Water Quality of Akaki rivers and its impact on irrigated vegetable farms

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

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DECLARATION

I hereby declare that the research reported in this MSC thesis is original and have been completed independently by myself (Kassahun Atalay Alehegne), under the supervision of Dr. Demeke Kifle. This MSc thesis has not been submitted for the award of any other degree or professional qualification.

Where other sources are quoted and full references are given.

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Glory to GOD forever!

ABSTRACT

Urbanization, industrialization and agricultural development practices are the main causes for the environmental degradation of surface waters including rivers. The highly impacted Akaki River, the subject of the present study, is being used for irrigation, watering livestock, sanitation and other domestic purposes. This represents a serious threat to public health and life of aquatic and terrestrial organisms. Thus, with the view of gathering information usable in the development of strategies of protection of this aquatic resource, physico-chemical and microbial water quality parameters of the irrigation water, irrigated soils and leafy vegetables cultivated on them were assessed from March to August, 2017. The biotic transfer factor (TF) and Target Health Quotient (THQ) for all measured metals were also calculated. The observed levels of Turbidity, TSS, TDS, TP, and Nitrite surpassed the acceptable levels set for domestic use and general water quality assessment criteria. DO and BOD_5 *levels also failed to comply with the safe limits set for aquatic life and general water quality assessment criteria. The levels of Faecal coliforms, Fe, Mn, Cu, Zn and Cr surpassed the maximum levels recommended for the safe use of wastewater for irrigation of vegetables. Vegetable farms in and around Addis Ababa, which were irrigated with the polluted waters of Akaki River exhibited concentrations of Zn, Cr, Cd and Cu in the soils of farm plots and of Fe, Zn, Cr, Ni, and Pb in vegetables grown on them that surpassed the safe limits recommended by international organizations. The potential health risk indicator (THQ) for Fe, Mn, Pb and Cd also reached values above 1, suggesting that they may pose health effect on consumers. The present findings suggest the need for immediate measures to protect consumers and the aquatic resource.*

Keywords*: Akaki River, Faecal Coliforms, Heavy metal, Nutrients, Soil, Total coliforms, Vegetable, Waste water*

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ACRONYMS

APHA- American Public Health Association

BCF-Bioconcentration factors

BOD5-5 day Biological oxygen demand

CCME-Canadian Council of Ministers for Environment

CFU- Colony Forming Unit

COD-Chemical oxygen demand

DO-Dissolved Oxygen

DOs- Saturated Dissolved Oxygen

E. coli-Escherichia Coli

EC-Electrical Conductivity

EEPA- Ethiopian Environment Protection Authority

EPHI Ethiopian Public Health Institute

FAO-Food and Agricultural Organization

FC- Faecal Coliform

FDRE MoH- Federal Democratic Republic of Ethiopia, Ministry of Health

ISO-International Organization for Standardization

NTU-Nephlometric Turbidity Unit

PACN-Pan Africa Chemistry Network

TC- Total Coliform

TDS- Total Dissolved Solids

THQ- target hazard quotient

TSS-Total Suspended Solids

UNICEF- United Nations Children’s Fund

USEPA-United States Environmental Protection Authority

WHO-World Health Organization

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1. INTRODUCTION

1.1. Background and Justification

Freshwater resources (rivers, lakes and reservoirs) have been of great importance to both natural ecosystems and human welfare. They are essential for agriculture, industry and human existence in general. These valued resources are, however, threatened by the rapidly growing human population and the consequent demand for more water of high quality for domestic purposes and economic activities. Human impacts on rivers are linked to many social and economic activities carried out by numerous stakeholders found within and around the river basins. These impacts include water pollution, water abstraction, siltation, habitat modification/destruction, etc.

The ecological health of aquatic ecosystems is dependent on the presence of the right levels of chemical constituents including nutrients, and heavy/trace elements, and physical variables, and composition and structure of communities and their interactions. Water pollution has, however, become one of the critical issues in environmental conservation. Surface waters can be polluted through direct or indirect discharge of wastes, without adequate treatment, into water bodies including rivers, lakes, wetlands and oceans. Pollutants get into water bodies mainly through anthropogenic activities from point and non-point sources (Xagoraraki and Kuo, 2008; Maa *et al.*, 2009).The ever-increasing urbanization, industrialization and agricultural development practices have led to widespread discharge of pollutants into nearby water bodies, which has impacted the life of humans and resident aquatic organisms.

Globally, many people lack access to improved drinking water sources and depend on poor sanitation services. According to the report released by the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), about 780 million people lack access to safe drinking water and rely on unimproved water sources, while 2.5 billion people lack adequate sanitation facilities (UNICEF/WHO, 2012). Across Africa, one-third and two-thirds of the populations have no access to clean water and clean sanitation, respectively (PACN, 2010).

Water is a vehicle of many diseases caused by different pathogenic microorganisms including bacteria, viruses and protozoa (WHO, 2008b; Woodall, 2009). Waterborne bacterial pathogens can be readily detected worldwide indifferent water sources. The human bacterial pathogens including *Salmonella* (Levantesi *et al.*, 2012; Momtaz *et al.*, 2013), *Shigella* (Faruque *et al.*, 2002),*Vibrio*

(Shanan *et al.*, 2011; Cantet *etal.*, 2013) and pathogenic *Escherichia coli* (*E. coli* O157:H7) (Benjamin *et al.*, 2013) have been detected in surface and drinking waters. Most of them cause diarrheal illness. Liu *et al.* (2012) reported that waterborne diseases accounted for annual deaths of 0.801 million (10.5% of total deaths) children younger than five years in 2010. Most of the waterborne diarrheal morbidity and mortality occurred in developing countries, of which the most vulnerable five countries were India, Nigeria, Afghanistan, Pakistan and Ethiopia (Kosek *et al.*, 2003; Liu *et al.*, 2012). The increasing presence of pathogens in surface and drinking water is troubling and needs due consideration in order to monitor the sources of these pathogens before they impose risks on human and animal health. In Ethiopia, waterborne and sanitation-related diseases, particularly diarrhea, pose risk of morbidity and deaths of children under five years of age (Liu *et al.*, 2012).This is due to inadequate access to safe drinking water and sanitation.

Owing to the scarcity of freshwaters, wastewater use is increasingly seen as an option to meet growing demand for water needed to produce food, supply industries and support human populations. The agricultural sector is currently the largest user of water and wastewater globally, accounting for approximately 70% of water use on average (FAO, 2010). The growing interest in the use of untreated wastewater for irrigation activities in urban and peri-urban areas is particularly profound (Qadir *et al.*, 2010). By contributing to food and water security, wastewater irrigation can alleviate the strain on water resources by providing a reliable year-round source of water with sufficient nutrients for crop growth (Drechsel *et al.*, 2010). This is especially critical in regions where climate change is expected to exacerbate water stress and increase precipitation variability (Hanjra *et al.*, 2012). Thus, urban crop production has been viewed as one strategy of tackling food insecurity (Mkwambisi, 2008). Besides, urban crop production has been shown to be an important source of food in developing countries and a critical food ‘insurance policy’ for poor urban households (Reardon, *et al.*, 2001). Moreover, urban crop production also affects household nutrition as it provides fresh, locally grown crops that meet the micronutrient requirements in poor households’ diets (Hendriks, 2003).The wastewaters comprise domestic effluents originating from kitchens and bath-rooms of households, discharges from commercial establishments and institutions like hospitals, and industrial effluents containing chemicals and dyes, storm water and other urban runoffs (Seneviratne, 2007). The use of untreated wastewater may, therefore, result in the contamination of soil and cultivated vegetables by heavy metals whose concentrations have often been reported to have surpassed the limits recommended by Food and Agriculture Organization of the United Nations for irrigation water and soil (Eshtawi & Kanyoka, 2012). Wastewater may contain heavy metals such as chromium (Cr), zinc (Zn), manganese (Mn), lead (Pb), cadmium (Cd), mercury (Hg), nickel (Ni), and iron (Fe) (He *et al*., 2005). However, studies show that the absorption of heavy metals by the plant biomass depends upon the metal speciation and concentration, reactivity of the biomass and the composition of the wastewater (Krishnani *et al*., 2008). According to studies made on the concentration of trace metals in vegetables that were grown with wastewater, high concentrations of cadmium, chromium, copper, mercury, nickel and zinc gave evidence of industrial pollution (Uher *et al*., 2011). Dietary exposure to heavy metals like cadmium, lead, and chromium has been identified as a risk posed to human health through the consumption of vegetables (Peralta-Videa *et al*., 2009).

Irrigation is a common water use practice in the city of Addis Ababa. Urban farming is not new to Addis Ababa as it has been a major part of the urban scene from the very beginning of the city's development as the capital of Ethiopia. Due to this, irrigated vegetable production accounts for about 60% of the total market supply for the city (Van Rooijen *et al*., 2010). However, there are significant health implications associated with the use of wastewater for agriculture (WHO, 2006) as the rivers receiving domestic and industrial wastewaters, Little Akaki and Big Akaki Rivers, are being used for irrigating vegetable farms. The major vegetable production bases in and around Addis Ababa use these two rivers and produce large quantities of vegetables for the city of Addis Ababa. The consumption of vegetables irrigated with rivers that serve as disposal systems for domestic and industrial wastewaters represents a serious threat to public health. The protection of public health necessitates the gathering of data on the physico-chemical and microbiological quality of the river waters, and the levels of metals in the freshly harvested vegetables and the soils of the vegetable farm plots. The purpose of the present study was, therefore, to investigate the physical, chemical and microbiological quality of river waters polluted with wastewaters, and the metal content of vegetables irrigated with waste waters and the soils of the farm plots on which the vegetables were cultivated.

1.2. Statement of the problem

Surface water that can be used for various purposes becomes grossly polluted under the growing burden of waterborne wastes released through municipal effluents, agricultural run-offs and industrial discharges. Rivers in particular are water resources essential for various commercial purposes. In urban areas, they have became the bases of economic development. Washers, tanners, dyers, beer brewers, or slaughterhouses, for example, use them likewise for cleaning. This, in turn, results in their contamination (WHO, 2004; Corcoran *et al*., 2010). Often this leads to serious conflicts in the demand for water between water polluters and other commercial ventures requiring clean water (Billen *et al*., 1999).

Akaki river, which is the growth collider of Addis Ababa city, is highly influenced by different man mad activities; in spite of it, the agricultural practice is taking place by using these polluted rivers.

The domestic and industrial wastes that enter surface waters including rivers are likely to cause an increase in the nutrient, microbial and heavy metal loads of the receiving waters, thereby leading to the overall degradation of their water quality. Little and Big Akaki rivers, which receive domestic and industrial wastewaters, are no exception. These rivers are very much used to irrigate farm plots on which vegetables are cultivated. The consumption of vegetables irrigated with wastewaters of domestic and industrial origin poses a serious risk to public health. The development of strategies geared towards the protection of public health depends largely on the availability of adequate scientific information. Hence, this study was initiated to investigate the physico-chemical and microbiological water quality of the rivers used for irrigation and the levels of selected heavy metals in the rivers, freshly harvested vegetables and the soils of the farm plots on which the vegetables were cultivated.

1.3 Research Hypothesis

The research hypothesis was that wastes of domestic, agricultural and industrial origin have severely affected the water quality of Akaki Rivers, soils of vegetable farms irrigated with them and the leafy vegetables grown on them.

1.4 Research Questions

- Do the physicochemical water quality parameters of Akaki River surpass acceptable standards of water quality?
- Is the river water microbiologically contaminated? (How is the microbiological water quality of the river?)

- Which heavy metals and at what level have polluted the irrigation water, soil and the selected leafy vegetables?
- What is the extent of bioaccumulation of heavy metals by the leafy vegetables?
- Is there potential health risks associated with the consumption of the selected leafy vegetables?

1.5 Objectives

1.5.1 General objective

To investigate the current water quality status of Akaki rivers and its impact on irrigated farms to develop strategies geared towards the protection of human health and other aquatic life.

1.5.2 Specific objectives

- To assess the spatial variations in physicochemical water quality parameters of Akaki Rivers.
- To investigate the microbiological quality of the river water.
- To identify and quantify heavy metal pollutants of irrigation water, soil and selected leafy vegetables
- To determine the extent of biosorption of heavy metals by leafy vegetables.
- To evaluate the potential health risks associated with the consumption of leafy vegetables irrigated with the rivers.

1.6 Significance of the study

The two Akaki Rivers are among the most important investment site rivers in Ethiopia, and hence protecting the ecological health of the rivers is vital for the country. The data that emanated from this research work will have multiple benefits. The data generated are expected to be usable in efforts geared towards developing system-based approaches for the protection and restoration of Akaki River. It is also important in the creation of awareness of decision makers, various stakeholders and the general public about the need for proper wastewater management and the undesirable consequences of disposal of untreated wastewater into rivers with regard to their physico-chemical and microbiological water quality. The results of the study will also unravel the potential risks to public health associated with the use of polluted rivers for irrigating farms on which vegetables are cultivated. Thus, institutions like Environmental Protection Authority, Ministry of water, Irrigation and Power, Ministry of Agriculture, Ministry of health, etc. and researchers will obviously benefit from the results of the present study.

2. LITERATURE REVIEW

Water is an essential constituent of living organisms. Without it, life would not be possible. Improving access to safe water is the cornerstone of public health and sustainable development (WHO, 2008b). However, water can be polluted through direct or indirect discharge of raw or inadequately treated wastes into water bodies including rivers, lakes, wetlands and oceans. These pollutants get into water bodies mainly through anthropogenic activities rendering the receiving water body unsuitable for human and animal uses (Xagoraraki and Kuo, 2008).

Water pollution sources can generally be categorized as point and nonpoint sources (Maa *et al.*, 2009). Point source water pollution is the contamination of water from a single, identifiable source such as sewage discharges from industrial plants. Nonpoint source pollution is pollution that results from diffuse sources such as agricultural runoff, and urban storm water runoff (Hogan, 2013).

Water can be polluted with physical, chemical and microbiological pollutants (WHO, 1996). Chemical contaminants may include organic substances such as detergents, food processing wastes, insecticides and herbicides, and inorganic substances such as fertilizers containing nitrate and phosphate, ammonium inorganic acids of industrial origin, and heavy metals (present in urban runoff and mine tailing area runoff). These pollutants lead to toxicity, discoloration and increased turbidity of water (Smith, 2010; Hogan, 2013).

2.1 Physico-chemical parameters of water quality

Water pollution is a serious problem in human life. The health of surface water depends on the quality of its water, which is influenced by the presence of pollutants. The quality of water is generally assessed by a range of water quality parameters, which express physical, chemical and biological properties of water (Medudhula *et al.*, 2012). Adak *et al.*, (2002) reported that different physico-chemical parameters of water are very important for effective management of water through appropriate control. In the understanding of the ecology of freshwater systems, analyses of physico-chemical parameters are very essential. For instance, dissolved oxygen (DO) is a function of temperature, pressure, salinity and biological activity in a water body (Radojevic and Bashkin, 2006). The report by Krishnan (2008) stated that, phosphorus appeared to be a limiting factor for the growth of aquatic plants but its excess amount causes water pollution. Water quality parameters such as temperature, pH, DO, electrical conductivity(EC) are major factors that regulate various abiotic as well as biotic processes in the aquatic ecosystem (Ojha and Mandloi, 2004; Radhika *et al*., 2004; Badillo-Camacho *et al*., 2015).

Heavy metals are some of the chemical pollutants of water bodies. Heavy metals are members of a loosely defined subset of elements that exhibit metallic properties. Metallic elements that are toxic and have high density, specific gravity or atomic weight, and with a potential negative health effect or environmental impact may be termed heavy metals (Kabata and Pendias, 1999). There are over 50 elements that can be classified as heavy metals, but only 17 are considered to be both very toxic and relatively common. They are commonly found in the top soil of the earth with their occurrence being associated with agricultural processes and other human activities (Gratao, *et al*., 2006). Heavy metals occur naturally in aquatic ecosystems with large variations in their concentrations (Mohsen and Salisu, 2008). They can be found in the solid phase and in solution, as free ions, or adsorbed onto soil colloidal particles. Chromium, cadmium, lead, mercury, copper, manganese, zinc, and nickel are often given particular attention as regards water pollution.

Toxicity levels of heavy metals depend on the type of metal, its biological role, and types of organisms that are exposed to them. Toxic metals are often added to rivers or streams as salts (sulfides, phosphates and carbonates), and are very insoluble in hard water and are usually transported with sediments. Their transformation into readily accessible materials is a complex process and depends on many factors such as pH, sediment presence and hardness. The availability of these metals is determined by precipitation-dissolution reactions, which are strongly affected by pH. Therefore, at lower pH, heavy metals are more available and more reactive. Many of these metals then undergo methylation, as a result of bioaccumulation, where bacteria absorb these elements and convert them from a metallic state into a toxic organic metallic state. By becoming incorporated with an organic component, these metals become readily available to the first trophic level of the food chain and eventually lead to biological magnification throughout the system (Laura and Susan, 2009).

Accelerated water pollution caused by the excessive inputs of heavy metal loads from industrial and domestic wastes can pose a serious threat to the health of people who may consume vegetables irrigated with this polluted rivers and the rivers' ecosystem in general. The rate of loading of these pollutants to the rivers varies from place to place depending on the human activities in the nearby environment. Long-term monitoring and comprehensive analysis of the physicochemical parameters is crucial in a holistic approach to solve environmental problems.

2.2 Microbiological parameters of water quality

Indicator organisms are used for indicating the occurrence of fecal contamination, water treatment efficiency and the deterioration and post-contamination of drinking water in distribution systems (Bitton, 2005).Consequently, interpretation of the presence of microbial indicator bacteria may warrant establishing whether or not a water body is polluted by disease causing microorganisms. According to Bitton (2005), indicator bacteria must be exclusively of fecal origin, present when pathogens are present and absent otherwise, occur in greater numbers than the associated pathogens, are more resistant to environmental stress and persist for a greater length of time than the pathogens, do not multiply in the environment, can be easily detectable and are non- pathogenic. The following are the major indicator organisms.

Coliform bacteria

Coliform bacteria are Gram-negative, rod-shaped, non-spore-forming, aerobic and facultative anaerobic bacteria that are able to grow in the presence of bile salts (NHMRC/NRMMC, 2011). They are diverse groups of bacteria and include *Escherichia coli, Enterobacter, Klebsiella* and *Citrobacter* and belong to the family *Enterobacteriaceae*. They are always present in both polluted and non-polluted waters, soils and plants, as well as in the feces of warm- blooded animals (Bitton, 2005).

Total coliforms (TC) are coliforms, which are common in the environment and are generally harmless. They are able to ferment lactose to acid and gas within 24 h at 35 ± 2^0C. Fecal (thermotolerant) coliforms (FC) are a subgroup of TC bacteria. They occur in the intestines and feces of people and animals. The organisms produce acid and gas from lactose at 44 - 45^0C. The presence of fecal coliforms in drinking water often indicates recent fecal contaminations (WHO, 2011a). *Escherichia coli (E. coli)* belongs to fecal coliforms. Most strains of *E. coli* are harmless and natural inhabitants of the intestinal tract of humans and other warm-blooded animals. Nonetheless, some strains can cause illness. They can be differentiated from the other thermotolerant coliforms by their ability to produce indole from tryptophan or by the production of the enzyme β-glucuronidase (ISO, 2000a). They are generally not found growing and reproducing in the environment. They are the only coliforms that satisfy criteria for an ideal fecal indicator. Hence, their presence in water samples is the best indicator of fecal pollution and the possible presence of enteric pathogens due to their prevalence in the guts of warm-blood animals (NHMRC/NRMMC, 2011).

Determining the bacterial quality of surface water is the single most important water quality test. This is because one glass of water containing just a few disease-causing microorganisms can cause illness. When minimal exposure creates an immediate health risk, that contaminant is known as an acute contaminant. Bacterial contaminants such as *E. coli* and other fecal coliforms in drinking water represent an acute health risk. The total coliform test is the starting point for determining the microbiological quality of drinking water. This test is performed frequently because of the acute risk that disease-causing organisms pose to the users of that water supply.

Risk Associated with Coliform Types

There are a number of subgroups within the coliform group. The presence of bacteria from each progressively smaller subset heightens the concern that disease-causing organisms may also be present in the water. These groups and their relative risk implications are discussed below.

Total Coliform: These organisms are prolific in the soil. The presence of total coliform by itself does not imply an imminent health risk but does indicate the need for an analysis of all water system facilities and their operations to determine how these organisms entered the water system. Public notice to water system users is required since a properly constructed and maintained water system should not have total coliform. When total coliform are present, the water system is allowed to stand for 30 days before public notice is given to customers that the water supply has violated a drinking water standard. This lengthy period indicates regulatory agencies' perception of a low degree of immediacy to the risk.

Faecal Coliform: This is a subset of the total coliform group. Fecal coliform bacteria generally originate in the intestines of mammals. They have a relatively short life span compared to other coliform bacteria. Their presence could be related to improper disposal of sanitary waste. Immediate public notice and a boil order to the users (within 24 hours) are required due to the higher likelihood of disease organisms also being present in water.

***Escherichia coli* (*E. coli*):** This is a species within the fecal coliform group. *E. coli* originates only from the intestines of animals including humans. As with other fecal coliforms, it has a relatively short life-span compared to non-faecal coliform bacteria. Its presence indicates a strong likelihood that human or animal wastes are entering the water system. Immediate public notice and a boil order (within 24 hours) are required due to a higher likelihood of disease causing organisms are also present in the water.

2.3. Wastewater use in agriculture

Wastewater is used for irrigation in treated and untreated forms, varying by geographic and economic context, albeit with the majority in untreated form in developing countries (Scott *et al.*, 2010). Wastewater is commonly discharged into water bodies with little or no treatment due to the limited availability of treatment facilities in many countries (Qadir *et al.*, 2010). This untreated wastewater is frequently used for urban or peri-urban agriculture, which comprises approximately 11% of all irrigated croplands globally (Thebo *et al.*, 2014). Untreated wastewater often contains a large range of contaminants emanating from municipal, agricultural and industrial sources. Excreta-related pathogens, skin irritants and toxic chemicals originating from these sources pose health risks to farmers and agricultural workers, their families, communities living in proximity to wastewater irrigation, as well as the consumers of wastewater-irrigated crops (Qadir *et al*., 2007).

Due to frequent contact with untreated wastewater, agricultural workers are exposed to heavy metals including chromium, cadmium, lead, copper, nickel, zinc, manganese, iron and mercury due to prolonged consumption of contaminated foods or occupational ingestion or inhalation of irrigated soils, which are linked to a wide range of chronic health effects. For instance, accumulation of cadmium, particularly in the kidneys, leads to kidney damage and osteoporosis. This is known as itai-itai disease in Japan, where the condition was originally linked to irrigation of rice paddies with highly contaminated water (Järup, 2003).

Due to these widespread health risks, organizations/institutions including the World Health Organization (WHO), FAO and EPA have developed guidelines to ensure that contaminant levels in wastewater are below limits that are harmful to human health (WHO, 2006). While irrigation with untreated and inadequately treated wastewater presents a serious public health risk to farmers and consumers who are exposed to a range of contaminants, its use is important for smallholder livelihoods, particularly in economically disadvantaged regions or water-stressed areas (Raschid-Sally and Jayakody, 2008). In many cities of developing countries, farmers in urban and peri-urban areas are dependent on wastewater to irrigate their crops despite the significant contamination that contributes to a large burden of water-related diseases (Qadir *et al*., 2010). The use of wastewater is also emerging as a form of climate change adaptation because it provides a consistent source of water in areas with variable rainfall or dry conditions (Trinh *et al*., 2013). The complex drivers associated with wastewater use mean that steps to reduce health risks must be balanced with the need for increased food security, nutrition and livelihoods (Drechsel *et al*., 2002). In the context of these health challenges the full extent of exposure to wastewater contaminants requires further exploration. The goal of this research was thus to critically evaluate the current pollution status of Akaki Rivers in light of physicochemical, microbiological and heavy metal water quality parameters, and assess the potential health risks associated with wastewater use in agriculture.

In addition to occupational and food consumption risks, people living or commuting near wastewater-irrigated land may experience indirect exposure. For example, cricket games in proximity to contaminated soil were reported as possible sources of accidental ingestion (Ensink *et al*., 2006).

In high income countries, there are still health risks for communities in proximity to wastewater irrigation areas where lower levels of treatment are used to grow non-food crops. For instance, contamination of groundwater and drinking water supplies, as well as nearby areas (e.g. fields with food crops) was linked to wastewater use for energy crops (used as sources of biomass) in Northern Ireland and Sweden (Carlander *et al*., 2009).

Children in particular are more vulnerable to some wastewater contaminants (Blumenthal *et al.* 2000), and this exposure was referenced in several articles (e.g. Mara *et al*. 2007; Yang *et al*. 2006). Children may be exposed to wastewater through playing in contaminated areas, which increases the frequency and duration of environmental exposures (An *et al*. 2007). Children are also less likely to practice sanitary behaviors like hand washing (Nwachuku and Gerba, 2004). In addition, children are often involved in helping with agricultural work. For instance, in a wastewater-irrigated area in Marrakesh, one study reported that boys who helped with agricultural work had a greater risk of *Salmonella* infection than girls who stayed at home (Melloul and Hassani, 1999). However, all children in the wastewater area, particularly those aged lower than 10, had a higher prevalence of diseases compared with control areas.

A key challenge to assessing the health risks of wastewater use is that people living in wastewater-irrigated areas may face exposures from a range of sources, and assessment of specific risk factors is made more difficult. The sources of exposure include poor living conditions, such as lack of access to water for drinking, domestic uses and sanitation, which was considered in several studies (e.g. Blumenthal *et al.*, 2001; Ensink *et al.*, 2008). In addition, practices such as animal husbandry and use of excreta in agriculture were further pathways of exposure to excreta-related pathogens. For instance, Trang *et al.* (2007) reported that wastewater use in peri-urban agriculture in Hanoi, Vietnam, did not increase the risk of helminth infection, while lack of sanitation facilities and use of excreta for fertilizer did. Ferrer *et al.*, (2012) identified a range of exposure routes to contaminants through recreational activities such as swimming, bathing, and fishing in canals contaminated with untreated domestic and industrial wastewater in Bangkok, in addition to exposures associated with consumption of vegetables grown in farms irrigated with wastewaters. Increasing urbanization and industrial development in the Bangkok region have increased contamination levels in canals, so these multiple pathways of exposure present serious health risks.

Studies in South Asia focused more on inorganic chemicals (e.g. Pb, Cd, Cr and Zn). This corresponds to areas where industrial development has resulted in industrial effluent entering municipal wastewater and water bodies, presenting a risk of heavy metal exposure due to consumption of crops (Jan *et al.*, 2010; Tang *et al.*, 2011andGupta *et al.*, 2012). Studies in Sub-Saharan Africa and Southeast Asia largely focused on microbiological contaminants, and chemical contaminants have generally been considered to be lower priority health risks in low-income countries (Bos *et al.*, 2010). However, research is needed in areas experiencing growing industrial development in order to assess a greater number of contaminants (WHO, 2006).This will be needed to identify, monitor and prioritize health risks as well as to build capacity for enforcing safe disposal. Regulatory guidelines for many of these contaminants are still being developed and many cannot be monitored or detected (Terzić *et al.*, 2008). In general, these environmental contaminants are difficult and expensive to measure, despite representing a growing public health concern, especially in regions using treated wastewater that is considered safe (Dodgen *et al.*, 2013).Thus, more research is needed on health risks of wastewater use in the water-stressed areas relying heavily on such waters for irrigation (Grangier *et al.*, 2012).

Contaminant uptake into the food chain is a key concern associated with wastewater irrigation, as this is the most widespread exposure route. Accumulation of even small amounts of metals in soil is a challenge in areas with long-term wastewater irrigation due to chronic exposure of consumers. In the case of heavy metals and metalloids, uptake is determined by a range of factors including soil conditions and vegetable type. For instance, Khan *et al*., (2008) found that leafy vegetables had higher transfer of Cd, Cu, and Ni from soil to plants in Tianjin, China. Singh *et al*., (2010) compared a range of vegetables contaminated with heavy metals near Varanasi, India and found highest concentrations in cabbage, brinjal (egg plant) and the leafy vegetables lady's finger and spinach, compared with other vegetables such as gourd varieties.

Information on varying uptake levels among crop types might be used to determine which vegetables should be grown in areas with specific contaminants (Simmons *et al*., 2010). For instance, in a comparison of leafy vegetables in Nigeria, Agbenin *et al*., (2008) found that lettuce contained much higher levels of As and Cr, but lower levels of Cd compared with amaranth. Pandey *et al*., (2012) found that while root vegetables showed greater uptake of heavy metals over leaves and fruits irrigated with wastewater, leafy vegetables showed greater contamination levels when the inputs of atmospheric deposition were considered together with wastewater irrigation. A challenge for understanding and comparing risks identified in these studies is the range of methods used to assess contamination, including dry or wet weight of chemicals and ratios of soil to plant matter.

Until recently, vegetables did not constitute a major part of the Ethiopian diet, except during the fasting period. However, since recent years their consumption is increasing gradually, particularly among the urban communities. This is due to increased awareness about the food value of vegetables, as a result of exposure to other cultures and acquiring proper education.

Vegetables grown in Addis Ababa include: potato (*Solanum tuberosum* L.), Swiss chard (*Beta vulgaris* L. var. *cicla*), carrot (*Daucus carota* L.), cabbage (*Brassica oleracea* L. var. *capitata*), Ethiopian kale (*Brassica carinata* A. Br.), lettuce (*Lactuca sativa* L. var. longifolia), spinach (*Beta vulgaris* var. *cicla*), cauliflower (*Brassica oleracea* L. var. bo*trytis*) and red beet (*Beta vulgaris* L. var. *vulgaris*). These are often grown on the embankments along the major rivers within Addis Ababa and the neighboring towns of Akaki, Alem Gena, and Sebeta (Mogessie Ashenafi, 1989).

The vegetable farms at Saris 58, Echu Gebere, Mekane Biruh and Were Geno are among the biggest farms in the capital, where a substantial amount of vegetables is being produced seasonally. These farms are irrigated with the wastewater from Little and Big Akaki Rivers. Before several decades, the water from the rivers in the capital was clean. However, with the increase in the urban population and industrialization, the water has now become contaminated with various pollutants, among which are heavy metals (Fisseha Itanna, 1998). Vegetables grown at contaminated sites could take up and accumulate metals at concentrations that are toxic. In addition, they could be contaminated as farmers wash vegetables with wastewater before bringing them to market (Fisseha Itanna, 2002).

3. MATERIALS AND METHODS

3.1 Description of the study area

Addis Ababa covers an area of about 540 Km^2, of which 18.2 Km^2 is rural/suburban. The city lies at the foot of the 3,000 meters high Entoto Mountains. Addis Ababa enjoys a mild, Afro-Alpine temperate climate. Besides the residents of rural parts of Addis Ababa, the city dwellers also participate in animal husbandry and cultivation of crops (Addis Ababa City Council, 2004).

Two major rivers flow through the capital city of Ethiopia, Addis Ababa, namely Big Akaki and Little Akaki rivers, which are tributaries of the Awash River. Big Akaki and Little Akaki basins have catchment areas of about 900 and 540 km^2, respectively. Little Akaki originates from Entoto and flows through Gefersa down to Lake Abasamuel, while Big Akaki emanates from Legedadi Reservoir and flows down to Lake Abasamuel. The little Akaki River flows from Northwest through Gefersa Reservoir down to the center of the city and passes through the industrial area before finally ending up in the Aba-Samuel impoundment, while the Big Akaki River flows from Legedadi Reservoir in the Northeast of the city down to Kebena, finally flowing through Bole to Lake Abasamuel. Throughout their flows, these rivers and their tributaries are the main recipients of most of the industrial wastes, urban sewage and storm water drained from Addis Ababa and its suburbs (Addis Ababa City Council, 2004). Akaki rivers are occupied by few medium and large industries (Addis Ababa and Dire Tanneries, Addis Ababa glass factory, Ethio-Marble Factory, Tikur Ababy shoe Factory, Dil oil and Gulele soap factories, workshops and big garages, Batu tannery, abattoirs, oil and beverage factories are among the industries found at the riverbanks of both Little Akaki and Big Akaki rivers, (Tegegne, 2012) which finally join the Aba Samuel Reservoir. This reservoir is now serving as an oxidation pond. According to Zewdie Abate's (1994) report, the biochemical oxygen demand (BOD_5) in Little Akaki and Big Akaki was 4665 kg/day and 1000 kg/day, respectively. Tamiru Alemayehu *et al*., (2003) showed that there is an increasing concentration of heavy metal, coliform and pathogen pollution in the surface and ground water in Addis Ababa. Water from the rivers is being used for various purposes including irrigation, sand mining, industrial consumption, cleaning of materials, bathing, cattle watering, and waste disposal.

Table 3. 1**. Location of the sampling sites.**

Sampling sites	***Longitude***	***Latitude***	***Altitude (m.)***
Saris 58	038.45’464	08.56’971	2212
Echu Gebere	038.44’782	08.53’172	2059

Mekane Bruhe	038.46’360	08.51’887	2061
Were Geno	038.49’833	08.58’518	2248

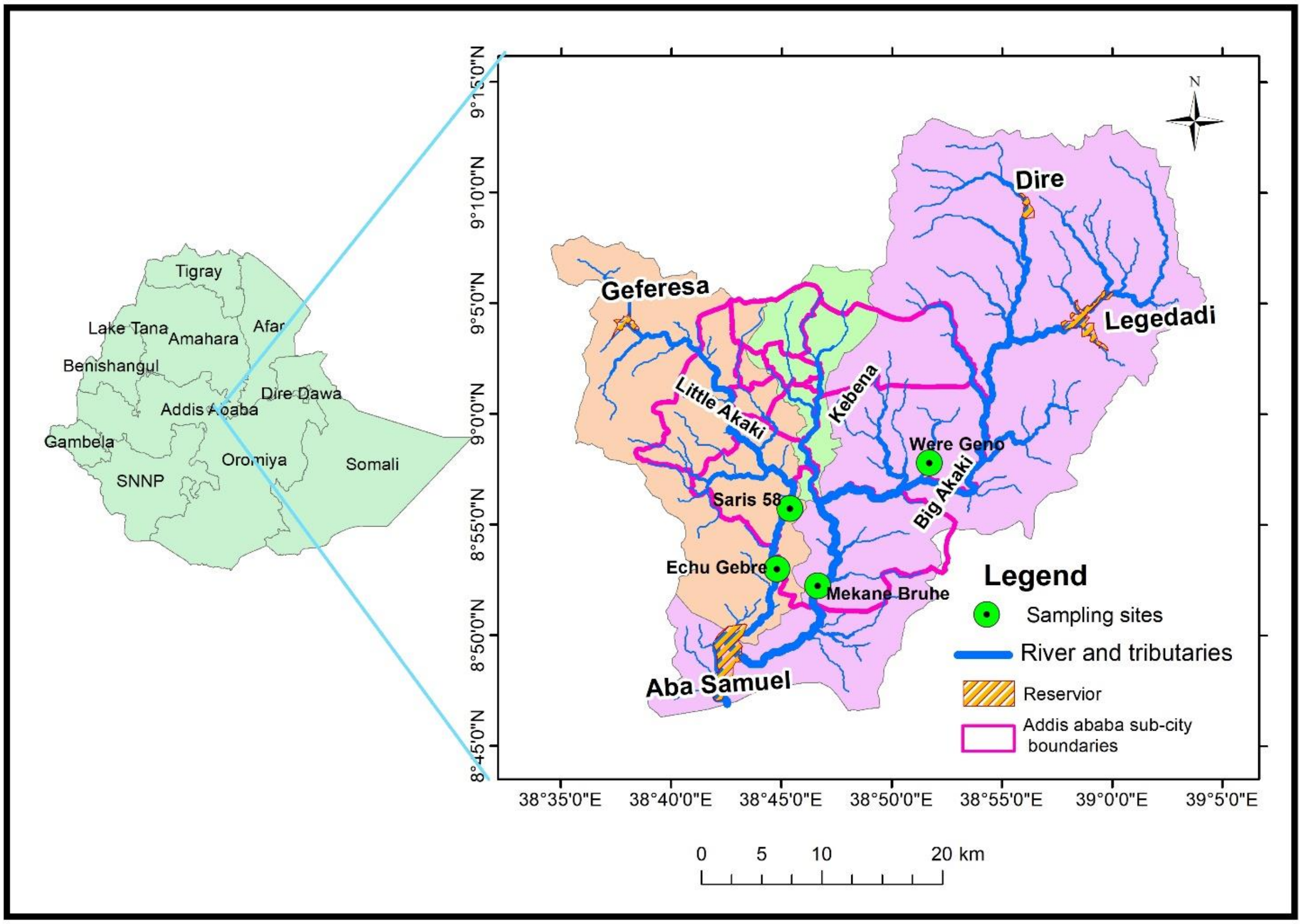

Figure 3. 1. Map showing the location of the present study sites found along the course of Little and Big Akaki rivers.

3.2. Sampling design and sample collection

Four purposive sampling sites were selected based on availability of vegetables year round, easy access to the selected vegetables, irrigation practice, waste disposal activities, and so on. These sampling sites are found along the course of Big and Little Akaki rivers. Samples were collected from the selected sampling sites, which are located at the middle and lower ends of the course of the two Akaki Rivers during March, April, May July and August, 2017. The collected samples were used for the analyses of major nutrients, indicator microbes, and physicochemical water quality parameters including selected heavy metals in the irrigation water (river water), irrigated soil, and frequently consumed leafy vegetables. Water samples were collected using pre cleaned plastic bottles for nutrient analysis. All the collected water samples were taken on the same day of sampling to the appropriate laboratories and stored at $4^{\circ}c$ until analysis was made.

3.3.Measurement of physicochemical and biological parameters

3.3.1.*In-situ* measurements of physico-chemical parameters

Physicochemical parameters were measured after all field equipments were calibrated according to the manufacturer’s specification. Temperature, pH, electrical conductivity and dissolved oxygen, were measured *in situ* with a portable multimeter (HACH, HQ 40d, USA) designed for water samples, while turbidity was measured by a portal digital Turbidimeter (T-100 Singapore).

3.3.2.Analysis of macronutrients and other physical/chemical parameters

Aliquots of each water sample (100 ml) were filtered through 47 mm diameter and 0.45µm pore size membrane filters (HAWG04756, Millipore, Cheshire, UK), and used for the analysis of soluble reactive phosphorous (SRP) and Total phosphorous (TP), after persulfate digestion) and analyzed by the Ascorbic Acid method. Ammonia-nitrogen **(**NH_3+ NH_4^+-N) was determined by the Phenate method, while Nitrite- nitrogen (NO_2-N) was measured by a colorimetric method and nitrate-nitrogen (NO_3-N) was analyzed by sodium salicylate method following the standard procedures outlined in APHA, *et al.*, (1999).

Total suspended solids (TSS) was measured as dry weight of seston filtered onto a glass fiber filter paper (GF/F, 47mm pore size) pre-dried at 105°C and subsequently dried with seston at the same temperature for 1 hr. and estimated as the increase in weight using the following formula (Estefan *et al*., 2013):

$$\text{TSS (mg/L)} = \frac{(W2\_W1)\ X\ 1000}{V}$$

Where:

W_1= Weight of dried clean filter paper (mg)

W_2= Weight of dried clean filter paper and seston (mg)

V= Volume of water sample filtered (mL)

Total dissolved solids (TDS)

A 50 ml sample was filtered through a glass-fiber filter with vacuum applied. The total filtrate (with washings) was transferred to a dried and weighed evaporating dish, evaporated and dried in an oven for at least 1 hr. at 180 ± 2°C, and then cooled in a desiccator and subsequently weighed. Allowing to dry overnight at 95 degree centigrade, the weight of dried residue in an evaporating dish was weighted and the TDS in mg L^{-1} was calculated by the following formula:

$$\text{TDS (mg total dissolved solids/l)} = \frac{(A\_B)\ X\ 1000}{sample\ volume, ml}$$

Where:

A=weight of dried residue+dish, mg and B= weight of dish, mg

BOD_5 was determined by the Winkler method described in section 5220-B of APHA *et al*., (1999) and used for the determination of a 5-day biological oxygen demand. The concentration of oxygen (mg /l) was calculated as follows:

$$\text{BOD5 in sample} = (\text{IDO} - \text{DO5}) * \text{dilution factor};$$

Whereas;

$$Dilution\ Factor = \frac{\text{Bottle volume(300ml)}}{Sample\ volume, ml}$$

Where:

IDO=Initial Dissolved Oxygen, DO_5= Oxygen concentration after 5 days incubation

Chemical oxygen demand (COD), which is the amount of a specified oxidant that reacts with the sample under controlled conditions, was analyzed following the standard procedures outlined in section 5220-B of APHA *et al*., (1999)

3.3.3 Microbiological analysis

Samples for microbiological analysis were collected in sterilized 300ml bottles to avoid any prior bacterial contamination. Irrigation water samples were then transported in an ice box and analyzed within 24 hours of collection following the methods described in APHA *et al*., (1999). Indicator microorganisms (total coliforms and faecal coliforms) in the collected water samples were analyzed by direct plate count and the membrane filtration method, respectively. Aseptic procedures were used throughout the analysis.

After sample collection from the study sites, dilutions were made using sterilized distilled water (to make colony easily countable), and appropriate nutrient or culture media (Reasoners 2 A agar for total coliforms and Membrane Laurite Sulfate for faecal coliforms) were selected.

Direct plate count for Total coliform count

Total coliform count of water samples were determined by the direct plate count method as described in APHA *et al.*, (1999) using Reasoners 2 A agar. Serial dilutions of the samples were made with 0.1% buffered peptone water; 1 ml from each dilution (10^{-1} to 10^{-5}) was plated. The plates were incubated at 37°C for 24h. After incubation, plates with colonies between30-300 were counted (Roberts and Greenwood, 2003).

Membrane filtration method for faecal coliform count

Membrane Laurite Sulfate was dispensed into a sterile Petri dish, evenly saturating the absorbent pad. Forceps, which were dipped in ethanol and flamed, were used to remove the 0.45µm pore size membrane filters from the sterile package. The membrane filter was placed in the funnel assembly. After flaming the pouring lip of the sample container, 5 ml sample was poured into the funnel. The vacuum pump was turned on and the sample was allowed to draw completely through the filter. The funnel was rinsed with sterile buffered water. The vacuum pump was again turned on and the liquid was allowed to draw completely through the filter. After flaming the forceps, the membrane filter was removed from the funnel and placed in the prepared Petri dish containing an absorbent pad evenly saturated with the Membrane Laurite Sulfate. Finally, the filter was incubated at 45^{0}C for 24 hr.

During incubation, each faecal coliform bacterium develops into a visible yellow colony as Faecal coliform bacteria produce acid from the lactose in membrane Lauryl sulfate broth, and the acid changes the colour of the phenol red pH-indicator to yellow. The colonies were then counted. Test report of faecal and total coliform bacteria was expressed as colony-forming units per 100ml. Since the counts were for 5 ml (the volume of sample filtered), this was multiplied by 20 to obtain the faecal coliform count per 100ml.

All microbiological analyses were carried out in the *Bio-instrumentation Unit* of the Department of Microbial, Cellular and Molecular Biology, College of Natural and Computational Sciences, Addis Ababa University.

3.4 Sample collection and preparation for the analysis of heavy metals/trace elements

Sample collection

Irrigation water and soil samples were collected in pre-cleaned highland bottles and polyethylene bags, respectively while vegetable samples were collected with envelopes to facilitate absorption of moisture. A specimen of each vegetable was pressed for identification in the laboratory.

Figure 3. 2. Vegetables selected for analysis of metals at Echu Gebere site

Sample preparation of Green leafy vegetables

The vegetable samples were collected randomly at intervals of 3-meter. Leafy vegetables were preferred for this study because of their availability and considering the fact that leafy vegetables have greater capacity of accumulating heavy metals than other vegetables (Khan *et al.*, 2008). The green leafy vegetables, which were collected from the sampling sites were Lettuce (*Lactuca sativa L*.), Swiss chard (*Beta vulgaris L.var cicla*) and Ethiopian kale (*Brassica carinata A.Br*.).

Pretreatment

The collected vegetable samples were washed with distilled water to remove dust particles. The samples were then cut to separate the roots, stems and leaves using knife. The edible part (leaves) of vegetables were air-dried and subsequently dried in an oven at 100ºC. Dried samples of the vegetables were ground into fine powders using mortar and pestle and stored in aluminum bags for digestion.

Soil samples

After considering average field conditions, i.e. extreme high and low value, for example, slope, and appearance of crop, a grid line was established at regular intervals (15-30 cm) and each intersection area of 1m diameter was sampled. The depth of sampling was for shallow rooted crops, 0-6cm and for deep-rooted crops, 6-12cm depths are suitable for sampling. Contamination was prevented at all stages. As crushing is easier at the right moisture level, the soil was passed through 2-3mm nylon sieve and air-dried and then oven-dried at 100^0c. Then the sample was stored in a polyethylene bag till digestion.

Irrigation Water Samples

Water samples were collected in1 litter capacity plastic bottles. Before sampling, all plastic and glass wares were cleaned by soaking in diluted HNO_3 (10% v/v) and rinsed with distilled water prior to use. The source for the water samples is the water from the river used for irrigation at the point of its entry into the channel leading to the farm land. The plastic bottles were rinsed with the irrigation water before water samples were collected and then transported to the laboratory in iceboxes for analysis.

In the laboratory, samples were filtered with 0.45μm filters and preserved with 1ml of 70% HNO_3. The filtered samples were stored in a refrigerator without freezing to minimize volatilization and biodegradation until analysis (Weldegebriel *et al.*, 2012) and the concentrations of heavy metals was were measured at Bless Agri Food Laboratory Services PLC.

Preparation of standards and analysis of samples

All plastic and Glassware were cleaned by soaking in diluted HNO_3 (10%v/v) and rinsed with distilled water prior to use. All reagents were of analytical grade (99% purity). Working standard solutions of heavy/trace metals were prepared from the stock standard solutions containing 1000ppm of the element in 2N nitric acid using dilutions. Calibration and measurement of the elements were done using AAS. The calibration curves were prepared for each element individually applying linear correlation by the least square method. Blank readings were taken and the necessary corrections were made during the calculation of concentration of the various elements.

The selected heavy metals were analyzed by AAS (Agilent, 700 Series) with the main gas supply of argon used as to the plasma, nebulizer and optics interface purge and also required to purge the polychromatic assembly with its Purity: 99.996% and regulated with recommended flow rate: 0.7 to 32 L/min Cu, Fe, Mn, Zn, Cd, Cr, Ni and Pb metals were analyzed by using ISO 11885:2012 test method following microwave digestion, added 5ml of concentrated nitric acid and 2ml concentrated hydrogen peroxide in digestion tube including blank and digested the sample in milestone start D microwave digester with maximum temperature of 250^{o}c and pressure of 1200 psi for fifteen minute and diluted into 25ml Erlenmeyer flask and made up to the mark with 2% nitric acid solution, filtered through 0.45µm pore diameter membrane filter to avoid possible contamination .The samples were analyzed in the same operational manner used in the calibration routine and the calibration solution was prepared from1ppm and10ppm- standard (99.99%) and five calibration solutions were prepared (1ppm, 2ppm,3ppm, 5ppm and 10ppm) by plotting calibration curve with recommended wavelengths of 327.395, 238.204, 257.612, 213.857, 230.299, 283.305, 267.716 and 214.439 nm respectively due to its sensitivity and overall acceptability and corrected for spectral interference and the prepared sample was analyzed and concentration of Cu, Fe, Mn, Zn, Ni, Pb, Cr and Cd metals were calculated using the formula:

$$\text{Conc. of heavy metals in (ppm)} = \frac{(\text{conc.in sample} - \text{conc.in blank}) * \text{extracted volume} * \text{dilution factor}}{\text{amount of sample}(\text{gm or ml used})}$$

3.5 Estimation of the bio transferable factors(BTF) of heavy metals

The transfer factor expresses the bioavailability of a metal at a particular position on a species of plant (Khan *et al*., 2009). It is calculated as the ratio between the concentration of heavy metals in the vegetables and that in the corresponding soil (both based on dry weight) for each vegetable separately (Cui *et al*., 2004; Shanker *et al*., 2004; Liu *et al*. 2013). The transfer factors (TF) were calculated using the following formula (equation 1):

$$BTF = \frac{Cvegetable}{Csoil} \quad \text{...} \text{ Equation 1.}$$

Where: BTF=Biotransfer factors

$C_{vegetable}$=Concentration of the particular pollutant in vegetable

C_{soil} =Concentration of the particular pollutant in the soil habitat of the vegetable.

3.6 Vegetable Consumption-associated Health risk Assessment

Potential health risk of exposure to heavy metals of Addis Ababa residents through local leafy vegetable consumption was assessed using target hazard quotient (THQ), which was first proposed by the United States Environmental Protection Agency for assessing the potential health risks to human health associated with exposure to pollutant (USEPA, 2000, Chen *et al*., 2002, Liu et al., 2013).THQ is defined as the ratio of the body intake dose of a pollutant to the reference dose. If the THQ is equal to or higher than1, there is a potential health risk (USEPA, 2002). THQ below 1 means that the exposed human population is unlikely to experience obvious adverse effects. A target hazard quotient (THQs) is based on the following equation:

$$THQ=\frac{EF*ED*FI*MC*}{RfD*BW*AT}*10^{-3}$$ ………………………………………………….. Equation 2.

Where, THQ is target hazard quotient, EF is the exposure frequency (365 days/year), ED is the exposure duration (64.7 years), FI is the food ingestion (g/person/day), MC is the metal concentration in vegetables (mg/kg), RfD is the oral reference dose (mg/kg/day), BW is the average body weight (adult, 60 kg), AT is the average exposure time for non-carcinogens (365 days/year × number of exposure years, assuming 64.7 years in this study).

3.7 Statistical analysis

Data analysis was performed using Microsoft Excel XP version 2013 for data recording and filing, SPSS package 20.00 to analyze means and standard deviations of the levels of physicochemical parameters and microbial concentrations for all sampling sites. One-way ANOVA (analysis of variance) was used to compare the study sites in order to detect the statistical significance of differences ($p < 0.05$). Sigma plot version 10 software was used for graphical presentation. Multivariate analysis with the package using CANOCO 4.5 software was also used to show the relation of environmental data and sampling sites.

4. RESULTS

4.1 Spatial variations in selected water quality parameters of Akaki River

4.1.1 Spatial variations in physico-chemical water quality parameters of Akaki River.

Physico-chemical parameters including nutrients and organic pollutants measured in the present study varied spatially (Table 4.1).

Table 4.1 Spatial variations in mean values of physico-chemical parameters recorded for the sampling sites of the present study on Akaki Rivers.

Physico-chemical parameters	Sampling Sites				
	Saris 58	Echu Gebere	Mekane Biruh	Were Geno	Kruskal Wallis Test at 0.05
pH	7.69±0.31	7.49±0.71	7.59±0.73	7.89±0.56	0.04
EC	254.10±85.72	240.62±117.66	166.92±52.09	173.96±15.76	0.018
DO	2.73±2.05	2.97±2.85	2.92±2.39	3.14±2.21	0.002
DOs	39.66±26.64	44.98±39.89	35.64±32.48	47.46±28.48	0.007
Temp	20.18±0.87	21.04±1.50	21.32±2.22	20.42±2.14	0.022
Turbidity	228.60±56.07	276.40±144.45	508.40±337.94	262.20±79.23	0.471
TP	36.09±11.51	24.05±18.03	18.81±8.88	24.81±15.11	0.042
SRP	12.13±7.39	18.55±6.24	10.25±3.81	12.99±5.23	0.408
NO_3-N	0.31±0.04	0.26±0.05	0.26±0.15	0.22±0.05	0.08
NO_2-N	0.47±0.08	0.20±0.14	0.53±0.15	0.22±0.17	0.565
NH_3+NH_4-N	3.91±2.02	5.91±2.62	4.82±0.71	5.05±1.12	0.326
TSS	744.80±298	744.16±522.43	580.67±344.96	697.40±306.34	0.134
TDS	1473.07±407.14	1233.20±515.92	1339.44±312.50	1174.00±585.21	0.378
BOD5	60.75±36.36	51.10±33.68	47.83±38.41	69.914±54.88	0.003
COD	430.57±286.64	251.35±196.67	66.17±43.18	123.93±78.15	0.018

Mean TP values (mg L^{-1}) ranged from 18.81 at the Mekane Biruh site to 36.09 at the Saris 58 sampling site, with significant difference (p=0.042) in TP concentrations among sampling sites. Mean SRP varied from a minimum of 10.25 for the Mekane Biruh site to a maximum of 18.55 for the Echu Gebere site although there was no significant difference in mean SRP levels among sampling sites (p=0.408, Table 4.1). Mean nitrate concentration (mg L^{-1}) ranged from 0.22 at the Were Geno site to 0.31 at the Saris 58 sampling site although its spatial variations were not statistically significant (p=0.089). Nitrite (mg L^{-1}**)** ranged from 0.20 at the Echu Gebere site to 0.53

at the Mekane Biruh sampling site, with statistically no significant difference in its levels among sampling sites (p=0.565). The mean concentration of ammonia (mg L^{-1}) in Akaki Rivers ranged from 3.91 of the Saris 58 site to 5.91 of the Echu Gebere site although the difference in ammonia levels among the sampling sites was not statistically significant (p=0.326).

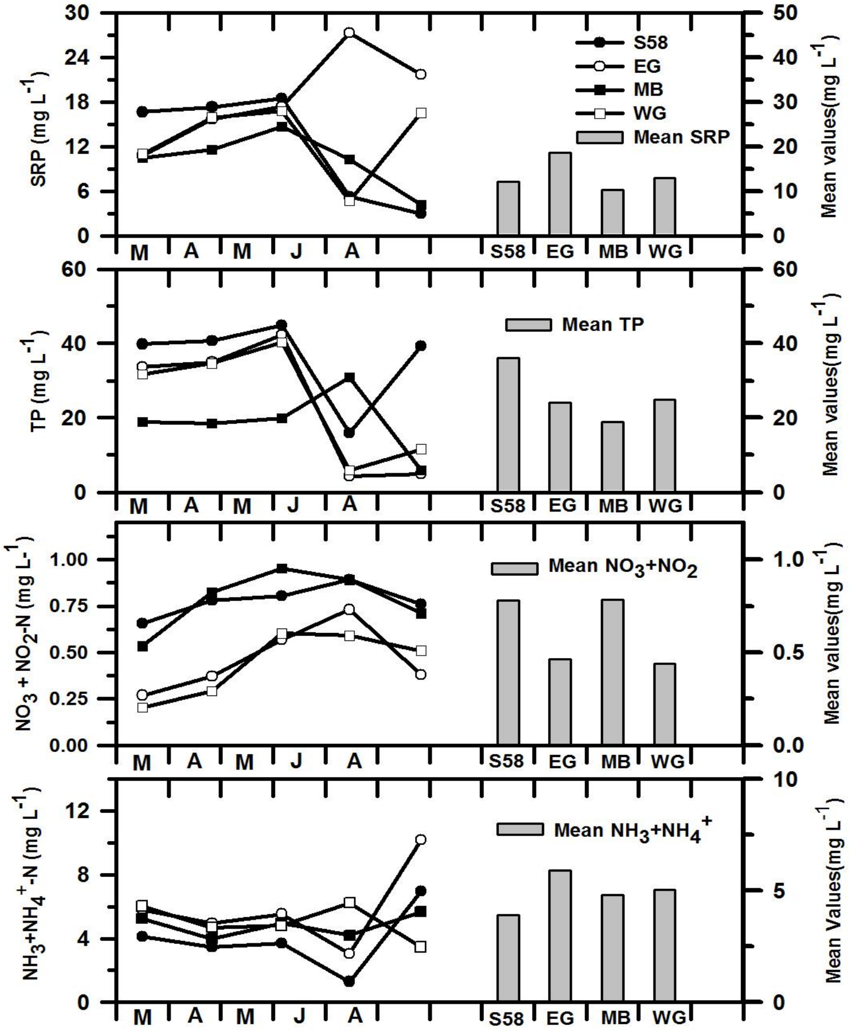

Figure 4. 1 Monthly observations (line plot) and means (bar plot) of inorganic nutrients at the four sampling sites along the course of Akaki River:S58-Saris 58, EG-Echu Gebere, MB-Mekane Biruh, WG-Were Geno.

The mean pH values recorded in the present study varied significantly among sampling sites (p=0.04) ranging from a minimum of 7.49 at Echu Gebere site to a maximum of 7.89 at the Were Geno Site (Table 4.1). Electrical conductivity (EC) varied significantly among sampling sites (p=0.018, Table 4.1), while ranging from 166.92 µS cm^{-1} at the Mekane Biruh sampling site to

254.10 µS cm^{-1} at the Saris 58 site of the present study on Akaki Rivers. The mean TDS values(mg L^{-1}) varied from 1174 to 1473, with the lowest and highest values occurring at Were Geno and Saris 58 sites, respectively, although there was no significant difference(p=0.378) among sampling sites of the present study. Although the difference in the level of TSS among sampling sites was also not significant (p=0.134, Table 4.1), mean TSS values(mg L^{-1}) ranged from the lowest value of 580 at the Mekane Biruh site to the highest value of 744.80 at the Saris 58 site. The mean turbidity values(NTU) varied between 228.60 at the Saris 58 site and 508.40 at the Mekane Biruh site although the differences in turbidity levels among sampling sites of the present study period were not statistically significant (p=0.471).

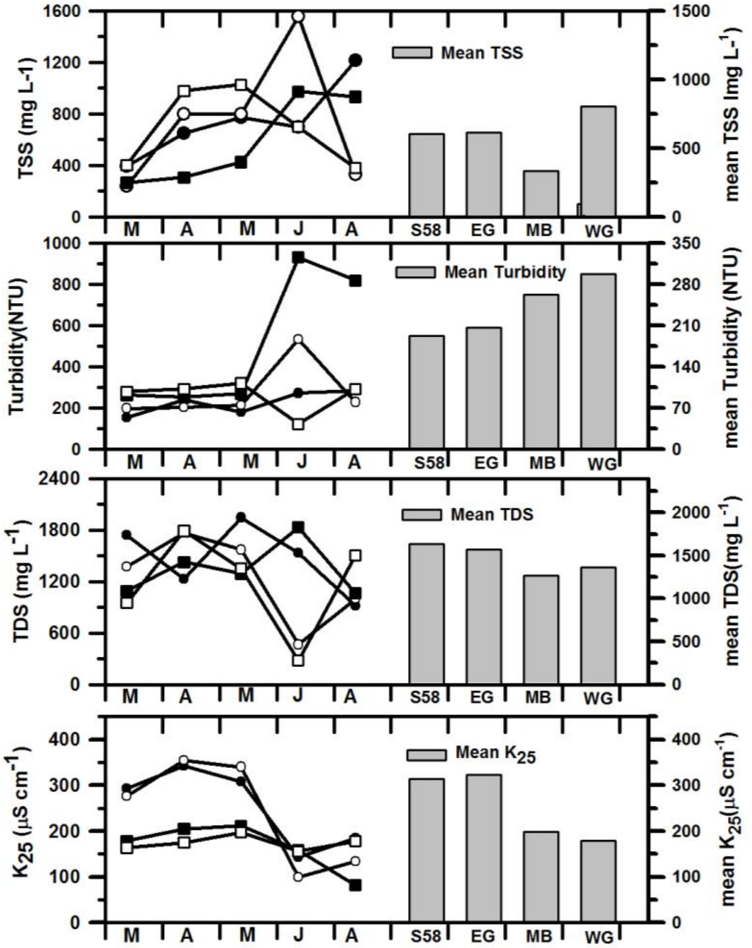

Figure 4. 2 Monthly observations(line plot) and means (bar plot) of Total Suspended solids(TSS), Turbidity, Total Dissolved Solids(TDS) and Specific conductance(K25) of the four sampling sites along the course of Akaki River. S58-Saris 58, EG-Echu Gebere, MB-Mekane Biruh, WG-Were Geno.

The level of mean water temperature measured at the study sites ranged from 20.18 °C at the Saris 58 Site to 21.32°C at the Mekane Biruh site(Table 4.1), with significant difference among sampling sites (p=0.022, Table 4.1). The level of mean dissolved oxygen (DO) concentration, which exhibited significant spatial variations (p=0.002, Table 4.1), ranged from 2.73 mg L^{-1} at the Saris 58 site to 3.14 mg L^{-1} at the Were Geno Site. Mean BOD_5 (mg L^{-1})varied from 47.83 at the Mekane Biruh site to 69.91 at the Were Geno site, while mean COD values ranged from the minimum value of 66.17 at the Mekane Biruh to the maximum of 430.57 at the Saris 58site, with significant spatial variations in both BOD and COD (p=0.005 and p=0.018, respectively).

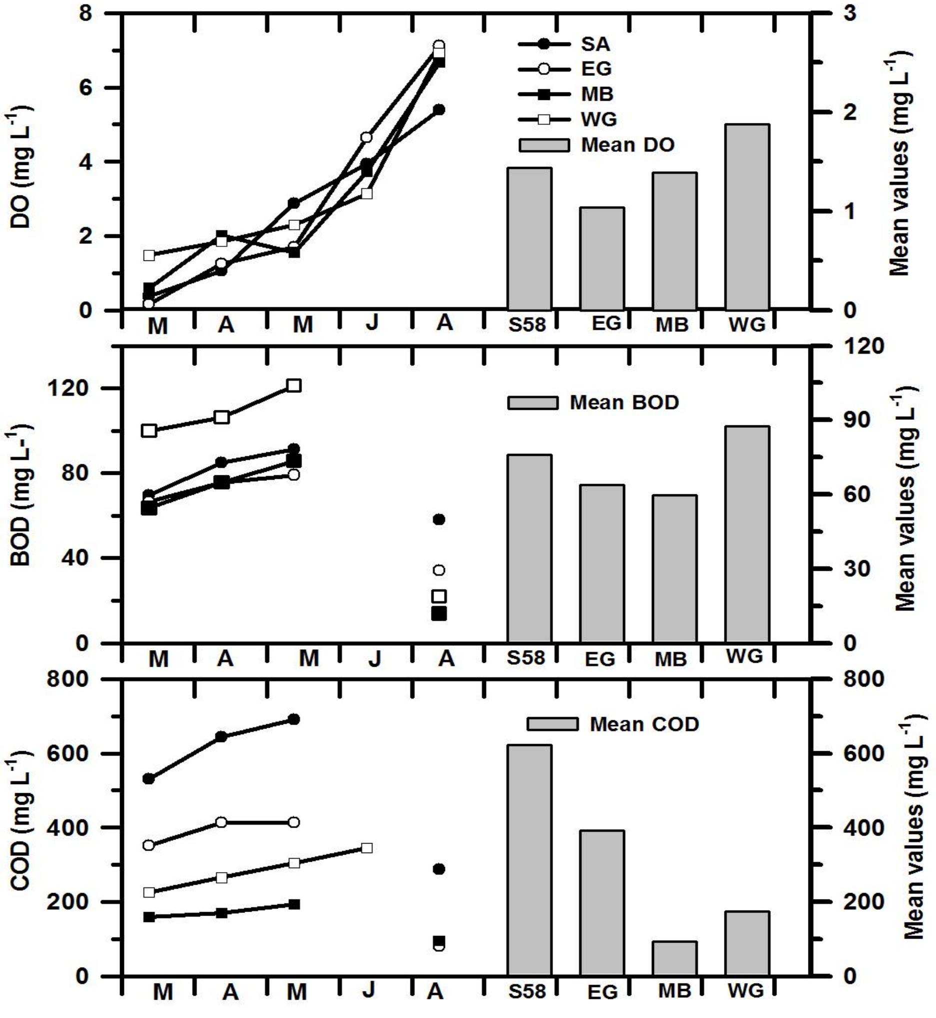

Figure 4. 3 Monthly observations (line plot) and means (bar plot) of Dissolved oxygen(DO), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand(COD) at the four sampling sites along the course of Akaki River S58-Saris 58, EG-Echu Gebere, MB-Mekane Biruh, WG-Were Geno.

4.1.2 Spatial variations in the counts of indicator microbes in Akaki Rivers during the study period.

Table 4. 2 Counts of Indicator microbes: mean ± standard deviation

Indicator microorganisms	Saris 58	Echu Gebere	Mekane Biruh	Were Geno	Kruskal Wallis Test at 0.05
TC_{water}	6.754±1.41	6.672±1.34	6.342±1.80	6.312±1.95	0.007
TC_{soil}	4.77±4.37	4.648±4.26	4.624±4.24	4.882±4.47	0.001
FC_{-water}	3.72±0.26	3.588±0.30	3.550.336±	3.786±0.21	0.003
FC_{soil}	2.182±2.01	2.096±1.93	2.188±2.02	2.256±2.07	0.001

Mean of the log-transformed counts of total coliforms in water, TC_{water}, (log CFU ml^{-1}) ranged from the lowest value of 6.312 for the Were Geno site to the highest of 6.754 for Saris 58 site, with significant spatial variations (p=0.007, Table 4.2). The mean counts of TC_{water} were closely similar for Saris 58 and Were Geno and also for Echu Gebere and Mekane Biruh. The TC counts, however, varied more temporally than spatially, with the lower counts consistently occurring during the months of the major rainy period (July-August) at all sampling sites. Whereas, the log transformed mean value of TC_{soil} (log CFU ml^{-1}), which differed significantly among sampling sites (p=0.001, table 4.2), varied from 4.624 of Mekane Biruh to 4.882 of Were Geno site.

The mean value of TC(in log CFU ml^{-1}) in soil samples was highest (8.10) for the Saris 58 site, and lowest(3.49) for the Were Geno sampling site. The TC counts increased consistently from their lowest levels in March to their highest in May at all sampling sites except Were Geno for which the unexpectedly lowest level was recorded in May. It is interesting to note that despite the noticeable difference in their location, the upper three sampling sites had mean TC counts, which were closely similar (Fig. 4.4).

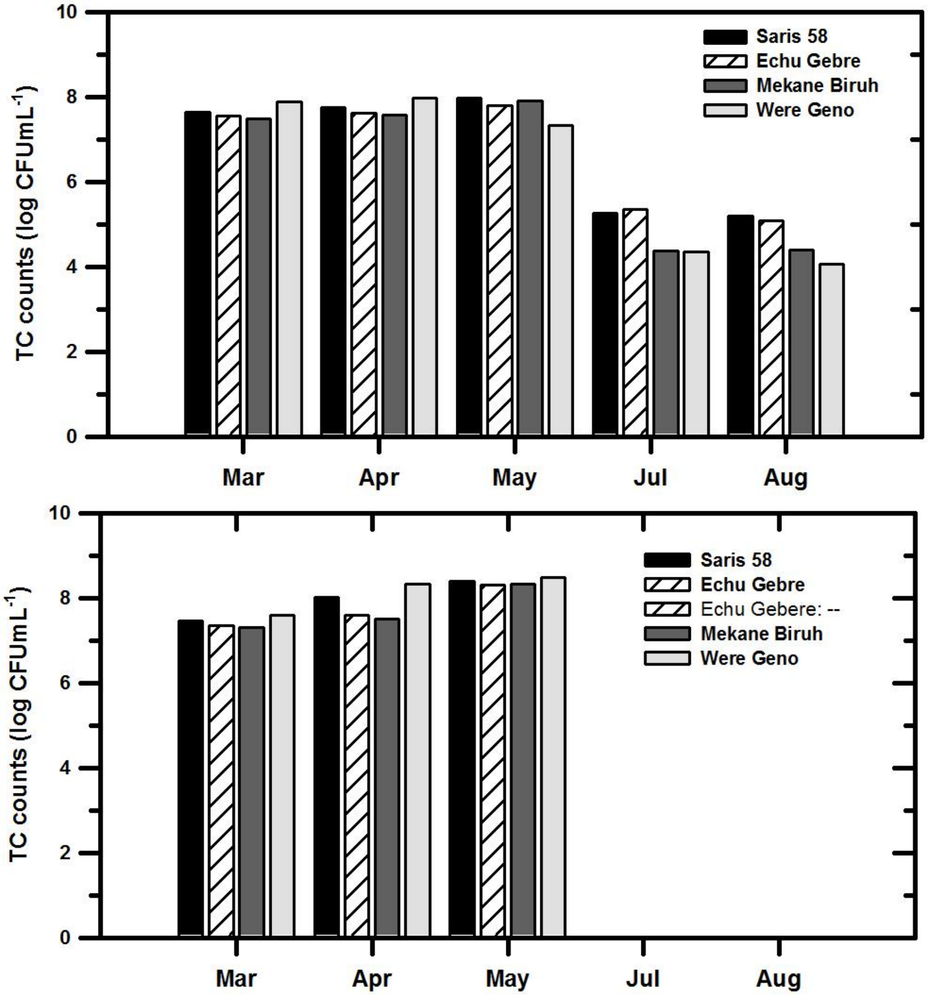

Figure 4.4 Figure 4. 4 Counts of Total coliforms (TC) in irrigation water(above) and irrigated soil(below) at the four sampling sites of the present study on Akaki River.

The mean log transformed counts of faecal coliforms in water, FC_{wate}r [log CFU (100ml)$^{-1}$] ranged from 3.55 for the Mekane Biruh site to the highest of 3.786 for the Were Geno site, with significant spatial variations (p=0.003, table 4.2). The log transformed mean value of FC_{soil} [log CFU (100ml)$^{-1}$], which differed significantly among sampling sites (p=0.001, table 4.2), varied from 2.96 of Echu Gebere site to 2.256 Were Geno site.

The lowest level of FC [log CFU (100ml)$^{-1}$] was recorded in May, while the highest was documented for April at all sampling sites. Levels of mean concentration (log CFU (100ml)$^{-1}$) of faecal coliforms in water samples collected from Akaki River varied from 3.70 of Mekane Biruh site to 3.91 of Were Geno site and with intermediate values occurring at the other two sites. The FC count in soil samples (log CFU $(100ml)^{-1}$) varied temporally in a pattern similar to that of FC count in water, with the lowest and highest counts occurring in May and April, respectively. The lowest FC counts were recorded for Echu Gebere site, while the highest was observed for Were Geno site, a spatial pattern, which is similar to that of FC counts of water samples (fig. 4.5).

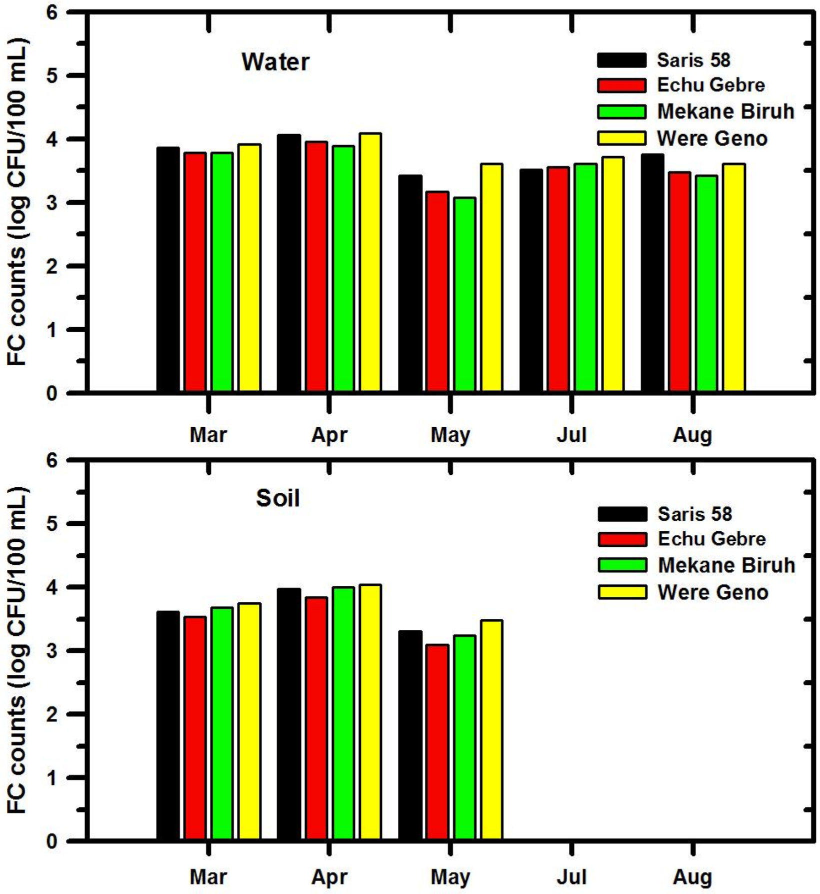

Figure 4. 5 Counts of Fecal coliforms (FC) in irrigation water(upper) and irrigated soil(lower) at the four sampling sites of the present study on Akaki River.

4.1.3 Spatial variations in the concentrations of heavy metals in Akaki River water, soil and vegetables.

All heavy metals except Cadmium in all samples and Lead in samples from Were Geno, were detectable in Akaki River water during the months of the minor rainy period. The concentrations(mg L^{-1}) of Fe varied from 5.77 to 12.39, while those of Cr ranged from 2.57 to 3.1. The lowest and highest levels(mg L^{-1}) of Cu were 0.44 and 2.81, while those of Zn were 1.62 and 2.6, respectively. Mn varied from 0.8 to 1.6, whereas Ni ranged from 1.18 to 1.26. Pb was as high as 0.91 mg L^{-1} when it was detectable. During the major rainy period, the levels of all metals except Fe and Mn in Akaki river water collected from all sampling sites were found to be below the detection limit of the method of analyses. Fe and Mn varied from 2.51 at Echu Gebere site to 11.5 at Saris 58 site and from 0.41 at Mekane Biruh site to 0.75 at Were Geno site, respectively.

During the minor rainy season, all analyzed heavy metals were detected in the soil samples collected at all study sites. Mn had the highest concentrations (mg kg^{-1} dwt) of all analyzed metals, with its values varying from 1185 of Were Geno to 1864 of Echu Gebere. The concentrations(mg kg^{-1}) of Zn varied from 84.03 of Were Geno to 402.4 of Saris 58, while those of Fe ranged from 140.39 of Saris 58 to 244.02 of Echu Gebere. The levels(mg kg^{-1}) of Ni ranged from 116.2 of Mekane Biruh to 208.66 of Saris 58, while those of Cr varied from 48.89 of Saris 58 to 142.64 of Echu Gebere. The lowest and highest concentrations(mg kg^{-1}) of Pb were 65.28 of Were Geno and 128.52 of Echu Gebere, respectively. Cu, whose concentrations were generally the second lowest, had levels that varied from 24.14 of Saris 58 to 52.18 of Echu Gebere(52.18). Cd had the lowest concentrations, with recorded values varying from 4.12 of Were Geno to 6.76 of Echu Gebere. The maximum concentrations of most heavy metals were detected in samples from Echu Gebere site, while those of Zn and Ni were measured in samples collected from the Saris 58 sampling site; Most heavy metals (except Cd and Ni) were detectable in the soil samples collected from all study sites during the main rainy season. Thus, the concentration of Fe was highest at Were Geno (≈4853) and lowest at Mekane Biruh (≈3910.4), while that of Mn was lowest and highest in samples from Echu Gebere (≈109.9) and Saris 58(158), respectively. The third most abundant heavy metal was Cr, which varied between 37.9 at Were Geno and ≈70.8 at Echu Gebere. Zn was the fourth most abundant metal (≈5.74-8.25), followed by Pb(≈4-5.2) and Cu(≈ 1.7-2.4), with the highest and lowest concentrations of Zn and Cu occurring in samples from Mekane Biruh and Were Geno, respectively. The highest and lowest levels of Pb, however, occurred in samples from Saris 58 and Mekane Biruh, respectively.

In samples collected during the minor rainy season, Fe occurred at the highest levels in Lettuce(mean=1638 mg /kg dwt^{-1}) samples at all study sites, while Zn was the second most abundant heavy metal in Kale(mean=498.81 mg /kg dwt^{-1}), Lettuce(mean=370.94 mg /kg dwt^{-1}) and Swiss Chard(355 mg /kg dwt^{-1}) samples. The mean concentration(mg kg^{-1} dwt) of Fe was highest in Swiss Chard(348.50) and lowest in Kale(321.50), while that of Zn was highest in Kale (498.81), and lowest in Swiss Chard(355). The maximum concentration of Mn was recorded for Lettuce(238.94), while the minimum was observed for Kale(73.94). The concentrations of Ni in the tested vegetables were closely similar, with recorded values varying from 193.56 of Kale to 211.7 of Lettuce. Cu had similarly low levels in Lettuce(10.82) and Swiss Chard(10.09) although its level in Kale(140.86) was quite high. Cr had concentrations that varied between 10 and 15 mg kg dwt with the highest in Swiss Chard(14.52 Pb and Cd had the lowest concentrations of all metals with their maxima occurring in Lettuce (5.71)and Swiss Chard(1.27), respectively. During the main rainy season, Fe occurred at the highest levels in Lettuce (mean ≈521 mg /kg dwt^{-1}) samples at all study sites, while Mn was the second most abundant heavy metal in all Lettuce (mean ≈16.5mg /kg dwt^{-1}**)** and Swiss Chard (mean ≈13.9 mg /kg dwt^{-1}) samples except in the Swiss Chard sample obtained from Saris 58 where its concentration(≈ 2.2 mg /kg dwt^{-1}) was surpassed by that of Zn(≈3.6 mg /kg dwt^{-1}). Although the highest levels of Fe and Mn were measured for either Swiss chard or Lettuce samples, the lowest levels of both heavy metals were always recorded for Kale samples. Zn was the third most abundant heavy metal in all vegetables collected from all sampling sites(mean≈3-4.6mg /kg dwt^{-1}) apart from the Swiss Chard samples from Echu Gebere (≈4.3 mg /kg dwt^{-1}) and Mekane Biruh (≈3.2 mg /kg dwt^{-1}) and Lettuce sample from Echu Gebere (≈16 mg /kg dwt^{-1}) in which its concentrations were exceeded by those of Cr (≈4.6, 3.7 and 23.6 mg/kg dwt^{-1}, respectively). Cr was more often detectable than Cd, Pb and Ni and occurred at much higher concentrations than those of Cd, Pb, and Ni. Pb, when its concentrations were detectable, often occurred in Swiss Chard and seldom in Lettuce. The measurable concentrations of Cd and Ni were almost always below 1 mg /kg dwt^{-1}.

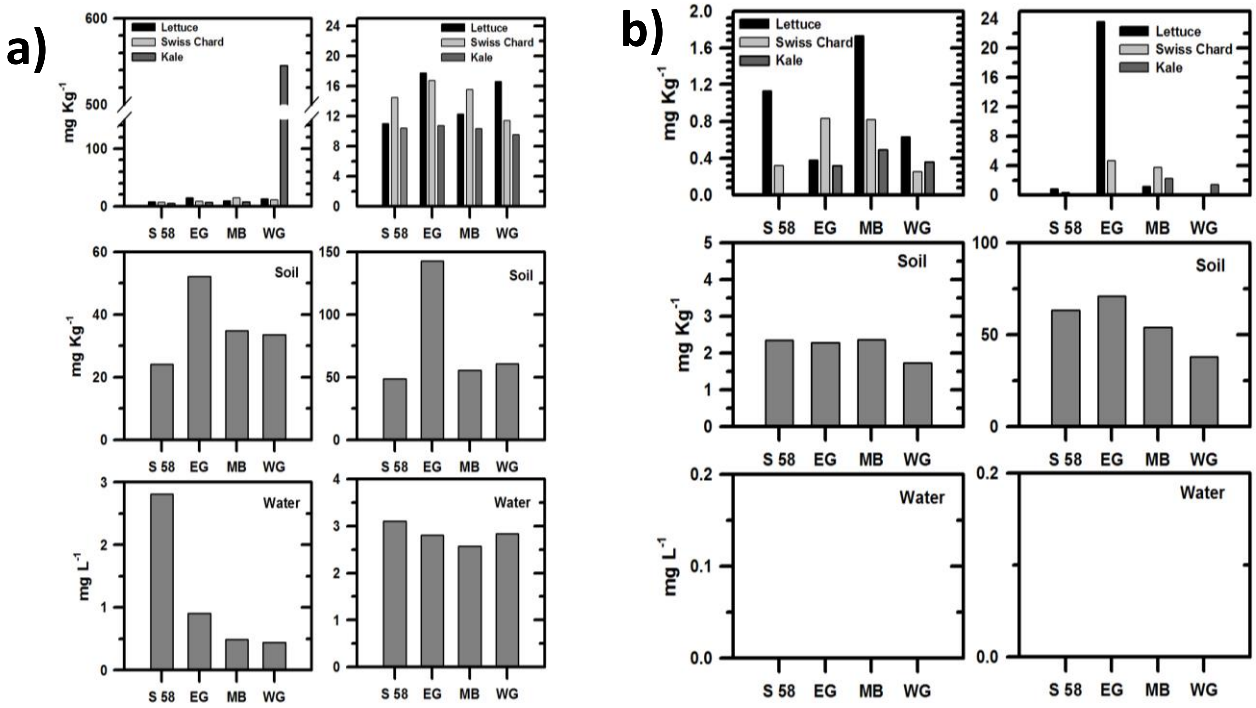

Figure 4. 6 Levels of Copper(left) and Chromium (right) in irrigation water, irrigated soil and leafy vegetables (Lettuce, Swiss Chard and Kale) at the four sampling sites: S 58-Saris 58, EG-Echu Gebere, MB-Mekane Biruh, WG-Were Geno. Missing data points on the plots correspond to concentrations less than 0.1 mg L^{-1} or mg Kg^{-1}dwt (a) minor rainy season and; b) main rainy season.

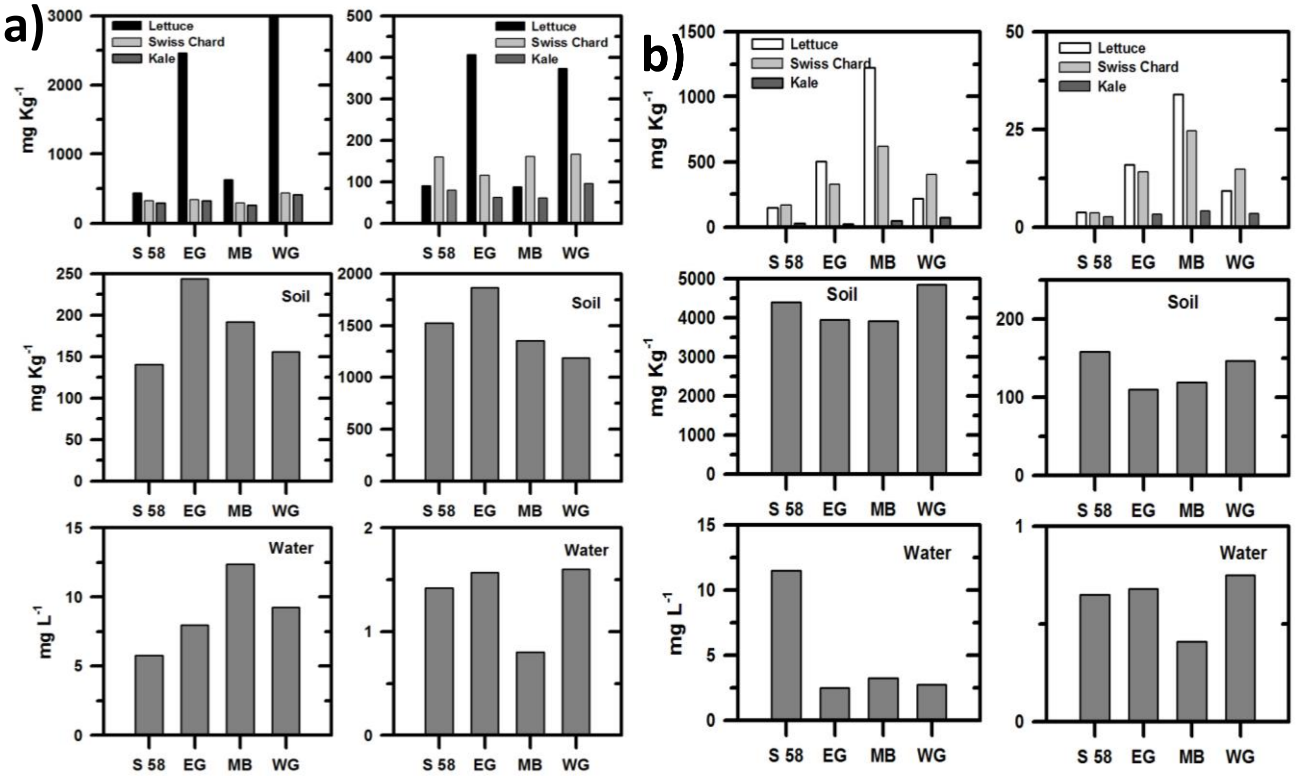

Figure 4. 7 Levels of Iron(left) and Manganese (right) in irrigation water, irrigated soil and leafy vegetables (Lettuce, Swiss Chard and Kale) at the four sampling sites: S 58-Saris 58, EG-Echu Gebere, MB- Mekane Biruhe, WG-Were Geno. Missing data points on the plots correspond to concentrations less than 0.1 mg L^{-1} or mg Kg^{-1}dwt for (a) minor rainy season and; b) main rainy season

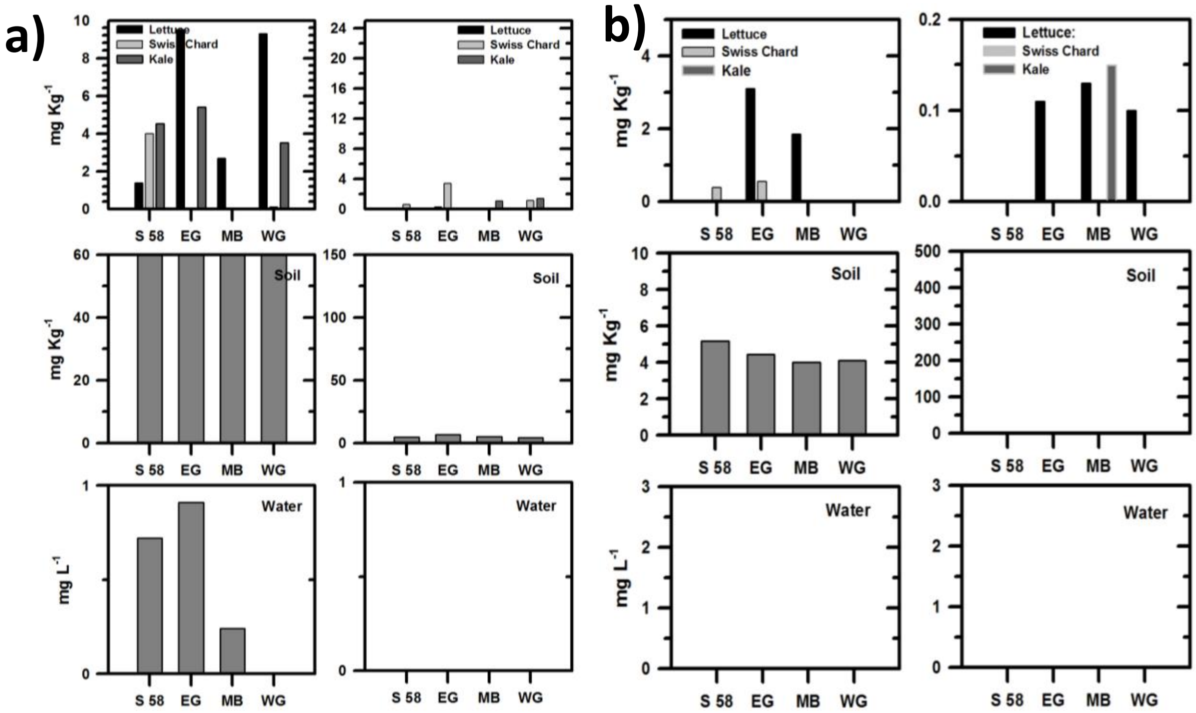

Figure 4. 8 Levels of Lead (left) and Cadmium (right) in irrigation water, irrigated soil and leafy vegetables (Lettuce, Swiss Chard and Kale) at the four sampling sites in Akaki River. S 58-Saris 58, EG-Echu Gebere, MB-Mekane Biruh, WG-Were Geno. Missing data points on the plots correspond to concentrations less than 0.1 mg L^{-1} or mg Kg^{-1} (a) minor rainy season and; b) main rainy season)

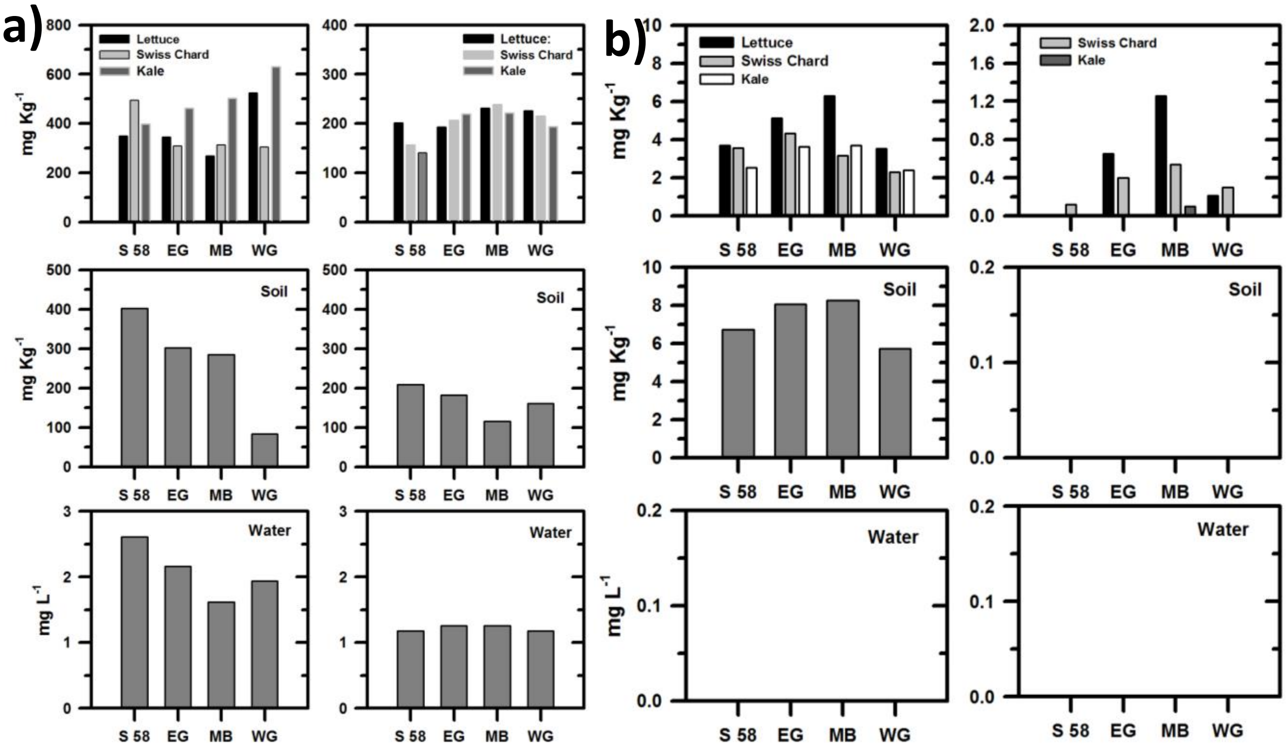

Figure 4. 9 Levels of Zinc (left) and Nickel (right) in irrigation water, irrigated soil and leafy vegetables (Lettuce, Swiss chard and Kale) at the four sampling sites along the course of Akaki River. S 58-Saris 58, EG-Echu Gebere, MB-Mekane Biruh, WG-Were Geno. Missing data points on the plots correspond to concentrations less than 0.1 mg L-1 or mg Kg-1 (a) minor rainy season and b) main rainy season

Bio-transferable factor (BTF)

Table 4. 3 Soil-plant transfer factor (TF) of vegetables collected during the minor rainy season

Sampling site	**Vegetables**	**TF_{Cu}**	**TF_{Fe}**	**TF_{Mn}**	**TF_{Zn}**	**TF_{Cd}**	**TF_{Cr}**	**TF_{Ni}**	**TF_{Pb}**
Saris 58	Swiss Chard	0.268	2.329	0.105	1.229	0.125	0.296	0.749	0.058
	Kale	0.194	2.080	0.052	0.992	0.000	0.212	0.672	0.066
	Lettuce	0.293	3.125	0.059	0.869	0.000	0.225	0.965	0.020
,Echu Gebere	Swiss Chard	0.163	1.388	0.062	1.019	0.499	0.117	1.126	0.000
	Kale	0.124	1.338	0.033	1.526	0.000	0.075	1.196	0.042
	Lettuce	0.275	10.076	0.218	1.134	0.034	0.124	1.055	0.074
Mekane Biruh	Swiss Chard	0.406	1.530	0.119	1.098	0.002	0.280	2.049	0.000
	Kale	0.209	1.343	0.045	1.765	0.207	0.186	1.909	0.000
	Lettuce	0.255	3.265	0.064	0.940	0.031	0.221	1.987	0.030
Were Geno	Swiss Chard	0.336	2.788	0.140	3.615	0.272	0.187	1.336	0.002
	Kale	16.235	2.632	0.080	7.513	0.333	0.157	1.200	0.054
	Lettuce	0.386	19.427	0.314	6.224	0.000	0.272	1.400	0.142

The soil-plant transfer factor for heavy metals whose concentrations were always measurable in soil samples of the minor rainy season (Fe, Cu, Zn, Mn, Pb, Cr, Ni and Cd) was found to vary from 0 of Pb in Kale(Mekane Biruh), and Swiss Chard(Echu Gebere and Mekane Biruh), Cd in Kale(Saris 58, Echu Gebere), and Lettuce(Saris 58 and Were Geno) to about 19.427 of Fe in Lettuce of Were Geno site. Among the vegetables, Lettuce had the highest soil-plant transfer factor of nearly all measurable heavy metals, while Kale was associated with the lowest soil-plant transfer factor of most measurable heavy metals.

Table 4. 4 Soil-plant transfer factor (TF) of vegetables collected during the main rainy season.

Site	**Vegetables**	**TF_{Fe}**	**TF_{Cu}**	**TF_{Zn}**	**TF_{Mn}**	**TF_{Pb}**	**TF_{Cd}**	**TF_{Cr}**	**TF_{Ni}**
Saris 58	Swiss Chard	0.038	0.137	0.531	0.014	0.073	0	0.005	0
	Kale	0.006	0.000	0.374	0.014	0.000	0	0.000	0
	Lettuce	0.034	0.483	0.548	0.044	0.000	0	0.013	0
Echu Gebere	Swiss Chard	0.083	0.364	0.537	0.129	0.121	0	0.065	0
	Kale	0.006	0.140	0.448	0.030	0.000	0	0.000	0
	Lettuce	0.127	0.167	0.637	0.145	0.697	0	0.333	0
Mekane Biruh	Swiss Chard	0.158	0.347	0.383	0.207	0.000	0	0.069	0
	Kale	0.013	0.208	0.445	0.034	0.000	0	0.041	0
	Lettuce	0.312	0.733	0.762	0.285	0.460	0	0.020	0
Were Geno	Swiss Chard	0.083	0.145	0.415	0.101	0.000	0	0.000	0
	Kale	0.015	0.209	0.415	0.023	0.000	0	0.036	0
	Lettuce	0.045	0.366	0.613	0.063	0.000	0	0.000	0

The soil-plant transfer factor for heavy metals whose concentrations were always measurable in soil samples (Fe, Cu, Zn, Mn, Pb and Cr) during the main rainy season was found to vary from 0 of Pb in Kale from all sites and lettuce from Saris 58 and Were Geno and Swiss Chard from Were Geno and Echu Gebere to about 0.762 of Zn in Lettuce from Mekane Biruh site. Among the vegetables, Lettuce had the highest soil-plant transfer factor of all measurable heavy metals, while Kale was associated with the lowest soil-plant transfer factor of all measurable heavy metals.

Vegetable Consumption-Associated Health risk Estimation

Table 4. 5 THQs estimated for each leafy vegetable collected from each sampling site during the minor rainy season.

Heavy Metals	THQs for each leafy vegetable collected from each sampling site											
	Saris 58			**Echu Gebere**			**Mekane Biruh**			**Were Geno**		
	Swiss Chard	Kale	Lettuce	Swiss Chard	Kale	Lettuce	Swiss Chard	Kale	Lettuce	Swiss Chard	Kale	Lettuce
Cu	1.574	1.137	1.719	2.059	1.566	3.480	3.429	1.770	2.159	2.739	132.357	3.150
Fe	4.538	4.052	6.089	4.701	4.531	34.121	4.077	3.577	8.698	6.030	5.693	42.018
Mn	110.673	54.643	62.622	80.143	43.020	281.888	111.888	41.806	60.194	115.357	65.745	258.469
Zn	16.020	12.920	11.317	9.998	14.968	11.123	10.127	16.280	8.670	9.836	20.440	16.935
Cd	5.634	0.000	0.000	32.737	0.000	2.234	0.097	10.394	1.554	10.880	13.309	0.000
Cr	0.094	0.067	0.071	0.108	0.069	0.115	0.100	0.067	0.079	0.074	0.062	0.107
Ni	75.912	68.155	97.794	100.115	106.260	93.748	115.634	107.746	112.171	104.599	93.889	109.601
Pb	11.074	12.573	3.802	0.000	14.988	26.367	0.000	0.000	7.466	0.278	9.742	25.784

During the minor rainy season, most of the highest THQ values estimated for all vegetables collected from all sites were associated with Ni(68.155-115.634). Mn, whose THQ values were generally closely similar to those of Ni, had THQ values that exceeded those of Ni in Swiss Chard from Saris 58(110.673) and Were Geno (115.357) and Lettuce from Echu Gebere (281.888) and Were Geno(258.469). The highest THQ estimates for Ni and Mn were associated, respectively, with Lettuce and Swiss Chard, while their lowest were associated with Kale samples. The THQ values of Zn (8.67-20.44) generally exceeded those of Fe and Cu although they were consistently much lower than those of Ni and Mn. Pb also had THQ values, which ranged from 0.0 to 26.367, generally exceeding those of Fe and Cu. Fe had THQ values (3.57-42.018), which were consistently higher than those of Cu estimated for all vegetables from all sampling sites except the Kale sample from Were Geno(132.357). Cd had estimates of THQ values (0.0-32.737), which were at times higher than those of Fe and Cu. The THQ estimates for Cr were always much lower than 1(0.062-0.115) often approaching 0.

Table 4. 6 THQs for each leafy vegetable collected from each sampling site during the main rainy season

Heavy Metals	THQs for each leafy vegetable at each sampling site											
	Saris 58			Echu Gebere			Mekane Biruh			Were Geno		
	Swiss Chard	Kale	Lettuce	Swiss Chard	Kale	Lettuce	Swiss Chard	Kale	Lettuce	Swiss Chard	Kale	Lettuce
Fe	2.296	0.386	2.054	4.544	0.312	6.944	8.549	0.697	16.948	5.558	0.979	3.000
Cu	0.078	0.000	0.274	0.202	0.078	0.092	0.199	0.119	0.420	0.061	0.087	0.153
Zn	0.115	0.081	0.119	0.140	0.117	0.166	0.102	0.119	0.204	0.077	0.074	0.114
Mn	1.561	1.561	4.829	9.832	2.304	11.074	17.049	2.817	23.522	10.262	2.352	6.404
Pb	1.055	0.000	0.000	1.499	0.000	8.604	0.000	0.000	5.107	0.000	0.000	0.000
Cd	0.000	0.000	0.000	0.000	0.000	1.069	0.000	1.457	1.263	0.000	0.000	0.971
Cr	0.002	0.000	0.005	0.030	0.000	0.153	0.024	0.014	0.007	0.000	0.009	0.000
Ni	0.058	0.000	0.000	0.194	0.000	0.316	0.262	0.049	0.627	0.146	0.000	0.102

THQ of Fe was almost always associated with the highest THQ values (0.386 - 16.948) estimated for all vegetables collected during the main rainy season from all sampling sites. A closely related element, Mn, had THQ values (1.561 - 23.522), which were almost always the second largest for all vegetables collected from all sampling sites. The highest THQ estimates for Fe and Mn were associated with Lettuce samples. Cu and Zn had estimates of THQ (0.0 - 0.42 and 0.074 - 0.204, respectively), which were much lower than those estimated for Fe and Mn, but were still considerably higher than those of other measurable metals. The THQ values of Cr and Ni were less than 0.5, often approaching 0, except the single value (0.627) estimated for Lettuce samples collected for Mekane Biruh. The THQ of Cd was generally estimated at 0 although values approaching or surpassing 1 were recorded for Lettuce samples collected from Echu Gebere, Mekane Biruh and Were Geno and for Kale sample collected from Mekane Biruh. Although the THQ values of Pb for most vegetable samples were estimated at 0, levels between 1 and 9 were recorded for Swiss chard and Lettuce samples, with the higher values (about 5.1 and 8.6) for the latter.

5. DISCUSSION

5.1 Spatial variations in physico-chemical water quality parameters of Akaki River

The concentrations of TP in mg L^{-1}, which ranged from 18.81 at Mekane Biruh to 36.09 at Saris 58, greatly surpassed the maximum permissible limits set by the European Union (EU, 1980; 6.1 mg L^{-1}) and (WHO, 2004; 10 mg L^{-1}, Table 5.2).

The unusually high total phosphorous concentration at Saris 58 may have originated from urban waste discharges, sewage effluents, agricultural run-off (i.e., mainly from fertilizers), and slaughterhouse wastes of Kera. Phosphate and nitrate typically have short residence times in the water column after entering the river, primarily due to uptake by phytoplankton, but in the case of phosphate, adsorption to particulate matter and subsequent sedimentation is also an important net loss factor (Jarvie *et al*., 2000). Such behavior explains the discrete concentration peaks for nitrate and phosphate (Table 5.2), with a reduction in the carry-over to the immediate downstream sampling sites.

The concentration of PO_4^{3-} which ranges from 2.99 at Were Geno to 10.25 at Mekane Biruh in mg L^{-1} along the Big Akaki sites), also exceeded the guideline value (0.35 mg L^{-1}) set for drinking water by WHO, (2004) and European Community (EU, 1980). When compared with the phosphate values reported for Tinishu Akaki River in Ethiopia (0.15-7.8 mg L^{-1}) by Samuel Melaku *et al.*,(2007) and for Gilgel Abay River (0.15 to 7.8 mg L^{-1}) by Yirga *et al*., (2013), even the minimum value of phosphate recorded for Akaki river in this study was found to be considerably higher. Another study made by EPHI and FDRE MoH, (2017) reported phosphate concentrations with a range of 0.0 to 1.4 mg L^{-1} and median of 0.19 mg L^{-1} for Akaki river. The high values of phosphate in this study may have resulted primarily from agricultural runoff, and the continuous entry of domestic sewage. The high concentration levels of phosphate in this highly polluted river water could be attributed to the leaching of N-P-K fertilizer residues from agricultural farms and the use of phosphate additives in detergent formulations, which can be washed into the river system during the disposal of wastewaters generated municipally, domestically or industrially.

According to WHO (2004), the maximum permissible concentration of nitrate for public water supplies is 10 mg L^{-1}. The nitrate levels in all samples surpassed the WHO's guideline value (10 mg

L^{-1}). However, the concentrations of nitrate detected in the water samples are within the guidelines for drinking water quality of the European Community (EU, 1980) 25-50 mg L^{-1}. Yirga Kebede *et al.*, (2016) reported lower nitrate values that ranged from 0.038 to 4.14 mg L^{-1} for Gilgel Abay River, which may be due to the high dilution of the river water; due to the lower level of pollution; vicinity of the river to the city.

Another study made on physico-chemical water quality in the Amhara Region, Ethiopia, by Dagnew Taddese *et al*., (2012) reported relatively low nitrate values, which ranged from a minimum of 0.60 mg L^{-1} to a maximum of 10 mg L^{-1} for Gilgel Abay. Much Lower values of nitrate were also reported for Meki (0.22) and Katar (0.15) rivers by Mekuria Mekonnen, (2014). Another report by EPHI and FDRE MoH, (2017) documented a range of 6.36 to 192.59 mg L^{-1} and higher median value of nitrate (32.20) for Akaki River water. Thus, water quality with respect to nitrate concentrations at the sampling sites of the present study on Akaki River is in agreement with the upper limit of 50 mg/L of Canadian surface water standard and European Union drinking water's maximum permissible limit (CCME, 2001, Reeve, 2002).

Nitrate is generally more stable in aerated water and elevated concentration of nitrate suggests a waste water source further upstream (Hem, 1985). Elevated concentrations of nitrate are more commonly associated with agricultural runoff (Maybek, 1982). The high nitrate levels in this study, however, seem to have resulted from such different sources as domestic and industrial wastes and runoff from agricultural lands over which irrigated cash crops are grown and the use of inorganic fertilizers is rather frequent.

The concentration of nitrite at all sampling sites was above the desirable values recommended by CCME/EU, (2001), WHO, (2004) and EEPA, (2003) (Table 5.2). These high concentrations of nitrite may have originated from the decomposition of nitrogen containing organic compounds such as proteins and urea occurring in industrial and municipal wastewater discharges or human excreta disposed along the course of the river. Moreover, the study by Vega *et al.* (1998) has indicated that in the presence of high levels of organic matter, nitrate can be reduced to some extent to nitrite, which could explain the high concentration of this pollutant in Akaki River. Nitrite is generally unstable in aerated water and its elevated concentration is a potential indicator of waste discharge from nearby sources (Hem, 1985). EPHI and FDRE MoH, (2017) reported nitrite concentrations (mg L^{-1}) that ranged from 0.1 to 4.84, with a median value of 0.34. A study on water quality of Abay

River by Yirga Kebede *et al.*, (2016) reported much smaller concentrations that varied from 0.009 to 1.2 mg L^{-1}. Similarly low concentrations (mg L^{-1}) of nitrite were reported for Meki (0.09) and Katar (0.04) rivers by Mekuria Mekonnen, (2014). The high nitrite levels in the Akaki Rivers during this study is an indication of the higher level of pollution associated with discharges from the nearby manufacturing plants, domestic sources and agricultural activities etc.

The water quality of the river during the present study was found to be poor, with its scores lying between 2.5 and 9 according to the UK water quality criteria (Reeve, 2002) and with the ammonia levels varying from 3.91 to 5.91. When compared with the ammonia values of the previous study on Tinishu Akaki River in Ethiopia (0.4 to 35 mg L^{-1}) reported by Samuel Melaku *et al.*, (2007) and those of Meki(10.79) and Katar(13.87) rivers recorded by Mekuria Mekonnen, (2014), the ammonia concentrations recorded in this study were generally very low and this may be due to the rapid oxidation of ammonia to nitrate in aerated waters. Yirga Kebede *et al.*, (2016) reported considerably lower ammonia concentrations for Abay River, which ranged from 0.02 to 2.6 mg L^{-1}. Higher concentrations of ammonia are more commonly associated with urban wastes (Maybek, 1982). The observed high levels of ammonia might be associated with the leaching of residues of fertilizers used on agricultural farms and of wastes from the growing city of Addis into the river system.

All sampling sites exhibited pH levels that were near neutral to slightly alkaline (7.49 to 7.89), which is the usual range for river water. All the recorded values are within the limits of the guidelines set for livestock watering and irrigation water by various organizations [i.e., 5-9.5(CCME, 2001) and 6.5-9.2(WHO, 2002), and 6.5-8.5(EEPA, 2003) (Table 5.2)]. The present results are similar to those reported in an earlier study (7.3 to 8.9) by Samuel Melaku *et al.*, (2007) on Tinishu Akaki River and 7.42 to 8.18 by Prabu *et al.*, (2010) on Huluka and Alaltu Rivers of Ambo, and Yirga Kebede *et al.*, (2016) on Gilgel Abay River. The results of the study conducted by Yirgaalem Weldegebriel *et al.*, (2012) on Akaki river at Goffa (7.89), Kera (7.54) and Peacock (7.54) areas are similar to those recorded in the current study. The mean pH values of Meki (7.82 & 7.95) and Katar (7.66 & 7.85) rivers, which were reported by Mekuria Mekonnen, (2014); Girum Tamrie and Seyoum Mengistou, (2012), respectively, are also broadly similar to those of the present study. EPHI and FDRE, MoH (2017) also reported pH levels of Akaki River that ranged from a minimum of 5.96 to a maximum of 9.01 averaging 7.87, which are broadly similar to those recorded in the current study.

The high conductivity recorded at Saris 58 during the study period could be due to domestic effluent discharges as it is situated close to Koshe damping site of Addis Ababa and surface run-off from the cultivated fields. All the observed levels of EC are lower than the value recommended for potable water by different organizations (i.e. 400, WHO, 2002; EEPA, 2003) (Table 5.2).

Yirga Kebede *et al*., (2016) reported a broadly similar finding for Gilgel Abay River, in which conductivity varied from a minimum of 22 µS cm^{-1} of the rainy season at Gilgel Abay to a maximum of 292 µS cm^{-1} of the dry season at Damot-Gish. When compared with conductivity of Densu River in Ghana (273-402 µS cm^{-1}; Karikari and Ansa-Asare, 2006), Meki and Katar Rivers (328.33 - 575.36 µS/cm; Mekuria Mekonnen, (2014), Meki River water (450.6 µS/cm) and Katar River water (424.5µS/cm) reported by Girum Tamrie and Seyoum Mengistou, (2012), the conductivities of Akaki Rivers were found to be considerably lower. EPHI and FDRE, MoH (2017) also reported EC values for the water of Akaki Rivers which ranged from 70.2 to 3330, with a median value of 590 µS/cm. The average value of typical, unpolluted river is approximately 350 µS cm^{-1} Koning and Roos (1999). Therefore, this parameter is not the main water quality concern for the river and makes the water suitable for direct domestic use. Generally, high value of EC is related to phenomena of mineralization or weathering of sediments, and largely due to discharge of industrial and domestic wastes (Tamiru Alemayehu, 2001; Samuel Melaku *et al*., 2007).

The turbidity values recorded for Akaki River greatly surpassed the guideline values of both WHO (2004; 5NTU) and the national standard for drinking water (EEPA (2003; < 5NTU). Therefore, turbidity is among the main water quality concerns for Akaki River making the river water unsuitable for direct domestic use. The observed high turbidity may be attributed to the high level of domestic and industrial wastes, and soil erosion associated with the poor farming practices, which result in large quantities of top soil ending up in the river after heavy rains. A similar study made by Yirga Kebede *et al*., (2016) reported turbidity values that ranged from 27.5 NTU at Abay Mouth to a maximum of >1,000 NTU at Bikolo Abay and Abay River. Another report by EPHI and FDRE MoH (2017) on Akaki River recorded levels of turbidity that ranged from 10.3 to 2000 NTU, with a median value of 131.0 NTU during observations made in both the dry and wet seasons.

The mean TDS values, which varied from 1,174 to 1,473 mg L^{-1}, are quite high in comparison with the WHO's guideline value of < 600 mg L^{-1}. In the present investigation, all the TDS values were found to be above the CCME's desirable limit of 500 mg L^{-1} for drinking water. Yirga Kebede *et al*., (2016) reported lower TDS values ranging from 14 to 189 mg L^{-1} for Gilgel Abay River, which may be due to the high dilution owing to the higher water volume of Abay River in contrast to our study river of lower water volume. When compared with the TDS values of Tinishu Akaki River (28- 639 mg L^{-1}) reported previously by Samuel Melaku *et al*., (2007), the present TDS values are considerably higher. Therefore, the present TDS level of Akaki River is among the major concerns as it makes the water unsuitable for direct domestic use according to McCutheon *et al*., (1983). The palatability of water with TDS level less than 600 mg L^{-1} is generally considered to be good whereas water with TDS greater than 1,200 mg L^{-1}, such as that from the present Akaki River, is obviously unpalatable.

The mean TSS values, which varied from about 580 to 744.80 in mg L^{-1} are quite high in comparison with the WHO's, and EEPA'S guideline value of 50 mg L^{-1} (table 5.2). In the present investigation, all the TSS values were found to be above the CCME's desirable limit of 500 mg L^{-1} for drinking water.

Table 5. 1The UK General Quality Assessment (GQA) grades for rivers

GQA grade	Description	BOD (mg/L)	NH_3-N (mg/L)
A	Very Good	2.5	0.25
B	Good	4.0	0.6
C	Fairly Good	6	1.3
D	Fair	8	2.5
E	Poor	15	9
F	Bad	>15	>9

Table 5. 2 Mean concentration of Physico-chemical parameters and the guideline values set by different organizations/agencies.

Physico-chemical parameters	Sampling Sites				Guidelines		
	Saris 58	Echu Gebere	Mekane Biruh	Were Geno	Guideline values (Permissible limits)		
					EEPA (2003)	WHO (2004)	CCME[a] (2001)
Temp	20.18	21.04	21.32	20.42	-	-	15
pH	7.69	7.49	7.59	7.89	6.5-8.5	6.5-9.2	5-9.5
Conductivity	254.10	240.62	166.92	173.96	400	400	
DO	2.73	2.97	2.92	3.14	-	-	5.5-9.5
DO % Saturation	39.66	44.98	35.64	47.46	-	-	-
Turbidity	228.60	276.40	508.40	262.20	<5	<5	-
TP	36.09	24.05	18.81	24.81	5	-	-
SRP	12.13	18.55	10.25	12.99	-	10	0.35-6.1[b]
NO_3^{-}N	30.74	26.24	25.61	21.86	10	10	25-50 drinking water[b]
NO_2^{-}N	46.97	20.13	52.79	22.08	3	3	0.06-0.1
NH_3-N	3.91	5.91	4.82	5.05	0.02-0.025	-	1.37-2.20 For aquatic life
TSS	744.80	744.16	580.67	697.40	50	50	-
TDS	1473.07	1233.20	1339.44	1174.00	-	-	500-1500
BOD5	60.75	51.10	47.83	69.91	<5	50	
COD	430.57	251.35	66.17	123.93	260	250	

[a]CCME: Source: Canadian Council of Ministers for Environment; [b]EU: European Union

The temperature of the water samples analyzed, which was relatively constant during this study, ranged from 20.18 to 21.32°C and was always found to be above the maximum permissible limit (Table 5.2) set by the Canadian Council of Ministers for Environment (CCME, 2001) for community water used as aesthetic object. It is an important parameter in the characterization of natural water bodies and affects the water chemistry such as saturation and concentration of dissolved gases, especially oxygen and determines the rate of chemical reactions, with the rate generally increasing as temperature increases. Different authors have reported higher mean temperatures for Katar River (24.00 and 23. 87 °C by Mekuria Mekonnen, (2014) and Girum Tamrie and Seyoum Mengistou, 2012, respectively) and for Meki River water (23.33 and 26.07 by Mekuria Mekonnen, 2014 and Girum Tamrie and Seyoum Mengistou, 2012), respectively.

The levels of DO recorded at all sites do not fulfill the CCME's guideline for the protection of aquatic life (i.e., 5.5-9.5 mg L^{-1}, Table 5.2). The low DO level, < 4 mg L^{-1}, which may eventually lead to anaerobic conditions causing bad odors at almost all sampling sites, is an indication of the worsening of the water quality. The results of the present study are generally similar to those of the study conducted by Tenagne Addisu, (2009) on the impact of urban storm water runoff and domestic effluent on water quality of Lake Tana (0.79 to 4.63 mg L^{-1}). Similarly low mean DO values of Meki (4.77) and Katar (3.73) were also reported by Mekuria Mekonnen, (2014).

BOD_5 was >15 mg L^{-1} at all sampling sites (Table 5.2), failing to meet the UK general water quality assessment criteria for good water (Table 5.1) and falling under the category Grade F, i.e., bad (Reeve, 2002). These high BOD_5 values at all sampling sites suggest the influx of pollutants through industrial, municipal and domestic sewage at different locations along the course of the rivers. The higher BOD_5 values along with the lower DO accompanied by the continuous input of all kinds of wastes into the rivers exceeded the assimilative (the natural self-purification) capacity of the rivers. This in turn greatly impairs the water quality of the rivers and harms the aquatic life they support. EPHI and FDRE MoH (2017) reported BOD_5, which ranged from 0 to 319.2 mg/L with a median value of 15.54 mg/L in samples collected from Akaki River water.

The mean COD value measured during the study period peaked at Saris 58, which seems to be associated with the discharge of industrial wastes. The report of EPHI and FDRE, MoH, (2017) for Akaki River recorded a much higher median COD value of 169.53 mg L^{-1}, with individual observations ranging from 0 to 738.67 mg L^{-1}.

The spearman correlation at p=0.05 (table 5.3) shows that the physico-chemicals like Conductivity, DO, TP, BOD and COD with the TCwater have strong correlation.

Table 5. 3: Spearman Correlation at p=0.05 of physico-chemical parameters with Indicator microbes

Physicochemical Parameters	Microbial parameters			
	Total Coliform in Water	Total Coliform In Soil	Faecal Coliform in Water	Faecal Coliform in Soil
pH	-0.29872	-0.35955	-0.19496	-0.30346
Conductivity	0.610**	0.669**	0.255079	0.594**
Dissolved Oxygen	-0.651**	-0.570**	-0.502*	-0.771**
Temperature	0.228185	0.220534	0.342406	0.442842
Turbidity	-0.33095	-0.23081	-0.12942	-0.28664
Total Phosphorous	0.634**	0.729**	0.20918	0.494*
Soluble reactive Phosphorous	0.388116	0.429749	-0.13394	0.184104
Nitrate	0.135389	0.092478	-0.07223	-0.14293
Nitrite	-0.08575	-0.12667	-0.36945	-0.24547
Ammonia	-0.11512	-0.10378	-0.03312	-0.10491
Total Suspended Solids	-0.05942	0.036525	-0.155	-0.27033
Total Dissolved Solids	0.374577	0.405658	0.057186	0.311501
BOD_5	0.824**	0.949**	0.248963	0.744**
COD	0.670**	0.693**	0.248868	0.555*

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

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

5.1.2 Spatial variations in indicator microbes in Akaki River

The data on microbial loads showed that all the river water samples were contaminated with high levels of total coliforms (TC), and fecal coliforms (FC). According to the standard, the fecal coliform level must not exceed 1000 counts 100 ml^{-1} for the safe use of wastewater for irrigation of vegetables (WHO, 2004). The mean value of the log transformed TC_{water} count, which varied from 6.312 to 6.754, is higher than that reported previously (3.22-3.87) by EPHI and FDRE, MoH (2017).

The log transformed mean value of TC_{soil} (log CFU (100 ml)$^{-1}$) also varied from 4.624 to 4.88. The highest FC value recorded for Saris 58(4.88) seems to have resulted from such different sources as domestic and industrial wastes and wastes associated with agricultural runoff from the nearby Koshe damping area for which the high count of FC (1.37 -2.57) was previously reported by EPHI and FDRE MoH, (2017). The mean of log transformed counts of faecal coliforms in water (FC_{water}, logCFU/100ml), which varied from 3.55 to 3.786, is higher than that reported previously (2.09) by EPHI and FDRE MoH (2017). The mean log transformed value of FC_{soil} (log CFU/100ml), which also ranged from 2.096 to 256, is higher than that reported by EPHI and FDRE MoH, (2017).

In the present study, higher counts of microbial indicators were recorded from the water and soil samples. This may due to the higher quantities of suspended materials, which provide substrates rich in organic matter for the bacteria (Craige *et al.*, 2004), while decreasing sunlight inactivation and providing protection against predators such as protozoan and bacteriophages (Lee *et al.*, 2006; Friesa *et al.*, 2008).

The microbial load of Ziway water (Log CFU/100ml) reported by Mekuria Mekonnen, (2014) as log-transformed TC (4.11) and FC (3.90) counts is higher than that observed in the present study. Another report by Brihanu Roba, (2008) for same area estimated mean densities (log CFU/100 ml) of TC and FC at 1.90 and 1.72 during dry season, and at 1.68 and 1.43 during the wet season. Goraw Goshu, (2010) also reported TC and FC counts for Lake Tana water, which ranged from 2.4 to 6.3 and 0 to 6.2, respectively.

Mekuria Mekonnen (2014) also reported combined mean counts(log CFU/100 ml) of TC (4.08) and FC (3.86) for water samples from Meki and Katar Rivers, which are comparable with those of a recent report (TC and FC counts of 3.45 and 3.40, respectively) by Brihanu Million, (2008) for Lagabatu River (Central Highland of Ethiopia). Much higher mean FC count (log CFU/100 ml) of 5.17) has also been reported for Baynespruit River, in South Africa by Gemmell and Schmidt, 2012).

Principal component analysis

River water quality data sets were subject to principal component analysis (PCA) (Zhao, 2012). Principal component analysis (PCA) is used to reduce the number of variables and explain the same amount of variance with fewer variables (principal components). PCA analysis has been used after DCA analysis as lengths of gradient is 0.437 which is a less than 3 from DCA analysis. Sites versus physicochemical association were explained by components 1 and 2 (Fig. 5.1), where component 1 discriminates Were-Geno and Mekane-Biruh sites from Saris-58 and Echu-Gebere, with the highest TDS, nitrate, TC water, COD, BOD, TSS, pH, TP, SRP, nitrite; whereas Saris 58 was negatively correlated with DO (fig. 5.1)

Table 5. 4 Principal component analysis

PCA Axes	1	2	3	4	Total variance
Cumulative Parentage variance of data	63.6	86.8	99.3	99.9	
Eigen values	0.636	0.232	0.125	0.007	1.000
Sum of all Eigen values					1.000

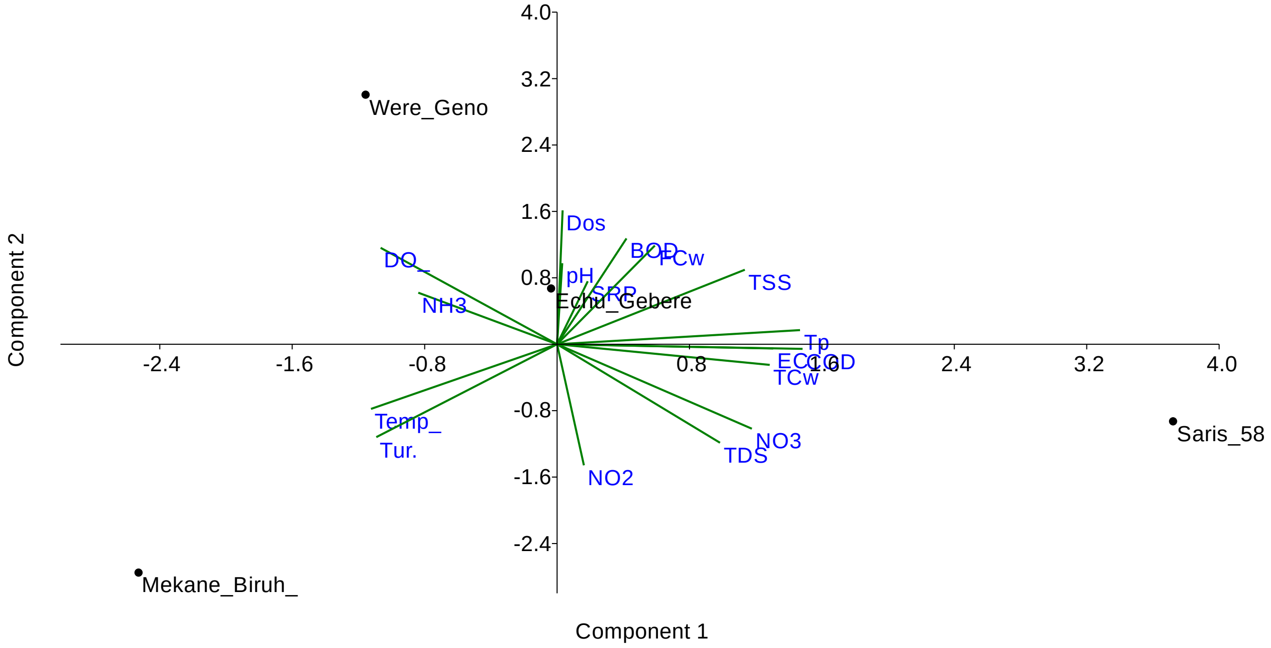

Figure 5. 1 Principal component analysis ordination diagram of the physico-chemical parameters in relation to microbial indicator parameters at study sites

5.1.3 Spatial variations in heavy/trace elements in Akaki River, soil and Vegetables

5.1.3.1 Concentration of heavy metals in irrigation Wastewater

Table 5. 5 Permissible limits (mg L^{-1}) of the concentration of heavy metals in water samples as set by different international organizations.

Sources	**Guideline values for Heavy Metals**							
	Fe	Cu	Zn	Mn	Pb	Cd	Cr	Ni
FAO (1985)	5	0.2	0.2	0.2	0.65	0.01	0.1	1.4
WHO (2004)	3.5	0.5	2	0.2	0.01	0.01	0.01	-
EEPA (2003)	1	0.5	0.03-0.5	0.3	0.05	0.05	0.55	0.1

In this study, Fe was found to have surpassed the maximum permissible limits of EEPA (2003) and FAO (1985) at all sampling sites (Table, 5.5, Appendices 3 and 4). The total iron content of water samples never complied with the WHO's guideline value of 3.5 mg L^{-1} and 1 mg L^{-1} of WHO (2004) and EEPA(2003), respectively (Table 5.5). Therefore, iron is a water quality concern for Akaki River and makes the water unsuitable for direct domestic use. Relatively low iron levels have been reported for Gilgel Abay River by Yirga Kebede *et al.* (2016), 0.1 to 8.8 mg L^{-1}) and Dagnew Tadesse *et al.*,(2012, 0.05 to 0.13 mg L^{-1}) and for Akaki river (0-38.55) by EPHI and FDRE, MoH(2017).

Manganese is also another water quality concern as its levels have surpassed the recommended limit of 0.2 (WHO, 2004) and of 0.3 (EEPA, 2003) (Table 5.5, Appendices 3 and 4). A study by EPHI and FDRE MoH, (2017) reported a median value of 1.06 mg L^{-1}, which was still higher than the permissible level. The concentrations of Mn (in µg L^{-1}) for Akaki river at Akaki(lower segment of a river) (161), Goffa(1414), Kera(804), and peacock(982) were reported by Yirgaalem Weldegebriel *et al*., (2012), while a much higher concentration of 1690 µg L^{-1} was reported for Kera by Fisseha Itana, (1998).

Thus, the river water of all sampling sites used to irrigate the vegetable farms had concentrations of Fe and Mn, which were higher than the maximum levels recommended for irrigation by EEPA

(2003) and FAO (1985). The concentration of Cu (0.44-2.81) observed during the minor rainy season surpassed the maximum levels recommended for irrigation (0.2) by FAO (1985), and that(0.5) set by both WHO(2004) and E EPA(2003)(Table 5.5, Appendix 3), while it was below the detection limit of the method of analysis in samples collected during the main rainy season(Appendix 4). The previously reported levels of Cu for Akaki river at Akaki (24), Goffa(nd), Kera(370 and) Peacock(166) areas by Yirgaalem Weldegebriel *et al*., (2012) are much higher than those observed in the present study; Fisseha Itana(1998) has also reported much higher level of Cu in Bulbula river (12.4) and Kera River(39), while the level of Cu (1.52) reported by Tamiru Alemayehu, (2007) is within the range of values observed in the present study. This might be due to the variation in location of the sampling sites and/or the intensity of industrial activities.

Zinc, whose concentration varied between 1.62 and 2.61) during the minor rainy season, was not detectable in samples collected from all sampling sites during the main rainy season (Appendices 3 and 4, respectively). This may due to be the high dilution during the main rainy period. Studies by Yirgaalem Weldegebriel *et al*. (2012) have reported much higher Zn concentrations for Akaki river at the Akaki(75), Goffa(190), Kera(618) and Peacock(360) sites, while Fisseha Itana (1998) reported moderately high levels for Bulbula (50.37) and Kera (193) area of Akaki river. The level of Zn (14.74) reported by Tamiru Alemayehu,(2007) for Akaki River is considerably higher than those observed in the present study, whereas that(0.12 µg L^{-1}) reported by EPHI and FDRE MoH, (2017) was extremely low suggesting a reduction in the Zn content of the industrial wastes entering the river. Thus, Zn levels observed during the minor rainy period of the present study have surpassed the permissible limits set by various organizations listed in Table 5.5 although it was not detectable during the main rainy season.

Pb levels of the present study (0-0.91) are not consistent with the finding of Yirgaalem Weldegebriel *et al*. (2012). Much lower levels (0-26.22 µg L^{-1}) were, however, recorded for Akaki River by EPHI and FDRE MoH(2017)and Tamiru Alemayehu, (2007). Similarly low levels (µg L^{-1}) of Pb were also reported for Bulbula (14.10) and Kera(33) rivers by Fisseha Itana, (1998).

Cadmium levels which were undetected in this study were reported by Yirgaalem Weldegebriel *et al*., (2012) (µg L^{-1}) for Akaki (18), Kera (33) and Peacock (21) areas. Levels of Cd, which are nearly comparable to those of the present study, were documented for Bulbula (0.07) and Kera (<1.00) rivers by Fisseha Itana (1998) and for Akaki River (0.1 mg L^{-1}) by Tamiru Alemayehu, (2007).

The concentrations of Cr measured in this study (2.57-3.1) surpassed the maximum allowable limit of 0.01 (FAO, 1985; WHO, 2004) and 0.05 (E EPA, 2003) (Table 5.5).

Even though the concentration of Cr was below the recommended maximum limit during the main rainy season, which may be due to high dilution of the river, the main sources of chromium in the river seem to be the leather processing industries as the highest level (3.1) was determined for the sample from Saris 58. Unlike the usual trend of observing high levels of Cr in rivers receiving tannery effluents, Cr in the irrigation water samples collected during the main rainy season was found to be below the recommended maximum concentration limit due to high dilution effect of the flood, which was also reported by Saadia *et al.* (2009).

The results of this study are similar to those obtained by Amare Hailu (2007), who reported that the level of Pb, Cd and Cr around Burayu area were below the detection limit of his method of analysis. Another study by EPHI and FDRE MoH, (2017), however, reported higher concentration of Cr (5.33 mg L^{-1}) for Akaki River. Nickel, which exhibited almost uniform spatial distribution, varied from 1.18 to 1.26 during the minor rainy season, while it was not detectable in samples collected during the main rainy season of this study. Much higher levels of Ni were reported in studies made at Akaki (133), Kera(216) and Peacock (180) areas by Yirgaalem Weldegebriel *et al*., (2012) and also on; Bulbula(2.26) and Kera(8.90).rivers by Fisseha Itana, (1998). Tamiru Alemayehu, (2007) also reported Ni level (1.81 mg L^{-1}) for Akaki River, which is considerably higher than the present concentrations for the same river.

Generally speaking, the differences in heavy metal concentrations between those of present and previous studies are attributable to the differences in the location of sampling points and proximity to the industrial sites. Moreover, the difference in the sampling period may have also contributed to the observed discrepancy in the results obtained as the present study was done only during the minor and major rainy periods, which may have resulted in the dilution of metal concentration.

5.1.3.2 Heavy metals concentration in vegetables farms' soils

Table 5. 6 Guideline values for heavy metals concentration (mg kg^{-1}) for soil samples

	Heavy Metals concentrations (mg kg^{-1})							
	Fe	Cu	Zn	Mn	Pb	Cd	Cr	Ni
Guideline values	5000[b]	100[a]	300[a]	2000[b]	100[a]	3[a]	100[a]	50[a]
Safe limit [C]	-	135-270	300-600	-	250-500	3-6	-	75-150
China	-	40	250	-	-	-	250	250

[a] Ewers, (1991); [b] Pendias and Pendias, (1992); [c] Awashthi (2000)

The present results (Appendices 5 and 6) show that the farm soils were enriched with all analyzed heavy metals during the minor rainy season, whereas they were enriched with only Fe, Mn, Cr, Zn, Pb and Cu during the main rainy season. The concentrations of the heavy metals determined in soil samples collected during the minor rainy season varied spatially. The concentration of Cu, which varied from 24.14 to 52.18), surpassed the 40 mg L^{-1}guideline value of China, while it can be regarded as safe in line with the guideline values of 100 and 135-270 of Ewers (1991) and Awashthi (2000), respectively(Appendices 5 and 6, Table 5.6).

The concentrations of Fe (140.39-244.015) and Mn(1185-1864) are below the acceptable limit set by Pendias and Pendias, (1992) (Table 5.6). Zn had concentrations (84.025-402.4), which were above the 300 and 300-600 mg kg^{-1} set by Ewers(1991)and Awashthi (2000), respectively, while some of its levels were below the China guideline value of 250(Table 5.6).

The concentrations of Cd (4.12-6.76), were above Ewers’s (1991) and Awashthi’s, (2000) guideline values of 3 and 3-6, respectively. The concentrations of Cr (48.64-142.64) were above the guideline value of 100 of Ewers (1991), but below 250 of China (Table5.6).

Levels of Ni (116.2-208.66) and Pb (65.28-128.52) were found to be below the permissible limit of Ewers (1991) and Pendias and Pendias (1992) (Table, 5.6). During the major rainy period, levels of

Fe(3910.39-4852.99), Cu(1.72-2.36), Zn(5.74-8.25), Mn(109.94-158), Pb(4-5.18), and Cr(37.9-70.79) were considerably lower than the standard or guideline values (Ewers, 1991; Pendias and Pendias, 1992; Awashthi, 2000) set for soils used for the irrigation of crops/vegetables farms. Fisseha Itanna (1998) has, however, reported much lower concentrations of Fe in mg kg^{-1} for farm plots irrigated with Bulbula (163.86) and Kera (79.70) rivers during the minor rainy season. Another study by EPHI and FDRE MoH, (2017) reported Fe concentrations that ranged from 72210 to 150500 mg kg^{-1}, and which are immensely higher than those of the present study.

The levels of Cu measured during the minor rainy season (24.14-52.18) were considerably higher than those recorded during the main rainy season (72 to 2.36). Fisseha Itanna, (1998) also reported similar concentration of Cu for soil samples from farm plots irrigated with Bulbula (38.96) and Kera (55) rivers during the minor rainy season. Another study by Tamiru Alemayehu *et al.*, (2006) also reported Cu concentration (35.93), which is closely similar to that for a farm plot at Bulbula Yirgaalem Weldegebriel *et al.* (2012) reported Cu concentration of 25.1, 32.9, 51.4 and 50.4 for farm soils at Akaki, Gofa, Kera and Peacock areas of Akaki river, respectively.

During the minor rainy season, the concentrations of Zn varied from 84.025 to 402.4, whereas during the main rainy season, they ranged from 5.74 to 8.25. Fisseha Itanna (1998) reported concentrations of Zn, which are higher than those of the sampling sites of the present study, for soils from farm plots at Bulbula (2985.50) and Kera (263.00) areas in 1998. Tamiru Alemayehu *et al.*, (2006) also reported Zn concentration (136.13 mg kg^{-1}) that lies within the range of values obtained for the present sampling sites. Yirgaalem Kebede *et al.*, (2016) have, however, reported relatively lower concentrations of Zinc, for farm soils at Akaki (106), Gofa(144), Kera(138) and Peacock(149 areas of Akaki river.

The levels of Mn recorded during the minor (1185-1864) and major (109.94-158) rainy periods for soil samples from the study farms are incomparably lower than those reported previously in other studies. Fisseha Itanna, (1998), for instance, reported several-fold higher concentrations of Mn for farm plots at Bulbula (6587.00) and Kera (3598) areas. Yirgaalem Weldegebriel *et al.*, (2012) have, however, reported concentrations of Mn, which are closer to the lower boundary value of the range of concentrations recorded during the minor rainy period of the present study, for farm soils from

Akaki (1000), Gofa (1054), Kera (1042) and Peacock (1044) areas. The levels of Pb in soils of the present study farms during the minor (65.28-128.52) and major (4-5.18) rainy seasons, are closer to those previously reported by Fisseha Itanna and Olsson, (2004) for other vegetable farms in Addis Ababa (32.7- 110 mg kg^{-1}) and at Bulbula (46.74). Pb concentration, which is higher than the levels recorded during the major rainy period was also reported by Tamiru Alemayehu *et al.* (2006) for Akaki river(12.5 mg kg^{-1}). Concentrations of Pb recorded in the present study were higher at Saris 58, which may be due to its proximity to the majority of industrial wastes.

The Cd content of soils from farms of the present study(0-6.76) are considerably higher than the levels reported by Fisseha Itana (1998) for soils in the Kera (0.44) and Bulbula(0.71) areas. The Cd concentrations in the soils of the farms of the present study are also close to 0.7 of peacock farm, 0.95 of Akaki vegetable farm, and 0.4 of Kera and Kolfe farms (Fisseha Itana, 2004). Yirgaalem Weldegebriel *et al.*, (2012), however, reported slightly higher concentrations for soils in the Akaki (1.6), Gofa (1.4), Kera (1.5), and Peacock (1.8) areas of Akaki river. Tamiru Alemayehu *et al.*, (2006) and EPHI and FDRE MoH, (2017) reported comparable concentrations for Akaki river (0.050 mg kg^{-1}) and (0.04-0.71), respectively.

EPHI and FDRE MoH, (2017) reported concentration of Cr (63.42) for a soil sample from Akaki river, which lies within the ranges of concentrations recorded during the minor (48.89-142.64) and major (37.9-70.79) rainy periods of the present study. The Cr levels recorded for the farm soils of the current study, however, seem to be lower than those observed previously in soils of other vegetable farms of Addis Ababa (81-283; Fisseha Itana, 2004). Tamiru Alemayehu *et al.*, (2006) have also reported higher concentration of Cr(159.5) for Akaki river. Yirgaalem Weldegebriel *et al.*, (2012), however, reported considerably lower concentrations of Cr (9.9-22.8) for farm soils from the same areas of Addis Ababa. EPHI and FDRE MoH (2017) reported Cr contents of soils ranging from 0 to 228 for farms irrigated with Akaki River.

The levels of **Ni** recorded in soils of the study farms during the minor rainy period (116.2-208.66) exceeded those reported by Fisseha Itanna (1998) for farm soils at Bulbula (74.13) and Kera (115.00) areas. Yirgaalem Weldegebriel *et al.*, (2012), however, reported lower concentrations (16.4-55.8) for soil farms of Akaki river at Addis Ababa.

In this study, the order of overall concentrations of metals by sampling sites was found to be Saris 58>Were Geno> Echu Gebere>Mekane Biruh.

This trend may be explained in terms of the proximity of Saris 58 and Were Geno farms to most of the factories, which discharge large amounts of industrial wastes. The general trend observed in this study was a decrease in metals' concentrations in farms with greater distance from industrial waste sources. Anthropogenic influences such as contamination from paint factories for Cd and Zn; gasoline for Pb, commercial fertilizers, uncontrolled disposal of plastics and abrasions for Cd, etc. (Itanna, 1998a; Rahlenbeck et al., 1999; Itanna, 2002; Manta et al., 2002) and Leather industries for chromium seem be responsible for the observed levels of metals.

5.1.3.3 Heavy metals concentrations in leafy vegetables

The leafy vegetables Swiss chard (*Beta vulgaris L.var cicla*), Ethiopian Kale (*Brassica carinata A.Br*.) and lettuce (*Lactuca sativa L. longifolia*) were analyzed for their total metal content.

Table 5. 7 Acceptable limits (mg kg^{-1} dry weight) for heavy metals concentrations in crops/vegetables

	Acceptable limits of Heavy Metals							
	Fe	Cu	Zn	Mn	Pb	Cd	Cr	Ni
FAO/WHO	425.50[a]	73.30a	99.4[a]	500.00[a]	0.30[a]	0.2[a]	2.3[a]	66.9[a]
SEPA	-	20[b]	100[b]	-	9[b]	-	0.5[a]	10[b]
Guide Line	425.5[e]	73.3	99.4[e]	500[f]	0.3[b]	0.2[b]	2.3[e]	67.9[e]
Indian Safe Limit	-	30[c]	50[c]	-	2.5		20[c]	1.5[c]
Pendias	-	5-30[d]	27-150[d]	30-300[d]	-	-	-	-

[a] FAO/WHO (2001) Joint Codex Alimentarius Commission; [b] SEPA (2005);[c] Awashthi (2000); [d] Pendias (2000); [e] Weight (1991) and [f] Pendias and Pendias(1992).

During the minor and major periods of the current study, Lettuce was found to accumulate the maximums amount of Fe(1638 and 521.47, respectively) which are higher than the 425.50 and 425 limits set by different organizations(FAO/WHO, 2001; Weigh, 1991). Swiss Chard and Kale were, however, found to accumulate amounts of Fe lower than the guideline values, (Table, 5.7, and

Appendices 7 and 8). The study conducted by Wubishet Gezahegn *et al.* (2017) reported concentrations of Fe in Swiss Chard from Kera farm (193.6 mgKg^{-1} and in the dark-leafed Abyssinia kale from around Akaki(184.9 mg/Kg), which are less than the permissible limits set by FAO/WHO,(2001) and Weigh (1991). They also found Fe concentration in Lettuce from Kera area (132.5 mgKg^{-1}), which is clearly lower than that determined for Lettuce sample of the current study. Results of this study show that the concentration of Cu in all vegetables except Kale (140.86), was less than the upper permissible limit of the guideline (Table 5.7 and Appendices 7 and 8).

Concentrations of copper that ranged from 8 to 11.6 mg Kg^{-1}were reported by Wubishet Gezahegn *et al.*, (2017) for samples of Russian kale, Siberian kale, Swiss chard, and Lettuce from Debre Birhan research center, and cabbage and Swiss chard from Kera farm. The highest Copper content (11.6 mg Kg^{-1}) was detected in Swiss chard, while the lowest was observed in Russian kale (8.5mg Kg^{-1}) from the Debre Berhan research center. The study conducted at Kera and Peacock farm**s** by Cloudia Stith *et al.*, (2008 reported lower Cu levels (mg kg^{-1}) of 2.86 in Swiss chard, 3.77 in Abyssinian kale and 1.63 in Lettuce. The concentrations of Cu in the present study were found to be lower than the recommended values of earlier investigators (Codex Alimentarius, 2001a; Awashthi 2000; SEPA 2005). Cu concentration values in Lettuce and spinach were reported to be 25.5 and 17.4 mg kg^{-1}, respectively, by Wubishet Gezahegn *et al.*, (2017).

The concentrations of Zn recorded in the present study for all vegetables collected during the minor rainy period are above all the guideline values given in Table 5.7., whereas those observed in samples collected during the major rainy period are below the acceptable limits. A study conducted by Wubishet Gezahegn *et al.* (2017) reported very high concentration of Zinc (219.3 mg Kg^{-1}) in Swiss chard grown in a Kera farm followed by those in Lettuce (84.9 mg Kg^{-1}) and Siberian kale (78.9 mg Kg^{-1}), which were collected from a locality in Debre Berhan during the dry period. Wubishet Gezahegn *et al.*, (2017) also observed the lowest Zn content (10.9 mg/kg) in the Ethiopian Kale (with bright green leaf) that was collected from Debre Berhan. They attributed the high content of zinc in Swiss chard to the presence of higher Zinc concentration in the soil of the Kera area when compared with the soils of the other locations. Another study made by Cloudia *et al.*, (2008) in the Kera area recorded the highest and lowest Zn concentrations (mg Kg^{-1}) in Swiss chard (17.38) and

Lettuce (3.07), respectively, which are close to the results obtained for samples of the main rainy season of this study.

A study performed by Boamponsem *et al*., (2012) in Romania reported Zn concentrations in Lettuce and Spinach (45.5 and 82.4 mg kg^{-1} respectively) which are higher than the levels obtained during the major rainy season in the present investigation. Lower levels (mg Kg^{-1}) of Zn were also observed in the studies carried out in Ghana (1.64 & 1.85; Luc *et al*., 2015) and Burkina Faso (0.82 & 0.40; Gupta *et al*., 2012). Cauliflower and Spinach grown in a long-term waste water-irrigated agricultural land of tropical India were reported to have accumulated 90.87 and 148.04 mg Kg^{-1}, respectively(Mahmood and Malik, 2014). Zn level of Swiss chard from Kera farm was found to be higher than the permissible value recommended by FAO/WHO Codex Alimentarius (2001a).

The concentration of Ni during the minor rainy season of this study was always above the permissible limits given by the guidelines (Table 5.7), whereas it was always below the upper limit during the main rainy season of this study. In the study made by Wubishet Gezahegn *et al*., (2017), It was at the maximum level(212.74) for Lettuce sample followed by that for Swiss chard (203.96) and finally for Kale(193.56) during the minor rainy season., while during the main rainy season, the maximum level (11.6 mg Kg^{-1}) of Nickel was observed in Swiss chard, which was collected from an irrigated farm in the Kera area, while the minimum (0.7 mg Kg^{-1}) was detected in cauliflower leaf from the same farm. The levels of Ni in vegetables collected during the main rainy period of the present study are lower than the permissible limits recommended by different organizations (Awashthi, 2000; SEPA, 2005 and FAO/WHO Codex Alimentarius, 2001).

During both sampling periods, Mn accumulation in leafy vegetables of the present study areas are lower than the recommended maximum tolerable levels proposed by the Joint FAO/WHO Expert Committee on Food Additives (1999)(Table 5.7, Appendices, 7 and 8). The high concentration of Mn (868.5 mg Kg^{-1}), which was reported by Wubishet Gezahegn *et al*., (2017), is much higher than the maximum level of the present study.

The concentrations of Cr, which ranged from 10.23 to 14.52 and from1.805 to 2.883 during the minor and main rainy seasons, respectively, surpassed the upper limit of 2.3 set by FAO/WHO (2001) and 0.5 of SEPA (2005) except that for Kale(1.805) measured during the main rainy season.. The high concentration of Cr at Echu Gebere farm area as compared to those reported by Wubishet

Gezahegn *et al.* (2017) from Kera, Akaki and Debre Birhan farm areas may be due to the location of the sampling site, which receives several discharges from industries.

The concentration of Cr in Swiss chard and Lettuce collected from Echu Gebere farms and Swiss chard from Mekane Biruh were found to be higher than the recommended limit set by the different organizations (FAO/WHO, 2001 and SEPA, 2005). Only Lettuce collected from Echu Gebere was found to have accumulated Cr whose concentration is higher than the Indian safe limit (Awashthi, 2000). The concentrations of Pb, which ranged from 1.02 to 5.71 and from 0 to 2.47 of the minor and main rainy seasons, respectively, have largely surpassed the recommended limits (Table 5.7, Appendices 7 and 8).

The levels of Pb, in all vegetables except kale from Mekane Biruh, and Swiss chard from Echu Gebere and Mekane Biruh during the minor rainy season, and in samples of Swiss chard collected from Saris 58 and Echu Gebere and of Lettuce from Echu Gebere and Mekane Biruh during the main rainy season are much higher than the permissible level (0.3 mg Kg^{-1}) set by FAO/WHO (2001). The accumulation of elevated levels of Pb in the leafy vegetables obtained from farms at Echu Gebere, Mekane Biruh and Saris 58 might be attributed to the leakage of liquid waste from an Ink industry into the river water. Yirgaalem Weldegebriel *et al.*, (2012) reported higher concentrations of heavy metals in Swiss chard (0.12- 0.91), Ethiopian kale (0.33-1.13) and Lettuce (0.17-0.90) from Peacock, Kera, Goffa and Akaki farms.

Their report showed that Cd in all vegetables except Swiss chard and lettuce from Peacock and cabbage from Akaki and Pb in all the vegetables except lettuce and cauliflower from Peacock farm surpassed the maximum permissible limits. In these cases, consuming the vegetables may pose health risk due to the high Cd and Pb concentrations (Codex Alimentarius Commission, (2001). But, they indicated that the average concentrations of Cr, Cu, Mn, Ni and Zn in all the vegetables were below the maximum limits recommended by FAO/WHO, (2001). But, since the metal accumulation and translocation potential varies from metal to metal and from vegetable to vegetable, the variations did not follow any particular pattern. Thus, their impact on public health needs to be evaluated based on the elements that surpassed the maximum limits (Manzoor *et al*., 2006; Tiwari *et al*., 2008; Nabulo *et al*., 2011).

Thus, the variations in the heavy metals concentration of the current study from levels reported previously may be due to the variety of sampling sites in relation to human activities which discharges various types of pollutants to the nearby rivers.

Bio-transferable factor

Bio-transferable factor is a parameter used to describe the transfer of heavy metals from soil to edible parts of leafy vegetables.

The soil-plant transfer factor of Fe in Lettuce sample collected from Were Geno site(19.427) was the maximum of all metals recorded during the minor rainy season, whereas the 0 transfer factor determined for Pb in Kale(Mekane Biruh), Swiss Chard(Echu Gebere and Mekane Biruh), Cd in Kale(Saris 58, Echu Gebere), Lettuce(Saris 58 and Were Geno) is the minimum value observed.

The soil plant transfer factor for heavy metals whose concentrations were always measurable in soil samples of the main rainy season (Fe, Cu, Zn, Mn, Pb and Cr) was also found to vary from 0 of Pb in kale at all sites and lettuce (Saris 58 and Were Geno), Swiss Chard (Were Geno and Echu Gebere) to about 0.762 of Zn in Lettuce at Mekane Biruh site. Metal transfer factors from soil to vegetables were found to be less significant for Cr than for Zn, Mn, Cu, Fe and Cd (Prabu, 2009).

Among the vegetables of this study collected during the minor and major rainy seasons, Lettuce had the highest soil-plant transfer factor for all measurable heavy metals, while Kale was associated with the lowest soil-plant transfer factor of all measurable heavy metals.

Potential health risk estimation

Health risks associated with these heavy metals (Fe, Cu, Zn, Mn, Pb, Cd, Cr and Ni) through vegetable consumption were assessed based on the target hazard quotients (THQs). THQs were developed for the estimation of potential health risks associated with long term exposure to chemical pollutants (USEPA, 2007).

Calculation of THQs requires not only the intake of metals, but also the exposure frequency and duration, body weight and the oral reference dose. THQ is the ratio between measured concentration and oral reference dose (RfD), weighted by the length and frequency of exposure, amount ingested and body weight. If THQ >1, there will be a potential risk associated with the pollutant. If THQ<1, there will be no obvious potential risk associated with the pollutant (Harmanescu *et al*., 2011). Assumptions for the health risk calculations are;

1. Ingested dose is equal to the absorbed pollutant dose (Zheng, Wang, & Zheng, 2007).
2. Cooking has no effect on the pollutants (Han et al., 1998; Zheng et al., 2007).
3. The average body weight of an Ethiopian is 60 kg for adult (Guerra, Trevizam, Muraoka, Marcante, & Canniatti- Brazaca, 2012).
4. Average lifetime of an Ethiopian is 64.7 years (You, 2013)
5. Average exposure frequency (365 days/year)
6. C = concentration of the pollutant (mg kg^{-1}, on dry weight basis) in leafy vegetables:
Average concentration of Cu, Fe, Mn, Zn, Cd, Cr, Ni and Pb in Lettuce, Ethiopian Kale, and Swiss chard.
7. Average Daily green vegetable intake 25.4 kg/person*year (Ruel *et al*., 2005)
8. Reference Dose (mg $kg^{-1}day^{-1}$) Oral
    - Cadmium = 0.001 (Liu *et al*., 2009).
    - Chromium = 1.5 (WHO, 2011)
    - Copper = 0.040 (US EPA, 2007)
    - Iron = 0.700 (US EPA, 2007)
    - Lead= 0.0035 (WHO, 2011)
    - Manganese=0.014 (US EPA)
    - Nickel=0.020 (US EPA, 2007)
    - Zink= 0.300 (US EPA, 2007)

The THQ estimates of the analyzed heavy metals for each leafy vegetable were largely above 1 for samples of the minor rainy season, those of Cd from Kale at Saris 58 and Lettuce at Saris 58 and Were Geno sampling sites and Pb for Swiss Chard and Kale samples collected from Mekane Biruh site were below 1. Despite its many health problems, Cr was always below 1 in all studied leafy vegetables collected from all sampling sites. The results recorded for the main rainy season showed that Cr, Zn, Cu and Ni contamination of plants has the lowest potential to pose health risk to consumers (Table 4.5). Normally chromium is known to have a health effect, when it is above 0.1 mg/kg of vegetables (FAO/WHO, 2011).

However, based on the amount of vegetables consumed, the target hazard quotients (THQs) estimated for Cr were less than 1 in all the vegetables. Although lettuce has higher concentrations of Cr than other vegetables, the target hazard quotient (THQ) is lower (0.153) and the exposed population is assumed to be safe.

Thus, in this study the potential health risks that would be posed by Cr are considered negligible based on the results of THQ. A study made on Modjo River by Cui *et al*., (2004) has also reported that local residents of an area near Modjo River have been exposed to Cr through consumption of vegetables, but no risk was found. In the present study, the THQ for Zn, Cu and Ni were also below 1 and hence the vegetables may be safe for consumption.

On the other hand, Fe, Mn, Pb and Cd show THQ values above 1, suggesting that they may pose health effect on the consumers. Heavy metal pollutants in wastewater can adversely affect people who have direct or indirect contact, depending on the soil quality; the health of consumers of vegetables produced using wastewater and those who are working on wastewater farms (Warner, 2000 and Vol, 2006). The magnitude of these effects varies depending on the source of the wastewater and its composition and treatment level of the waste before discharging it into the nearby aquatic ecosystems.

6. CONCLUSIONS

It has become evident from the present study that, the water quality of Akaki River has deteriorated as a result of anthropogenic sources of domestic, industrial and agricultural origin.

Vegetable farms in and around Addis Ababa, which were irrigated with contaminated waters exhibited increased concentrations of metals both in the soils and vegetables grown on them. Among the study vegetables, Lettuce and Kale were found to accumulate the highest and lowest of all vegetables. Nevertheless, it was realized that different vegetables accumulate and translocate variable amounts of metals from the soil into their tissues.

The potential health risk indicator (THQ) for Cr, Zn, Cu and Ni shows that people feeding on vegetables grown in farms irrigated with Akaki River are safe for most of the Metals, whereas the THQ of Fe, Mn, Pb and Cd reached levels above 1 suggesting , that eating vegetables may pose a health risk.. Thus, the present findings underline the need for immediate measures to protect the consumers and the general environment.

7. RECOMMENDATIONS

Although Akaki River is obviously highly impacted by wastes of domestic, industrial and agricultural origin, it is used for irrigation, watering livestock, drinking water supply and sanitation without prior treatment. For sustainable management of this water resource and protection of public health and aquatic and terrestrial life, environmental protection agencies at different levels and other concerned governmental and nongovernmental bodies should develop workable strategies and translate into practice. Enforcement of environmental laws and creation of awareness about the on-going environmental degradation and the significance of effective waste treatment and proper disposal of wastes are imperative. Provision of different incentives including reducing taxes for those industrial firms with treatment plants and good environmental management practices could be another option of protecting aquatic resources. It also necessitates avoiding establishment of additional industries near water bodies including rivers. Continuous monitoring of selected physico-chemical parameters should be effected to have dependable information on the timely status of the system.

….. In addition, to minimize potential risks associated with the use of river water for irrigation, the river water should be properly treated, while cheap and efficient methods of reducing the microbial loads of microbially contaminated water used for irrigation needs to be developed and implemented.

In general, to reduce water pollution in Addis Ababa, the following measures should be taken:

- Properly controlling industrial effluent discharges and implementing industrial park principles,
- Construction of adequate public latrines in order to help reduce or stop disposal of human excreta in the open areas in the city
- Enhancing the environmental awareness of the population,
- Empowering the local authorities to take an active role in the enforcement of waste disposal regulations.

The systematic application of the aforementioned controlling mechanisms could cut the surface water pollution of the Akaki River and its tributaries.

8. REFERENCES

Amare Hailu, (2007). Metal Concentration in Vegetables grown In Northern Addis Ababa, Ethiopia. M.Sc. Thesis, Addis Ababa University, Addis Ababa.

A. Abdul-Razak, A. Asiedu, R. Entsua-Mensah, (2009). Assessment of the Water Quality of the Oti River in Ghana. *West African J. of Appl.Ecol.*

A. Kabat-Pendias, (1992). Elements of Group VIII. In: Trace Elements in Soils and Plants, CRC Press, Boca Raton.

A. Karikari and O. Ansa-Asare, (2006). Physico-Chemical and Microbial Water Quality Assessment of Densu River of Ghana. *West African J. of Applied Ecology*. **10**:1pp. 87-100.

Adeel Mahmood and Riffat Naseem Malik, (2014). Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan, *Arabian J. of Chem*.7: 91-99.

Agbenin, J.O., Danko, M. and Welp, G. (2009). Soil and vegetable compositional relationships of eight potentially toxic metals in urban garden fields from northern Nigeria. *J.Sci. Food Agric*. **89**:49-54.

Agency for Toxic Substances and Disease Registry (ASTDR), (1995). Toxicological Profile for Zinc CAS# 7440-66, Atlanta, GA: U.S.

Agency of Toxic Substances and Disease Registry (ATSDR), (2004). Toxicological Profile for copper: Us Department of Health and Human Service Atlanta U.S.

Aklilu Asfaw, Mengistu Sime, Fisseha Itanna, (2013). Determining the Extent of Contamination of Vegetables Affectedby Tannery Effluent in Ejersa Area of East Shoa,Ethiopia, *Sci. and Research Publications,* Volume 3, Issue 5:2250-3153.

An, Y.J., Yoon, C.G., Jung, K.W. and Ham, J.H., (2007). Estimating the Microbial Risk of *E. coli* in Reclaimed Wastewater Irrigation on Paddy FiHaileld. *Environ. Monit. Assess.* **129** :53–60.

APHA, (1999). Standard methods for the examination of water and wastewater, 20th ed., Washington D.C.

Awashthi, S.K., (2000). Prevention of food adulteration act no 37 of 1954. Central state rules as amended for 1999(3rd ed.). New Delhi: Ashoka Law House.

Badillo-Camacho J., Reynaga E., Barcelo-Quintal E., Orozco-Guareno C., Alvarez-Bobadila D., Gomez-Salazar S., (2015). J.Environ. Protec., **6**: 215-224

Benjamin, L., Atwill, E.R., Jay-Russell, M., Cooley, M., Carychao, D., Gorski, L. and Mandrell, R.E., (2013). Occurrence of generic *E. coli*, *E. coli O157* and *Salmonella* spp. in water and sediment from leafy green produce farms and streams on the Central California coast. *Int.J.Food Microbiol.* **165:** 65-76.

Blumenthal UJ, Cifuentes E, Bennett S, Quigley M, Ruiz-Palacios G., (2001). The risk of enteric infections associated with wastewater reuse: the effect of season and degree of storage of wastewater. *T Roy Soc Trop Med H* 95(2): 131–137.

Blumenthal UJ, Mara DD, Peasey A, Ruiz-Palacios G, Stott R., (2000). Guidelines for the microbiological quality of treated wastewater used in agriculture: Recommendations for revising WHO guidelines. Bull. World Health Organ. 78: 1104–1116.

Bos R, Carr R, Keraita B., (2010). Assessing and mitigating wastewater-related health risks in low- income countries: An introduction. In: Wastewater irrigation and health: Assessing and mitigating risk in low-income countries (Drechsel P, Scott CA, Raschid Sally L, Redwood M, Bahri A, eds). London: Earthscan, 29-47.

Brihanu Million, (2008). Assessment of the Contamination Level of Water at Collection Points and Determination of the Major Sources of Contaminants in the Central Highlands of Ethiopia (Yubdo-Legebatu PA). M.Sc. Thesis, Addis Ababa University, Addis Ababa.

Brihanu Roba, (2008). Physicochemical and Bacteriological Water Quality Assessment in Lake Ziway with a Special Emphasis on Fish Farming. M.Sc. Thesis, Addis Ababa University, Addis Ababa.

Cantet, F., Hervio-Heath, D., Caro, A., Mennec, C.c.L., Monteil, C., Que´me´re, C., Jolivet-Gougeon, A., Colwell, R.R. and Monfort, P., (2013). Quantification of *Vibrio parahaemolyticus*, *Vibrio vulnificus* and *Vibrio cholerae* in French Mediterranean coastal lagoons. *Res. Microbiol.* . **164:** 867-874.

Carlander A, Schonning C, Stenstrom TA., (2009). Energy forest irrigated with wastewater: a comparative microbial risk assessment. *J. Water Health* 7(3):413–433.

Chen, Y., Wang, C., & Wang, Z., (2005). Residues and sources identification of persistent organic pollutants in farmland soils irrigated by effluents from biological treatment plants. *Environment International,* 31, 778-783.

Cloudia Stith, Ion V. Popescu, Anca Gheboianu, M.Arina Frontasyeva, Antoaneta Ene, Gabriel Dima1, Ouna Bute1, Valerica Gh. Cimpoca, Valentina Stihi, Calin Dinu, Marilena Voicu1, (2008). Mineral content of native vegetables obtained by Energy Dispersive X- ray Fluorescence Spectrometry, *J.Sci. and Art.*

Codex Alimentarius, (2001a). Codex maximum levels cadmium in cereals, pulses and legumes, joint FAO/WHO standards, CAC/GL.

Craig, W.J., (1994). Iron status of vegetarians. *Am. J. Clin Nutr.* 59. pp1233-1237.

Craige, D.L., Fallowfield, H.J. and Cromar, N.J., (2004). Use of microcosms to determine persistence of *Escherichia coli* in recreational coastal water and sediment and validation with *in situ* measurements. *J. Appl. Microbiol.* **96:** 922-930.

Dagnew Tadesse, A. Desta, A. Geyid, W. Girma, S. Fisseha, and O. Schmoll, (2012). Rapid assessment of drinking-water quality in the Federal Democratic Republic of Ethiopia. *Country Report of the Pilot Project Implementation in 2004-2005*. WHO Library Cataloguing-in-Publication Data.

Dodgen LK, Li J, Parker D, Gan JJ., (2013). Uptake and accumulation of four PPCP/EDCs in two leafy vegetables. Environ Pollut 182:150-156.

Drechsel P, Blumenthal UJ, Keraita B., (2002). Balancing health and livelihoods: adjusting wastewater irrigation guidelines for resource-poor countries. Urban Agriculture Magazine 8:7-9.

Drechsel P, Scott CA, Raschid-Sally L, Redwood M, Bahri A., (2010). Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-Income Countries. London: *Earthscan*.

EEPA, (2003). Standards for industrial pollution control in Ethiopia, Part Three: Standards for Industrial effluents. ESIS project- US/ETH/99/068/ETHIOPIA, EPA/UNIDO, Addis Ababa.

Ensink JH, Blumenthal UJ, Brooker S., (2008). Wastewater quality and the risk of intestinal nematode infection in sewage farming families in Hyderabad, India. Am J Trop Med Hyg 79(4): 561-567.

Ensink JH, van der Hoek W, Amerasinghe FP., (2006). Giardia duodenalis infection and wastewater irrigation in Pakistan. *Trans R Soc Trop Med Hyg.* 100(6):538–542.

Eshtawi, T., & Kanyoka, P., (2012). Analyzing the trade-offs of wastewater re use in agriculture: An Analytical framework.

Estefan G., Sommer R. and Ryan J., (2013).Methods of Soil, Plant, and Water Analysis.**In:***A manual for the West Asia and North Africa region*, pp. 170 -176, (ICARDA, ed).Beirut, Lebanon.

European Community (EC) **(**1980): Official Gazette NO. L. 229/11-229/29.

Ewers, (1991). Standards, guidelines and legislative regulations concerning metals and their compounds E. Merian (Ed.), Metals and Their Compounds in the Environment: Occurrence, Analysis and Biological Relevance, VCH, Weinheim.

Faruque, S., Khan, R., Kamruzzaman, M., Yamasaki, S., Ahmad, Q. and Azim, T. (2002). Isolation of *Shigella dysenteriae* type 1 and *S. flexneri* strains from surface waters in Bangladesh: comparative molecular analysis of environmental *Shigella* isolates versus clinical strains. *Appl. Environ. Microbiol.* **68:** 3908-3921.

Ferrer A, Nguyen-Viet H, Zinsstag J., (2012). Quantification of Diarrhea Risk Related to Wastewater Contact in Thailand. Ecohealth 9(1):49–59.

Fisseha Ittana, (1998). Metal concentrations of some vegetables irrigated with industrial liquid waste at Akaki, Ethiopia. *Ethiop. J. Sci.* 21(1): 133-144

Fisseha Ittana, (2002). Metals in leafy vegetables grown in Addis Ababa and toxicological implications. *Ethiop. J. Health Dev*. 16 (3): 295-302

Food and Agriculture Organization of the United Nations (FAO), (2010). The Wealth of Waste: The Economics of Wastewater Use in Agriculture. FAO Water Reports 35.

Friesa, J.S., Characklisb, G.W. and Noble, R.T., (2008). Sediment–water exchange of *Vibrio* sp. and fecal indicator bacteria: implications for persistence and transport in the Neuse River.

G.A. Boamponsem, M. Kumi, I.Debrah, (2012). Heavy metal accumulation in Cabbage, Lettuce And Carrot Irrigated with Wastewater from Nagodi Mining Site in Ghana. *Int. J. of sci. tech. research.*

Gemmell, M.E. and Schmidt, S., (2012). Microbiological assessment of river water used for the irrigation of fresh produce in a sub-urban community in Sobantu, South Africa. *Food Res. Int.* **47:** 300-305.

Girum Tamire and Seyoum Mengistou, (2012). Macrophyte species composition, distribution and diversity in relation to some physicochemical factors in the littoral zone of Lake Ziway, Ethiopia. *Afr. J. Ecol.* **51:** 66-77.

Goraw Goshu, Byamukama, D., Manafi, M., Kirschner, A.K.T. and Farnleitner, A.H., (2010). A pilot study on anthropogenic faecal pollution impact in Bahir Dar Gulf of Lake Tana, Northern Ethiopia. *Ecohydrology and Hydrobiology.* **10:** 271-280.

Grangier C, Qadir M, Singh M., (2012). Health implications for children in wastewater-irrigated peri-urban Aleppo, Syria. Water Qual Expo Health 4(4):187–195.

Guéguen, C.; Gilbin, R.; Pardos, M.; Dominik, (2004).J. *Appl. Geochem.* 19, 153.

Gupta N, Khan DK, Santra SC. (2012). Heavy metal accumulation in vegetables grown in a long term wastewater-irrigated agricultural land of tropical India. *Environ. Monit. Assess.* 184(11): 6673–6682.

Halliday, J.W., (1998). Hemochromatosis and iron needs. *Nutr. Rev.* pp30-37.

Hanjra MA, Blackwell J, Carr G, Zhang F, Jackson TM. (2012). Wastewater irrigation and environmental health: Implications for water governance and public policy. *Int J Hyg Environ Health* 215(3): 255–269.

He, Z. L., Yang, X. E., & Stoffella, P. J., (2005). Trace elements in agroecosystems and impacts on the environment. Journal of Trace Elements in Medicine and Biology, 19(2), 125 140.

Hendriks, S. (2003). The potential for nutritional benefits from increased agricultural production in rural KwaZulu-Natal. South African. *J. of Agri.Extension*, 32, 28-44.

Hintsa Gitet, Masho Hilawie, Mehari Muuz, Yirgaalem Weldegebriel, Dawit Gebremichael and Desta Gebremedhin, (2016). Bioaccumulation of heavy metals in crop plants grown near Almeda Textile Factory, Adwa, Ethiopia, *Environ. Monit. Assess.*

Hogan, C.M., (2013). WaterPollution. Retrieved from http://www.eoearth.org/view/article/156920

J. D. Hem, (1985). Study and Interpretation of the Chemical Characteristics of Natural Water. *Department of the Interior, US Geological Survey*. Estuary, North Carolina, USA. *Water Res.* **42:** 941-950.

Jan FA, Ishaq M, Khan S, Ihsanullah I, Ahmad I, Shakirullah M. (2010). A Comparative Study of Human Health Risks via Consumption of Food Crops Grown on Wastewater Irrigated Soil (Peshawar) and Relatively Clean Water Irrigated Soil (lower Dir). J Hazard Mater 179:612–621.

Järup, (2003). Hazards of heavy metal contamination. Br Med Bull **68**(1):167-182.

Jarvie, H.P.; Neal, C.; Tappin, A.D.; Burton, J.D.; Hill, L.; Neal, M.; Harrow, M.; Hopkins, R.; Watts C.; Wickham, H, (2000). *The Sci. Total Environ*. 251/252, 55.

Jasim Uddin Ahmad and Md. Abdul Goni, (2010). Heavy metal contamination in water, soil, and vegetables of the industrial areas in Dhaka, *Bangladesh Environ. Monit Assess*. 166:347-357.

Keen, C.L., Ensunsa, J.L. and Watson, M.H., (1999). Nutritional Aspects of Manganese from Experimental Studies. *Neurotoxicology,* 20 pp 213-223.

Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG. (2008). Health Risks of Heavy Metals in Contaminated Soils and Food Crops Irrigated with Wastewater in Beijing, *China. Environ. Pollut.* 152:686–692.

Kimura, M.; Itokawa, Y., (1990). Cooking Losses of Minerals in Foods and Its Nutritional Significance. *J. Nutr. Sci. Vitaminol*: 36, pp25-33.

Kosek, M., Bern C. and Guerrant R.L. (2003). The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. *Bull. World Health Organ.* **81:** 197-204.

Krishnani, K. K., Meng, X., Christodoulatos, C., & Boddu, V. M. (2008). Biosorption mechanism of nine different heavy metals onto biomatrix from rice husk. *J. of Hazardous Materials,* 153(3), 1222-1234.

Lee, C.M., Lin, T.Y., Lin, C.-C., Kohbodi, G.A., Bhatt, A., Lee, R. and Jay, J.A. (2006). Persistence of fecal indicator bacteria in Santa Monica Bay beach sediments. *Water res.* **40:** 2593-2602.

Levantesi, C., Bonadonna, L., Briancesco, R., Grohmann, E., Toze, S. and Tandoi, V. (2012). *Salmonella* in surface and drinking water: Occurrence and water-mediated transmission. *Food Res. Int.* **45:** 587-602.

Liu, L., Johnson, H.L., Cousens, S., Perin, J., Scott, S., Lawn, J.E., Rudan, I., Campbell, H., Cibulskis, R., Li, M., Mathers, C. and Black, R.E., (2012). Global, regional, and national causes of child mortality: an updated systematic analysis for 2010 with time trends since 2000. *Lancet.* **379:** 2151-2161.

Luc T. Bambara, Karim Kabore, Moumouni Derra, Dr. Martial Zoungrana, Prof. Francois Zougmore, Dr. Ousmane Cisse, (2015). Assessment of heavy metals in irrigation water and vegetables in selected farms at Loumbila and Paspanga, Burkina Faso. *IOSR J. of Environ. Sci. Toxicology and Food Tech.* 9: pp 99-103.

M. Cempel, G. Nikel, and Nickel, (2006). A Review of Its Sources and Environmental Toxicology. *Polish J. of Environ. Stud*. Pp 375-382.

M. Meybeck, (1982). Carbon, nitrogen, and phosphorus transport by World rivers. *American J. of Sci.*. pp. 401-450.

Maa J., Ding Z., Wei G., Zhao H., Huang T., (2009). Environ. Manage. **90:**1168-1177

Maal-Bared, R., Bartlett, K.H., Bowie, W.R. and Hall, E.R., (2013). Phenotypic antibiotic resistance of *Escherichia coli* and *E. coli O157* isolated from water, sediment and biofilms in an agricultural watershed in British Columbia. *Sc. Total Environ.* **443:** 315 323.

Mapanda, F., Mangwayana, E. N., Nyamangara, J., & Giller, K. E., (2005). The effect of long-term irrigation using wastewater on heavy metal contents of soils under vegetables in Harare, Zimbabwe. *Agr. Eco.and Environ.* 107, 151-165.

Mara DD, Sleigh PA, Blumenthal UJ, Carr RM. (2007). Health risks in wastewater irrigation: Comparing estimates from quantitative microbial risk analyses and epidemiological studies. *J Water Health* 5(1):39–50.

Medudhula T., Samatha C., Chintha S., (2012). *Int. J. Env. Sci*. **3**: 437-445.

Mekuria Mekonnen, (2014). Occurrence of Waterborne Pathogens in Lake Zwai and Drinking Water System of Batu (Zwai) Town, Ethiopia:In Relation to Fecal Indicator Bacteria and Physicochemical Parameters. M.Sc. Thesis, Addis Ababa University, Addis Ababa.

Melloul AA, Hassani L., (1999). Salmonella infection in children from the wastewater-spreading zone of Marrakesh city (Morocco). *J Appl Microbiol* 87(4): 536–539.

Mkwambisi, D. D., (2008). Urban agriculture and food security in Lilongwe and Blantyre,Malawi. Agriculture in Urban Planning, 91.

Mogessie Ashenafi, (1989). Microbial load, incidence and antibiograms of some disease causing microorganisms on raw food items consumed in Ethiopia. *J. App. Micro. Biotechnol*. 5: 317-31

Mohamed H.H. Ali, Khairia M. Al-Qahtani, (2012). Assessment of some heavy metals in vegetables, cereals and fruits in Saudi Arabian markets, *Egyptian J. of Aquatic Research 3*8: pp31-37.

Momtaz, H., Dehkordi, F.S., Rahimi, E. and Asgarifar, A., (2013). Detection of *Escherichia coli, Salmonella* species, and *Vibrio cholerae* in tap water and bottled drinking water in Isfahan, Iran. *BMC Public Health.* **13:** 556-563.

Muchuweti, M., Birkett, J. W., Chinyanga, E., Zvauya, R., Scrimshaw, M. D., & Lester, J., (2006). Heavy metal content of vegetables irrigated with mixture of wastewater and sewage sludge in Zimbabwe: Implications for human health. *Agriculture Ecosystems & Environment,* 112, 41-48.

N. Gupta, D. K. Khan, S.C. Santra, (2012). Heavy metal accumulation in vegetables grown in a long term wastewater- irrigated agricultural land of tropical India, *Environ. Monit. Assess*. 184:6673-6682

N. Koning and J. Roos, (1999). The Continued Influence of Organic Pollution on the Water Quality of the Turbid Modder River. *Journal of Water South Africa*. 25: 3, pp. 285-292.

Nielsen, F.H. and Mertz, W. (Ed.) (1987). Importance of Trace elements in Human and Animal Nutrition. San Diego Academic Press.

Nwachuku N, Gerba CP. (2004). Microbial risk assessment: don't forget the children. *Curr. Opin. Microbiol.* 7:206–9.

P. Prabu, L. Wondimu, and M. Tesso, (2010). Assessment of Water Quality of Huluka and Alaltu Rivers of Ambo. *Ethiopia Journal of Science and Technology (Agr. Sci. Tech).*pp. 131-138.

PACN, (2010). African's Water Quality. A Chemical Science Perspective. A Report by the Pan Africa Chemistry Network.

Peralta-Videa, J. R., Lopez, M. L., Narayan, M., Saupe, G., & Gardea-Torresdey,J., (2009). The biochemistry of environmental heavy metal uptake by plants: implications for the food chain. The international journal of biochemistry & cell biology, 41(8), 1665-1677.

Qadir M, Sharma BR, Bruggeman A, Choukr–Allah R, Karajeh F., (2007). Nonconventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. Agr Water Manage 87:2–22.

Qadir M, Wichelns D, Raschid–Sally L, McCornick PG, Drechsel P, Bahri A, (2010). The challenges of wastewater irrigation in developing countries. Agr Water Manage 97:561–568.

R.S., Ayers, and D.W. Westcot, FAO, (1985). Water quality for agriculture FAO Irrig. Drain., Paper. 29 pp. 1-120

Radojevic M.and Bashkin V., (2006). Practical Environmental Analysis Second Edition, the Royal Society of Chemistry, UK

Rai, U.N., Tripathi, R.D., Vajpayee, P., Jha, V. and Ali, M.B. (2002). Bioaccmulation of toxic metal (Cr, Cd, Pb and Cu) by seeds of Euryale ferox Salisb. (Makhana). Chemosphere. 46(2): pp267-272.

Raschid–Sally L, Jayakody P., (2008). Drivers and Characteristics of Wastewater Agriculture in Developing Countries: Results from a Global Assessment. International Water Management Institute Research Report 127.

Reardon, T., Berdegue, J., & Escobar, G., (2001). Rural nonfarm employment and incomes in Latin America: overview and policy implications. World development, 29(3), 395-409.

Reeve, R., (**2002**) *Introduction to Environmental Analysis*, Wiley: England; p 59-61.

Res. Int. **47:** 300-305.

S. C. McCutcheon, J. L. Martin, T. O. Barnwell Jr, D. Maidment, (1983). Water Quality. *Handbook of Hydrology*, pp. 11.

Samuel Melaku, Taddese Wondimu, Richard Dams, and Luck Moens, (2007). Pollution Status of Tinishu Akaki River and Its Tributaries (Ethiopia): Evaluated Using Physico-Chemical Parameters, Major Ions and Nutrients. *Bulletin of the Chemical Society of Ethiopia*. pp. 13–22.

Scott CA, Drechsel P, Raschid–Sally L, Bahri A, Mara D, Redwood M, et al., (2010). Wastewater Irrigation and Health: Challenges and Outlook for Mitigating Risks in Low-Income Countries. In: Wastewater irrigation and health: Assessing and mitigating risk in low-income countries (Drechsel P, Scott CA, Raschid-Sally L, Redwood M, Bahri A, eds). London: Earthscan, 381– 394.

Seneviratne, M., (2007). A practical approach to water conservation for commercial and industrial facilities: Elsevier.

SEPA, (2005). The limits of pollutants in food. China: State Environmental Protection Administration. GB2762-2005.

Shanan, S., Abd, H., Hedenström, I., Saeed, A. and Sandström, G., (2011). Detection of *Vibrio cholerae* and *Acanthamoeba* species from same natural water samples collected from different cholera endemic areas in Sudan. *BMC Research Notes.* **4:** 1-4.

Sharma, R. K., Agrawal, M., & Marshall, F., (2007). Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Ecotoxicology and Environmental Safety, 66, 258–266.

Singh A, Sharma RK, Agrawal M, Marhsal FM., (2010). Health Assessment of Heavy Metals via Dietary Intake of Foodstuffs from the Wastewater Irrigated Site of a Dry Tropical Area of India. Food Chem Toxicol 48:611–619.

Singh, K. P., Mohan, D., Sinha, S., & Dalwani, R., (2004). Impact assessment of treated/untreated wastewater toxicants discharged by sewage treatment plants on health, agricultural, and environmental quality in the wastewater disposal area. *Chemosphere*, 55, 227-255.

Smith, S., (2010). Annual Drinking Water Quality Report. City of Bunker Hill Village. Technical Report No. (713) 467-9762. USA.

Tamiru Alemayehu, (2006). Heavy Metal Concentration in the Urban Environment of Addis Ababa, Ethiopia, Soil and Sediment Contamination: An *Int. J.*

Tang JC, Bai XR, Zhang WJ., (2011). Cadmium Pollution and its Transfer in Agricultural

Systems in the Suburbs of Tianjin, China. Soil Sediment Contam 20(6): 722–732.

Tenagne Addisu Wondie, (2009). The impact of urban storm water runoff and domestic waste effluent on water quality of Lake Tana and local groundwater near the city of Bahir Dar, Ethiopia. MSc thesis. Cornell University.

Terzić S, Senta I, Ahel M, Gros M, Petrovic M, Barcelo D, et al., (2008). Occurrence and fate of emerging wastewater contaminants in Western Balkan Region. Sci Total Environ 399:66–77.

Thebo AL, Drechsel P, Lambin EF., (2014). Global assessment of urban and peri– urban agriculture: irrigated and rainfed croplands. *Environ. Res. Lett.* 9(11):114002.

Trang DT, Mølbak K, Cam PD, Dalsgaard A., (2007c). Helminth infections among people using wastewater and human excreta in peri-urban agriculture and aquaculture in Hanoi.

Trinh LT, Duong CC, Van Der Steen P, Lens PN., (2013). Exploring the potential for wastewater reuse in agriculture as a climate change adaptation measure for Can Tho City, Vietnam. *Agr. Water Manage.* 128:43–54.

Tuzen, M., (2002). A comparison of sample preparation procedures for the determinationof heavy metals in lichen samples by GFAAS. *Analytical letters*, **35**(10), 1667-1676.

Uher, E., Mirande-Bret, C., & Gourlay-France, C., (2011). Environmental ChemistryGroup Bulletin.

UNICEF/WHO, (2012). Progress on Drinking Water and Sanitation. UNICEF and WHO,New York.

USEPA, (2014). Sample collection and Holding Time for Pesticides analysis. SW-846 Update Four-Revision 5

Van Rooijen, D. J., Biggs, T. W., Smout, I., & Drechsel, P., (2010). Urban growth, wastewater production and use in irrigated agriculture: a comparative study of Accra, Addis Ababa and Hyderabad. Irrigation and Drainage Systems, 24(1-2), 53-64.

W. R. Commission, (2003). Ghana Raw Water Criteria and Guidelines Series. Report Prepared for Ghana Water Resources Commission by CSIR-Water Research Institute.

Wakida, F. T., & Lerner, D. N., (2005). Non-agricultural sources of groundwater nitrate: a review and case study. Water research, 39(1), 3-16.

Weldegebriel, Y., Chandravanshi, B. S., & Wondimu, T., (2012). Concentration levels of metals in vegetables grown in soils irrigated with river water in Addis Ababa, Ethiopia. Ecotoxicology and environmental safety, 77, 57-63.

WHO, (1996). *Guidelines for Drinking-water Quality: Health Criteria and Other Supporting Information*. 2nd ed., Vol. 2 World Health Organization, Geneva pp. 77-279.

WHO, (2008b). *Guidelines for Drinking-water Quality: Incorporating 1st and 2nd addenda*. 3rd ed., vol. 1 WHO press, Geneva, pp. 240-241.

Woodall, C.J., (2009). Waterborne diseases – What are the primary killers? *Desalination.* **248:** 616–621.

World Health Organization, (2006) standards represent the World Health Organization potable water quality standards. Roberts, D., and M. Greenwood (editors). Practical Food Microbiology (3rd edi.).Blackwell Publishing Ltd, Osney Mead, Oxford OX2 0EL, UK. 5: 105 -109

Wubishet Gezahegn, A. Srinivasulu, B. Aruna, S. Banerjee, M. Sudarshan, P.V. Lakshmi Narayana, A.D.P. Rao, (2017). Study of Heavy Metals Accumulation in Leafy Vegetables of Ethiopia. *J. of Environ. Sci. Toxic. and Food Tech.* 11: PP 57-68.

Xagoraraki I.,and Kuo D., (2008). Water pollution: Emerging contaminants Associated with Drinking water. Elsevier Inc, Michgan State University,USA

Yadav, R. K., Goyal, B., Sharma, R. K., Dubey, S. K., Minhas, P. S., (2002). Post irrigation impact of domestic sewage effluent on composition of soils, crops and ground water a case study. Environment International, 28, 481-486.

Yang J., Skogley E., Schaff B., Kim J., (1998)). Soil Sci. Soci. *American J.* **62**: 1108-1115

Yang QW, Lan CY, Wang HB, Zhuang P, Shu WS., (2006). Cadmium in soil–rice system and health risk associated with the use of untreated mining wastewater for irrigation in Lechang, China. *Agr. Water Manage.* 84(1–2):147–152.

Yirga Kebede Wondim, Hassen Muhabaw Mosa, Manalebesh Asmara. Alehegn, (2016).Physico-chemical Water Quality Assessment of Gilgel Abay River in the Lake Tana Basin, Ethiopia.*j. environ. and human In press.*

Yirgaalem Weldegebriel a, Bhagwan Singh Chandravanshi b,n, Taddese Wondimu, (2012) Concentration levels of metals in vegetables grown in soils irrigated with river water in Addis Ababa, Ethiopia, *Ecotoxicology and Environmental Safety* 77, pp 57–63.

Zhao Y. Xia H., Yang Z., Wang F., (2012). Procedia Environmental Sciences, **13:**775-780

APPENDIXES

Appendix 1. Physico-chemical parameters data collected in Akaki rivers 2017

Site Name	Months	pH	EC	DO	Do saturation	Temp	Turbidity	Tp	SRP	NO3	NO2	NH3	TSS	TDS	BOD	COD
Saris 58	March	7.84	293	0.38	5.3	19.6	154	39.80	16.62	0.266908	0.390246	4.12	394	1742	69.70	530.8
	April	7.42	342	1.06	32	21.3	243	40.65	17.31	0.345028	0.434112	3.48	650	1230	84.85	644
	May	7.62	308	2.88	40.7	19.8	188	44.90	18.49	0.35675	0.44711	3.69	770	1942	91.21	690.04
	July	8.15	142.3	3.93	40.7	20.9	273	15.90	5.30	0.2769	0.6096	1.29	696	1533.33	-	-
	August	7.4	185.2	5.39	79.62	19.31	285	39.22	2.93	0.292948	0.466606	6.95	1214	918	58	288
Echu Gebere	March	8.07	276	0.17	2.4	22.3	199	33.74	10.79	0.233707	0.036061	5.79	240	1374	66.67	350.5
	April	6.3	354	1.25	24	22	205	34.97	15.67	0.256492	0.115671	4.97	799	1766	75.76	413
	May	7.4	340	1.69	25	21.3	215	42.29	17.36	0.28123	0.287889	5.54	798.2	1568	79.09	413.27
	July	7.71	99.1	4.65	76.2	21.1	534	4.28	27.27	0.34416	0.385371	3.05	1555.6	464	-	-
	August	7.96	134	7.11	97.3	18.5	229	4.98	21.66	0.197902	0.180659	10.19	328	994	34	80
Mekane Biruh	March	8.1	178.4	0.6	8.7	21.7	265	18.90	10.50	0.16861	0.36588	5.25	266	1090	63.64	80.1

Were Geno								
August	July	May	April	March	August	July	May	April
8.74	7.34	7.65	7.55	8.16	8.31	7.68	7.43	6.43
178.1	155.8	197.2	175	163.7	82	157.8	211.4	205
6.93	3.14	2.3	1.85	1.48	6.67	3.73	1.56	2.02
94	35	35	53	20.3	89.5	19	19	42
17.1	22.7	20.8	21.7	19.8	17.7	21.7	21.7	23.8
294	123	321	293	280	820	932	270	255
11.58	5.92	40.24	34.61	31.69	5.85	30.89	19.87	18.54
16.54	4.64	16.80	15.93	11.02	4.21	10.27	14.70	11.58
0.141916	0.266908	0.25259	0.24868	0.184231	0.139312	0.51342	0.24608	0.21483
0.369124	0.320383	0.34963	0.044184	0.019814	0.5741615	0.38212	0.70706	0.60958
3.47	6.23	4.81	4.70	6.03	5.68	4.20	4.97	4.00
380	700	1027	978	402	932	973.33	426	306
1504	278	1350	1788	950	1062	1831.21	1290	1424
22	-	121.21	106.36	100	14	-	85.76	75.76
96	-	193.84	169.6	160.2	48	-	107.63	95.1

Appendix 2 Total and Faecal coliforms count in water and soil samples data

Sites	Months	TCw	FCw	TCs	FCs
Saris 58	March	42300000	7160	28400000	4180
	April	55000000	11600	103000000	9600
	May	94000000	2640	245000000	2040
	July	179000	3280	-	-
	August	151000	5620	-	-
Echu Gebere	March	34300000	5960	22400000	3480
	April	41200000	9000	38500000	7000
	May	62000000	1480	201000000	1240
	July	221000	3600	-	-
	August	119000	3000	-	-
Mekane Biruh	March	30400000	6100	20100000	4860
	April	37200000	7800	31100000	10200
	May	81000000	1180	213000000	1740
	July	23100	4060	-	-
	August	24300	2600	-	-
Were Geno	March	74000000	8100	39400000	5680
	April	93000000	12400	213000000	11000
	May	21500000	4020	305000000	3080
	July	21600	5200	-	-
	August	11500	4100	-	-

Appendix 3 Concentration of heavy metals in water samples (mg L-1) of the minor rainy season data

Sites	Heavy Metals concentration							
	Cu	Fe	Mn	Zn	Cd	Cr	Ni	Pb
Saris 58	2.81	5.77	1.42	2.61	ND	3.1	1.18	0.72
Echu Gebere	0.91	7.99	1.57	2.16	ND	2.81	1.26	0.91
Mekane Biruh	0.49	12.39	0.8	1.62	ND	2.57	1.26	0.24
Were Geno	0.44	9.26	1.6	1.94	ND	2.84	1.18	ND
Minimum	0.44	5.77	0.8	1.62	ND	2.57	1.18	ND
Maximum	2.81	12.39	1.6	2.61	ND	3.1	1.26	0.91
Average	1.1625	8.8525	1.3475	2.0825	ND	2.83	1.22	0.4675

Appendix 4Concentration of heavy metals in water samples (mg L-1) of the main rainy season data

Sampling Sites	Concentrations of Heavy Metals							
	Fe	Cu	Zn	Mn	Pb	Cd	Cr	Ni
Saris 58	11.5	<0.10	<0.10	0.65	<0.05	<0.002	<0.10	<0.10
Echu Gebere	2.51	<0.10	<0.10	0.68	<0.05	<0.002	<0.10	<0.10
Mekane Biruh	3.28	<0.10	<0.10	0.41	<0.05	<0.002	<0.10	<0.10
Were Geno	2.78	<0.10	<0.10	0.75	<0.05	<0.002	<0.10	<0.10
Min	2.51	-	-	0.41	-	-	-	-
Max	11.5	-	-	0.75	-	-	-	-
Average	5.0175	-	-	0.6225	-	-	-	-

Appendix 5 Concentration of Heavy metals in soil samples (mg /kg dwt-1) of the minor rainy season data

Sites		Heavy Metals concentration					
	Cu	Fe	Mn	Zn	Cd	Cr	Ni	Pb
Saris 58	24.14	140.39	1524	402.4	4.65	48.89	208.66	69
Echu Gebere	52.18	244.015	1864	303	6.76	142.64	182.99	128.52
Mekane Biruh	34.82	191.935	1353	284.9	5.16	55.36	116.2	88.94
Were Geno	33.57	155.85	1185	84.025	4.12	60.85	161.14	65.28
Min	24.14	140.39	1185	84.025	4.12	48.89	116.2	65.28
Max	52.18	244.015	1864	402.4	6.76	142.64	208.66	128.52
Average	28.942	146.438	1185.2	214.865	4.138	61.548	133.798	70.348

Appendix 6 Concentration of Heavy metals in soil samples (mg /kg dwt-1) of the main rainy season data

Sampling Sites	Concentrations of Heavy Metals(mg /kg dwt^{-1})							
	Fe	Cu	Zn	Mn	Pb	Cd	Cr	Ni
Saris 58	4409.64	2.34	6.71	158	5.18	<0.10	63.11	<0.10
Echu Gebere	3947.4	2.28	8.05	109.94	4.45	<0.10	70.79	<0.10
Mekane Biruh	3910.39	2.36	8.25	118.95	4	<0.10	53.97	<0.10
Were Geno	4852.99	1.72	5.74	146.7	4.1	<0.10	37.9	<0.10
Min	3910.39	1.72	5.74	109.94	4	-	37.9	-
Max	4852.99	2.36	8.25	158	5.18	-	70.79	-
Average	4280.11	2.18	7.19	133.40	4.43	-	56.44	-

Appendix 7 Concentration of heavy metals in vegetable samples (mg /kg dwt-1) of the minor rainy season data

Sites	Heavy Metals concentration								
	Vegetables	Cu	Fe	Mn	Zn	Cd	Cr	Ni	Pb
Saris 58	Swiss Chard	6.48	327	159.5	494.75	0.58	14.46	156.29	3.99
	Kale	4.68	292	78.75	399	0	10.36	140.32	4.53
	Lettuce	7.08	438.75	90.25	349.5	0	10.99	201.34	1.37
Echu Gebere	Swiss Chard	8.48	338.75	115.5	308.75	3.37	16.72	206.12	0
	Kale	6.45	326.5	62	462.25	0	10.7	218.77	5.4
	Lettuce	14.33	2458.75	406.25	343.5	0.23	17.7	193.01	9.5
Mekane Biruh	Swiss Chard	14.12	293.75	161.25	312.75	0.01	15.51	238.07	0
	Kale	7.29	257.75	60.25	502.75	1.07	10.31	221.83	0
	Lettuce	8.89	626.75	86.75	267.75	0.16	12.24	230.94	2.69
Were Geno	Swiss Chard	11.28	434.5	166.25	303.75	1.12	11.38	215.35	0.1
	Kale	545	410.25	94.75	631.25	1.37	9.53	193.3	3.51
	Lettuce	12.97	3027.75	372.5	523	0	16.55	225.65	9.29
Average	Swiss Chard	10.09	348.50	150.63	355.00	1.27	14.52	203.96	1.02
	Kale	140.86	321.63	73.94	498.81	0.61	10.23	193.56	3.36
	Lettuce	10.82	1638.00	238.94	370.94	0.10	14.37	212.74	5.71

Appendix 8 Concentration of heavy metals in vegetable samples (mg /kg dwt-1) of the main rainy season data

Sampling Sites	Vegetables	Concentrations of Heavy Metals ((mg /kg dwt^{-1})							
		Fe	Cu	Zn	Mn	Pb	Cd	Cr	Ni
Saris 58	Swiss Chard	165.45	0.32	3.56	2.25	0.38	<0.1	0.31	0.12
	Kale	27.81	<0.10	2.51	2.25	<0.10	<0.10	<0.10	<0.10
	Lettuce	147.99	1.13	3.68	6.96	<0.10	<0.10	0.81	<0.10
Echu Gebere	Swiss Chard	327.46	0.83	4.32	14.17	0.54	<0.10	4.61	0.4
	Kale	22.45	0.32	3.61	3.32	<0.10	<0.11	<0.12	<0.13
	Lettuce	500.41	0.38	5.13	15.96	3.1	0.11	23.57	0.65
Mekane Biruh	Swiss Chard	616.02	0.82	3.16	24.57	<0.10	<0.10	3.73	0.54
	Kale	50.2	0.49	3.67	4.06	<0.10	0.15	2.23	0.1
	Lettuce	1221.27	1.73	6.29	33.9	1.84	0.13	1.1	1.26
Were Geno	Swiss Chard	400.53	0.25	2.3	14.79	<0.10	<0.10	<0.10	0.3
	Kale	70.55	0.36	2.38	3.39	<0.1	<0.10	1.38	<0.10
	Lettuce	216.21	0.63	3.52	9.23	<0.10	0.1	<0.10	0.21
Average	Swiss Chard	377.365	0.56	3.34	13.95	0.46	0	2.883	0.34
	Kale	42.7525	0.39	3.04	3.255	0	0.15	1.805	0.1
	Lettuce	521.47	0.97	4.66	16.51	2.47	0.11	8.493	0.71