Understanding the situation of wastewater irrigation in community based irrigation schemes

The case of Akaki catchment, Ethiopia

M.Sc. Thesis by Tadesse Animaw Sinshaw

August 2011

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Master thesis report for Irrigation and Water Engineering submitted for partial fulfilment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands.

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August 2011

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Acknowledgement

I wish to express my thanks to the Nuffic Netherlands Fellowship Programme for financing my M.Sc. study and research. My warmest gratitude goes to my major supervisor Dr. Ir. Frans Huibers for supporting me throughout the processes of research preparation to reporting phase. Your academic insight and critical reflections was very helpful throughout the research processing. Next, I would like to thank my local supervisor, Geremew Sahilu, for helping me during field data collection and his comments on progress of my work. Thanks are also extended to Dr. Liqa Raschid-Sally, URAdapt project leader and Dr. Semu A. Moges, partner in Addis Ababa University, for allowing me to conduct this study and use of facilities in Addis Ababa.

I would also like to thank local institutions; Addis Ababa Water Supply Authority, Ministry of Water and Energy, Urban Agricultural Development Bureau, Oromiya, Addis Ababa and Federal Environmental Protection Authority for their kind provision of data relevant to my research. I am also grateful to Assaye Ketema, for his help during water sampling for laboratory determination. My special thanks also go to all irrigators from Akaki River system for their kind willingness to answer my questions and share their experiences.

I would like to thank all, specially my parents, who have been on my side for successful thesis' completion. Finally I would like to thank all my friends for their support and encouragement for successful stay in Addis Ababa.

Abstract

Understanding the situation of wastewater irrigation helps to realize the risk it will pose for environmental, public and animal health and to give due attention to it for developing adaptation strategies. The objectives of this study were to assess water quality change of Akaki river system since the introduction of irrigation and farmers' adaptation corresponding to water quality change so that evidences of water quality challenges on irrigated agriculture were identified. Data were collected about water quality change of Akaki river system, waste management in Addis Ababa and its effect on Akaki river system, feature of traditional irrigation system and awareness of irrigators on water quality change. The finding revealed that the water quality of Akaki river system has changed remarkably over the past 40 years. The values of total coliforms and E.colis alarmingly exceeded WHO and FAO standard limits and are found as potential threat to public health. Some other interpreted parameters such as BOD, Mn, Cd, Co, Cr and Fe are beyond the acceptable level. There are proposed wastewater management plans by the concerned organizations, with implementation the water quality is expected to be improved in the next 30 year. However the total coliform and E.colis contamination is expected to challenge irrigated agriculture in the future as the origin of these contaminants are mainly slums which are too difficult to connect to the central sewerage system and open space sanitation which is difficult to manage.

On the socio-economic side land heritage from parents, market demand rise for vegetables and economical dependency; from technical factors accessibility of water with minimum expenditure, reliability and minimization for fertilizer application are found as the main argumentation to start irrigation. Farmers understand physical and chemical water quality change using direct and indirect indicators. While colour and physical observation are used as direct indicators, yield reduction and abnormal growth are used as indirect indicators for water quality change. Different adaptations were used to water quality change at field level such as irrigating when the water looks pure and clean, adjusting frequency of irrigation; field workers health risk protection by wearing boots and silt trapping at diversion structure. Besides this, local organization in the peri-urban area introduced tolerant crops that can mitigate or reduce risks of polluted irrigation and assist to adapt at field level. On the customer side, people from the main market area are observed buying the vegetables without a question of where it had grown. Some of the interviewed consumers mentioned that except children all family members used to eat raw vegetables which are treated with lemon juice.

Key words: Water quality change, irrigated agriculture, farmers, water quality parameters

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List of abbreviation

AA ....Addis Ababa

AAWSA..Addis Ababa Water Supply and Sewerage Authority

E-coli ....Escherichia coli

EPA..Environmental Protection Authority

FAO..Food and Agriculture Organization

WHO ....World Health Organization

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Chapter one: Introduction

1.1 Justification

Ethiopia is categorized as one of the least developed countries in the world with dominating agrarian community. Agriculture is the backbone of Ethiopia’s economy; it contributes more than 45% to the national GDP and 85% of the population livelihood depend on it (SDPRP, 2002). Despite its major contribution to the national economy, it has remained underdeveloped over the past years. Cultivation is highly dependent on rainfall where persistent drought and erratic rainfall has resulted in low performance of the agricultural sector. This puts the country to a large food self-sufficiency gap at national and food insecurity at household level (Teshome, 2006 in reference to EEA/EEPRI, 2004/05:145). The food insecurity makes poverty widespread in urban and rural areas with coverage of 33 % and 47 % of the respective population by 1995/96 (IMF, 2000). In this regards, the country confronts a challenge to alleviate the persistent problem of poverty.

Ethiopia is endowed with abundant water resources and fertile land with estimated gross irrigation potential of 3.7 million hectares (MWE, 2010). Despite this great irrigation potential, only 5% of potentially irrigable land is developed (Werfring, 2004). Shortage of financial capacity and skilled manpower are the main reasons for under development of water resource to stimulate agricultural economy. The state pursued for the development of medium and large scale irrigation schemes for production of cash crops (cotton and sugar cane) since the 1950s. However recently small scale irrigation schemes are found as effective in improving the livelihood of farmers and the national economy so that a focus shift is made. As a result the development of small scale irrigation schemes has continued under regional water bureaus. According to a 2004 assessment, a traditional irrigation scheme takes the largest share from total irrigated lands in Ethiopia (Table 1). This figure indicates the significant contribution of community based irrigation schemes.

Table 1 Type of irrigation schemes and estimated area

Scheme type	**Estimated area**	**Per cent of total**
Traditional	60,000	38.5
Modern communal	30, 000	19.2
Modern primate	6, 000	3.8
Public	60, 000	38.5
Total	156, 000	100

Source: Werfring, 2004

The research is conducted on one of the traditional schemes located in Akaki Catchment. The catchment harbours Addis Ababa, which is the largest and rapidly expanding city of Ethiopia. The population of Addis Ababa has grown alarmingly from 0.45 to 3.5 million between 1950 and 2008, and it is expected to grow between 4 and 8 million in 2030 (Figure 1). The high birth rates as well as rural to urban migration are the driving factors for rapid population growth than any cities in the country, according to Central Statistics Authority the growth rate is 3.7 % (CSA, 2005).

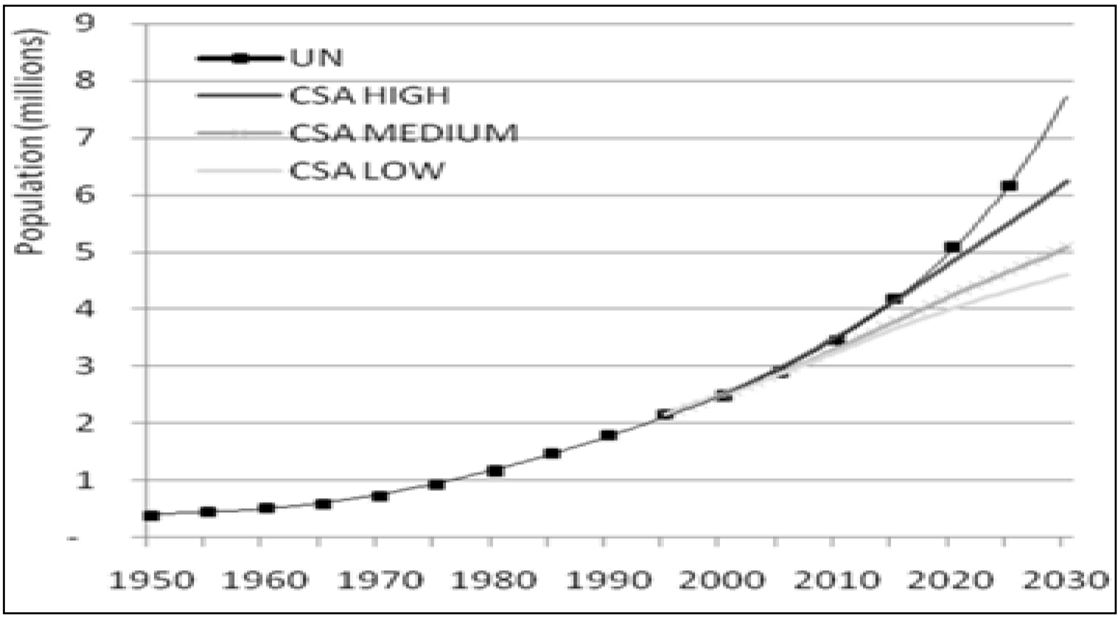


Figure 1 Population growth of Addis Ababa between 1950 and 2030

Source: CSA, 2005

Water demand for Addis Ababa city is supplied from both surface and ground water sources. The three river-fed reservoirs i.e. *Geferssa*, *Legedadi* and *Dire Dams* having a combined daily discharge of 195,000 m^3 are imported from surrounding rural areas. The three water reservoirs supply approximately 75% of the total supply. The remaining 25% supply comes from groundwater through 20 major springs, the Akaki and intercity wells systems with a combined daily discharge of 62,000 m^3 (AAWSA, 2005). The rapid population growth, expansion of industries and urban centres of Addis Ababa result in a rise of water demand. The 34th WEDC international conference report shows that the supply and demand gap for Addis Ababa is estimated to be 40-50%. In reaction new dams namely Sibilu and Gebri dam 30 km north of Addis Ababa are under construction (Van Rooijen, 2009). The water supplied for Addis Ababa return as a large volume of wastewater and contributes to the Akaki river flow.

The community based small scale irrigation in Akaki Catchment use Akaki River system as a source of irrigation water. The river has been used as a natural drainage for Addis Ababa city solid and liquid wastes. The natural water constituents of Akaki River have been changed due to urban wastes and thus the water quality for agricultural use becomes a point of focus. This research is aimed at understanding the situation of irrigated agriculture in Akaki River system by assessing water quality change and corresponding farmers' adaptation.

The research employed the reverse water chain approach, World Health Organization and Food and Agriculture Organization guidelines for agricultural water use. The concepts of reverse water chain approach were applied to understand the urban water system with a focus on interaction of upper stream polluters and end users (in these case irrigators) towards the water. By looking at upper stream wastewater management, base line information on water quality change in Akaki River system was investigated. Then farmers were studied to understand their adaptation strategy at field level in reaction to water quality change. To interpret water quality for agricultural use, the WHO and FAO guidelines are used. The research ends with recommendation for future challenges and suggestion for further studies.

1.2 Background

1.2.1 Rationality of urban agriculture and wastewater irrigation

Urban agriculture is the practice of growing crops in the vicinity of urban areas for cash earning or food producing activities. It can be categorized as homestead farming when farmers use their garden to irrigate mostly with tap water sources, or open space farming when a parcel of urban land used for agriculture with formal or informal land ownership. In case of open space agriculture farmers mostly takes the opportunities of direct or indirect wastewater use to support agricultural activities. Peri-urban agriculture on the other hand is practiced in between urban and rural transitional areas with direct or indirect wastewater use. In that sense, wastewater from cities is a valuable source of irrigation water to the majority of per-urban and urban farmers. Direct use of wastewater signifies the direct use of wastewater from collection or sewage channels, whereas indirect is to mean the use of wastewater after mixed with the natural river water.

Wastewater irrigation is substantially a growing worldwide practice. Globally, around 20 million hectares of land are irrigated with wastewater and this figure is likely to increase during the next few decades (Hamilton *et al.,* 2007). Wastewater irrigation has been practiced with several drivers. One, in water scarce areas (arid and semi-arid climate zones) the limited water source have insignificant contribution to support agricultural production, thus the direct or indirect use of wastewater is one way of sustaining agricultural production. Two, cities of low and middle income countries with rapid urban expansion produce a large volume of wastewater and this attracts farmers to enhance their agricultural practice with irrigated agriculture. Moreover, the rapid population growth results in market demand rise for vegetables which cannot be transported longer distance and encourages farmers near cities to grow vegetables. Three, the direct use of wastewater in some cases is driven by its ready availability compared with the huge cost needed to construct irrigation structures. Four, availability of plant essential nutrients from the biodegradable constituents of wastewater attracts farmers to use it for agriculture. In that sense, it enables farmers to reduce the expenditures on fertilizer and better production can be achieved. In some cases up to 37% increase in harvest is possible when raw wastewater is applied compared to freshwater irrigation with chemical fertilizer (Martijn, 2005 in reference to Shende, 1985; Scott et al., 2004).

Despite its positive contribution to stimulate agricultural production, unwise use of wastewater for irrigation has associated adverse impacts on environment public and animal health. Wastewater mostly comprised of organic matters, nutrients, heavy metals, pathogens and other miscellaneous constituents. The direct discharge of wastewater into nearby streams without pre-treatment will modify the natural water constituents. When the mixed water is used for irrigated agriculture, the wastewater constituents flowing to the field interferes beneficially or harmfully to the crop, environment public and animal health. When the concentration of harmful water constituents goes beyond the acceptable level, it has associated adverse effect on the crop, growing environment, public and animal health. However the presence of field management's practices like crop selection, minimum exposure for health risk, type of irrigation, field worker precaution and others can minimize the associated risks.

1.2.2 Describing the situation of Akaki catchment

1.2.2.1 Location

Ethiopia is divided into nine ethnical-based administrative regions and three chartered cities. The research area is located in the central highlands of Ethiopia harbouring the capital city (Addis Ababa) and part of Oromiya region (Figure 2). The catchment borders the mountain ranges of Entoto to the North which divide it from the Nile basin catchment and through Ababa Samuel confluence to the South joins the Awash larger catchment. It is situated at the North-Western Awash river basin between $8^0$46'-$9^0$14'N and 38^0 34'-39^0 04'E covering a total catchment area of 1500km^2 (Molla *et al*, 2007). Due to its geographical location along the western margins of the main Ethiopian rift valleys, the catchment has volcanic rocks overlain by fluvial and residual soils in which black cotton soils are predominant with varying thickness from a few centimetres to about 20 m (Molla *et al.*, 2007 in reference to AAWSA *et al.*, 2000)

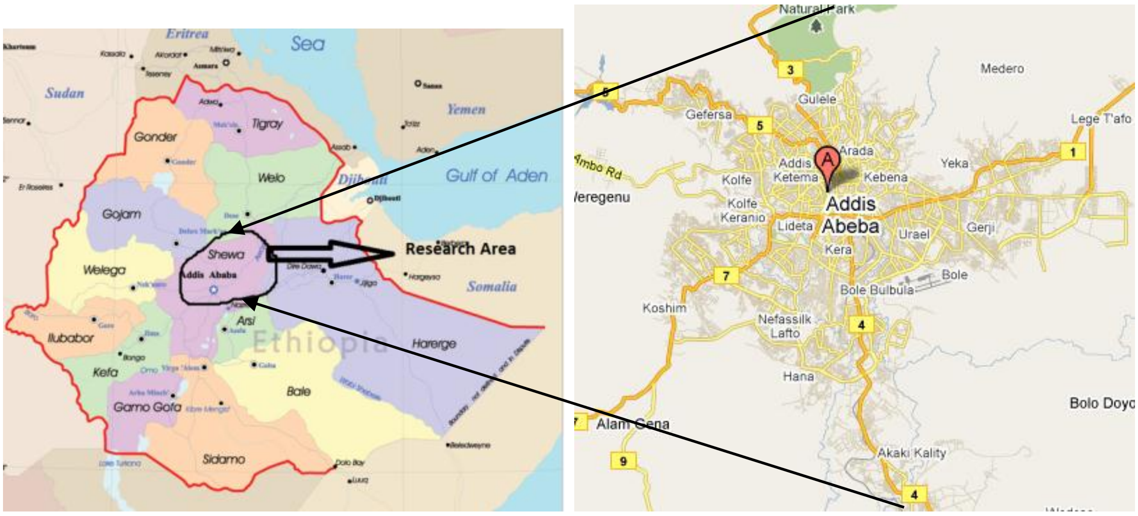


Figure 2 Location map of Akaki catchment in Ethiopia (http://wmasscatholicvoices.files.wordpress.com/2010/10/63-ethiopia-map2.gif, received on 12/01/2011)

1.2.2.2 Climate

To understand the availability of water and the growing environment, it is important to have basic information on the climate of the catchment. The catchment is situated in the sub-tropical highland zones of Ethiopia. According to local elevation based climatic zone definitions, Ethiopia's climate is broadly divided into five zones, i.e. Wurch (cold highlands above 3000 meters with annual rainfall above 2200-mm), Dega (cold, humid, highlands of 2500-3000 meters where rainfall ranges from 1200 to 2200-mm), Weina Dega (temperature, cool sub-humid, highlands of 1500-25000 meters, rainfall of 800-1200-mm), Kolla (warm, semiarid lowlands below 1500 meters of rainfall ranges from 200-800-mm) and Bereha (hot and hyper-arid, extreme forms of Kolla where rainfall is less than 200-mm)(USDA, 2002). For more information see Figure 3 which shows the spatial division of the agro climatic zones of Ethiopia. The research area has Woina Dega and Deg Agro-climates zones.

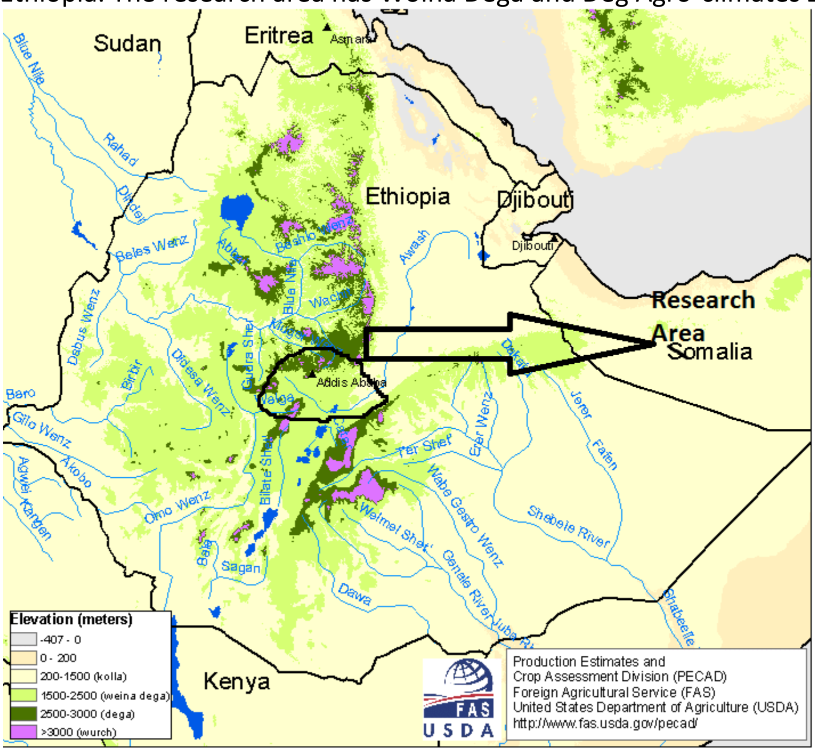


Figure 3 Agro climatologic zones of Ethiopia **Source: USDA, 2002**

Ethiopia in general and the Akaki catchment in particular, has highly variable weather conditions. There are three main representative metrological stations which record the daily temperature and rainfall for Addis Ababa and its surrounding area, i.e., Bole, Akaki and Addis Ababa metrological stations. According to the records of metrological stations, the warmest months are observed between February and May; and the coldest months are observed between October and February. The mean minimum daily temperature for the catchment is recorded in the months of November and December and the mean maximum daily temperature observed in May (Table 2). The daily average temperature ranges between 15-25^{o}c and the mean monthly total rainfall ranges between 5 and 245 mm. Akaki catchment has two rainy seasons, i.e. the main rainy season, namely *Keremit* is between June and September which contribute to more than 70% of the total annual rainfall and a small rain season time called *Belg* in between February and April.

Table 2 Monthly and daily weather data for Akaki catchment

Month	Mean Temperature ^{o}C		Mean Total Rainfall (mm)	Mean Number of Rain Days
	Daily Minimum	Daily Maximum		
Jan	15	24	15	3
Feb	16	24	35	5
Mar	17	25	65	7
Apr	17	24	85	10
May	18	25	75	10
Jun	17	23	120	20
Jul	16	21	235	27
Aug	16	21	245	26
Sep	16	22	140	18
Oct	15	23	30	4
Nov	14	23	5	1
Dec	14	23	5	1

Source: http://worldweather.wmo.int/060/c00162.htm, received on 20/01/2011

1.2.3 The water quality change causes in Akaki River system

A large volume of wastewater from domestic, commercial and industrial uses directly discharge or ultimately enter into the Akaki River system. The volume of liquid waste produced from the industries ranges from 1 to 1000 m3 /day (CSA, 1999) and the volume of wastewater discharged into Akaki Rivers is estimated to be 4,877,371 m3 / year (CSA, 1999). This figure is expected to increase when water supply increases in the future. In contrast to the high volume of waste generation, Addis Ababa has low sewer coverage for collection of domestic wastes and the existing central sewerage system serves only 5% of the population (EIA, 2008). There are two major rivers crossing the city, namely Little Akaki and Great Akaki, which are used as open waste disposal sites for Addis Ababa. The Akaki River system is part of the larger Awash River catchment, which drains to the central and eastern part of Oromiya and the confluence of which is at the Aba-Samuel reservoir. The downstream region, particularly the Akaki–Aba-Samuel wetlands, has an ecological importance for migratory birds. The description of the two major rivers follows below.

1. ***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 Akaki River at Gullele area where some of the factories are located, i.e. Gulele Soap, Shirt and Marble factories. Then around Merkato area the river crosses densely populated residential and commercial centres. Around Lideta area the river serves as dumping sites for Awash Winery effluents. Moreover, around Mechanisa irrigated area the river receives effluents from National Alcohol and Liquor factory. Tributaries from North Western direction receive wastes of major sources like Addis Ababa Abattoirs, which have direct alteration of water quality. Then in the downstream section crossing Akaki Kality sub city flow to

Aba Samuel and mixed with Great Akaki. The river system is used as irrigation water source around Kolfe Keranio, Lideta, intensively in Mechanisa and Akaki area.

2. ***Big Akaki***: The eastern branch of the river, the Great Akaki, rises north-east of Addis Ababa and flows into Aba-Samuel reservoir after 53 km. Great Akaki River system crosses residential areas in the upper stream, particularly in Kebena area, and Minilik hospital where wastes directly dumped in to it. Most of the hospitals dump their wastes directly or indirectly into Great Akaki. The lower course of Great Akaki crosses rapidly expanding urban centres of Addis Ababa including proposed site for future industrial expansion. In the low course the long section of the river is intensively used for irrigated agriculture and finally joins Aba Samuel reservoir.

Akaki Farmers in urban and peri-urban areas use the Akaki River system as a source of irrigation water for the continuation of cultivation during the dry season, normally from October to June. Farmers grow mainly vegetables contributing up to 60% of the vegetable demand for Addis Ababa. According to the local Urban Agriculture Development Bureau assessment, an estimated 1,574 farmers (28% women) are working on a total farm area of 400ha throughout the catchment (Gebre, 2009). Farmers irrigate with the threat of continually changing water quality. This situation is quite fascinating as it is in the country where irrigation is highly recommended and polluted water is used for irrigation with limited management capacities at field level. The use of polluted water for agriculture however is associated with environmental, public and animal health risks. Therefore to optimize the contribution of polluted water irrigation for agricultural economy, it is important to minimize associated risks by understanding the situation.

1.3 Problem statement

As mentioned in the background, Akaki River system is an important source of irrigation water to urban and peri-urban areas of Akaki catchment. The continual development without intervention will be risky for the environment, crops, public and animal health since Akaki is a natural drainage for industrial, commercial and domestic wastes. There are over 2,000 registered industries in Addis Ababa (65 % of all industries in the country), of which 90% lack facilities for some degree of onsite treatment plant, and discharge their effluents in to adjacent river (Gebre, 2009). Furthermore domestic and commercial wastes are disposed to the Akaki River system with almost negligible waste management. Given these situations, irrigation is practiced by urban and peri-urban farmers through community based irrigation system to grow vegetables. Moreover farmers have insufficient capacity to manage wastewater at field level .Thereby there is a need to conduct research focusing on exploration of the change in water quality over the past years of irrigation and the corresponding adaptation strategies used by farmers. The findings from this research will provide baseline information for better understanding of the situation for concerned authorities and basically for farmers.

Chapter two: Research approach

2.1 Study objectives

The general objective of this research is to understand the situation of polluted water irrigation in Akaki catchment. The research is aimed at assessing the change in water quality of Akaki River system since introduction of irrigation and farmer's adaptation strategy for associated adverse impacts of water quality change.

2.2 Conceptual framework

2.2.1 Theories and concepts of water quality

Water quality refers to the characteristics of water that will influence its suitability for a specific use. It can be defined as the chemical, biological and physical constituents of water. In other words it is the chemical, physical and biological requirements of water for a specific use. Water quality is a relative term to signify the suitability of water for intended use. For instance a given water quality suitable for irrigation might not be suitable for drinking water.

Pure water never exists in the natural water bodies. When different materials from the surrounding environment discharged in to the water bodies, the natural constituents of water will be modified. In that case, there is a possibility of losing its potential to support intended uses, such phenomena known as pollution. Pollution can be a result of both anthropogenic and natural activities. Anthropogenic contaminants such as domestic, commercial, agricultural and industrial wastes as well as the natural pollution sources like algae bloom; volcano, storm and earth quick are the main pollution sources. Anthropogenic contaminants are the main concerns of pollution since they originate from the broad socio-economic activities. Particularly urban areas have a large number of socio-economical activities which produce a huge amount of solid and liquid wastes. The direct and indirect discharge of these wastes without treatment will result in pollution. The major pollutants from urban sources are chemicals, pathogens, and physical components. The basic chemical components of urban wastes are oils, heavy metals, and nutrients where the harmful effect of these chemicals depends on the concentration and types of chemical as well as the type of use. Pathogens are disease causing micro-organisms mainly Protozoa, Virus and Bacteria which are hazardous to human and animal health. Physical constituents are suspended materials such as plastic bags, used dressings, sharp metals, and glasses which make the water turbid.

Water quality is examined through the following basic parameters: Temperature, pH, Electrical Conductivity, Total Dissolved Solids, Total Suspended Solids, Sulphide, Chloride, Ammonia, total N, total P, COD, BOD, Coli forms, heavy metals (Zn, Pb, Cu, Cr, and Co) and others. Definition for some of the parameters are given in the next section

- Temperature determines the metabolic activity of living organisms. When temperature increase, metabolic activity will also increase and the amount of available oxygen in the water will reduce.
- pH is a measure of hydrogen ion which determines the acidity or alkalinity level of water. When the power of hydrogen increases, the water become more basic whereas when the power of hydrogen become lower, the water will be more acidic. Fresh water and well buffered have more or less neutral pH ranges, between 6 and 9. The pH component has a significant effect on the crops and is therefore considered in this research as a parameter for interpreting significance of wastewater for irrigated agriculture.
- Electrical conductivity is the ability of water to pass electric current in a solution. When the ionic content of water increases, the conductivity will also increase. The ionic contents are mainly the result of dissolved salts; hence the high electric conductivity indicates the presence of large concentration of salts and dissolved chemicals.

- Total dissolved solid is a measure for the soluble substances in the water. Total dissolved solid includes both organic and inorganic molecules and ions mainly cat ions of calcium, magnesium, sodium, and potassium as well as carbonate, bicarbonate, chloride sulphate and nitrate ions.
- BOD is a measure of the biochemical oxygen needed by aerobic micro-organisms at a certain temperatures to breakdown organic matter into its simpler forms of Carbon dioxide and water. The break down is a means of water purification. The higher BOD value indicates the presence of large concentration of biodegradable wastewater components. Since the ultimate or total oxygen completion by biochemical test takes too long time, BOD test is normally taken as the 5-day oxygen consumed by biochemical oxidation of waste contaminants.
- Heavy metals such as chromium, zinc, lead, copper, iron, cadmium, and manganese found as trace quantity. Some of these metals are essential for plant growth; however the presence of these metals in excessive of the acceptable level will have a toxic effect on plants and consumers.
- COD: The oxidizable constituents of wastewater can be classified as biodegradable and non-biodegradable chemicals. While the BOD test shows the oxygen demand of biodegradable oxygen demand, COD determines the oxygen demand for both biodegradable and non-biodegradable components.
- Coli form organisms: bacteria are found in intestinal tract of man. Since the coli forms are numerous and more easily tested than pathogenic organisms, they are taken an indicator for pathogenic organisms. Escherichia coli (E-coli) are entirely of faecal origin.

2.2.2 Reverse water chain approach

Understanding the situation of wastewater irrigation requires knowledge on the mechanisms of urban wastewater system through consideration of upstream polluters and end users connectivity. The urban wastewater system is a cycle where fresh water extracted for urban water supply is released back to the water system as wastewater. The system is comprised of water supply, wastewater sources, treatment plants, management activities, end users and the environment as interacting units. These components have interconnectivity in the up-downstream section of water flow. In this system domestic, commercial and industrial centres are the main urban water users. The generated wastewater from domestic, commercial and industrial uses has a mixture of organic matters, nutrients, heavy metals, pathogens and other materials and is ultimately enter into the natural water ways. Then treated or untreated waste constituents flow downstream interacting with different end users. In this situation, the quality of water flowing to the end users becomes a point of tension.

The Reverse water chain approach was used as a tool for studying the situation of polluted water irrigation in Akaki Catchment. Wastewater use for agriculture comprised of a wide range of issues such as the food production, the water, treatment technology, hydrology, health issues related to consumers and field workers and environment risks (Huibers.F.P and Van Lier.J.B. 2005). These issues overview are a make of Reverse water chain approach. The wastewater use for growing crops is a means of recycling water and nutrients provided the water is treated or field adaptation measures used to exclude the hazardous constituents. In this case the polluters and end users have strong link as they have interesting conflicts.

In this research focus was made on selected technical and socio-economic factors governing wastewater irrigation. On the technical side, the interaction between urbanization and vulnerable communities was studied. Irrigators are vulnerable communities both in urban and peri-urban areas; hence the change in water quality associated with urbanization was taken as baseline information to understand the associated adverse impacts. From socio-economic factors, farmers were studied to understand their economical dependency on wastewater irrigation, awareness on water quality change and adaptation strategies used at field level to adapt water quality change. The reverse water chain approach is attached in the Annex 1 and schematic description on the reverse water chain approach can be found in this part.

2.2.3 FAO and WHO standards for interpreting irrigation water quality

Use of polluted water has associated adverse impacts on public and animal health, surrounding environment and cultivated crops as mentioned in the background section. There are a set of guide lines and standards developed by FAO and WHO to interpret water quality for agricultural use. The set of FAO and WHO standards applied in this research are discussed below.

I. FAO guidelines

Agriculture has its own water quality requirements under a set of growing condition. Thus, the use of water for irrigation needs evaluation of its microbial and biochemical properties. These values should then be compared with the agricultural water quality standard limits. Literally, wastewater irrigation is recommended when the constituents meet agricultural water quality standards or if mitigating measures used at field level to safeguard environment, public, and animal health from the associated adverse impacts. These preconditions are the basis for assessing the situation of polluted water irrigation under the existing growing conditions.

Once information is known on the microbial and biochemical constituents, management requirements can be determined for a given use that can mitigate or reduce the adverse impacts of poor quality water. Management strategies can be pre-farm such as regulation of inappropriate waste discharge into nearby streams with a set of pre-treatment standards or on farm field management to adapt the associated adverse impacts of polluted water irrigation at field level. Treatment minimizes the pollutant load of wastewater before discharged to nearby streams or before water is applied to irrigation. Wastewater treatment needs strong financial and managerial capacities depending on the magnitude of treatment. The magnitude of treatment on the other hand depends on downstream use, particularly public health and environment requirements. For instance investment made for complete elimination of pollutant load needs excessive cost and result in loss of plant important nutrients. In contrast, wastewater discharged into streams without treatment will have negative impacts on environment, crop public and animal health. In that sense, treatments in consideration with agricultural requirements have a net gain for both the responsible organization and end users. In least developed countries, particularly in Ethiopia, treatment capacity for wastewater is limited because of low managerial and financial capacities. Researchers recommend different field management strategies for low income countries to adapt associated risks, among which crop selection, appropriate irrigation system, adjusting fertilizer application and others are some of the strategies.

Based on the past year worldwide experiences of irrigation, FAO developed bio-physical and chemical water quality standards for interpreting agricultural water quality. The standards help to evaluate the potential of irrigation water to create soil and crop problems. The crop and soil problems are categorized as toxicity, salinity, infiltration and miscellaneous problems. The problems are often complex and occur in combination. It is easier to evaluate single problem than a combination of problems, therefore for separate identification the following factors are evaluated for each of the problems:

- The type and concentration of salts causing the problem from industrial components ;
- The soil-water-plant interactions that may cause the loss in crop yield;
- The expected severity of the problem following long-term use of the water;
- The management options that are available to prevent, correct, or delay the onset of the problem.

The detail information on laboratory determination for restricted use and allowable limit under a set of conditions are found in Annex 2.

I. WHO guidelines

Wastewater use for agriculture exposes field workers and consumers to infectious water borne diseases. According to WHO 2006 guidelines, the most commonly diseases are categorized in to two broad groups:

• Viral, bacterial and protozoan diseases, for which the health risks are determined by quantitative microbial risk assessment (QMRA);

• Helminthic diseases, for which the Guidelines set a guideline value on the basis of epidemiological studies.
Based on these categories, the tolerable diseases and infection risks are shown in Table 3.

Table 3 Classification of diseases relevant in wastewater irrigated agriculture

Category	Environmental transmission future	Major examples of infection	Exposure groups in urban agriculture and relative infection risks
Non-bacterial Faeco-oral Diseases	Non-latent [a] Low to medium persistence [b] Unable to multiply High infectivity	Viral: Hepatitis A and E Rotavirus diarrhoea Norovirus diarrhoea Protozoan: Amoebiasis Crytosporidiasis Giardiasis Cyclosporiasis	Fieldworkers:+ Customers:+++
Bacterial Faeco-oral Diseases	Non-latent Low to medium persistence Able to multiply Medium to low infectivity	Campylobacteriosis Cholera Pathogenic Escherichia Coli infection Samonellosis Shigelloisis	Fieldworkers:+ Customers:+++
Geohel-minthiasis	Latent Very persistent Unable to multiply Very high infectivity	Ascariasis Hookworm infection Trichuriasis	Field workers:++ Customers: +++

+++ High risk, ++ medium risk, + low risk (These risks refer to the use of untreated wastewaters; treatment and post-treatment health protection control measures can reduce these risks to the tolerable level of =< 10^{-3} per person per year)
A Latency is the length of time outside human host required for the pathogen to become infective.
B Persistence is the length of time that the pathogen can survive in the environment outside a human host.
C Note that fieldworkers are commonly also consumers. Source: Drechsel *et al.,* 2006

The general set of standards developed to evaluate risks with number of pathogenic organisms mentioned in Annex 2.

2.3 Main research question

'How did farmers adapt to the change in water quality of Akaki River system since irrigation was introduced and how can they adapt it for the next 30 years?

2.4 Research sub-questions

1. How has the water quality of Akaki River system been changed since the introduction of irrigation?
A. How has waste management in Addis Ababa changed over time?
B. How the water quality at irrigation extraction points of Akaki River has changed since the introduction of irrigation?
C. what will be the water quality change over the next 30 years?
2. What has changed with farmers in respect to water quality change?
A. What were the arguments to start irrigation (technical and socio-economic drivers)?
B. How have the changes in water quality affected the farmers in the past years of irrigation?
C. How did farmers change field activities in reaction to water quality change?
D. How did farmers and customer’s awareness on water quality change over time?
3. How can farmers adapt to the change in water quality over the next 30 years?

Chapter three: Research methodology

3.1 Study site selection and sampling

The study was carried out in the Akaki catchment located in the central highlands of Ethiopia. The catchment was selected for two main reasons. One, the catchment harbours Addis Ababa which is one of the largest cities in Ethiopia. The city has a poor sanitation system where untreated municipal, commercial and industrial wastes are directly or indirectly disposed to the Akaki River system. The wastes mixed with Akaki River water are used as a source of irrigation water for growing vegetables. The vegetable production has a high importance for socio-economic development of the area; it is assumed that above 60% of the vegetable demand for the city is supplied from polluted water irrigated agriculture (Gebre, 2009). Two, though studies have been done on the identification of irrigated agriculture and its importance for socio economic development of the surrounding area, there is almost no research done to understand how farmers adapt to the change in water quality since the introduction of irrigation; thus, this study improves the knowledge for understanding the situation of polluted water irrigation in the Akaki catchment. In addition the study findings are expected to give insight for other cities in the country or similar polluted agriculture practices somewhere else.

Sampling was done based on geographic location. The catchment includes Addis Ababa city and a small part of Oromiya region. Addis Ababa city is divided into 10 sub cities which represent as one administrative unit. Locations of irrigated agriculture were identified based on these administrative units, i.e. Kolfe Keranio, Yeka, Bole, Nefasl Silk Lafto, Akaki sub city and Oromiya. Study site included four administrative units (Excluding Yeka sub city farms since farm sizes are relatively too small) and sample respondents (urban farmers in our case) are chosen accordingly. Target groups for this study were urban and peri-urban irrigators from Akaki sub city. At the beginning, sub-cities were identified based on the presence of irrigated agriculture criteria, and then irrigators in the selected sub-cities were selected using predefined criteria's. Despite financial and time constraints, great attention was given to improve the reliability of the information during respondent's selection. Accordingly, the number of years where farmers spent in irrigated agriculture is considered as primary selection criteria. Moreover, farmers' economical dependency on irrigated agriculture was considered. For achieving this goal, respondents were selected in collaboration with a representative of the peasant association. In addition a number of respondents were randomly interviewed while working in their field and in their home after field work.

3.2 Secondary data collection

Secondary data were collected for fulfilling data required to analyse water quality change of Akaki River system. The data were collected both qualitatively and quantitatively since the introduction of irrigation. The qualitative data contains historical information on waste management of Addis Ababa with consideration of socio-economic growth as a base line. Experimentally determined water quality data were collected for the purpose of comparing the water quality with agricultural water use standards. The details of these data are as follows.

I. Waste management in Addis Ababa

Information on the solid and liquid waste disposal was collected from Addis Ababa Water and Sewerage Authority, Central Statistical Authority, Addis Ababa EPA, Federal EPA and Oromiya EPA. The information contains spatial distribution of major industries and organizations along the river as well as industrial growth trend of Addis Aba since the 1950. Since most of the pollution sources dispose wastes to the nearby streams without treatment, the growth of these socio-economic activities have linear relation with water quality change. Hence it was taken as a basin line indicator for water quality change.

II. Laboratory determination of water quality

For evaluation of irrigation water quality, experimentally determined data were collected from AAWSA, Federal, Oromiya and Addis Ababa EPA. However due to limited institutional and financial capacities, there is very limited laboratory water quality data to assess historical trends. Though recently little data are available, the sampling time and location are not clear and it is incomplete in addressing the full range of parameters. Moreover the samples were not representative since the peak discharge time of major waste sources is not known. Considering these facts, the collected data use will be limited for indication of water quality change.

3.2 Primary data collection

3.2.1 Experimental test

To have a clear figure on the current situation of water quality around irrigated areas, grab samples were collected at irrigation water extraction points. The sampling site was stratified into two parts, i.e. the urban area where residential and commercial spots alter the river water quality to a great extent and per-urban site where human intervention is very limited. Two samples were taken per sampling location. Samples were taken with three bottles of each 2 litres; one preserved with nitric acid for preservation of heavy metal, one for BOD and COD analysis, and the third bottle for analysis of other parameters. The pH and temperature measurement were done at time of data collection, other parameters were examined in Addis Ababa Environmental Protection Authority.

3.2.2 Semi-structured interviews

To meet the socio-economic data demand of this research, interviews were held with irrigators (farmers), irrigated agriculture product customers, employed field workers and people working in concerned organization who are supposed to have local knowledge on irrigated agriculture. Farmers were interviewed to express their experience over the past year of irrigation, whereas people who have local knowledge and local customers were interviewed with unstructured question to express their perception and observation regarding the situation.

The contents of the interviews gave historical information about change of irrigator's perception towards water quality change since the introduction of irrigation, adaptation strategies at field level, customer's awareness on use of irrigation product, and precaution taken by field worker. On the other hand topics such as current irrigation systems, crop types, and time spent on irrigated agriculture compared with other income earning activities, institutional support, water related problems, and other cash earning activities were treated. Another topic dealt with in the interviews was the farmer's plan in respect to future water quality change. From the collected water quality data and information for future proposed waste management services, future water quality change was projected (ideal projection). Based on this projection, irrigators were asked about their plan at field level, willingness to participate and collaborate with concerned organization to solve the problem. A total of 45 respondents were interviewed in the catchment. The majority of farmers were interviewed through participatory technique while working on their own field. Others were interviewed in their house after field work and during weekend; other cash earning work place; and peasant association offices.

3.2.3 Observations

While working in the field, observations were made to understand how major industries dispose their wastes; water quality situation with observable parameters like colour, floating and suspended materials; farmers precaution at field work (use of health risk protection tools), field management practices, crop types, crops health and others) are made. These observations were used for triangulation of the information gathered in the interviews and background information.

3.3 Data management and analysis

The data collected through three research methodologies was stored in the daily reports which were updated after every field day. These daily reports have all an objective of daily information aimed to gather in the field. Impressive feature of field observation and the practice of field staffs were captured through the use of photo and video camera. The pictures were very useful to show features of the surrounding environment when writing results.

Chapter four: Results and discussion

4.1 Introduction

In this chapter the results obtained from physical observation, laboratory analysis, interviews and the data gathered from institutions are discussed. The chapter starts with results on the identification of irrigated farms along the Akaki River system. It then discusses the water quality change in reference to historical information on wastewater management of Addis Ababa and experimentally determined water quality data, water quality interpretation for irrigation use and projection of future water quality. The later section treats the results of the interviews and observations for describing argumentations to start irrigation, awareness on water quality change, and water quality change adaptation measures taken by farmers at field level. The last section discusses the future adaptation strategy based on different countries experience and local trends.

4.2 Identification of irrigated farms in the Akaki River system

To get the general overview of irrigated farms in the Akaki catchment, information is needed about the location of farm plots, number of farmers, the character of irrigation schemes and the surrounding environment. Based on the 2006 figures, there are 2033 household farmers working on a total farm size of 481 ha using small scale irrigation river diversion methods. These farms are found in five sub cities of Addis Ababa and Oromiya region, namely Akaki (170 ha), Bole (95 ha), Yeka (7 ha), Kolfe-Keranio (56 ha), and Nifas-Silk Lafto (153 ha) (Annex 3). Farms located in Yeka, Bole, Nefas Silk Lafto and Kolfe-keranio sub city are situated in urban centres, whereas farmers in Akaki sub city and Oromiya region are found in the peri-urban area. Majority of the farms, above 35% of irrigated farms in the total catchment, are located in the middle and downstream section of the catchment, i.e., in Nefas Silk Lafto sub city, Akaki sub city and Oromiya region. During interviews and field visits, it is observed that some of the farm lands of urban area were allocated for construction of residential houses; in contrast rapid farm expansion was observed in peri-urban areas. Urban farmers are irrigating on temporarily owned lands, thus whenever there is shortage of land for urbanization or change in master plan, these farm lands will be the first to be reallocated. In Kolfe Keranio, part of the irrigated farm was allocated for expansion of urban centres one year ago. In contrast, irrigated farms in peri-urban area have a space for further expansion of irrigated farms. In peri-urban area of Akaki, it is observed that irrigated farms are fostering. The next section discusses the features of urban and peri-urban irrigated farms in Akaki catchment.

4.2.1 Urban agriculture irrigation schemes

Irrigated farms in Kolfe Keranio, Bole, and Nefas Silk Lafto sub city are located in urban centres and are developed with traditional surface irrigation system. Except in some part of Nefas Silk Lafto sub city farms, namely Lideta area farms; the slope of the land and existence of numerous small streams in most of urban area allow diverting the water with gravitational flow. In contrast, the feature of land in Lideta area does not allow water diversion with gravitational energy; rather water is pumped from wells which are the chief irrigation water sources in combination with the stream source. Irrigation water is distributed to agricultural fields by earthen canals. Farm lands are owned on temporary bases; and farm size has been decreasing. Therefore, future continuation of urban irrigated farms is questionable. In the next section, the features of traditional irrigation schemes in Nefas Silk Lafto sub city are described in support of schematic picture. These schemes are selected as a representative for urban irrigation systems.

Nefas Silk Lafto Irrigated Area

Nefas Silk Lafto sub city is located in the South Western part of the catchment. The sub city host major industries of Addis Ababa , residential areas and commercial centers. Little Akaki(LA) has 22 stream orders in the total catchement of which LA14, LA13, LA12, and LA7 stream orders are situated in Nefas Silk Lafto subcity. Irrigation water is extracted around LA14(namely Lideta area), LA13(namely Mechanisa and Kera) and LA7(namely Goffa area) stream orders (Figure 4). The irrigation systems at these extraction points have the following features.

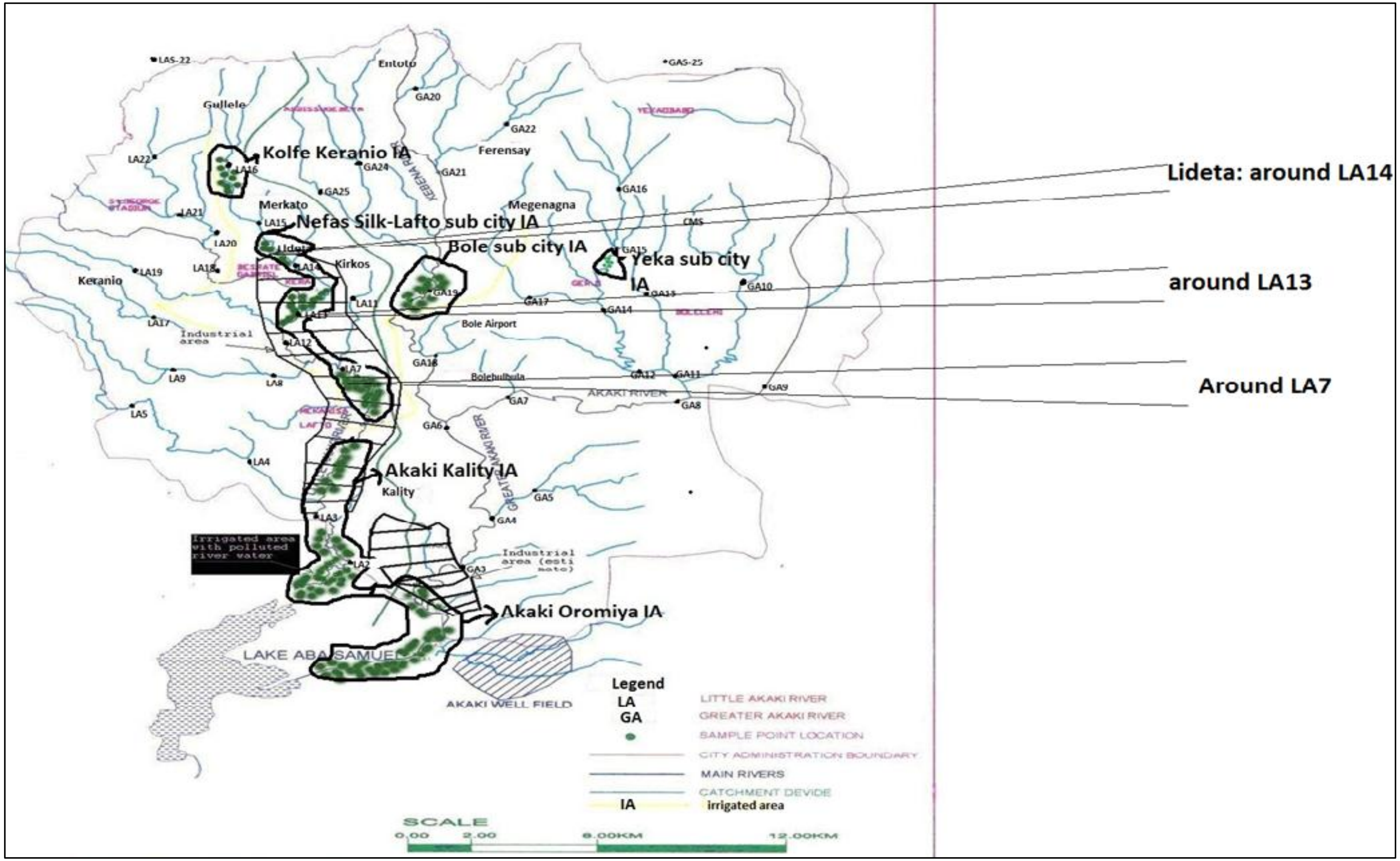


Figure 4 Hydrological map of Akaki Catchment with including irrigated farm location

A. Lideta Irrigated area(LA14)

In this area, the river bank is confined with very old slums. Domestic waste from the slum is directly discharged into the nearby streams and some of them connect thier toilet illegaly to the river. The area has a pungent smell and excessive amount of plastic bags, used dressings and other solid wastes were observed inside and out side of the river (Figure 5).The river banks have a hard rock basement and the water is flowing in a deep gorge. In the upper section, farmers were observed pumping water from hand dug well. Going a little downstream, farmers use a combination of water released from upperstream irrigation canal and pumped water from Little Akaki iver to irrigate thier land. The topography is more rugged in the upstream than in the downstream part. More over at the downstream of this area, few farmers are fully depend on the river water to irrigate thier farms.

A. Mechanisa, and Kera irrigated area farms around LA13

The irrigated area around LA13 can be split up into three sections for elaboration of thier specific features as follows (Figure 6).

Section 1

Little Akaki flow recieves National Alcohol and Liquor factory effluents around Mechanisa area. Downstream of the National Alcohol and Liquor factory, another tributary named as 'kera' from north eastern side joins the main little Akaki river. Section one is the upstream part of little Akaki river before Kera tributary mixes with it, called mechanisa area. The rugged topography of the river bank in this setion makes construction difficut, as a result the surounding area is relatively less populated. Irrigated farms are located close to National Alcohol and Liquor Factory. The river water in the upperstream of the factory has a relatively good physical quality, however human excreta's are observed inside and near by areas of the river. The irrigation system is developed with a traditionally constructed diversion structure made of coarse stones and sand filled bags, an earthen main canal excavated along the countour borders of the factory and at field level the water is distributed with furrows. Close to the National Alcohol and Liquor factory, the irrigation canal overlay the effluent drainage canal of the factory. The factory effluents are directly dicharged into little Akaki with out treatment (Figure 7). A mixture of this waste , redish colour, is observed in the field furrows. The effluents leaked from the factory were observed in the nearby environemnt.

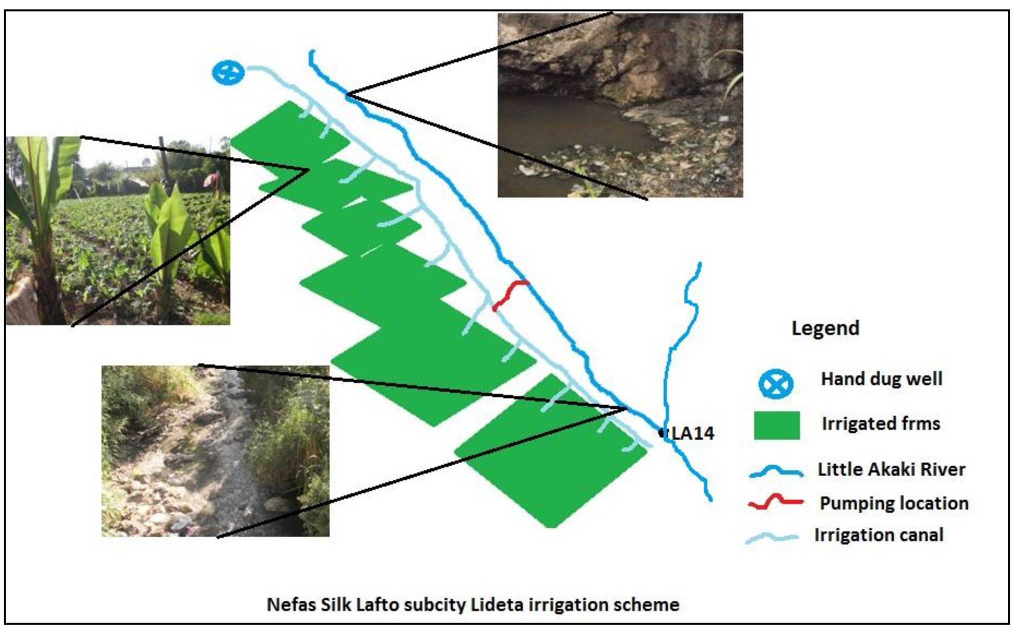


Figure 5 Schematic picture of irrigated system in Lideta area

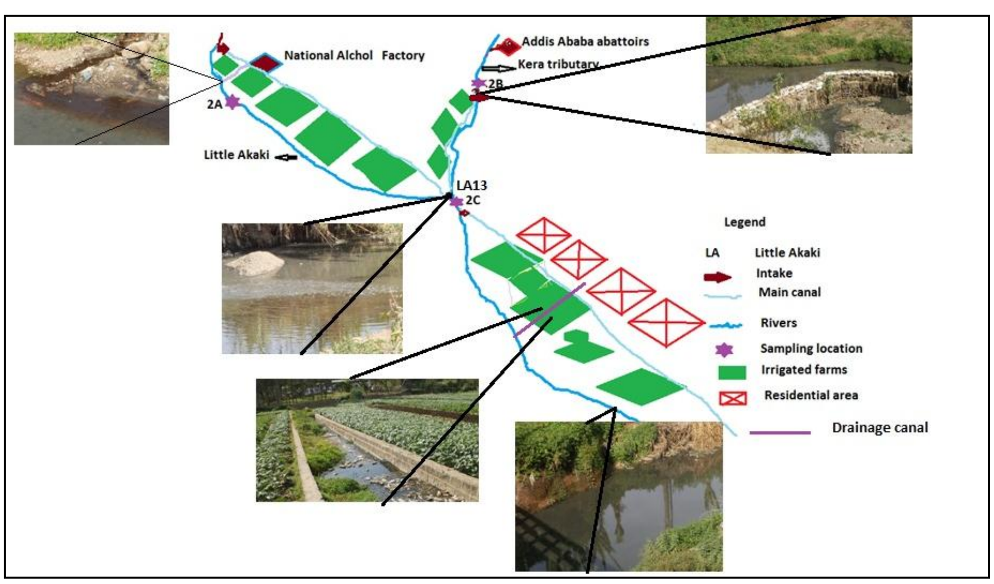


Figure 6 Schematic picture of Nefas Silk Lafto irrigated area around LA13

Figure 7 Irrigated land close to National Alcohol and liquor factory

Figure 8 Diversion structure from Kera tributary

Figure 9 Intersection of point of Kera tributary and Little Akaki River

Figure 10 Irrigated area farms around LA7

Figure 11 the plastic bag cleaned from farms

Source: Tadesse,22/11/ 2010

Section 2
Kera tributary recieves a large volume of effluent from Addis Ababa Abbatoirs in the upstream section. As a result, irrigation water extracted from Kera tributary is highly turbid, dark and contains a large amount of suspended solid around the diversion structure (Figure 8). The irrigation system is developed with diversion structure made of sand filled bags and coarse stones, earthen main canal and field furrows.

Section 3
This section represents farms irrigated with water from little Akaki after Kera tributary mixed with. The water constituents are dominated by a combination of effluents from National Alohol and Liquor factory and Addis Ababa Abattoirs. At the intersection point of Little Akaki and Kera tributary, a dark water observed when mixed with redish color water (Figure 9). At the downstream section of the intersection point, a residential wastes are directly conveyed to the river through a drainage canal. The canal brings a large amount of suspended solids into the river and toilet wastes were observed inside the canal. The irrigation system is similar to section 1 and 2.

A. **Irrigated area around Gofa area (LA7)**

The remaining irrigated farms are located in Gofa area, downstream of Mechanisa and Kera area. The water in this section has a relatively better physical quality with light dark colour as shown in Figure 10. The water is flowing with relatively high velocity compared to the upper stream section and the purification effect of high turbulence associated with high speed could be a reason for better water quality.

4.2.2 Peri-Urban irrigation system characterization

Peri-urban irrigation systems are developed on relatively flat land. The topography of urban farms range between 3000 to 2400m, whereas in the peri-urban area it ranges between 2400 to 1800m. The topography of the peri-urban area is not suitable for developing gravity irrigation, thus farmers are forced to use pump irrigation system using motor pump, flexible hose and field furrow. Although farmers spend considerable amount of pumping cost, the presence of irrigable land and rise of market demand attracts farmers. The farm lands will be completely flooded between June and September; thereby it leaves a large volume of solid mater after rainy season. The large volume of solid materials creates a work burden for farmers to clean the land during the first growing season and they are confronted with a challenge to clean sharp metals. The reference picture as shown in

4.3 Water quality change trend in the Akaki River

4.3.1 Introduction

As mentioned in the background section, the population of Addis Ababa grew from 0.45 to 3.5 million over the past 60 years. The rapid population growth has been associated with expansion of commercial, institutions, industries, and residential centres. These broad socio-economic activities in turn generate a large volume of solid and liquid wastes which are a threat to the surrounding environment. As surface water is the main environmental component, the generated wastes became major sources of contaminants for the Akaki River system. The major sources of wastes in Addis Ababa can be divided into four groups; Municipal, Industrial, Medical/Clinical and Others (Such as Agricultural, Chemical, Fuel Stations and Garages). The next section of this paper discusses the water quality change of Akaki River as a consequence of rapid socio-economic development since the introduction of Irrigation (for the past 40 years). Industrial growth trend, commercial and residential centre expansion as well as their waste disposal systems is taken as an indicator for water quality change. Even though experimentally determined data for water quality change of Akaki River is limited due to lack of institutional and financial capacity, statistical analysis was made for determining water quality change with available time series data.

4.3.2 Historical waste management in Addis Ababa

I. **Municipal waste**

The municipal waste comprised of solid and liquid wastes generated from residential and commercial areas. This kind of waste is a main challenge in Addis Ababa as there is low coverage of waste management service. The detail information about the daily waste generation, its composition and waste management services in the city are discussed below.

***A. Solid wastes**:*

Solid wastes are non-liquid organic and non-organic generated from household, commercial, industrial and other institutions. Solid wastes have been disposed to open ground, stream banks, and bridge areas. There has been significant contribution of solid waste to the pollution of the Akaki River system. Currently solid waste is collected by dumpsters that are available on open grounds of residential and commercial areas. The collected wastes are then disposed by trucks as land fill site located at the South periphery of Addis Ababa. Since there is no adequate service of dumpsters, some of dumpster overflow and part of the solid waste falls in the open ground (Figure 12). There are 42 trucks for collecting solid and liquid waste of Addis Ababa, among which only 29 trucks are functional (Asfaw, 2007). The solid wastes overflowed from dumpsters are transported into adjacent streams via storm and run-off and becomes a source of pollution for Akaki River. As a result solid waste pollution is considered to be among the most serious environmental problems of Addis Ababa and the daily solid waste production is estimated as 0.252kg/capita/day (EPA, 2005). Currently the population of Addis Ababa is around 3.5 million; accordingly the daily waste production of the city is estimated to be 882 tones. From the daily generation of solid waste 65-% is collected, 5-% recycled, and 5-% composted; whereas the remaining 25-% dumped into open site, drainage channels, rivers, streets and valleys (EPA, 2009).

Figure 12 Solid waste collectors (dumpsters) in Bole sub city
Source: Taken November, 2010

The large amount of solid waste, approximately 76-%, is generated from households whereas the remaining is generated from industries (3-%), street sweeping (5-%), commercial and other institutions (9-%) and 1-% is from hospitals. The solid waste comprised of 60-% of organic matter which can be used for making compost, 15-% of recyclable materials and 25-% others. The detail composition is 4.2 % vegetables, 2.5 % paper, 2.9 % rubber/plastics, 2.3 % wood, 1.1 % bone, 2.4 % textiles, 0.9-% metals, 0.5-% glass, 15.1 % combustible leaves, 2.5 % non-combustible stone and 65-% of all others (EPA, 2005).

The land fill site for Addis Ababa is situated at Repi from which the dumped waste is observed leaking to the nearby streams, ultimately entering into little Akaki River. As a result, the river water quality has been deteriorated. The ultimate impact is observed as a major environmental problems (including bad smell) and negative effect on vegetable farms along the river; for instance accumulation of excessive plastic bags (non-degradable) carried by Akaki Rivers are observed in Akaki Kality irrigated farms area as shown in Figure 13.

Figure 13 Plastic bag pollution along Akaki River irrigated farms
Source: Tadesse, November 18/2010 close to Akaki Bridge

B. **Liquid waste:**

Domestic liquid waste from overflowing and seeping pit latrines, septic tanks, public and commercial toilets, open ground excreta defection and grey water from kitchens and bath rooms flow to the Akaki River either through drainage lines or other mechanisms. Liquid waste generation and management for Addis Ababa are discussed under two categories as follows.

Liquid wastes from toilets, open urination and defecation places

The situation of sewage collection and disposal in Addis Ababa is poor as sanitary services are inadequate. Studies indicate that open space defecation and urination in vegetated areas, valleys and on the sides of streams had used as a widely used waste disposal system before 1950. However the gradual increment of pit latrines as a common toilet discourages open defecation and urination. Further, the construction of central sewerage collection system promotes few numbers of people to use flash toilet.

Currently human excreta in the city are disposed of using pit latrines, centralized system and open space urination and defection. Pit latrines are the most widely used disposal systems and has been used for a long time. According to the 2005 EPA assessment, 57 % of the total population use pit latrines among which 17 % use private and 40 % use shared and communal pit latrines. The pit latrines have to be emptied when they are full of sludge through evacuating cars. Sludge collection is running with low capacity for two main reasons:

1. The services are inadequate to cover the task of emptying full pit latrines
2. The city has poor road infrastructure and the latrines are not accessible for emptying cars.

Because of this problem, overflowing of pit-latrines is commonly observed in many parts of the city. Through run-off and storm, the overflowed sludge is transported to the adjacent streams; in such case it is a source of pathogenic and other pollution source for Akaki River system.

Around 12 % (437,500) of the total population uses flush toilets (A.A EPA, 2005). Sewages from flush toilets are connected to septic tanks which have to be emptied by vacuum cleaner when they get full to storm water drainage system or to centralized sewage collection system which convey to treatment plant. A centralized sewage collection in Addis Ababa was constructed in the late 1960s designed to collect sewage. The centralized sewage collection system was designed for a peak flow of 540L/second, which corresponds to an equivalent of 200,000 inhabitants, with an average wastewater production rate of 110 l/day. Currently there are two treatment plants, namely Kaliti and Kotebe, which are designed to treat sewage channelled from centralized sewage collection system and the sludge brought by pit latrine evacuating cars. Kality treatment plant has a capacity of 7,500 m^3/day sewage mainly from sewer lines and 30,645 m^3/day of drying beds. The Kotebe plants have a capacity of 30,000 m^3/day of drying beds. The sludge receiving capacity of Kotebe is 400 m^3/day; however it receives only 98 m3/day from evacuating cars (Mohammed, 2002).

The remaining 30 % of Addis Ababa dwellers have no access to toilet facilities, and yet they use to defecate and urinate in open ground. Akaki River system is used as open-air urination and defecation site. The weight of human waste generated from an average person per day is estimated as 0.75 kg (AA EPA, 2005). From this the daily excreta dispose to open soil and water can be estimated as 0.30*3,500,000*0.75=787,500 kg. As a result, open defecation and urination contribute for contamination of Akaki River system.

Liquid waste from bathrooms, laundries and kitchens

Liquid wastes from bathrooms, laundries and kitchens have been disposed improperly to open space available in residential and commercial areas. Before 1990, more than half of the Addis Ababa residents did not have access to potable water through a tap on the compound or in the house (AWWSA, 1990). The Akaki River system was used by some residents, particularly the poorest, for sanitary purposes for cloth and kitchen utensil washing. During this time almost all liquid wastes from bathrooms, laundries and kitchens were directly discharged into the Akaki River system. After the recognition of liquid wastes discharged to open ground as environmental problems, open ditches were constructed in different parts of the city for collection and discharge of liquid waste into the nearby water course. Currently wastewater generated from bathrooms, laundries and kitchens is discharged into the nearby water courses and streams through ditches, open grounds, shallow-bore sewers or disposed of on available open ground. It is estimated that 70 % of water supplied to Addis Ababa city returns as wastewater of high organic matter content and approximately 60 % of this wastewater flows directly to Akaki River (AA EPA 2000 in reference to Adane 1999). In all cases the wastewater flowing to Akaki River brings organic pollutants from kitchens and chemicals from detergent flushed from bathrooms, laundries and kitchens.

II. **Industrial wastes**

Industrial waste disposal:

Even though the government of Ethiopia gives priority for agricultural economy as structural development program, there are few industries which contribute to the country's economy. These industries are manufacturing and processing industries such as tannery, food, beverage, tobacco, textile, paper and printing. Around 65 % of the total industries in the country are established in Addis Ababa. Currently there are around 2200 registered industries in Addis Ababa and the rapid population growth expects to accelerate industrial expansion in the near future (AAEPA, 2008).

With regard to waste management, most of industries in the city are established along the river banks of Little Akaki. These industries discharge their effluents into the Akaki River system. Industrial wastes are relatively easy to identify since they are point source pollution and can be regulated with controlling programs. In Addis Ababa, there is an established industrial effluent discharge standard at national level, however there is no strong monitoring program for implementation and yet the standards are incomplete to fully address all contaminants which are a concern for environmental health. The absence of strong regulation for discharge of industrial effluents results in poor management of industrial wastes in addition to the limited financial capacities to treat industrial wastes. Consequently 90 % of the total industries of the city have no onsite treatment plant and dispose their wastes directly to the nearby water bodies (AAEPA, 2008). Most of these industries are not connected to sewerage systems of the city. The remaining 10 % of industries have pre-treatment plant which is not operational at all times; rather the wastes pass through it without upgrading the concentration of organic and inorganic constituents (Interview with Dr. Aynalem from EPA, 2010). In general, industrial wastes discharged into the Akaki River system are untreated and their pollutant loads, both organic and inorganic, is expected to be high. The waste generated from these industries comprise of organic materials, metals, acids, bases, and others, including toxic chemicals and heavy metals. In general sense, industrial development in Addis Ababa does not incorporate environmental concerns. Rivers are the main environmental components which are adversely affected by industrial wastes. Therefore to safeguard the surrounding environment from the hazards of pollution, a strategic action plan is needed to minimize chemical risks.

Industries distribution and growth along the Akaki River:

Addis Ababa's industrial expansion goes without the concern of environment; therefore industrial growth could be used as bases to understand the extent of pollution associated with expansion of industries. Moreover industrial pollutants relatively play a bigger part in river pollution than pollutants from other sources. In Addis Ababa there is a significant industrial growth over the last 40 years as shown in
Figure 14. When irrigation was introduced in Akaki catchment (1971-1980), the number of industries was 90. After a decade, the rate of industrial growth was almost insignificant. However after two decades the rate of industrial growth became tripled. In these years it is expected that farmers would have relatively different water quality access from Akaki River than the two decades before. During interviews this year is considered as a reference to understand whether farmers realized the change and if any field activity changed correspondingly or not. Industrial growth rate was high between 1991 and 2000; around 1226 industries were established in Addis Ababa. The alarming number of industrial growth in these years is expected to be the critical time where farmers in any case will come to feel significant water quality change.

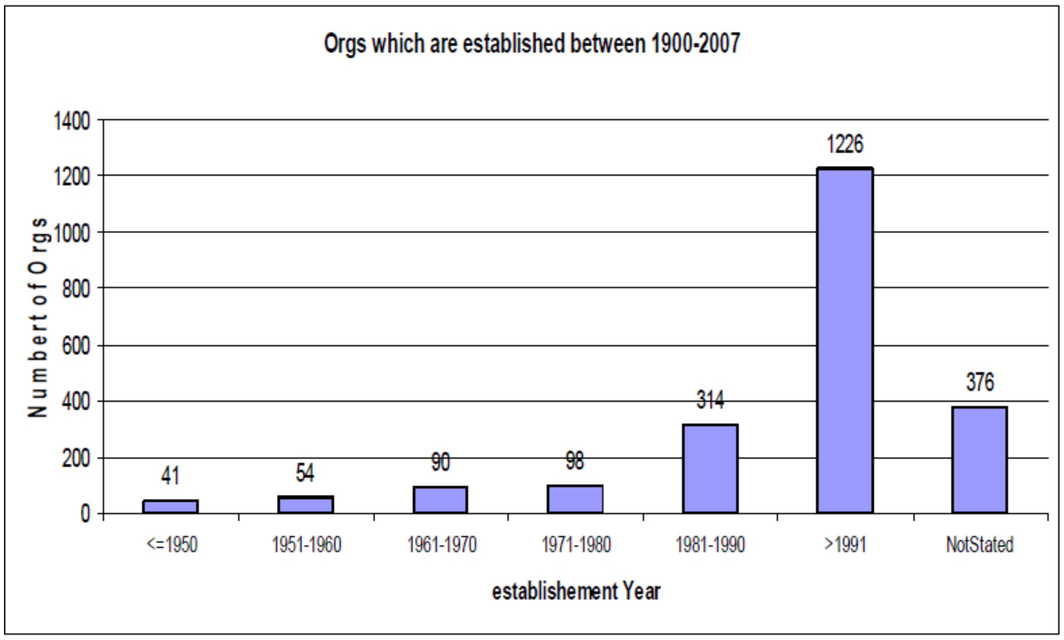


Figure 14 Trends of industrial growth in Addis Ababa
Source: AAEPA, 2007

Currently, there are around 2200 registered industries in Addis Ababa. The industries are categorized as leather and tanning, textiles, chemicals, plastics, health care industries, metal and non-metal industries, garages, and ware houses. The city has a large number of wood garages and ware houses, pulp paper, metallic and non-metallic and health facility factories (Figure 15).

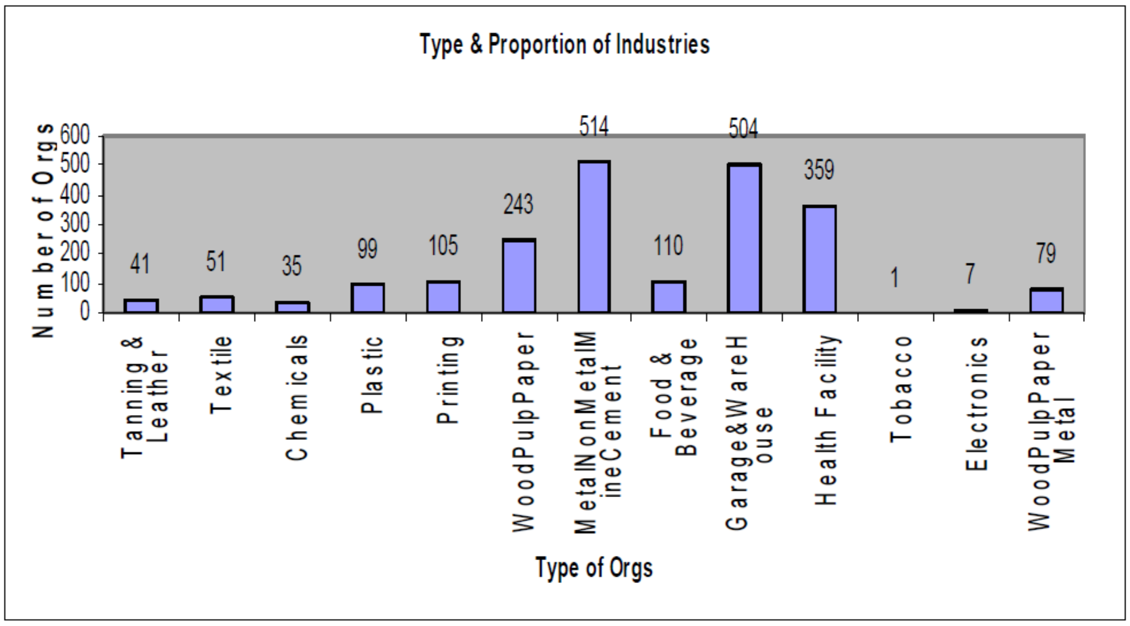


Figure 15 Major industries in Addis Ababa
Source: AAEPA, 2005

Laboratory examination of industrial effluents in Addis Ababa shows that most industrial effluents contain high concentration of pollutants (Table 4).

Table 4 Mean concentration of water quality parameters of industrial wastes in Addis Ababa

Sub Sector	BOD	Ammonia	Nitrate	Phosphate	PH	SS	Cd	Cr	Pb
Tannery	1942	300	70	16	7	1158	0.4	2.6	1.7
Beverage	913	46	4.8	18.5	8	1212	0.1	0.1	0.3
Food	566	44	17.1	31	9	231	<0.1	0.1	<0.1
Chemical	249	11	38	9.7	9	5906	0.2	0.2	0.7
Textile	46	0.7	4.1	2	9	70	<0.1	<0.1	0.2
Metal and Non metal	15	0.5	3.8	1	8	222.4	<0.1	<0.1	0.1

Source: Mohamed, 2002

Table 5 Provisional industrial effluent standards of Ethiopia

BOD	Ammonia	Nitrate	Phosphate	PH	SS	Cd	Cr	Pb
100	4.5	50	0.7	6 to 9	50	<1	<1	<1

Source: EPA, 2011

According to the effluents discharging standards of the country (Table 5), some of the constituents of industrial constituents exceed the standard limits and some of other fall within the standard limit. The value of BOD, Phosphate, SS and NH_3 for all industry types exceeds the standard limit. Those parameters which are within the standard limit do not necessary indicate the reality, because sampling was done without the knowledge of peak effluent discharge time of industries, rather random samples were taken.

The industrial effluents from major industries make the Little Akaki one of the most polluted rivers in the country. The water is observed as black in Akaki Kality irrigated area.

Figure 16 Colour of Little Akaki Water at section farmers take water for irrigation
Source: Tadesse, taken on 18/11/2010

Geographical distribution of industries along the Akaki River system

The difference in the density and type of industries along the river results in difference in water quality as one goes from upper stream to downstream section of the river. Industries in the Akaka River system are distributed unevenly along the different sections of the river (Figure 17). Most of the industries are situated along the river banks of Little Akaki River. Above 45 % of the total industries in the city are located at 50 meter distance from the river banks of Little Akaki and only 18 % of the industries are established in the area designated as industrial zone. As a result, the major industries along Little Akaki discharge untreated effluents to Little Akaki. On the other hand, there are only few industries established along the Great Akaki River and receives a relatively few industrial effluents.

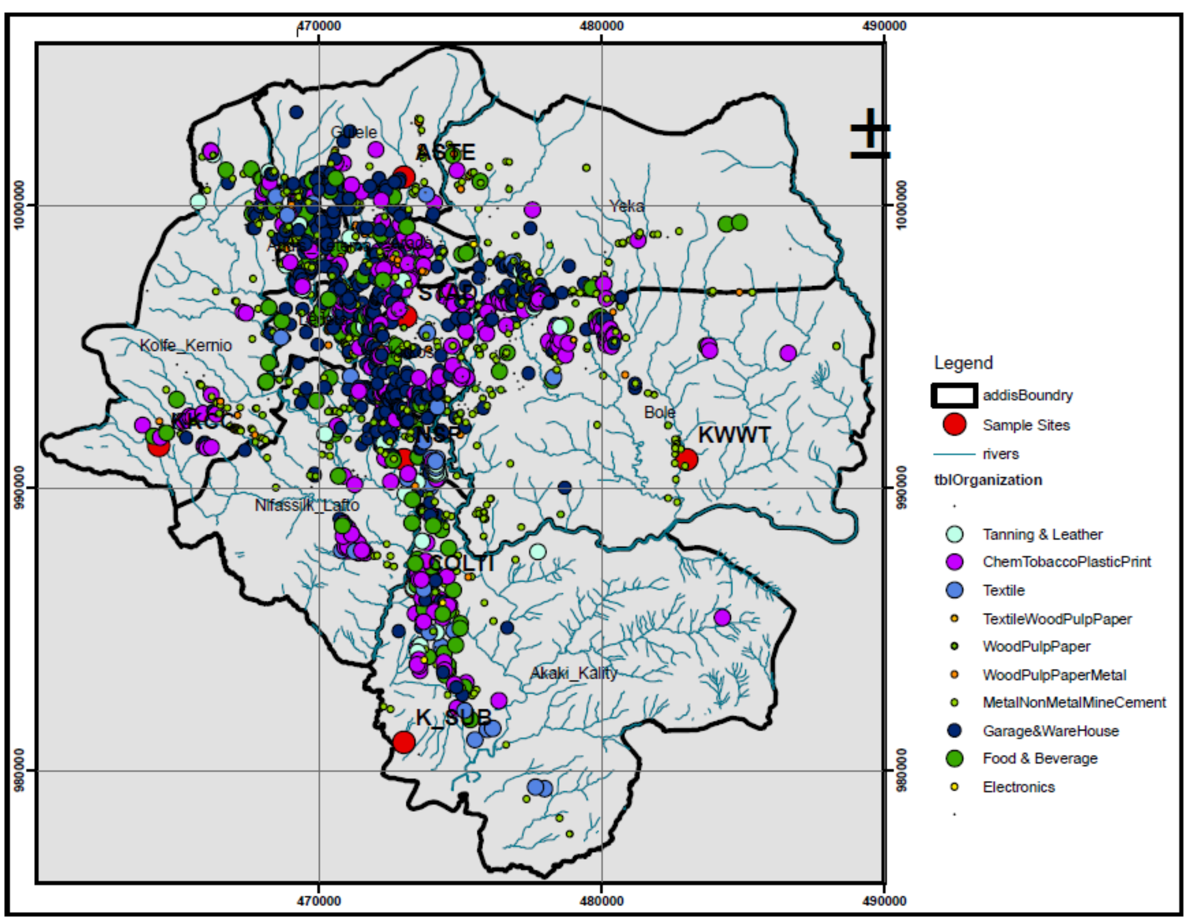


Figure 17 Distributions of industries along the course of Akaki Rivers
Source: AAEPA, 2008

Industrial distributions along Akaki River affects irrigated lands through different water quality access. Farmers irrigating in Yeka and Bole sub cities divert irrigation water from the upper stream section of the Great Akaki River system; thereby contaminates of industrial effluents has insignificant adverse impact on vegetable production. Irrigated farms located in Kolfe-Keranio, Nefas-Silk Lafto and Akaki sub cities are irrigated with water diverted from Little Akaki River system which is highly polluted with industrial effluents.

III. **Medical wastes**

Medical wastes are wastes generated from health centres, i.e. clinics and hospitals which are categorized as general and medical wastes. The general wastes comprised of 75 to 90 % of the total waste generated from medical centres mainly constituents of office and kitchen wastes. The remaining 10-25 % is clinical wastes which have a potential health risks to human (WHO, 1998). The clinical wastes include infectious waste such as laboratory cultures, waste from isolation wards, tissues, used dressings; pathological waste such as body parts, human foetuses, placenta, blood, other body parts; and sharps like needles, blade and broken glasses. Currently there are more than 24 hospitals owned by the ministry of health (Table 6) and a large number of privately owned small medical centres (their number is unknot known) found in Addis Ababa.

Table 6 Location of hospitals in the city along Little and Great Akaki River system

Number	Hospitals name	Location of in the city			Akaki Catchment	
		Western	Central	Eastern		X
1	Black Lion		X			X
2	Zewuditu		X		X	
3	Balcha	X			X	
4	Paulos	X			X	
5	Amanuel	X				X
6	Petros		X		X	
7	ALERT	X				X
8	Yekatit		X			X
9	Menelik			X		X
10	St.Gabrel			X		X
11	Ayat			X		X
12	Tibebe		X		X	
13	Betel		X			X
14	Gandi		X			X
15	Ras Desta		X			X
16	Bete Zata		X			
17	Ethio-Tibib	X				X
18	Zembaba General hospital		X			
19	MMd hospital			X		X
	19	**9**	**9**	**4**	**6**	**13**

Source: EPA, 2005

From Table 4 and Figure 17 we can see that most of the hospitals are located along the Great Akaki River system and few of them are located along the Little Akaki River system. Most of the hospitals and clinics in Addis Ababa do not have on-site waste treatment facilities and they directly or indirectly dispose their wastes into stream that are tributaries of either Little or Great Akaki Rivers system. Observation and survey of four specialized hospitals (Petros, Amanuel, ALERT and Paolos) indicates that these hospitals discharge untreated wastes into the Akaki River system (EPA, 2005). Even though there are some hospitals such as Zewuditu, Yekatit, Black Lion, Menilik, Balcha and Police hospital which have waste storage tanks, their leakages and overflows in one way or another brings infectious wastes into the Akaki Rivers systems.

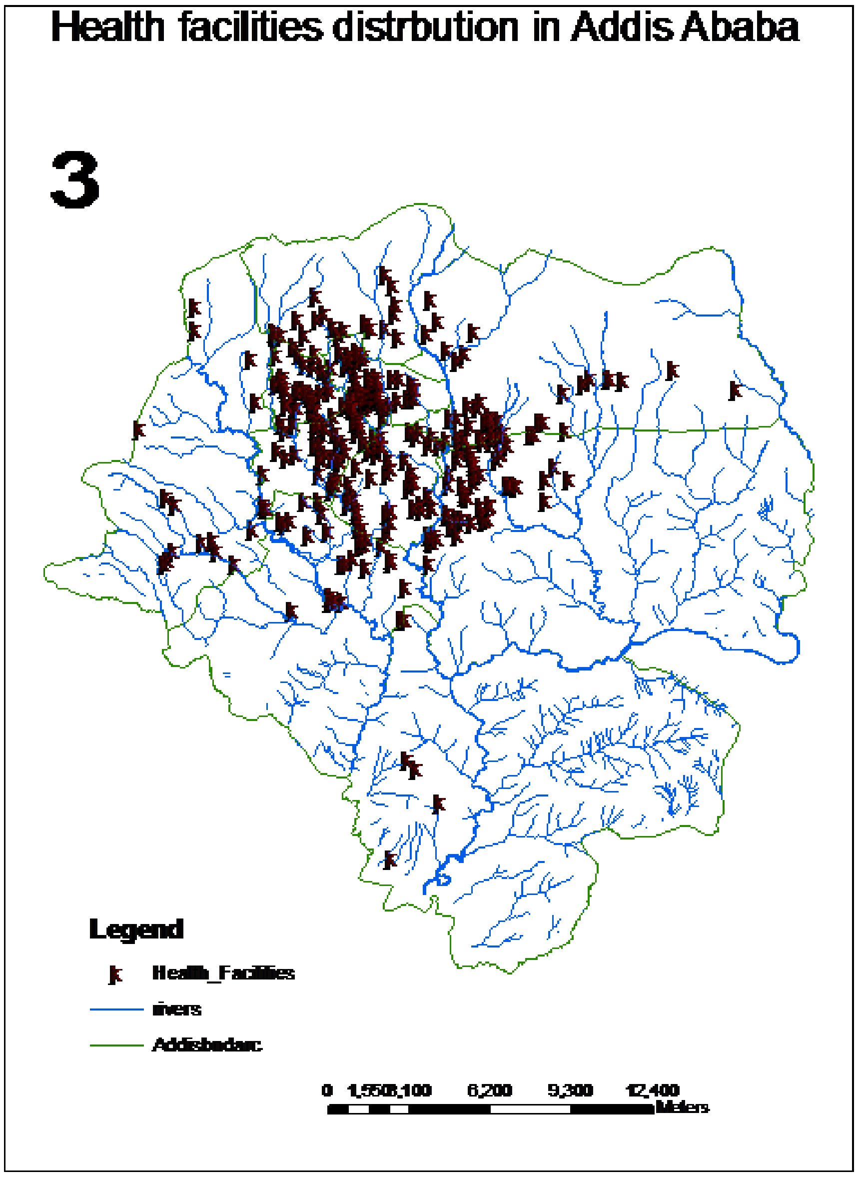


Figure 18 Spatial distribution of health centres in Addis Ababa
Source: AAEPA, 2008

IV. Other wastes

Wastes other than industrial, medical and municipal include oily wastes from garages, fuel stations, and animal excreta.

I. Waste from garages and fuel stations

There are a large number of garages and fuel stations in Addis Ababa. By 2005 there were 22 Total, 22 Mobile, 46 Shell and a number of new fuel stations serving as oil change and car washing centres for Addis Ababa (AAEPA, 2005). The wastes from car washing such as waste oil, wastewater and the sludge from the bottom of collecting tanks released directly to the adjacent ditches or streams. Though the exact number is not known, there are also large number of garages belonging to government institutions and private sectors. The waste oil from garages is not managed properly and disposed to the nearby water bodies. Thus these become a major source of contaminant of Akaki Rivers system. The waste generated from garages and fuel stations are oily materials which are combustible and environmentally objectionable. Observation of these services by EPA indicates that most of the stations do not have on-site treatment and the wastes are disposed to ditches, nearby water courses and streams. Oils are floatable liquids that are toxic to the surrounding environment, when we consider vegetable production; they have a drying effect and destroy the crops.

II. Waste of animal excreta

The total number of domestic animals in Addis Ababa is estimated to be 500,000 (AAWSA, 2000). The excreta from these domestic animals are disposed to open space, ditches, water courses and streams. Like other waste sources, animal excreta ultimately enter into Akaki Rivers system through tributaries flowing from different direction.

4.3.3 Water quality change trend through laboratory examined data

It is mentioned that historically there is inadequate waste management service in Addis Ababa for collection and disposal of urban wastes. The generated untreated liquid and solid wastes have been directly or indirectly discharged to Akaki River system.

As a result the pollution load of Akaki River system has been increased. However this information is not sufficient to understand the impact of water quality change on vegetable production, and further assessment of water quality is needed with experimentally tested data to interpret with standards developed for agricultural water use. For instance from agricultural water use point of view, all wastes are not pollutants. Part of the biodegradable component is a source of plant important nutrients (notably N and P) and therefore should be considered as positive contributor for vegetable production. Moreover the tolerance level of vegetables towards the negative effect of polluted water depends on the concentration of bio-physical and chemical constituents. In general we can say the water is polluted when it does not support vegetable production anymore under the given growing condition or when it needs extra cost for managing the negative impacts which will pose on growing environment, human and animal health.

Akaki River system has a seasonally variable quantity of flow which affects the water quality. Farmers irrigate twice per year, i.e. a first growing season that runs from October to February and the second from March to June. In times of high river flow, the concentration of water constituents per unit volume will be lower, whereas in times of low discharge there will be high concentration of water constituents. The first growing season (October to February) starts at the beginning of the dry season where the river has its minimum flow, whereas during the second growing season there is light rainfall that increases the river discharge (Table 7) . During the non-irrigating season between July and September the river will have a maximum quantity of flow. Considering the seasonal variations, water quality trend analysis was made on the basis of different geographical location of irrigated areas along the river, i.e. starting from upper stream to downstream sections and on three seasons in which the river will have different quantity of flow.

Table 7 Mean monthly flow of Akaki River between 1987 and 2004

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow(m^3/sec)	2.62	5.08	5.35	18.1 1	13.76	31.5 0	84.70	170.57	116.6	17.2	2.78	0.76

Source: Asfaw, 2007

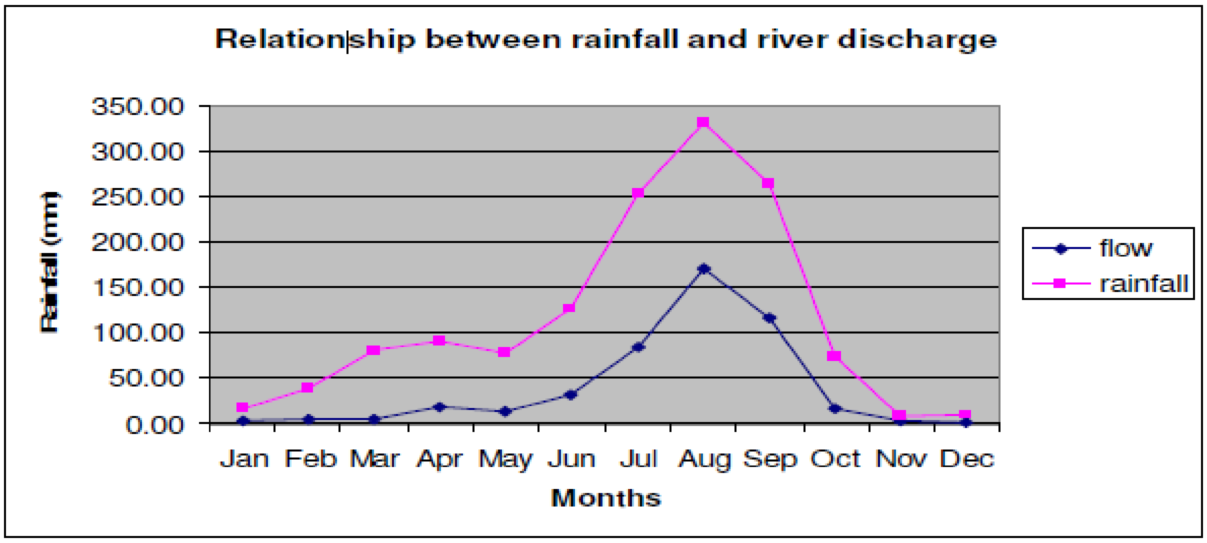


Figure 19 Relation between rainfall and river discharge
Source: (Asfaw, 2007)

Trend analysis is important to understand the water quality changes since the introduction of irrigation. Some of the Akaki farmers irrigate more than 40 years. Hence 1970 is used as a reference year to assess the annual water quality change. Trend analysis needs regular examination of the bio-physical and chemical quality of water for a long time either in yearly, seasonally, monthly or daily basis. Since there is lack of institutional capacity and long term development plan in Ethiopia, such data does not exist. Though there is some laboratory analysis done by EPA and AAWSA for few years, the data lack complete analysis of conventional parameters and other necessary information such as sampling time and locations. This makes water quality trend analysis for Akaki River system difficult. Due to this fact the trend analysis of Akaki will be assessed in two categories, i.e.

I. Between 1973 and 2000 water quality tests are categorized as incomplete data as the time and location of sampling are not fully addressed. In this category data is available only for Little Akaki as it crosses the long section of the urban area (old urban centres with currently insignificant development) and it receives most of industrial effluents of the city. Great Akaki was not examined as the industrial waste contribution is negligible and there is limited data available on it. Under the next section, the water quality under these year category discussed with data collected with overview of previous studies.

Table 8 Pollution loads on the Little Akaki River by 1973

Sampling sites	pH	SS	Nitrate	PO4	BOD5	DO
5 km above from Addis Tannery	8	75	0.22	2.2	45	12.5
Above Marble Industry about 1 km from its beginning	7	100	0.22	0.63	15	11
Downstream below Mekanissa Distillery About 10 km from Addis Tannery	8	200	8	2.2	20	6
About 5km above Mekannisa Distillery	8	400	0.33	13	160	3

Source: Mohamed 2002 in reference to Komolrite and Zawide (1974)
All values are expressed as mg/l except pH

Table 9 Pollution loads on the Little Akaki River and tributaries in 1989

Sampling sites	BOD	DO	Ammonia	Chloride
Before Gulele soap factory	3	7	0.53	5
Addis Jimma road bridge	339	0.8	32.3	110
Zenebe Work Area	40	0.6	8.8	50
Fifth Police Station Bridge	535	0	63	83
Addis Ababa Abattoirs Area	444	0	71	85
Near Behere Tsiga Park	252	0	52.5	65
Kality Wastewater Treatment	105	0	80.6	235

Source: EVDSA, 1989 as quoted in Mohamed, 2002
All values are expressed as mg/l except pH

Table 10 Little Akaki River water quality in 1997

Parameters	PH	SS	BOD	DO	NH3	PO4	NO3	Cd	Cr
Upper catchment	8	697	161	3	24	4	23	<0.1	<0.1
Middle Catchment	7	186	316	2	27	19	3	<0.1	<0.1

Source: EPA 1997

Table 11 Akaki River water quality in Bole sub city (East of Bhere Tsega garden)

Parameters	PH	Na	K	Mg	Ca	Cr	Cd	Fe	Pb	Zn	No3	Cu	Mn
Concentration	8	50	27	16	53	0.1	0.1	0.41	0.1	0.1	11	0.08	0.58

Source: Ejigu, et al., 1997/96 as quoted in Mohamed, 2002

Table 12 Little Akaki River water quality in 1998

Parameters	PH	SS	BOD	DO	NH3	E.coli
Upper catchment	8	66	12	6	3	3,480,000
Middle catchment	8	198	24	3	24	66,400,000
Lower catchment	8	172	30	4	14	-

Source: Nigusse, 1998 as quoted in Mohamed 2002.

The summery of the four years data indicate that the middle catchment is more polluted than the upper catchment as major industries are located in this section. The BOD values have increased and dissolved oxygen has decreased over these years which are indicators for overall increment of pollutant load. Compared with FAO and WHO standards, all measured values except pH exceed the standard limit and the water does not fit for irrigation purpose

Table 13 Water quality change of Little Akaki between 1973 and 2000

Year	BOD	DO	AMMONIA	NITRATE	PHOSPHATE	PH	SS
1973	60	8	-	2.0	5.0	8	194
1989	246	1	44	-	-	-	-
1997	81	4	8	14	8	8	931
1998	175	3	20	-	-	8	176
Standard	<20		0-5		0-2	6.4-8.5	<20

II. The second category is comprised of the water quality discussion for the last 10 years. The establishment of governmental organizations such as Oromiya, Addis Ababa and Federal Environmental Protection Authorities as well as the growth of in-country research programs at academic institutions in the field of environment and water contribute to the availability of water quality data since 2000. This analysis is based on four years data which were collected by over viewing the 2002, 2005 and 2008/09 laboratory findings and on the results of 2010/11 water quality examinations (Annex 4). The examinations were done for three seasons to understand the pollution load under different water quantities. The first sampling season was summer, from August to October, where the catchment receives sufficient amount of rainfall and known as wet season. The second sampling was during the dry season, from December to February, where the rainfall contribution is negligible. The third collection was between March and May with relative small rains.

In this research the dry season water quality change trend is selected for interpretation of irrigation water quality as cultivation is fully dependent on irrigation during the dry season. The sample locations were selected for each water extraction points of irrigated farms. A number of bio-physical and chemical parameters which determine the suitability of water for irrigation were examined. The water constituents are categorized as harmful or important by comparing the values with FAO and WHO standards for agricultural use. The next section discusses the water quality change in time at different water extraction points for irrigated farms. The surrounding environment of water extraction points in Akaki River system has the following feature.

I. **Kolfe-Keranio irrigated area sampling site**

At this point irrigation water is diverted from Little Akaki River system for cultivation of vegetables. A large amount of solid waste and human excreta are observed at the sides and inside of the river. The area is densely populated where house hold wastes through drainage lines mix with the river.

II. **Nefas Silk Lafto irrigated area sampling sites**

In Nefas Silk Lafto sub city, around 153 hectares of land are irrigated for cultivation of vegetables. At this section, the long profile of little Akaki River system is used as a source of irrigation water. Extracted water at diversion locations in the long profile of the river has different mixture of major effluents. Therefore this area is split up into three water extraction points as follows to understand the water quality change due to different mixture of effluents.

A. Below Addis Ababa Abattoirs, around "Kera Sefer", a tributary of Little Akaki is used for cultivation of vegetables. In this section the river is highly polluted by human excreta, solid wastes and Kera Abattoirs effluents. On one side of the river irrigated agriculture is practiced, whereas on the other side the abattoir's wastes such as blood, ruminants and bones by-products accumulate in the area.

B. From the section of Little Akaki, next to National Alcohol and Liquor factory, water is diverted to irrigate carrot, red bit, and kale, cabbage, and salad farms. In this section the water is mixed with untreated effluents of the National Alcohol and Liquor factory. Solid and liquid wastes as well as human excreta are observed on the river sides.

C. Downstream of Addis Ababa Abattoirs, Little Akaki River system crosses Gofa Sefer where another vegetable farm is irrigated. The area is a residential area where solid wastes from house hold and others mix the river.

III. ***Akaki sub city irrigated area sampling sites***

Three extraction points were sampled in Akaki sub city which have the following feature,

A. In the first site the wastewater treated from Kality treatment plant is used as a source of irrigation water. Kality treatment receives waste from the central sewerage system.

B. A little downstream of Kality treatment plant, the treated wastewater mixes with the main Little Akaki River system. At this point the area is agricultural land where the water is brown in colour and it has a lot of foam showing that some contaminants from the treatment plant are mixed with the river water.

C. Further going a little down, there are peasant association where a bulk of vegetable production is practiced such as cabbages, carrots, and kale.

IV. **Bole irrigated area sampling site**

The area is densely populated from which the house hold wastes are mixed with the river. Inside the river dead animals, animal excreta, and solid wastes are observed. At this point water from the Great Akaki River is diverted to irrigate Kale, Cabbage, Red bit, and Carrot. Urban centre expansion is recent along Great Akaki River, as result little attention has been given to Great Akaki River compared to Little Akaki. Consequently, there is only a few year data available for water quality trend assessment.

V. **Akaki Oromiya irrigated area sampling sites**

Great Akaki in AKaki sub city, along Debrezeit Road, is used to irrigate vegetables. The river is mixed with textile factory effluents at this point.

In consideration with the above feature of sampling locations, the results were interpreted as follows. The water quality parameters which are basic to interpret agricultural water use are categorized into three groups, namely pathogenic organisms, heavy metals and miscellaneous parameters. Pathogenic organisms are always harmful for irrigated agriculture through posing health risks for field worker and consumers; whereas heavy metals and miscellaneous parameters are important to crops when their concentration is within the standard limits and have adverse impacts to crop, environment and public heath when present in excess. Based on this category, the values of water quality discussed as harm full (risky) or use full as follows.

A. **Risky constituents**

The total coli form bacteria, faecal coliform bacteria, and E.colis is considered as indicators for contamination of water with highly infectious pathogens. The presence of total coliforms in excess of the standard limit causes health problem to irrigated agriculture field workers or people living on or around the land where the contaminated water is used as well as people who consume or handle the products of contaminated water irrigation. According to WHO standards for agricultural use, the maximum tolerable limit of total coliforms and E.colis for raw eaten and other crops is 200 and 1000 consequently (Annex 3). However, the obtained results of faecal coliforms for Akaki irrigation water ranges between 2,500 and 11,000,000(Annex 4). This indicates that the river water is highly contaminated with human excreta's, household and health organization wastes. When the laboratory results for total coliforms and E.colis are compared to the WHO standards, the water does not fit for irrigation use. In all years and sampling sections, the values of the total coliforms and E-coli alarmingly exceeded the standard limit (Figure 20). The highest number of total coliforms and E.colis were observed by 2005. The total coliforms and E.colis contaminations are found to be relatively low in the upper catchment, and highest in the middle catchment where it receives more wastes and lowest in the downstream area as human intervention is low. In this regard, public health hazards associated with irrigated agriculture from Akaki River system is expected to be high. Moreover the agronomical activities in Akaki such as cultivation of highly transmitting fresh vegetables (lettuce and carrot), hand harvest, hand cultivation of food crops, and direct contact with water are categorized as highly risky and expected to aggravate the health hazards.

Heavy metals are other harmful constituents of wastewater if present in excess of the acceptable quantity. Heavy metals are required by human beings and plants in trace quantity; however when their amount exceed the threshold, they are toxic to plants, transmit to consumers and are dangerous for public and animal health. Trace metal examination results in Akaki River also show a remarkable variation at different water sampling locations. In Bole and Kolfe-keranio sampling locations, the concentration of manganese and cobalt exceeded the standard limit over the last years. Cobalt is not freely available in the environment and when it is not bounded with soil or solid particles, the uptake by plants is higher and results in accumulation in the plant body. Consequently, people will be exposed to cobalt through consuming vegetables. Skin contact with water and soil contamination with cobalt can also cause health problem to field workers. On the middle and downstream catchment extraction points, i.e., Nefas Silk Lafto and Akaki, chromium, cadmium and iron values exceeded the standard limit in addition to cobalt and manganese (Figure 21). The presence of chromium in excess of the threshold value is harmful to animals, plants and humans. Chromium is a vital element for human being; however, consumption of plants with excess accumulation chromium affects the skin, irritating it and causing skin damage. It has also a long term effect such as damage to liver, kidneys and nerve cells. Cadmium similarly can cause gastrointestinal disturbances, convulsions, liver problems, kidney disorders and damage to bone and blood. Furthermore, heavy metals may have toxic effect to plant depending on the tolerant level of the plant type.

The other constituents of concern are those which have adverse effect on soil, effect on choice of irrigation system and other environmental problems. The total suspended solids (TSS) results exceeded the standard limit for most of sampling years and locations. In this regard, the use of drip irrigation will be challenged by clogging problem and soil pores will be clogged by larger particles. The BOD values are also above the standard limit which has an implication for high level of pollution.

B. Important constituents

In addition to the direct economic benefit by supporting irrigated agriculture, wastewater has importance in supplying plant important nutrients. In contrast to the health and environmental problem pertaining to the use of wastewater irrigation, it is used as a liquid fertilizer.

The laboratory examination results show that the river is rich in nitrogen and phosphorous (Figure 22). The current laboratory examinations for total nitrogen show a presence of between 10 to 50 mg/l as ammonia, nitrate and nitrate form in Akaki river water. Similarly the phosphorous concentrations range between 3 and 7 mg/l. Therefore the contribution in reducing the cost of fertilizer application should be appreciated provided that farms are aware of this.

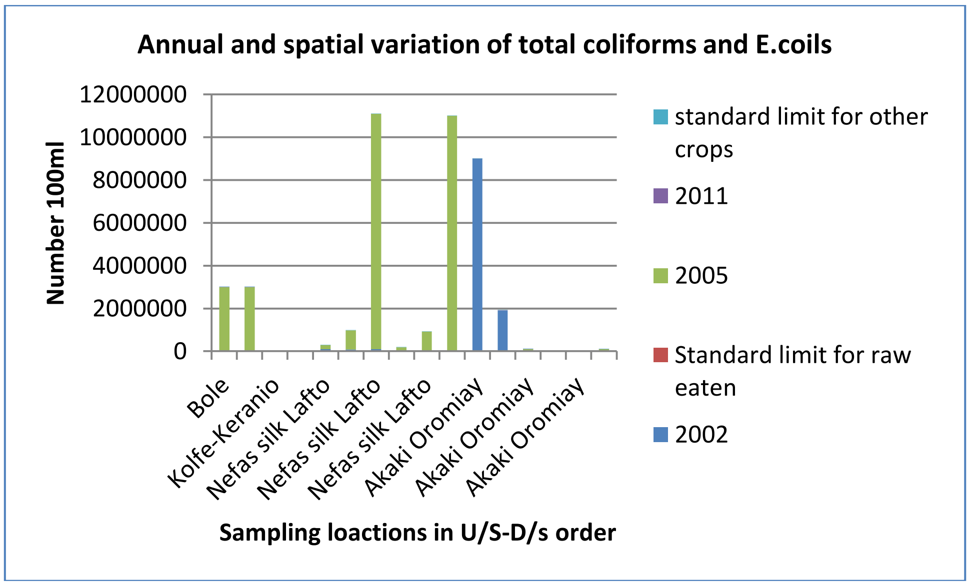


Figure 20 Spatial and annual variation of total coli forms and E.colis for Akaki River system

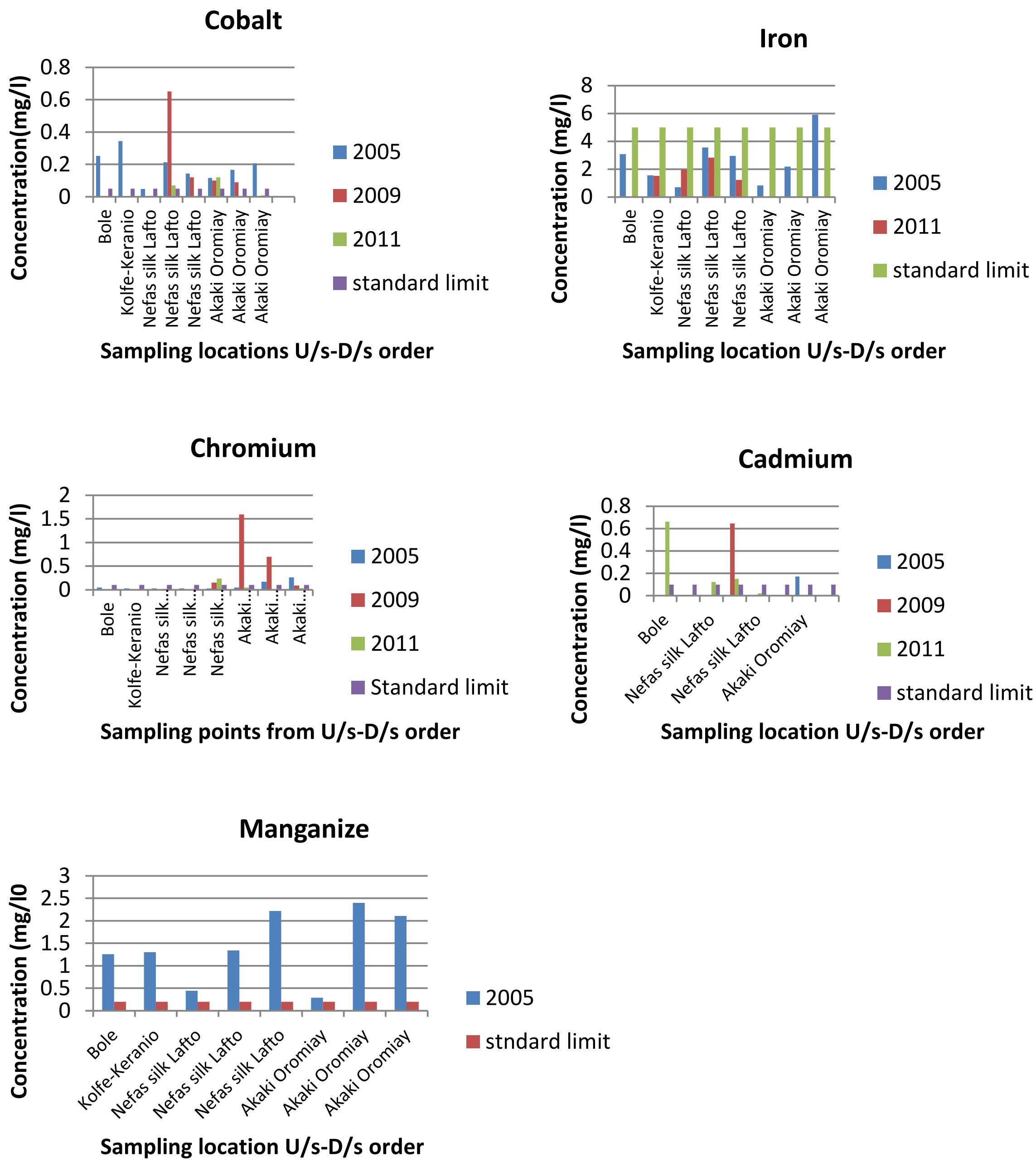


Figure 21 Heavy metal concentrations in Akaki river system

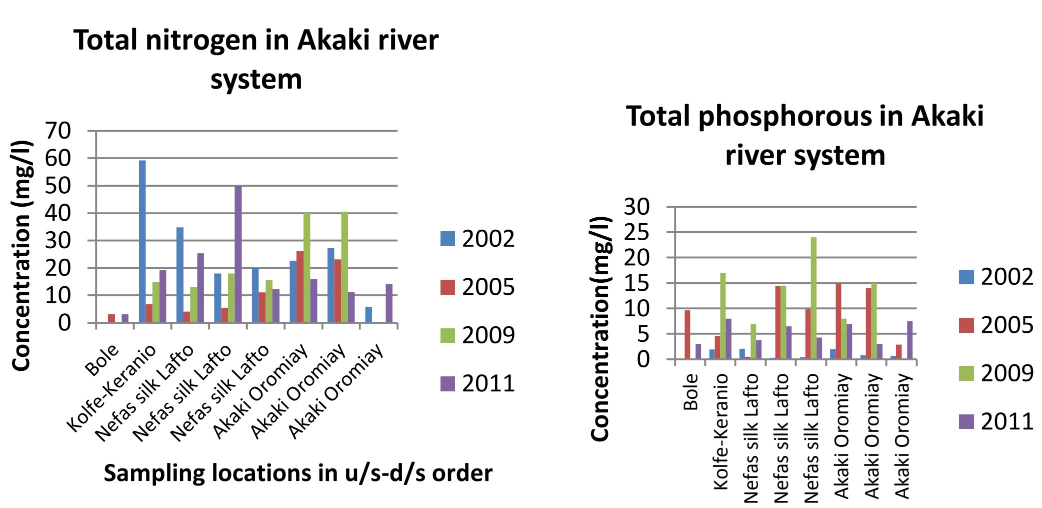


Figure 22 Total nitrogen and phosphorous concentration for Akaki river system
Source: Self-elaborated, EPA 2005 and Mohamed 2002.

Conclusion

It is noted above that the quality of Akaki river water has showed remarkable changes for the last 40 years. Among the various quality parameters which were used to evaluate the suitability of Akaki rivers water quality for irrigation use, the findings of total coliforms and E.coli; heavy metals particularly cobalt, chromium, cadmium, manganese and iron; and miscellaneous constituents such as total suspended solids and BOD exceeded the standard limits over the last years. The total coliforms and E.coli results exceeded threshold values alarmingly and are a primary concern for public health hazards. The presence of high concentrations of suspended solids in irrigation water has adverse effect on soil structure. The colloids and undisclosed suspended matters have the capacity to clog soil pores. The higher the BOD value on the other hand indicates the lower oxygen content and result in reduction of the self-purification capacity of the river. As a result the natural treatment will be less and the pollutant load propagates downstream. Some other parameters like pH, temperature, total dissolved solids, and lead show that the concentration are within FAO irrigation water quality limits. The quantity of ammonia, nitrate, nitrite, and phosphate were found as significant from NPK requirement point of view. Therefore the Akaki river water is assisting as liquid fertilizer.

4.3 Future water quality change

Review of recent and past findings of water quality assessment shows that Akaki river pollution has increased over the past years of irrigation. The laboratory examination results for selected water quality parameters indicates that the total coliforms, E.colis, BOD, Mn, total suspended solids, Cd, Co, Cr, and Fe went beyond the standard limits. Among the examined parameters, the river water is alarmingly polluted with total coliforms and E.colis. Moreover the numbers of coli forms and E. coli have increased between 2002 and 2005. Similarly the BOD values have increasing trend over the last years of irrigation. However, the results of total suspended solids have decreasing trend. Some of others show irregular change and cannot be categorized as an increasing or decreasing trend. Without intervention on wastewater management, the water quality changing trend is expected to increase more in the future. However it is worth to consider the proposed wastewater management of Addis Ababa to project future pollution load.

AAWSA: is a responsible organization for the provision of sanitary services through expanding sewage collection and treatment plants. Currently there are two on-going projects for the expansion of treatment plants, namely Akaki I and Chefe WWT works, and sewers system. Chefe WWT is designed to treat 20,198 m^3 of wastewater per day at its full capacity, whereas the Akaki I WWTP designed to treat 59,639 m3/day. Completion of these treatment plants is expected to reduce the pollution load of Akaki river system. The total waste generation by 2030 is estimated to be 59 438 846 m^3/year; whereas the waste collection system and treatment capacity of the proposed and existing systems will be around 58 768 260 m^3/year (AAWSA, 2010). These figures indicate that within 20 years, the wastewater collection and treatment coverage from nonpoint pollution sources will be much better. However the pathogenic pollution will be more challengeable in the future because of the following reasons. One, total coliforms and E.colis are faecal origin and the more excreta discharge to the river, the more number of infectious micro-organisms. In Addis Ababa, majority of people are living in the slums and some used to illegally dispose their toilet sludge to Akaki river system. Similarly 30% of the dwellers are homeless who uses open defecation and urination and this is difficult to monitor. Two, the proposed sewerages system is designed to receive wastes mainly from modern houses to be built in the future and therefore give little attention for slums.

Regarding point source pollution, industrial pollution regulation No. 159/2008 approved to prevent industrial pollution in accordance with Article 20 of the environmental pollution control Proclamation No. 300/2002. The regulation provides a gestation period of five years for existing industries to bring their effluent discharge within the water quality standards. AAEPA has planned to work with the industrialists towards this direction. Therefore the industrial pollutants are expected to decrease within the next five years.

4.2.3 Arguments to start irrigation

Argumentation to start irrigation was studied for understanding livelihood dependency on polluted water irrigation and value given to polluted water. There are a number of technical and social indicators to identify drivers for irrigated agriculture. In this research, livelihood dependency (in terms of time spend for irrigated agriculture compared with other cash earning activities), access to fresh water, reliability and adequacy of polluted water, comparison of irrigated versus rain fed agriculture, and other cash earning activities were investigated. The findings of these indicators are mainly from interpretation of the data obtained from farmers at field level, and also somehow from observation, the general information obtained from local people and local agricultural offices.

I. Socio-economic drivers

The findings on socio-economic driver indicate that irrigated agriculture has a historical root with land ownership. Addis Ababa has an undulating topography, river banks are mainly lowlands which are difficult for construction with local capacities, and majority of the lands are not allocated for urban centre expansion. Historically urban agriculture has been practiced on these farm lands, thereby urban expansion has low influence in reallocating farm lands for construction. The implication behind long year agriculture is that land inheritance from parents promoted some of the farmers to start irrigated agriculture. This has been proved through interview data, for instance interviewed farmers mentioned that most of irrigated farms around Nefas Silk Lafto irrigated area are inherited from parents. Taking the opportunity of land heritage, farmers start irrigation as a means of cash earning for living expenditure. For some of them the income from irrigated agriculture covers more than 75 % of cash needed for living expenditures. For most of the other farmers, irrigated agriculture is the only means of cash earning activity from October to June for covering living expenditures. For most of the farmers it is a full time job during dry and intermediate seasons, whereas for few of them it is a part time job spending half day for field work. During summer time some of them will look for other job opportunities and others will use still the cash earned from irrigated agriculture as the only cash for covering living expenditures in all seasons.

Almost all farms in Akaki sub city and Oromiya (peri-urban irrigators) are developed with pump irrigation system and most of them start irrigated agriculture within the last 10 years. Peri-urban farmers earn cash from rain fed agriculture by growing cereals and keeping livestock in addition to cash earned from irrigated agriculture. Hence, the growing demand of vegetables in the catchment is found as the likely driver compared to investment cost for diverting the river water. Therefore, from socio economic point of view, land heritage from parents, economic dependency on the cash earned from irrigated agriculture and market demand are the main drivers.

I. **Technical drivers**

From a technical point of view access to fresh water, reliability and adequacy of polluted water were used to investigate the argumentation to start irrigation. Access to fresh water was identified based on the difficulties encountered to use other fresh water sources. Water scarcity can be defined as physical if shortage is from natural hydrological cycle or when the available fresh water is already fully allocated for use; whereas it can be socio-economic scarcity when local institutional and financial capacities limit use of fresh water. In that sense, irrigated farms were observed for their accessibility for fresh water. The possible sources of fresh water in Akaki catchment are rainfall and ground water sources. The area gains plenty of rainfall during summer time and light rainfall from February to June. The hydrogeological studies indicate that there is untapped groundwater potential in the catchment. Therefore one can expect that physical water scarcity is not a reason for introduction of polluted water irrigation, though a water balance study is not made to assess the supply and demand gap. The occurrence of flood during summer season on the other hand does not support cultivation of vegetable along Akaki river system. Because of their topographical feature, most of the irrigated farm lands are flooded during summer. Though urban farmers take the advantage of light rain in the intermediate season to supplement irrigation, unexpected flood also challenges peri-urban farmers during the intermediate season. On the other hand ground water irrigation is expensive for farmers as drilling and pumping costs are unaffordable and Only few farmers in peri-urban have idea about ground water use for irrigation. Some other farmers seem to be interested in minimizing the cost of irrigation using polluted water rather than extracting water from ground water though they have awareness about water quality and capacity to develop ground water irrigation. Few irrigators were irrigating directly from a wastewater collecting ditch of Akaki textile factories using gravitational flow. However when the textile factory closed two years ago, they shifted to use pumped irrigation from Great Akaki river. Therefore economic water scarcity is the main reason where farmers continue to use polluted water irrigation.

The other two indicators identified were reliability and adequacy of Akaki Rivers for supporting irrigated agriculture. According to interview data, the quantity of river flow has increased over the last years. The consumption of more water due to rapid urbanization and improvement of living standards increases the wastewater volume and is the likely reason for flow rise. A gradual increment of river flow is very helpful for farmers in the section of the river where water is scarce due to intensive agricultural use. For instance it helps farmers to increase the frequency of irrigation. In Nefas Silk Lafto-Lideta and Bole irrigated farms, the irrigation water sources are not reliable in all seasons to support irrigated agriculture. In Nefas Silk Lafto-Lideta area, the river is flowing in a gorge and is highly polluted with toilet wastes. Farmers in this area have good awareness on water quality and use ground water as a source of irrigation water. However the ground water is not reliable and farmers use highly polluted river water when ground water is not adequate. Some of the lands in Nefas Silk Lafto-Lideta are abandoned from cultivation due to shortage of water. In Bole irrigated area Bulbula and Kebaena, tributaries to the major Great Akaki River is used as a source of irrigation water. Kebena has a relatively better water quality, whereas Bulbula has a relatively high mixture of organic and inorganic waste mixtures. Irrigated farms are established in the land between the two rivers flowing closely and in parallel. Farmers' preference for high organic mixture in water (in their view dark colour) results in high irrigation extraction from Bulbul River. The high extraction at the upper stream of Bulbula limits water availability for downstream farmers. These downstream farmers use night irrigation to cope with water scarcity. There are also some other factors which affect the reliability of water in the irrigation canal. Urban farmers use traditional diversion structure constructed from sand filled bags and coarse stones. The diversions are not strong enough to the high summer discharge and will be damaged easily by high river flow; therefore there is fluctuation of water in irrigation canal during the beginning of the dry season. On the other hand, some farmers mentioned that frequent sedimentation of solid materials causes fluctuation of water in the irrigation canal.

A number of technical and socio-economic factors were identified to understand the drivers for irrigated agriculture in Akaki catchment. On the socio-economic side, land acquisition through heritage and corresponding economical dependency on the cash earned from irrigated agriculture as well as market demand for vegetables are found as the main drivers for polluted water irrigation. On the technical side, accessibility of polluted water with minimum capacity, gradual increasing river flow and adequacy of river water are main drivers for irrigated agriculture.

4.2.4 Awareness of farmers on water quality change and adaptation strategies at field level

Though polluted water irrigation has a positive contribution for socio-economic development of the area, it has associated adverse health and environmental impacts. Farmers have a different perception towards associated adverse impacts. Almost all Akaki farmers were found to have a common view on the positive contribution of polluted water to generate income for covering living expenses. Though farmers understand water quality change over the past years of irrigation, some urban farmers are not willing to tell what they experienced so far. Inhabitants around urban growing environment complain about the products which make farmers to be fear full for losing their farm land. As a result, they tell the wrong or hide story of water quality change. The next section discusses the findings of farmer's awareness towards water quality change at different sections of the catchment.

Kolfe-Keranio irrigated area

Farmers in Kolfe Keranio irrigated area use mainly the Shankila River which is a tributary to major Little Akaki. The tributary originates from Gullele area where wastes from Marble, Shirt and Gulele soap factory are discharged into the river. The irrigated area is observed as highly polluted with solid waste and human excreta. The wastes from surrounding densely populated area are released to the river via drainage lines. Considering this baseline information and water quality trend analysis through laboratory tested data, farmers were asked to give their understanding on water quality changes since the introduction of irrigation. Moreover their adaptation strategies at field level were assessed as an implication of awareness for water quality change.

Farmers in this area understand that the water does not have a good quality for irrigation. Farmers argue that the water problem causes abnormal growth of vegetables and corresponding yield reduction. Farmers observe chemicals mixed in river water having white colour, suspended materials and toilet wastes. The chemicals observed in turn changed the colour of vegetable and sometimes result in total crop loss. Obviously farmers understand that the wastes are dumped from upper stream factories, residential areas and commercial centres like hotels. Most of these farmers have irrigated for more than 30 years and found potential of river water to support irrigated agriculture continually declining. Corresponding to water quality change, farmers used to irrigate from alternative sources. When the white chemical in the river is observed as high during the irrigation day, water will be diverted from a nearby spring. However, the spring does not have sufficient amount of water to irrigate all nearby farms. Currently the spring flow is diverted to an inaccessible direction due to construction of residential houses and farmers do not have an alternative source. Some other farmers mention their inability to use adaptation mechanisms because of limited financial capacity and shortage of technical knowledge. Among the possible on farm adaptation strategy, crop selection is doable for developing countries. However, in this region priority is given for market demand than selection of tolerant crops. Moreover farmers are observed working in the field without health protection tools and they did not mention anything about the associated health risks. In contrast, the water quality examinations indicate that the water is highly polluted with coli forms and E.colis which are dangerous to public health.

Bole irrigated area

Bulbula and Kebena are tributaries of Great Akaki which have been used for irrigation in Bole sub city. Farmers have as common view that Bulbula water contains more wastes than Kebena. The waste components viewed as advantageous from an agricultural point of view and disadvantageous from field worker health point of view. Some of the farmers irrigating from Bulbula mentioned that when the water is black, it will enable better yield and preference is made to irrigate when the river has black colour. However, it's disgusting colour and pungent smell is dangerous for field workers health. Farmers are challenged by loss of vegetables when chemical wastes mix with river water. Farmers have a clear insight from where the waste is released. They expect the black wastes from toilet leakage and chemicals from organization like hospitals. There are farmers who have a feeling that the water has quite good quality because whatever constituents mixed with water, it sustains our life through supporting irrigated agriculture. Furthermore the sedimentation of suspended materials, particularly plastic bags in diversion structure, reduces the quantity of flow to be diverted to irrigation canal and resulted in shortage of water for downstream farmers. To alleviate the water shortage problem, regular irrigation intervals were developed four years ago. Interviewed farmers have 40 to 15 years' experience on irrigated agriculture. When they start irrigation 40 years ago, the water was good and farmers were using the river water for household consumption. Farmers argued that the water quality has been changed badly over the last 30 years. The river has highly variable water quality on a daily basis. Farmers use different strategies to adapt water quality change i.e. for instance use of filtering membrane at diversion structure to trap suspended materials and adjust irrigation time with better quality flow within a 24 hour flow. Though the interviewed farmers have an understanding that the water quality might pose health risk for field worker, they are not using health protection tools. One of the reasons to work without globes and shoes is their thought that these dressings are not comfortable for field work.

Nefas Silk lafto

The sub city is among urban sites where irrigated agriculture is intensively practiced. The farms were observed and farmers interviewed based on three geographically varied sections. The upper stream part consists of Lideta area irrigators who use a combination of river water and ground water. Middle stream and downstream contains irrigators from Kera tributary who use water mixed with Abattoirs wastes; irrigators from Little Akaki around Mechanisa area who are vulnerable to National Alcohol and Liquor factory effluents; and irrigators after Kera tributary mixed with Little Akaki who use water mixed with Abattoirs and factory effluents.

Interviewed farmers in Lideta area argue that the water is highly polluted and is not suitable for irrigation. Some of the farmers use the river water only for land preparation but the land will be flushed with ground water before crop planting. Other farmers use the river water for irrigation when the ground water flow in irrigation canal is not sufficient. As a result farmers have been challenged with yield reduction and sometimes total loss of crop. In Mechanisa irrigated area only farmers who have farm lands close to the National Alcohol and Liquor factory complain about the quality. Wastes from the factory leak to their farm and they encounter frequent failure of cultivation. Kera farmers can be seen in two categories i.e., those irrigating close to abattoirs who are adversely affected by the Abattoirs waste (for instance farmers mentioned that while working at field frequently infected with flue) and those irrigating a distance away downstream of abattoirs who are benefited with the Abattoirs wastes as it enable cultivation without fertilizer application. Downstream of Mehanisa and Kera farm, farmers welcome Abattoirs waste but the chemicals from the factory adversely affect vegetables. Farmers mentioned that the chemicals have red colour and the concentration vary on a daily bases. Apart from the aforementioned major problems, farmers are challenged by suspended materials particularly sharp metals which damage their body while working in the field. Furthermore, summer floods also resulted in accumulation of suspended materials in the farm.

With regard to understanding water quality changes over time, farmers have different experience. For instance Lideta farmers found the water quality bad since the introduction of irrigation. Other farmers found the water quality challenging after establishment of National Alcohol and Liquor factory and Abattoirs. Few farmers mentioned that expansion of residential centres along the river worsened the problem. The corresponding adaptation by Lideta farmers is irrigating from ground water source, whereas Mechanisa, Kera and Gofa farmers use to irrigation when the water looks pure and clean. Farmers close to Abattoirs, who are affected by bad smell, move the diversion structure from downstream to upper stream of Abattoirs. Some of the farmers observed wearing protection shoes and work without gloves.

Akaki sub city and Oromiya

Unlike urban farms, irrigated agriculture is rapidly expanding in peri-urban area. Farmers are more free and willing to share the challenges of water quality than urban farmers. Irrigators' awareness is identified separately for Great and Little Akaki farmers as follows.

Interviewed farmers from Great Akaki understand that the water has bad quality for irrigation. The water is viewed as highly polluted with suspended materials and toxic chemicals with varying concentration and the colour has been changing more frequently. Moreover farmers are informed by local health officers that products of irrigated agriculture will have health risks to consumers because of the high concentration of heavy metals and pathogenic organisms. Farmers also mentioned that summer flood will bring glasses, excessive plastic bags, sharp metals, medical equipment, and others to farm land; thereby it will make land preparation difficult. These all are implications for farmers' awareness on water quality change. Few of the interviewed farmers who grew up in the area mentioned that before 1960 the river water was used for household purpose and there were considerable fish stocks. There were people who rely on cash earned from fish hunting during these times and now shift to other activities. The water starts to become bad for irrigation since 1980, particularly after expansion of industries like textile and tanneries at the downstream section of the river. Farmers adapt the water quality change in different ways. Some of the farmers were irrigating from textile drainage which ultimately enters into Great Akaki downstream of the farms. However, the productivity has declined 8 years ago due to the release of different chemicals and forced most farmers to start irrigation from Great Akaki with pump irrigation system. Some other farmers adjust irrigation time when to better water quality flow in a sense of observable clean water. Others who got technical advice on crop selection from local agricultural development bureau use to cultivate only onion and tomato.

Irrigators from Little Akaki on the other hand are highly challenged by water quality problems. Based on interviews, one of the main challenges of irrigated agriculture in this area is found to be frequent flood in all season which expose vegetables to waste contaminants. Farmers mentioned that the river is highly polluted with toilet waste, and other major industries which have toxic effect to vegetables. They mentioned that whenever there is rainfall, there are associated floods on the heart of their farms. As a result, the quality problem is also aggravated by frequent floods. It is observed that when the river is flowing at full supply level and the water level has approximately the same level as the farm lands. As a result the water has high probability to over flow with small increment of discharge. Some of interviewed farmers mentioned that they are forced to stop irrigated agriculture due to incapability to adapt to the situation. The problem has been worse since the 1990s. Farmers use drainage to evacuate the overflow as main adaptation strategies.

Conclusion

It is noted above that most of the interviewed farmers in urban and peri-urban areas have good awareness on water quality change. From the stated information we can conclude that farmers use direct and indirect indicators to identify water quality change. While colour and observable materials are used as direct indicators, yield reduction, loss of vegetables and leaf colour changes are used as indirect indicators. Using colour farmers are able to identify colourful toxic contaminants. For instance white colour relate to waste released from the Marble factory in Kolfe-Keranio, a red mixture in Mechanisa area identifies the National Alcohol and Liquor factory contaminants, while colourful water is as indicator to identify textile wastes in Akaki sub city area.. Understanding water quality change enables farmers to adjust irrigation time when the colours are not observed and farmers mentioned such adaptation measure is working well. Moreover through physical observation, farmers identify suspended materials such as plastic bags, used dressings, sharp metals, glasses, and other wastes. Such materials either accumulate in farm land after flood season or adversely affect diversion structures and pumps. Sharp metals damaged the hands of some farmers as observed while conducting interview. As a reaction, farmers developed filtering membrane to protect coarser material entrance to irrigation canal, particularly in Bole sub city; whereas others use filtering membrane at pumping site. On the other hand, understanding of yield reduction and crop loss associated with water quality change seems discouraging some of the farmers to continue irrigated agriculture. For instance farmers who were irrigating from textile drainage canal were forced to stop irrigation, though few of them switched to use Great Akaki River. Farmers in per-urban areas are informed by local health organization about the health risk of customers and give technical advice on the selection of crops which are tolerant for constituents and less risky to public health. Farmers are now practicing the technical advice given from local agricultural development bureau.

The other controversial conclusion is regarding field workers precaution against pathogenic organisms. Laboratory analysis of coli forms and E-colis indicate that the number of pathogens exceed the standard limit. Health protection measures at field level are unsatisfactory when compared with recommended methods by WHO (
Table **14**). Therefore working in the field with body contact with the water (without gloves and footwear) infects field workers with pathogenic organisms. Most of the interviewed farmers work without gloves and some of them without boots (protection shoes). Moreover some of the field workers use the river for sanitary purpose after field work and enter into the water for maintenance and construction of diversion structures. However field workers seem to tolerate the situation because they mentioned that they never experience health problem. This needs further investigation on how farmers could adapt infectious pathogenic organisms.

Table 14 Interpretation of WHO health protection for Akaki case

Health protection measures	Location	WHO recommended	In Akaki Farmers	Protected groups
Treatment options	Pre-farm	Municipal wastewater treatment plants(e.g., waste stabilization ponds, constructed wetlands)	There is waste stabilization pond but only for waste collected from 5% the population.	Farming communities and consumers
	On farm	On-farm treatment systems (e.g., sedimentation traps or tanks, sample ponds, sand filters	Not used	Farming communities and consumers
Post-treatment (or non-treatment) options		Protective clothing, including gloves, and footwear	Some of farmers use footwear but no one observed to use gloves	Farming communities only
		Safe collection and application of wastewater(e.g., low-cost drip irrigation, splash reduction, reduced helminthic egg uptake from sediments)	Most of the farms are irrigated by surface irrigation, application rate is not on the bases of predetermined rate	Consumers only
	Off farm (post-	Crop restrictions (to exclude e.g. crops eaten uncooked or grow only non-edible crops)	Partly applied in peri urban area.	Consumers only
		Produce-washing disinfection, peeling and/or cooking	Washing is observed at market centre, some use cooked , some other used uncooked	Consumers only

Source: Self-elaborated

The last conclusion is about seasonal quality effect on irrigated agriculture. Farmers mentioned that the river has better quality at the beginning of the dry season, normally September and October, and has a bad quality at the beginning of the rainy season, May and June. The most likely reason is that summer runoff has a purification effect through washing solid and liquid wastes disposed in urban areas and at the beginning of the dry season the river has relatively better water quality. Likewise the solid and liquid wastes disposed in the open spaces of urban area start to be transported at the beginning of the rainy season to nearby streams through runoff. As a result the river will be highly polluted at this time.

4.2.4 Customers awareness

Awareness of customers towards polluted water irrigation has been studied to understand their perception towards associated health and environmental risks. The information was collected mainly through observation of market centres at different sub cities of the city and by conducting unstructured interview with local people. Customers give their experiences on the use of vegetables whether they do have understanding on how it is cultivated. As a main indicator, customers were asked to reflect how vegetables are consumed and what health problem encounter associated with consuming vegetables. Most of the customers have good awareness on how vegetable are cultivated and what health problem are associated with consuming raw vegetables. Some others, though they have awareness on how the vegetables are grown, do eat raw vegetables treated with lemon juice. Some of interviewed people mentioned that they do not allow children to consume raw vegetables as they are easily infected with cholera, whereas other members of the family are allowed to consume raw vegetables.

On the other hand, observation has been made in the market chain to understand whether the vegetables cultivated by Akaki river water have a difference in price compared to those produced from other place with fresh water. Three big market were observed on Saturday, namely i.e. Merkato, Piasa and Akaki market. Merkato and Piasa market centres are busy on Saturday which is a main market day for local people. Consumers are observed dealing with sellers about the price while buying vegetables. The price seems a preference than with what water has grown. Though consumers have good awareness about the associated health risks, it is difficult for them to identify the products in the market whether they are produced with Akaki water and other water sources. In Akaki market place, which is close to the peri-urban irrigated farms, customers have relatively more awareness on the product and sellers mentioned that all the vegetables in this market are a product of irrigated agriculture along Akaki River. Sellers in Akaki market place are observed washing carrot and tomato in the market as shown in Figure 23.

Figure 23 Customers in market centres

This lead to a conclusion that customers have awareness on how the vegetables have grown, however, they undermine the possible associated health risks of eating raw vegetables. The awareness enables them to prohibit children from raw vegetables consumption and disinfect vegetables with lemon juice for raw consumption though its effectiveness to mitigate the associated health risks is not known. Furthermore the market chain difficulty to identify vegetables cultivated with fresh water limits the consumer's preference.

Chapter 5: Conclusion and Recommendation

The purpose of this study was to provide evidence on wastewater irrigation by assessing farmer's reaction towards water quality change. The major water extraction points for urban and peri-urban irrigated agriculture were identified. The water quality change since the introduction of irrigation, socio-economic factors governing wastewater irrigation and farmer's adaptation at field level were investigated.

Addis Ababa city has low sanitation coverage. Open defecation and urination as well as open space disposal of solid and liquid wastes are common sanitary systems in the city. About 90 % of the industries in the city do not have a pre-disposal treatment plant and most of these industries are concentrated along the Little Akaki river system. Solid and liquid wastes disposed at different urban centres ultimately enter into the Akaki river system. Previous and recent year findings on water quality for Little and Great Akaki Rivers indicate that the river waters are indiscriminately polluted by domestic, industrial, hospital, garages, and fuel stations. The total coliforms and E.colis alarmingly pollute the river since the introduction of irrigation and in all water diversion sections. When the total coliforms and E.colis examination results compared with WHO standard limit, the river water does not fit for agricultural use and found as the potential threat to public and animal health. The pathogenic contamination is expected to be high in the future as the origin of faecal waste is from slums which are difficult to connect to the central sewerage system and homeless dwellers are still use open defecation and urination. Similarly, except temperature, total dissolved solids, sulphide, and pH; most of the evaluated parameters are beyond the limit of irrigation water quality standards. Most of these parameters have been increased over the last years of irrigation.

There are a number of drivers for polluted water irrigation, among which land heritage from parents, raise of market demand for vegetables, means of cash earning for living expenditure, accessibility with minimum expenditures and reliability are found to be main drivers for Akaki farmers. Most of the farmers in Akaki inherited the farm land from their parents. Irrigated agriculture plays a critical role to farmers as it generates cash for covering living expenditures. The cash earned from irrigated agriculture covers above 75 % of the living expenses for the majority of urban farmers in Akaki catchment. Though Peri-urban farmers earn more cash from diversified sources, market rise for vegetable attracts them to start irrigated agriculture. The river water is chosen for its accessibility with minimum expenditure compared with other water sources. Irrigated agriculture is practiced mainly in two growing season, from October to January and from February to June. Rainfall is used as a supplementary to irrigation from February to June, however the summer rainfall does not support cultivation as farm lands will be flooded. There are plenty of ground water sources in the catchment; however most of farmers do not afford the drilling and pumping costs to use ground water irrigation and few of them do not have knowledge on ground water irrigation.

Literally, most of the farmers have an understanding on some of the chemical and physical water quality changes over the last years of irrigation and the reason for water quality change. The majority of farmers have low formal education; however through experience they use direct and indirect indicators to understand water quality change. Among the direct indicators colour and physical observation has been used; whereas indirectly associated adverse effects such as yield reduction, drying of vegetables and leaf colour change taken as indicators for water quality change. Colour indicators help farmers to identify colourful industrial contaminants. Understanding direct indicators of water quality change enables farmers to adjust irrigation time with flow of better water quality and farmers mentioned such adaptation measure is working well. The interference of suspended solids is also reduced by incorporating filtering membrane at the diversion site. Indirect indicators on the other hand seems discouraging farmers in peri-urban area, for instance few farms abandoned irrigated agriculture due to frequent exposure to contaminants with unexpected flood.

Farmers have little understanding on the biological water quality change. The majority of farmers do not use skin protection tools such as gloves and footwear, though few farmers were observed when using foot wears. Laboratory examinations in contrast indicate that the total coli forms and E-colis alarmingly exceeded the agricultural water quality standards and have implications for massive threat to public health. In contrast most farmers mentioned that they never infected while working at field. When the field health protection used by Akaki farmers compared with WHO (2006) health risk managements, farmers seem tolerant for health risks rather than protecting at field work or they are unaware of infection arising from wastewater irrigation. Customers in the main market on the other hand were observed buying vegetables without knowledge on the source of water it had been irrigated with. Interviewed consumers however mentioned that except children everybody used to eat raw vegetables treated with lemon juice. However the effectiveness of lemon juice to destroy pathogenic organisms is not known. Therefore we can conclude that customers like farmers give little attention to health risks of consuming vegetables irrigated with polluted water.

Considering the high level of pollution and its use for irrigated agriculture, the following recommendations are developed.

- Immediate action is required by concerned governmental and nongovernmental organization to launch awareness creation program for farmers on associated health risks. The awareness should be provided for famers and field workers equipped with introduction of health risk protection methods appropriate for developing countries. There are different alternatives of risk management which can be used with low capacity, for example the use of gloves and footwear and low cost treatment possibilities. Possibilities for use of non-conventional (low energy demanding) treatment with existing financial and managerial capacity developed by WHO (2006) need to be further investigated.
- Though observation, overview of previous findings and interview was made to identify the associated adverse effects since the introduction of irrigation, the prevalent disaster level associated with polluted water irrigation cannot be

known clearly because of two main reasons. One, the irrigation systems are traditional where irrigation frequency, application rate and quantity are applied arbitrarily. On the other hand, FAO and WHO standards are developed with the assumption that the maximum concentration is based on a water application rate which is consistent with good irrigation practices (10,000 m3 per hectare per year). If the water application rate greatly exceeds this value, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m3 per hectare per year. However in Akaki case, the amount of water applied per irrigation turn is not known. Therefore it is advisable to develop predetermined irrigation application rate considering crop, soil and weather conditions. Second, most of the farmers are reluctant to tell the exact problem faced so far as they are fear full that irrigation with such water will be banned by local administration.

- Unexpected flood in all seasons results in frequent contamination of soil and water in downstream of Akaki Oromiya farms. The contamination is ultimately transmitted to field workers and customers. As a short term solution, it is worth to give space for flooding and farm plots should be moved a distance away from the river course. For long term, grass root solution is needed to protect the flooding problem through approaching at system level (upper-downstream connectivity).
- The existing water users (peasant associations) are established to deal with further development of irrigated agriculture. All these associations are recognized by local agricultural development bureau. Therefore, more initiatives are required from the concerned organisation to develop adaptation strategies though a participatory approach with farmers.
- Wastewater is an important liquid fertilizer which has plant important nutrients particularly nitrogen, phosphorous and potassium. The application of deficit or excess amount of NPK however has undesirable effect on the crops. The laboratory examination results show the presence of high amount of total N and P in Akaki River. However whether the applied NPK from water is in excess or deficit is not known as application rate is practiced arbitrarily. Therefore further investigation is required to understand how the NPK from the water help vegetable production.

References

AAEPA, 2007. Akaki river water pollution situation in Addis Ababa: a report on the effect of urban on river water deterioration, Ethiopia.

AAEPA, 2008. Trends of industrial water pollution in Addis Ababa, the case of tanneries, textiles, paint, food and beverages

Andrew J. H, Stagnitti.F, Xiong.X, Kreidl.S.L, Kurt.K, 2007. Wastewater Irrigation: The State of Play. November 20, 2007.

Asfaw, 2007.Modeling on Akaki Liquid waste disposal and base flow separation: M.Sc. thesis for partial fulfilment of environmental science degree, Addis Ababa University Ethiopia.

AWWSA, 1990. Master plan study for Addis Ababa city sewerage system development.

Ayers.R.S, and Westcot.D.W, 1994.Water quality for Agriculture: Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00100 Rome, Italy.

Bekele.T, Tadesses.G and Peden.D, (date unknown). Community-based traditional irrigation systems for the case of Akaki catchment, Ethiopia.

Central Statistical Agency of Ethiopia. "Census 2007, preliminary (**pdf-file**)", Retrieved on 2009-05-21.

Central Statistical Authority (Ethiopia), 2005. Statistical abstract of Ethiopia. CSA, Addis Ababa, Ethiopia.

Drechsel P, *Scott.A.C, Raschid-Sally.L, Redwood.M, and Bahri.A, 2006.* Wastewater irrigation and Health: Assessing and Mitigating risk in low income countries, International water management, papervISBN 978-1-55250-475-8.

EIA, 2008. Environmental Impact assessment: for waste treatment plants and Sewerage network of Akaki Sewerage catchment, Addis Ababa, Ethiopia.

EPA, 2005. Assessment report of Akaki River water pollution: for the case of Addis Ababa, Ethiopia.

Gebre.G & Van Rooijen.D, 2009. Urban water pollution and irrigated vegetable farming in Addis Ababa: 34 the WEDC International Conference, Addis Ababa, Ethiopia.

Government Environmental Protection Bureau and the Royal Netherlands Embassy held in A.A.
Hamilton, A.J*, Stagnitti.F, Xiong.X, Kreidl.S.L, Benke.K.K, and Maher.P, 2007. Wastewater Irrigation: The State of Play, Published online November 20, 2007.
https://portal.wur.nl/Courses/IWE30306_2009_2/Shared%20Documents/Literature%20block%203%20-%20Week%204-5/B03A02_Hamilton_2007_wastewater%20irrigation.pdf assessed on 11/03/2010)

Huibers.F.P and Van Lier.J.B. 2005. Use of wastewater in agriculture: the water chain approach.
IRRIGATION AND DRAINAGE, Irrig. And Drain. 54: S3. Wageningen University, the Netherlands.

IMF, 2000. Ethiopian interim on Poverty Reduction Strategy: Paper 2000/01- 2002/03 November.
Irrigation schemes performance: A case study of upper Awash River basin of Addis Ababa sub-catchment.
http://km.fao.org/fileadmin/user_upload/fsn/docs/CommunityBasedI_TadeseBekele.pdf Assessed on 12/03/2010

Martijin.E.J and Redwood.M, 2005: Wastewater irrigation in developing countries-limitation for farmers to adopt appropriate practices .International Development Research Centre, Ottawa, Canada.

Mohamed. A, 2002. Industrial pollution and its impact on the Little Akaki River: for the case of Addis Ababa.

Molla.D, Stefan Wohnlich.S, Brihanu.G and Stichler.W, 2007. Groundwater recharge in the Akaki catchment, central Ethiopia: evidence from environmental isotopes (d18O, d2Hand 3H) and chlori, *Hydrol. Process.* 21, 807–818.

Pescod.M.B, 1992. Wastewater treatment and use in agriculture: FAO irrigation and Drainage paper 47.
(http://www.fao.org/docrep/T0551E/t0551e00.htm assessed on 04/04/2010)

Scientific report on Ethiopia's ground water vulnerability mapping of Addis Ababa Water supply aquifers, 2003.

SDPRP, 2002. Sustainable Development Poverty Reduction Paper Ethiopia: Ministry of Economic Development and Cooperation.

Teshome A, 2006. Agriculture, Growth and Poverty Reduction in Ethiopia: Policy Processes around the New PRSP (PASDEP). Institute of Development Studies, 20-22 March 2006.

Tilaye N.; and Mesfin T. (1998) "Waste management and Environmental sanitation in Addis Ababa. Proceedings of A workshop organized by the Addis Ababa

UN-Habitat (2005). Situation Analysis of Informal Settlements in Addis Ababa. http://www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2332

Van Rooijen .D and Tadesse.G, 2009. Urban sanitation and wastewater treatment in Addis Ababa in the Awash Basin: 34th WEDC International Conference, Addis Ababa, Ethiopia.

Van Rooijen. D J., Biggs T. W., Ian Smout & Drechsel.P, 2009. Urban growth, wastewater production and use in irrigated agriculture: a comparative study of Accra, Addis Ababa and Hyderabad. Irrig Drainage Syst DOI 10.1007/s10795-09-9089-3 (http://www.springerlink.com/content/e749744553628469/fulltext.pdf assessed 13/03/2010 assessed 12/03/2010)

Werfring A, 2004. Typology of irrigation in Ethiopia. Thesis, University of Natural Resources and Applied Life Sciences Vienna.

WHO, 1989. Health guidelines for the use of wastewater in agriculture and aquaculture. Technical Report No. 778. WHO, Geneva 74 p.

Web pages

Ethiopia ministry of water and Energy, 2010. http://www.mowr.gov.et/index.php?pagenum=4.2, assessed 12/11/2010

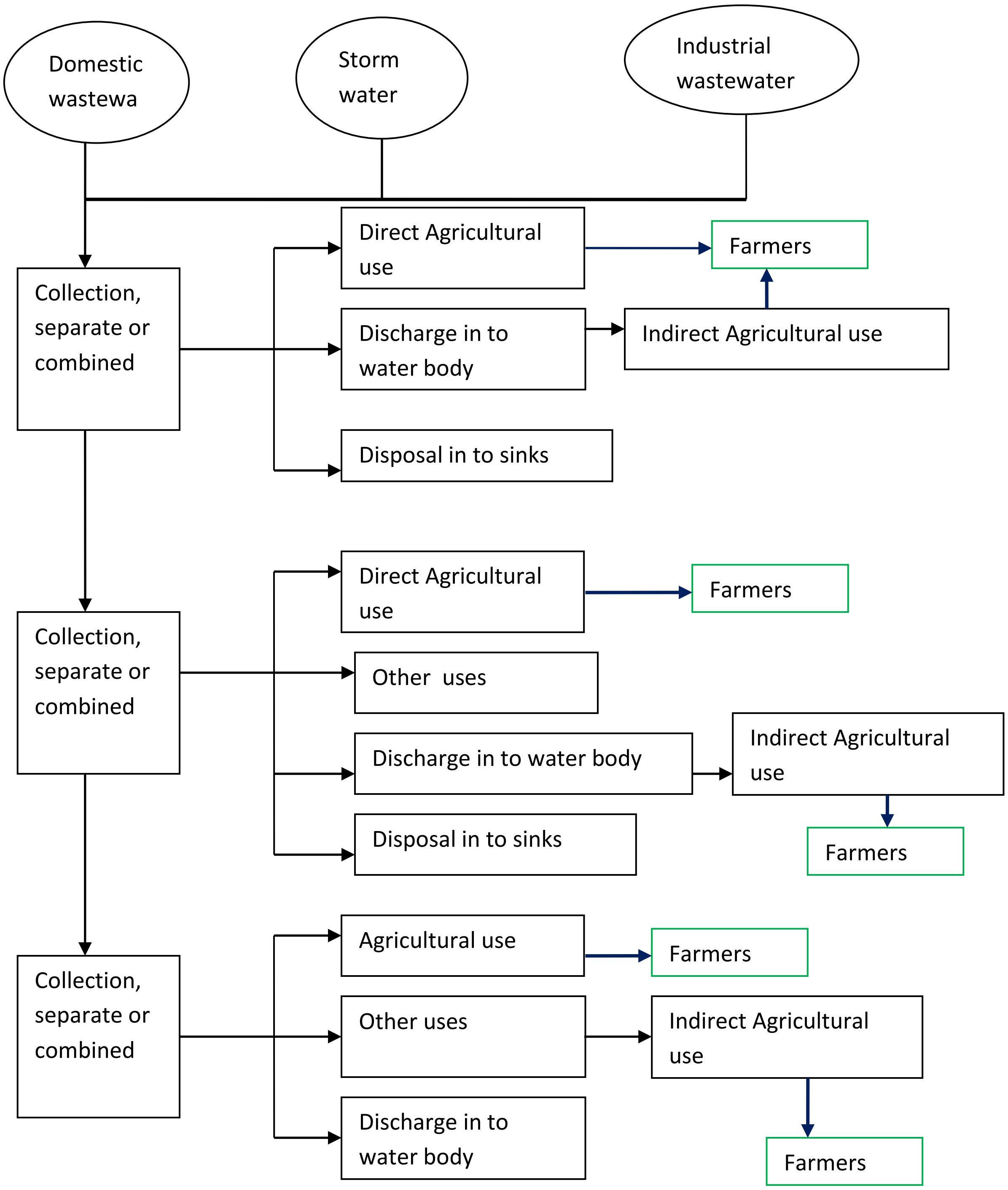
http://wmasscatholicvoices.files.wordpress.com/2010/10/63-ethiopia-map2.gif, received on 12/01/2011

Water Wiki: http://www.iwawaterwiki.org/xwiki/bin/view/Articles/3)+ADDIS+ABABA+(Ethiopia)+3

World metrology organization, Addis Ababa: http://worldweather.wmo.int/060/c00162.htm , received on 20/01/2011

USDA: Production Estimates and Crop Assessment Division Foreign Agricultural services: Agro-Climatic zones of Ethiopia: http://www.fas.usda.gov/pecad2/highlights/2002/10/ethiopia/baseline/Eth_Agroeco_Zones.htm, received on 24/01/2011

Annex 1. Reverse water chain approach



Annex 2. Irrigated farm and household sizes in the Catchment

Table 1 Small-Scale irrigation with river diversion in Akaki-Kality and Akaki-Oromiya area

Name of Association/Administrative kebele number	Plot size ha	Member size		
		M	F	Total
Yemekanana Bruhi Tesfa Vegetable production ass.	37	16	36	52
Yechelo Enatochi Vegetable production ass	8		42	42
Yenur Aregawuiane Abat Turetegnochi Vegetable production ass.	8	24	11	35
Mekana Abat Turetegnochi Vegetable production ass	8	12	10	22
Abu Chefe Vegetable Production ass	14	17	4	21
Fanta Vegetable Production ass	10	25	3	28
Arenguade Limat Vegetable Production association	10	16	2	18
Kilinto Fechuna Koye Vegetable production ass	8			128
07/08/09 kebele farmers	18			288
O1/03 Administrative Kebele	20			320
02/04 Administrative Kebele	6			96
05/06 Administrative Kebele	8			128
10/11 Seriti Administrative Kebele	15			240
Total	**170**			**1418**

Table 2 Bole sub city farm and household sizes

Administrative zone (kebele)	Small Scale irrigation with River diversion farming	
	ha	Number of house hold farmers
2	3	4
14/15	2.1	47
04/06/2007	9	59
01	80	50
12/13	0.16	2
Total	**94.26**	**162.**

Table 3 Kolfe Keranio farm and household size

Administrative zone (kebele)	Small scale irrigation with river diversion	
	ha	Number of house hold farmers
02	3	4
04	5	20
06	2.1	11
07	4.4	22
08/09	19.96	38
10/11	21.34	45
15/16	1.11	25
Total	**56.91**	**165**

Table 4 Farm size and household number in Nifas Silk Lafto

Administrative zone (kebele)	Small scale irrigation with river diversion	
	ha	Number of house hold farmers
2	3	4
09/14	150	240
Total	**153**	**244**

Table 5. Yeka sub city farm size and household number

Administrative zone (kebele)	Small scale irrigation with river diversion	
	ha	Number of house hold farmers
2	3	4
20/21	4	40
Total	**7**	**44**

Source: Akaki sub city Urban Agriculture bureau

Annex 3. Summary of standards for wastewater use for irrigation

Table 1 FAO guidelines for interpretation of irrigation water quality

	Units	Degree of restriction on use			Remark
Parameters		None	Slight to moderate	Severe	
TDS	mg/L	<450	450-2000	>2000	Excessive quantity presence result in salinity and affect crop water availability
Cl (Surface irrigation)	mg/L	<106.5	>106.5		
NO3–N f	mg/L	< 9.5	91.5–518.5	> 518.5	
pH					Normal range 6.4-8.4

* NO3-N means nitrate nitrogen reported in terms of elemental nitrogen (ammonia, nitrate, nitrite etc.)

Use restriction guidelines developed based on several assumptions. It is assumed that the growth is with full production capability of crops; with site of soil type ranging from sandy loam to clay loam and with climate of semi-arid and arid where rainfall is low; applicable for localized surface and surface irrigation; and water uptake is assumed for upper 40% only. However in conditions where this assumption does not concur with local condition, use of the standards will result in wrong decision. In that sense, there will be 10 to 20% above or below the guideline value and the following laboratory values are applicable in normal field condition.

Table 2 Laboratory determinations needed to evaluate common irrigation water quality problems

Water parameter	Symbol	Unit[1]	Usual range in irrigation water	
SALINITY				
Salt Content				
Electrical Conductivity	EC_w	dS/m	0 – 3	dS/m
(or)				
Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
Cat ions and Anions				
Calcium	Ca^{++}	me/l	0 – 20	me/l
Magnesium	Mg^{++}	me/l	0 – 5	me/l
Sodium	Na^{+}	me/l	0 – 40	me/l
Carbonate	CO^{--}_3	me/l	0 – .1	me/l
Bicarbonate	HCO_3^-	me/l	0 – 10	me/l
Chloride	Cl^-	me/l	0 – 30	me/l
Sulphate	SO_4^{--}	me/l	0 – 20	me/l
NUTRIENTS[2]				
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^+	mg/l	0 – 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 – 2	mg/l
Acid/alkaline	pH	1–14	6.0 – 8.5	
Sodium Adsorption Ratio[3]	SAR	(me/l)[1], [2]	0 – 15	

Table 3 The permitted limit for interpretation of grey water use for irrigation

Test	Irrigation of ornamental fruit trees and fodder crops	Irrigation of vegetables likely to be eaten uncooked
BOD5	<240	<20
TSS	<140	<20
Thermo tolerant coli forms (cfu/100 ml)	<1000	<200

Table 4 FAO guideline for trace metals in irrigation water

Element	Recommended maximum concentration	Remarks
Pb	5	Can inhibit plant cell growth at very high concentrations.
Cr	0.10	Note generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Co	0.05	Toxic to tomato plants at 0.1mg/L in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cd	0.10	Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Mn	0.20	Toxic to a number of crops at a few tenths to a few mg/L, but usually only in acid soils.
Fe	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Zn	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils

Source: Food and Agriculture Organization Sourece. *Water quality for agriculture, Irrigation and Drainage Paper 29 Rev. 1*, 1985.
*The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10 000 m3 per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m3 per hectare per year. The values given are for water used on a continuous basis at one site.

Table 5 Recommended microbiological quality guidlines for wastewater use in agriculture

Category	Reuse conditions	Exposed groups		Intestinal nematodes [b] (arithmetic mean no. of egg per litre [c]	Wastewater treatment
A	Irrigation for crops likely to be eaten uncooked sports fields, public Parks d [d]	Workers, consumers, public	<=1	<=1000 c	A serious of stabilization ponds designed to achieve the microbiological quality indicated or equivalent treatment.
B	Irrigation of cereal crops industrial crops, fodder crops, potassium and trees [e]	Workers	<=1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helmininth and faecal coli form removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

In specific cases local epidemiological socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly.

[b] Ascaris and *Trichris* species and hookworm

[c] During the irrigation time

[d] A more stringent guideline (<200 faecal coli forms per 100ml) is appropriate for public lawns, such as hotel lawns come into direct contact

[e] In the case of fruit trees irrigation should cease two weeks before fruit is picked and no fruit should be picked off the ground sprinkler irrigation should not be used

Source: WHO (198

Annex 4 Water quality exmination results for irrigation extraction points

Table 1 Kolfe-Keranio irrigated area

Parameters	Standards	2002	2005	2009	2011
To	<25	15.5	17	14.5	15
PH	6.4-8.5	8.04	6.5	6.4	6.89
TSS	<20	278	126		65
TDS	0-2000	276			390
BOD mg/l	<20	22	100	80	
COD/mg/l	No fit standards	82	284	110	86.4
S^{2-} mg/l			0.037		
NH_3	0-5	3.73	0.15	0.9	
No_{2-}N mg/l		1.1	6.6		
No^{-}_{3-N} mg/l	0-10	54.4	0.045	14	
TN		59.23	6.795	14.9	19.3
Po_4^{3-}	0-2	1.956	4.6	17	8
So^{2}_{-4}		28.3	26	20	38
Cl^{-}	<106.5	45	76.21		
Coliform	<200		4900		
Per 100ml					
E.coli per	<200		4900		
1000ml					
Pb	0-5		Nil	nil	0.008297
Cr	<0.10		0.03055	nil	0.003473
Mn	<0.20		1.303	nil	
Cd	<0.10		Nil	nil	0.0006802
Co	<0.05		0.3447	nil	0.000207
Fe	0-5		1.55	nil	1.51

Table 2. Bole irrigated area

Parameters	Standards	2002	2005	2009	2011
To	<25		16		17
PH	6.4-8.5		6.5		6.9
TSS	<20				21
TDS	0-2000		562		313
BOD mg/l	<20				22
COD/mg/l	<6mg/l		165		33.6
S^{2-} mg/l			>0.6		
NH_3	0-5		2.14		
No_{2-}N mg/l			1		
No^{-}_{3-N} mg/l	0-10		0.026		3.1
Po_4^{3-}	0-2		9.6		3
So^{2}_{-4}	0-20		18		225
Cl^{-}	<106.5				
Coliform	<200		3,000,000		12,240
Per 100ml					
E.coli per	<200		3,000,000		7,350
1000ml					
Pb	0-5				0.01169
Cr	<0.10		0.04773		0.0000125
Mn	<0.20		1.259		
Cd	<0.10		Nil		0.6629
Co	<0.05		0.252		0.002714
Fe	0-5		3.08		0.001486

Table 3. Nefas Silk Lafto irrigated areas

Parameters	Location	Standards	2002	2005	2009	2011
To	Mechanisa	<25	15.5	18	24.3	17
	Kera	<25	16	18	22	15.7
	Gofa	<25	17	16	23.9	21
PH	Mechanisa	6.4-8.5	7.61	6.5	7.4	6.8
	Kera	6.4-8.5	7.72	6.5	7.3	7.08
	Gofa	6.4-8.5	7.85	7	7.64	7.31
TSS	Mechanisa	<20	1414.9			70
	Kera	<20	867.3		170	366
	Gofa	<20	1307.6	73	321	255
TDS	Mechanisa	0-2000	279	534		405
	Kera	0-2000	131	597		108
	Gofa	0-2000	213	454	500	356
BOD mg/l	Mechanisa	<20	58	13	247	57
	Kera	<20	7	204	142	36
	Gofa	<20	15	144	244	203
CODmg/l	Mechanisa	No fit standards	244	913	334	119.65
	Kera		33	641	322	84.3
	Gofa		84	610	386	126.3
S^{2-} mg/l	Mechanisa					
	Kera					
	Gofa					
NH_3	Mechanisa	0-5	8.54		10	
	Kera	0-5	1.79	0.12	6	
	Gofa	0-5	4.04	0.11	7.5	
No_{2}-N mg/l	Mechanisa	No fit standards	0.675	4.1		
	Kera		0.268	5.4		
	Gofa		0.296	10.9		
No^{-}_{3-N} mg/l	Mechanisa	0-10	25.6	0.03	3	4.9
	Kera	0-10	15.9	0.02	12	
	Gofa	0-10	15.8	0.049	8	
	Mechanisa	No fit standards	34.815	4.13	13	25.3
TN, mg/l	Kera		17.958	5.54	18	50
	Gofa		20.136	11.059	15.5	12.3
Po_4^{3-}	Mechanisa	0-2	2.07	0.5	7	3.75
	Kera	0-2	0.33	14.4	14.5	6.5
	Gofa	0-2	0.41	9.8	24	4.3
So^{2}_{-4}	Mechanisa	0-20	25.1	70	64	28
	Kera	0-20	18.8	14	69	6
	Gofa	0-20	22.9	39	83	22

Table 4. Akaki sub city and Oromiya irrigated areas

Location	2002	2005	2009	2011
Kality TP	17	20		20
Yechu	18	17		18
Road	13	18		20
Kality TP	7.78	7	7.75	7.6
Yechu	7.64	7	7.75	7.42
Road	7.82	6.5		7.3
Kality TP	3790	11	285	175
Yechu	1564	35		21
Road	25.3			275
Kality TP	218	305	98	76
Yechu	243	558	400	313
Road	184	597		627
Kality TP	43	200	135	147
Yechu	17	70	65	22
Road	1	50		46
Kality TP	264	67	286	189
Yechu	128	170	62	33.6
Road	4	57		130.8
Kality TP		0.007		
Yechu		0.345		
Road		0.0069		
Kality TP	2.21	25	18	
Yechu	3.05	18.3	7.5	
Road	0.86	over		
Kality TP	0.48	1.1	14	
Yechu	0.9	4.8	18	
Road	0.261	0.8		
Kality TP	20	0.025	8	9
Yechu	23.3	0.02	15	3.1
Road	4.7	0.12		12.2
Kality TP	22.69	26.125	40	16
Yechu	27.25	23.12	40.5	11.24
Road	5.821	>0.92		14.19
Kality TP	2	14.9	8	7
Yechu	0.81	14	15	3
Road	0.69	2.9		7.5
Kality TP	19	16	25	5
Yechu	17.6	37	17	225
Road	15	72		75

Cl^-	Mechanisa	<106.6	45					Kality TP	38	12.5	130	
	Kera	<106.6	20		523			Yechu	41	39.5	190	
	Gofa	<106.6	35	87.21	160			Road	25	25		
Coliform	Mechanisa	<200	100,000	190,000				Kality TP	9,000,000	>2400		10,000
Per 100ml	Kera	<200	80,000	900,000				Yechu	1,900,000	>2400		12,240
	Gofa	<200	100,000	11,000,000				Road	5,000	90,000		15,400
	Mechanisa	<200		190,000				Kality TP	nil	>2400		2500
E.coli per	Kera	<200	20,000	900,000				Yechu	nil	>2400		7,350
1000ml	Gofa	<200		11,000,000				Road	nil	90,000		8,640
Pb	Mechanisa	<5		nil	nil	0.0057		Kality TP		nil	nil	0.045
	Kera	<5		nil	0.07	0.0082		Yechu		0.1197	0.078	0.001169
	Gofa	<5		nil	0.009	0.0153		Road		nil	0.0089	0.003337
Cr	Mechanisa	<0.10		0.02963	nil	0.0144		Kality TP		0.04611	1.59	0.045
	Kera	<0.10		0.0305	nil	0.0016		Yechu		0.1686	0.7	1.25E-05
	Gofa	<0.10		0.02681	0.15	0.2355		Road		0.26260	0.09	0.03472
Mn	Mechanisa	<0.20		0.4443	nil			Kality TP		0.2865	nil	
	Kera	<0.20		1.339	nil			Yechu		2.397	nil	
	Gofa	<0.20		2.21900	nil			Road		2.10500	nil	
Cd	Mechanisa	<0.10		nil	nil	0.1228		Kality TP		nil	nil	0.002326
	Kera	<0.10		nil	0.645	0.1521		Yechu		0.1705	nil	0.000663
	Gofa	<0.10		nil	nil	0.023		Road		nil	nil	6.74E-05
Co	Mechanisa	<0.05		0.04856	nil	0.0062		Kality TP		0.1171	0.1	0.120022
	Kera	<0.05		0.2134	0.65	0.0702		Yechu		0.1672	0.09	0.002714
	Gofa	<0.05		0.14270	0.12	0.0021		Road		0.20550	nil	0.00828
Fe	Mechanisa	<5		0.696	nil	1.9785		Kality TP		0.815	nil	0.002151
	Kera	<5		3.55	nil	2.822		Yechu		2.18	nil	0.001486
	Gofa	<5		2.94000	nil	1.23		Road		5.90000	nil	0.004895

Legend

[grey box] ....Results exceeded the standard limit

[white box] ....Results with in the standard limits

Annex 5: Summery of interview data

Table 1. Kolfe-Keranio irrigators

			Drivers		Awareness on water quality			Awareness changes			
	Irrigator name	Description	Socio economic	Technical drivers	Irrigation method	Crop types	Field workers precaution	Recognition of water quality change	Adaptation strategies corresponds to water quality change	Customers perception	Willingness to participate for managing pollution
1	Sebrekeri K. (former irrigators from Kolfe keranio behind ehil berenda)	Interviewed on 14/12/2010 while chatting with partner close to newly built residential area.	It was the only means of cash earning activities for covering living expenses; start irrigation by 1966.	Presence of irrigable land and water.	Surface irrigation system (Diversion ditch which is extended as irrigation canal and field furrow); with 5 to 6 days irrigation interval	Swiss chard, salad, cabbage, and sometimes potato	No precaution taken by dressing boots and globes.	Chemical concentration sometimes dry vegetables and sometimes the colour of vegetables changed.	Use of spring water the water when Shankla river have white colour.		Yes I am willing to participate and collaborate to sol
2	Lemlem A. (Irrigator in Kolfe Keranio)	Interviewed on 14/12/2010 while working in the field; start irrigation by 1977.	It is a means of cash earning activity for covering monthly expenditure in addition to working as a merchant after losing part of my farm land.	Availability of irrigable land and water.	Surface irrigation with simple diversion structure made of stone; with 6 days irrigation interval	Swiss chard, salad, cabbage, and lettuce	She is observed working at field without precaution dressings.	Chemicals inside the water sometimes retard growth of vegetables; suspended materials make the field difficult to work with it.	Before two years there was a spring source used as alternative to adapt the river water quality change.		Yes I am willing to collaborate and participate to solve the problem
3	Kibru Y. (Kolfe Keranio behind Ehil Berenda)	Interviewed on 14/12/10wwhile working on his field; start irrigation by 1969	It is the only means cash earning activity except during summer time where I use to employ as a labourer	Presence of irrigable land and water	Surface irrigation (diversion structure, irrigation canal and field furrow)	Pumpkin, Swiss chard, salad, and cabbage	He is observed working with protection shoes but without globe	In flow of high chemical concentration, vegetables will dry. Used dressings and plastic bags interfere at field.	No change has been made as crop should match with market demand and expensive to change irrigation system.		Yes I am willing to collaborate and participate to solve the problem.
4	Nure k. (Kolfe Keranio downstream of Ehil Berenda	Interviewed on 16/12/2010 while working in the field ; start irrigation by 1980	It is a means of cash earning activity for covering living expenditure during irrigation season.	Presence of irrigable land and water	Surface irrigation(diversion structure, irrigation canal and field furrow); with 6 to 7 days irrigation interval	Pumpkin, Swiss chard, Salad, cabbage and onion.	He is observed working with boots, but without hand globes.	Vegetables dry sometimes, leafy vegetables change their colour. Potential of river water to support irrigation has been decreasing.	I didn't change so far because I don't have knowledge on it.		Yes I am willing to collaborate and participate to solve the problem.

Table 2 Bole sub city irrigators

	Name of Irrigator	Description	Drivers		Awareness on water quality			Awareness changes			
			Socio economical	Technical drivers	Irrigation method	Crop types	Field workers precaution	Recognition of water quality change	Adaptation strategies corresponds to water quality change	Customers perception	Willingness to participate for managing pollution
1	Kedir A. (Next to Pikok park irrigating from Bulbula river)	Interviewed on 08/11/2010 while supervising field workers; start irrigation by 1978	Experience gained from employment as field worker drive and is a means of income generating activity.	Getting irrigable land and availability of water	Surface irrigation system (Diversion structure made of traditional filled sand bags and stones, main canal and field furrow)	Mainly we cultivate Salad, Cabbage (Local vegetable) , where as in general Onion, Carrot, Coli-flower, red beat and cabbage	He is observed dressing protection shoes while supervising field worker.	The river has highly turbid water and dark colour; excessive accumulation of plastic bags and suspended materials; It is a problem for field worker health.	No adaptation is taken		Yes I am willing to contribute and participate to solve the problem
2	Endale M. (next to Pikok Park irrigating from Bulbula River)	Interviewed on 02/12/2010 while working on his field; start irrigation by 1970	The motive behind this heritage of land from my father and as the only means of cash earning activity to cover the living expenses	Presence of irrigable land and irrigation water source.	Surface irrigation systems (Temporary diversion structure made of locally available material like filled sand bags and); irrigation with 6 days interval and there is shortage of water. I use night irrigation.	Onion, salad, potato, Swiss chard, red beat, and Spinach	He is observed working without protection shoes and globes.	Plastic bags accumulated in irrigated farms; toxic chemicals dry vegetables; when the water has dark colour i don't need fertilizer and much better product is achieved than cultivated with commercial fertilizer	We installed filtering membrane at intake side to trap suspended materials; matching irrigation time with better quality flow time of the day; however during night irrigation it is difficult to recognize the issue.		Yes I am willing to participate and collaborate to solve the problem.

3	Fedlu A. (Downstream of Pikok park irrigating from Bulbula river)	Interviewed on 16/11/2010 while taking his vacation time after work; start irrigation by 1990	It is a means of cash earning activity for covering living expenses;	Presence of irrigable land and water source	Surface irrigation system(diversion structure made of sand filled bags and coarser stones, main canal and field furrow)	Salad, onion, Swiss chard, carrot, cabbage, etc	He is observed working without any field working dressings	Toilet wastes(assist as a source of plant important nutrients) and suspended materials mixed with river; plastic bags quantity showed increment	Incorporation of filtering membrane at intake side to trap suspended materials		Yes I am willing to contribute and collaborate to solve the problem
4	Yihera A. (Downstream of Pikok park irrigating from Bulbula river)	Interviewed on 16/11/2010 while working in his field; start irrigation by 1976	It is a means of cash earning activity for covering living expenditure from September to May	Presence of irrigable land and water	Surface irrigation system (diversion structure made of sand filled bags and coarser stones, main canal and field furrow); with 7 days irrigation interval	Swiss chard, habitat cabbage, Salad, carrot, onion, etc.	He is observed dressing protection shoes however he said his hand adapt the situation	Sedimentation at intake side fluctuates water in the irrigation canal	Cleaning the sediments from the diversion section.		Yes I am willing to contribute and collaborate for solving the problem.
5	Seid M. (Back side of Pikok park irrigating from Kebena river)	Interviewed on 13/11/2010 while working in his field; start irrigation by 1989.	It is the only means of cash earning activity to cover living expenditure except during summer time where cash earned from shop assistant employment.	Presence of irrigable land and water	Surface irrigation system(Temporary diversion structure made of and filled bags and coarser rocks, main canal and field furrow); with 7 days irrigation interval and sometimes 5 to 6 days interval; surplus water	lettuce, Swiss chard, cabbage, Salad and carrot	My skin adapt the water quality and no dressing is used	Sometimes human excreta's and suspended materials mixed with river water.	No adaptation is used by changing farm system and crop types.		Yes I am willing to contribute and participate to solve the problem.
6	Johannes B. (At the back side of Pikok park irrigating from Kebena river)	Interviewed on 19/12/2010 while working his field ; start irrigation by 1984	It is a means of cash earnings to cover living expenses in addition to part time employment during irrigation season and full time employment during summer	Presence of irrigable land and water	Surface irrigation system(temporary diversion structure constructed from sand filled bags and coarser stones, irrigation canal and field furrows); with	cultivate Red beat, cabbage, Salad, carrot, and sometimes tomato	Use of protection shoes and washing his hand with tap water after field work.	Sometimes the water is polluted with toilet and household wastes	No change made since the existing water quality doesn't have serious effect.		Yes I am willing to participate to collaborate and contribute to solve the problem

7	Mebratu C. (Downstream of Ureal Church irrigating from Kebena river)	Interviewed on 19/12/2010 while working in his field; start irrigation by 1995	It is a means of covering living expenses during irrigation season.	The presence of irrigable land and water	Surface irrigation system(temporary diversion structure constructed from sand filled bags and coarser stones, irrigation canal and field furrows); with	lettuce, cabbage, Salad and Swiss chard	Use protection shoes but not globes since difficult to work with it	Blades damage my hand; waste material crowded the land and it takes one day per week to clean the farm.	No change made.		Yes I am willing to contribute and collaborate to solve the problem.

Table 3 Nefas Silk Lafto irrigators

	Irrigator name	Description	Drivers		Awareness on water quality			Awareness changes			
			Socio economical	Technical drivers	Irrigation method	Crop types	Field workers precaution	Recognition of water quality change	Adaptation strategies corresponds to water quality change	Customers perception	Willingness to participate for managing pollution
1	Alemtsehaye B. (Downstream of LA13)	She is interviewed in her restaurant by Nov 8/2010 ; participatory interview technique; she start irrigation by 1980	Land heritage, means of cash earning From October to May.	Surface water is suitable for cultivation than rainfall, reliable and adequate. The rainfall is disastrous and it is expensive to irrigate with well source.	surface irrigation (diversion structure, main canal & field furrow)	Salad, Swiss Chard, lettuce, cabbage, Coli flower,	Employed labourers, no precaution with globes and boots	Red mixture will dry vegetable leafs.	Matching irrigation time when the red mixture low in the water.		Willing to participate with contribution of labour.
2	Alemayehu Y. (Downstream of LA13)	Field worker employed by land owner, intervieweAd November 08/2010 while working; irrigating since 1999	Working on irrigated lands is better than construction site.		surface irrigation (diversion structure, main canal & field furrow)	Salad, Swiss Chard, lettuce, cabbage, Coli flower	My body adapted the water quality change and no precaution used	Since I start working, the water has bad quality having red and black colour, vegetables dry sometimes	No adaptation is used.		I am sure the owners will be willing to collaborate and participate
3	Girmaye N. (Close to National Alcohol factory)	Former irrigator but now employed as security, interview in his working place as a participatory interview technique	It was a means of incoming for covering living expense to my family	The water was accessible and was sufficient to cultivate	surface irrigation (diversion structure, main canal & field furrow)	Salad, Swiss Chard, lettuce, cabbage, Coli flower	No precaution is taken.	Vegetables dry sometimes, human excreta's mixed and have variable water quality.	Irrigating at time of flow where the river water have clean colour		During irrigating time, I was willing to contribute and participate in managing the wastewater.

4	Teklu W. (Kera tributary)	Farmer interviewed while working on his field; start irrigation by 1983	Inherited land, It covers more than 75% living expenditure for the family	The river is easy to divert to our land.	surface irrigation (diversion structure, main canal & field furrow)	Mainly Salad, Swiss chard, Habesha cabbage and sometimes coli flower	No precaution used with Globes and Boot	For irrigation it is good quality. For others ruminants, bloods and blades make it bad quality for drinking.	No adaptation since mentioned components help me to reduce expenditure on fertilizer application		Willing to contribute and collaborate for excluding only blades.
5	Workinesh .M (Close to National Alcohol industry)	Interview in her field through participatory interview techniques; start irrigation by 1979.	My husband and me have been engaged in irrigation to generate income for living expenditures	The river is accessible to divert and the land is easily irrigated by gravity.	surface irrigation (diversion structure, main canal & field furrow)	Cabbage, salad, Swiss chard and carrot	We use to dress boots but for our hand nothing as it is difficult to work with it	Leakage and mixture of national alcohol industry dry the vegetables leave.	We use to irrigate when the concentration of industrial waste do have low.		For leakage from National alcohol factory they have money, they have to treat it.
6	Mare W/M (Next to Addis Abattoirs)	Interviewed in his field while working; start irrigation by 1992.	It is a means of income for covering living expenditure; water quantity increased through time	The water is easily accessible	surface irrigation (diversion structure, main canal & field furrow)	Coli flower, Swiss chard, Salad, carrot, Cabbage	Since my skin is adapted the quality, I do not use any dressings	Plastic bags and sedimentation pose problems ` at diversion side.	diversion structure is constructed with a strong filtering membrane at intake section		I am willing to collaborate and participate to manage the problem.
7	Medirfirtus K. (Next to Addis Abattoirs)	Interviewed on Sunday while he is enjoying his weekend; start irrigation by 1974	My life depends on it, except a little income charted by my son, monthly living expenditure are covered from cash obtained by selling produced vegetables	The availability of land and water in area promote me to use irrigated agriculture in the area.	surface irrigation (diversion structure, main canal & field furrow)	Salad, coli flower, cabbage and Swiss chard.	We use nose closes to prevent infection with flue as the abattoir wastes have offensive odour. For our hand and foot still nothing as our skin adapt the situation	The abattoir wastes have health risk to field workers and were infected frequently with flue and intestinal diseases.	To adapt the problem the diversion site is moved from downstream to upper stream of Addis Abattoirs. Pipe system is applied to convey the water.		I am willing to participate and collaborate to solve the problem.

8	Yeshi.s (Around Lideta area)	Interviewed on Sunday while enjoying her weekend; start irrigation by 1995	A means of cash earning for living expenditure in addition to cash obtained from part time work	The river water is inaccessible. However the presence of natural well enable for start of irrigation.	Surface irrigation system (well and river pumping, main irrigation canal and furrow at field level)	Carrot, Cabbage, Swiss chard and paper	No precaution take by field worker	The river water has bad quality; we use ground water, but still are not sufficient to cover demand.	The river water is used for land preparation and the land has to be washed with well water before germination.		Yes I am willing to collaborate and contribute for solving the problem.
9	Mekuriw H. (In mid-section of the river around Lideta)	Interviewed in his field while working on the field; interviewed on 1980	It is a means of income for living expenditure with land inherited from my parents	The water is relatively accessible than upper stream section of Lideta area	Surface irrigation system(Released water from upper stream irrigators and by pumping from river, furrows at field level)	Carrot, lettuce, Cabbage, Swiss chard and paper	I do not use gloves since it is not suitable to work with and my hand is damaged badly.	Vegetables stunted, dry, skin damaged, the colour of water is variables.	Take the advantage of water left from upper stream irrigators in the irrigation canal.		I am willing to participate and collaborate.
10	Zure M. (Downstream section of Lideta area)	Interviewed on his home in vacation time ; start irrigation by 1985	The only means of earning cash for coverage of living expenditures	The water is accessible to divert by gravity flow	Surface irrigation system (Small diverting canal, and furrows at field level)	Potato, Carrot, lettuce, Cabbage, Swiss chard and paper	I do not use field worker precaution tools because my skin adapt the situation	Offensive smell, vegetables dry	Shifting to irrigate from upper stream canal left water.		I am willing to collaborate and contribute for solving the problem.

Table 4 Akaki sub city and Oromiya irrigators

	Name of Irrigator	Description	Drivers		Awareness on water quality			Awareness changes			
			Socio economic	Technical drivers	Irrigation method	Crop types	Field workers precaution	Recognition of water quality change	Adaptation strategies corresponds to water quality change	Customers perception	Willingness to participate for managing pollution
1	Elias K. (Farmer from Great Akaki along main bridge)	Interviewed on 22/12/2010 while working in his field; start irrigation by 1975 using land inherited from his parents	Is a means of earning cash for living expenditure	The presence of land and water promote for use of pumped irrigation	Pumped irrigation(Pump, main canal, furrow at field levels), 15 days irrigation interval	Mainly potato and carrots as well as cabbage, lettuce, Swiss chard, and red beat sometimes	Use boots to protect foot s	By 1950 there were fish stocks, the water starts to dry, health organization test it and decide the vegetables will have health risks.	Shifting of irrigation source from textile effluents to Great Akaki water source by using pump irrigation		Willing to participate with contribution of labour.
2	Gemena W. Along main bridge of Great Akaki	Interviewed on 22/12/2010 while he enjoying after working time; start irrigation by 1990	Is a means of cash earning activity for living expenditure to my family in addition to cash earned from working as a security guard?	The presence of irrigable land and irrigation water source.	Pumped irrigation(Pump to extract water, main canal and field furrows)	Mainly Potato and Carrot. Sometimes Lettuce, Swiss chard, cabbage	I use to dress boots and sometime nose masks to prevent water borne diseases	The textile effluents dry vegetables, excessive plastic bags left in the field after summer flood.	Shift of cultivation from textile effluents to great Akaki water sources.		Willing to participate with contribution of labour.
3	Shewalem B.	Interviewed on 23/12/2010 while working in his field; start irrigation by 1996	It is the only means of cash earning for living expenditure.	The presence of irrigated land together with availability of water	Pumped irrigation system (Pump, main canal and field furrow); 15 days irrigation interval; for ‘’Fesolia’’ with 7 days interval	‘’Fesolia’’, Pumpkin, Potato, Carrot, Cabbage, Swiss chard	No precaution is taken because my body adapt the water quality.	Skin damage with water contact at field work; Vegetable dry sometimes; excessive accumulation of plastic bags and other solids after summer flood.	Matching irrigation time with time of river flow where the river will have better quality; colour identification		Yes I am willing to participate and to collaborate

4	**Dessalegn Goda and work partners (Akaki Ormia Close to Aba-Samuel Reservoir)**	BSc degree holder farmer interviewed on 23/12/2010 while working together with his partner; start irrigation by 2008	It is a means of strengthening income for living expenditure in addition to part time employment	Attracted to irrigated agriculture by presence of irrigated land and water source.	Pumped irrigation system(Pump, main canal and basins at field level)	Cabbage, Lettuce, onion and potato	I use to dress protection shoes to protect from blade damage.	Excessive accumulation of plastic bags after flood time retard growth of vegetables; I assume improper use of vegetables produced from our farm will have health risk.	Since advice given from local agricultural development bureau, I am currently cultivate only onion and potato		Yes I am willing to contribute and participate
5	**Rauda M and her partners (Akaki Ormia Close to Aba Samuel Reservoir)**	Interviewed on 24/12/2010 while working at field together with her partner; start irrigation by 1995	It is the only means of cash earning activity to cover living expenditures	Presence of irrigated land and water	Pumped irrigation system(Pump, main canal and basin at field level); 15 days irrigation interval	Onion, red root, potato, cabbage, and lettuce.	They are observed working with protection shoes.	Toxic chemicals sometimes dry vegetables; plastic bags after flood time damage crops.	After technical advice from, local agricultural development bureau before two years, only potato and onion are cultivated.		Yes I am willing to participate and contribute for solving the problem.
6	**Sisay B. (Akaki Oromia area close to Aba Samuel)**	Interviewed on 24/10/2010 while working in his field; start irrigation by 2007.	It is the only means of earning cash for covering living expenditures	The presence of irrigable land and water	Pumped irrigation system(Pump, main canal and basin at field level); with 15 days irrigation interval	Cabbage, Potato, carrot and red beet	No precaution taken	Plastic bags affected farm lands during flood time.	No adaptation taken yet.		Yes I am willing to contribute and participate.
7	**Tadesse K. (Great Akaki along the main bridge)**	Interviewed on 25/12/2010 while taking rest after work; start irrigation by 1985.	It is the only means of cash earnings to cover living expenditure for my family	Presence of irrigable land and water in the surrounding area.	Pumped irrigation systems (Pump, main canal and furrow); with 15 days irrigation interval	Swiss chard, carrot, cabbage, paper, lettuce and red beat	He is observed using protection shoes	Textile effluents have toxic effect on vegetables, great Akaki with plastic bag accumulation problem and my cow died when drunk the water.	Shifting irrigation water source from textile effluents to		Yes I am willing to participate and collaborate to solve the problem.
8	**Asrat M. (Mid-section of the river between Akaki Bridge and Aba Samuel Reservoir)**	Interviewed on 24/12/2010 while working in his field; start irrigation by 1995	It is the only means of cash earning activity for covering living expenditures	The presence of irrigable land and water is technical driver.	Pumped irrigation system(Pump, main canal, and field furrow); with 15 days irrigation interval	Mainly carrot, lettuce and paper	He is observed working without field worker protection tools like boots and globes.	Accumulation of excess quantity of plastic bags in the farm area after summer flood. Suspended maters affect pump performance of pump .Chemicals dry vegetables sometimes. Variable colour	The vegetables cultivated in my farm area recommended by the Local agricultural development bureau; no other adaptation used.		Yes I am willing to contribute and collaborate to solve the problem.

9	**Negash A.(Akakila village, from Little Akaki)**	Interviewed on 28/12/2010 while working in the field; start irrigation by 2002	It is a means of cash earning for living expenditure in addition to livestock agriculture and agriculture.	Presence of irrigable land and water as well as experience gained from upper stream farmers	Pumped irrigation system(Pump, drainage canal; main canal); irrigation interval depends on flooding status ranging from to 30 days	Potato, cabbage, carrot, red beets using irrigation, cereals mainly ''teff'' using rain fed	No precaution is used by field worker.	Bad smell; frequent flooding adversely affect crops because of its waste components; dark colour; mainly toilet waste and industrial chemicals.	Use frequent drainage to minimize the length of contact between water and vegetables; use of big irrigation interval		Yes I am willing to contribute and collaborate to solve the problem
10	**Kacha H. (In Akakila Village irrigating from Little Akaki)**	Interviewed on 28/12/2010 while selling his product to distributers; start irrigation by 1996.	It is a means of cash earning for living expenditure in addition to livestock agriculture and agriculture; has better market demand	Presence of irrigable land and water source	Pumped irrigation system(Pump, drainage canal, main canal and field furrow); irrigation depending of occurrence of flood (15 to 30 days)	Potato, paper and onion using irrigated agriculture and cereals using rain fed agriculture	No special precautions because the water is used even for household purposes.	Dark colour and bad smell; over flow to farms retard vegetable growth and sometimes dried	Drainage and use of wide irrigation interval		Yes I am willing to collaborate and contribute to solve the problem.
11	**Balcha T.** **(** Yechu Kebele next to Akakila Village**)**	Interviewed on 28/12/2010 while selling the product of irrigated agriculture; start irrigation by 1995	It is a means of cash earning activity for covering living expenses in addition to Livestock agriculture.	The presence of irrigable land and water	Pumped irrigation system(pump , main canal, drainage canal and field furrow); with 15 days irrigation interval except red beat irrigated with 3 days	For irrigated agriculture potato, red beat and cabbage; rain fed agriculture to cultivate cereals in other lands	No special precaution since the water is used for drinking and livestock	In case of overflow to irrigated farm, vegetables will dry; bad smell and difficult to work with it; changing badly from time to time.	Draining overflowed water and use of big irrigation interval		Yes I am willing to contribute and participate to solve the problem
12	**Regassa T. (Yechu Kebele next to Akakila Village)**	Interviewed on 28/12/2010 while working in his field; start irrigation by 1998	It is a means of cash earning activity for covering living expenses in addition to employment as local area administration, and livestock agriculture.	The presence of irrigable land and water	Pump irrigation system (pump, main canal, drainage canal and field furrow); irrigation interval depends on the overflow of the river to irrigated farm.	Tomato, potato, red beat and onion	No precaution is used even though he understands it is bad quality water because of adaptation.	Bad smell; dark colour; over flow will either dry vegetables or reduce production level	Use of drainage to evacuate overflowed water from irrigated farms		Yes I am willing to collaborate and contribute to solve the problem.

Annex 6. Observation

Observation have been made during introductory field visit and interview time

Observation results:

- Irrigation schemes characterization
- Farm area surroundings
- Field workers precautions(Globe and protection shoes uses)
- Market chain of vegetables including how they will be sold, i.e. processed through food packing machines or directly available from field
- Customer intention towards vegetables available in the market(whether ask about how they produced)
- Major contaminant sources for Akaki river system

Annex 7. Data collection sheet: interview questions and quality data

Questioners

1. Introduction interview
   - Introduce myself, who am I?
   - What I am going to do here in Akaki Farmers?
   - Why I am doing this in their irrigation system?
   - What is the main aim of my study?
   - How knowledge is very important and can help me for my research?
   - What will be done with the results from this interview?
   - Time it will take to conduct the interview?

   Name of interviewee…………….
   Family size
   a…………………………….. b. ……………………..
   Farm size……………….

Opening questions:

- Is farming a full time job for you?
- Other cash-earning activities?
- Rain fed-VS-Irrigated?
- Typical crops?

2. Irrigation history
   a. Since when did you start irrigation?
   b. How frequent you irrigate your field?
   c. How reliable is the source of water(Akaki River)
   d. How adequate is to irrigate?
   e. What other sources do you use? (why/why not)

3. How do you perceive the water quality of Akaki River?
   a. Is it good quality water for irrigation? For other uses?
   b. If the water is not good, what exactly is the problem?
   c. What do you think is the cause of the problem?
      Always been so, or recently changes?
   d. Have you made any changes in your farming system (irrigation; crops) over the past years because of the water quality?
   e. Do authorities (including farmer’s organization) know about the problem?
   f. What is their reaction?
4. What is the futurity of irrigated agriculture?
   a. What is your future plan with irrigated agriculture to adapt water quality?
   b. Are willing to participate to solve the problem in collaboration with institutions? Willingness to pay for treatment?

Table 1 Water quality test data

Parameters analysed	August to October			December to March			April to July		
T(o c)									
PH									
Electrical Conductivity(EC), µs/cm									
Total dissolved solid(TDS),mg/l									
Total Suspended solids, mg/l									
Sulphide, mg/l									
Chloride, mg/l									
Ammonia (as N), mg/l									
Total Nitrogen(as N), mg/l									
Total Phosphorous (as P), mg/l									
Phosphate, mg/l									
Sulphate, mg/l									
COD, mg/l									
Nitrate, NO-3									
BOD5, mg/l									
Total Coliforms , CFU/100ml									
Faecal Coliforms, CFU/100ml									
Cobalt(Co), µg/l									
Chromium (Cr), µg/l									
Copper (Cu), mg/l									
Lead (Pb), µg/l									
Zinc(Zn), mg/l									