kokebetsibah, respectively. According to Prabu (2009), Cu is essential in trace amounts for human life, but high doses may lead to anemia, liver and kidney damage, stomach and intestinal irritation also induces hypertension, coma and sporadic fever. The level of copper was significantly varied with variation of seasons (ANOVA, p=0.05).

The heavy metal concentrations in Kebena river samples were decreased in the order of Pb> Cd> Ni and Cu and BKK river metal concentration were decreased in the order of Pb>Cr> Cd> Ni and Cu (Figure 40). Pollution mapping of Pb along BKK-Kebena showed that Kurtume river and Banyteyiketu river are the most polluted during dry seasons. Due to dilution effect BKK+ K river in the wet seasons are less polluted (Figure 40).

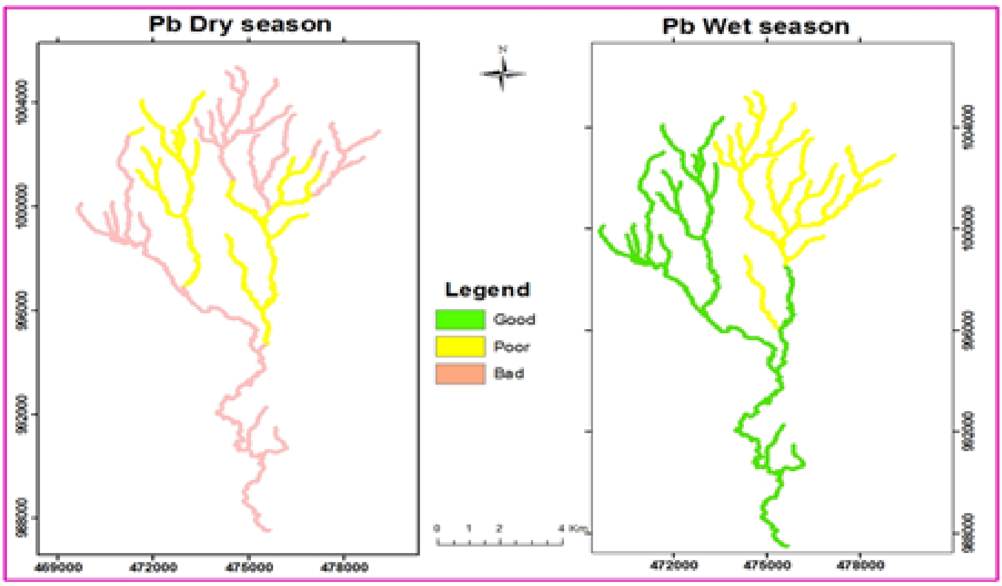


Figure 40: Pb pollution map along BKK +K in wet and dry seasons

3.3. Big Akaki River Pollution Assessment

3.3.1 Physic-chemical Water Quality of Big Akaki River

The physiochemical and heavy metal parameter results along big Akaki river (kersa to big Akaki) indicated that the pollution load increased from upstream to downstream. This indicates the load of pollutant from different domestic and commercial sources along the bank of the river (Figure 42, 43 and 44).

pH

The temporal variation of pH in the Big Akaki river within the upper and lower set limits was 8.93 and 7.93 for dry season and 7.67 and 8.51 for wet season (Figure 42). The first half of the sampling sites showed a uniform trend among sites with the exception of site Bulbula which showed a steeper decrease in pH and steep increase toward the end of the first half of the sampling sites. This could be attributed to the greater volume of water at the site was originating from the hydro-power plant and thus the semi-stagnant state of the water within the dam could be leading to the difference in the pH of the water.

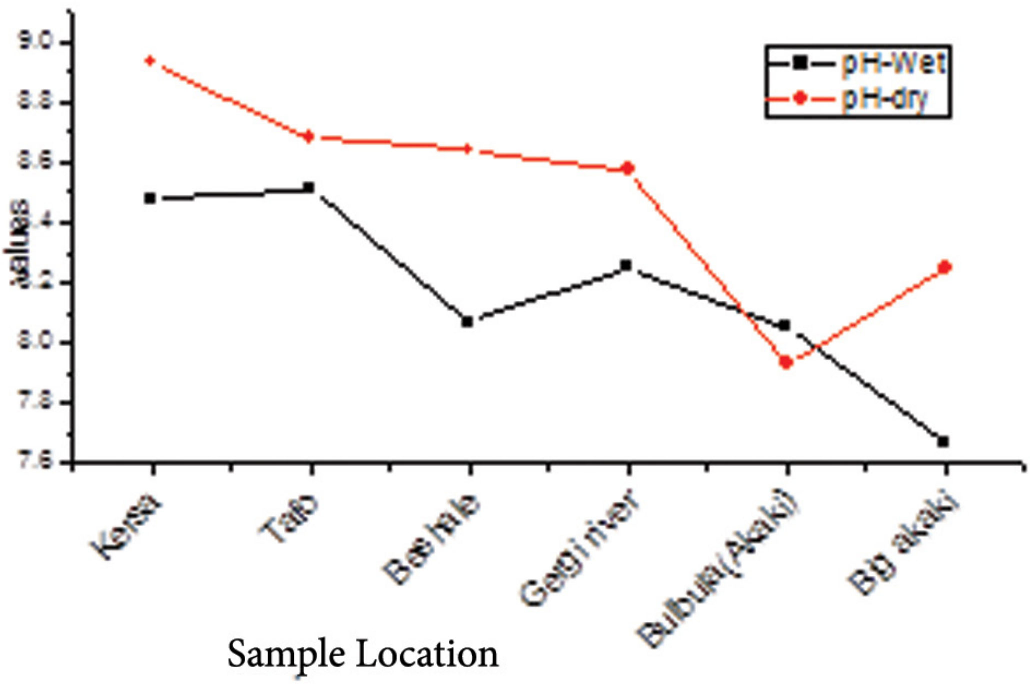


Figure 41: pH status along Big Akaki River

Electrical Conductivity

The electrical conductivity (EC) of water is a useful and convenient indicator of its salinity or total salt content, and the values for the water of big Akaki river ranged between 213.2-596 µS/cm during the dry season and ranged from 49.8-422.9µS/cm during the wet season. The recommended value of electrical conductivity for potable water is below 2500 µS/cm [GEMS, 1988]. The lowest and the highest electrical conductivity values along big Akaki river water were observed at Kersa river (upstream) and Gerji river (low stream), respectively. Based on the data measured during both seasons, the level of electrical conductivity reflected the worsening river quality from up to downstream of the big Akaki river, but within permissible limit of the WHO (Table 6 and 7).

The lowest and highest EC values are within the recommended value of EC of potable water (750 μS/cm). Generally, the EC increases downstream river (kersa to big akaki river) apparently due to the accumulation of domestic and sewage wastewater and also to the enrichment of electrolytes from mineralization or weathering of sediment.

Total Dissolved Solids, Alkality and Turbidity

The value of total dissolved solids (TDS) is an important property used to evaluate the suitability of water for irrigation since the solids might clog both pores and components of the water distribution system and the values for the water of big Akaki river were between 194.9-537.2 mg/l during the dry season and between 92.65-380.7mg/l during the wet season. Maximum values of TDS were obtained furthest downstream (Gerji river) during both seasons. The increase in TDS can probably be related to pollution through discharge of domestic and sewage wastewater into the river. However, although some TDS values are higher than normal, it is found to be above the CCME guidelines for drinking water, i.e. 500 mgL-1 for Gerji and Bulbula rivers sites for dry season and all TDS values are found to be below the CCME guidelines for drinking water, i.e. 500 mgL-1 for wet season. The higher TDS value and its increasing pattern towards the downstream of river can be attributable to the increasing anthropogenic activities and long term farming and quarry practices that result higher TDS by increase in weathering and erosion of soil (Zhang etal., 1995). Turbidity was found to vary with the location of sampling suggesting greater addition of particulate matters along the cities on the bank river. The trends of alkalinity concentration increased from upstream to downstream and exceed the prescribed limit of 300mg/l of WHO guidelines suggesting contributions of alkaline salts as the river flows down along the route.

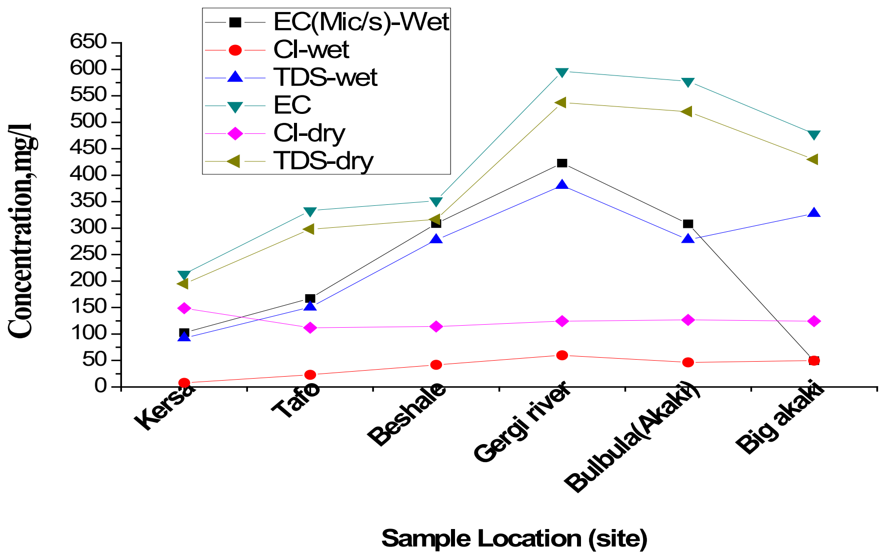


Figure 42: EC,Cl and TDS status along Big Akaki river (Dry and wet seasons)

Dissolved Oxygen, Biological Oxygen Demand and Chemical Oxygen Demand

Traversing downstream the value of dissolved oxygen (DO) steadily decreases with values ranging from 10.08-5.26mg/l for dry season and ranging from 5.8-1.18 mg/l for wet season which is an indicator that the quality of water increasingly worsens as it flows further downstream.

Except for those at Kersa, Tefo and Beshale rivers sampling sites during dry season and except kersa for wet season, all other sample sites were found critically out of range in DO and do not conform to the value in the CCME guideline for the protection of aquatic life, i.e. 5.5-9.5 mg/l. The higher DO level for Kersa sampling site indicating high rate of photosynthesis (Tripathi etal., 1991) by the phytoplankton present in the river. High DO favors the self-purification capacity of water which may be attributed to largely high quality, self-purification and bactericidal properties of the water from Kersa river(upstream-undisturbed area). The low DO level causes anaerobic conditions resulting in foul odour of the Big Akaki river. The lower levels of DO downstream may be attributed to the microbial utilization of DO in the breakdown of organic compounds introduced by the discharge of domestic and sewage wastewater.

The pollution profile as indicated by BOD and COD is depicted graphically in Figure43. They ranged from 3.84 to 25.7 mg/l and 9.33 to 118.7 mg/l, respectively for dry season and they ranged from 30 to 276 mg/l& 58.6 to 824mg/l for wet season. Most of these values for dry season and all the values for wet season were above acceptable ranges. The downstream samples were approximately eight times higher in BOD, and seven times higher in COD than the upstream samples for dry season and the downstream samples were approximately nine times higher in BOD, and fourteen times higher in COD than the upstream samples their BOD values exceed 15 mg/l, which is categorized as bad/grossly polluted according to the UK general water quality assessment criteria (Table 6 and 7).

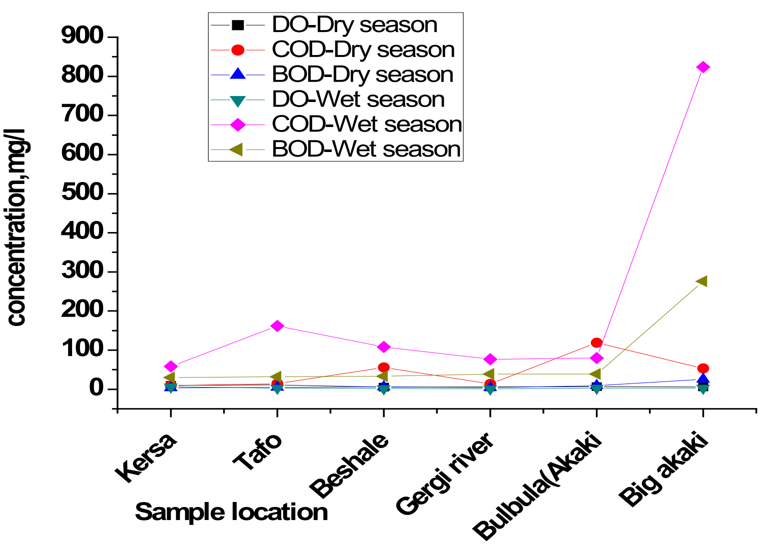


Figure 43 BOD and COD status along Big Akaki River (Dry and wet seasons)

Nutrients and Major Anions

Total Nitrogen (TN) and Ammonia

The concentrations of TN and ammonia in river water were found to range from1.34 (Kersa) to 131mg/l (Bulbula) and 0.87 (Beshale) to 5.01 mg/l (Gerji)for dry season and 3.4 (tefo) to 9 mg/l (gerji) & 1.2 (tefo) to 8mg/l (gerji) respectively. According to the CCME [GEMS, 1988], the maximum concentration of Ammonia Nitrogen for Protection of Aquatic Life is 1.37-2.20 mg/l. In the river water samples for this survey of the study area, all sample locations were found to be fair to good according to the UK water quality criteria [Reeve, 2002], except Gerji location where the ammonia levels falls poor water quality range. The high level of ammonia might be due to the leaching of fertilizer residues used on agricultural farms into the river system. Important increases in ammonia concentrations, occasionally accompanied by lower NO_3^- values, suggest suboxic conditions [Guèguen et al., 2004] especially at Gerji site.

Measurement of Cl- ion concentration showed an increasing pattern along the downstream of river Akaki. As chloride is mostly found in nature in the form of various salts which indicates more anthropogenic activities towards downstream due to leaching process in the river water. Concentration of SO_{42}^- was found to be modestly increased along the downstream of the river. It is to be noted that the concentration of sulphate was found to be markedly low (7.33-43.7 for dry season and 5-36 mg/l for wet season which was significantly lower than standard given by FAO (400mg/l) and WHO(250mg/l) suggesting a controlled sulfate generating factors in the surroundings.

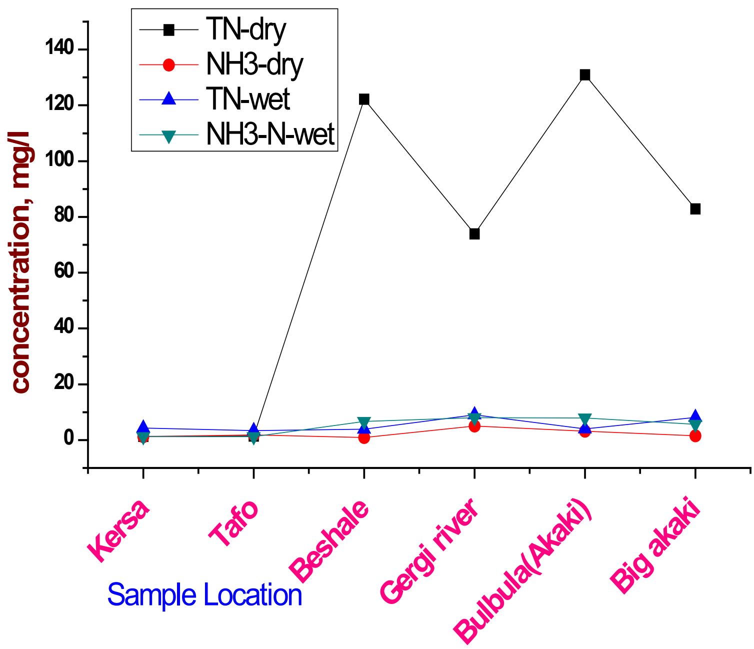


Figure 44: TN and Ammonia status along Big Akaki River (Dry and wet seasons)

3.3.2 Heavy Metals Along Big Akaki River

Heavy metal analysis in Big Akaki river (Kersa to Akaki), like Kebena river, showed that Chromium and Cobalt were below the detection limit of the equipment from all the sampling sites. Lead (Pb) concentration is found to be the highest concentration in all the sampling sites.

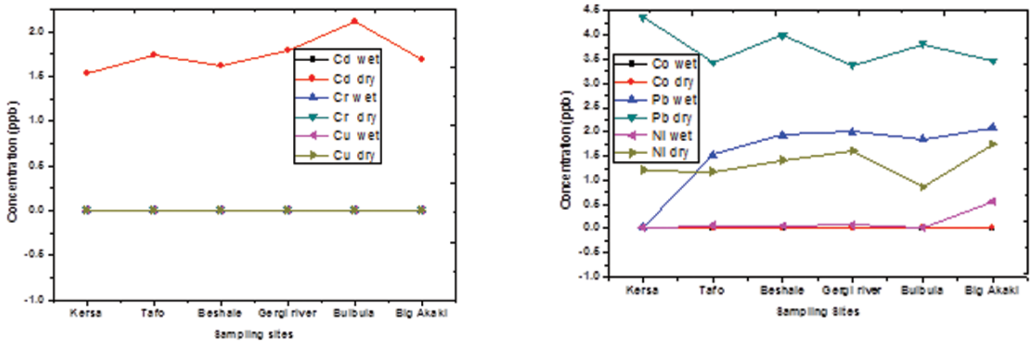


Figure 45: Heavy metal water quality of BigAkaki river

Pb concentration in Big Akaki river ranged between 3.38 and 4.37ɥg/l in the dry seasons. In the winter seasons, the level was between 0.023 and 2.086 ɥg/l (Figure 46). The concentration of lead was significantly higher in the dry seasons than in the wet seasons (ANOVA, $p<0.05$). On the other hand, the concentration of lead was not significantly varied with variation of sampling sites (ANOVA, $P=0.47$). The possible sources of Pb may be the discharge of geologic, industries from Tafo, car wash and Garaje wastes from leaded gasoline, tire wear, lubricating oil and grease, old lead acid batteries, solder, rust inhibitors, and plastic stabilizers (WHO, 2011), into feeder streams and drainages of the Big Akaki river. Cd concentration in Big Akaki river ranged between 1.53 and 2.12 ɥg/l in the dry season and it was below the detection limit in the wet seasons. The Maximum Cd level is recorded in Bole Bulbula (2.12ɥg/l). The level was significantly higher in the dry season (ANOVA, $p<0.05$). The level was not significantly different among sampling sites (ANOVA, $p=0.5$). Ni concentrations of Big Akaki river was ranged from 0.85 to 1.75ɥg/l in the dry seasons. The level of Ni was between 0.018 and 0.549 ɥg/l in the winter seasons. All the three heavy metals (Pb, Cd and NI) in Big Akaki river have higher concentration than Kebena river. But Cu was found to be lower, detected only in three sampling sites, 0.27, 0.24 and 0.02ɥg/l at Beshale, Bole Bulbula and Big lower Akaki river, respectively. The metal concentrations in Big Akaki river samples were decreased in the order of Pb> Cd>Ni and Cu.

3.4. Pollution Profiles Along Little Akaki Rivers

Little Akaki river is a recipient of unsorted domestic and untreated industrial, municipal, commercial, clinical and other types of wastes (solid and liquid), it is being utilized by a peripheral population for irrigation purposes. Moreover a significant number of people use this river and its major tributaries for washing vegetables, clothes, livestock watering, bathing and even for drinking purposes in and around the City(Figures 46,47 and 48).

Figure 46: People using TAR for bathing

Figure 47: People using TAR water for bathing

Figure 48: People discharge toilet and domestic waste water to TAR

3.4.1 Little Akaki River Quality Parameters

The water quality assessment results of little Akaki reflects that organic matter (BOD and COD), nutrients, bacterial faecal origin and heavy metals (pb) were observed to dominate the river pollution problems (Figure 49, 50 and 51).

pH

Little Akaki river has pHvaluesnear neutral to slightly alkaline ranging from 7.1-8.1 for dry season and 7.8-8.4for wet season. All values are within the limits of the CCME guidelines for livestock watering and irrigation water;5-9.5 and 5-9, respectively, and those of the WHO standards (Table 6 and 7).

Electrical Conductivity

The electrical conductivity values ranged from 38.7-1102 for dry season and 20.56-972 µS/cm for wet season. The recommended value [GEMS, 1988] of electrical conductivity for potable water is below 2500 µS/cm. The lowest and the highest electrical conductivity values in little Akaki river water were observed at Sululta and Gofa for both seasons, respectively (Figure 49).

The higher values may have resulted from different domestic wastes and sewerage leakage;whereas, the upper and outside part of the City, rather showed lower conductivity values. However, comparing the seasonal variation along the little Akaki river, the dry season showed relatively higher concentration peaks which could be due to the absence of mixing during the dry season and the higher evaporation rate that leaves salt behind. The temporal concentration of EC in both seasons had crossed the threshold value of the World Health Organization (WHO) i.e 500 µS/cm and the upper control limit.

Total Dissolved Solids (TDS)

The TDS varied from 35 to 995 mg/l with more than 71% of the samples having TDS greater than 100 mg/l for dry season and 18.5 to 502.4 mg/l for wet season. The maximum values were obtained at Gofa and lowest at Sululta). In the present investigation, the TDS values in the little Akaki river water samples at site 44 river , Germen bridge, Gofa, Kera river and Bihere Tsige for dry season and Germen bridge for wet season were found to be above the CCME guidelines for drinking water, i.e. 500 mg/l, and the rest were below this maximum limit. The variations in TDS in TAR can probably be related to pollution through the discharge of domestic and industrial wastes into the little Akaki river.

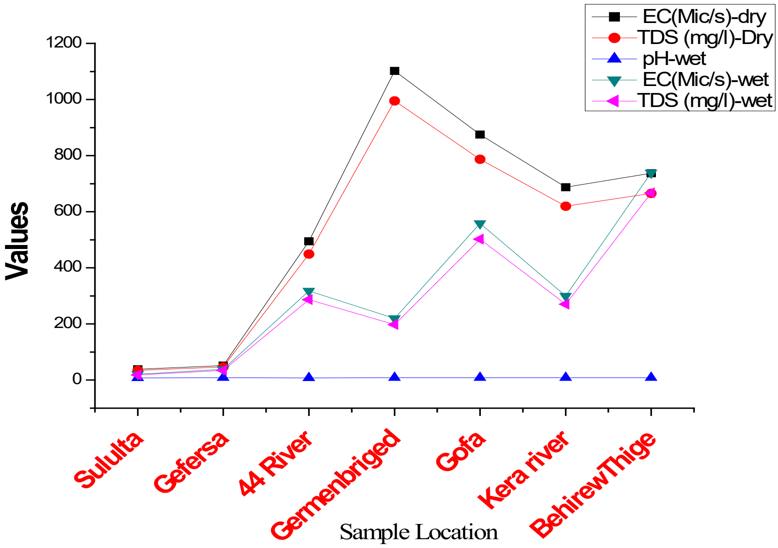


Figure 49: Dissolved oxygen (DO), Chemical and Biological Oxygen Demand (COD and BOD) of TAR

The DO concentration along little Akaki river ranged from5.01 (Germen bridge& Kera river) to 14 mg/l(Gefersa). In general, the DO concentration declined critically from up to downstream of the river, again an indication of worsening water quality. The levels of dissolved oxygen in all sites, except Sululta, Gefersa and 44 river, were found critically low and do not fulfill the CCME guideline for the protection of aquatic life i.e., 5.5-9.5 mg/l. lower DO level, < 3 mg/l, causes anaerobic conditions and bad odors of the TAR.

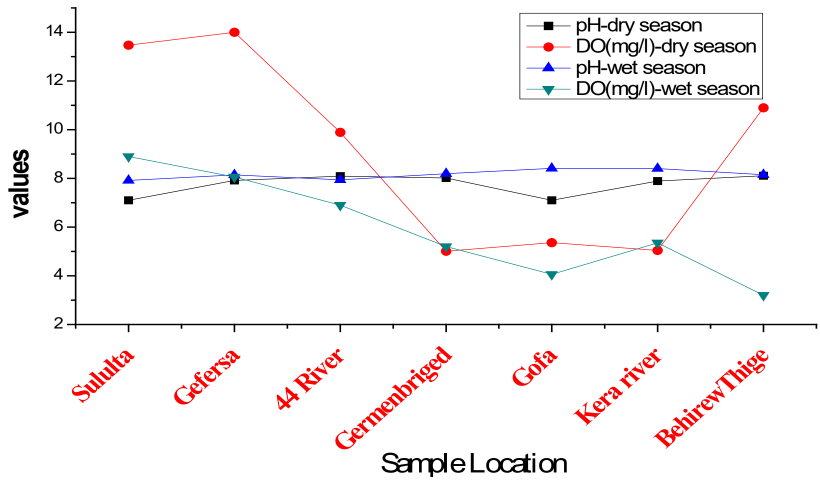


Figure 50: Wet and Dry season DO & pH Pattern along little Akaki river

The COD for the little Akaki river water ranged from 15.33 (Gefersa) to 391 mg/l(Gofa). The BOD varies from 5.23 (Gefresa) to 137 mg/l (Kera river). Around 71% of the sampling sites contained more than 15 mg/l of BOD values, exceeding the UK general water quality assessment criteria (Table 6 and 7)and categorized under Grade F i.e. bad [Reeve, 2002].The relatively high BOD at sites 44 river to Behere Tsege; indicates the problem of industrial, municipal and domestic sewage pollutions at different locations along the river. The higher BOD values along with the lower DO (Figure 51) accompanied by the continuous input of all kinds of wastes into the little Akaki river exceed the assimilative (the natural self-purification) capacity of the little Akaki river. This in turn greatly impairs the water quality of the river and harms aquatic life.

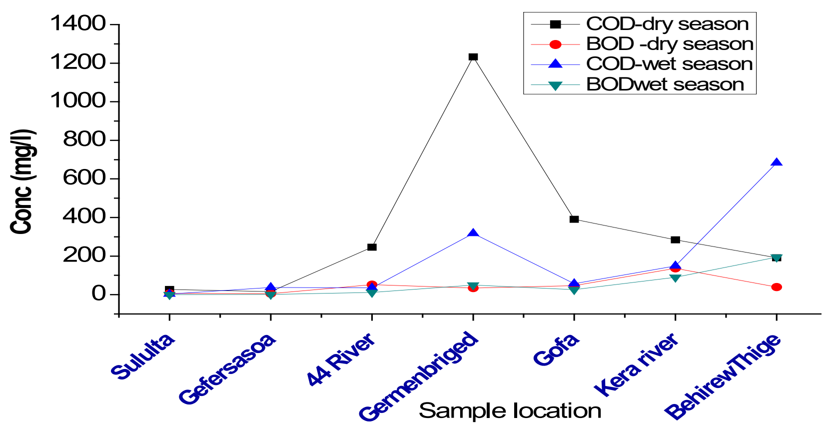


Figure 51: Wet and dry seasons BOD & COD pattern of TAR

NUTRIENTS

Total Nitrogen (TN), Ammonia and Phosphate

The concentrations of TN and ammonia in river water, as measured were found to be 1mg/l(Sululta) to 132.9mg/l (Gofa) and 0.09 (Gefersa) to 3.57 mg/l (Kera river), respectively. According to the CCME [GEMS, 1988], the maximum concentration of Ammonia Nitrogen for Protection of Aquatic Life is 1.37-2.20 mg/l. In the river water samples for this survey of the study area, Sululta, Gefersa, Germen bridge, Gofa and Behire Tsege were found to be fair to very good according to the UK water quality criteria [Reeve, 2002], while for 44 river and Kera river the ammonia levels were exceeded. The high level of ammonia might be due to the leaching of fertilizer residues used on agricultural farms into the river system. Important increases in ammonia concentrations, occasionally accompanied by lower NO3- values, suggest sub-oxic conditions (Guèguen et al., 2004) especially at sites 44 river and Kera river.

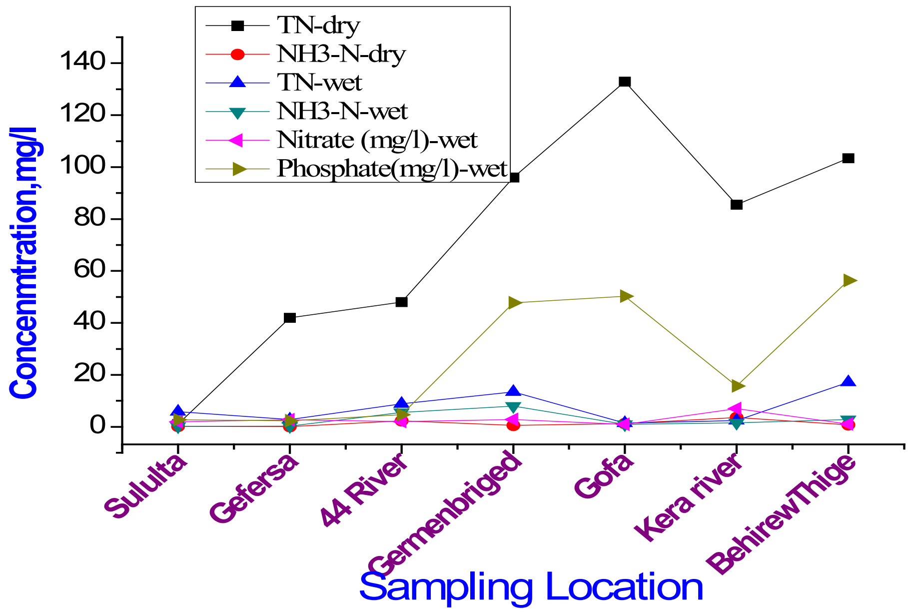


Figure 52: Wet and dry season's nutrients pattern of little Akaki river

The concentration of phosphate in both seasons (Figure 53) showed a higher variation than any of the other parameters. And both seasons displayed a concentration above the maximum permissible WHO limit. Dry season concentration of phosphate along Little Akaki river higher than the wet season. There are concentrations of industries along little Akaki river in addition direct domestic wastewater discharge that might contribute to the high level of phosphate concentrations.

Chloride and Sulphate

Chloride ion impacts a salty taste to water. In the present study, the chloride ion content in little Akaki river water samples ranged from 24.5 (Sululta) to 477.3 mg/l (Gofa). The concentration of chloride in the TAR water samples was found within the limits of the CCME for use as irrigation water (Table 6 and 7) and the limits for domestic purpose fixed by EPA (EPA, 1989), i.e., 250 mg/l. The possible sources of chloride at Gofa could be municipal and domestic sewages. The sulfate ion in the river waters may have several sources, that is, dissolution of evaporates such as gypsum, oxidation of sulfides, and atmospheric input. The sulfate ion concentration in littla Akaki river ranged from 3.9 (Sululta) to 91.33 mg/l(Germen Bridge) and all water samples were within the limit given by CCME for livestock use i.e., 1000 mg/l(Table 6 and 7).

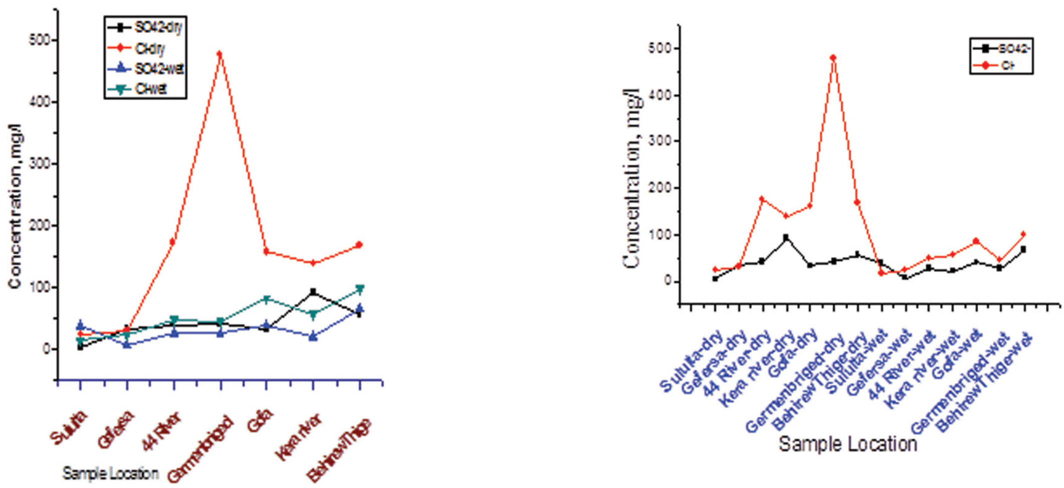


Figure 53: Wet and dry season's sulphate and chloride pattern of little Akaki river

Correlation Analysis of Little Akaki River

The correlation coefficient analysis for the Little Akakiriver showedhigher correlation for pH and BOD than pH and COD at r = 0.299 and 0.130 respectively. DO negatively corrulated with BOD and COD.

Table 11: Pearson Correlation of mean conc. of physicochemical parameters in little Akaki river

	pH -d	pH -w	DO -d	BOD -d	COD -d	DO -w	COD -w	BOD -w
pH -d	1							
pH -w	-0.07116	1						
DO -d	-0.00777	-0.72842	1					
BOD -d	0.229508	0.614293	-0.64393	1				
COD -d	0.306515	0.267729	-0.70017	0.183233	1			
DO -w	-0.23082	-0.63934	0.645613	-0.41295	-0.36206	1		
COD -w	0.507575	0.135974	-0.10774	0.06519	0.274751	-0.71573	1	
BOD -w	0.449802	0.296684	-0.16835	0.34769	0.097069	-0.75736	0.930602	1

The correlation between COD andBOD is due to the fact that they are closely related to organic contamination. According to Goel *et al* (2008) BOD can be estimated from COD if a significant correlation can be established on a specific case.

Table 12: Pearson Correlation of mean concentration of physiochemical parameters in little Akaki river

	TN-d	TN-w	NH3-N-d	NH3-N-w	NO3 (mg/l)-w	PO43--w	EC(Mic/s)-w	EC(Mic/s)-d	SO4-d	SO4-w	TDS-d	TDS-W
TN-d	1											
TN-w	0.14476	1										
NH3-N-d	0.2375	-0.2651	1									
NH3-N-w	0.2386	0.6405	0.0956	1								
NO3 (mg/l)-w	-0.0514	-0.3534	0.6917	-0.0397	1							
PO43--w	0.8619	0.5006	-0.1388	0.3267	-0.33988	1						
EC(Mic/s)-w	0.7929	0.5082	0.0933	0.2275	-0.4113	0.8463	1					
EC(Mic/s)-d	0.8233	0.0667	0.6948	0.2562	0.3883	0.6010	0.6195	1				
SO4-d	0.6310	0.6064	-0.0611	0.8218	-0.082	0.6931	0.4767	0.4397	1			
SO4-w	0.2199	0.5425	0.1618	-0.06483	-0.07702	0.43299	0.6161	0.3872	-0.0244	1		
TDS-d	0.8217	0.0678	0.6969	0.257365	0.3898	0.5991	0.6191	0.9999	0.4393	0.3881	1	
TDS-W	0.79164	0.5103	0.0931	0.2278	-0.4110	0.8456	0.9999	0.6187	0.4766	0.6177	0.6182	1

3.4.2 Heavy Metal Concentrations Along Little Akaki River

Metal contamination in the little Akaki river has been assessed for Ni, Pb,Cr, Cd, Co and Cu. With the exception of Ni, Cu,Pb and Cd, all the other heavy metals analyzed were below detection limit (BDL) in all the samples collected.

Lead (Pb) is the most significant toxin of the heavy metals. The main sources of lead contamination of the aquatic environment are the industrial discharges from smelters, paints and ceramics, through vehicular emissions, runoff from contaminated land areas, atmospheric fallout and sewage effluents. In some cases, lead is used to stabilize land pipes/plastic pipes and results in lead contamination of river water (WHO, 1995). The concentration of lead was varied from 0.13 to 5.08 µg/l in the dry seasons and 0.01 to 2.59цg/l in winter season. The level of lead was not significantly different between the dry and winter seasons (ANOVA, p=0.54). Similarly, the concentration was not significantly different with variation of sampling sites (ANOVA, p=0.22). This could be due to poor environmental control, increasing industrialization and population of the City. However, the obtained values (except for Sampling Sites) were less than the international guideline values for irrigation water of 5mg/l (FAO, 1994).

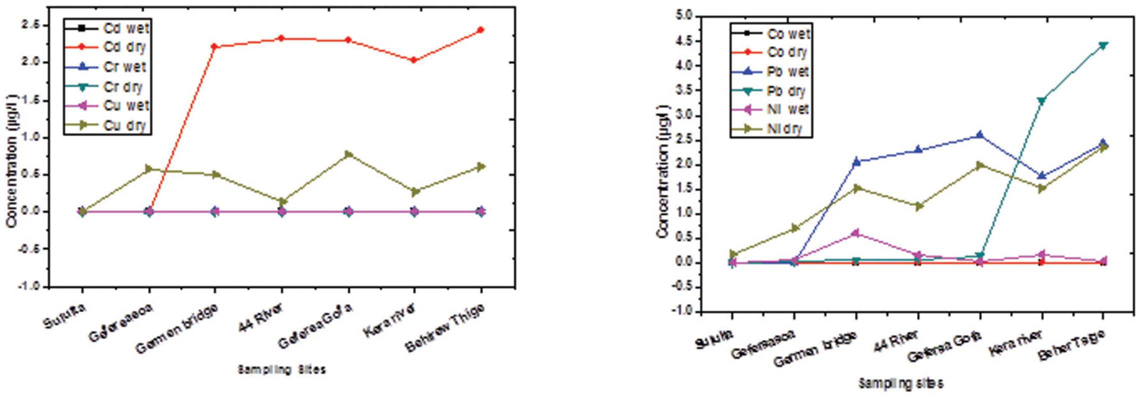


Figure 54: Pb, Cu, Ni and Cd concentration at different locations along the little Akaki river river

Copper (Cu) is an essential nutrient and is present in water in ionic form or in complex organ mineral. At low concentrations Cu ions cause headache, nausea, vomiting and diarrhea and at high concentrations it causes coronary heart diseases, chronic anemia, and gastrointestinal disorder and also leads to liver, high blood pressures and kidney malfunctioning (USEPA, 1999). The concentration of Cu in the analyzed water samples ranged from 0.00-0.77µg/l in dry seasons. The level in the winter seasons was below the detection limits.

The concentration of Ni in the collected water samples was between 0.17 and 2.35µg/l in dry seasons. It was 0.024 and 0.608µg/lin the winter seasons. The analysis of variance showed that the concentration Nickel was significantly varied with variation of sampling season (ANOVA, $p<0.05$). However, it was not significantly varied with variation of sampling sites (ANOVA, $p=0.5$). Nickel (Ni) contamination can arise from various industrial activities, domestic wastes, municipal sewage, multicolored paints, electroplating, coal and oil combustion, household appliances, pigments and batteries.

Effluents from industries such as battery production, dye and manufacture of pigments and alloys making are the major sources of elevated cadmium (Cd) in the water bodies (Rao and Yoshida, 2004). In this study, Cd concentration varied between 0.55 and 2.44µg/l, which is much less than the recommended upper limit for Cd in drinking water of 0.003 mg l-1 set by the WHO. Furthermore, the values for Cd did also exceed the international guideline for irrigation water of 0.001 mg l-1 (FAO, 1994). Cd is a poisonous metal and can cause serious health problems even if ingested in small amounts. It has the tendency to accumulate in body tissues causing lung problems, kidney lesions, neurological disorders and skeletal damage (Abdul et al., 2012; Makino, 2012; Jarup, 2003).

3.5. Microbial Pollution Load Along BKK-Kebena, and Akaki Rivers

The examination of microbiological river water quality is obligatory for use-related aspects such as for drinking water production, irrigation or recreation. The result of microbiological water quality data for *total coli forms, faecal coliforms and Escherichia coli* showed differences regarding spatial and seasonal variance. Microbiological water quality of little and big Akaki rivers and BKK - Kebena rivers for both dry and wet seasons has been assessed by the concentrations of standard microbiological parameters, classified by 5 quality classes as indicated in Table 13 below.

Table 13: Class limit value for bacteriological determinant (Kavka&Poetsch, 2002)

Microbiological Water Quality Assessment		**Class 1 (low)**	**II(moderate)**	**III(critical)**	**IV(strong)**	**V(excessive)**
Determined	Pollution by organic matter					
Colony count		< 500	>500-10,000	> 10,000-100,000	>100,000-750,000	>750,000
determined	Fecal pollution	low	moderate	critical	strong	excessive
Total coli forms	In 100ml water	< 500	>500-10,000	>104-105	>105-106	>106
Fecal coli forms	In 100ml water	<100	>100-1000	>103-104	>104-105	>105
Fecal streptococci	In 100ml water	<50	>50-100	>102-103	>103-104	>104

3.5.1 Microbial Water quality of BKK and Kebena Rivers

Bacteriological examination results in both wet and dry seasons showed that upper river source has low level of TC,FC and E-coli. This may be due to low access to human population and other pollutant source whereas down ward from the source, the level of fecal contamination increased with maximum at Afinchober site in dry season where as at Kokebetsiba sampling site the concentration was in excessive microbial load during wet season as shown in Figure 56.

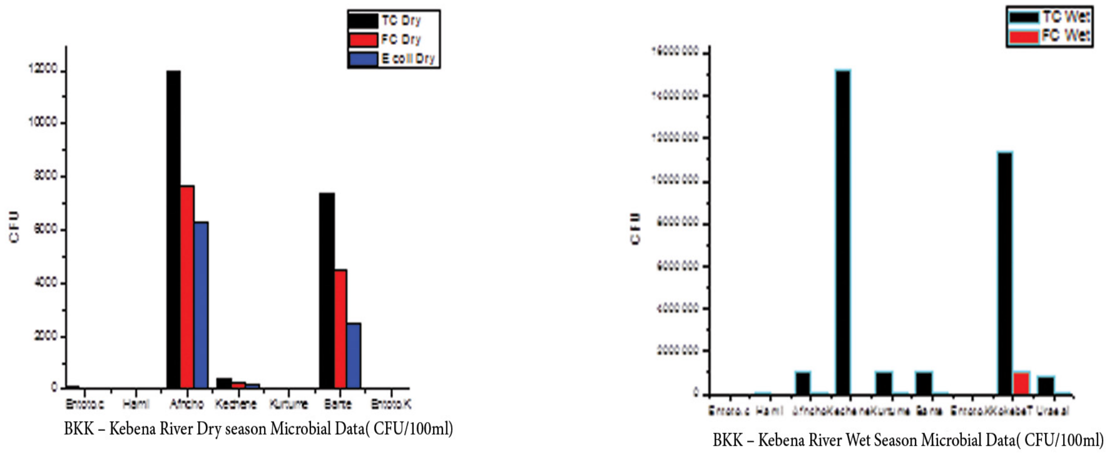


Figure 55: Microbiological water quality of BKK and Kebena river in dry and wet seasons

The middle and lower parts of BKK and Kebena rivers were loaded heavily with coli forms, which may be due to the direct discharge of untreated sewage water and illegal channeling of toilets to the river including open defecation along the sides of the river bank. The variation of total coliform and fecal coliform is shown in microbiological water quality map below (Figure 57). In terms of FC, the middle part of Kebena river is more polluted than BKK river. This may be due to discharge of sewerage in to the river, particularly at Shenkla-sefer.

E. coli and faecal coliform are the best indicators for the assessment of recent *faecal* pollution, mainly caused by raw and treated sewage and diffuse impacts e. g. from farm land and pasture. *E. coli and faecal coliform* indicate also the potential presence of pathogenic bacteria, viruses and parasites (Kavkaand Poetsch, 2002). Detailed knowledge of faecal pollution in aquatic environments is crucial for watershed management activities in order to maintain safe waters for recreational and economic purposes (Farnleitner et al., 2001).

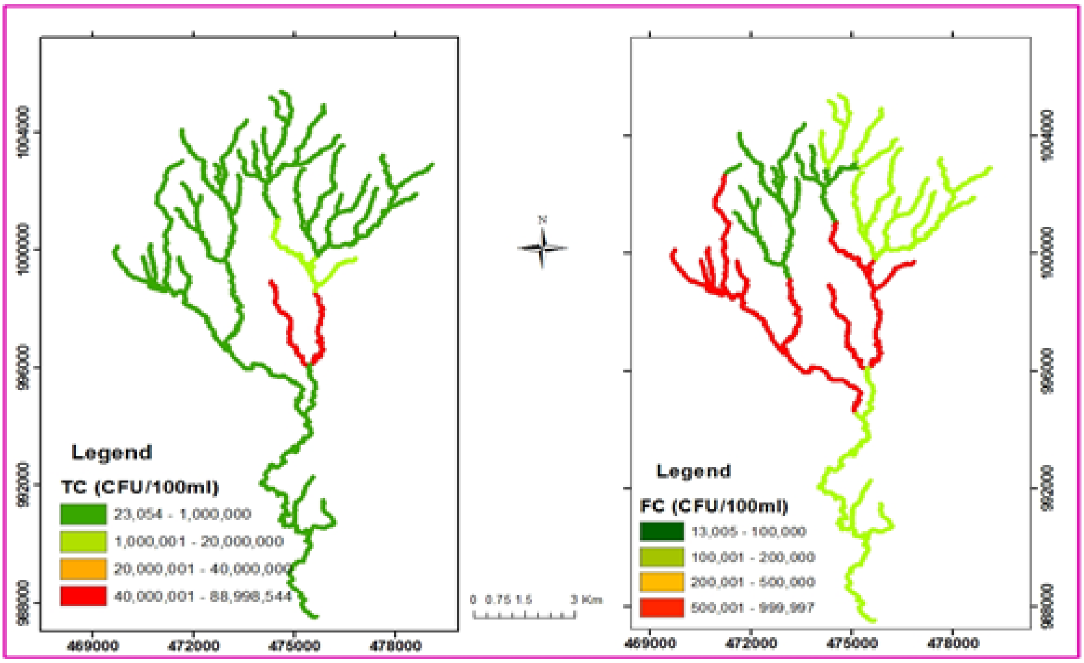


Figure 56: Wet season variation of total coliform and fecal coliform along BKK + Kebena river

The microbiological test results showed the bulky existence of indicator organisms in water samples. The variations in the number of colony forming units per 100 ml among the water sources were however wide depending on the level of exposure and access to the community. Generally, the average total coli form and fecal coli form density was relatively high in unprotected water sources compared to the source in both seasons. Data in wet season showed comparably high load of microbial loading than in dry season.

The presence of *E. coli* in water suggests enteric pathogens and faecal pollution and has been reported to be the causative agent of diarrhoea, urinary tract infection, hemorrhagic colitis, and haemolyticuraemia syndrome in other studies. These results provide insight into the potential health risks found in water in the community. As indicated in Figure 56 above, in both dry and wet season, microbial data of little and big Akaki rivers showed the excessive concentration of TC whereas, *FC* and *E-coli* were critically in high concentrations.

3.5.2 Microbiological Water Quality of Little and Big Akaki River

At source of little and big Akaki river (Sululta sampling site), the CFU count were undetectable for *FC and E.coli* which could be attributed to low level of source contamination. In contrast to that, at the site of Bole Bulubula in dry season and at the site of big Kebena in wet season excessive amount of FC were detected (Figure 58);which could indicate the level of faecal origin pollution at this site and downstream to the river.

Faecal indicator bacteria like total and faecal coliform (thermo-tolerant coliform),*E. coli and intestinal enterococci (faecal streptococci)* are excreted by humans and warm blooded animals, pass sewage treatment plants to a great amount and survive for a certain time in the aquatic environment (Kavkaand Poetsch, 2002).The bacteriological examination for the river water clearly reveals that there is a high bacterial pollution. This may lead to water-born diseases if the water is used for the human consumption. In fact it could be concluded that people living at the banks of the river are more prone to infectious diseases.

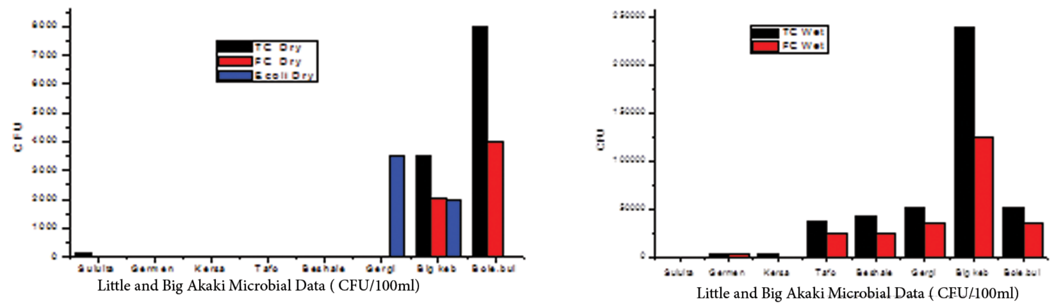


Figure 57:Microbial load along Litter and big Akaki rivers

3.5.3 Impacts of Akaki River Pollution

The lack of clean water supply and inadequate sanitation facilities are the main reasons for diarrheal diseases in many developing countries. According to the World Health Organization's (WHO) 2008 report, every year 2.2 million people die from diarrheal diseases, about 45.5% of these live in sub-Sahara Africa. In Ethiopia diarrheal diseases are among the most important burden of diseases due to the majority of the people lacking clean water. Many of the rural and semi-urban populations obtain their water from raw water sources which are contaminated with pathogens from wastewater. As reported by the United Nations Education, Scientific, and Cultural Organization (UNESCO, 2004), almost 68%of the population in Ethiopia lacks reasonable access to clean water and adequate sanitation facilities, which is both a rural and urban problem. In major cities such Addis Ababa and its environs, the current clean water supply system meets only 53% of the demand for clean water (AASWA, 2008). Although the supply is projected to increase, it is unlikely to meet the demand due to high population growth and the influx of people from rural areas to the capital.

The high levels of pollution in the Akaki river water of Addis Ababa have impacts on human and animal health, as well as on the urban ecosystem. Akaki river water can be a source of pathogens transmission which can be sources of intestinal infections, and common water-borne diseases in Addis Ababa that include typhoid, dysentery and cholera. According to EPA (2005) all of the people using the Akaki river water are affected by these pathogens. According to the information obtained from Addis Ababa Health Bureau, Acute watery diarrhea (AWD) that occurred in 2016, which was caused by *Vibro colera 01* type strain, was detected in Little Akaki river across Addis Ketema and Kolfe Keranio Sub cities in all 11 sampling points taken (Figure 59).The same type of *Vibro Colera 01* type strain also found in clinical data in the study area, vegetables washed by the polluted river, and meat of cattle's that drank polluted Akaki river. These sites are along little Akaki river where high concentrations of all physiochemical pollutants, heavy metals and faecal coliform were also obtained in the present study. Therefore the polluted Akaki river can continue to be potential sources of the AWD outbreak and other waterborne infectious diseases unless proper wastewater treatment and sanitation facilities are implemented with routine water quality monitoring and surveillance. The City Health Bureau together with other stakeholders put the necessary excreted efforts to manage and put under control the 2016 AWD outbreak with the cost of more than 100 million Ethiopian Birr.

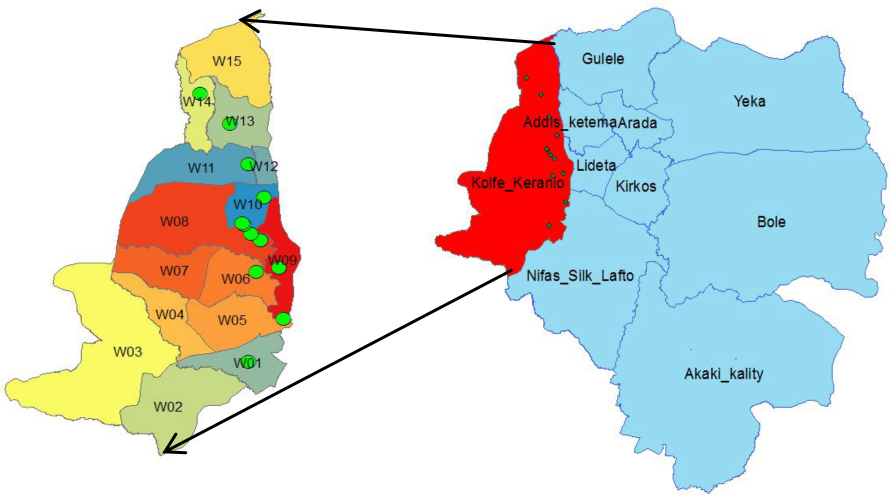


Figure 58: Acute watery diarrhea (AWD)assessment sites

In addition to microbial pathogen pollution, the people are also exposed to heavy metal toxicity found in the vegetables that are grown using the polluted Akaki river. Although most levels of metals have been found to be tolerable, it is feared that metals will build up in vegetables. Fears of vegetable food from wastewater are worsened by the fact that 60% of the city's vegetable consumption is supplied by urban farmers, who irrigate their crops using polluted river water((Fissha Itanna, 2002;Weldesilassie, 2008).

One of the environmental effects of the pollution of the water sources of Addis Ababa is eutrophication caused by excessive use of phosphorous and nitrogen in agriculture, and effluents from sewerage and pit latrines and municipal wastes. Eutrophication causes growth of algae and weeds which deplete the oxygen level of the water bodies and in turn affect aquatic fauna and flora. According to the Addis Ababa Environmental Protection Authority (AAEPA, 2002), the pollution of the Akaki river is blamed for the emergence of water hyacinth weed in the Aba Samuel Lake. By the year 2000, the weed had covered almost 50 per cent of the lake.

3.6. Sediment Heavy Metal Concentrations Along BKK-Kebena and Akaki Rivers

3.6.1 BKK River Sediment Heavy Metal Concentration

Heavy metals are of particular concern due to their environmental persistence, biogeochemical recycling and ecological risks. Pollution of the natural environment by heavy metals is worldwide problems as these metals have toxic effects on living organisms when they exceed a certain concentration limit (MacFarlane and Burchett, 2000).

Exposure to heavy metals has linked to several human diseases such as development retardation or malformation, kidney damage, cancer, abortion, effect on intelligence and behavior, and even death in some cases of exposure to very high concentrations. Sediments sample was collected from different sampling site from upper, middle and lower stream of BKK, Kebena, little and big Akaki rivers and sediment heavy metal concentration were analyzed.

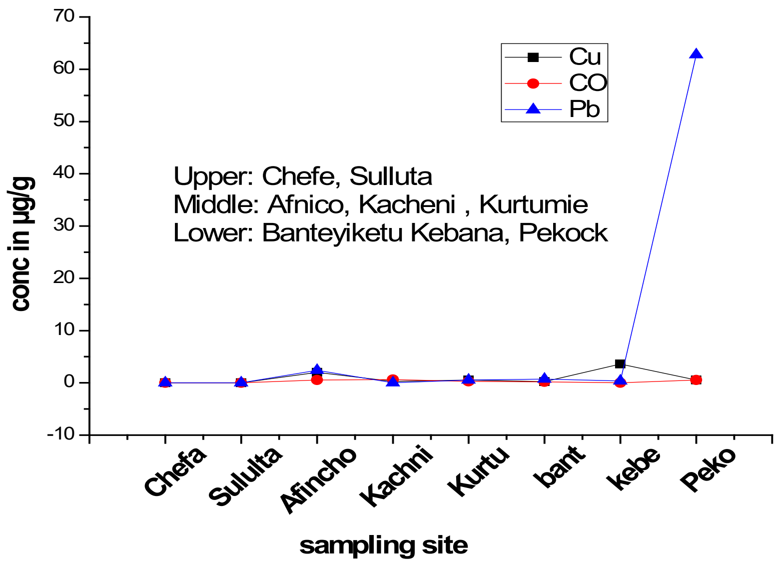


Figure 59: BKK River Sediment Heavy Metal Concentration

The result of BKK river as shown in the Figure 60 indicates the incremental level of heavy metal concentration as the river flows down wards from the source from the middle stream of the river. Afnchober site exhibited comparable high concentration of Pb and Co. Sediment heavy metal contamination level for Cd and Cr were under detection limit of flame AAS (< 0.005 µg/g) whereas the other metal contents were ranging over following intervals: Pb: ND -62.8 µg/g; Co: ND-0.6306 µg/g; Cu ND -3.6 µg/g dry weights

At Pekock sampling site exceptional high concentration of sediment lead were observed; comparing with US EPA maximum contamination level of heavy metals, it falls within heavily polluted sediment category. Major part of heavy metal is expected to accumulate on the surface of soil and in the upper layers of bottom sediments of water basins. The main cause for that could be untreated industrial discharges and garages' wastewater discharge into the river. The heavy metal amounts in soil, river and lake bottom sediments depend on what human settlements and industrial objects are in the neighborhood (Liu et al., 2009; Martin-Puertas et al., 2009; Jernstrom et al., 2010).

Table 14: US EPA maximum contamination levels for heavy metals

	Cd	Cr	Cu	Pb	Hg
Drinking water, in µg/L1	5	100	1,000	15	2
Water supporting aquatic life, in µg/L2	12	100	20	100	0.05
Natural sediment, non-polluted, in µg/L3	-	<25	<25	<40	<1
Natural sediment, Moderately polluted, in µg/L3	-	25-75	25-50	40-60	-
Natural sediment, heavily polluted, in µg/L3	>6	>75	>50	>60	>1

1. US EPA, 1992
2. US EPA, 1992
3. Great Lake Water Quality Board, 1982

Sediments represent one of the ultimate sinks for heavy metals discharged into environment (Bettinetti et al. 2003; Hollert et al. 2003). Therefore high amount of heavy metal concentration on river sediment is expected in addition to that, the strong "hydrophobic" characteristic of Pb make it adsorbs onto sediment particles more readily than remaining in solution.

Correlation between heavy metals (Cu, Co, and Pb) at BKK River as indicated in Table 15 below showed that Cu with both Co and Pb were negatively correlated where as Pb and Co has positive correlation which could indicate both Pb and Co may have the same source.

Table 15: BKK river heavy metal correlation

	Cu	Co	Pb
Cu	1		
Co	-0.09312	1	
Pb	-0.10355	0.440041	1

The metal concentrations of Kebena river results as indicated in Figure 60 below revealed that sediment metal contamination level for Cd and Cr were under detection limit of flame AAS (<0.005 µg/g whereas the other metal contents were ranging over following intervals: Pb: ND -356.6 µg/g; Co: ND-2.397µg/g; Cu ND -4.426 µg/g dry weights

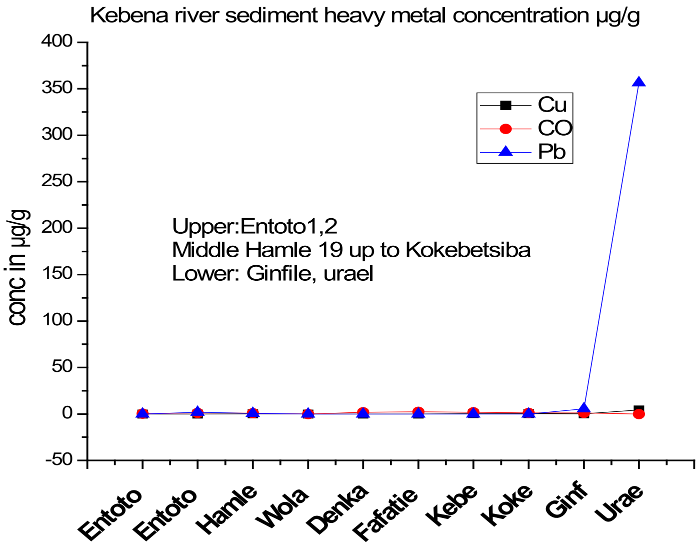


Figure 60: Kebena River sediment heavy metal concentrations

Unlike other metals in the sample sites, the Pb concentrations in sediments showed excessive rise at Urael sampling station with concentration of 356.6µg/g. The spatial distributions of Cu, Co and Pb concentrations in sediment were regular below detection at the source and highest at downstream.

Lead sediment concentration at Kebena river were much greater than the US EPA maximum contamination level of heavily polluted sediment whereas the other metals fall below the range of moderate level of contamination. The lead contamination level were comparable higher than BKK, little and big Akaki rivers.

Correlation between heavy metals (Cu, Co, and Pb) at Kebena river as indicated in Table 16 below showed that Co has negative correlation with both Cu and Pb where as Pb and Cu has positive correlation which could indicate both Pb and Cu may be released to Kebena River from exact source.

Table 16: Kebena river heavy metal correlation data

	Cu	Co	Pb
Cu	1		
Co	-0.4322	1	
Pb	0.992735	-0.44943	1

The metal concentrations of Big Akaki river results as indicated in Figure 61 below revealed that sediment metal contamination level for Cd and Cr were under detection limit of flame AAS (<0.005 μg/g) except the Cd at sampling station of Gerji river where as the other metal contents were ranging over following intervals: Pb: ND -305.4±0.299μg/g; Co: ND-1.991±0.1294 μg/g; Cu ND - 0.6054±0.0223 μg/g dry weights.

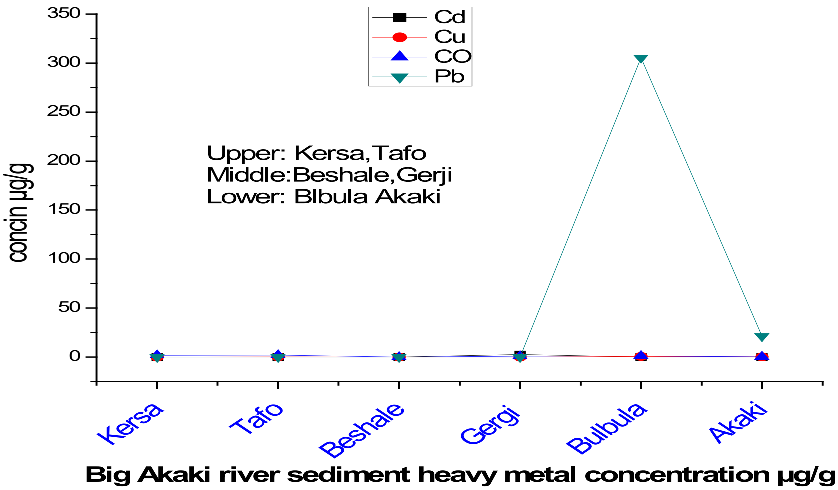


Figure 61: Big Akaki river sediment heavy metal concentrations

Excessive Pb concentration were observed at Bulbula river sampling site with the concentration of 305.4±0.299μg/g at downstream of the river this concentration is much greater than the US EPA maximum contamination level of heavily polluted sediment. Correlation between heavy metals (Cd Cu, Co, Pb) at Big Akaki river as indicated in Table 17 shows that all variables Cd, Cu, Co, Pb show positive correlation with each other and may be from the same source.

Table 17: Big Akaki heavy metal correlation data

	Cd	Cu	Co	Pb
Cd	1			
Cu	-0.16856	1		
Co	-0.05759	0.013596	1	
Pb	-0.21649	0.969519	-0.02328	1

At Little Akaki river sampling stations, the metal concentrations along little Akaki river results as indicated in Figure 62 below revealed that sediment metal contamination level for Cd and Cr were under detection limit of flame AAS (< 0.005 μg/g) except the Cr at sampling station of Germen bridge river where as the other metal contents were ranging over following intervals: Pb: ND -98±1.808 μg/g; Co: ND- 0.54±0.144 μg/g; Cu ND - 1.158±0.005 μg/g dry weights.

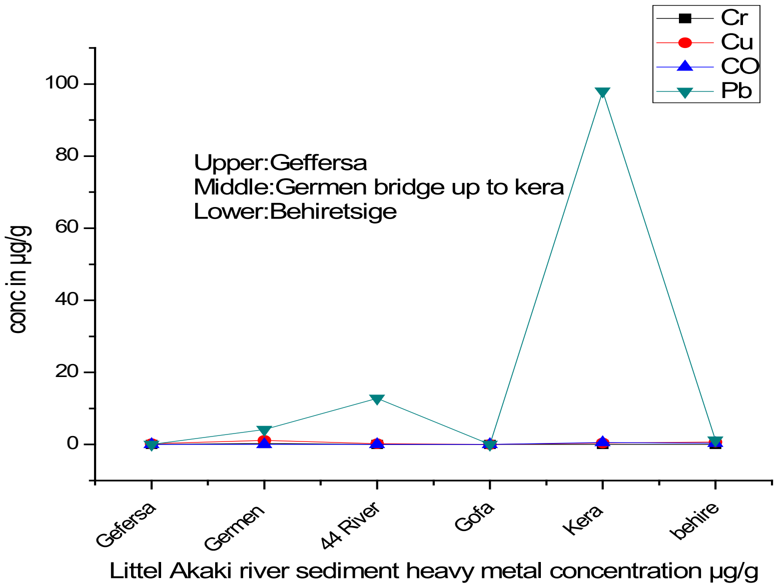


Figure 62: Little Akaki river sediment heavy metal concentration

Unlike the other rivers the concentrations of Cu at the middle river stream were below detection limit and at Gofa sampling station all metals were below detection limits except Cu. Correlation between heavy metals (Cr Cu, Co, and Pb) at little Akaki river as indicated in Table 18 below showed that Cr is positively correlated with Cu. Whereas Co and Pb has negative correlation with Cr. Cu is positively correlated with Co and negatively correlated with Pb. Pb has negative correlation with Cr and Cu and positive correlation with Co.

Table 18: Little Akaki heavy metal correlation

	Cr	Cu	Co	Pb
Cr	1			
Cu	0.856243	1		
Co	-0.30644	0.098239	1	
Pb	-0.19208	-0.05597	0.779441	1

Soil sample were taken at highly irrigated areas at Gofa and Peacock as indicated in Figure 63 below. At the sampling of Gofa the total contents of heavy metals were clearly higher in soils than associated sediments. This maybe due to runoff water washing out the top sediments which resulted in a higher concentration in soils than in sediments. Pb were at high concentration at Peacock sampling station.

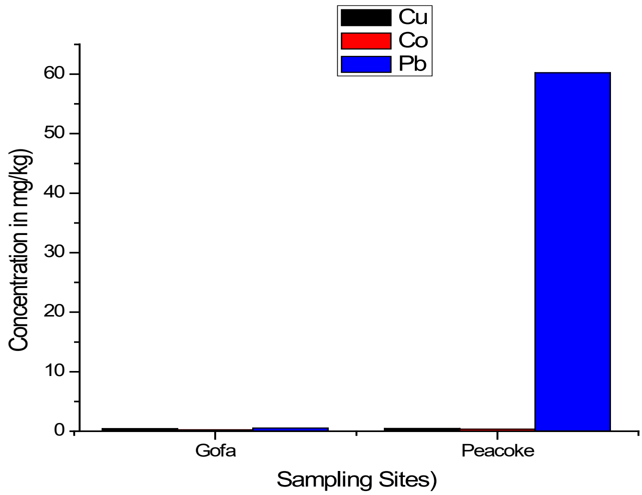


Figure 63: Soil sample heavy metal concentration at irrigation site

In general, all the four major rivers showed high accumulation of heavy metals analyzed in this study (Cr Cd, Cu, Co and Pb). The extent of Pb concentration in BKK+ Kebena, little and big Akaki rivers was much more serious and show high level of accumulation in river sediment. Below detectable amount of metals at the source could be a good indicator of the anthropogenic source of heavy metal pollution of the river downstream.

3.7. Pesticides Contamination in BKK, Kebena and Akaki Rivers

Pesticide analysis was performed using Agilent Technologies, 7820A gas chromatography (GC) equipped with Agilent Technologies, 5977E inert mass spectrometry (MS) detector. GC separations were carried out on a Hp-5ms ultra inert capillary column (25 m x250 µm 0.25 µm). Helium gas was used as carrier gas at a flow rate of 1 mL min-1 and data were interpreted using mass hunter Chem-Station. The oven temperature program employed for separation were as follows: 130 °C for 0 min; increased at 25 °C min-1 to 185 °C held for 1 min; then increased at 9 °C min-1 to 200 °C for 1 min and 10 °C min-1 to 290 °C held for 1 min. The GC oven temperature and the injection port temperature were maintained at 290 °C and 250 °C, respectively.

The qualitative analysis was done by the use of Pest.l and NIST11.L library with minimum quality of 90 and 0 respectively. Accordingly, there were no pesticides detected in any of the sample under consideration (water, soil and sediment samples) (Figure 64 and 65). The peak observed in the chromatogram at the right side indicates the presence of other organic pollutants other than analyte of interest.

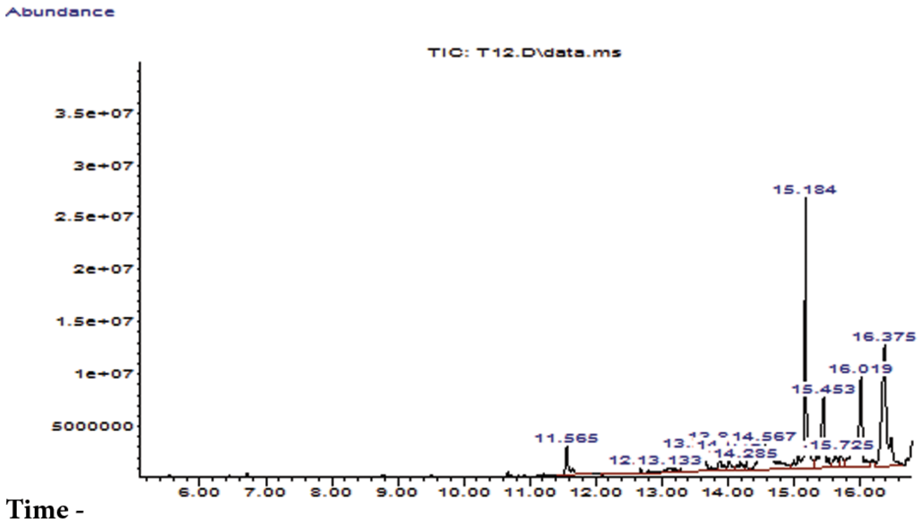


Figure 64: Chromatogram of real water sample (without addition of any pesticide standard)

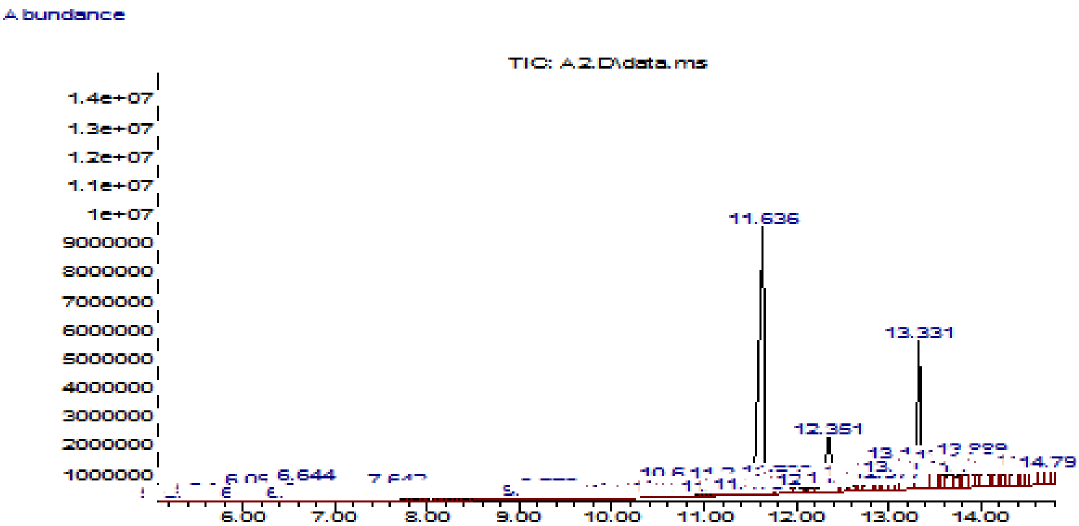


Figure 65: Chromatogram of real sediment sample (without addition of any pesticide standard)

The method was validated by spiking representative pesticide (atrazine, diazinon, chlorothalonil, ametryn, malathion, chlorpyrifos and dimethametryn) to real samples shown in Figure 65. The percent relative recoveries, which were calculated as the ratio of peak area of spiked real sample extract to peak area of spiked reagent water extract at the same spiking level multiplied by hundred were done by spiking the real sample and de-ionized water at 10 μg L-1. The relative recovery of Gofa waste water as an example, were in the acceptable range; atrazine (101.80), diazinon (107.24), chlorothalonil (100.78), ametryn (102.36), malathion (111.83), chlorpyrifos (100.77) and dimethametryn (99.28).

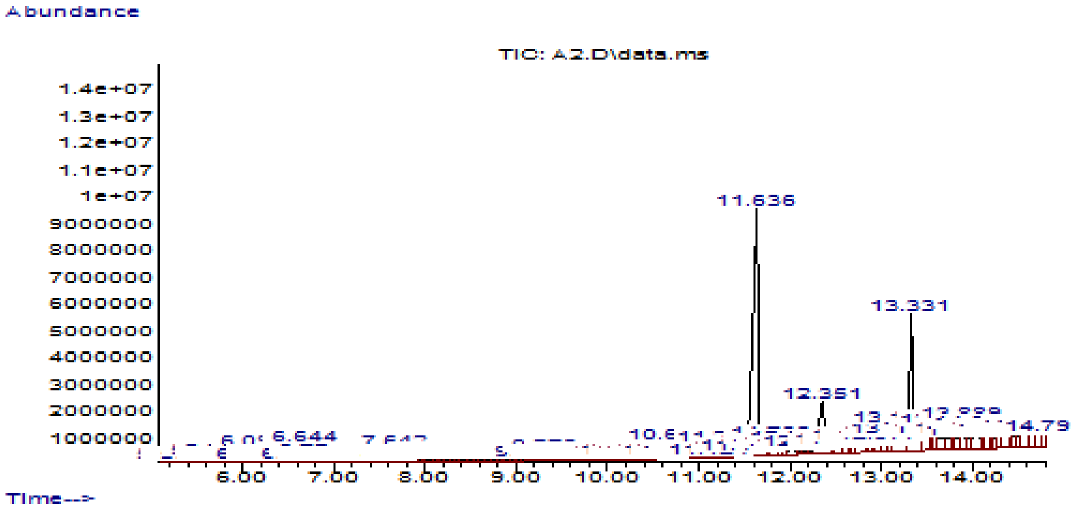


Figure 66: Chromatogram of real sediment sample (without addition of any pesticide standard)

The method was validated by spiking representative pesticide (atrazine, diazinon, chlorothalonil, ametryn, malathion, chlorpyrifos and dimethametryn) to real samples shown in Figure 66. The percent relative recoveries, which were calculated as the ratio of peak area of spiked real sample extract to peak area of spiked reagent water extract at the same spiking level multiplied by hundred were done by spiking the real sample and de-ionized water at 10 µg L-1. The relative recovery of Gofawaste water as an example, were in the acceptable range; atrazine (101.80), diazinon (107.24), chlorothalonil (100.78), ametryn (102.36), malathion (111.83), chlorpyrifos (100.77) and dimethametryn (99.28).

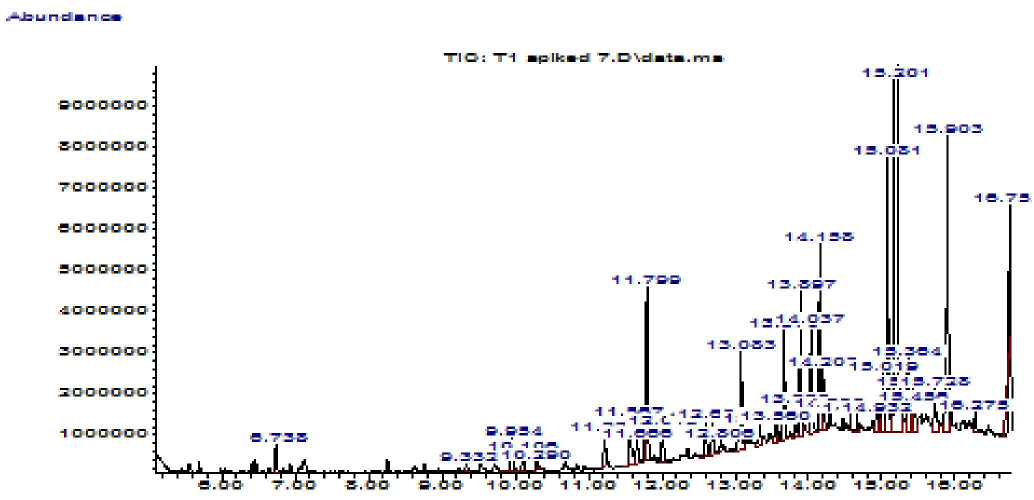


Figure 67: Chromatogram of spiked real water sample (with addition of pesticide standard at 10 µg L-1).

Peaks: 9.332, Atrazine; 9.954, diazinon; 10.290, chlorothalonil; 11.222, ametryn; 11.7999, malathion; 12.015, chlorpyrifos; 12.539, dimethametryn

3.8. Vegetables Heavy Metal Concentration in BKK, Kebena, and Akaki Rivers

Water from the rivers (BKK+K, little and BigAkaki) is being used for various purposes such as: irrigation, sand mining, industrial consumption, washing of materials, and bathing, cattle consumption and waste disposal. Irrigation is advisable water use practice in the City. All of the irrigation sites are using Akaki river water through surface irrigation, with or without the use of a pump. Irrigated vegetable production accounts for about 60% of the total market supply for the City.

During the project work there was unexpected rain during the dry season, as a result the farmers were not using river water for irrigation. Hence, circumstances forced to use secondary data, from published journals, for vegetable analysis. According to Fissha Itanna(1998)and (2002) report, vegetables grown using polluted Akaki river showed high level of heavy metal contamination. For example, Lettuce and Swiss chard leafs at the Goffa site and as well Carrot and Red beet samples at the City outskirt site (Kality) collected for heavy metals analyses showed that high concentration of Cadmium, Chromium, Copper, Mercury, Nickel and Zinc found in the tested vegetables (Table 19). This give evidence of industrial pollution traced back in agricultural crops.

Another study conducted by Fissha Itana (2002) showed that vegetables grown around Kera and Peacock,such as Lettuce had generally the highest concentrations of Cd,Co, Cr, Fe, and Mn; while Swiss chard contained the highest concentrations of As, Cu, Ni, Pb and Zn. The study also showed that in few cases, As, Cr, Fe and Pb in these vegetables have surpassed maximum permitted concentrations (Table 19).Metal transfer factors from soil to vegetables were significant for Zn, Mn, Cu, Fe and Cd and accumulation of Cr and Ni was comparatively less while that of Zn, Fe, Cu and Mn is more in vegetable plants (Prabu, 2009).

Long term exposure to low levels of heavy metal pollutants can lead to chronic health effects and enhance the risk of adverse pregnancy outcomes. Even though all of these metals have not yet reached the phytotoxic levels, some of the vegetables have surpassed the naturally expected levels. This is particularly true for Cd, Cr, Cu, Hg, Ni and Zn in potato and Cr in onion and red beet. For a long time, it has been known that intake of food that contains high levels of heavy metals, poses risks to human health (Pendias&Pendias, 1984).

Table 19: Trace metal content in vegetable leafs in Addis Ababa (Fissha Itanna, 1998).

Vegetables	Metal Content (mg/kg)						
	As	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Zn**
Cabbage	0.105	0.03	1.80	3.28	0.218	0.64	29.7
Onion	0.105	0.018	2.81	5.24	0.201	0.44	15.4
Potato	0.113	0.076	2.26	8.72	0.355	1.75	47.4
Red Beet	0.170	0.057	2.87	8.92	0.142	1.47	27.3
Swiss Chard	0.038	0.044	1.25	8.96	0.218	0.79	38.1
WHO Standard	0.50	0.10	5.0	-	0.05	-	15

Table 20: Metal Concentration in Leafy Vegetable from Kera and Peacock Farm (Source: Fissha, 2002)

Elements Mg/kg	Cabbage		Lettuce		Swiss Chard		Recom. Max. L. for Vegetable
	Kera	Peacock	Kera	Peacock	Kera	Peacock	
As	0.13	0.11	1.04	0.31	1.21	0.34	0.43
Cd	0.02	0.01	0.13	0.08	0.8	0.04	0.2
Cr	0.89	1.61	9.43	1.21	2.05	1.04	2.3
Pb	0.21	0.29	1.59	0.39	1.79	0.61	0.3

According to Fissha(2002) Cabbage is the least Accumulator of metals so it may be less risk to cabbage from Kera and Peacock park farms, than eating lettuce and Swiss chard from health standpoint. The element Cd, Cr and Pb are more concentrated in Lettuce and Swiss chard vegetables from Kera than Peacock farms (Table 20. This revealed that little Akaki river is more polluted by industrial activities than big Akaki river. One can expect the heavy metal pollution and its bio-accumulation in leafy vegetables grown along these rivers as a result of increasing number of industries with continued discharge of untreated waste waters directly into City rivers.

3.9. Overall Picture of Addis Ababa City Rivers Pollution

Anthropogenic contamination of the environment is a growing concern. In particular, the increasing number of contaminated water bodies world-wide, including the BKK and Kebena, little and big Akaki rivers and its tributaries in Ethiopia, both degrade the surrounding environment and threaten local human health.

Characterization of wastes is essential for an effective waste management program. It helps in the choice of treatment methods; deciding the extent of treatment, assessing the beneficial uses of wastes and utilizing the waste purification capacity of natural bodies of water in a planned and controlled manner.

The physiochemical characteristics of the river water samples taken from Kechene and Banteyiketu for the some important river water quality parameters such as COD, BOD, TN, Cl-, TDS and Alkalinity reported to be 378.7, 27.9, 198, 397.5, 951, 726 mg/l, respectively. The findings revealed that the pollution level of the river is higher than not only the permissible limits used by various bodies for surface water quality parameters but also it is by far higher than the wastewater characteristics for typical untreated domestic wastewater except for BOD (Table 21-32). It is also to be noted that during the sampling period, May- August, the flow of City rivers was more than expected due to an unusual heavy rainy period. The observed pollutant concentrations could have even be higher if the samples were taken representing the actual dry season. Still the obtained results for most of the pollutants is by far more than the normal values for surface water quality parameters than that of typical values for untreated domestic waste water. This infers that the pollution sources of the river are not limited to sewerage lines as confirmed by the baseline information. Industries, sewerage lines, hospitals, commercial centers, etc. are identified to be major sources of pollution for Addis Ababa City rivers. Therefore, if proper wastewater treatment and solid waste management system will not be implemented, the river which can be called untreated domestic wastewater, continue to affect the life and livelihood of the society particularly the rural poor surrounding Finfine by polluting the soil, surface and groundwater.

A chemical and physical characteristic of BKK+K, little and big Akaki is compared with untreated domestic wastewater to show the pollution level of the river (Table 21-32). The typical characteristic of the untreated domestic wastewater (UDWW) is adapted from unpublished thesis and from Metcalf and Eddy (1991) Wastewater Engineering. Treatment Disposal Reuse, G. Tchobanoglous and F.L. Burton (Eds.), 1820 pp. New York: McGraw-Hill.

Domestic wastewater typically constitutes a combination of flows from bath room, toilets, floor traps, kitchen sinks, dishwashers and washing machines. However, apart from domestic wastewater originated from residence, other premises such as commercial, institutional and industrial also contributes to a domestic wastewater component to the sewer system. The physiochemical parameters of typical untreated domestic wastewater such as COD, BOD, TN, Cl-, TDS and Alkalinity can reach up to 200-700, 100-400, 20-50, 30-100, 250-850, 50-200 mg/l,respectively.

Chafe, Entoto, Kersa and Sululta are the upper sources of the river taken as a baseline for Kechene and Banteyiketu, big and little Akaki rivers, respectively. The upper streams or sources are taken as a baseline as the river is relatively undisturbed at the source. The laboratory results of the source confirmed that the source is almost unpolluted which can be directly used for irrigation and safe for existence of aquatic life. The dissolved oxygen of the river decreased along the river from source while other chemical parameter such as BOD, COD and others dramatically increased along the river. The heavy metal constituents of the rivers from the source down to the river are compared with the inland discharge limit of set by Ethiopian government. The result revealed that the constituents are within the limit except the lead. Concentrations of fecal coliforms along these rivers were also significantly increased downstream with little Akaki being the severely contaminated indicating that City rivers are the major sources and culprits of waterborne infectious diseases.

Table 21: Physiochemical parameters of Kechene and Banteyiketu

Physiochemical Parameters									
	pH	Temp.	EC(µs/cm)	Cl-	TDS	TSS	Hard	ALK	Turb
Chafe	6.53	24.3	53.07	44.9	46.5	3.2	74.97	75.9	1.2
Kechene and BY	7.92-8.65	22.4-24.6	414.5-1063	84.5-397.5	374.7-951.2	10.03-111	90-399.7	52.3-726.8	2.1-47.8
UDWW	5.5-8	15-35	220-367	30 -100	250 -850	220 - 350		50 - 200	

Table 22: Chemical parameters of Kechene and Banteyiketu Rivers

Biological and Chemical Parameters (mg/l)							
	DO	COD	BOD	TN	NH_3^-N	SO_4^{2-}	S^{2-}
Chafe	8.35	16	14.39	1.39	0.12	5.033	0.0011
Kechene and BY	4.14-5.97	25.3-378.7	10.5-27.9	54.2-198	1.66-31.9	8.37-31.2	0.005-0.32
UDWW		200 -700	100 - 400	20 -50	5-20	30 - 40	

Table 23: Heavy metal constituents of Kechene and Banteyiketu rivers

Heavy Metal Constituents of the Samples (mg/l)						
	Ni	Cr	Cu	Co	Pb	Cd
Chafe	1.41	ND	0.23±0.3	ND	2.67±0.95	1.88±0.3
Kechene and BY	0.75-1.49	11.09 (max)	0.3 (max)	ND	4.26-8.06	1.13-1.67
Untreated domestic wastewater	3	2	2	1	0.5	1

Table 24: Physico-Chemical parameters of Kebena River

Physiochemical Parameters(mg/l)									
	pH	Temp.	EC(μs/cm)	Cl-	TDS	TSS	Hard	ALK	Turb
Entoto	8.235	22.2	52	51.5	637.5	99	60.5	39.8	3.92
Kebena	7.753-8.65	21.9-23.4	372.2-953.7	84.7-198.6	276.7-741.8	2.3-100.4	80-287	52.3-522.12	3.1-73.2
Untreated DWW	5.5-8	15-35	220-367	30 -100	250 -850	220 - 350		50 - 200	

Table 25: Chemical parameters of Kebena River

Biological and Chemical parameters (mg/l)							
	DO	COD	BOD	TN	NH_3-N	SO_4^{2-}	S^{2-}
Entoto	10.08	2.4	7.5	6.3	2.19	1.13	0.172
Kebena	9.91-12.3	9.7-149.7	3.4-52.3	12.1-13.7	1.8-45.2	8.37-30.1	0.008-6.02
		200 -700	100 - 400	20 -50	5-20	30 - 40	

Table 26: Heavy metal constituents of Kebena river

Heavy Metal Constituents of the Samples (mg/l)						
	Ni	Cr	Cu	Co	Pb	Cd
Entoto	0.75	ND	0.38	ND	8.48	0.82
Kebena	0.49-1.19	3.66 (max)	0.55 (max)	ND	3.22-11.02	1.36-1.5
EPA discharge limit (ETH.)	3	2	2	1	0.5	3

Table 27: Physico-chemical parameters of big Akaki compared with untreated domestic wastewater (UDWW)

	Physiochemical Parameters								
	pH	Temp.	EC (µs/cm)	Cl-	TDS	TSS	Hard	ALK	Turb
Kersa	8.93	22.6	213.2	148.9	194.9	2.7	67.5	89.2	4.4
Big Akaki	7.93-8.68	22.4-24.5	333.2-596	111.8-126.7	298.1-537	35.7-401.4	125.4-327.6	147.8-705.33	32.8-93.8
UDWW	5.5-8	15-35	220-367	30 -100	250 -850	220 - 350		50 - 200	

Table 28: Chemical Characteristics of big Akaki compared with typical UDWW

	Biological and Chemical parameters (mg/l)						
	DO	COD	BOD	TN	NH_3^-N	SO_4^{2-}	S^{2-}
Kersa	10.08	9.33	3.84	1.34	1.18	7.33	8.2
Big Akaki	5.26-11.02	14.48-56	4.3-25.7	1.43-131	0.87-5.013	13.2-43.7	5.5-197
UDWW		200 -700	100 - 400	20 -50	5-20	30 - 40	

Table 29: Heavy metal constituents of big Akaki river

	Heavy Metal Constituents of the Samples (mg/l)					
	Ni	**Cr**	**Cu**	**Co**	**Pb**	**Cd**
Kersa	1.18	ND	ND	ND	3.44	1.74
Big Akaki	0.85-1.75	ND	0.27 (max)	ND	3.44-4.00	1.74-2.12
UDWW	3	2	2	1	0.5	3

Table 30: Physiochemical constituents of little Akaki relative to typical UDWW

	Physiochemical Parameters								
	pH	Temp.	EC (µs/cm)	Cl-	TDS	TSS	Hard	ALK	Turb
Sululta	7.097	22.2	38.67	24.5	35.03	7.25	10.3	31.5	10.7
Little Akaki	7.1-8.11	22.5-23.5	494.7-1102	159.38-477.29	448.9-995.4	65.7-248.9	196.2-3504	454.4-918.7	3.65-113.8
UDWW	5.5-8	15-35	220-367	30 -100	250 -850	220 - 350		50 - 200	

Table 31: Chemical constituents of little Akaki river relative to UDWW

Biological and Chemical parameters (mg/l)							
	DO	COD	BOD	TN	NH_3-N	SO_4^{2-}	S^{2-}
Sululta	13.47	26.66	6.91	1	0.2	3.9	2.2
Little	5.04-10.9	191-1232.7	34.5-137	48-132.9	0.59-3.57	32.7-91.33	79.97-1438
UDWW		200 -700	100 - 400	20 -50	5-20	30 - 40	

Table 32: Heavy metal constituents of little Akaki

Heavy Metal Constituents of the Samples (µg/l)				
	Ni	Cu	Pb	Cd
Sululta	0.17	-	5.92	1.55
Little	1.15-2.35	0.5-0.77	3.3-5.08	2.03-2.3
EPA discharge limit (ETH.) mg/L	3	2	0.5	3

It is evident from our findings that the water quality of the BKK+K, little and Big Akaki rivers shows a pattern of behavior linked to anthropogenic sources and reflecting the intensity of human pressure associated with industrial effluent, domestic wastes and agricultural activities. Most of the measured variables showed a similar declining quality trend from upper stream to downstream of the rivers. The major tributaries of the City rivers also added to the pollution load of the rivers, as they are used as a receptacle of all kinds of wastes.

The values of certain parameters have been evaluated with respect to the acceptable standard limits and guidelines for drinking and surface water. An increase in BOD, COD, NH3-N, Pb, Cd and Ni levels and a decrease in DO concentrations downstream of the Kebena and big Akaki were observed with increasing domestic, industrial and agricultural activities in the downstream. The Pb, Cd, Ni, and Cu concentrations exceeded their most common surface water quality criteria; 0.05, 0.05, 0.1 and 0.01mg/l, respectively.

Table 33: Surface water quality classification

PARAMETER	CONDITION OF THE WATER				
	EXCELLENT	ACCEPT-ABLE	SLIGHTLY POLLUTED	POLLUTED	GROSSLY POLLUTED
PH	6.5-8.0	6.0-8.4	5.0-9.0	3.9-10.1	<3.9->10.1
DO (%)	68-112	75-15	50-150	20-200	<20->200
BOD5 (MG/L)	1.5	3.0	6.0	12.0	>12.0
COD (MG/L)	10	20	40	80	>80
SS (MG/L)	20	40	100	278	>278

AMMONIA (MG/L)	**0.1**	**0.3**	**0.9**	**2.7**	**>2.7**
NITRATE (MG/L)	**4**	**12**	**36**	**108**	**>108**
CHLORIDE, MG/L	**50**	**150**	**300**	**620**	**>620**

Based on the technical standard grade system and WHO drinking water guideline (2004), the water quality of the little and big Akaki river basins have been classified as badly polluted to very badly (grossly) polluted water (Grade IV to V). Obviously, in neither of the grade categories, is the water suitable for domestic uses and or irrigation. Table 29 shows the comparison of water quality of the main rivers in Addis to that of different Technical Standard and WHO drinking water quality guidelines. The presence of trace metals in the tested samples indicates that industries have a significant contribution to surface water pollution. The presence of high concentrations of *fecal and total coliform* bacteria in the samples indicates *fecal* matter pollution due to uncontrolled discharge of domestic wastes, open defecation and dumping solid wastes along the rivers.

The discharge of untreated effluent, solid wastes and wastewater from industries, households and institutions are the main sources of water pollution in Addis Ababa. Water pollution due to fecal matter contamination and poor sanitation practice may be the major cause of the top ten leading causes of outpatient visit, hospital admission and death among children and elderly, in Ethiopia in general and Addis Ababa City in particular.

4 MANAGEMENT AND TECHNOLOGICAL OPTIONS FOR CITY RIVERS POLLUTION RESTORATION

4.1. Urgent Need for City Rivers Rehabilitation and Management

From the foregoing findings, it has been clearly shown that industries, sewerage lines, hospitals, commercial centers, etc. were identified to be major sources of pollution for Addis Ababa City rivers. Most of the large and medium scale industries do not have their own effluent treatment plants. Moreover, there are no common effluent treatment systems to treat the effluent from these industries and as a result these industries contribute to the point source pollution of river water bodies, especially in the little and great Akaki rivers as well as Kurtumie-Kechene – Baneyiketu and Kebena rivers. In addition to industrial wastewater, domestic wastewater is also directly discharged from slums, residential areas, and smaller drains into the sewerage network. In most cases sewage directly enters the rivers at various places all along these rivers.

From the foregoing assessment of the sources and pollution status of the City rivers, it was identified that the main sources of pollution and problems of the selected rivers of the City include:

- Settlements along the river banks and by the sides of the river directly impacting on the rivers and its water bodies;
- Piped and channeled sewage lines from the residential and commercial centers directly to the river water course;
- Open defecation and urination along the river banks/sides
- Disposal of solid waste directly on the riversides
- Erosion and runoff mixed with sewage or drainage during rainy season

Therefore, if proper wastewater treatment and solid waste management system will not be implemented at City wide level, the City river which can be called untreated domestic wastewater, continue to negatively affect urban environment, damage its aesthetic value, and threatens the livelihood of the society particularly downstream rural poor communities surrounding Finfine by polluting the soil, surface and ground waters.

Moreover, the City rivers in Addis Ababa lack Clear river and river sides management system. A riverside is the area of land along the rivers and other open river water bodies. River sides are essential to the ecology of river aquatic systems. River sides, due to their location between surface river waters and adjacent land areas, provide a range of important functions such as:

- Trapping/removing sediment, phosphorus, nitrogen, and other nutrients from runoff, as these pollutants lead to pollution of the river water bodies;
- Trapping/removing other contaminants, such as heavy metals, pesticides and other contaminants;
- Providing habitat and contiguous travel corridors for wildlife;
- Stabilizing river banks and reducing channel erosion;
- Storing flood waters, thereby decreasing damage to property;
- Maintaining habitat for fish and other aquatic organisms by moderating water temperatures and providing woody debris;
- Improving the aesthetics of river corridors (which can increase property values); and
- Offering recreational and educational opportunities.

Because they maintain all of these services, riversides/buffers can be thought of as a "conservation bargain." Preserving a relatively narrow strip of land along rivers, which is frequently unsuitable for other uses can help maintain good water quality, provide habitat for wildlife, protect people and buildings against flood waters, and extend the life of reservoirs. The preservation and restoration of natural river buffers is considered to be the single most important management practice to protect river water resources.

Any sustainable approach to City rivers pollution control and management should include the following components: (1) environmental management; and (2) housing and resettlement; and (3) flood control;. The approach usually includes the following components:

Environmental Management: River ecosystems will remain degraded if liquid wastes are untreated before entering the watercourse and if it is used as damping site of solid waste. The establishment of environmental management systems (EMS) geared to improve solid waste collection and management as well as sewage treatment will help address pollution problems. The EMS may include regulations on river easement in order to minimize or prevent solid waste dumping, and policies to abate pollution loading from untreated industrial wastewater and sewage.

Housing and Resettlement: Many of the urban riverbanks are lined with informal settlements, so that the orderly and peaceful resettlement is relevant for the health of the river ecosystem and the safety of riverbank communities. A livelihood program can be provided to affected communities to maintain, restore and/or enhance their incomes that may have been disrupted due to relocation. Despite planned strategies, community people may still protest against many demolition and subsequent relocation projects for economic reasons. This can be addressed by opening avenues for their participation within the formal planning process.

Erosion/Runoff Control: City Rivers are usually part of cities' drainage systems so that flooding especially during the rainy season are very likely. River rehabilitation programs therefore involve flood mitigation through the construction and/or improvement of revetment, parapet or river wall and soil embankment among other flood control operations like dredging, sanitation works and warning systems. The clearing of structures, dredging the river, and waterways that drain into the river are done to reduce frequency and degree of flooding.

4.1.1 Environmental and Social Benefits of River Restoration

Environmental Benefits: Restoring the river's original form allows the natural processes of erosion and deposition which can sustain a rich variety of aquatic life.

Improving the River Corridor: iven space and rivers meander across their flood plains to create rich and fertile meadows. Re-creating this lost link between the river channel, its corridor and flood plain allows rivers to be part of a living 'green network'. For example, deep-water refuge areas help to keep fish alive during high and low flows, or when the river is polluted. A healthy river corridor also allows plants and animals to move between different green spaces across the City.

Improving Flood Storage Capacity: Reinstating flood plains provides a natural increase in the flood storage capacity of the whole river, which contributes to flood protection downstream. Slowing down the speed of water during flood events is also important as it reduces the risk of plants and animals being washed away.

Social Benefits: Re-establishing natural channel processes Local communities can benefit from river restoration schemes, especially if they are actively involved in the project from its outset. One of the aims of the City government strategy is that the people of the City should have access to a quality natural place. River restoration certainly offers Addis Ababa's Municipality a chance to create many attractive, accessible, and quality natural areas along river corridors.

Improving Wellbeing: Having an attractive and safe place to get away from traffic can encourage people to start exercising more and spend more time outside.

Balancing Community Access and the Needs of Wildlife: River restoration provides spaces for walking, jogging, cycling, playing, picnicking, feeding the ducks and generally connecting with nature. Children love these areas because they provide new and exciting natural environments to explore.

Educating the Community: The improved natural environment and its wildlife can provide valuable opportunities for formal and informal learning, helping develop people's appreciation of their local environment and raising their awareness of environmental issues. Signs alongside rivers can provide information about the site and local schools can visit the area on field trips.

Economic Benefits: Generating sustainable development and attracting business Sustainable riverside development has become an integral part of many urban regeneration schemes. As more people visit a restored river, it begins to provide a focal point for local people. This can then lead to local economic development as businesses are drawn towards the more attractive and newly invigorated environments.

4. 2. Proposed Rehabilitation and Management Methods

River restoration' describes a wide range of activities aimed at restoring the natural state and functioning of rivers and the water environment. Restoring a river's natural conditions brings considerable benefits for people and the environment, from improving wellbeing by creating attractive landscapes to ensuring a healthy, thriving ecosystem. The main sources of pollution for selected rivers in Addis Ababa have been identified qualitatively and quantitatively. Accordingly, the following methods are proposed to be the restoration mechanisms:

4.2.1 Resettlement of the residents along riversides

Many of the urban riverbanks are lined with informal settlements, so that the orderly and peaceful relocation is relevant for the health of the river ecosystem and the safety of riverbank communities. A livelihood program can be provided to affected communities to maintain, restore and/or enhance their incomes that may have been disrupted due to relocation. Despite planned strategies, community people may still protest against many demolition and subsequent relocation projects for economic reasons. This can be addressed by opening avenues for their participation within the formal planning process

This will be done through livelihood restoration and continuous public consultation. The public consultation is recommended to be done with directly affected society and relevant stakeholders until agreement will reach between the government (project office) and the residents. For such an approach a practical resettlement action plan (RAP) is required to guide for its implementation.

4.2.2 Cleanup of Polluted Rivers and River Banks Along BKK + Kebena

Kurtumie-Kechne-Banteyiketu and Kebena rivers are grossly polluted by solid waste dumping along the riverbanks and water ways. The little and big Akaki rivers are also in similar situations and it is even worse downstream these rivers as the solid wastes are carried by runoff and floods during rainy seasons. For proper management and restoration of the polluted rivers and river banks, there should be planned and organized cleanup process through involvement of communities dwelling along the river sides. Strategies and incentive mechanisms should be devised on how to involve the community particularly the youth in the massive cleanup processes of the rivers all along the selected segments.

The cleaning of the wastes in and around the river can be made

- Collecting the wastes around the river manually. This can be done by waste collection associations of the city through contracting. The municipality cleansing agency in collaboration with the City's river rehabilitation project office can take the management of the work.
- The collection of dispersed solid wastes in the river can be manually cleaned during the dry season by waste collection association of the city through provision of safety shoes and other safety equipment. This can be supported by pre-investigation of the depth of the river in some places. The dry season is proposed as the river from the source is very limited and

the volume of the river at this season is very small.

4.2.3 Sewage Management

The present coverage of wastewater management of Addis Ababa is less than 10%. However, the population and socio-economic developmental activities of the City are increasing from time to time. And this will further challenge the wastewater management of the City. The above mentioned problems have initiated the City administration to work on water and sanitation, and attempts are being made by Addis Ababa Water and Sewage Authority (AAWSA), Water and sanitation Development and Rehabilitation Project Office. Sewage Management is considered to be long term solution for the piped and channeled sewages to the river. Sewage from the households, institutions, commercial centers, hospitals, industries and others must be collected, channeled and treated at the proposed zones of the central treatment plants by AAWSA. The ongoing expansion activities of City sewer lines and wastewater treatment plants by AAWSA include:

A. Treatment plant and sewer line expansion and rehabilitation in Kality catchment

The engineering design of this project was carried out by Marrison Hershfield International Inc. in association with ARMA Engineering PLC in 2012. And the environmental and social impact assessment for the same was carried out by Beles Engineering PLC in 2014. The existing Kality Wastewater Treatment Plant (WWTP) has a design capacity of 7,500 m3 per day. This is equivalent to a population of 75,000 just assuming the per capita sewage production to be 100 liters per day. The new treatment plant, however, is designed to accept 100,000 m3 per day and this is equivalent to a population of 1,000,000. This project covers Bole, Kirkos, Akaki-Kality, and Nefs Silk-Lafto sub-cities.

B. Wastewater management for the eastern part of Addis Ababa

Eastern part of Addis Ababa is one of the areas of the City that are getting fast development and high population growth. This is mainly attributed to real-estate development and housing projects in the area by government and private sectors. The Addis Ababa Water and Sewage Authority, recognizing the fast development and high population growth, plans to provide sewerage system in the area. This project covers Yeka and Bole sub-cities.

The engineering design and the environmental and social impact assessment of this project were carried out by MS Consultancy in 2008. Hence, we strongly recommend, as a long-term plan, the Addis Ababa City Administration to realize the above two projects and keep on increasing the wastewater management coverage to the other parts of the City (Arada, Lideta, Addis Ketema and Gulele sub-cities) so as to protect the rivers of Addis Ababa from pollution. Parallel to this, as a short-term intervention scheme, we propose a decentralized wastewater treatment systems originating from diffuse sources at different segments along the Kurtumie-Kchene- Banteyiketu river and Kebena river trenches covering piped sewages that are not connected to the existing sewer lines within the City and that are directly connected to the river courses.

Sewage management is proposed to be compulsory condition for the rehabilitation of the river for two main reasons (i) the main stressor of the river such as population growth, hotels, commercial centers and the like are expected to grow dramatically, (ii) the proposed treatment methods along the river sides cannot withstand the volume and concentrations that will be discharged to the proposed treatment scheme to be established along these rivers.

4.2.4 Wastewater Management Originating from Industries, Hotels, Condominium and other Point Sources

Industries should be responsible and put in place wastewater treatment systems following existing regulations and policy provisions in order to treat their wastewater prior to discharge either to City sewer lines channeled to central effluent treatment or directly to the river systems. The later should be allowed on the basis of strict water quality standards for surface waters. Responsible City Government organization should make sure that wastewaters originating from point sources (industries, garages, service sectors such as hospitals, hotels, commercial centers, etc.) is treated to acceptable level prior to discharges to receiving environment.

4.2.5 Construction of Public Toilet/Common Sanitation Facilities

Public toilets are essential to equitable access to public outdoor spaces. They allow for the space put it differently river sides to become a destination for extended periods for socializing, exercise, commuting and accessing community and commercial services. This is true for streetscapes and open spaces such as parks, gardens and river sides. The municipality must play a key role in providing public toilets that are safe, accessible, clean and environmentally sustainable. There should be public toilet strategy that intended to guide where public toilets are provided and how the community of the City of Addis Ababa experiences them. The key standards guiding the construction of existing and proposed facilities are demand, accessibility, environmental impact and cost. To achieve the vision of safe, accessible, clean and environmentally sustainable public toilets, a series of policies and actions must be included and or reviewed if it does exist for Addis Ababa City or for the country at large. Construction of the public toilet by the government and private companies deemed necessary in rehabilitating the polluted river and for the sanitation of the City as well.

Service Coverage of the City: According to AAWSA Business Plan and GTP II document, only 6-7% of the City's population is connected to the municipal sewer network. The vast majority, about 80%, of the housing units rely on private or shared on-site wastewater disposal systems such as septic tanks and pit latrines; while 13-14% does not have any type of sanitation facility at all. At present, some 20,920 m3/day of fecal sludge and wastewater are collected and treated at sludge and waste water treatment plants. With conventional sewer system about 19,720m3 of wastewater is conveyed to the treatment plants every day. Vacuum trucks managed by AAWSA and private owners collect on average about 1,200m3 of sludge every day from the on-site disposal sanitation facility users.

Considering the isolated sewer networks for different condominiums, recently connected condominiums to Kality system and AAWSA's record of sewer connections there are around 51,500 domestic connections and 2,164 non domestic connections totaling to 54,089 customers connected to the sewer system. About 96% of the connections are domestic connection serving the domestic consumers, 1.8% of the connections are non-domestic industrial and 2.27% of the connections are non-domestic public & institutional customers.

Plan of the City on Public and Communal Toilet Construction: Along with the stretched GTP-II plan, in 2009 E.C, AAWSA has planned to build 114 public, 570 communal and 890 movable toilets through all of its eight branch offices and at the project office. Currently, the project office alone had already started the construction of 60 public toilets, to be realized in all the ten sub cities of Addis Ababa.

Table 34: AAWSA's recent plan of 2009 E.C

S/No	Types of Toilets	To be constructed by the project office	To be constructed by head office & branch offices	Total
1	Public	114	-	114
2	Communal	-	570	570
3	Communal	-	890	890
	Grand Total	**1574**		

It is also planned to construct architecturally modern G+2, G+1, G+0 and underground toilet typologies with the aim to enhance both sanitation service for the residents of Addis Ababa and to improve scenic beauty to the City. Construction of the public toilet plays a pivotal role in rehabilitation of the City's river. The consultant strongly recommends and wishes the realization of the plan as it significantly impact the objective of the river rehabilitation.

4.2.6 Storm Water Management

Storm water has long been regarded as a major culprit in urban flooding, 'Jemo' condominium site is good metaphor for case of Addis Ababa, however, still the policymakers don't appreciate its significant role in degrading the rivers and other water bodies in urban and suburban areas of Ethiopia. Large volumes of rapidly moving storm water can harm species habitat and pollute sensitive drinking water sources, among other impacts. Urban storm water mixed with sewerage lines of the City is estimated to be the primary source of impairment of rivers in Addis Ababa.

Urbanization-the conversion of forest and agricultural lands to suburban and urban areas is proceeding at an unprecedented pace in Addis Ababa. Storm water discharges have emerged as a problem because the flow of water is dramatically altered as land is urbanized. During the site visit it was observed that the storm water from the various condominium sites and other mixed building facilities are directly discharged to the river courses in the vicinity.

Storm water discharges have emerged as a problem because the flow of water is dramatically altered as land is urbanized. Typically, vegetation and topsoil are removed to make way for buildings, roads, and other infrastructure, and drainage networks are installed. The loss of the water-retaining functions of soil and vegetation causes storm water to reach the urban rivers in short concentrated bursts. In addition, roads, parking lots, and other "impervious surfaces" channel and speed the flow of water to streams. When combined with pollutants from motor vehicle garages, domesticated animals (in and around Addis Ababa), industries, and other urban sources that are picked up by the storm water, these changes have led to water quality degradation in virtually all urban rivers.

Storm Water Management Approaches: Even in the absence of regulatory changes, there are many storm water management approaches that can be used to prevent, reduce, and treat storm water flow. Addis Ababa City Environmental Protection Authority Storm Water Program is the requirement for permits to develop storm water pollution prevention plans that include storm water control measures.

Storm water control measures are grouped in two categories: nonstructural and structural. Nonstructural storm water control measures include a wide range of actions that can reduce the volume of runoff and pollutants from a new development. Examples include the use of products that contain less pollutants; improved urban design, for example, of new developments that have fewer hard surfaces; the disconnection of downspouts from hard surfaces to instead connect with porous surfaces; the conservation of natural areas; and improved watershed and land use planning.

Structural storm water control measures are designed to reduce the volume and pollutants of small storms by the capture and reuse of storm water, the infiltration of storm water into porous surfaces, and the evaporation of storm water. Examples include rainwater harvesting systems that capture runoff.

From roofs in rain barrels or tanks; the use of permeable pavement; the creation of "infiltration trenches," into which storm water can seep or is piped; the planting of rain gardens on both public and private lands, and the planting of trees along the roadside that capture and treat storm water.

Nonstructural storm water control measures be considered first before structural practices, because their use reduces the reliance on and need for structural measures. Moreover, illegally connected sewage lines with storm water ditches must be re-designed and the City must have a penalizing and controlling system.

4.2.7 Establishment of a Solid Waste Management System

The inefficient collection of solid wastes was seen as a major contributor to river pollution, either through direct dumping of wastes in the waterways or via throwing of uncollected garbage near the riverbanks. Solid waste accumulated as sludge in the waterways and impeded the drainage of flood waters. Upon recognizing this, the City government should strictly enforce anti-dumping ordinance and introduce a refuse collection policy with the target of creating an effective solid waste management system, with a garbage collection efficiency rate of more than 98% with the aim of preventing direct or indirect dumping of solid wastes on waterways. This should be coupled with improving the City's principal drainage system through massive dredging operations and bank improvements in order to reduce flooding. Develop the whole stretch of the river into a recreational park through tree planting on the banks to prevent erosion and encourage communities to field their own patrols to stop those who dump garbage will also increase sense of ownership and sustainability.

4.2.8 Enforcement of the Environmental Statutory of the City and the Country at Large

The government and private institutions, commercial centers, industries and mixed buildings must treat their liquid waste to acceptable level. This can be enforced by the Constitution of the Federal Republic of Ethiopia, adopted in August 1995, has a number of provisions, which have direct policy and legal relevance to environmental protection matters in connection with development projects and it operations. Any gaps to existing policy and regulatory framework should be identified and pertinent regulations be amended, if any, for a good marriage of policy and practice for bringing City rivers into its natural state and continue to render it ecological, economic and social services.

4.3. Technological Options for River Pollution Abatement

The acceleration of urbanization and rapid development of economy led to making surface water pollution problem becoming more critical in the City of Addis Ababa. In order to sustainably manage waste waters entering City river and control pollution on a sustainable basis, it is critical that a series of technological options assessed, evaluated and the best suitable technological packages selected. Technological options that are suitable for river pollution control and remediation systems can be physical, chemical and biological or combination of these. Recent developments, however, give more weight to bio-remediation technologies (i.e. remediation using aquatic plants, remediation using aquatic animals, and microbial remediation) as one of the effective ways to deal with the pollution of natural water systems. Trends show that approaches to alleviate the river pollution problems should utilize the bio-remediation as the primary technique, followed by the physical and chemical remediation as the supplementary means. Accordingly series of technological options are assessed with a view of selecting appropriate and feasible technological packages that will address the existing City river pollution problems in conjunction with the management options outlined in the above sections.

4.3.1 Physiochemical Processes

Various chemical water treatment methods were utilized for both surface water and groundwater. For instance, flocculation, sedimentation and chemical agents can be used to treat water with a large number of suspended solids and algae. Despite the fact that in-situ chemical technologies offer significant benefits over the conventional ways, their use is still very limited because of technical uncertainties and regulatory or procedural barriers. In addition, caution needs to be taken in handling chemicals because these chemical treatment techniques inherently involve use of potentially hazardous chemicals, sometimes in large quantities. Effort is also needed to prevent mobilized contaminants from migrating into the surrounding environment.

4.3.2 Aeration Techniques

Presently, the utility of river aeration technology has relatively been mature in many countries. Research and practical applications showed that the artificial aeration can improve water quality effectively. Practically, Aeration systems can be utilized as standalone systems or as a support for other treatment facilities. Researches on using aeration as a primary system showed increase in dissolved oxygen concentration as well as decrease in BOD5 and COD values. However, such an approach may not be feasible to the existing river water bodies in the City of Addis Ababa. Besides aeration, water diversion and sediment dredging were used as physical water treatment methods for surface river water. But water diversion found to be large and the cost was relatively high and sediment dredging would cause re-suspension of sediment and this is also difficult to apply to the existing rivers in the City of Addis Ababa.

4.3.3 Bioremediation Technologies

In the bioremediation process, indigenous or cultivated microbes and other organisms are used to transform the poisonous and harmful pollutants to non-toxic substances under the controllable environment. Phytoremediation is also a component of bioremediation where efficient plants are used to remove pollutants and stabilize waste waters. According to the degree of human intervention, the bioremediation could be divided into natural and artificial bioremediation, and the latter could be divided into in-situ bioremediation and ex-situ bioremediation. Bioremediation technologies were advanced rapidly since 1990. Bioremediation is considered as one of many advantages, such as reduced cost, low environmental influence, no secondary pollution or pollutant movement, reducing pollutant concentration by the maximum extent, available for the sites where regular pollution treatment technology is difficult to be applied. Indeed, many in-situ remediation processes such as ecological floating bed techniques and constructed wetlands have been developed for bioremediation of polluted surface water and have obtained satisfactory results.

4.3.3.1 Phytoremediation Technologies

The plants with strong absorption for pollutants and good tolerance could be planted in the polluted water and or river banks to serve as a bio filter mechanism. Accordingly these plants can mitigate or fix water pollutants through adsorption, absorption, accumulation and degradation for water purification. However, plants vary considerably in their tolerance of pollutants and in the amount of that they can take up from soils and water. Some of these accumulating plant species reveal the mineral composition of those substrates, for example, in the soil, sediment and water. This ability can be used in contamination bio-indicators or, if the biomass and bio-productivity are high, in Phytoremediation.

The plants with strong absorption for pollutants and good tolerance could be planted in the polluted water and or riverbanks. Accordingly water pollutants can be removed or fixed through adsorption, absorption, accumulation and degradation by the plants for water purification. The plants for restoration commonly used Reed, E. crassipes(water hyacinth), cattail, A. philoxeroides, Pistiastratiotes, common reed (Phragmites communis), cattail (Typhalatifolia), macrophytes, duckweed and Canna indica. Buffers planted with good candidate plants have a higher ability to remove TN, TP and nitrate nitrogen as well as heavy metals and pathogens. Therefore, based on the purpose and the available facilities, aquatic plants can be introduced for surface water remediation in different treatment systems such as constructed wetlands and floating bed systems or it can be submerged like algae.

Remediation mechanism is not only by assimilating pollutants directly into plant's tissues, but these plants also act as catalysts for purification reactions. Plus, aquatic plants increase the environmental diversity in the rhizosphere and promote variety of chemical and biochemical reactions that enhance purification. The major characteristics of aquatic plants involve their extensive root system and rapid growth rate which made them an attractive biological support media for bacteria. Besides, Motility and chemotaxis enable the bacteria to move towards plant roots where they can benefit from root exudates as carbon and energy source, and may therefore contribute to survival and rhizosphere colonization. In addition to the organic pollutants, aquatic plants can also be used for the removal of heavy metals and other hazardous pollutants. Table 1 shows the pollutant removal capabilities used in river pollution restoration schemes adopted from various researchers.

Table 35: Major aquatic plants based systems used for surface water remediation

System	**Target Polluted Water**	**HRT**	**Removal Efficiency**			
			BOD	**COD**	**TN**	**TP**
Constructed Wetlands	Polluted rivers Domestic wastewater	2-10 days	2-10 days	78-84	78-84 (	78-84
Floating Bed Systems	Polluted rivers	2-5 days		94.6	72-86	63-6
Artificial seaweed (AquaMats)	Polluted rivers or streams	7.8 Hours	72.7±6.4	58.1±5.2	25.9±4.3	-

Source: Ruan et al., 2006; Saeed et al., 2012; Sun et al., 2009; Jiao et al., 2011

Phytoremediation (planted based) systems is in most cases regarded as a low-cost, solar-energy-based and eco-friendly technology for in situ purification of surface water as an important ecological remediation to control water eutrophication.

Figure 68: Constructed wetland using phragmites (P. karka) for treating tannery industrial waste waters at Mojo, Ethiopia

4.3.3.2. Microbial Remediation Technology

In this technology microorganisms are used to decompose, transform, absorb the pollutant in the water. Results to date generally confirm the existence of the appropriate microbial functional groups, e.g. nitrifiers, denitrifiers, SRB, SOB etc., responsible for removal of specific pollutants the wastewater. Nitrogen is one of the major nutrients that wastewater treatments attempt to eliminate in order to avoid water pollution. Biological nitrogen removal is traditionally achieved by autotrophic nitrification and heterotrophic denitrification processes. Presently, nitrogen (ammonia) removal is mostly carried out through two conversion steps, namely, aerobic nitrification and anaerobic denitrification.

Anaerobic ammonium oxidation (anammox) is the microbial conversion of ammonium and nitrite to dinitrogen gas. The functional microbes of anammox reaction are anammox bacteria, which were discovered in a wastewater treatment system for nitrogen removal. Anammox bacteria are prevalent in anoxic ecosystems and play an important role in both biological nitrogen cycle and nitrogen pollution control. On the other hand, Autotrophic nitrification consists of two successive aerobic reactions, the conversion of ammonium to nitrite by ammonium oxidizing bacteria (AOB, Nitroso-) and the conversion of nitrite to nitrate by nitrite oxidizing bacteria (NOB, Nitro-). AOB and NOB use CO2 and bicarbonate for cell synthesis and ammonium or nitrite as the energy source. The genera *Bacillus, Micrococcus* and *Pseudomonas* are most common in soils while Pseudomonas, Aeromonas and Vibrio are more common in aquatic environments.

Recently, several new nitrogen-removal processes have been developed, one of which is completely autotrophic nitrogen- removal over nitrite (CANON). In the CANON process, two major groups of bacteria are responsible for autotrophic nitrogen removal: aerobic ammonium-oxidizing bacteria (AerAOB) converts ammonium to nitrite with oxygen as the electron acceptor and anaerobic ammonium oxidizing bacteria (AnAOB) subsequently oxidizes ammonium with nitrite as the electron.

Microbial dosing and biofilm methods are two practical approaches in river water purification processes. Microbial dosing technology uses specific and efficient microorganism to decompose, transform, absorb the pollutant in the water, to purify quality of the river by sifting of the efficient microorganism, optimized construction of the microorganism. The bio-film technology utilizes bio-membrane attached to the natural river bed and micro-carrier to move the pollutants in the river through adsorption, degradation and filtration under the conditions of artificial aeration or dissolved oxygen. Gravel contact oxidation method, artificial packing contact oxidation method, thin layer flow method, underground stream purification method, etc. The strengthening purification technology of the bio-film technology for river purification in Japan and South Korea and other countries researched by Japanese were mainly indirect purification, which was to build the purification facilities on the side of the river (Wang et al, 2012).

Further, biofilm processes, such as aerated bio-filter biological fluidized bed, suspended carrier biofilm reactors (SCBR), etc., are commonly used in surface water remediation. Immobilization of biomass in the form of biofilms is an efficient method to retain slow growing microorganisms in continuous flow reactors. These systems operated as aerobic or anaerobic phases with freely moving buoyant plastic biofilm carriers (Wang et al., 2005).More specifically, microorganisms grow attached on small carrier elements that are kept in constant motion throughout the entire volume of the reactor, resulting in uniform, highly effective treatment. The moving bed reactors provide distinct advantages, including being simple in operation, at low risk of losing the biomass and less temperature dependent (Wang et al., 2005). In addition, they have better control of biofilm thickness, higher mass transfer characteristics, they are not subject to clogging and they have a lower pressure drop (Moussavi et al., 2009)

4.3.3.3. Biofilteration

Bio filters (also called trickling filters, percolating filters and bacteria beds) are an old process for the secondary treatment of domestic wastewater dating from the beginning of the 20th century and there are many thousands of bio filters in use in both industrialized and developing countries. However, for use in tropical climates they should be used with modern fly control techniques. Bio filters produce high quality effluents (e.g<20 mg BOD/l and <30 mg SS/l) without requiring large areas of land or consuming vast quantities of electricity. In many situations in developing countries they are much more appropriate than activated sludge processes. Biofilteration systems are typically robust, simple to construct and have low energy requirements (Pipe Martin et al., 2010). The most common technologies are sand filtration, biological activated carbon (BAC) filtration, river bank filtration and managed aquifer recharge.

4.4. Selection and Design of Appropriate Treatment Technologies

The various design criteria developed for commonly used biological treatment methods have been summarized in Table 36below with particular reference to certain important parameters such as power requirements and their performance based on which a choice can be made. Table36compares the performance of selected treatment technologies in terms of various criteria or parameters of design and operation in order to guide users to make an informed choice regarding the method to be used. On the basis of the performance efficiency, ease of operation and suitability of a given technique and or combinations of techniques, the values for the various technical options can be used for making an objective assessment and choice to be used for the treatment and management of City rivers pollution in Addis Ababa.

Table 36: Typical performance characteristics for various methods of sewage treatment

Item	Extended aeration	Conventional activated sludge	Conventional trickling filter	UASBS	Slow sand filtration combined with wetland and septic tank
Performance (Typical):					
BOD Removal, %	95-98	85-92	80-90	75-85	>90
Nutrient Removal, % N	15-30	30-40	15-20	-	>90
Nutrient Removal, % P	10-20	30-45	10-20		>90
Coliform Removal, %	60-90	60-90	60-90	-	>90
Sludge Handling	No digestion, dry on sand beds or use mechanical dewatering devices.	First digest then dry beds or use mechanical devices	First digest then dry beds or use mechanical devices	Directly dry on sand beds or use mechanical devices	simplest
Process power requirement (kWh/person-year)(d)	16-19	12-15	7-11	Nill	Nill
Equipment requirement (excluding screening and grit removal which might be required in all cases)	Aerators, recycle pumps, sludge scrapers (for large settlers)	Aerators, recycle pumps, scrapers, thickeners, digesters, dryers, gas equipment	Trickling filter arms, recycle pumps, sludge scrapers, thickeners, digesters, gas equipment	Nill (except gas collection and flaring; gas conversion to electricity is optional	simplest

Operational characteristics	Simpler than activated sludge	Skilled operation required	Skilled operation, simple required	Simpler than activated sludge	Simplest of all
operation cost	high	high	low		Lowest of all

Other process requirements: The various other factors affecting the choice of a process include requirements in terms of the following:

- Availability of land
- Power consumption. There are two aspects here: power or energy requirement and the effect of its dependability on the process. Ability of a process to withstand power failures.
- Operating (and control) equipment requirement and its indigenous availability.
- Availability of skilled staff at given salary and working conditions.
- Nature of maintenances problems (in terms of equipment, machinery, instrumentation, structures, etc)
- Extent of sludge production and its disposal requirements. Sludge is often difficult to handle and may involve quite a substantial part of plant cost
- Ease of stage wise extension of plant with time

Ultimately, the choice of treatment system depends on various factors which can be grouped under three key words: affordability, acceptability, and manageability. The various aspects involved in each of the three factors are delineated below.

Affordability: Firstly depends on the financial ability of the community to be served and secondly, on the requirements of the process in terms of power and land requirements. The typical questions concerning this factor are: Is the requisite electric power available and affordable? Can we find or spare the land needed for setting up the plant?

Acceptability: Mainly depends on the performance of the treatment system. The acceptability of the system generally depends on two groups of individuals: firstly, the pollution control authorities who have to approve the treatment proposed and, secondly, the riparian public who have to live near the treatment facility. The questions concerning these factors are: will the authorities approve of the proposed scheme? Does it meet the discharge standards? Is the project likely to give rise to nuisances like mosquitoes and foul odor in its vicinity? Will the neighbors accept it at the expected level of performance? The answers to these questions must satisfy all the people concerned.

Manageability: refers to both the routine operation of the plant, and its maintenances and repairs when needed. Here the following questions are asked: will staff employed to run the plant be able to manage it? Are they competent enough to handle the project or is it too skilled and specialized for them? Can the staff be trained reasonably soon in the skill required? Will be possible to repairer the machinery locally when something goes wrong or will imports be needed (and not readily available) from other cities or countries?

If the three key tests of 'affordability, acceptability and manageability' are met by a process or treatment method, the latter should be considered for adoption, regardless of how simple it is. An appropriate technology is also most likely to be a sustainable one.

Taking into consideration the suitability of the existing technologies for river pollution abatement as well as considering the existing situation of Addis Ababa City rivers, slow sand filtration (SSF) technology with septic tank as a primary treatment was chosen in combination with constructed wetland systems along the river banks is considered to be appropriate in attaining water quality standards and feasible in terms of construction and operation. The treatment plants will be located at 18 segments of the selected river to be implemented to the left and right of the river at the junction points. The selected junction points are;

Location of the Plants along Kebena river:

1. Around Ferensay Embasy
2. Abo Sefer –Ferensay
3. German Embasy
4. Balederes-Around Ethio Community KG
5. Ginfile-Swedish School
6. Before Urael Church
7. Peackok park

Location of the Plants along Kechene River:

1. Above Kechene Medianialem Church-Around Addis Ababa Primary School
2. Semen Mezegaja-Around Degim Berhan School
3. Afichober To Chilot Street-Around Atse Neakuto Leab Primary Public School
4. Above Nigerian Embasy-Senegal Street-Around Praeter Law College
5. Doro Menekiya –Around Seba Dildil
6. Ambasador Park Area

Location of the Plants along Kurtume River:

1. Esrael Embasy Condimium-Above Enkulal Fabrica
2. Between Paulose Hospital And Abebe Bikila Stadium
3. Burkina Feso Street-Aba Koran Sefer
4. Around Chew Berenda
5. Around Habte Giorgis Bridge

The locations of the treatment facilities along the BKK-Kebena segments were selected on the basis set criteria such as pollution load; settlement density; distance between treatment plants; water shed catchments; existing structures (church, parks, embassy etc.).

Similarly slow sand filtration in combination with constructed wetland based systems is chosen over other advanced and conventional treatment methods due to:

1. Quality of treated water: No other single process can effect such an improvement in the physical, chemical, and bacteriological quality of normal surface waters as that accomplished by flows through a sand-bed with a thin layer populated by microorganisms. Hereby, the water gets purified through various biological, physical and chemical processes. The delivered water does not support after growth in the distribution system, and no chemicals are added, thus obviating one cause of taste and odor problems. The slow sand filtration is very effective for removal of pathogens (bacteria, protozoa), turbidity, heavy metals (Zn, Cu, Cd, Pb) and moderately effective for removal of odor, taste, iron, manganese, arsenic and organic matter.

2. Cost and ease of construction: The simple design of slow sand filters make it easy to use local materials and skills in their construction. The cost of imported materials and equipment may be kept to almost negligible proportions, and it is possible to reduce and the use of mechanized plant to the minimum and to economize on skilled supervision. Design is easier, little special pipework or equipment is required, instrumentation can be almost completely eliminated, and a greater latitude in the screening of media and selection of construction materials can be permitted. Only when a high price has to be paid for land and when expensive superstructures are necessary for protection against low temperature is the capital cost of slow sand filters likely to equal or exceed that of comparable rapid sand filters.

3. Cost and ease of operation: The cost of operation lies almost wholly in the cleaning of the filter-beds, which may be carried out either mechanically or manually. In developing countries like Ethiopia and elsewhere labor is readily available, the latter method will be used, in which case virtually the whole of operating cost will be returned to the local economy in the form of wages
   No compressed air, mechanical stirring, or high pressure water is needed for backwashing, thus there is a saving not only in the provision of plant but also in the cost of fuel or electricity.

   The operator of a biological filter requires far less training and skill than does his colleague in charge of rapid gravity filter, and less supervision and support (e.g., laboratory testing of chemical quality) are called for. Slow sand filters automatically accommodate minor fluctuation in raw water quality, temperature, and climate conditions and can stand short period of excessive turbidity or demand without breaking down.

4. Disposal of sludge: Sludge storage, dewatering, and disposal are less troublesome with slow sand filters than with mechanical filters, particularly when the latter contain chemical coagulants. Since the sludge from biological filters is handled in a dry state there is virtually no possibility of polluting neighboring watercourses, and the waste material is usually accepted by farmers as a useful dressing for their land, the mixture of sand and organic matter being especially suitable for conditioning heavy clay soils.

The currently, piped and channeled sewerages from the households will be collected and primly treated in septic tank in two sides of the river bank (left and right) and finally treated with slow sand filtration. The septic tanks will be used as primarily treatment methods and helps for significant reduction of turbidity. The design and location of the slow sand filtration will be made along the sides of the river and will be divided by segment.

4.5. Physical Restoration of a River

This part points out some main restoration approaches and physical structure restoration techniques necessary to achieve ecological integrity in degraded river ecosystems. Techniques used in restoration of a river's physical structure:

- In stream processes;
- Stream bank treatment; and
- Channel reconstruction.

Table 37: Inseam physical restoration

Practice	Practice Description	Application
Boulder clusters	Group of boulder placed in the base flow channel to provide cover , create scour holes , or areas of reduced velocity	Can be used in most stream habitat types
Weir or sills	Boulders, or quarry stone structures placed across the channel and anchored to the stream bank and/or bed to create pool habitat, control bed erosion, or collect and retain gravel	Can be appropriate in streams where natural or human placed obstructions.
Grade control measures	Rock and other material structures placed across the channel and anchored in stream banks to provide a " hard point" in a streambed that resists the erosion forces of the zone of degradation, and/or to reduce the upstream energy slope to prevent bed scour	

Table 38: stream bank treatment

Practice	**Practice Description**	**Application**
Bank shaping and planting	Regarding stream banks to a stable slope, placing topsoil and other materials needed for sustaining plant growth, and selecting, installing and establishing appropriate plant species	Most successful in stream banks where moderate erosion and channel migration are appropriate

Vegetated gabions	Wire-mesh, rectangular baskets filled with small to medium size rocks and soil and laced together to form a structural toe or sidewall. Live branch cuttings are placed on each consecutive layer between the rock filled baskets to take root, consolidate the structure, and bind it to slope	Useful for protecting steep slopes where scouring or under cutting is occurring or there are heavy loading condition. Vegetative planting to stabilize the upper bank and ensure regenerative source of stream bank vegetation.

Table 39: Channel Reconstruction

Practice	Practice Description	Application
Maintenance of hydraulic connections	Maintenance of hydraulic connectivity to allow movement of water and biota between the stream and abandoned channel reaches	Used to prevent losses of aquatic habitat area and diversity
Stream meander restoration		

4.6. Restoration of River Bank Vegetation

Restoration of river banks with selected indigenous plants is pivotal for increasing nutrient retention capacity and self-Purification ability of the river systems. This is very important for infiltration of the nutrients from solid and liquid wastes. Selection of indigenous plants that have the capacity to absorb nutrients and heavy metals will be selected and planted along the BKK-Kebena river banks.

5 DESIGN OF TREATMENT TECHNOLOGIES FOR WASTEWATERS ORIGINATING FROM DIFFUSE SOURCES ALONG BKK AND KEBENA RIVER SEGMENTS

5.1. Design Structures and Location of the Treatments Facilities Along the River Segments

The slow sand filter in combination with constructed wetland is recommended for the treatment of wastewaters from diffuse sources along BKK and Kebena segments. Eighteen segments for the establishment of treatment facilities were selected by taking into consideration the pollution load and other criteria as described earlier in Section 4. Design of the SSF integrated with constructed wetland system is also done on the basis of set technical considerations.

5.2. Description of Waste Water Treatment System

A. General Description

As it is described in the previous section of this study, Addis Ababa City Administration has to increase the wastewater management coverage using sewerage system as a long-term solution to protect the City Rivers from pollution. Otherwise, as a short-term plan, a wastewater treatment system is provided at thirty six (36) points along the rivers just to deal with the piped domestic sewage that is coming to the rivers due to the absence of sewerage system.

First, the rivers are generally divided into eighteen (18) segments considering different factors (see section 4.3 above). And the average population in each segment is determined (this is just to calculate the average sewage quantity from each segment) using the data from the Socio-Economic team of the same project.

The pipe that collects the raw sewage from each segment and takes to the treatment plant is then designed (ϕ=300mm). Finally, considering the characteristics of domestic sewage - meaning settle able solids, suspended solids, oil and grease, dissolved organic matter, pathogens and nutrients - a feasible treatment system is developed and the reactors are designed. The cost for the construction of the treatment system is also estimated (refer the annexed cost estimation).

B. Description of the Treatment System

The wastewater treatment system is a combination of Septic Tank (ST), Slow Sand Filtration (SSF) and Constructed Wetland.

Septic Tank (ST)

The aim of septic tank is to remove settle able `solids, oil and grease. Substances denser than water settle to the bottom of the tank while fats, oil and grease float to form a scum layer. Then, the reactor (watertight tank) for these physical processes is designed. Refer the annexed design report for the dimensions of the tank and the desludging time. However, the effluent of septic tank still contains pathogens and high level of dissolved solids. Therefore, septic tank effluent requires further treatment.

Slow Sand Filtration (SSF)

Slow sand filtration is frequently and successfully applied as secondary treatment of domestic sewage. The main objective of slow sand filtration is the removal of dissolved organic matter, suspended solids that remain in the liquid fraction and reduction of pathogens and nutrient loads. The basic structure consists of a watertight box filled with fine sand (refer the design report for the ES - the effective sand size). The effluent from the septic tank is applied to the top of the slow sand filter, percolates through the sand and is then collected in the drainage system. The effluent from the septic tank is first stored in a dosing tank or chamber and is then applied intermittently on the filter surface by an electric pump. Refer the annexed design report for the design parameters and dimensions of the filter box.

Constructed Wetland

Constructed wetland is used to polish the effluent from secondary treatment facility. It is mainly designed to remove nutrients from domestic sewage. Horizontal-flow constructed wetland is used in this design. The effluent from the slow sand filter enters through the inlet zone and flows horizontally through the bed. The plant that is used in this constructed wetland is a reed, reported to have high pollutant removal efficiency.

The plants themselves and, the bacteria and other organisms due to the conditions provided by the plants remove the nutrients and other remaining inorganics including pathogens more efficiently. However, the treatment level is determined by the hydraulic retention time (HRT). Refer the annexed design report for the design parameters and dimensions of the basin.

5.3. Cost Estimations

The corresponding cost estimation for the SSF integrated with constructed wetland system construction and establishment of the treatment facilities is computed and bill of quantities prepared to guide and plan the construction of the treatment technology/.

5.4. Management, Operation of the Slow Sand Filtration (SSF) and Implementation Approaches of River Restoration

It is recommended that where a slow sand filter is established, working procedure should be availed which will support the technical management of the systems. The project office in collaboration with Addis Ababa City Environmental protection authority and AAWSA should strengthen the operator management capacity with training and technical backup.

5.4.1 Recommended Procedures of Slow Sand Filtration Cleaning

Draining the Filter and Preparing it for Cleaning

When filter has reached the end of its run and arrangements for its cleaning have been made, the raw water inlet valve is closed, to initiate the cleaning operation, thus allowing the filter to continue to discharge at a reducing rate to the clear water tank for as long as possible (usually overnight). The outflow valve is then closed (e.g. next morning) and the remaining water above the sand is run to waste. The water within the bed is then lowered about 100mm below the surface of the bed by opening the drain valve.

Cleaning the Filter

Cleaning should start as soon as the dirt cover is dry enough to handle. If the filter is left too long, it is likely to attract scavenging birds that will not only pollute the filter surface but disturb the sand to a greater depth than will be removed by scraping. If, as is normal, mechanized methods are not available, workers using square bladed shovels should strip off the dirt cover and the surface sand adhering to it and stack it in ridges or heaps for removal.

Great care should be taken to minimize disturbance of the upper layers of filter media so that the biomass is protected. For this reason, dumpers or other machines used for removal should be designed to operate with low pressure tyres and barrows or handcarts should always be run on protective planks.

Cleaning is a simple matter when the dirt cover consists largely of filamentous algae forming an interwoven mat. The knack of curling back this making reasonably large section is quickly acquired, provided that the operation is timed so that the material is neither waterlogged nor so dried out that it is brittle. Cleaning will be less easy if the dirt cover consists largely of non-filamentous algae and greater care will be necessary to control the depth of scraping, which should be between 15 and 30mm.

After removal of the scrapings the bed should be smoothed to a level surface. The quicker the filter-bed is cleaned the less will be the disturbance to the biomass and consequently the shorter the period of re-ripening. The microorganisms immediately below the surface will quickly recover, provided they have not been completely dried out, and will adjust to their position relative to the

new bed level. A day or two should be sufficient for re-ripening in this event.
Before refilling the filter, the walls below normal top water level should be swabbed down to discourage the growth of slimes and algae.

Refilling the Filter

The filter is refilled by closing the drain valve, reopening the outflow valve and allowing the filtered water to back flow through the under drain system until there is sufficient depth on the sand surface to prevent disturbance of the bed by inflowing raw water. When the filter is sufficiently charged the outflow valve is closed. The raw water inlet valve is then gradually opened and the filter is filled to normal operating level.

Disposal of Scrapings

The material removed from the filter, depending on the size and available equipment at the works. May be washed for reuse or disposed of on land by burial or used in agriculture. The workforce who scrape the filters or wash the sand should be instructed in necessary hygiene practice.

Recommended Procedure for Re-sanding Slow Sand Filter

Each cleaning of the filter removes between 10 and 15 mm of filter sand, so that after twenty or thirty scrapings the thickness of the sand bed will have been reduced to its minimum design thickness, usually about 300mm and re sanding is then necessary. The following procedure is recommended for re-sanding a slow sand filter. The filter can either be re-sanded by the 'trenching' method which makes use of the residual sand, or by refilling with new sand. Generally, re-ripening of the filter is quicker if the trenching method is employed.

Preparation

The bed is cleaned, as described in section 5.3.2 above, and the water level lowered to the bottom of the sand layer

A. Re-sanding - The 'trenching' Method

Most of the residuals and is removed from a strip of the filter along one wall thus forming a trench, taking care not to disturb the underlying gravel layer by leaving 100 to 150 mm of residual sand above it. The sand is placed adjacent to the filter for later re-use. Fresh sand (either new or washed sand from filter cleaning) is placed in the trench to a thickness which, with the residual sand, equals the depth of sand in the filter prior to re-sanding or as determined in consultation with the designer.

Residual sand from the adjacent strip is "thrown over" on top of the freshly placed sand in the first strip, fresh sand is placed in the second trench just formed and sand from the next adjoining strip is "thrown over".

This process is continued until the entire filter has been re-sanded and the residuals and from the first strip is placed on top of the last strip filled. In this way, the residuals and forms the upper layer of the re-sanded filter and the new sand the lower layer. The filter-bed may have a layer of crushed shells incorporated near the bottom, to correct the pH, where the raw water is naturally aggressive. The residue of the shell layer must normally be removed and replaced during re-sanding operations. The consultant recommends, a layer of activated carbon about 100mm deep is placed near the bottom of the filter-bed to absorb traces of taste and odor-producing substances that have passed through the filters. This layer should be removed and replaced during the re-sanding operations, as the carbon will have become saturated with the impurities and/or inactivated.

B. Resanding – clean Sand Method

An alternative to the trenching method described above is to remove all the old sand from the bed down to the support gravel and refill with clean sand.

Refilling the Filter

The bed should be smoothed to a level surface and refilled with filtered water through the under drainage system.

Re-ripening the Filter

The ripening of a filter with clean sand will take longer than the time for re-ripening a filter re sanded using the trenching method. Care must be taken to ensure that a satisfactory quality out flow is being produced before the filter is put back into service.

5.4.2 Capacity Building

- The availability of trained technical personnel within the community is important for the O&M of the system. Hence, training of such technical people and provision of continuous support is very critical for sustainability. Various modules of training plans should be developed based on need. Some of these are listed below:
- The provision of turbidity measurement kits and strengthening the reporting capacity on the situation of the water supply system.
- At states/locality level enhancing construction supervision activities, monitoring and technical backup as well as on water quality monitoring including the provision of mobile water quality testing kits.
- At federal level a refresher workshop on slow sand filter design, construction and operation and management for all stakeholders.

The management, operation and maintenance of slow sand filters require skilled personnel. Skilled, trained people who understand how slow sand filters function should be assigned at states/localities as well as at each location of a slow sand filter.

5.5. Treatment Plant Management and Control

5.5.1 Introduction

Proper management of the water treatment function (in addition to proper plant operation and maintenance) is vitally important in order to safeguard the health of consumers and to ensure optimal utilization of available resources (water, money, manpower).
Management can be defined as those actions and activities (of a manager) required realizing desired objectives through the inputs and efforts of other people (typically subordinates, but also other groups such as colleagues, contractors, consultants, suppliers, etc). This definition refers to the general tasks of all managers and includes the following activities: planning, organizing, staffing, leading, controlling. In addition to these general tasks of all managers, each manager also has certain specific technical or administrative tasks that are different for different managers.

5.5.2 Management Roles in the Water Treatment Function

There are different levels of managers involved in the water treatment function of any organization. This range includes the Chief Executive, Engineering Manager, Plant Manager or Superintendent, Chief/Senior Process Controllers or Operators, Foreman, etc., each with specific administrative and/or technical functions in addition to the general management functions of planning, organizing, staffing, leading and controlling. These managers must all contribute towards achieving the overall goals of the organization. Let us now consider different functional aspects in wastewater treatment and examine the role of different levels of managers in each function.

Water Quantity Management: The amount of wastewater treated and the variation must obviously be known to plan and control the efficiency of the envisaged treatment plant. Projections for future wastewater generation must be done to allow sufficient time for planning and construction of extensions or to build a new treatment plant or to divert it the planned central treatment plant of the City. These planning activities are normally expected to be done by a specialist planning function, i.e. higher level of planning. The plant manager must have access to this type of information to make provision in his planning and budgets for any possible new developments.

On the operations side the water quantity aspect or more specifically the plant water balance is important, as it is the primary factor that determines costs and the economy of the operation. In order to manage this function properly at the plant level the following information is required on a daily basis:

- Raw water intake
- Treated water produced
- Volume of sludge from septic tank /dirt material from slow sand filtration
- Percentage water and wastewater loss in different processes and overall for the plant

This information will alert the plant manager for inefficiencies and must prompt investigations to improve efficiency if the performance falls below design levels or if it is lower than that of comparable plants. Since large volumes of water are produced and the losses are typically very small, accurate information is required.

Another important aspect is how the plant output relates to design capacity. When the demand is low, i.e. when the plant operates under capacity there is little pressure to optimize operations. However, when demand grows and it is sometimes required to operate the plant in excess of design capacity, the management input becomes much greater. It then becomes critical to optimize all processes, to keep equipment in full operation continuously, to plan for maintenance, etc. Under such conditions the effective manager will successfully perform the management functions of planning all aspects of the operation, motivating and leading the whole team, and controlling that everything goes according to plan.

Water Quality Management: One of the key functions of managers involved in wastewater treatment is to ensure that the quality of the water produced complies with the requirements for discharge to the river. In water treatment for discharge to the river the specific process requirements must be achieved, e.g. TSS, BOD, COD heavy metals and other biological constituents must be treated to the required level.

As a first step the treatment plant should be designed to accomplish the specific water quality criteria decided upon by the organization, taking into account the raw water quality, variations in water quality, the size of the population to be served, the characteristics of the distribution system, etc. The philosophy of multiple barriers when treating polluted water must be built into the design. The design should then be translated into an operation manual in which the philosophy of the design is spelt out and specific operated instructions given for each process, group of processes and the plant as a whole.

The performance of the different processes and the whole plant must be monitored for certain key operational constituents in the water and a quality surveillance program must be developed for the final water.

The selection of treatment processes, and all accessory materials must be addressed in the design of the plant and in the operations manual. However, it is the plant manager who must manage all aspects of the process, from the development of a monitoring and surveillance program, through all other management aspects down to control and the taking of corrective action in order to ensure that no water leaves the plants that does not comply with the set quality requirements.
Record keeping of essential information on analysis and operational performance is vitally important for possible queries or complaints regarding the quality of water produced.

Cost Management: The total cost of treatment includes a number of cost elements including capital, repairs and replacements, maintenance, electricity, cost of raw water, laboratory costs, staff costs, cost of water losses, etc. The contribution of each of these elements to the cost of water must be determined on a monthly basis. These cost contributions must be analyzed, inefficiencies identified and savings measures instituted where necessary.

The cost elements consist of fixed and variable costs. Fixed costs are those that remain unchanged irrespective of the volume of water treated. It includes capital and staff costs and the cost of laboratory and other services provided. Variable costs are directly related to production and include the cost of electricity, maintenance, etc. It is important to determine these costs accurately and maintain a full record of all costs.

Budgets and Budgetary Control: One of the most important functions of a plant manager is to compile the annual budget for the operation of the treatment plant, in order to ensure that sufficient funds are available for operation and maintenance of the plant.

If the procedure is followed all the cost details are available to facilitate the process of budgetary control. This means that monthly financial reports must be compiled and compared with the approved budget. Any items where deviations occur must be investigated, the reasons for deviation ascertained and a programme of corrective action developed to rectify the situation.

Management of Plant Performance: All the processes in a treatment plant must individually and as a whole perform according to specification in order to produce treated water of the required quantity and quality at the lowest cost. The plant manager and his staff must have a good knowledge of the operating principles and characteristics of each process, what needs to be done to optimize operation of each process and the plant as a whole, what the possible causes of malfunctioning or under performance could be, possibilities for upgrading processes and performance. These activities should involve the plant manager, operators as well as laboratory staff.

In order to be able to optimize processes, or to identify and quantify possible problems, accurate record keeping of certain key parameters is necessary. These include flow, retention times, physical and chemical parameters and visual inspections and observations. However, just accumulating sheets and sheets of daily or hourly data does not mean much and is often a source of frustration for operators if they have the perception that nothing is being done with the data. The records must be analyzed and transformed into usable information. Today it is rather simple even with a basic PC to calculate and plot running averages, to determine trends in data, to get the system to pick up deviations from pre-set limits, etc.

One of the important functions of a manager is to lead and motivate his team. Discussing operating performance on a daily or weekly basis with teams and setting of performance target is an excellent way of achieving this. At the same time such discussions can also be used to perform the manager's controlling function by setting action in motion to rectify deviations.

The provision, retention and training of operators to enable them to carry out their functions in the best way possible are perhaps the most demanding management task of the plant manager.

Management of Plant Integrity: Proper functioning equipment is a prerequisite for a proper operating plant. Management of the servicing, maintenance and replacement function of a treatment plant is one of the important functions of a plant manager.

This entails a number of aspects, including:

- Establishing complete schedules of all equipment that needs servicing and maintenance with details of the frequencies of action to be taken
- Establishing a program of actions by servicing and maintenance staff to carry out the required actions
- Controlling that these programs are carried out properly
- Developing inspection schedules and techniques to detect imminent problems before they occur

5.5.3 Proposed Management Structure of Waste water Treatment

The Operations of the treatment plant shall be supervised by a dedicated Operations Management Committee comprising of external professionals and experts. The members (governmental bodies) may have minimal involvement in day-to-day operations of the plant. The O & M of plant can be outsourced for qualified private companies under a contract pinning responsibilities and accountability or it can be managed by the municipality by establishing organizational structure of its own. The issues relating to plant performance, technical difficulties, operations problems, etc. will be resolved by Operations Management Committee (OMC).

The Operations Management Committee will ensure that the plant operates to its best potential and provide recommendations for up gradations as and when required. Chief Executive Officer (CEO) will look after day to day issues of plant operation and conveyance related issues. There will be a team of qualified personnel from Engineering and Science field having experience to operate the treatment plant efficiently and effectively. The OMC will ensure to comply with all the directives issued by competent authority time to time for smooth functioning of the proposed treatment plant and legal compliance in this regards. The OMC will set up the hierarchy for operation, maintenance and monitoring of the treatment plant with the individual job chart.

Guidelines for Management, Operation and Maintenance of the plant issued by Ministry of Environment, Forest and Climate Change and Addis Ababa Environmental protection Authority in collaboration with City river project office will be followed to operate the plant effectively and efficiently. Maintenance Schedule of the treatment plant for various units will be planned in advance, considering standby storage facility, availability of manpower, availability of required spares, equipment parts, maintenance tools, safety equipment, and other required facility, so that maintenance activity will be completed without any delay.

The developer will set up the sophisticated laboratory equipped with facilities for carrying out analysis of environmental related samples, i.e. water, wastewater, and hazardous wastes. The treatment plant can use the laboratory facilities of Addis Ababa environmental protection Authority until it will establish its own laboratory.

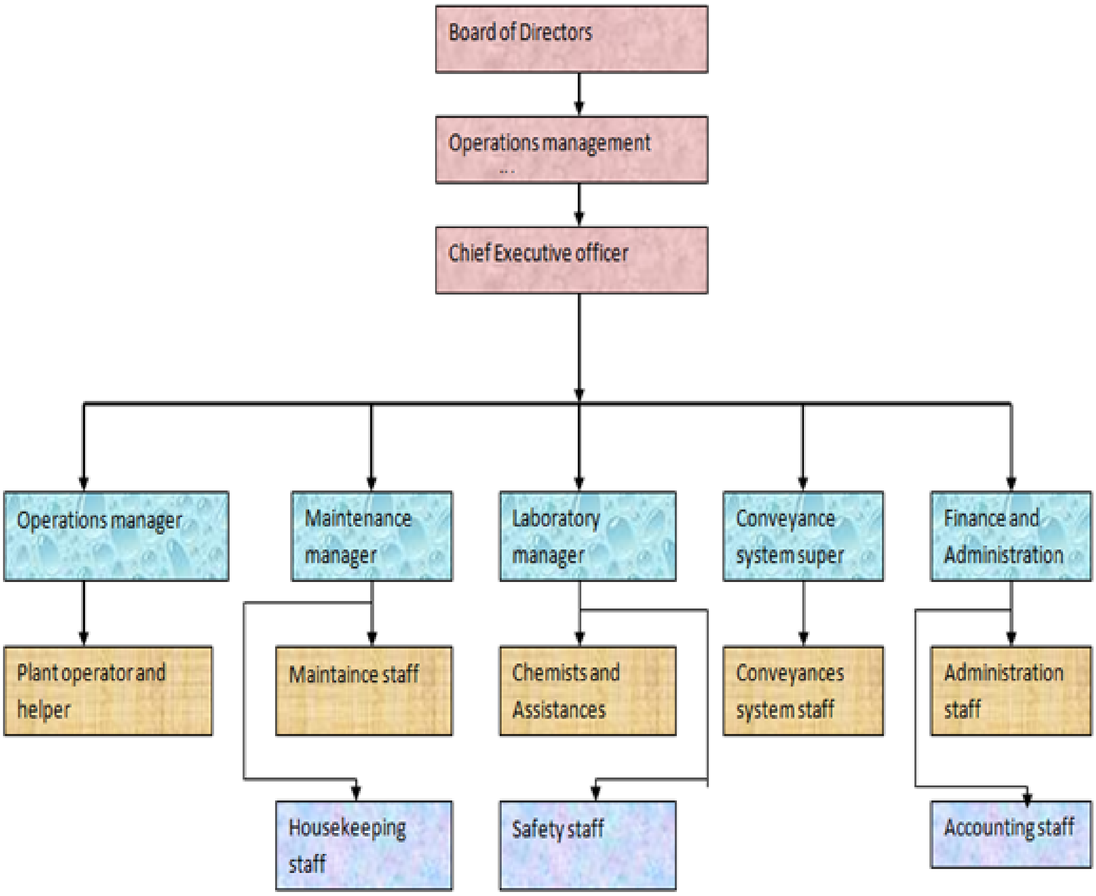


Figure 69: Organizational Chart of the Treatment Plant Operation and Management

Table 40: Estimated cost for Treatment Plant management and operation

S/N	Activity	Estimated Cost per Annum in Birr
1	Basic salary of onsite workers	720,000.00
2	Cost of daily laborers for cleaning of the sand filter	276,000.00
3	Cost of electricity	240,000.00
4	Cost of occupational safety	120,0000.00
5	Other costs such as maintenance cost , resanding , training and etc	67,000.000
Total		**1,423,000.00**

5.6. Monitoring of the Treatment Plant

Monitoring is an essential component for sustainability of any developmental project. It is an integral part of Environmental management plan. Any development project introduces complex interrelationships in the project area between people, various natural resources, biota and the many developing forces. Thus, a new environment is created. It is very difficult to predict with complete certainty the exact post-project environmental scenario. Hence, monitoring of critical parameters is essential in the post-project phase.

5.6.1 Checklist for Operation

For proper operation of slow sand filters, various activities are required at various times. One or more persons might be responsible for the activities. People that take part in the activities could be pump operator, trained technician, daily labor etc depending on the type and agreed upon management and operation modalities of the treatment system. Therefore, the person(s) responsible for each level of activities should perform and document that:

On daily basis:

1. Check the raw water intake (some intakes may need checking less frequently)
2. Check and adjust the rate of filtration
3. Check water level in the filter
4.Check water level in the clear water well
5. Sample and check water quality
6. Check pumping system, if pump is used
7.Check for residual chlorine, if chlorination is applied
8. Enter observations in the logbook of the plant

On weekly basis::

1. Check and grease any pumps and moving parts
2. Check the stock of fuel; order more if necessary
3. Check the distribution network and taps; repair if necessary
4. Clean the site of the plant

On monthly basis:

1. Scrape the filter beds if necessary
2. Wash the scrapings; store the retained sand

On yearly basis: Re-sand the filter unit

Other components are dependent on the scope and type of monitoring information that is provided. The primary aim of monitoring is to provide information that will aid impact management, and secondarily, to achieve a better understanding of cause-effect relationships and to improve the efficiency of the treatment methods.

Monitoring will be used to:

- Check their compliance with agreed conditions and standards;
- Facilitate impact management, e.g. by warning of unanticipated impacts; and
- Determine the accuracy of impact predictions and the effectiveness of the treatment plant.

Monitoring of environmental indicators signal potential problems and facilitate timely prompt implementation of effective remedial measures. It will also allow for validation of the assumptions and assessments made in the present study. Monitoring becomes essential to ensure that the mitigation measures planned for environmental protection function effectively during the entire period of project operation. The data so generated also serves as a data bank for prediction of post project scenarios in similar projects

5.6.2 Parameters Needs to be Monitored

Chemical characteristics of select parameters of the effluent will be monitored by assigned staff of the river and riverside cleansing management office on daily or weekly basis and the data will be sent to the operator of the treatment plant. Chemical characteristics of select parameters and the flow rate of the effluent inlet and the effluent outlet to the plant will be carried out on weekly basis.

The parameters to be monitored are as follows:

Sewage effluent flow (per hour and per day)

- **Physiochemical Characteristics**
    - o pH
    - o COD
    - o Total Dissolved Solids (TDS)
    - o Suspended Solids (SS)
    - o Oil & Grease
    - o BOD
    - o Total Kjeldahl Nitrogen
    - o Ammoniacal Nitrogen (as N)
    - o Total Residue Chlorine
- -Chromium (total) (as Cr)
    - o Copper (as Cu)
    - o Lead (as Pb)
    - o Nickel (as Ni)
    - o Zinc (as Zn)
    - o Arsenic (as As)
    - o Mercury (as Hg)
    - o Cadmium (as Cd)
- -Fluoride (as Fe)
    - o Boron (as B)

Surface Water

Physiochemical Parameters: pH, Salinity, Conductivity, TDS, Turbidity, D.O., BOD, Phosphates, Nitrates, Sulphates, Chlorides.
Biological/Microbiological Parameters: Phytoplankton (No. of species and their density), Zooplanktons (No. of species and their density), Total Coliform (TC), and E. Coli.

Table 41: Summary of Environmental Monitoring programmed for implementation during project operation

S/N	ASPECTS	PARAMETERS TO BE MONITORED	FREQUENCY OF MONITORING	LOCATION
1	SEWERAGE EFFLUENTS			
	Physico-chemical parameters	Flow rate, pH, COD, Total Dissolved Solids (TDS), Suspended Solids (SS), Oil & Grease, BOD, Phenolic compounds, Total Kjeldahl Nitrogen, Ammoniacal Nitrogen (as N), Cyanide (as N), Total Residue Chlorine, Chromium (total) (as Cr), Copper (as Cu), Lead (as Pb), Nickel (as Ni), Zinc (as Zn), Arsenic (as As), Mercury (as Hg), Cadmium (as Cd), Fluoride (as Fl), Boron (as B)	Weekly	At inlet and outlet of the plant

Table 42: The cost required for implementation of Environmental monitoring program during operation phase

S.N	Parameter	Annual Cost in Birr
1	surface water	720,000.00
2	Cost of laboratory	720,000.00
3	other costs	72,000.00
4	Total	1,512,000.00

5.7. Implementation Approaches for River Environment Restoration

Sequence of measures to restore a healthy river environment is introduced together with the activities to be undertaken on step by step basis.

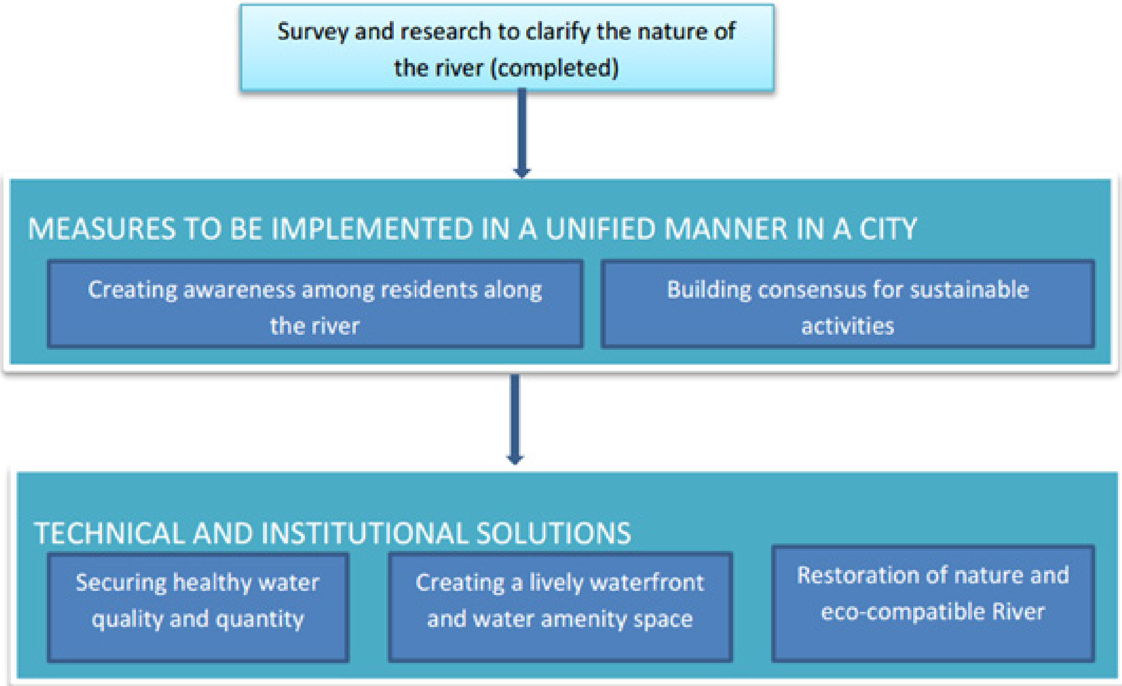


Figure 70: Counter measure chart for river restoration

5.7.1 Techniques to Achieve Implementation Approaches

This counter measure introduces concrete techniques /policies to achieve Implementation approaches for river environment restoration (Adopted from Asian River restoration Network guideline, 2009)

Survey and research to clarify the nature of the river (completed by different teams of the project but requires further ratification of the assessment at different time)	
Phase 1: **Principle Cconcept**	Collection of basic information for understanding the river
	Studies and research to obtain new knowledge
Phase 2 : **Basic Approach**	Collection and classification of basic information (channel shapes, growth and habitation of living things, hydrologic data, water level, water quality, etc.)
	Survey on the nature and social properties around the river (grasp basic properties according to nature and climate, living environment, industrial economy, social culture etc.)

	Hydrologic survey (rainfall, water level, flow volume, flow velocity etc.), water quality survey (physical/chemical water quality, biological water quality)
	Survey on waterfront utility , facilities, river landscape etc.
	Grasp of the ecosystem in river zones (physical characteristics of the ecosystem dynamics, characteristics of vegetation, etc. in the river zones)
	Grasp the condition of water cycle system (basic survey/method of leaning past/present/future condition of water cycle system, etc.)
	Quantitative measurement by water pollution analysis etc., and forecast
	Collection of related guideline on river restoration
Phase3: Advanced Approach	Promotion of research and survey for obtaining new findings (setting of water quality items, elucidation of water pollution phenomena, development of prediction/evaluation techniques, study on river ecology etc.)
	Implementation of pilot projects for deeper understanding and recognitions (setting of model rivers etc., implementation of pilot projects)
Creating awareness among residents living along the river	
Phase 1: Principle/ concept	Environmental education and capacity building
	Information sharing
Phase 2: Basic Approach	Establishment of information sharing system
	Public announcement and publicity activities for the effect of the project (information provision to mass media, etc.)
	Public relations and awareness rise on river restoration (brochure, newsletter, books etc.)
	Information dispatch (river condition, water quality, water level safe information etc.)
	Environmental education
Phase 3: Advanced Approach	Program development of environmental education and personal training
	Establishment and publication of data base on rivers, establishment of support center
Building Consensus for Sustainable Activities	
Phase 1: Principle/concept	Building consensus and legal/institutional Scheme
	Co-ordination with stakeholders (cooperation and adjustment with various plans)

Phase 2: **Basic Approach**	Local commitment (basic policy, cooperation between promoting bodies, promotion system, assessment)
	Installation or reconstruction of legal and institutional framework
	Economic evaluation of environmental value
	Training of facilitators for helping consensus formation
	Others (installation of public –involvement system, town meeting)
Phase 3: **Advanced Approach**	Establishment of co-researcher/technological development organization by public sector combination
	Development of river management system
Securing Healthy Water Quality and Quantity	
Phase 1: **Principle/Concept**	Approaches toward water quality
	Approaches to improving quantity of flow
Phase 2: **Planning /Design**	Setting environmental standards for water quality (health items, living environment items, etc.)
	Setting consolidation object of water quality (appropriate goals according to the purpose of the water use, causes of contamination, etc.)
	Legislation concerning wastewater control (factory law, agricultural chemicals regulation law, water pollution control law, Environmental pollution prevention act, etc.)
	Comprehensive measures concerning water pollution (water quality conservation measures, river water quality conservation measures, etc.)
	Formulation of sewerage plan (design of Central treatment plant at the City level), improvement plan/ improvement of proposed design for treatment facilities (sewage treatment, sludge disposal, storm water drainage plan, water treatment facility, etc.)
	Improve proposed project cost (calculation of construction cost and Maintenance expense, etc.)
	Adaptive /step-by step implementation of project (adaptive management that performs a project step by step with feedback to the plan according to situations).

Phase 3: Construction/maintenance	Direct purification technology for river execution method, device considered for the site
	Construction method for sewage treatment method facilities etc. and device considering for the site (construction of piping facility, pumping station facilities, water treatment facilities, sludge treatment facilities, etc.)
	Implementation of continuous monitoring (water quality control[river, sewage facility, etc.]
	Implementation of follow-up and assessment (environmental standards achievement ratios and proper assessment of the effect of policies)
	Formulation of monitoring method and implementation of monitoring (implementation method, system establishment, etc. for monitoring pollutant sources).
Creating a lively water front and water amenity space (the detail of the plan is describe by land scape team)	
Phase 1: Principle/concept	Creating a waterfront in the City
	Water amenity activities to re-discover the attraction of the water front
Phase 2: Planning /Design	Formulation of river landscape plans (development of good rivers cape)
	Formulation of policy to utilize the environment, disaster prevention, and space function providers by the rivers).
	Planning recreation activities related to history and culture
Phase 3: Construction/Maintenance	Construction method considering the surrounding environment and device considered for the site (construction with less impact on the surrounding environment)
	Implementation of continuous (monitoring for conservation of river landscape etc.)
	Setting and implementation of Maintenance (formulation of a Maintenance plan etc.)
Restoration of Nature and Eco-compatible River	
Phase 1: Principle/concept	Securing the continuity of the river

Phase 2: Planning/Design	Conserving a diversified ecosystem by using the regenerative ability of the nature
	Setting the environment to be preserved
	Formulation of a nature-friendly river work project (measures for cancelling problematic river works, and measures for raising the entire level of the river works)
	Formulation of a nature restoration project plan
	Plan harmonizing flood control with environmental policy (particularly urban river improvement plan, Maintenance of flood control function, conservation of biodiversity, etc.)
Phase 3: Construction/Maintenance	Engineering method, construction method, and device considered for the site in nature restoration projects, consideration for elements that influence the river and structure of their surrounding space, securing continuity with branch rivers and flood areas through correction level difference in water surface, etc.
	Implementation of follow up and assessment (impact evaluation and minimization of harmful impact)

5.8. Stakeholders for Rehabilitation of Addis Ababa River and Riversides Restoration

1. Ministry of Environment, Forest and Climate change
2. Addis Ababa Environmental protection Authority (AAEPA)
3. Addis Ababa Water supply and Sewage management Authority (AAWSA)
4. Addis Ababa Health Bureau
5. Addis Ababa River and river side restoration project office
6. Addis Ababa Solid waste Management Agency
7. Addis Ababa sanitation beautification and park development agency
8. Addis ababa urban agriculture office
9. Oromia Rural land and Environmental Protection Bureau
10. Oromia Health Bureau
11. Oromia Agricultural Bureau

6 CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Anthropogenic contamination of the water bodies is a growing concern. In many parts of the world this remains a major challenge, especially in urban areas where a large number of people live in a relatively smaller area. Addis Ababa is one example of this and including the BKK + K , little Akaki and big Akaki rivers and its tributaries, all degrade the surrounding environment and threaten local community's health.

From the survey findings in the study area all the rivers in Addis Ababa City are severely polluted has been evident from our findings that, the water quality of the Kurtume, Kebene, Kechene Banteyeketu, little Akaki and big Akaki rivers shows pattern of behavior linked to anthropogenic sources with the intensity of human pressure associated with industrial effluent, domestic wastes and agricultural activities. The pollution sources are typically associated with a very compacted living conditions of citizens (slum areas), various hotels and restaurants mostly built at the edge of the rivers, presence of numerous schools (KGs, Primary schools, secondary schools and colleges), hospitals and health centers, printing enterprises, condominium apartments, car washes, fuel stations, etc. Most of these sources do not have proper waste management systems and the wastes are being directly discharged into the rivers. The solid wastes and wastewater loads from the various pollution sources shows that generation of solid wastes from the various enterprises is estimated at 270.49 m3/day, whereas that of wastewater is 4,525.11 m3/day.

Most of the measured variables showed a similar declining quality trend from up to downstream of the river. High concentration and variation of pollutants along the river course was found mostly inside and outside (upper and downstream) the City of Addis Ababa. This variation likely arises due to the rapid urbanization and industrialization the City.

Except DO all parameters analyzed in the study, the values and variation of these parameters increases spatially along the river course. Most of the measured variables showed a similar declining quality trend from upper stream to downstream of the rivers. The major tributaries of the City rivers also added to the pollution load of the rivers, as they are used as a receptacle of all kinds of wastes. Except total dissolved solids, sulphide, and pH; most of the evaluated parameters are beyond the limit of irrigation water quality standards.

The values of certain parameters have been evaluated with respect to the acceptable standard limits and guidelines for drinking and surface water. An increase in BOD, COD, NH_3^-N, Pb, Cd and Ni levels and a decrease in DO concentrations downstream of the Kebena and big Akaki were observed with increasing domestic, industrial and agricultural activities in the downstream. The Pb, Cd, Ni, and Cu concentrations exceeded most common surface water quality criteria (; 0.05, 0.0) for big Akaki river. little Akaki displayed the highest peak and showed concentration variation of both parameters during the dry season. The general spatial setting also showed that the little Akaki is the recipient of most of the pollutants than Big Akaki. And this is likely because the big Akaki only traverse through residents and commercial centers. Whereas, the little Akaki passes through the highly concentrated industrial, agricultural and municipal parts of the City of Addis Ababa.

Based on the technical standard grade system and WHO drinking water guideline (2004), the water quality of the little and big Akaki river basins have been classified as badly polluted to very badly (grossly) polluted water (Grade IV to V). Obviously, in neither of the grade categories, is the water suitable for domestic uses and or irrigation. The presence of trace metals in the tested samples indicates that industries have a significant contribution to surface water pollution. The presence of high concentrations of fecal and total coliform bacteria in the samples indicates fecal matter pollution. Concentrations of fecal coliform along these rivers were also significantly increased downstream with little Akaki being the severely contaminated indicating that City rivers are the major sources and culprits of waterborne infectious diseases.

The discharge of untreated effluent, solid wastes and wastewater from industries, households and institutions are the main sources of water pollution in Addis Ababa. Water pollution due to fecal matter contamination and poor sanitation practice may be the major cause of the top ten leading causes of outpatient visit, hospital admission and death among children and elderly, in Ethiopia in general and Addis Ababa City in particular. Poor sanitation and sewerage coverage as well as lack of strong monitoring strategy is responsible for water quality change

6.2. Recommendations

- Establishing regular water quality monitoring program for all the parameters to ensure the safety of the river waters, the health of the community and the integrity of the river ecosystems.
- Initiate cleanup of solid wastes already dumped into the City rivers on a case by case basis involving communities and the youth residing along the rivers.
- Establish environmental management systems (EMS) geared to improve solid waste collection and management as well as sewage treatment will help address pollution problems.
- City wide sewage management through connecting all sewer lines to the established and to be established wastewater treatment systems as a permanent and lasting solutions

- Enforce decentralized wastewater treatment systems for all small, medium and large scale industries including service giving institutions such as health centers, condominiums, hotels, and etc.
- The proposed management and technological options should be combined with proper education, community awareness and participatory processes.
- Landscaping and beautification should give due attention to rivers physical restoration with proper restoration of river banks with selected indigenous plants for increasing nutrient retention capacity and self-purification ability of the river systems.
- For good river water recharge especially during dry seasons, proper watershed management at the upper catchment is desirable.

References

Abdul R. M., Mutnuri L., Dattatreya P. J. and Mohan D. A. (2012).Assessment of Drinking Water Quality Using ICP-MS and Microbiological Methods in the Bholakpur Area, Hyderabad, India. Environmental Monitoring and Assessment 184 (3): 1581–92.

Alemayehu, T., 2005.Uncontrolled ground water exploitation from vulnerable aquifer of Addis Ababa, Ethiopia. International Workshop on groundwater management in arid and semi arid countries. 4-7 April 2005, Cairo.

Bettinetti, R., Giarei, C., &Provini, A. (2003).A chemical analysis and sediment toxicity bioassays to assess the contamination of the River Lambro (Northen Italy).Archives of Environmental contamination Toxicology, 45, 72–80.

Canadian Council of Ministers of the Environment (CCME-online), http//www.ccme.ca/publications.html, 1999.

EPA (2005). Assessment of the Akaki river pollution status. Unpublished Report, Environmental Protection Autority, Addis Ababa Environmental Protection Agency and Oromia Environmental Protection Office, Addis Ababa.

El-Bestawy E., El-Masry M. H., and El-Adl N.E. (2005).The potentiality of free Gram-negative bacteria for removing oil and grease from contaminated industrial effluents.World Journal of Microbiology and Biotechnology. 21: 815–822. 12.

European Community (EC), "Protection of the environment" Official Gazette of EuropeanUnion, No.L.229/11-229/29, 1980.

Facchin, S., Alves, P. D. D., de Faria, S. F., Tatiana, M. B, J´unia, M. N. V.And Evanguedes, K. (2013)."Biodiversity and secretion of enzymes with potential utility in wastewater treatment," J. Ecology.3 (1): 34–47. 13.

Farnleitner, A.H., Hocke. L. Beiwl, C., Kavka, G.G., Zechmeister T., Kirschner A.K.T., and MACH, R.L. (2001): Rapid enzymatic detection of Escherichia coli contamination in polluted river water, Letters in Applied Microbiology, 33, 246-250.

Fissha Fissha Itanna, 2002. 'Metals in leafy vegetables grown in Addis Ababa and toxicological implications'. Ethiopian Journal of Health and Development 16(3):295-302.

Fissha Fissha Itanna, 1998. Metal concentrations of some vegetables irrigated with industrial liquid waste at Akaki, Ethiopia. Ethiopian Journal of Science 96 Vol. 21(No. 1): 133 144.

GirmaTadesse, T. (2004) Solid Waste Management, University of Gondar in collaboration withMinistry of Health, Ethiopia.

Gueguen, R. Gilbin, M. Padros, and J. Dominik, "Relationship between water hardness andmetal toxicity", Appl. Geochem., 2004, 19, 153-159.

Hollert, H., Keiter, S., Konig, N., Rudolf, , Ulrich, M., &Braumbeck, T. (2003). A new sediment contact assay to assess particular-bound pollutants using zebrafish (Daniorerio) embryos.Journal of Soils and Sediments, 3, 197– 207.

Jernstrom J., Lehto J., Dauvalter V., Hatakka A., Leskinen A., Paatero J. 2010. Heavy metals in bottom sediments of Lake Umbozero in Murmansk Region, Russia.EnvironmentalMonitoring and Assessment.Vol. 161. P. 93–105. DOI 10.1007/s10661-008-0730-7

Jiao, Y., Zhao, Q., Jin, W., Hao, X., & You, S. 2011. Bioaugmentation of a biological contact oxidation ditch with indigenous nitrifying bacteria for in situ remediation of nitrogen-rich stream water. Bioresource technology, 102(2), 990–5

Kavka, G. G.&Poetsch, E. (2002): Microbiology. - In: Technical Report of the InternationalCommission for the Protection of the Danbue River. Eds. PéterLiteráthy, VeronikaKollerKreimel, Igor Liska. Eigenverlag ICPDR. 138-150.

Kiely, G. (1997).Environmental Engineering. McGraw-Hill. England. P 628 26.

Lan W.U., Gang, G.E. and Jinbao W.A.N. (2009). Biodegradation of oil wastewater by free and immobilized YarrowialipolyticaW29, J. Environmental Sciences.

Liu J., Li Y., Zhang B., Cao J., Cao Z., Domagalski J. 2009. Ecological risk of heavy metals in sediments of the Luan River source water.Ecotoxicology.Vol. 18. P. 748–758. DOI 10.1007/s10646-009-0345-y

Macfarlane, G. R., & Burchett, M. D. (2000).Cellular distribution of Cu, Pb and Zn in the greymangrove Avicennia marina (Frorsk.)Vierh. Aquatic Botany, 68, 45–59.

Makino T., 2012. National Instytue for Agro-Environmental Science. Japan, 3: 1-3.

Martin-Puertas C., Valero-Garces L., Pilar Mata M. Moreno A., Giralt S., Martinez-Ruiz F., Jimnez-Espejo F. 2009. Geochemical processes in a Mediterranean Lake: a high-resolution study of the last 4,000 years in Zonar Lake, southern Spain. Journal of Paleolimnology. DOI 10.1007/ s10933-009-9373-0

Molla D, Stefan W ,Tenalem A. 2006. Vol.51.pp 421-431. Soil and groundwater pollution of an urban catchment by trace metals: case study of the Addis Ababa region, central Ethiopia.

Moussavi, G., Mahmoudi, M., & Barikbin, B. (2009). Biological removal of phenol from strong wastewaters using a novel MSBR. Water research, 43(5), 1295–302.

Pendias, A.K., and Pendias, H. (1984). Trace elements in Soils and Plants. CRC Press, Inc., Boca Raton, Florida

Pipe-Martin, C., Reungoat, J. and Keller, J. (2010) Dissolved Organic Carbon Removal by Biological Treatment. Water Quality Research Australia, Adelaïde (Australia).

Prabu, P. C., 2009. Impact of heavy metal contamination of Akaki River of Ethiopia on soil and metal toxicity on cultivated vegetable crops:Electronic Journal of Environmental, Agricultural and Food Chemistry, Vol. 8 No. 9 pp. 818-827.

Rao, V. S.,and Yoshida 2004. "An Ecological Study of Three Freshwater Ponds of Hyderabad- India.I. The Environment*."Hydrobiologia38(2): 213-223

Reeve (2004) "Introduction to Environmental Analysis", Wiley Publications, London,

Ruan, X., Xue, Y., Wu, J., Ni, L., Sun, M., & Zhang, X. (2006). Treatment of polluted river water using pilot-scale constructed wetlands. Bulletin of environmental contamination and toxicology, 76(1), 90–7.

Saeed, T., & Sun, G. (2012). A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: dependency on environmental parameters, operating conditions and supporting media. Journal of environmental management, 112, 429–48.

Sahu, K. R., Katiyar, S., Tiwari J. And Kisku, C. G. (2007). "Assessment of Drain Water Receiving Effluent from Tanneries and Its Impact on Soil and Plants with Particular Emphasis on Bioaccumulation of Heavy Metals," J. Environmental Biology, 28 (3): 685- 690. 37.

Singleton, V.L.& Rossi, J.A. Jr.(1965).Colorunetryof total phenolics with phosphomolybdic-phosphotungstic acid reagents. Amer. J. Enol. Viticult.16:144-58.

Sun, L., Liu, Y., & Jin, H. (2009). Nitrogen removal from polluted river by enhanced floating bed grown canna. Ecological Engineering, 35(1), 135–140.

TamiruAlemayehu, DagnachewLegesse, TenalemAyenew, YirgaTadesse, Solomon Waltenigus and Nuri Mohammed (2005).Hydrogeology, Water Quality and the Degree ofGround Water Vulnerability to Pollution in Addis Ababa, Ethiopia.UNEP and UNESCO. AddisAbaba, Ethiopia.

Travis, M.J., Weisbrod, N. And Gross, A. (2008). Accumulation of oil and grease in soils irrigated with grey water and their potential role in soil water repellency. Science of the Total Environment. 394: 68–74. 43.

Tripathi BD, Sikandar M, Shukla SC. Physicochemical characterization of City sewage discharged into river Ganga at Varanasi, India. Environment International 1991; 17: 469-78.

UN-Habitat and CGAA (City Government of Addis Ababa) (2005).Inner City Slums andNeighbourhood Upgrading Programs in Addis Ababa. Addis Ababa, Ethiopia.

United State Environmental Protection Agency (USEPA), "Handbook for Capacity Development. Developing Water System Capacity under the Safe Drinking Water Act", Office of Water (WH-550), Washington, DC, 1989.

Wang, J., Liu, X. D., & Lu, J. 2012. Urban River Pollution Control and Remediation. Procedia Environmental Sciences, 13(2011), 1856–1862.

Wang, R.-C., Wen, X.-H., & Qian, Y. (2005). Influence of carrier concentration on the performance and microbial characteristics of a suspended carrier biofilm reactor. Process Biochemistry, 40(9), 2992– 3001

Weldesilassie, A. B. (2008). Economic Analysis and Policy Implications of Wastewater Use in Agriculture in the Central Region of Ethiopia. Ph.D. Dissertation. Institute for Farm Management, University of Hohenheim.

Viessman, W. And Hammer, M.J. (1998). Water Supply and Pollution Control. Sixth edition. Addison Wesley Longman, Inc. Menlo Park, California. P 827. 44.

Zhang J, Huang WW, Letolle R, Jusserand C. Major element chemistry of the Huanghe (Yellow river), China weathering processes and chemical fluxes. Journal of Hydrology 1995; 168(1-4): 173-203.

Annex

Annex 1. Study Team Members

Name of Experts	Role	Institution
Seyoum Leta (PhD)	Environmentalist, Team Leader	Centre for Environmental Science, Addis Ababa University (AAU)
Andualem Mekonen (PhD)	Environmental Science	Pollution, Centre for Environmental Science, AAU
Eshetu Alemu (PhD Fellow)	Environmental Science	Pollution, Centre for Environmental Science, AAU
Tadesse Alemu,(PhD)	Environmental Microbiology	Centre for Environment al Science
Zerihum Abate (MSc)	Environmental Engineer	Addis Ababa Institute of Technology, AAU
Eyob Yilma (MSc)	Civil/Sanitary Engineer	Ethiopian Institute of Architecture and Building Construction (EIBC), AAU
Gulelat Teshome (MSc)	Water and sanitation expert	Addis Ababa Water and Sewage Authority
Hanna Habtemariam (PhD Fellow)	Environmental Toxicology	Centre for Environmental Science, AAU
Challa Ragassa (PhD Fellow)	Environmental Chemistry	Department of Chemistry, AAU
Mesfin Sahle (PhD Fellow)	GIS expert	EIABC, AAU

Annex 2: Description of Selected Sample sites

Big Akaki Sampling Sites

SAMPLE CODE	SAMPLE SITE	NO OF SAMPLING POINTS	SAMPLE SITE AREA DESCRIPTION
BA1	CHAFEE (ENTOTO)	1	**Source of Kechene River:** 1 **Local Name** = Chaffe • The water is used for drinking (spring development) TDS=80, PH=7.4, • Soil brown **Down to the River** • It covers areas above Shiromeda and is characterized by a relatively high relief and forest covered land features, no industrial point sources, and a radial drainage pattern. **Buffer Zone**- undisturbed • Only few vegetation on the river bank • Eucalyptus (white), '*sensel,* Junipers (Local). • In some part zero buffer zone **Pollution Load** • Open defication is common on the river bank especially estern part of *Entoto Mariam* • Solid waste dumping and open defecation on river sides • The river is connected to domestic waste, drainage and swear line • House built on the river • Community toilet near to the river (4m) • Water: offensive odder, dark brown colour • *Guarage* and massive car wash stations
BA2	KERSA RIVER	1	**Source of Legetefo/Kersa River** • **The upper part of the catchment is agricultural activity** • The sources of 'Abadho and Tafo is 'Kersa spring. • While searching for Kersa through the condominium we have seen that the municipality is building a Big canal that collects all the run-off and 'sewer line channeled to Tafo river' •The sewer line from Abaddo condominium was overflowing and discharged to Tafo River. • ***The social issue is considered as it has detrimental effect on the rehabilitation existence and healthy of the river.***

BA3	**AFIN-CHO-BER**	**2**	**Junction point b/n Kechene 1 and Kechene 2** Little vegetation, Unplanned settlements on the bank **Buffer zone** • Very steepy slop, with settlement to the eastern **Pollution load** • Water: color brown, high pollution load, turbid and smelly • Car wash station on the shore of the river • domestic waste discharge line connected to the river • Open defecation **Selection criteria** • To assess the pollution load from Kechene 1 and Kechene 2
BA4	**TAFO RIVER**	**1**	**Channel of the River:** The River bends here and there. The water flows on the basalt /igneous type of Rock. Width of the river is estimated to be (10-12m). **River Bank:** The land next the river /bank is very steepy/high slope (left of the River). • This is estimated to be about (15-18m). The settles to the left of this river at this point is estimated to be about (40-50m). • There is open Space (land) to the left upper of the river which can be developed to "wetland " The settlements to the right of the river are very near to the river Bank. The vegetation cover is poor (sparsely planted). **Flood Plain:** The flood plain to this river is very low /very minimum **Water Flow:** The flow is very high during the site visit and expected to much higher during winter. However, the flow during the summer is very minimum almost dry. • The flow during the summary mainly sourced from sewer of 'Abadho condominium •Water: depth 20cm, 2m width and veloCity 0.5 m/s • **Pollution:** the river is polluted by solid waste (municipal) and open defecation and at the bank of the river • Drainage and sewer discharge due to the new settlement around the river.
BA5 **BA6**	**FILWUHA**	**2**	**Two sampling Site:**Kurtume and Kechene • Junction point between Kurtume and Kechene **Pollution Load** • Toilet connected to both rivers • Solid waste damping along the river cannal and dranage system that directly channeled to the rivers • Hospital waste discharge (Tikranbesa and Zewditu hospital) channeled to the river **River Bank** •Vegetation and bamboo on river banks • Selection criteria –To assess the pollution source between two rivers –To assess the combined pollution effects of upper tributaries
BA7	**KEBENA**	**1**	Below mixing with Minilik Hospital waste (Discription of the river will be done)

BA8 **BA9**	**PEACOCK PARK**	**2**	Junction point between Banteyiketu and Kebena • Domestic wastes discharge in to the river • EC 730, TDS 370 and pH 7.76 Buffer zone = – Urban agricultural area in the west and settlement in the south and east – Pekok recreational area in the north **River Bank**- wetland grasses and vegetation **Pollution Load** • Turbid, pungent smell • Kebena looks darker in colour than Banteyiketu • Domestic waste line connected to Kebena river at Bole bridge
BA-10BA11	**Bal'oo/Gerji river**	**2**	**Junction between Gerji river and Beshalle** • Gergi river: is more brown color, foul smelling, carries domestic solid wastes • The water flows on a wider area of plain of Akaki. • Buffer zone: no vegetation cover • Few rural settlement • Disturbed by a number of quire, stone crash **Flood Plain:** The flood plain to this river is moderately high run off from the agriculture; a number of crusher sites a located along the river. • The crusher plants located along Akaki River from Bole to Kaliti are highly affecting the life and livelihood of the society. • It is one of the reasons for the pollution, landslide and erosion and infiltration of the springs. • The crushing plants should be handled as socially and environmentally irresponsible way. ***Recommendation:*** *The crusher sites needs to rehabilitate the site. They need to socially responsible.*
BA12 **BA 13**	**BOLE** **BULBULA**	**2**	**Junction point between Kebena and Akaki (Bulbula)** **Pollution Load** • Akaki contain dissolved soil • EC 780, TDS 390 and pH 8.2 • Big kebena has brown colour and forming foam • High sediment load in the Akaki river Buffer Zone • The buffer zone bear with some bushes in the bank of the river • Disturbed by quarry/mining activities
BA 14	before Aba Samuel	1	**Before Aba Samuel (End of project site)** • Before aba Samuel lake • Year round agricultural area • EC 730, TDS 370ppm and pH 7.7 • Intensive Agricultural practices
TOTAL NO. OF SAMPLES		**14**	

Little Akaki Sampling Sites

SAMPLE CODE	SAMPLE SITE	NO OF SAMPLES	SAMPLE SITE AREA DESCRIPTION
LA15	GULALE ENTOTO		**Shegole River Source** **River Bank:** the left and right of the river are covered with Gulalle Botanical garden (forest). No settlement is seen around the river sources. The water is undisturbed with low sediment load. **Flood Plain:** run off is not expected because of the good vegetation coverage in the area. **Water Flow:** The water flow during the site visit was very small. But it is expected to be very high during the rainy season. **Vegetation Cover:** The vegetation cover is managed and relatively good. **Pollution Load :** There was no human interference at the source area
			Source for Gefersa River-Upper Stream of Little Akaki • Is situated 18 km west of Addis Ababa • The Gefersa River and its feeder streams are part of the Akaki river catchment. • The area surrounding the reservoir is covered by grasses and eucalyptus woodland, while the croplands are situated far from the reservoir area. • The dominant land cover types found in the catchment area are: grassland, eucalyptus woodland (young and mature) and wooded – shrub-grassland which are important for environmental protection. • The water comes out of the Gefersa might contain heavy metal residue of the treatment system.
			Shegole River and Medhanialem River Junction **Buffer Zone:** Protected, no settlement within 25 m river bank **Channel of the River:** The River bends here and there with black columnar basalt rock. **River Bank:** • Width of the river is estimated to be about (25-30 m). • The river has more than 25 m buffer zone to the left and to the right. • There is a protected forest to the right of the river which locally called Arba-Arat forest. • To the left of the river which is uphill covered with bushes but there is a probability of bank erosion. • To the North of the river the area between densely populated village and river is covered with 'Enset' or false banana. • After the two rivers join they flow down from high elevation and form a beautiful fountain 'fuafuate" **Flood Plain:** The flood plain is very minimum **Water Flow:** The water flow during the site visit was moderately high. But it is expected to be very high during the rainy season. **Vegetation Cover:** The vegetation cover is very good. **Pollution Load:** The water is highly polluted with solid waste, sediment load, industries, commercial and institutional wastes.

LA18 **LA19**	**MEKEN-ISA AND KERA RIVER**	**2**	**Channel of the River:** The river bends here and there. The river flows on the alluvial soil. **River Bank:** The river flows on the plain area with left and right of wide urban agriculture. **Flood Plain:** The flood plain to the river is moderately high from the agriculture. **Flow:** The flow is very high during the site visit and expected to much higher during winter. **Vegetation Cover:** vegetation cover on the river banks **Health:** The water is highly polluted with solid waste, sediment load, commercial, Industrial and institutional wastes. **Source of Pollution:** Residential, commercial, industrial, urban agriculture
			Junction Point between Two Rivers from Kera and Mekanisa Sewer line connected to the river **Source of Pollution:** Residential, commercial, industrial, urban agriculture.
LA 21	**LOWER LITTLE AKAKI**		**To see the effects of pollution load on the downstream of little Akaki river**
AB22	**ABA SAMUEL**		**To be completed**

Annex 3: Checklists to Assess the Potential Environmental Pollution Impacts of City Rivers

This check list/questionnaire is prepared to assist in the collection andcompilation of waste wand wastewater management practices in the City; pollution sources identification and categorization along the rivers; as mapping pollution sources and types, etc.

1. Description of the river

Name of the River-------------

- Tributaries ---------------------
- River bank description -------------------------
- Mouth ----------------------------
- Wetland----------------------
- Depth of the river------------------
- Width of the river-------------
- Flow rate-------------------------
- Vegetation coverage (very good, good, bad), local name of the trees
- Settlement pattern (very near, near, far),
- Rock type-------------------
- Volume of waste disposed to the river (solid, liquid etc.) -------------
- Economic contribution of the river ---------------------------

2. Current Surrounding Land Use

Direction	DISCRIPISION
North	
East	
South	
West	

3. Is there any sewer line and drainage connected to the river?
4. Is there any buffer zone along the river? If yes ------m from the river
5. Is there any open defecation?
6. Is there any toilet facility in the community? If yes what type?
7. Which types of pollutants are common in the sampling point and upper catchment? Industrial, domestic, hospital, commercial…
8. Are there any rehabilitation requirements?
9. Which types of Akaki river pollution risks are common on the sampling sites?

- Odors - prevailing wind direction
- Surface water pollution – risk
- Ground water pollution – risk

  o Distance to nearest bore hole/well
  o Presence of aquifers
  o Shallow ground water table
  o Deep ground water table
  o Uncertain

- Soil contamination - risk

  Chemicals and Oils
  Animal by-products
  Pathogens
  Micro-organisms (e.g. Nematodes)

- Pathogens (Water-associated diseases e.g. typhoid, salmonella, nematodes, faecal coliforms, bacteria, etc

10. What will be the use of the river? Inputs and Outputs
11. What type of insecticides and pesticides are used by the farmers?

Interviewee

Name: --------------------------. Organization/----------------------
Title---
Years associated with the site ---
Site Information: ____
____

Annex 4. Dry and Wet Seasons City Rivers Water Quality Parameters

Annex 4A. Dry season organic matter and nutrient status of Kechene, Kurtume and Banteyeketu rivers

Location	S.No		DO	COD	BOD	TN	NH3-N	SO42-	S2- (mg/l)
Chefa	KC1		8.35	16±0.3	8.39±0.02	1.39±0.5	0.12±0.06	5.033±0.12	0.0011±0.35
Afinchiober	KC2		4.83	88.7±15	21.3	90±0.5	19±0.76	31.2±0.28	0.0106±0.55
Kecheniee	KC3		4.69	171.7±17	10.5±0.01	124±0.12	17±0.22	30.7±0.5	0.0053±0.61
Kurtumee	KU1		4.14	378.7±0.7	47.9±0.01	198±0.1	31.9±0.23	29.5±0.37	0.3187±.58
Banteyeketu	BY1		5.97	86.33±0.6	22.8±0.05	54.2±0.3	14.2±0.76	26±0.01	0.0223±0.25
Pecok	KB11		5.53	25.3±0.6	11.2±0.001	58.5±0.6	10.3±0.3	29.87±0.26	0.0343±0.25
Big Kebena	KB12		5.78	36.4±4	27.9±0.011	77.13±	1.66±0.02	8.37±0.55	0.0648±0.7

Location	S.No	pH	Temp.	EC (µs/cm)	Cl-	TDS	TSS	Hard	ALK	Turb
Chefa	KC1	6.53	19.5	53.07	44.9±0.13	46.5±0.4	3.2±0.26	74.97 ±0.1	75.9±0.1	1.2±0.4
Afinchio-ber	KC2	7.923	21	923.3	129.1±0.11	841.4±0.1	44±0.17	153.3±57	574.2±0.2	7.1±0.07
Kecheniee	KC3	8.013	23.4	780	397.5±0.3	702.7±0.4	50.1±0.1	350±0.3	545.8±0.4	4.94±0.3
Kurtumee	KU1	7.982	22.8	1063	186±0.22	951.2±0.12	111±0.25	399.7±0.7	726.8±0.15	2.1±0.09
Banteyek-etu	BY1	8.266	23.5	811.9	112±0.5	741.07±0.26	30.03±0.06	291±58	442.2±0.15	4.7±0.08
Pecok	KB11	8.055	23.1	710.8	84.5±0.1	484.9±0.1	10.03±0.06	90±0.16	413.6±0.5	37.8±0.4
Big Kebena	KB12	8.65	22.4	414.5	111.9±0.1	374.7±0.25	100.4±0.6	135.8±2.5	52.3±0.62	47.8±0.2

Annex 4B. Wet season organic matter and nutrient status of Kechene, Kurtume and Banteyeketu rivers

Location	S.No	DO	COD	BOD	TN	NH3-N	NO3-	PO43-	SO42-	S2- (Micg/l)	TSS
Chefa	KC1	7.6	34± 5.01	14.03± 5.12	2.4± 0.01	ND	2	0.9	ND	0.001± 0.001	ND
Afinch-iober	KC2	5.6	81± 20.2	74.98± 22.1	23.3± 0.32	7±0.31	7.8	14.3	42± 1.2	6.8± 0.091	70.5±0.1
Kechen-iee	KC3	6.3	499± 39	114.4± 30.12	17.8± 0.02	9.65±0.02	6.1	14.4	33.1± 0.06	4.9±1.0	111±0.04
Kurtumee	KU1	5.9	502± 33	146.74± 32.8	15.6± 0.6	15.9±0.12	0.9	25	60.1± 0.22	13.5±0.03	182±0.012
Banteye-ketu	BY1	6.5	481.5± 44	110.08± 0.1	17.8± 0.5	11.2±0.1	3.9	10.7	28.1± 0.01	7.9±0.05	727±0.032
Pecok	KB11	4.5	365± 23.6	80.14± 15.32	8± 0.07	11.5±0.04	0.5	19.7	18.2± 0.018	3.6±0.08	181.2±0.13
Big Kebena	KB12	5.1	165.8± 18	54.54± 13.18	28± 0.01	7.8±0.032	2.1	12.4	22± 0.034	4.3±0.06	112±0.021

Location	S.No	Temp. C0	pH	EC (Mic/s)	Cl-	TDS	Hard	Alk	TUR (NTU)
Chefa	KC1	18.2	6.13	38.04	6.22± 0.02	39.3± 0.01	35.3± 0.012	32.53± 0.2	1.2±0.01
Afinchiober	KC2	17.9	7.92	511.2	94.4± 0.05	460± 0.012	118.7± 0.9	78.23± 0.031	19.8±0.015
Kecheniee	KC3	18	8.3	448.9	73.8± 0.01	408.6± 0.025	171± 0.38	144.6± 0.1	11.5±0.72
Kurtumee	KU1	19.7	7.73	527.8	110.64± 0.03	486.3± 0.062	134± 0.13	152± 0.014	39.5±0.02
Banteyeketu	BY1	19.8	8.123	506.7	91.71± 0.05	458± 0.037	138± 0.09	180.8± 0.02	83.9±0.01
Pecok	KB11	20.5	8.3	381.1	66.8± 0.04	344.4.4± 0.07	107± 1.8	150.9± 0.032	93.2±0.012
Big Kebena	KB12	20.6	8.63	408.6	53.83± 0.013	369.6± 0.003	130± 0.025	161.4± 0.051	102.1±0.025

Annex 4C. Dry season Organic matter and nutrient status of Kebena rivers

Location	S. cod	pH	DO	BOD	COD	TN	NH3-N	SO42-	S2-
Entoto 1	Kb1	8.235	10.08	2.4±0.2	7.5±0.05	6.3±0.3	2.19±0.9	1.13±0.12	0.172±0.8
Entoto 2	Kb2	7.753	6.03	9±0.85	15±0.96	0.85±0.09	0.6±0.05	21.4±0.45	0.014±0.26
Hamle 19	Kb3	8.052	9.91	16.09±0.2	24.3±0.3	55.4±0.5	45.2±0.8	28.3±0.25	0.008±0.1
Wolamo River	Kb6	8.129	10.58	20.4±0.01	53.9±0.2	24.3±0.25	13.8±0.01	23.2±0.2	0.039±0.25
Denkaka River	Kb7	8.561	9.97	3.4±0.001	9.7±1.5	13.7±0.15	10.5±0.01	36.2±0.12	0.027±0.5
Fafatie River	Kb4	8.209	12.35	13.6±0.01	24.3±0.5	49.97±0.2	14.5±1.3	29.5±0.41	0.056±0.1
Kebena at GE	Kb5	8.283	5.33	28.6±0.03	81±17	30.5±0.07	22.6±1.2	25.4±0.37	6.028±0.25
Kokebetse-bah	Kb8	8.416	5.87	25.6±.03	71.2±1.4	74.9±0.4	24.6±0.2	30.1±0.1	0.048±0.26
Ginfle	Kb9	8.103	5.02	52.3±0.01	149.7±12	133.9±0.3	42.2±0.4	26.23±0.24	0.098±0.12
Uraeal	Kb10	8.307	5.53	6.58±0.02	19.3±1.2	50±0.25	9.73±0.3	23.33±0.17	0.079±0.5
Pekock	BA11	8.06	5.02	28.3±0.6	68.97±0.1	12.1±0.2	1.8±0.01	28.03±0.05	0.029±0.5
Big Kebena	BA12	8.055	5.53	25.3±0.6	11.2±0.01	58.5±0.6	10.3±0.3	29.87±0.26	0.034±0.25
Standard			5.5-9.5				0.1	<200	<1

Location	S. cod	Temp	EC (Mic/s)	Cl-	TDS	TSS	Hard	ALK	TUR
Entoto 1	Kb1	22.2	52.98	51.5± 2.7	637.5±0.5	9.04±0.05	60.5±0.45	39.8±0.03	3.92±0.1
Entoto 2	Kb2	22.5	372.2	112± 0.7	741.8±0.1	10.24±0.25	80±0.1	104.7±0.35	3.1±0.1

Hamle 19	Kb3	21.9	725	121.4± 1.3	428.7±0.2	11.2v0.15	162±0.6	393.87±0.32	3.9±0.1
Wolamo river	Kb6	22.3	450.7	124.3± 0.1	276.7±0.5	2.3±0.25	167.5±0.06	267.9±0.4	73.2±0.2
Denkaka river	Kb7	22.2	953.7	198.6± 0.5	559.4±0.6	39.2±0.29	287±0.34	522.1±0.25	28.9±0.1
Germen Embacy1	Kb4	22.5	795.4	84.7± 0.3	474.3±5	10.4±0.52	145v0.1	433.7±29	1.2±0.03
Germen Embacy2	Kb5	22.4	671.3	99.5± 0.6	402.8±0.7	8.24±0.39	115±0.1	378.5±0.2	39.6±0.5
Kokebe tsebah	Kb8	22.2	754.5	89.4± 0.22	429.4±0.5	4.13±0.15	130 ±0.05	424.8±0.3	49.2±1.1
Ginfle	Kb9	21.5	740.3	149 ± 0.3	443.33±2	36±0.8	249.8±0.3	487.4±0.15	13.2±0.2
Uraeal	Kb10	22.1	725.1	131.3± 0.4	450.2±0.1	4.13±0.32	233± 57	400.8±0.7	10.6±0.2
Pekock	BA11	23.4	708.1	116.8± 0.1	637.13±0.2	8.03±0.06	250±0.11	413±0.1	3.9±0.1
Big Kebena 1	BA12	23.1	710.8	84.5± 0.1	484.9±0.1	10.03±0.06	90±0.16	413.6±0.5	37.8±0.4
Standard			750	100	500		100-200		

Annex 4D. Wet Season Organic Matter and Nutrient Status of Kebena Rivers

S. code	Location	pH	DO	COD	BOD	TN	NH3 -N	NO3-	PO43-	SO42-	TSS
KB2	Entoto 1	7.34	7.83	62± 0.07	16.2± 0.12	1.7± 0.01	0.28± 0.02	2.9	0.6	34± 0.01	ND
Kb3	Hamle 19	7.61	4.84	153± 0.01	53± 0.01	1.9± 0.2	3.9± 0.1	19.5	60.1	48± 0.085	362± 0.01
Kb6	Wolamo river	7.712	3.45	152± 0.06	48.9± 0.32	5.7± 0.13	1.9± 0.06	12.5	64.3	290± 0.12	527± 0.04
Kb7	Denkaka river	7.84	2.5	86.5± 0.02	28.1± 0.01	8± 0.8	5.4± 0.03	73	59.3	71± 0.07	494± 0.3
Kb4	Fafatie river	8.06	2.1	53± 0.08	42.32± 0.1	3.6± 0.5	18.8± 0.03	71.9	65.9	280± 0.1	727± 0.02
Kb5	Kebena at GE	8.23	1.96	27± 0.04	25.3± 0.2	16± 0.35	6.5± 0.03	86.2	47.4	63± 0.06	389± 0.13
Kb8	Kokebets-ebah	8.6	2.53	28± 0.051	9.34± 0.061	137± 0.1	11± 0.02	26.1	11	57± 0.03	100±0.021
Kb9	Ginfle	8.36	2.57	200± 0.01	68± 0.003	8.1± 0.78	4.9± 0.068	23.8	51.9	270± 0.6	457±0.9
Kb10	Uraeal	8.42	2.68	78± 0.035	27.3± 0.06	8.3± 0.01	5.4± 0.051	-	39	76± 0.032	325±1.1

KB11	Pekock	8.05	4.5	365± 23.63	80.2± 15.3	8± 0.07	11.5± 0.04	0.5	19.7	18.2± 0.018	3.6±0.08
KB12	Big kebena	8.65	5.1	165.8± 18	54.54± 14	28± 0.01	7.8± 0.032	2.1	12.4	22± 0.034	4.3±0.06

S. Code	Location	T e m p C0.	EC (Mic/s)	Cl- (mg/l)	TDS (mg/l)	Hard (mg/l)	Alk (mg/l)	TUR (NTU)
KB2	Entoto 1	20	133.3	19.94± 0.02	119.5± 0.031	80±0.02	32.9±0.01	1.2±0.01
Kb3	Hamle 19	17.5	20.9	34.8± 0.7	18.71± 0.11	67±0.05	22.6±0.21	380±0.05
Kb6	Wolamo river	19.3	74.3	16.95± 0.21	67.13± 0.32	26±0.75	26.6±0.06	394±0.02
Kb7	Denkaka river	19.9	106.6	24.92± 0.09	95.3± 0.07	59±0.023	40.2±0.01	395±0.62
Kb4	Fafatie river	19.5	101.6	23.92± 0.057	100.1± 0.036	49±0.65	41.8±0.02	490±0.1
Kb5	Kebena at GE	18.8	137.3	25.92± 0.03	123.3± 0.01	59±1.05	39.6±0.032	486±0.2
Kb8	Kokebetsebah	18.4	418.2	25.9± 0.04	376.7± 0.02	108±0.14	133.4±0.011	200±0.05
Kb9	Ginfle	18.4	156.6	34.6± 0.02	141.1± 0.1	66±0.05	53.2±0.01	52.2±0.1
Kb10	Uraeal	18.5	208.5	37.9± 0.015	188.2± 1.03	59±0.01	68.2±0.021	196±0.06
KB11	Pecock	20.5	381.1	66.8± 0.04	344.4.4± 0.07	107±1.8	150.9±0.032	93.2±0.012
KB12	Big kebena	20.6	408.6	53.83± 0.013	369.6± 0.003	130±0.025	161.4±0.051	102.1±0.025

Annex 5A. Wet and Dry Seasons Organic Matter and Dissolved Oxygen of Little Akaki Rivers

Location (Sample code)	Sample Code	Dry Season			Wet Season		
		DO	COD	BOD	DO	COD	BOD
Sululta	LA1	13.47	26.66	6.91	8.9	3	0
Gefersasoa	LA2	14	15.33	5.23	8.06	37	1.6
44 River	LA3	9.89	246.33	51.89	6.9	35	11.4
Gofa	LA5	5.36	391	47.2	4.06	56.9	26
Kera river	LA6	5.04	284.67	137	5.35	149	90
Germen Bridge	LA4	5.01	1232.7	34.5	5.2	317	50
BehirewThige	LA7	10.9	191	39.8	3.2	683	194
Before Aba samuel	LA8	N	209	32	4.5	39	6
After Aba samuel	LA9	6.7	17	20	7.8	4	1

Annex 5B. Wet and Dry Seasons Nutrients of Little Akaki Rivers

Location (Sample Code)	Sample Code	Dry Season				Wet Season					
		TN	NH3 -N	SO42-	S2-	TN	NH3 -N	Nitrate (mg/l)	Phosphate (mg/l)	SO42-	S2- (Micg/l)
Sululta	LA1	1	0.2	3.9±0.1	2.2	5.8	0.16	1.9	2.7	38	5.2
Gefersasoa	LA2	42	0.09	32.7	240.5	2.8	0.29	2.7	2.3	7	2.1
44 River	LA3	48	2.33	40.8	100.3	8.9	5.5	2	4.7	26.7	8.9
Gofa	LA5	132.9	1.24	41.8	1395	1.4	0.9	0.9	50.3	27	11
Kera river	LA6	85.5	3.57	32.7	79.97	2.4	1.5	7	15.7	40	20.8
Germen Bridge	LA4	96	0.59	91.33	1438	13.4	8	2.8	47.7	21.7	6.8
Behirew Tsige	LA7	103.4	0.701	56.33	115	17.2	2.8	1	56.3	67	115
Before Aba samuel	LA8	189	57	40	Nill	16.27	3.2	1.47	Nill	28.1	Nill
After Aba samuel	LA9	2.3	0.66	Nill	Nill	4	0.86	0.26	Nill	15	Nill

Annex 5C. Wet and Dry Seasons Physical Parameters of Little Akaki Rivers

Location	Sample Code	Dry Season					Wet Season				
		pH	EC (Mic/s)	Cl-	TDS	TSS	pH	EC (Mic/s)	Cl-	TDS	TSS
Sululta	LA1	7.097	38.67	24.5	35.03	7.25	7.92	20.56	14.9	18.49	3.2
Gefersasoa	LA2	7.92	51.58	30.4	46.77	6.8	8.14	38.5	24.92	34.68	3.4
44 River	LA3	8.09	494.7	173.97	448.9	65.7	7.94	318	48.84	286.9	14
Gofa	LA5	7.103	1102	477.29	995.4	174.1	8.41	219.8	45.9	198.1	452.1
Kera river	LA6	7.89	874.9	159.38	787.1	248.9	8.4	558.9	83.73	502.4	400
Germen Bridge	LA4	8.015	687.3	139.2	619.6	82.5	8.19	300.1	57.81	270.2	131.5
Behirew Tsige	LA7	8.111	737.2	168.6	665.8	95.6	8.15	739	99.68	667.4	208
Before Aba samuel	LA8	8	573.2	142	899	219	7.82	931	27	218	40.5
After Aba samuel	LA9	7.8	137	57.5	410	9.8	7.82	972	25	184	25.3

Annex 6A. Wet and Dry Season's Organic Matter and Dissolved Oxygen of Big Akaki Rivers

Location (Sample code)	Sample Code	Dry Season			Wet Season		
		DO	COD	BOD	DO	COD	BOD
Kersa	BA8	10.08	9.33±9	3.84±0	5.8	58.6±0.006	30±0.012
Tafo	BA9	11.02	14.48±1.2	4.81±0.003	2.81	162±0.8	31.9±0.01
Beshale	BA10	5.26	56±13.9	6.4±0.03	1.75	108±015	33±0.038
Gergi river	BA11	5.82	13.58±37	4.3±0.02	1.18	77±0.13	38.6±0.2
Bulbula(Akaki	BA 13	6.98	118.7±21	9.4±0.04	2.75	80±0.06	39±0.05
Big Akaki	BA 14	6.34	53.67±4	25.7±0.3	3.24	824±0.0253	276±0.04

Annex 6B. Wet and Dry Seasons Nutrients of Big Akaki Rivers

Sample code (Location)	S . Code	Dry Season				Wet Season		
		TN	NH3-N	SO42-	TN	NH3-N	SO42-	S2-(Micg/l)
Kersa	BA8	1.34±	1.18± 0.05	7.33±0.5	4.3±0.01	1.2±0.02	5±0.06	0.53±0.1
Tafo	BA9	1.43±	1.89± 0.02	43.7±0.6	3.4±0.012	1.27±0.01	13±1.03	2.5±0.71
Beshale	BA10	122.2±	0.87± 0.02	24.4± 0.75	3.9±0.52	6.7±0.32	18±0.06	3.8±0.84
Gergi River	BA11	73.9±	5.013± 0.02	34.4± 2.9	9±1.6	8±0.012	36±0.22	6.9±0.008
Bulbula (Akaki)	BA 13	131±	3.18± 0.02	13.2± 2.8	4±0.031	7.9±0.61	20.5±0.01	73.1±0.009
Big Akaki	BA 14	82.9±	1.58± 0.02	20.2± 1.7	8.1±0.05	5.6±0.081	28±0.018	4.7±0.02

Annex 6C. Wet and Dry Season's Physical Properties of Big Akaki Rivers

Sample Code (Location)	S. Code	Wet Season					Dry Season				
		pH	EC (Mic/s)	Cl-	TDS	TSS	pH	EC (Mic/s)	Cl-	TDS	TSS
Kersa	BA8	8.48	102.6	7.97± 0.2	92.65± 0.1	117± 0.013	8.93	213.2	148.9± 03	194.9± 0.2	2.7± 0.26
Tafo	BA9	8.51	167	22.9± 0.16	150.7± 0.12	65± 0.01	8.682	333.2	111.8± 0.04	298.1± 0.17	35.7± 0.6
Beshale	BA10	8.07	308.5	41.9± 0.721	278± 0.01	272± 0.3	8.64	351.8	114.1± 0.2	316.3± 0.53	174.2± 1
Gergi river	BA11	8.25	422.9	59.8± 0.081	380.7± 0.63	451± 0.15	8.577	596	124.4± 0.2	537.2± 0.05	60.7± 0.8
Bulbula (Akaki)	BA 13	8.05	308.2	46.5± 0.035	278.2± 0.06	274± 0.042	7.93	577.6	126.7± 0.02	520± 114	401.4± 1.2
Big Akaki	BA 14	7.67	49.84	49.84± 0.3	327.4± 0.17	189± 0.025	8.25	478	124.3± 0.07	429.7± 0.45	88.5± 0.5

Annex 7A. Dry Season BKK River and KebenaRiver Microbial Count

S. Code	Location	TC (MPN/100ml)	FC (MPN/100ml)	E.Coli (MPN/100ml)
GA1	Entoto (Cheffe)		633.333	900
BA1	EntotoKebena		7333.333	4166.67
GA3	Afnchober	12000	7666.67	6300
5008	Uruel	5533.33	2500	1466.67
GA6	Kechene	373.33	240	206.67
BA7	Banteyiketu	7400	4500	2466.67
BA(6+7)	Big Kebena 1	3533.33	2300	2066.67
BA (10+11)	Gergi + Beshale (Bole Bulbula)	8000	4200	4000

Annex 7B. Wet Season BKK River and Kebena River Microbial Count

S. Code	Location	TC (CFU/100ml)	FC (CFU /100ml)
GA1	Entoto (Cheffe)	ND	ND
LA1	Sululta	2000	1000
BA3	Hamle 19	23000	13000
GA6	kebena	180000	152000
GA3	Afnchober	1*106	>1*105
LA4	Germen bridge	3000	2200
KC	Kurtume	>1*106	>1*106
Kb5	kokebetsebaha	1.14*107	1000000
GA6	kechene	>1*106	>1*106
Kb9	uraeal	8.9*107	1000000
BA7	Banteyiketu	>1*106	>1*106
BA(6+7)	Big kebena	239000	125000

Annex 7C. Wet and Dry Season of BKK River and Kebena River Microbial Count

S. Code	Location	Dry Season			Wet Season	
		TC (CFU/100ml)	FC (CFU /100ml)	E.Coli (CFU/100ml)	TC (CFU/100ml)	FC (CFU /100ml)
KB1a	Entoto (Cheffe)	100			633.333	ND
	Hamle 19				23000	13000
	Afnchober	12,000	7666.67	6300	1000000	100000
	Kechene	373.33	240	206.67	1.52*107	ND
KC	Kurtume				1*106	100000
	Banteyiketu	7400	4500	2466.67	1*106	100000
KB1b	EntotoKebena	ND	ND		ND	ND
KB5	Kokebetsebaha				1.14*107	1000000
KB9	Uraeal				8.9*107	1000000

Annex 8A. Sediment Heavy of BKK (Banteyektaw+ Kurtumee+ Kechene) Rivers

Sample Location	Sample Code	Heavy Metal in µg/g				
		Cd	Cr	Cu	CO	Pb
Chefa(Entoto) upp	GA1	ND	ND	ND	0.021±0.0537	ND
Sulultaupp	LA1	ND	ND	ND	ND	ND
Afinchiober mid	GA3	ND	ND	2.002±0.045	0.554±0.192	2.384±0.2643
Kachni mid	GA6	ND	ND	0.284±0.0052	0.6306±0.374	ND
Kurtumee mid	KC	ND	ND	0.5334±0.0241	0.265±0.3	0.554±00362
Banteyektaw low	BA7	ND	ND	0.235±0.0012	0.210±0.012	0.7±0.095
kebena low	BA(6+7)	ND	ND	3.6±0.003	0.006±0.110	0.35±0.21

Peackock low		ND	ND	0.53±0.0066	0.563±0.2	62.8±1.143

Annex 8B. Sediment Heavy of Kebena River

Sample Location	Sample Code	Heavy Metal in µg/g				
		Cd	Cr	Cu	CO	Pb
Entoto 1 UPP	Kb1A	ND	ND	ND	0.3458±0.00311	ND
Entoto 2 UPP	KbB	ND	ND	ND	1.017±0.0525	1.751±0.025
Hamle 19 M ID	Kb2	ND	ND	0.1759±0.0019	0.806±0.012	0.5598±0.0332
Wolamo river M ID	Kb6	ND	ND	ND	ND	ND
Denkaka river M ID	Kb7	ND	ND	ND	1.922±0.1008	ND
Fafatie river M ID	Kb3	ND	ND	ND	2.397±0.1794	ND
Kebena at GE M ID	Kb4	ND	ND	0.4023±0.086	1.82±0.0809	ND
Kokebetseba M ID	Kb5	ND	ND	0.41±0.0058	0.9988±0.1537	ND
Ginfle lower	Kb8	ND	ND	0.1653±0.0032	1.103± 0.1181	5.547±0.0.284
Uraeal lower	Kb9	ND	ND	4.426±0.0061	0.006±0.1101	356.6±0.3235

Annex 8C. Sediment Heavy of Big Akaki River

Sample Location	Sample Code	Heavy Metal in µg/g				
		Cd	Cr	Cu	CO	Pb
Kersa Upp	BA8	ND	ND	ND	1.681±0.263	ND
Tafo(baso9) Upp	BA9	ND	ND	0.1458±0.0007	1.991±0.1294	ND
Beshale Mid	BA10	ND	ND	0.0295±0.0028	0.114±0.0682	ND
Gergi river Mid	BA11	2.69±0.021	ND	0.0952±0.0026	0.9154±0.2520	ND
Bulbula(Akaki)Low	BA 13	ND	ND	0.6054±0.0223	1.017±0.0525	305.4±0.299
Akaki(BA1) Low	BA 14	ND	ND	0.152±0.032	0.2956±0.202	21.35±0.306
Gofa			ND	0.4352±0.0054	0.2363±0.303	0.523±0.0052
Peacock (sedB6+B7 soil				0.461±0.0168	0.336±0.31	60.22±0.629

Annex 8D. Sediment Heavy of Little Akaki River

Sample Location	Sample Code	Heavy Metal in µg/g				
		Cd	Cr	Cu	CO	Pb
Gefersa	LA2 Upper	ND	ND	0.2217±0.0199	ND	ND
44 River	LA3 Mid	ND	ND	0.2078±0.0122	ND	12.82±0.0227
Kera river	LA4 Mid	ND	ND	0.3949±0.0055	0.54±0.144	98±1.808
Gofa	LA5 Mid	ND	ND	0.022±0.01	ND	ND
Germen Bridge	LA6Mid	ND	0.3221±0.0167	1.158±0.005	ND	4.143±0.098
BehirewThige	LA7 Low	ND	ND	0.6503±0.0111	0.354±0.012	1.23±0.010

Annex 8E. Water Heavy Metals Characteristics µg/l (dry season)

S. cod	Location	Ni	Cr	Cu	CO	Pb	Cd
1	Chefa	1.41± 0.3	ND	0.23±0.3	ND	2.67±0.95	1.88±0.3

2	Afinchober	1.05±0.36	3.09±0.51	ND	ND	4.26±0.21	1.67±0.55
3	Kecheniee	0.75±0.36	11.09±0.29	ND	ND	5.95±1.46	1.19±0.03
4	Kurtumee	0.9±0.46	ND	ND	ND	7.15±0.94	1.18±0.25
5	Banteyeketu	1.49±0.02	ND	0.28±0.81	ND	6.13±0.1	1.13±0.52
6	Entoto 1	0.75±0.04	ND	0.38±0.23	ND	8.48±2.06	0.82 ±0.31
7	Entoto 2	0.68±0.13	ND	0.09±0.13	ND	10.15±0.74	1.27±0.63
8	Hamle 19	0.49±0.21	ND	0.53±0.24	ND	10.15±.75	1.48±0.42
9	Denkaka	1.03±0.09	ND	0.16±0.01	ND	3.44±1.61	1.46±0.20
10	Wolamo	0.68±0.19	ND	0.27±0.08	ND	3.93±1.47	1.44±.11
11	Germen Embassy 1	1.4±0.17	ND	0.19±0.1	ND	11.02±0.45	1.50±0.21
12	Germen Embassy 1	1.09±0.28	ND	ND	ND	2.61±.03	1.36±0.44
13	Kokebetsebah	0.69±0.34	ND	0.55±0.1	ND	3.35±.68	1.43±0.04
14	Ginfle	0.84±0.04	ND	0.31±0.01	ND	5.86±0.84	1.72±0.21
15	Uraeal	1.22±0.05	ND	ND	ND	4.39±0.15	1.75±.35
16	Pekok	1.02±0.07	ND	ND	ND	7.55±0.14	1.21±0.22
17	Big Kebena 1	0.78±0.35	3.66±0.2	ND	ND	8.08±1.2	1.4±.3
18	Big Kebena2	1.19±0.17	ND	0.45±0.98	ND	3.22±0.5	1.84±0.03
WHO Standard			0.1	0.2	0.05	0.01	0.1
FAO		0.2		0.2		5	0.01

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