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Causes and impact of surface water pollution in Addis Ababa, Ethiopia

Orsaker och effekter av ytvattenföroreningar i Addis Abeba, Etiopien

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Abstract

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Surface water is globally becoming more and more a scarce resource, and in Addis Ababa the capital of Ethiopia, river water quality has been degraded due to anthropological forcing for many years. Therefore, the study objective was to investigate causes and impact of surface water pollution in Kebena and Great Akaki rivers. The technical aspect of the study focused on analysing the parameters E. coli, phosphate, nitrate and total ammonia nitrogen in 34 different sampling sites in the western part of the Great Akaki catchment. The other aspect was to evaluate authorities' and companies' perspective on the water quality, usage and future plans to mitigate further pollution of rivers. Another perspective was to interview households and farmers regarding their view on usage, water quality and health risks.

The main finding was a high surface water contamination in both Kebena and Akaki river, throughout the city, mostly from domestic, municipality and industrial wastewater and solid waste. E. coli concentrations exceeded thresholds given by WHO. Concentrations of phosphate and total ammonia nitrogen strongly indicated eutrophication. Nitrate values were lower than expected with no perceived health risk. The interview study with authorities, households and farmers indicated irrigation as the main usage. Little to moderate health risks perceived by farm users and high health risks perceived by authorities for farmers were found.

Therefore, addressing a stronger collaboration between authorities and the local community is important. In addition, the implementation of mitigation strategies should be strengthened and the stakeholders need to be accountable for their actions. A continued monitoring of pollutants as well as a multi-sectoral approach to solid waste and wastewater management will help improve the river water quality.

Keywords: Akaki river, E. coli, health risk, interview study, irrigation, physico-chemical parameters, water samples

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REFERAT
Orsaker och effekter av ytvattenföroreningar i Addis Abeba, Etiopien
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Ytvatten blir globalt allt mer en knapp resurs och i Addis Abeba, huvudstaden i Etiopien, har flodernas vattenkvalitet under många år försämrats på grund av antropogen påverkan. Denna studie syftar till att undersöka orsaker och påverkan på ytvattenföroreningar i floderna Kebena och Akaki. Den tekniska aspekten av studien inkluderar vattenanalyser av parametrarna *E.coli*, fosfat, nitrat och totalt ammonium kväve som utfördes på 34 olika provtagningsplatser i västra delen av Great Akakis avrinningsområde. Den andra aspekten var att utvärdera myndigheters och företags perspektiv på vattenkvalité, flodvattnets användningsområden och framtida planer för förbättring av föroreningsgraden i floderna. Ett annat perspektiv var att intervjua hushåll och lantbrukare angående deras bild av ytvattenanvändning, om vattenkvaliteten och hälsorisker.

Studiens huvudsakliga upptäckt är en genomgående hög föroreningsgrad i stadens flodvatten. Föroreningen består till största del av avlopp och avfall från hushåll, kommuner och industrier. Koncentrationerna av *E.coli* överskred WHO:s gränsvärden. Halterna av fosfat och totalt ammoniumkväve indikerade övergödning. Nitratvärdena visade lägre halter än förväntat och därmed ingen påvisad hälsorisk. Intervjustudien med myndigheter, hushåll och lantbrukare påvisade att ytvattnet mest används för bevattning av åkermark. Lantbrukarna uppfattade en liten till medelhög hälsorisk med denna användning, medan myndigheter ansåg att lantbrukarna utsattes för en hög risk.

Därför är ett starkare samarbete mellan myndigheter och samhället viktigt. Dessutom behöver implementationen av förbättringsåtgärder förbättras och alla aktörer måste göras ansvariga för sina handlingar. En fortsatt övervakning av föroreningar och ett multi-disciplinärt arbetssätt vid avfall- och avloppshantering kommer att vara till hjälp vid förbättring av vattenkvaliteten i floden.

Nyckelord: Akaki, *E. coli*, fysikalisk-kemiska parametrar, hälsorisker, intervjustudie, vattenprover

PREFACE

This Master's Thesis is a joint 30 credits degree project of the Master Programme in Environmental and Water Engineering at Uppsala University and Swedish University of Agricultural Sciences. The project has been a result from discussions with Professor Girma Gebresenbet and Dr. Annika C. Nordin, Department of Energy and Technology at Swedish University of Agricultural Sciences on the idea of evaluating the water quality and impact, and to be of benefits to a community far away, in a city in Addis Ababa, Ethiopia. The project has been funded by Swedish International Development Cooperation Agency (SIDA) under the programs **Minor Field Study** (Jonathan Sigvant) and **Linnaeus-Palme** (Malin Eriksson). Furthermore, the project has been a collaboration between Swedish University of Agricultural Sciences and Addis Ababa University, Institute of Technology. The field data collection was conducted in Addis Ababa, Institute of Technology under the supervision of Dr. Bikila Teklu Wodajo, Dr. Annika Nordin and Professor Girma Gebresenbet, during a three month stay in Addis Ababa.

In field Jonathan Sigvant and Malin Eriksson participated equally in the work of interviews, observations and water sample analysis. Chapter 1 and 7 is the product of shared discussions and collaboration, while Jonathan had the head responsibility for chapter 2, 4.1, 5.1 and 5.5. Malin had the head responsibility for the chapters 4.3, 5.2 and 5.3. The rest of the report was written together and both authors take on responsibility for the entire report.

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POPULÄRVETENSKAPLIG SAMMANFATTNING
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Vatten är en av vår världs mest värdefulla resurser. Ett av de *Globala målen för hållbar utveckling*, antagna av FN 2015, är *Rent vatten och sanitet*, eftersom rent vatten är grundläggande för människors hälsa och utveckling. Samtidigt är förorenade floder och sjöar ett stort problem i världen och vatten börjar bli en mer och mer begränsad resurs. Sjöar och vattendrag utsätts för förorening från många olika källor, till exempel jordbruk och dålig avfall- och avloppshantering. Detta får följder både för livet i vattnet och för de människor som är beroende av vattenkällan. Ett problem som är mycket uppmärksammat är övergödning. Övergödning beror på att näringsämnen, oftast fosfor och nitrat, tillförs vattendrag i större utsträckning än normalt på grund av mänsklig aktivitet. Det näringsämne som oftast begränsar tillväxten i sötvatten är fosfor, så när fosfor plötsligt finns i större mängder kan växter och alger växa till sig mycket mer än innan. Detta orsakar ibland så kallade algblomningar, då ytan av vattnet täcks av alger. En följd av detta blir att mindre solljus kan tränga ner i vattnet, vilket påverkar de djur och växter som lever på ett större djup. När växterna och algerna dör sjunker de till botten och bryts sedan ner, en process som förbrukar mycket syre. En ökad mängd växter att bryta ner leder till en större förbrukning av syre, vilket i förlängningen leder till syrebrist. Mindre ljusinsläpp och stor syreförbrukning leder tillsammans till döda bottnar, det vill säga bottnar där varken djur eller växter kan leva. En viktig orsak till övergödning är i stora delar av världen jordbruket, men näring kan också tillföras vattnet från urbana miljöer, oftast som en följd av dålig hantering av avfall och avlopp. Ett av hushållens bidrag till fosforförorening är tvättmedel, som ofta innehåller så kallade fosfater.

Dålig hantering av avlopp kan också få följder för människors hälsa. Då mänsklig urin och avföring sprids till vatten så sprids också de smittämnen som kan förekomma i avföringen. Exempel på sjukdomar som kan spridas är tyfoid, kolera och mask. Icke fullständig rening av avloppsvatten kan också leda till spridning av virussjukdomar. För att säkerställa att människors hälsa inte påverkas negativt av vatten finns gränsvärden givna av Världshälsoorganisationen (WHO) för hur mycket av vissa ämnen som får förekomma i dricksvatten eller vatten som används i jordbruk.

Jordens befolkning ökar och fler och fler människor bosätter sig i städerna. Mellan åren 2000 och 2015 fördubblades antalet människor som bor i städer världen över. I många delar av världen hinner infrastrukturen för avfall och avlopp inte byggas ut i samma takt som befolkningsökningen. Addis Abeba, huvudstaden i Etiopien, är ett exempel på en sådan plats. Där är endast 16% av staden anslutet till ett avloppssystem och industrier släpper ut sitt avloppsvatten direkt ut i floderna, utan rening. Samtidigt har bönder inget annat val än att använda sig av flodvattnet för bevattning av sina åkrar under torrperioderna.

I denna studie undersöktes vad som orsakar föroreningar av vattendrag i Addis Abeba. Kvaliteten på vattnet i floderna i staden undersöktes genom att samla in vattenprover från olika platser i de olika floderna i staden samt i sjön Aba Samuel, som floderna mynnar ut i. Koncentrationerna av nitrat, fosfat och ammonium undersöktes, framförallt för att bedöma huruvida vattendragen var övergödda. Dessutom bestämdes koncentrationen av bakterien *E. coli*. Denna bakterie används inom forskningen för att ta reda på om det finns rester från avföring från människor eller djur. Inom projektets ramar undersöktes också hur vattnets grad av förorening påverkar de som lever kring floderna. Det gjordes genom att genomföra intervjuer med hushåll och bönder. För att få en bättre bild av hur föroreningsläget såg ut och vad som görs för att förhindra förorening och rena vattnet genomfördes intervjuer även med myndigheter och företag. Floderna var i fokus under hela projekttiden och alla observationer relaterade till projektets syfte registrerades, vilket bidrog till att skapa en bild av föroreningsgraden och vad vattnet används till.

Observationer och intervjuer visade att det är allmänt känt i staden att de industrier som finns inte renar sina utsläpp och att mycket av stadens avlopp och avfall hamnar direkt i floderna. Under insamlingen av vattenprover blev det tydligt att floderna är stadens ”baksida”. Här dumpas avfall från både hushåll och industrier och människor som inte har något hem använder flodkanterna som sin toalett.

I vattenproverna hittades mycket *E. coli*, vilket innebär att det är förorenat av fekalier. Detta innebär i sin tur att vattnet inte uppfyller de riktlinjer som satts av WHO och inte är lämpligt att använda till bevattning. Risken att hälsofarliga bakterier, virus och andra organismer sprids till det som odlas är stor och de som sedan äter grödorna riskerar att bli sjuka.

Analyser av vattenproven visade också att vattnet innehåller höga koncentrationer av ammonium och fosfat. Däremot var halterna av nitrat relativt låga, något som är positivt då höga halter nitrat kan vara skadligt för människor. De höga koncentrationerna av ammonium och fosfat talar om att både floderna och sjön Aba Samuel är övergödda. I Aba Samuel observerades mycket algblomning, ytterligare ett tecken på övergödning. Låga koncentrationer av nitrat kan förklaras av att det finns mycket organiskt material i floderna, vilket leder till en hög förbrukning av syre och därmed förhindrar att kväve i andra former omvandlas till nitrat.

På grund av att vattnet är så pass smutsigt används det nästan inte alls av de som bor i staden. Endast de som är riktigt fattiga använder vattnet för att tvätta sig och sina kläder. Utanför staden används flodvattnet dock till bevattning av åkrar, där framförallt olika typer av grönsaker odlas. Bönderna är medvetna om att vattnet är förorenat och därför använder de det inte i sina hushåll, men de flesta ser ingen risk med bevattningen. Intervjuerna med myndigheter visade att det finns en stor medvetenhet om att floderna är förorenade och vilka problem det orsakar. Det finns också många lagar som ska förhindra förorening, till exempel måste fabriker rena sitt avloppsvatten tills det

uppfyller vissa krav och gränsvärden. Tyvärr följs inte dessa lagar och den bevakning av industrierna som krävs finns inte i tillräckligt stor omfattning. När ett företag efter ett antal tillsägningar fortfarande inte renar sitt vatten får de ändå fortsätta med sin verksamhet eftersom det vore dåligt för landets ekonomi om de stängs ner.
Tjänstemän och boende i staden är alla överens om att det krävs ett bättre samarbete mellan olika myndigheter, och en ökad förståelse kring problemen hos befolkningen för att lösa föroreningsproblematiken. Dessutom måste de myndigheter som arbetar med frågorna börja ta sitt ansvar och inte skjuta över problemet på någon annan. Det är också viktigt att de som idag utsätts för risker blir informerade om detta, så att de efter bästa förmåga kan skydda sig.

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1 INTRODUCTION

The world's most valuable natural resource is water, and one of the most pressing global environmental issues is the contamination of water resources. The United Nations' *2030 Agenda for Sustainable Development* declares the importance of water by Goal 6 *Clean water and sanitation*. Changes in physical outline of rivers and lakes, addition of anthropologic pollutants and introduction of invasive species create a poor water quality and has a huge impact on the life quality of those using the water. (UNESCO, 2019). Human impact on aquatic ecosystems is big and ecosystem services are threatened to be diminished (Beyene *et al.* 2009a). To evaluate causes and impacts on river water quality and to develop mitigation strategies, monitoring of pollutants is needed (Awoke *et al.*, 2016)

Pollutants can be many different substances and reach the river from many different sources. One common problem is addition of nutrients as phosphorous and nitrogen, which can cause eutrophication in rivers and lakes. Nutrients originate from both agricultural and urban areas; through fertilizers, detergents and human and animal excreta (Mekonnen & Hoekstra, 2018; Sawant *et al.*, 2018). Eutrophication can radically change the ecosystems, causing big growth of some organisms and death of others (Nyenje *et al.*, 2010). Another issue is contamination of untreated or insufficiently treated sewage in surface waters, since many farmers in developing countries have no choice but to use surface water from the natural system for irrigation (Woldetsadik *et al.*, 2018). This usage of insufficiently treated wastewater in irrigation can severely harm farmers and people living around the rivers (Qadir *et al.*, 2010). In developing countries, urbanization outgrows the sanitation infrastructure and waste disposal practices, and untreated sewage and solid waste is usually released into the rivers of the cities (Woldetsadik *et al.*, 2018).

Ethiopia has one of Africa's fastest growing populations. The urban population reached 19 million people in 2015, of whom around 4 million resided in the capital Addis Ababa. In 2030, Ethiopia's urban population is expected to reach 37 million (UN, 2018). Along with the increased population comes an establishment of industries. In Addis Ababa there are now more than 2,000 industries and around 90% of these release their effluents untreated to the river network (Mengesha *et al.*, 2017; Yohannes & Elias, 2017). Urban farmers in Addis Ababa have been growing vegetables for the last 60 years, using the Akaki river as the main source of irrigation water. Today around 60% of the city's vegetables are irrigated with river water (Aschale *et al.*, 2017; Woldetsadik *et al.*, 2017). Because of an increasing population, urban farming, industrial expansion and lack of sewage treatment, the city of Addis Ababa is suffering from serious surface water pollution (Yohannes & Elias, 2017). To establish sustainable conditions in the surface water and reduce human health risks, addressing the pollution problem and start mitigation processes is highly needed. Environmental studies as well as establishment of management systems are necessary.

1.1 OBJECTIVE

1.1.1 General objective

The main objective of the project was to investigate causes and impacts of surface water pollution in Addis Ababa, the capital city of Ethiopia. Major contamination sources, such as solid waste and discharge of untreated wastewater from industries or households, were identified. The impact of domestic wastewater and farming on the water quality and the spatial distribution of pollution in the city was evaluated by water samples. The project also provided an understanding of how the surface water is used as a resource and what risks the users are exposed to with the current water quality. Another objective was to investigate the organisation behind local water management and what means that are taken to improve the water quality of the city rivers.

1.1.2 Specific objective

- How are the major contamination sources perceived by authorities, households and farmers?
- How can the quality of surface waters of Addis Ababa be described with regard to content of faecal indicator bacteria, phosphorous and nitrogen?
- Can any trends in spatial distribution of pollutants be identified by monitoring the concentrations of *Escherichia coli* (*E. coli)*, phosphate, ammonium and nitrate at different locations?
- Is the surface water used as drinking water, for any household chores or in agricultural practices?
- Are there any risks regarding public health with the water quality and water usages?
- Are there any mitigation plans in place to improve the quality of the surface waters of Addis Ababa?

Hypothesis for the project were that:

- A major contamination source is domestic wastewater.
- The surface waters contain bacteria from faecal contamination.
- The surface waters are somewhat eutrophicated.
- Concentrations of *E. coli*, phosphate, ammonium and nitrate at different locations will show that the river water continuously gets more contaminated during its passage through the city.
- Surface water is used for drinking, bathing, washing and irrigation.
- There are no mitigation plans in place.

1.2 LIMITATIONS

This study was limited to the river network in the central part of the city Addis Ababa, which form tributary to the Great Akaki and flow out into lake Aba Samuel, south of the city. The parameters studied were *E. coli*, phosphate, nitrate and ammonium.

For the interview study, authorities and companies were chosen with regard to relevant professions and insight in the river water quality, usage and policies. Only authorities and companies working directly with the field of study were contacted. Furthermore, households in the northern part of the city and farmers south of the city, in the downstream area of Kebena and Akaki river were selected, to represent the usage both in a dense urban area and a farming area.

2 BACKGROUND

One of the principal causes of health problems is linked to poor water management (Raji & Oyeniyi, 2017). Wastewater contaminated water can become a health risk because of the presence of pathogens, especially from faeces, depending on the usage of the water resource. Usage in agriculture poses a risk for both farmers in contact with the water and crop consumers through transfer of pathogens from water to crop (WHO, 2006). Some examples of waterborne diseases are gastroenteritis, cholera, hepatitis, diarrhoea, typhoid fever and dysentery (Belachew *et al.*, 2018). To determine faecal contamination *E. coli* is commonly used as an indicator organism (Raji & Oyeniyi, 2017; Woldetsadik *et al.*, 2017).

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

Another anthropogenic source of phosphorous and nitrogen is untreated or insufficiently treated wastewater. The average nitrogen and phosphorous content in excreta from adults in the Ethiopian village Bolo Silasie (located 75 km east of Addis Ababa) is 3.9 kg per person per year respectively 0.85 kg per person per year (Dagerskog, 2017). This amount highly depends on the diet. Washing clothes in surface water, a common practice in many developing countries, also directly add phosphorous through usage of detergents and soaps which many times contains phosphates. One bucket of water (15 litre) for washing of cloth will be unsuitable for secondary use, such as irrigation or drinking, after adding a few grams of detergents or soap (Sawant *et al.*, 2018).

The anthropogenic contribution of phosphorous and nitrogen cause increased nutrient loads in rivers and lakes. This increase of nutrients can cause a higher biomass production and a growth of harmful cyanobacteria (Nyenje *et al.*, 2010). With an increased biomass production, the degradation of organic materials will increase, causing low oxygen concentrations at the lake/riverbed. It also limits the amount of light that can pass through the water column, affecting deep living organisms.

Since water is a scarce resource in many parts of the world, the World Health Organisation (WHO) discuss how to use wastewater for irrigation in agriculture in a safe way in the report *Guidelines for the safe use of wastewater, excreta and greywater* (WHO, 2006). Amongst other parameters they give thresholds for the concentration of *E. coli* in the irrigation water (Table 1). They classify the irrigation as restricted or unrestricted where restricted irrigation implies that the crops that are irrigated are not eaten raw, while unrestricted irrigation is the use on crops that are normally eaten raw.

Table 1. Thresholds for *E. coli* concentrations in wastewater used for unrestricted or restricted irrigation

Type of irrigation	*E. coli* per 100 ml
Unrestricted	$_{a}10^{3}$–$_{b}10^{4}$
Restricted	$_{c}10^{4}$–$_{d}10^{5}$

[a]Root crops, [b]Leaf crops, [c]Labour-intensive, high contact agriculture
[d]Highly mechanized agriculture

The WHO have also given out standards for drinking water (WHO, 2017). Many countries have their own regulation for drinking water, but it is many times based on the WHO standards. The Ethiopian standards (Technical Committee for Water Quality (TC 78), 2013), together with the guides from WHO and standards of the European Union (European Union, 1998) are given in Table 2.

Table 2. Drinking water standards for the parameters NH_4, NO_3 and *E. coli*

Standard	NH_4	NO_3	*E. coli*
WHO[a]	No guideline	50 mg/l	0 in 100 ml
EU[b]	0.5 mg/l[d]	50 mg/l	0 in 100 ml
Ethiopian[c]	1.5[e]	50 mg/l	0 in 100 ml

[a](WHO, 2017). [b] (European Union, 1998). [c](Technical Committee for Water Quality (TC 78), 2013).
[d]As indicator. [e]NH_3+NH_4.

There are several previous studies on river water quality in Ethiopia and Addis Ababa. Awoke *et al*. (2016), focused on ecological status of major river systems in Ethiopia, by evaluating physio-chemical parameters and bioindicators. The physio-chemical parameters showed a deterioration of water quality in surface water in the rivers compared to non-impacted sites, and the study concluded that the river water pollution in Ethiopia is increasing. The Ethiopian Public Health Institute (Mengesha *et al.*, 2017) similarly pointed out, as a result of their study of microbiological, bacteriological and chemical parameters, that the river quality in Addis Ababa is being highly affected by anthropogenic pollution. Beyene *et al.* (2009), and Akalu *et al.* (2011), both assessed the ecological status and resilience in the major rivers in Addis Ababa with macroinvertebrates and diatoms as indicator organisms. The result showed little presences of both organisms in the sampling sites in Akaki river, which indicates a low ecological status.

In previous studies of the Great and Little Akaki rivers in Addis Ababa the concentrations of phosphate have shown to be in the range of 0–25 mg PO_4/l (Akalu *et al.*, 2011; Weldesilassie *et al.*, 2011; Mengesha *et al.*, 2017). Nitrate levels in rivers ranged from 0.21 to 18.2 mg NO_3/l in the Kebena river catchment in dry season (Beyene *et al.*, 2009a; Tegegn, 2012). Looking at the whole city and a mix of dry and wet season the maximum values found is over 850 mg/l (Tegegn, 2012). Previous studies have found concentrations of total ammonia nitrogen (TAN) of 1.4–40 mg/l

(Beyene *et al.*, 2009a; Akalu *et al.*, 2011; Weldesilassie *et al.*, 2011; Mengesha *et al.*, 2017). Where the lower values are from sampling sites in the outskirts of the upstream part of the river.

It has also been concluded that the rivers in Addis Ababa are contaminated by human waste and have *E. coli* concentrations of 0–6.96 $\log_{10}$ /100 ml (Weldesilassie *et al.*, 2011; Mengesha *et al.*, 2017; Woldetsadik *et al.*, 2017; Colombani *et al.*, 2018). Concentrations have shown to be higher in dry season than in wet season (Weldesilassie *et al.*, 2011). The conclusion of all studies is that the levels are higher than what is recommended by the WHO, and the water is not safe to use as an irrigation source (Mengesha *et al.*, 2017).

Another focus in previous studies is metal content, in river water, in sediments and in irrigated crops. Yard *et al.* (2015) investigated the exposure of metals in communities near the Akaki river by measuring metal levels in the surface water as well as in blood, urine and drinking water in 101 households. The study support that high levels of metals are present in the river water, but most of the exposure of metals found was unlikely to cause acute health risks. In the study of Aschale *et al.* (2016), several metal levels in sediments were shown to exceed the standards in sediment quality guidelines. Metal levels have also been studied by Mengesha *et al.* (2017), who concluded that metals are transferred from the river water to soils and crops. Some of the metal levels found in vegetables could pose a health risk for consumers.

When it comes to spatial trends in water quality in Addis Ababa the studies go apart. By evaluation of physio-chemical parameters in Little Akaki and Great Akaki river basins Tegegn (2012) showed that no spatial pattern for the surface water could be found. Between Little Akaki and Great Akaki, the first showed higher pollution levels (Tegegn, 2012). Akalu *et al.* (2011) showed a clear trend of downstream increase of phosphate between the sampling sites in the inner city, with values from sites upstream of the city that are significantly lower than other values. On the other hand, Tegegn (2012) showed a downstream decrease of phosphate, attributed to the presence of parks in the upper part of the catchment. As for phosphate studies show that the concentrations of both nitrate and ammonia are lower upstream of the city, but there is no clear trend of downstream increase or decrease within the city (Beyene *et al.*, 2009a; Akalu *et al.*, 2011).

Some previous studies have investigated health risks and perceived health risks. Mengesha *et al.* (2017), as well as Weldesilassie *et al.* (2011) and Woldetsadik *et al.* 2018) found health risks due to the usage of polluted river water for irrigation, because of metal and pathogen content. The risk may be significantly higher for farm workers downstream compared with upstream for using the same river as an irrigation source (Weldesilassie *et al.*, 2011; Woldetsadik *et al.*, 2018). Woldetsadik *et al.* (2018) found that perceived health risks, related to usages of river water, was skin diseases.

There are also investigations on what is done to mitigate pollution in Addis Ababa. One of the objectives of Awoke *et al.* (2016) was also to evaluate the present policies and regulatory frameworks within management of surface water. The study revealed a lack in cooperation between authorities and stakeholders in management and implementation of regulations. Aschale *et al.* (2016) argue in his study that a “comprehensive environmental management strategy should be formulated to address the pollution of the sediments. In parallel, there should be a strict prohibition of discharge of contaminated wastewater into the river”. Mengesha *et al.* (2017) go as far as to say that it is necessary to not establish more industries along the Akaki river. Mitigation to address surface water pollution calls for a revision of policies as well as greater awareness and a strengthened collaboration between all stakeholders in society (Awoke *et al.*, 2016).

Another relevant field of study is the water consumption of residents in Addis Ababa, since this will affect the surface waters of the city. The daily water consumption per capita in Addis Ababa varies a lot in between studies. Addis Ababa Water Supply and Sewage Authority (AAWSA) is estimated to supply an average of 80 litres per capita per day to its customers of which approximately 20% is due to physical losses in the supply system (Elala, 2011). Another study pointed out that the average domestic water consumption in Addis Ababa is 37 l per day per capita, and that water is on average supplied 4 days a week and then available at 14.8 hours per day (Kidanie, 2015). Kidanie (2015) also showed that in the slum areas of the city the average daily water consumption could instead be estimated to 15.50 litres per capita. In comparison, the study of Woldemariam and Narsiah (2014) showed and average daily water consumption of more than 20 litres per person in 60% of households in Addis Ababa. Adane *et al.* (2017) concluded that in the slum areas in Addis Ababa average water consumption was 11.5–14.6 litres per person and day. Furthermore, a study from 2017, estimated the average daily water consumption to 110 litres per person by using the total observed consumption and the estimated total population of the city in the year of 2012 (Kifle Arsiso *et al.*, 2017).

3 MATERIALS AND METHODS

3.1 SITE DESCRIPTION

Ethiopia is one of Africa's biggest countries with a population of 110 million people and the capital city, Addis Ababa, has a population around 6 million people (UN, 2017). The city is growing fast due to urbanization and is in the process of a huge infrastructure development. Addis Ababa is home to more than 2,000 industries, ranging from potable water, cement, textile, beverage and alcohol, tobacco, leather, tannery, plastic and food factories. The metropole serves as the country's industrial, cultural, administrative, commercial and modern hub (Aschale, 2016). It is also one of the central hubs in Africa, with its many international organisations and institutions. It is home to the African Union, United Nations Economic Commission for Africa and more than hundred embassies. It is said to be Africa's diplomatic capital and a beacon of humanitarian progress nowadays on the African continent.

Addis Ababa is located in the central parts of Ethiopia with the Entotto mountain ridge on the northern side, Figure 1. The city lies in the highland with an altitude ranging from 2,200 to 2,500 m above sea level. The river network within Addis Ababa can be divided into two catchments, the Great Akaki catchment (900 km^2) and the Little Akaki catchment (540 km^2) (Aschale *et al.*, 2017), which both drain to the lake Aba Samuel (Figure 2). From the Great Akaki catchment two major river branches can be distinguished, the Kebena river and the Great Akaki river, each with its own network of smaller tributaries. The Kebena river runs through the dense parts of the city and then joins the Great Akaki river, and in this way forms a sub-basin to the Great Akaki catchment (Figure 2). Apart from the Kebena river, there is one major river in the Kebena catchment, called Bantyketu.

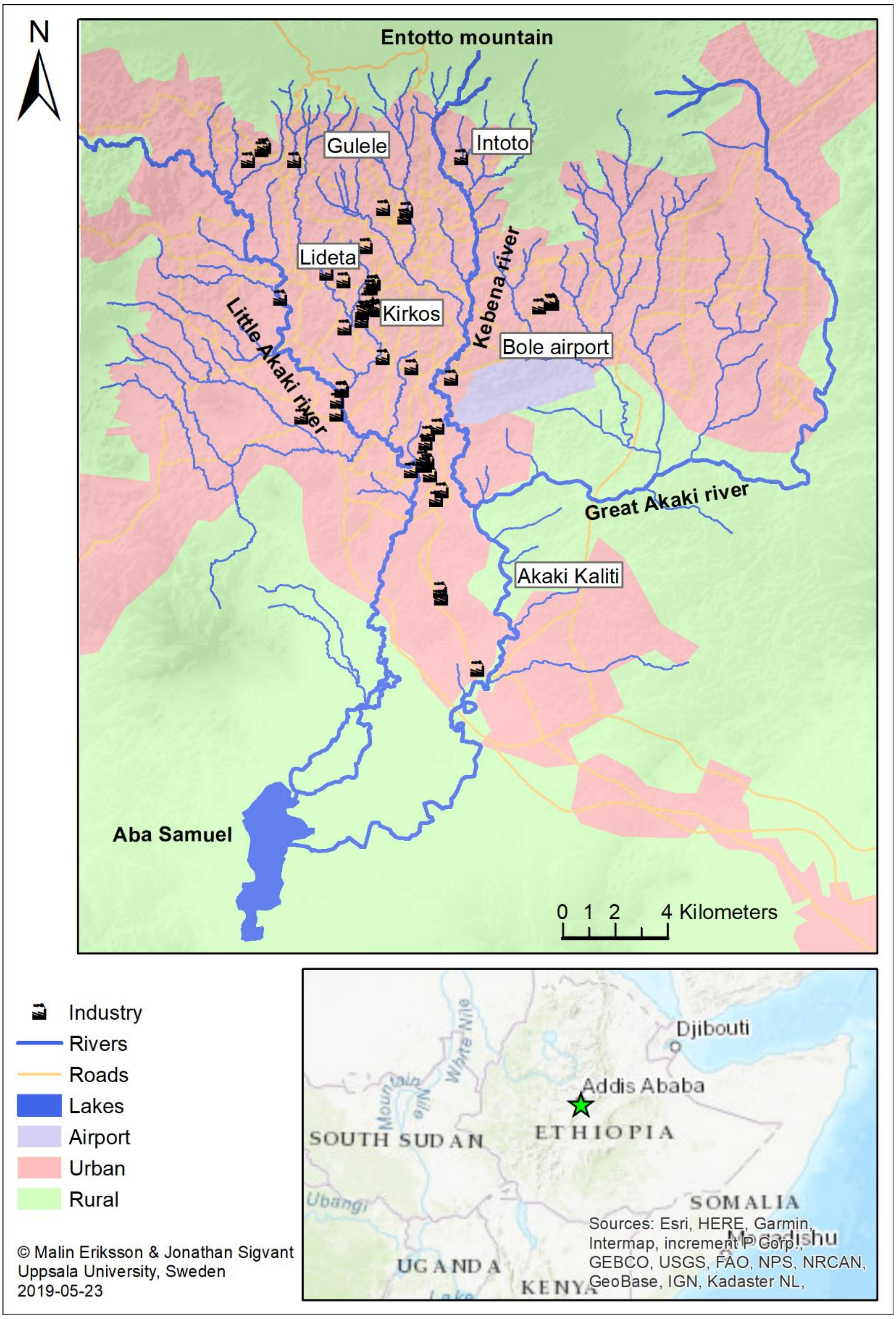

Figure 1. *The extent and location of Addis Ababa, Ethiopia, river network and industries in and around the city. Rural areas are mainly agricultural fields. Map creation details in Appendix D.*

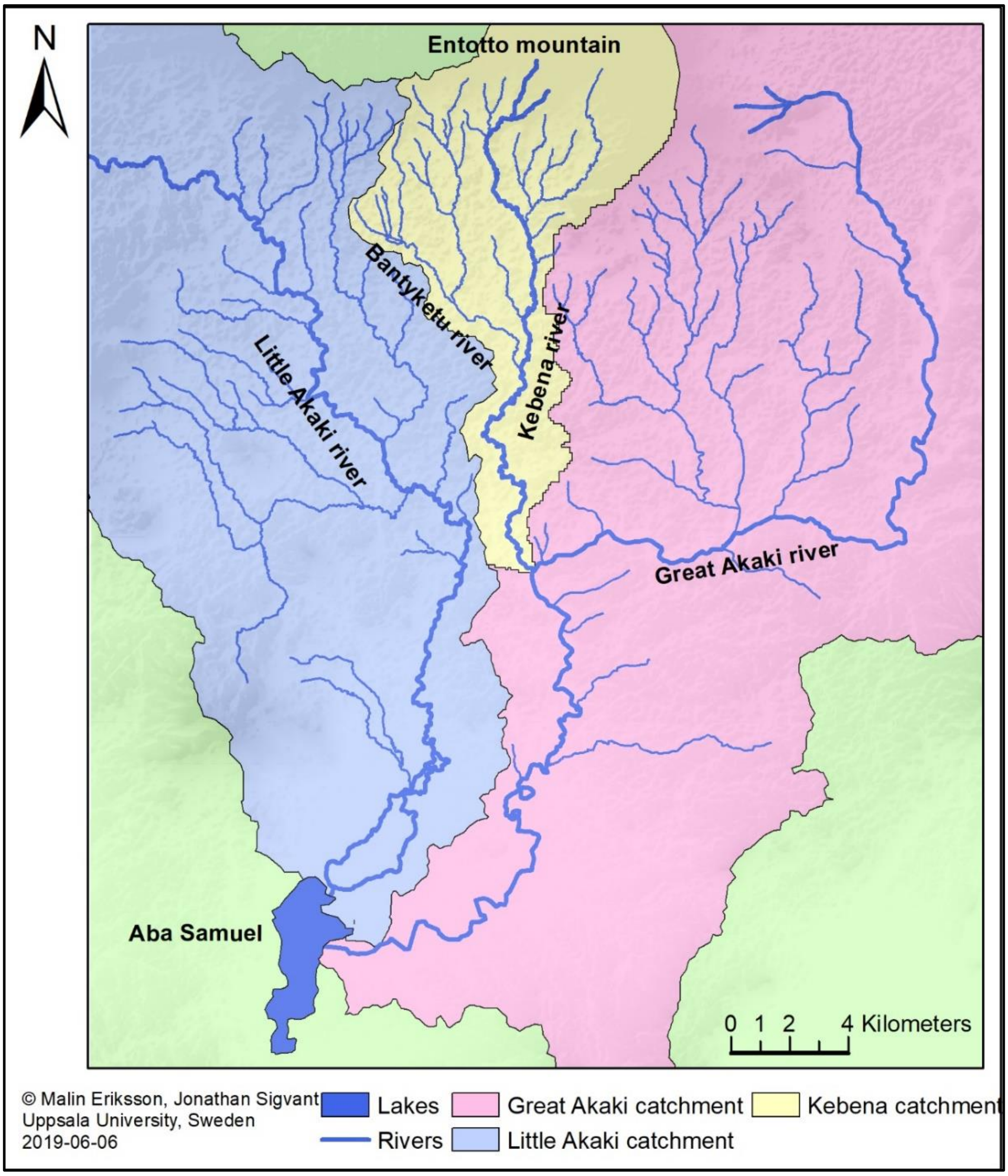

Figure 2. *Little and Great Akaki catchments and the Kebena sub-basin with river networks in and around Addis Ababa, Ethiopia. Map creation details in Appendix D.*

The Little Akaki river is affected by many of the city's industries established alongside the river and its tributaries (Figure 1 above). The catchment of Great Akaki is less densely populated but the up-stream areas are residential and commercial. It then runs through an area of agricultural fields before it joins with the Kebena river. After the join the river flows through a denser city area with industries present, before it leaves the city and enters another agricultural area (Figure 1 above).

Aba Samuel is a lake located around 53 km from the city center of Addis Ababa. It was constructed in late 1930s when a dam was built to generate electricity. Today it is highly polluted from industrial and municipality wastewater coming from either Little Akaki or Great Akaki (Yohannes & Elias, 2017).

The land use in the city includes residential, recreational, urban agricultural, industrial, commercial, open-market and green areas. In the city, most of the riverbank areas and surroundings have settlers living there without permission. Illegal settlement is a big problem in Addis Ababa, and consequently; the river is used as a garbage dump and toilet, when at the same time used for washing cloth. Domestic waste is released without any proper treatment, and pipelines coming from various sources, have outputs with discharge directly into the rivers (Yohannes & Elias, 2017). In the sub-city of Akaki Kaliti, there are many established industries along the Great Akaki river. The wastes generated at these either directly or indirectly end up in the river. Akaki Kaliti also have many landfill areas which are flooded in rain season, resulting in the landfill being carried away to the downstream river network (Aschale, 2016). Agricultural fields are mainly located to the south of Addis Ababa and cover a land area of more than 160 hectares, used to grow vegetables that supply the city markets. Typically, the vegetables are grown close to the river, where irrigation water is present. The water is either directly pumped up using a motor pump or diverted using channels (Aschale, 2016; Aschale *et al.*, 2017).

Addis Ababa has an Afro-Alpine climate and experiences average temperatures of 10 and 25 ℃ in wet respectively dry season. The rain season starts around June and ends around September, whereas the dry season experiences its driest month in April and May in Addis Ababa. The average annual precipitation is approximately 800–1000 mm (Aschale, 2016).

3.2 INTERVIEWS

Interviews were conducted with authorities, one company households and farmers, and all the interviewees were given a clear background and introduction of the intention and objective of the project. Furthermore, the consent from everyone involved was given to record, transcribe and publish the interviews in this report.

To get a greater understanding of the problems that existed and the laws and policies that are in place, meetings with local authorities and one company were organised (Table 3). Semi-structured interviews (Adams, 2015) were conducted with managers and experts at these authorities and the company. For the interviews a questionnaire was constructed as semi-structured interview questions, presented in appendix A, with the themes: perception on water quality, water usage and health risks as well as future plans and mitigation. Depending on the interviewee’s area of expertise more time was spent on different themes. This allowed for information that had not been thought of beforehand to be discovered. At most interview occasions more than one expert was present, which sometimes resulted in several subjects being spoken about at the same time. The interviews were held in English, but further explanations and clarifications were sometimes made by an interpreter present at all meetings. All the interviews were recorded on-site and transcribed. Only things said in English were transcribed.

Representatives from five authorities and one company were interviewed (Table 3, Figure 3). The authorities and the company were selected with regard to relevant professions and insight in the river water quality, usage and policies. Only authorities and companies working directly with the field of study were contacted. The time for the interviews ranged from eight minutes to three hours.

Table 3. Authorities and company interviewed, interview dates and name of interviewees

Authority/company (interview date)	**Contact name, *position/role***
Addis Ababa Environmental Protection Agency (14-02-2019)	Gutama Moroda Gobana[a], *Deputy Manager* Bayou Tolesa, *Environmental Director* Fantu Kifle, *Research team*
Addis Ababa Water and Sewage Authority, (AAWSA) (20-02-2019)	Ephrem Negatu, *Wastewater Treatment and Reuse sub-process Water*
Ethiopian Public Health Institute (14-02-2019)	Abel Weldetinsae, *Associate Researcher, Environmental Public Health and non-infectious disease research team*
G-two Investment and Environmental Consulting PLC (20-02-2019)	Tolosa Deso Rorisa, *Economist*
Oromia[b] Environmental Protection Agency (04-03-2019)	Bekede Wakjire, *Expert in monitoring of Environmental Law, Department Oromia Environment - Forest & Climate Change Authority*
Oromia[b] Special Zone (04-03-2019)	Bekele Yadu, *Environmental Protection Team Leader*

[a]Contact person, not interviewed
[b]Oromia is one of the 11 regions of Ethiopia. Addis Ababa is a detached region, that lies within the geographical extent of Oromia region. The Oromia EPA is located in Addis Ababa.

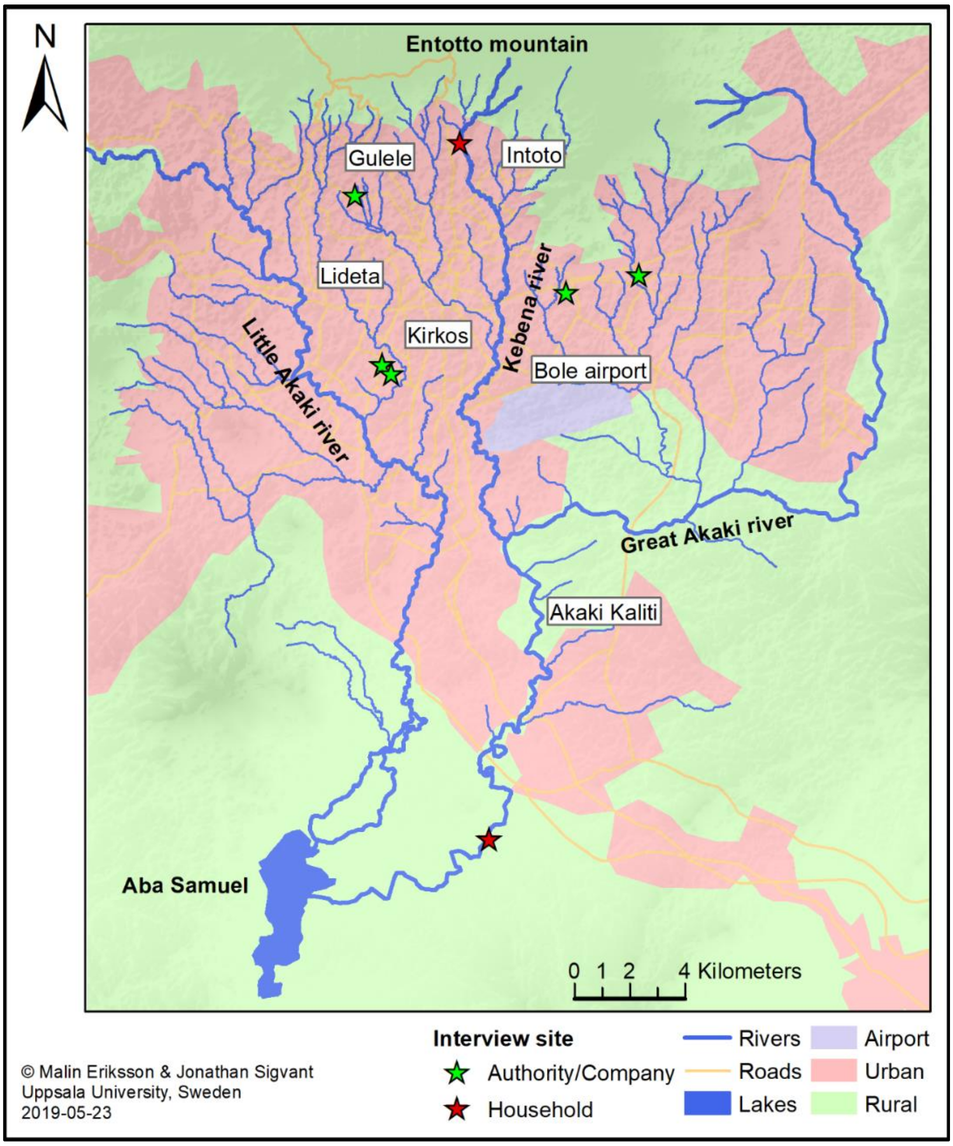

Figure 3*. Location of the interview study in and outside the city of Addis Ababa. Map creation details in Appendix D.*

Semi-structured interviews were also conducted with farmers and herders in the Akaki Kaliti area of Addis Ababa (Figure 3 above) to get a further understanding of the usage of river water. As for the authorities, a questionnaire (Appendix B) was used as a base, but the interviewee was let to speak freely about the usage and the issues that they saw with it. Naturally more time was spent on questions regarding agricultural usage in farmer interviews.

Household interviews were conducted in the same manner in the densely populated area of Intoto (Figure 3 above). The focus for these interviews was the perception of the river water quality and what was being or should be done about it. It was also asked in what way they used the river water.

Interviewees for farmer and household interviews were chosen on-site from who was found by passing on the road and willing to be interviewed. Questions were asked in

English and then translated by an interpreter to Amharic or Oromo. Answers were then translated back to English. Interviews were recorded on-site and transcribed. Only things said in English were transcribed.

The farmer and household interviewees in this study are presented in Table 4 and the area where the interview was conducted is presented in Figure 3 above.

Table 4. Farmers, herders and households, dates in which the interviews were conducted and location of the interview

Name	Date
Kendu Derese, farm owner (1)	24-02-2019
Unknown onion farm worker (2)	24-02-2019
Makone, farm owner (3)	24-02-2019
Tade Demise and Dama Dabala, cattle owners (1)	24-02-2019
Tardesa, household (1)	16-03-2019
Aster, household (2)	16-03-2019
Abera, household (3)	16-03-2019
Basalem, household (4)	16-03-2019

3.3 OBSERVATIONS

Observations were made to identify use of river water that may not be covered by the interviews. Additionally, an intent was made to identify and map as many sources of pollution as possible. Such observations were mainly done during collection of water samples, by photo documenting the appearance of the river at sampling sites and by identifying point sources of pollution (as pipe-outlets) and water use (as laundry). The geographical coordinates of observations were noted and pictures were geo-referenced to these using the phone application Collector for ArcGIS. The sites observed during water sampling covered different type of areas and land use, from slum areas to more modern city parts and farming areas. In additions to the observations done during water sampling, travelling through the city for interviews etc also gave opportunities to observe other parts of the rivers.

3.4 WATER SAMPLE ANALYSIS

3.4.1 Collection of water samples

In total 34 water samples were collected at different sites (Figure 4–10) in and around the city of Addis Ababa. The samples were collected in the Kebena catchment and the southern part of Great Akaki catchment after the join of Kebena river and Great Akaki river. Sampling sites were selected to include parts of the city where rivers were exposed to domestic waste, as well as farming areas downstream of the city, where the river water is used for irrigation. Sites downstream in Great Akaki was selected due to observations of irrigation done during the interview study. Another selection criterion was proximity to pollution sources such as domestic wastewater and hospital effluent outlets. Since it was not possible to access the river anywhere, sites had to be chosen at such places where it was easy to walk down to the river. This is why a majority of the sites were located next to bridges. Another reason for sampling under bridges is that many pipelines, typically for stormwater, run directly into the river at these places, bringing contaminants from the surrounding area. Sampling sites were named after which rivers they were taken in. K for Kebena river, Ba for Bantyketu and all the tributaries flowing into Bantyketu, O for outside to represent the rivers to the east of Kebena and A for Great Akaki after the join with Kebena river. It should be noted that the site K05 is not in the Kebena river but in a small tributary right next to the river, as can be seen in Figure 7.

The sampling was conducted during a period of about three weeks, from March 14 to April 2 in 2019. Samples were mostly collected in the morning. The collection procedure followed the routines of the Department of Aquatic Sciences and Assessment at the Swedish University of Agricultural Sciences (SLU, 2018). In brief, the 100 ml sampling bottle was submerged in the river with the opening facing downstream. With the hand kept downstream of the bottle it was then turned to face the flow. Using water from a first filling of the bottle the cap was rinsed. The bottle was then emptied and refilled using the same procedure. When the depth of the river allowed, the bottles were filled all the way to the top. Water was collected at a place with steady flow. To make sure the river was mixed, so that the water sample would be representative, samples were taken downstream an area of turbulence, when possible. Water samples were put in a cooler immediately after collection and were after reaching the laboratory kept refrigerated at all times to prevent any reactions or microbiological activity.

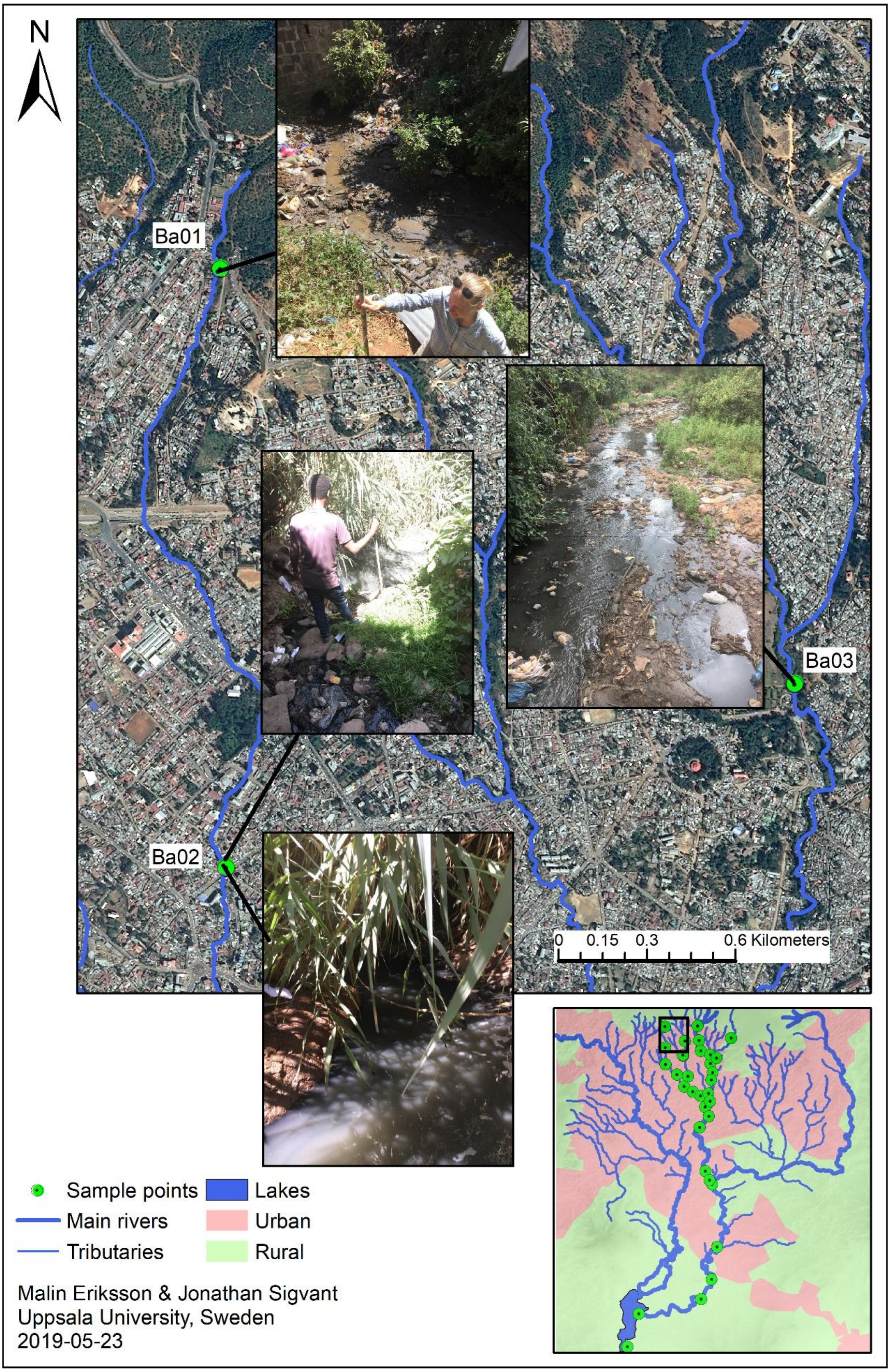

Figure 4. *Sampling sites Ba01, Ba02 and Ba03, location and appearance at the time of sampling. Northern part of Addis Ababa, Ethiopia. Orthophoto © Ethiopian Mapping Agency. Map creation details in Appendix D.*

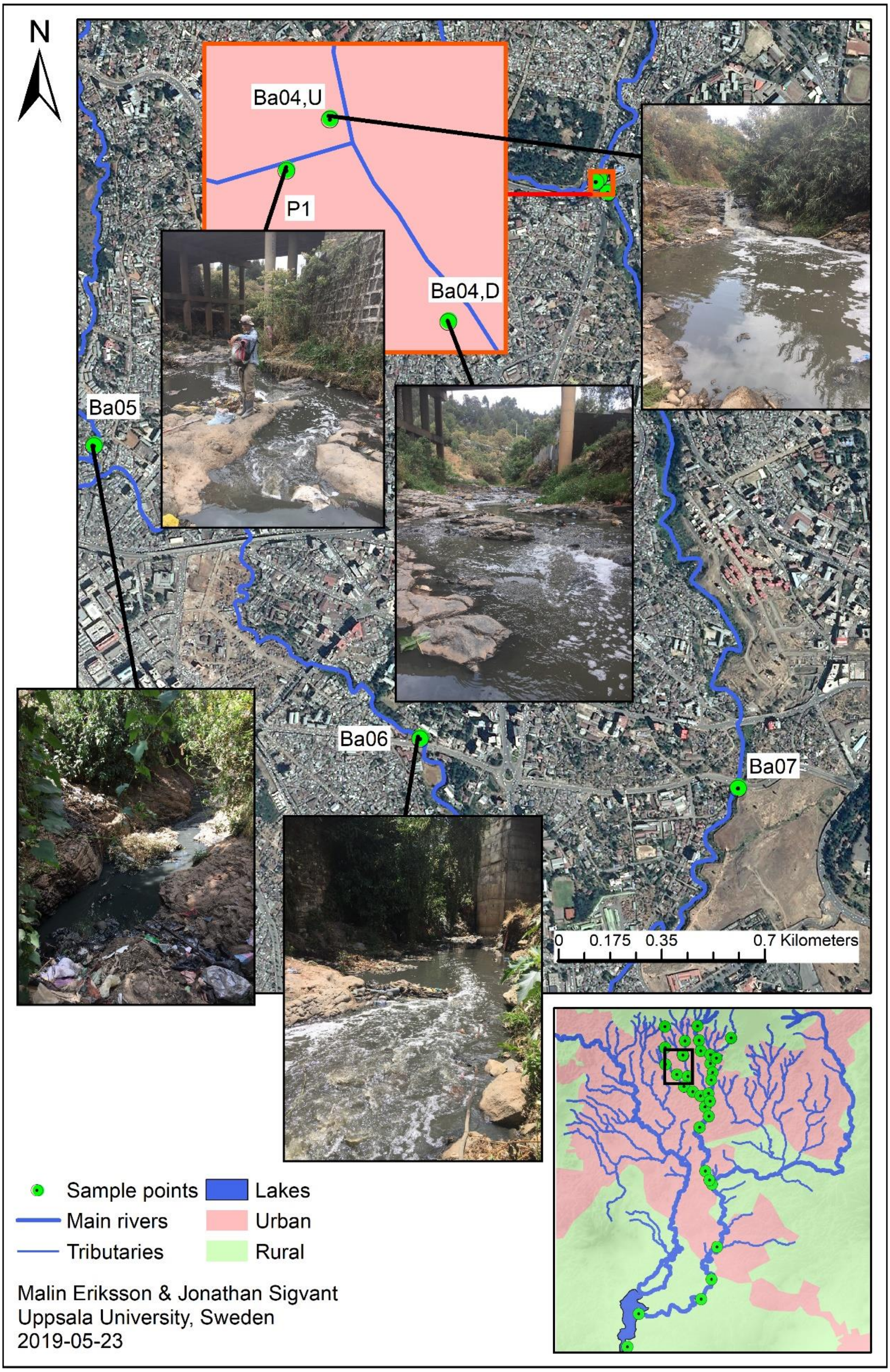

Figure 5. S*ampling sites Ba04,U, Ba04,D, P1, Ba05, Ba06 and Ba07, location and appearance at the time of sampling. Northern part of Addis Ababa, Ethiopia. Orthophoto © Ethiopian Mapping Agency. Map creation details in Appendix D.*

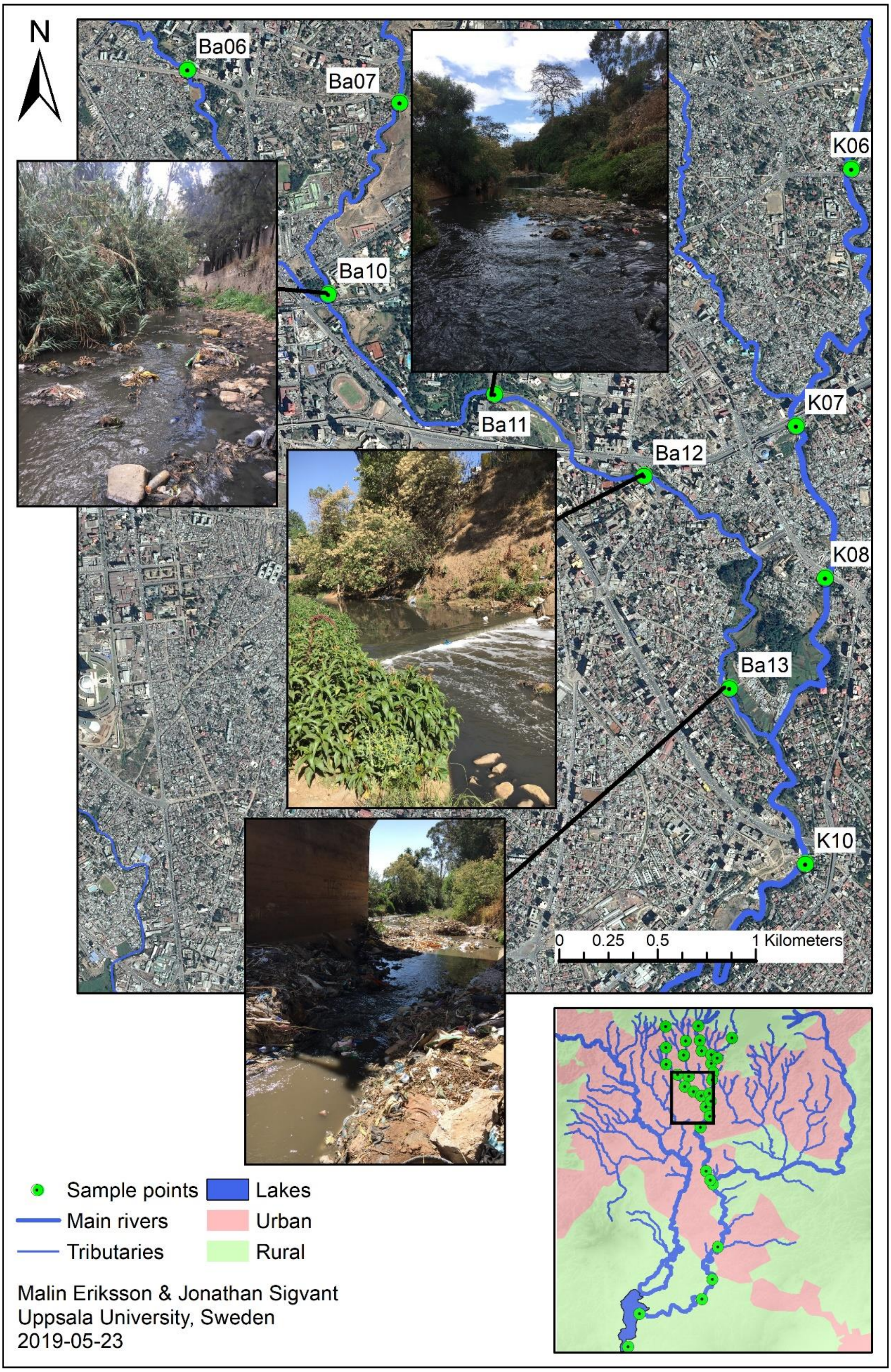

Figure 6. *Sampling sites Ba06, Ba07, Ba10, Ba11, Ba12, Ba13, K06, K07, K08 and K10, location and appearance at the time of sampling. Central part of Addis Ababa, Ethiopia. Orthophoto© Ethiopian Mapping Agency. Map creation details in Appendix D.*

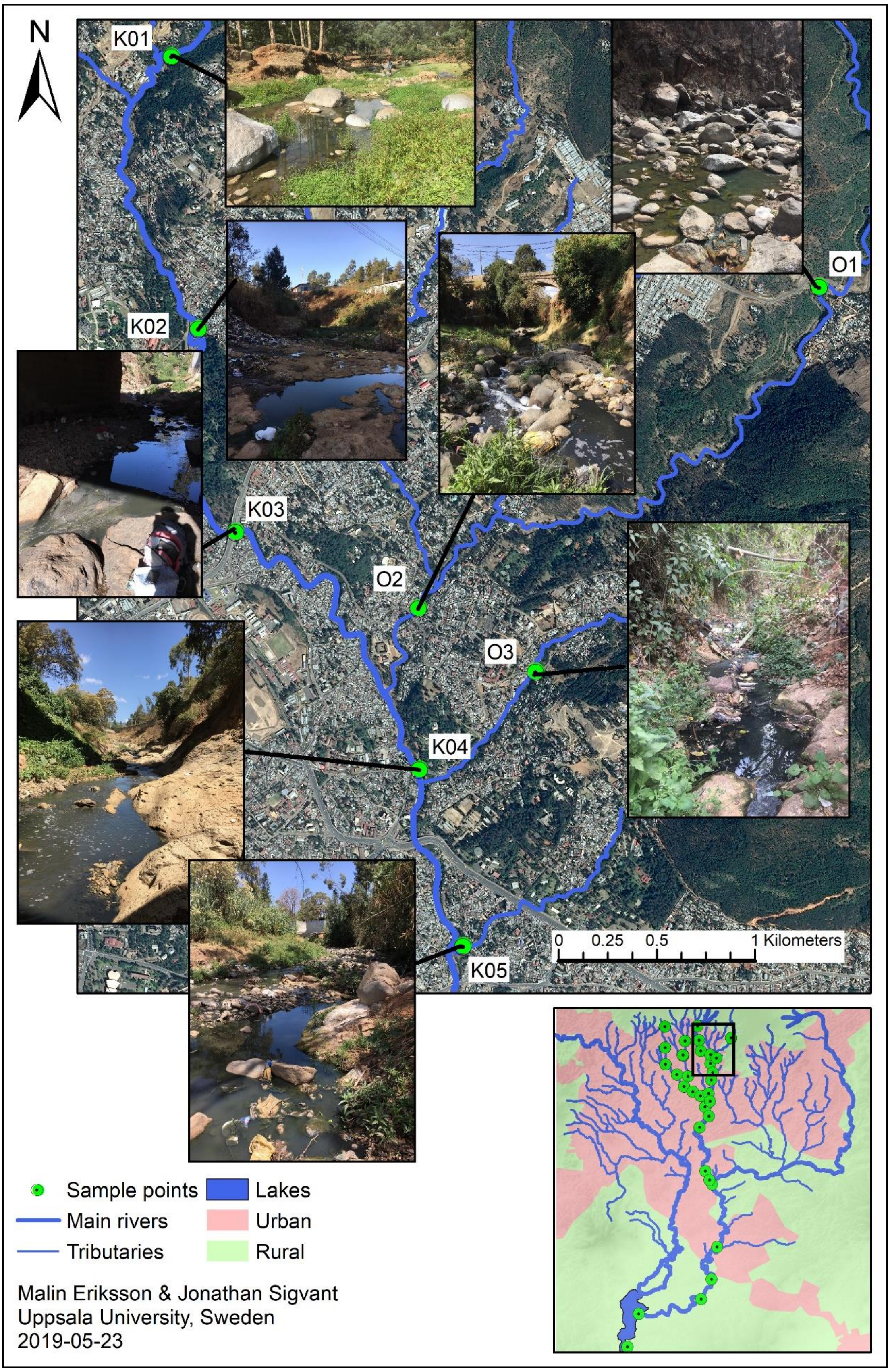

Figure 7. *Sampling sites K01, K02, K03, K04, K05, O1, O2 and O3, location and appearance at the time of sampling. North eastern part of Addis Ababa, Ethiopia. Orthophoto © Ethiopian Mapping Agency. Map creation details in Appendix D.*

Figure 8. *Sampling sites K06, K07, K08, K10, K11, Ba12 and Ba13, location and appearance at the time of sampling. North eastern part of Addis Ababa, Ethiopia. Orthophoto © Ethiopian Mapping Agency. Map creation details in Appendix D.*

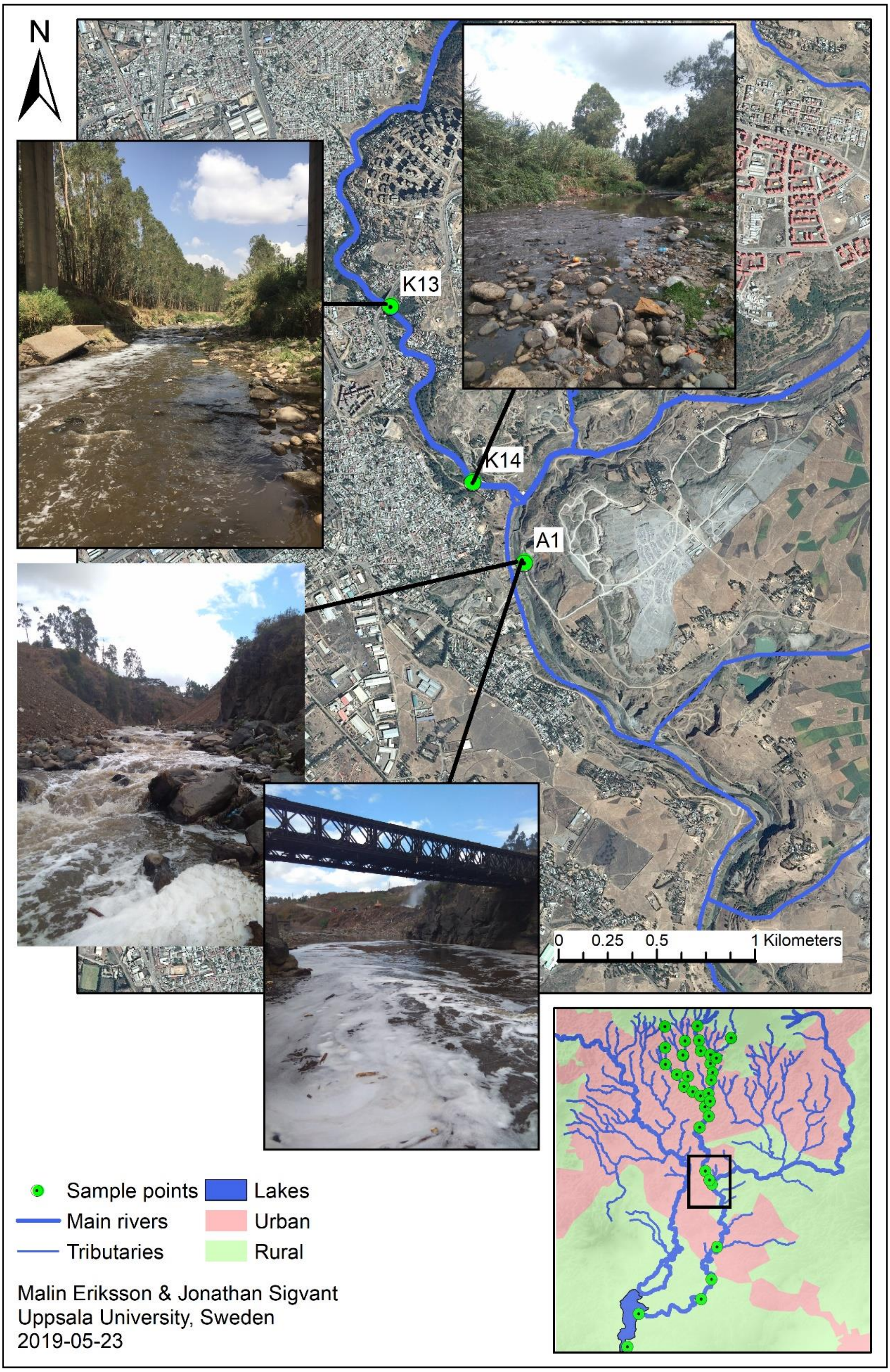

Figure 9. *Sampling sites K13, K14 and A1, location and appearance at the time of sampling. Southern part of Addis Ababa, Ethiopia. Orthophoto © Ethiopian Mapping Agency. Map creation details in Appendix D.*

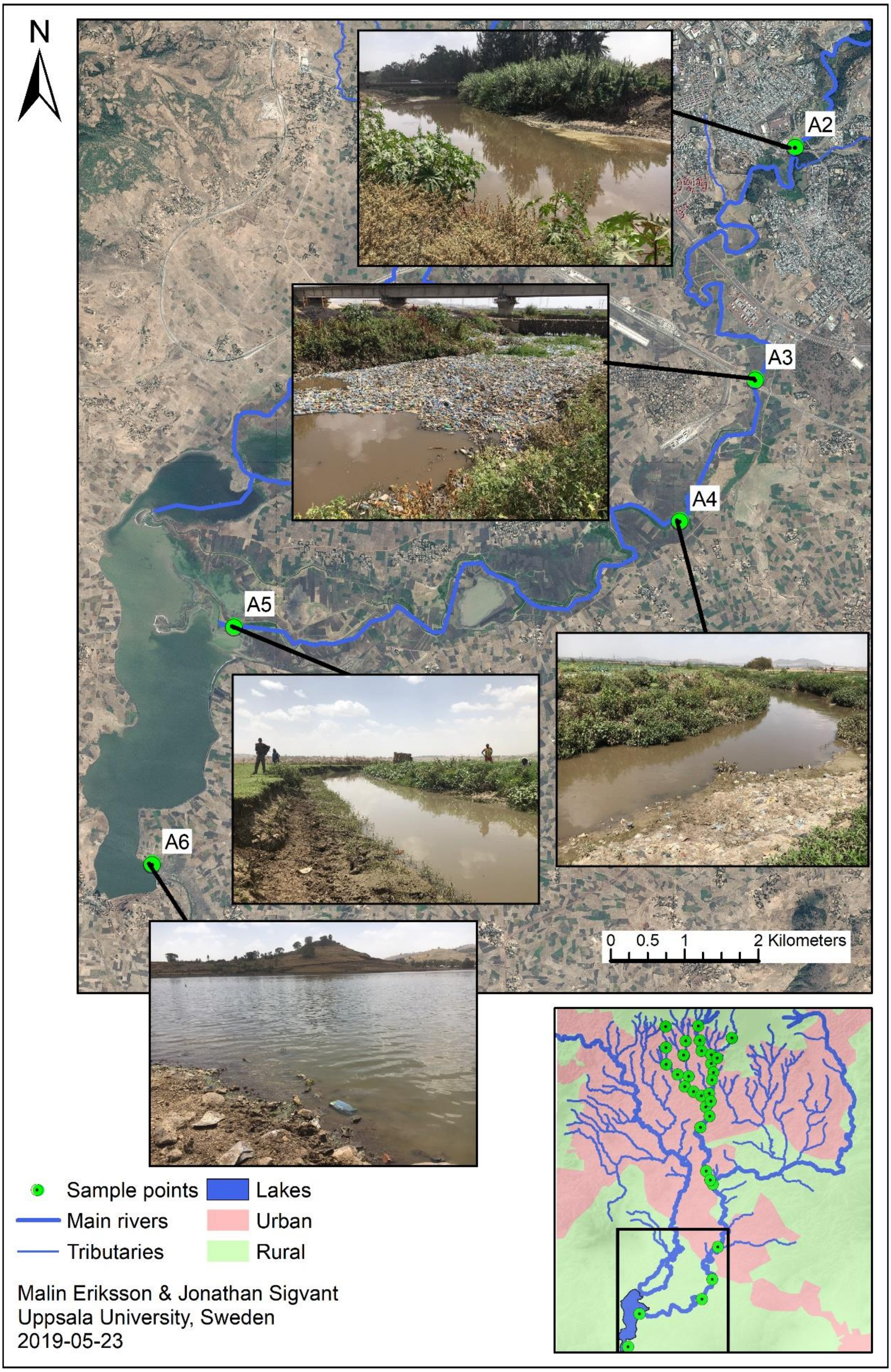

Figure 10. *Sampling sites A2, A3, A4, A5 and A6, location and appearance at the time of sampling. Southern part of Addis Ababa, Ethiopia. Orthophoto © Ethiopian Mapping Agency. Map creation details in Appendix D.*

3.4.2 pH

The pH of all water samples was measured at the same day in the end of the collection. Some of the sample was added to a tube and allowed to warm up to the temperature of the room before the measurements started. The pH meter used was a VWR pH110. Calibration of the pH meter was done before the measurements started. An accuracy of 97% was then acquired.

3.4.3 *E. coli*

The concentration of *E. coli* was determined using Compact Dry ECO plates (HyServe, Germany), a chromogenic medium to enumerate *E. coli* that is dry/inactive until the sample solution is added. The method has an accuracy of ± 0.5 $\log_{10}$ and a detection limit of 1 colony forming unit (CFU) per ml. Using a 1:0.1 ml pipet with an unused sterile tip 1 ml of the sample solution was added to the medium plate. For the samples where the concentrations of *E. coli* exceeded 300 CFU per ml the sample water was serially diluted with physiological (0.9%) NaCl solution, according to the manufacturer's instructions. Different dilutions were plated to find the one where the colonies were countable. For most samples two or three different dilutions were plated. The diluted sample was added to the plate in similar manners as the undiluted sample. Inoculated plates were then incubated (up-side-down) for 24 (±2) hours. The incubation temperature varied from 30 to 35 °C due to the limited availability to incubators, which meant compromises had to be done with other students. After incubation, *E. coli* colonies, present as blue colonies, were counted.

The *E. coli* analysis was always initialized within the first 48 hours after collection. The standard scheme of conducting a first incubation the same day as the collection gave the opportunity to make a second round of new dilutions the following day, after seeing the results from the first incubation, in order to find a dilution which gave a result of between 30 and 300 CFU per plate.

3.4.4 Phosphate

The phosphate concentration was determined using Spectroquant reagents kit 1.14842.0001 (Merck, 2019c). The kit can determine concentrations of orthophosphate of 1.0–30.0 mg PO_4-P/l and has an accuracy of ± 0.5 mg PO_4-P /l. The method is based on reaction between the orthophosphate in the sample and ammonium vanadate and ammonium heptamolybdate which result in orange-yellow molybdovanado-phosphoric acid, and is analogous to APHA 4500-P C. Particles in the samples were allowed to sediment, to prevent high turbidity to interfere with the results. No pre-treatment was done as the samples were all within the pH-range needed. Reagents were mixed with the sample according to the procedure of the kit. A blank of distilled water with the same reagent additions as the samples were used for the analysis. Using a spectrophotometer (Spectro UV-VIS Double Beam PC (UVD-3200), Labomed INC) and 10 mm cells, the absorbance of wavelength 410 nm was measured. Up to 16 samples were prepared and analysed at the same time. For conversion from absorbances to concentrations a standard curve was prepared with concentrations 1, 10, 20 and 30 mg PO_4/l prepared from standard solution (1000 mg PO_4/l, Merck). In the cases the sample concentration was found to be higher than the measuring range for the method a 10-fold dilution was prepared with distilled water and the analysis repeated.

3.4.5 Ammonium

The total ammonia (NH_3+NH_4^+) concentration was determined using the Spectroquant reagents kit 1.14752.0002 (Merck, 2019a) and was presented as a concentration of total ammonia nitrogen (TAN). The kit can determine concentrations of 0.05–3.00 mg NH_4-N /l and has an accuracy of 0.08 mg NH_4-N /l. The method is based on reaction between ammonia and a chlorinating agent which form monochloramine, that in turn form a blue indophenol derivative together with thymol. The method is analogous to APHA 4500-NH_3 F. Particles in the samples were allowed to sediment, to prevent high turbidity to interfere with the results. No pre-treatment was done as the samples were all within the pH-range needed. Reagents were mixed with the sample according to the procedure of the kit. Using a spectrophotometer (Spectro UV-VIS Double Beam PC (UVD-3200), Labomed INC) and 10 mm cells, the absorbance of wavelength 690 nm was measured. Up to 16 samples were prepared and analysed at the same time. For conversion from absorbances to concentrations a standard curve was prepared with concentrations 0.1, 0.5, 1 and 3 mg NH_4/l prepared from standard solution (1000 mg NH_4/l). The standard curve was prepared without using a blank, and accordingly, no blank was used for the analysis of samples. In the cases the sample concentration was found to be higher than the measuring range for the method a 10 or 100-fold dilution was prepared with distilled water and the analysis repeated.

3.4.6 Nitrate

The nitrate concentration was determined using the Spectroquant reagents kit 1.09713.0002 (Merck, 2019b). The kit can determine concentrations of 1.0–25.0 mg NO_3-N/l and has an accuracy of 0.6 mg NO_3-N /l. The method is based on reaction between nitrate and 2,6-dimethylphenol (DMP) which result in the formation of 4-nitro-2,6-dimethylphenol, and is analogous to DIN 38405-9. Particles in the samples were allowed to sediment, to prevent high turbidity to interfere with the results. No pre-treatment was done as the samples were all within the pH-range needed. Reagents were mixed with the sample according to the procedure of the kit. Using a spectrophotometer (Spectro UV-VIS Double Beam PC (UVD-3200), Labomed INC) and 10 mm cells, the absorbance of wavelength 340 nm was measured. Up to 16 samples were prepared and analysed at the same time. For conversion from absorbances to concentrations a standard curve was prepared with concentrations 1, 10, 20 and 30 mg NO_3/l prepared from standard solution (1000 mg NO_3/l, Merck). The standard curve was prepared without using a blank, and accordingly, no blank was used for the analysis of samples.

3.4.7 Data analysis

During the route of the study the laboratory procedures for nitrate, phosphate and total ammonium were somewhat changed. There was a change of pipette, some samples were (by mistake) shaken before analyses and some dilutions were made with NaCl solution instead of distilled water. Some analyses were also repeated because the resulting concentrations were very far from the expected, based on previous studies. In these cases, at least two new analyses were made to confirm the results. This resulted in repeated analyses for some samples, while other samples were analysed only once. To be able to present the result in a good and representative way, where a comparison between both sample sites and parameters was possible, only one value was chosen for every sample site and parameter. This choice was preceded by an analysis of all the results.

The data for samples with more than one value was analysed to decide if any values could be considered to be wrong and be excluded. In doing so, any deviation from the method procedure, the difference between values and the waiting time from sampling to analysis was considered. It was also analysed if values outside of the range of the standard curve, but within the method range could be used or not.

Values out of range of the methods were excluded, but extrapolation of the standard curve was made for values within the method range. Results from analysis where the procedure somehow differed were excluded since many of these had a significantly lower or higher value than the rest. Even though no clear trend could be seen with waiting time the earliest conducted analyse (of the not excluded values) was chosen as the final result.

The variation of results for samples analysed more than once was analysed, to determine the actual accuracy of the methods used. For this all values that were not excluded because of the analyse procedure, as described above, were used. The maximal difference between two results for the same sample was calculated and normalised with the mean of all (not excluded) results for the same sample.

A mean value over all sampling sites and the standard deviation and coefficient of variation (standard deviation over mean value) was calculated. The same was also done with the three most upstream sampling sites (Ba01, K01 and O1) excluded. The results were analysed for spatial trends by ordering the values in the way they are located in different tributaries and marking when the tributaries meet. To better visualise the spatial differences the result was coupled to the geographic coordinates of the sampling sites and maps were prepared in the software ArcMap, showing the locations and the river network of the city. Because of the proximity between the sites P1, Ba04,U and Ba04,D their locations on the map had to be changed to present the results. The coordinates of the site K05 were also changed to clarify that the sample was taken in a tributary to the Kebena river.

Correlation between the different parameters was tested. The data was first tested for normal distribution with the Shapiro-Wilk test and thereafter the Kendall rank correlation coefficient (Tau) was calculated to determine the strength of dependence between every pair of parameters. The Kendall correlation test was chosen because the data of some of the parameters significantly differed from normal distribution.

For comparation purposes an estimation of the average concentration of total phosphorous and total nitrogen in wastewater produced in households (hereafter *estimated domestic wastewater*) was done. Calculations were based on the total phosphorous and total nitrogen excreted per person per day as determined by (Dagerskog, 2017) and the water usage per person per day as described by Elala (2011) and Woldemariam and Narsiah (2014). The physical losses in the supply system that are discussed in the study of Elala was considered and so the average usage is considered to be only 80% of the supplied volume.

4 RESULTS

4.1 INTERVIEWS

4.1.1 Authorities and the company

The following results are presented from the interview study based on the authorities and the company, stated in Table 3. The analysed data are the main findings from the transcriptions from the interviews with authorities and the company. The full questionnaires used in the interview study are shown in appendix A and B.

In Ethiopia there are many ancient cultural stories about water so when asked: “what does good river water quality mean to you” the participants from the authorities and the company answered either through their scientific understanding or from a more cultural and religious perspective. For example, Mr. Bekede Wakjire, Oromia Environmental Protection Agency said:

> Every water has chemical, biological and physical levels to be considered and people here in Addis should cohere to the standards set by the government and Environmental Protection Agency (EPA). In Ethiopia the rural areas, in some areas you can get potable water from a spring source that is even better than the bottled on here in Addis Ababa. Even branded water can also be a source for pollution, but here in Addis Ababa we used to have very good quality water, but now only in the rural areas. There is a cultural assumption from 200 years back that water is self-cleaning and being of good quality, the water had the ability from the ecosystem to self-clean, naturally. But today it doesn't work.... it's a disturbance in the balance of the ecosystem and by science the water is not quality water.
>
> (Wakjire, 2019)

Another quote, from Abel Weldestinae, Associate Researcher at Ethiopian Public Health Institute:

> When you see the water you don’t need to conduct any kind of analyses. Physical observation can tell you that the water is highly polluted. It is almost grey and black, different colours you can find. So it is highly polluted with municipal waste, it’s highly polluted with solid waste and you can see that there is a lot of open defecation around the rivers.
>
> (Weldetinsae, 2019)

As Abel stated, the high pollution level of the river can be seen just by observation, an example of this is given in Figure 11.

Figure 11*. Plastic bottles in Great Akaki river, in the downstream area of Akaki Kaliti.*

Among the different authorities, the common thoughts, as stated, was around such kind of quality that could be proved by reaching a certain standard. They meant that good quality will allow biological organisms to live within the ecosystem and the river to provide humans with what is necessary for their living. This water should not be a source of health problems. In general, all participants interviewed from authorities in the study gave the same answer; that the rivers in Addis Ababa is of very bad quality, the rivers have been of bad quality since around the last 50 years, and it started when the first industries established. They informed that industries are usually located around the river to easily be able to use the water in their production and discharge their effluents directly back into the rivers. Another question raised was if the river water is of good enough quality for irrigation or not. The response to this is that there is a conflict of interest; the farmers today need a livelihood; they know the surface water is of bad quality but they need it, they do not have any choice.

Mr. Bekede Wakjire, Oromia Environmental Protection Agency says:

> The early urban establishment of the industries of all Ethiopia did not consider the environment at all. The main focus was the economic growth.
> (Wakjire, 2019)

What is considered to be the major cause for the highly polluted rivers in Addis Ababa ranges from effluents from municipality wastewater plants, open defecation, solid waste, industrial effluents from tannery, textile, liquor and alcohol factories, the weak sewage system and agricultural practices. The authorities and the company agreed that effluents are discharged directly into the river more or less without any treatment.

The respondents thought that there might be a lack of know-how of the wastewater treatment process, the chemicals needed are often imported from other countries and there is a lack of laboratory technologies for evaluation of the effluents. Since owning of land is very expensive most companies are not likely to expand their area to improve or install a treatment plant. Another common problem seems to be the assignment of "wrong person" that has a background or education little or nothing to do with the position. It could be derived from building a social network for her or his own protection or gain, says Tolosa Deso Rorisa (2019). He continues to say that there is also a lack of resources from governmental institutions, and a lack of research to carry out and implement a sustainable solution to the water quality problem. Even if policies are in place to support the local community, the appropriate person from government office to handle it doesn't have the right knowledge nor the right network to continue. Tolosa Deso Rorisa said that:

> Corruption is very high; people usually are more likely to care about their own business and think what is it in for themselves. Environmental protection is not clear and it is not clear who is responsible, and the accountability. (…) The local community is always the victim, because they live along the rivers in rural areas and are the receivers of the pollution.
>
> (Rorisa Deso, 2019)

Since most of the industries are located along Little Akaki river and the central parts of the city, there is more industrial pollution in Little Akaki than in Great Akaki. In the eastern part of the city there are more domestic waste affecting the rivers, especially Kebena river. According to Ephrem Negatu (2019) (AAWSA) "the sewage pipeline network is today only covering around 16% of the whole Addis Ababa". There are 2 major wastewater treatment plants in Addis Ababa and with a total capacity of 135 000 m^3 per day. The decentralised wastewater treatment plants have a total capacity of 27 000 m^3 per day, which treat wastewater from small communities. Households that are not connected to the sewage system may have drainage directly into the river and many city dwellers and people in local communities that have no access to a toilet use the river bank area instead.

To answer what the main challenge is when monitoring and mitigating the river quality, Fantu Kifle at the Addis Ababa Environmental Protection Agency, Research team said:

> The industries, specifically the industries, because they are capable to manage their own waste, but they are ignorant and don't want to improve the environment, they only focus is their product, focus on mass production and not on their own waste, recycling, treatment plant, mainly because it's expensive. Even we go there, and told them to do this, and they say yes, but they didn't do it you know. This treatment plant refuses to implement the cleaning process and even they hide the waste and are not following the rules and regulations. We try to improve the awareness and that's the main challenge. But local people are building their homes along the river slum area and stay there for a long period of time, and for us to help replace them to other areas is very difficult. This is an

> integration problem is there. The Integration is a big challenge. These households are contributing to the domestic pollutant to the river.
>
> (Tolesa et al., 2019)

And Bayou Tolesa, Environmental Director at the Addis Ababa Enviornmental Protection Agency said:

> The greater challenge is the illegal settlements, industries to start their business at a certain area, and the focus is economic growth, mass production and not the environment nor the treatment of harmful substances. Because the industries start investing in an area that is not an industry area, and then it now becomes a very big problem to replace them, relocate to another area. They ask huge finance to relocate. Another problem is the weak collaboration between authorities, institution and local stakeholders around the area of the rivers in the city.
>
> (Tolesa et al., 2019)

According to Ethiopian Public Health Institute, the health risk of the usages of the river water are mostly an issue for the farmers that use it for agriculture. People living on the riverbanks and around might have to use the surface water directly from the river for washing and cleaning purposes. This applies to those who do not have access to tap water, which is common in the slum areas along the river. Some consider the river water as dead water and it is in general a risk for the population. Many farmers use the river water without any protection for their body, in that way they might be exposed to skin hazards. Furthermore, the level of awareness about the risks is not well understood in many local communities. Even if there is an understanding, coming from a relatively poor economic background, they have no option (Weldetinae, 2019). As Abel Weldestinae, Associate Researcher at Ethiopian Public Health Institute, said:

> Farmers that are using the river water for irrigation to their crops daily are exposed to the pollutants either through inhalation, ingestions and/or dermal contact, they are at risk of cancerogenic and non-cancerogenic hazards. (…) The second one is the population in general because these vegetables will accumulate heavy metal, microbiological contaminants. We don't know the level of attention of washing sanitation procedure in the households. This might cause diarrhoea, especially those of the lower economic status.
>
> (Weldetinsae, 2019).

Just as Abel stated, that there is a risk for the farmers in the usage, the picture (Figure 12) was taken during the interview study.

Figure 12. *Farm workers in Akaki Kaliti area, washing carrots with the water from the Great Akaki river downstream.*

Different authorities and stakeholders said that the level of awareness must increase among different groups in the society in order to make a change regarding the river quality. It is important to empower the local community, to help them understand and empower their rights and responsibilities, because the local community living downstream of the river is the victim, the recipient of the pollution. Tolosa Deso Rorisa continued to say that:

> There is no liability, business ethics are weak and environmental anti-corruption should be there to enhance and practically carry out the proclamations and laws that is.
>
> (Rorisa Deso, 2019)

The industries have to be confronted and driven to clean their effluents. During our interview at Addis Ababa Environmental Protection agency, Bayou Tolesa and Fantu Kifle (Tolesa *et al.*, 2019) agrees on that the awareness of the local community is one key factor, another is to successfully implement the written laws and proclamations. The problem is to give people in Ethiopia an understanding of the value of nature and environmental issues, just as Bayou Tolesa argues:

> The problem is related to lack of awareness and they don't consider the environment to be an issue, they only focus on the economy, what they can get from it, how will it benefit me. But if they don't focus on the environment, their development cannot be sustained, so the focus of the government and EPA is now on sustainable development; which means taking the social, economy and environmental issues into consideration. If they consider these aspects, then the environment problems will be reduced. So, any development must pass through the Environment Impact Assessment, if the project pass through this assessment in the future it will

> be good and we can establish sustainable development, our rivers will be protected, and this is our direction and plan.
>
> (Tolesa et al., 2019)

At the Oromia Environmental Protection Agency, Bekede Wakjire (Wakjire, 2019), talked about the so-called Addis Ababa Riverside Project. The project is a long-term project, which aims to clean up the rivers in the city, create a buffer zone for the river, treat all wastewater before released into the river and make the river land costly to attract rich people to live close to the river. Bekede Wakjire adds that this is part of the Government master plan, to clean-up the rivers.

> There is a collaboration with Addis Ababa Administration Government and Oromia Administration to work together of Akaki river area, to rehabilitate the rivers. The part of Akaki and Addis river is controlled by the Government body, but the law says by constitution that the river is governed within Oromia area, but practically it's all managed by the Federal Government. This is a very critical component for the city and the rural areas around Addis because the issue, the nearby community which is affected by, even without boundaries geographically, has to have the chance/opportunity to speak which the law enforces but it is not working.
>
> (Wakjire, 2019)

He concludes that this is a vital function; collaboration for all stakeholders and communities to recover the rivers quality to its natural levels.

For one of the specific areas of Oromia, in the downstream area of Akaki Kaliti, Bekele Yadu, Environmental Protection team leader for Oromia Special Zone said:

> In our special zone in Oromia area, we need only one thing; the clean and pure water to supply for our farmers, there are so many farmers and they use horticulture and it is very polluted. (…) For the river side, the solution can be using a fence and huge cleaning processes like a big treatment facility maybe could be the long-term solution. But for the short-term solutions the farmers need pure water for their horticulture and cattle.
>
> (Yadu, 2019)

Addis Ababa Water and Sewage Authority is now expanding to reach more customers to connect to their sewage network and spread knowledge about how the sewage system works. Their plan is also to build a new wastewater treatment plant in the eastern region of the city (Negatu, 2019).

4.1.2 Households and farmers

The farmers working on their farmland in the area of Akaki Kaliti are highly dependent on the river water from Great Akaki for irrigation to their crops. They usually rent the land in order to use it for cultivation and selling the vegetables is their only source of income.

In the agricultural fields, the farmers grow cabbage, carrots, onions, tomatoes, garlic, potatoes, lettuce and haricot vert. All the farmers encountered in the area of Akaki Kaliti use a pump, pumping up surface water directly from the river without any treatment to irrigate their land. Kendu Derese, one of the farm owners in the Akaki Kaliti area, says:

> Even this pumping water need natural gas that is also very expensive, even to treat. It's very difficult for us to treat the water because too expensive. Even the pumping water is very expensive. You see!
>
> (Derese, 2019)

During the interview study, farmland was visited, and one downstream site is presented in Figure 13 as one of the sites where the river water was used for irrigation purposes.

Figure 13. *Kendu Derese's farmland, using the river water for irrigation.*

All the farmers perceived the river water quality of downstream Great Akaki to be of very bad quality, highly polluted by municipal wastewater, domestic waste and foremost industrial waste. When asked how they would rate the quality from one to five, where five is the worst and one the best quality, all farmers rated the water number five; the worst quality. That is the general perception of the surface water quality. Therefore, they said it can only be used for irrigation purposes. Kendu Derese continued to say:

> We cannot use for drinking, for food preparation and others … only for irrigation. (…) Before ten years this water used for drinking for cattle and human. Before ten year. But after ten years this all is changed. Nobody can use it for drinking.
>
> (Derese, 2019)

Another herder, by the name Tade Demise, said:

> The cattle drink not from Akaki river, this one, they go to Lencho river in another area. (…) One animal may be sick, one or two can also drink from Akaki river, if they drink some cattle, they urinate diarrhoea like, they can be diseased. They are not willing to drink only some cow will drink not all. (…) The river looks like bensin, black colour, not good quality the worst. The water is dead water. The main problem is, all waste material is discharged directly into the Akaki river, because of that the river is polluted.
>
> (Demise & Dabala, 2019)

Many farmers considered the river water quality to pose a health risk, but it depends on the awareness level as Kendu Derese said:

> If you have no experience working on this vegetables your dermatitis, and the skin can be hurted. Some kind of problem you encounter. (…) It is not healthy, since I'm not a physician I don't know what kind of problem is created on my skin or accumulate inside.
>
> (Derese, 2019)

The herders Tade Demise and Dama Dabala said that:

> Nobody uses this water, before the water was polluted the people used for drinking and bathing and the others. Nowadays nobody can use it, they use tap water from underground water for drinking. The river is bad odour, and no one can use it. (…) For us there is no health risk.
>
> (Demise & Dabala, 2019)

But even though they expressed that the water is not good enough for any other use than irrigation no one of the interviewee saw any health issues with eating crops farmed with the polluted water.

When we asked about any comments or future mitigation plans, Kendu Derese argues with his fellow farmers:

> This is controversy. Two ideas. One he said this water cannot be pure. Other person said this water can be pure if we make treatment at the source, source of the river.
>
> (Derese, 2019)

In the dry season many households interviewed around the upstream area of Kebena river used the river water for irrigation of vegetables for household usage. However, during the rainy season some people may also use it for cleaning and bathing. Many people with poor background in the area do not have access to a house and a clean toilet and are therefore forced to take water from the river for cooking, cleaning and bathing.

The families and households interviewed agreed that the river water is very dirty. Tardesa, one family's father, said:

> The quality is very bad, at present time, and in the rainy season more and more substances join into the river and pollute it.
>
> (Tardesa, 2019)

The results also show that the Government will start with a cleaning process alongside the river, The Riverside Project, and Tardesa said:

> The Government will have our house and construct a recreational area here and they will support us with a new home.
>
> (Tardesa, 2019)

In another household, Aster, the family's mother, said that:

> Treatment, we do not have any support from organization. But by our own free will at the end of the month we will pick up some plastic from the river, and so many people will participate in this. This is the only thing we can do to help clean the river.
>
> (Aster, 2019)

The community upstream can be seen in Figure 14, and Abera, a participant from the community in Intoto said:

> People will come once in a month to pick garbage from households, people that is hired by the Government to collect it. But between this time, many people are using the river to dump their garbage. But since people are coming only once a month the situation is not improved. But Government is going to treat it.
>
> (Abera, 2019)

Figure 14. *Community living in the river area in upstream area of Kebena river.*

The main issue with the river management in the area is that people that has no home uses the river area as an open defecation. Furthermore, many pipelines from households in the area run directly to the river for disposal. Another issue raised during interviews was the population growth. More and more people come and live in the area and as a consequence; more and more have to dispose their garbage directly in the river, something that usually occurs during night time.

Basalem, a mother of six children, living in Intoto; said:

> The water is pure when it starts from up the mountain, but the problem is that, people are living here in the society and are using it the wrong way and the awareness is not there to change this problem. If we use it in a better way, we can change the problem. But people don't have this awareness and because this is the effect of ourselves. And now the garbage is a lot in the river.
>
> (Basalem, 2019)

The health problems related to the river water usages seem to be very few because not many people use it. However, some of the people in the Intoto area are very poor and have no access to any other water source. Regarding these people Basalem said:

> I don't have a relation with the people, and she [Basalem herself] don't use it, therefore she didn't encounter problems. But she can imagine for those who go there, there is some problem that will happen to them, maybe skin or stomach pain.
>
> (Basalem, 2019) [writer's comment]

The farmers confirmed that they use only the river water for irrigation, and depending on how they use the water, it may be a health risk to them or not. But often this is their only source of income for their livelihood to use the water for irrigation, that means they have no choice. The households; the family's interview in and around upstream area of Kebena river, talks about the present state of the river being very polluted compared to before many years back. A time when they could actually bath in the river water and use it for cleaning of cloth for an example.

4.2 OBSERVATIONS

To the rivers in the city there is a constant addition of stormwater. As the wastewater from many households is disposed directly to the stormwater system this leads to a constant addition of domestic wastewater. Many different industries are established along the rivers of Addis Ababa, mostly in the western and southern parts. Wastewater is discharged directly into the river, or into the stormwater system; as can be seen in Figure 15–17.

Figure 15. *Outlet observed in the Kebena river, likely part of stormwater system.*

Figure 16. *Outlet observed in the Kebena river, likely part of stormwater system.*

Figure 17. *Outlet observed in the Kebena river, likely part of stormwater system.*

Solid waste and human faeces are present everywhere in and around the river. It is clear that solid waste is brought to and dumped by the river, which can be seen in Figure 18–19. In general, the observed attitude to littering is that; what I do, does not make a difference because the pollution level is already so high.

Figure 18. *Left: Middle part of Kebena river, observed waste in the river. Right: Upstream part of Kebena river, observed waste in the river.*

Figure 19. *Left: Central Addis Ababa, Kebena river, observed waste dumped by the river. Right: Downstream part of Kebena river, observed waste in the river.*

Irrigation with the river water is common both in urban farming and in the bigger farming area outside the city in the southern area of Akaki Kaliti. Some of the locations for irrigation, as well as the main areas of farming adjacent to the river, are presented in Figure 20. A use of fertilizers on the farmland was also observed. In the farming areas of Akaki Kaliti cattle were grazing along the riversides. A picture of an observed urban farm site alongside Kebena river is presented in Figure 21. At some places the river was used for washing clothes.

Figure 20. *Observed irrigation using water from Great Akaki river, in Akaki Kaliti.*

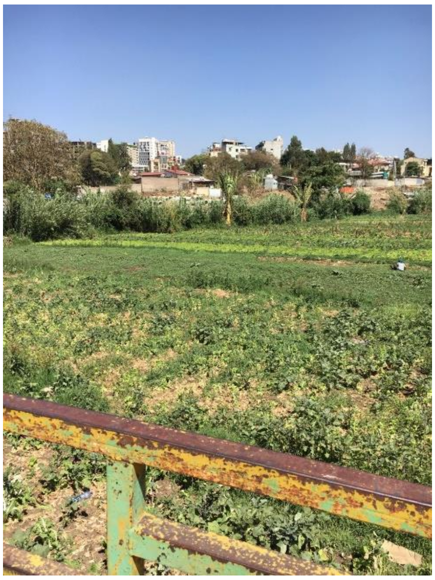

Figure 21. *Urban farm site along the Bantyketu river.*

Furthermore, observations made upstream of the city showed that the flow is very low in all rivers before they enter the city, which is presented in Figure 22 and 23.

***Figure 22**. Left: Low flow in the upstream area of Bantyketu river (Ba01). Right: Low flow in the upstream area of a river east of Kebena river (O1).*

***Figure 23**. Low flow in the upstream area of Kebena river (K01).*

In the lake Aba Samuel, where almost all the surface water ends up, a lot of algae was observed on the surface (Figure 24).

Figure 24. *Observed algae in the lake Aba Samuel, close to sampling site A06.*

4.3 WATER SAMPLE ANALYSIS

The collected water samples are presented in the Figure 25, showing the sample labels and dates in which, they were taken. The colour of the water was very different at different sampling sites.

Figure 25. *The collected water samples; K01–K14, P01, O1–O3, Ba01–Ba13 & A1–A6.*

The standard curves that were produced to calculate concentrations from measured absorbances had a r^2 of 0.9999, 0.9997 and 0.9999 for TAN, NO_3 and PO_4 respectively.

The pH of the water samples was between 7.01 and 7.72, with a mean value of 7.36 and a median of 7.35. The lowest pH was found in A5 just before the river enters lake Aba Samuel and the highest pH in A1, at the join between Kebena and Great Akaki rivers.

The minimum and maximum values of TAN, NO_3, PO_4 and *E. coli*, along with the mean and median are presented in Table 5. The concentrations, pH and geographical coordinates of each sampling site can be found in Table C1. A mean value over all the sampling sites except the three samples located most upstream, K01, Ba01 and O1, is also presented. The lowest concentration of *E. coli* was found in the lake Aba Samuel, but apart from this, and for all other parameters the lowest values are in K01. The maximum values of TAN and NO_3 are in K05, while the maximum of PO_4 and *E. coli* are in P1 and Ba07 respectively.

Table 5. Total ammonia nitrogen (TAN), nitrate (NO_3), phosphate (PO_4) and *E. coli* concentrations presented as the outermost range and mean and median values for the 34 water samples, and mean value when K01, Ba01 and O1 are excluded (Mean_exl)

	E. coli [log_{10} CFU/100 ml]	PO_4-P [mg/l]	TAN [mg/l]	NO_3-N [mg/l]
Minimum	2.95	0.455	0.838	0.103
Maximum	6.91	16.6	62.9	0.625
Mean	5.70	7.35	21.2	0.293
Mean_exl	5.86	8.00	23.2	0.309
Median	5.98	7.12	19.5	0.279

Concentrations of TAN, NO_3, PO_4 and *E. coli* are generally lower upstream of the city, higher within the dense parts of the city and then lower again in the downstream field area of Akaki Kaliti (Figure 26–29).

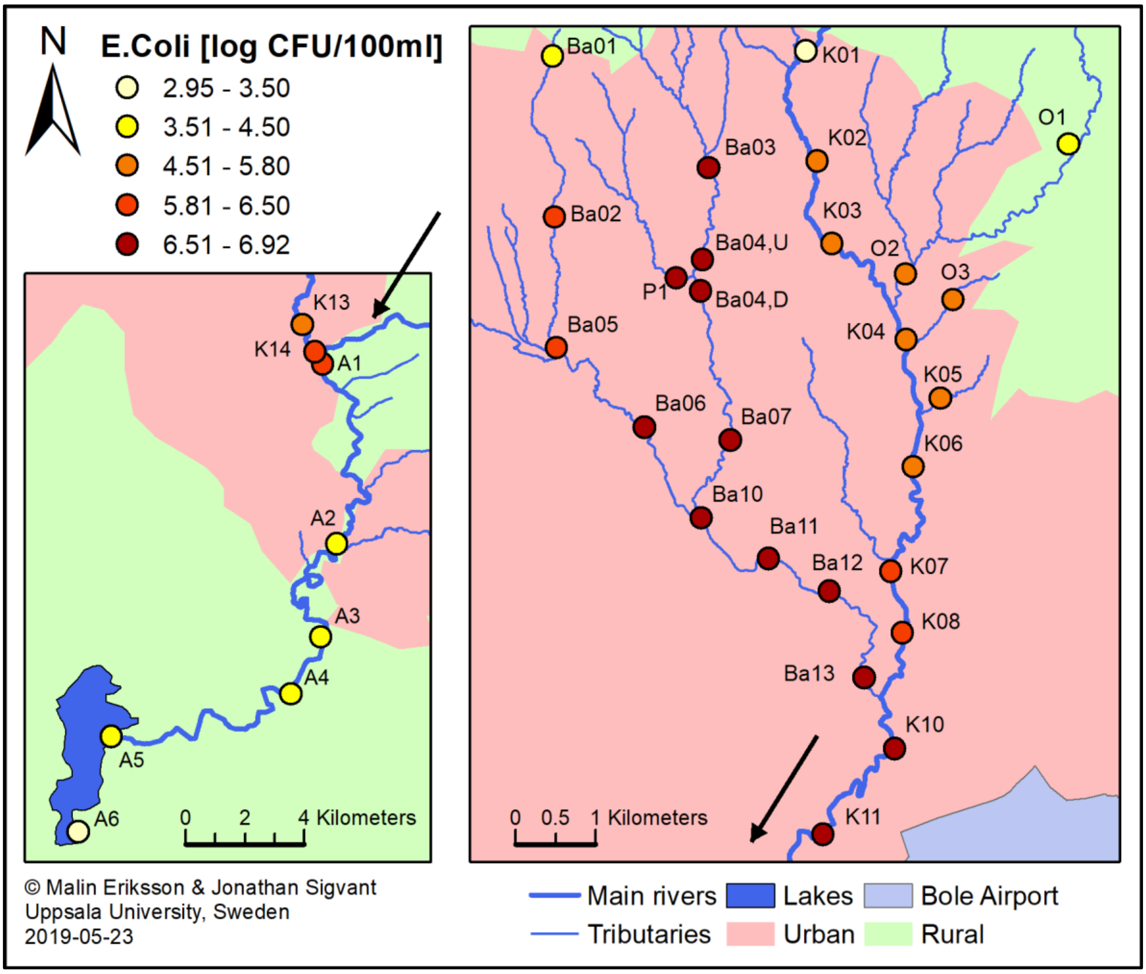

Figure 26. *E. coli concentration [log$_{10}$ CFU per 100 ml] in water samples collected March to April 2019 in the Great Akaki, Kebena and Bantyketu rivers in the city of Addis Ababa, Ethiopia. Coordinates of P1, Ba04,U, Ba04,D and K05 edited. Map creation details in Appendix D.*

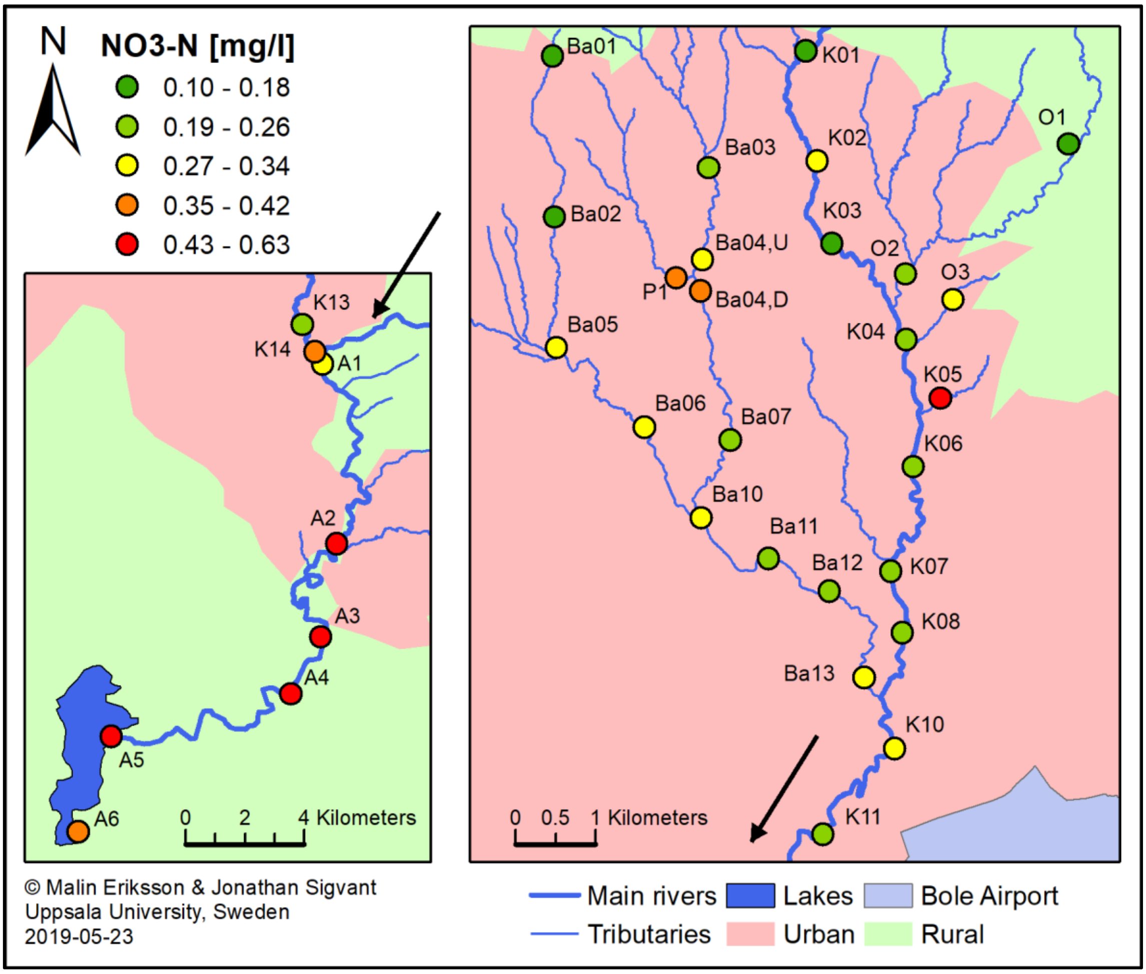

Figure 27. *Nitrate (*NO_3*) concentration [mg/l] in water samples collected March to April 2019 in the Great Akaki, Kebena and Bantyketu rivers in the city of Addis Ababa, Ethiopia. Coordinates of P1, Ba04,U, Ba04,D and K05 edited. Map creation details in Appendix D.*

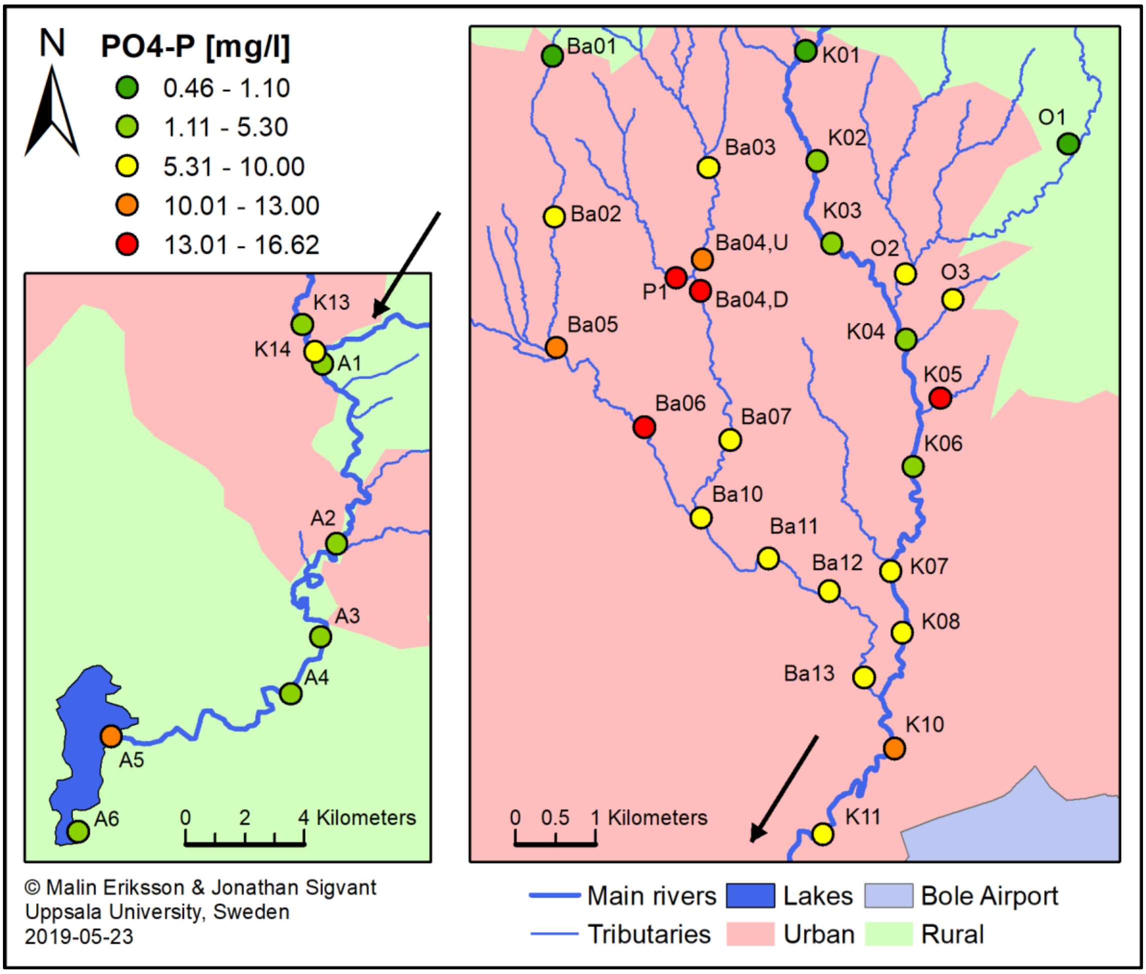

Figure 28. *Phosphate (*PO_4*) concentration [mg/l] in water samples collected March to April 2019 in the Great Akaki, Kebena and Bantyketu rivers in the city of Addis Ababa, Ethiopia. Coordinates of P1, Ba04,U, Ba04,D and K05 edited. Map creation details in Appendix D.*

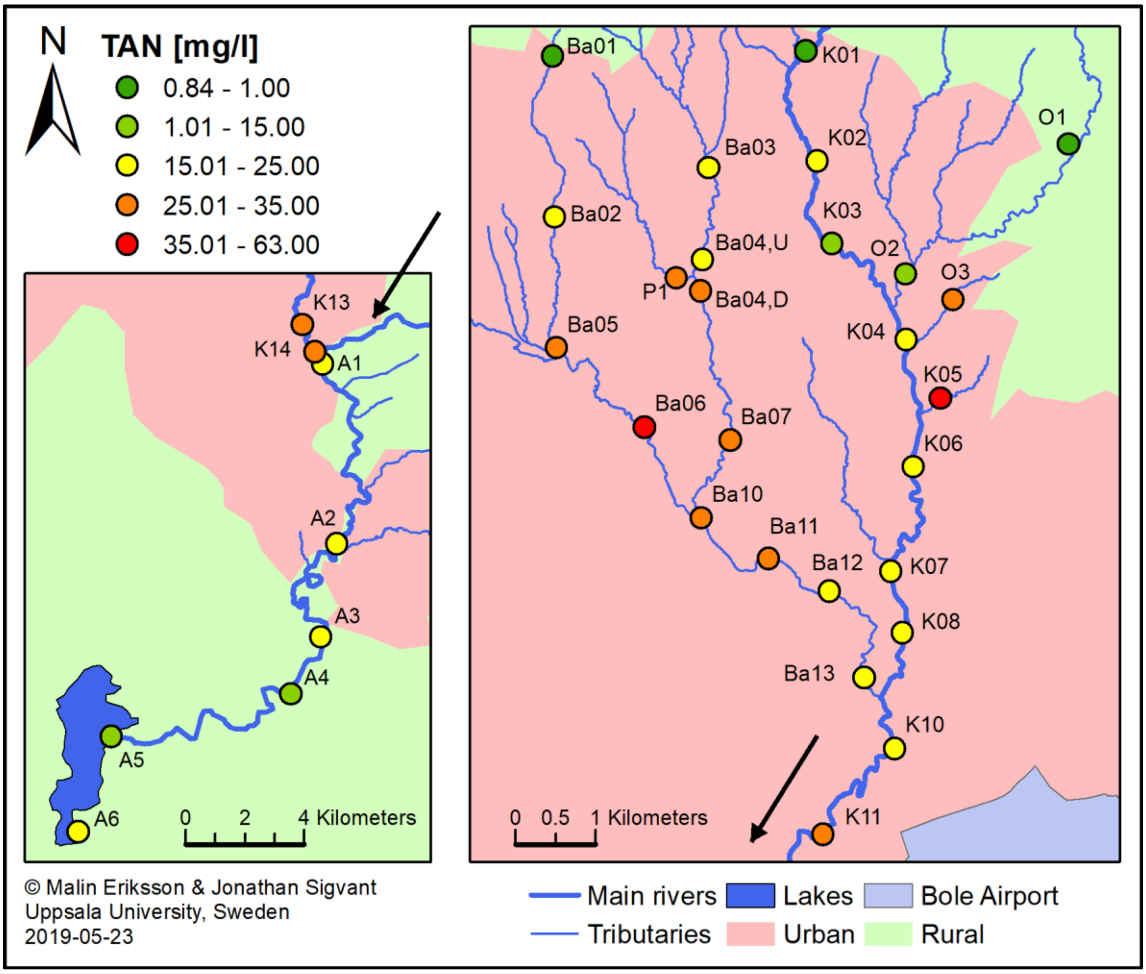

Figure 29. *Total ammonia nitrogen (TAN) concentrations [mg/l] in water samples collected March to April 2019 in the Great Akaki, Kebena and Bantyketu rivers in the city of Addis Ababa, Ethiopia. Coordinates of P1, Ba04,U, Ba04,D and K05 edited. Map creation details in Appendix D.*

According to the Shapiro-Wilk test the TAN and *E. coli* data is not normally distributed (confidence of 95%) but the hypothesis of normal distribution cannot be rejected for the NO_3 and PO_4 data. Kendall rank correlation test show a significant (confidence of 95%) correlation between all parameters except for NO_3 and *E. coli*, though all correlations with NO_3 are weak (Table 6).

Table 6. Correlation coefficients (Tau) and associated p-values for Kendall rank correlation test between each pair of parameters

	TAN		NO_3		PO_4	
	Tau	p-value	Tau	p-value	Tau	p-value
NO_3	0.2773	0.0215				
PO_4	0.4759	$4.228 \cdot 10^{-5}$	0.3131	$9.448 \cdot 10^{-3}$		
E. coli	0.5031	$2.903 \cdot 10^{-5}$	0.0107	0.9291	0.5138	$1.956 \cdot 10^{-5}$

For the calculated *maximal difference between two results for the same sample*, the average over all samples and the absolute maximum difference are presented in Table 7, along with the normalised values.

Table 7. The maximal difference between two results for the same sample for the parameters TAN and PO_4

	TAN	PO_4-P
Maximal difference [mg/l]		
Average	5.76	1.30
Absolute maximum	27.6	4.79
Normalised maximal difference		
Average	0.268	0.212
Absolute maximum	0.687	0.327

The average concentration of total phosphorous and total nitrogen in *estimated domestic wastewater* is presented in Table 8 together with the water consumption used for the calculations. Water consumptions are based on the studies of Elala (2011) and Woldemariam and Narsiah (2014).

Table 8. Average concentration of total phosphorous and total nitrogen

Water consumption [l/(p·d)]	Total phosphorous [mg/l]	Total nitrogen [mg/l]
60	39	178
20	116	535

5 DISCUSSION

5.1 INTERVIEW STUDY

5.1.1 Authorities and the company

The interview study points out that different stakeholders; authorities and the company, in Addis Ababa are well aware of the pollution problem in the rivers. The answers conclude that the surface water is highly polluted. However, the reason given for the bad surface water quality depends on which authority you ask, as does how to address the problem. Many argue that the nature of the problem calls for a multi-sectoral mitigation approach, this is in line with the study by Yohannes and Elias (2017). Another may stress on the industrial sector that must have a sufficient treatment facility. The differences in answers to why the surface water is of bad quality may depend on the different backgrounds the authorities have. As pointed out by G-two Investment and Environmental Consulting PLC, that a usual problem is that people have been placed in a position not based on their education nor their background, but on who they know. This may cause a lack of the whole picture and affect how effective the implementation of mitigation strategies is. Furthermore, the interviews showed that there is a weak collaboration among authorities. Awoke *et al.* (2016), came to the same conclusion and also argues that the authorities do not have the right strategy for implementation because of a lack of knowledge. Additionally, they suggest that policies might be too weak to address such a water quality problem as the one found in Addis Ababa. However, this interview study shows that the policies and legal frameworks needed are in place, it is rather the implementation that is the problem. Accordingly, the study by Yilma *et al.* (2018) points out the inadequate management to achieve implementation needed. Zikargae (2018) and Okereke *et al.* (2019) agrees on the existence of the legal frameworks but argue that it is rather weak.

For the health aspect, previous studies can confirm what has been found in interviews with authorities in this study, that users of the river water in Addis Ababa are exposed to a risk (Weldesilassie *et al.*, 2011; Belachew *et al.*, 2018).

The interview study showed that many authorities, and especially the G-two Environment consultant company, knew why the rivers are polluted. At the same time, they knew the importance of the job opportunities the many industries provide for the people in Addis Ababa. On the one hand there is the environment that needs to be protected and companies which do not follow the environmental laws should be closed. On the other hand, there is the economy of the country and the many inhabitants depending on these companies and the job opportunities they present. Hence, there is a conflict of interests, highlighting the need for a multi-sectoral problem approach. Yohannes and Elias (2017) agrees that a strong collaboration between authorities should be established to tackle the serious environmental problems of the city rivers.

The authorities agreed that one of the major measures in order to improve the situation is to empower the local community. At the same time, they also stressed on the importance of having a stronger collaboration between all the different stakeholders in the society. It seems to be disputed among stakeholders what the future plan is to solve the core issues of the implementation and what the most important means to be taken to improve the quality of the rivers are. It seems Addis Ababa Environmental Protection Agency wants to take accountability for the problem, but many seem to be holding back and wait for the implementation of the so-called Riverside Project, which is supposed to be implemented by the Government. Many of the solutions suggested by the authorities aimed to either treat the polluted wastewater at its source or empower the local community to engage in awareness creation.

From what has been discovered in this interview study it is clear that a mix of social, economic and environmental approaches is needed and that this cannot be done by only one authority. The Riverside Project cannot fix everything, authorities still need to collaborate and come together with a joint plan where it is clear which is the responsibility of each authority. In addition, they need to work together with the community. The same conclusion has been pointed out by Yohannes and Elias (2017).

When constructing the questionnaire towards authorities, the focus was on open-ended questions, and to first build up a trust to the interviewee. The aim was to ask the same kind of questions repeatedly, but in different ways, to make the answer clear and trustable. However, in the interview moment, the preparation was good and necessary, but the situation called for another strategy when interviewees moved the conversation to other areas. Because the interviews were semi-structured and usually more than one person participated at the same time some additional uncertainties arose. When interviewees were not objective on the issues, they stressed on the areas important for them, possibly leaving out other things.

5.1.2 Farmers and Households

Farmers and families living next to the Kebena and Akaki river perceived the Kebena and Akaki rivers as highly polluted from varies sources, such as municipality wastewater, domestic waste and industrial waste. The same result has also been observed in another interview study made by Woldetsadik *et al.* (2018). However, different farmers and households said different things about where the pollutants came from. Furthermore, it also differed contra the authorities, which could be explained by differences in education levels and points out the huge awareness gap. Many farmers stated that the river water quality is of bad status and continues to argue that the quality was much better many years before. This is in line with a farmer in the study of Woldetsadik *et al.* (2018) saying that they used to eat the vegetables raw directly from the field, but if they do so nowadays, they experience food poisoning due to the water from the river used on the agricultural field. But then again, the farmers usually have no choice but to use the polluted river water downstream of Akaki Kaliti. They know the water is very dirty, but some seem not to perceive the irrigation to be a health problem, not to themselves in usage nor for the consumers eating the vegetables. This goes hand in hand with the strong belief at the authorities of the importance of bringing awareness to the community and to educate about the health risks. Especially the Ethiopian Public

Health Institute stressed on creating awareness among users. However, it is not only a problem of low awareness but also a lack of other options. A low income may force poor families to use the river water for washing.

The interview study, together with observations such as informal conversations at the university, on the streets and among friends living there, reveals people's different perceptions of the rivers in Addis Ababa. This shows that people generally want to improve the water and sanitation situation, particularly the surface water status, but they just do not know how to do it. Even when a person is in a good position to act, it is often the lack of knowledge or research on the targeted issue that prevents them. Somehow, they feel that, it is not up to them, it may be up to the Government and authorities to fix the river water quality. During field observations, we saw how citizens dispose their garbage in the river and riverbanks, and the households upstream told us that the river is the main waste area. Even many households dispose their waste at night-time to avoid being seen. Many households may believe that they have no choice than to dispose the waste in the river, and a citizen living in Intoto, complained that the government only collects the household waste once in a month, pointing out this is not enough. It seems people living in the upstream community fail to understand that they also must be a part of the solution, as has been pointed out by the authorities. However, another Intoto resident, said that many people gather every month to collect plastic from the river, implying there is at least a will to help restore the river quality. But then again, addressing these issues may need the authorities to carry out the appropriate awareness creation and carry through capacity building projects on-site. At the same time authorities and the company stressed that empowering the local community is crucial in mitigating the water pollution locally. The same conclusion has been pointed out in a study by Awoke *et al.* (2016)

The general opinion among farmers and households suggested to clean up the rivers from physical objects and treat the river water as it is rather than on enforcing prevention and mitigation at source or upstream. Compared with authorities, the local community sought to act for the short-term and authorities more onto the long-term solution. Even though authorities are leaning more towards the long-term solution it is not clear what exactly needs to be done to solve for the long-term, it may need further research to empower the implementation process.

During the interviews with farmers and households, they wanted to tell us about other problems they encountered, in belief that we might be a voice that could reach out to other involved authorities to help them.

5.2 WATER SAMPLE ANALYSIS

5.2.1 Evaluation and comparison of values

All samples had a neutral pH, therefore there was no risk for high concentrations of NH_3. It can also be concluded that the surface waters are not exposed to acidification.

The *E. coli* concentrations (Table 5, Figure 26) were for all water samples, except K01 (up-stream of the city) and A6 (lake Aba Samuel), above the limits given by WHO guidelines (Table 1) for irrigation with wastewater in *unrestricted* irrigation and in labour-intensive *restricted* irrigation. In the up-stream sample points (K01, O1 & Ba01) and in the farming area of Akaki Kaliti (A2–6) the concentrations were below the threshold for highly mechanized restricted irrigation. The interviews have not been clear on the subject, but the unsure answers in interviews, together with observations, indicate that some of the vegetables that are grown in the area are eaten raw. The irrigation should therefore be classified as unrestricted, and the surface water is only suitable for irrigation at sampling site K01 and A6.

The different incubation temperatures for *E. coli* analyses affected how easy it was to count the colonies. A lower temperature resulted in smaller colonies, probably due to a higher competition with other bacteria. This made the counting less certain. Since the accuracy of the method is only ± 0.5 $\log_{10}$, meaning the actual number of CFU is in a range of 1 $\log_{10}$ (for example; for a counting of 200 the actual number of CFU is between 63 and 630), the slightly less certain counting does not make a big difference.

The WHO thresholds are given to reduce the health risks associated with usage of wastewater in agriculture. High levels of *E. coli* is an indication of faecal contamination and the average *E. coli* concentration found in this study is about the same as the concentration found in wastewater before treatment, which can be in the range of 5.2 to 8.7 $\log_{10}$ CFU per 100 ml (Lisle *et al.*, 2004; Bréchet *et al.*, 2014; Ofred *et al.*, 2016). Even though concentrations of *E. coli* found in some previous studies (Mengesha *et al.*, 2017; Colombani *et al.*, 2018) are 1–3 $\log_{10}$ lower than those found in this study, the conclusion about faecal contamination is the same. Therefore, it can be argued, the risks associated with irrigation with this water are about the same as those for usage of un-treated or insufficiently treated wastewater.

The most frequently encountered health risk due to irrigation with wastewater is for both farmers and consumers intestinal worm (WHO, 2006). In Addis Ababa hookworm eggs have previously been found in lettuce irrigated with Kebena or Great Akaki river water (Woldetsadik *et al.*, 2017), which indicate a transfer from irrigation water to crops. According to the WHO (2006) the risk for bacteria to be transferred to crops, and subsequently consumers, is generally lower because they die off more rapidly. However, the use of wastewater for irrigation of vegetables have still been observed to cause outbreaks of cholera, typhoid and dysentery. Faecal coliforms have been found in vegetables grown in the studied areas (Woldetsadik *et al.*, 2017; Mengesha *et al.*, 2017) and the high concentrations of *E. coli* in the river water, exceeding 10^4 per 100 ml, can cause an increase of non-specific diarrhoea for consumers (WHO, 2006). Farmers are also exposed to protozoa, which for example increase the risk for amoebiasis and the direct contact with wastewater contaminated irrigation water cause skin irritations such as dermatitis (WHO, 2006). Hence, the current use of the Great Akaki river water for irrigation on vegetable farms induce a health risk for both farmers and consumers.

The high r^2 number of the standard curves indicate that the method has a high accuracy, in line with that given for the reagents kit. Because of the high linearity found and the fact that the methods should give a linearity for all concentrations within the range of the method extrapolation was made from the standard curves, as long as the obtained concentrations was within the range of the method. The high accuracy of the method is contradicted by the analysis of multiple runs for the same sample which show that the variation within a sample is greater than that given for the kit for both PO_4 and TAN (Table 7). This indicates that the method as a whole has a greater uncertainty. Samples were stored for a different amount of time before analysis, but a quick analyse of the values show no correlation between time stored and measured value for any of the parameters. The uncertainty of the results is not considered to have a big impact on the evaluation of values, since comparations with thresholds and previous studies are valid even if the average maximal difference is added or subtracted.

There is no international guideline for phosphorous in drinking or irrigation water, but when the phosphorous concentrations are raised, compared to natural or historical values, the surface water is in risk of eutrophication. To put the PO_4-P concentrations found in this study in a context, they can be compared to those of a so-called trend river in Sweden (Miljödata MVM, 2018) where the median concentration in 2018 was less than 0.001 mg PO_4-P/l. The average concentration found in Addis Ababa (Table 5) is about one thousand times higher than this and even the minimum is more than a hundred times higher.

With regard to the amount of phosphorous in the water, the rivers of Addis Ababa can be likened to wastewater in Uppsala, Sweden, where the wastewater treatment plant *Kungängsverket* has the same concentration of total phosphorous in the incoming wastewater as the PO_4-P concentrations in the rivers of Addis Ababa (7 mg P/l vs 7.35 mg PO_4-P/l) (Uppsala Vatten, 2016). The outgoing water, which complies with Swedish regulations, has a phosphorous concentration of 0.1 mg/l, lower than the minimum value found in this study (0.455 mg PO_4-P/l).

Though the numbers are roughly estimated, it is of more interest to compare the PO_4-P in the river water to the total phosphorous concentration in the *estimated domestic wastewater* (Table 8). The comparison between river water and wastewater depends on which water usage volume is used for calculations, since the concentrations in wastewater, of course, depend on the amount of pure water that dilutes faeces and urine. Concentrations of PO_4-P found in this study are about one-fifth of the total phosphorous concentrations in the wastewater when the flow of 60 l/(p·d) is used (7.35 mg PO_4-P/l vs

39 mg P/l), but much lower when the flow of 20 l/(p·d) is used (7.35 mg PO_4-P/l vs 116 mg P/l). Since it is not known what the actual water usage of the households not connected to the sewage system is, it is not possible to say to which extent the river water is similar to pure wastewater. The total phosphorous concentrations in the household waste is calculated from average adult excrements in the village of Bolo Silasie and may not be completely representative for the Addis Ababa citizens. Furthermore, the addition of phosphorous from bathing, dishing and cleaning in households (e.g. phosphates from detergents) have not been included, which should otherwise increase the phosphorous content in the household wastewater.

During these comparisons of PO_4-P concentrations and total phosphorous concentrations it is also important to keep in mind that the measured PO_4-P does not equal to the total amount of total phosphorous in the river water. Phosphorous in (waste)water may exist in other forms, such as organic or inorganic particles (Gikuma-Njuru *et al.*, 2010). In urine the phosphate is about 90% of the total phosphorous, while it is only 20% in faeces (Jönsson *et al.*, 2005). However, the PO_4-P alone fills up a great part of the total phosphorous concentrations it has been compared to here.

Concentrations of PO_4 found in this study are higher than those found by Mengesha *et al.* (2017) and Akalu *et al.* (2011). The reason for this is discussed further below.

Compared to the Swedish trend river *Kolarebäcken* the TAN concentrations found in this study are very high (21.2 mg TAN/l vs 0.0228 mg NH_4-N/l) (Miljödata MVM, 2018). TAN levels found in previous studies (Beyene *et al.*, 2009b; Mengesha *et al.*, 2017), are generally lower than those presented here, but still high compared to *Kolarebäcken*, and 40 times higher than the outgoing water at *Kungsängsverket* (Uppsala Vatten, 2016), which indicate a big anthropogenic impact on the rivers.

The NO_3-N concentrations are overall low with the average of 0.293 mg/l (Table 5, Figure 27), in the same log as the combined NO_3 and NO_2 concentration (0.157 mg/l) in the trend river *Kolarebäcken* (Miljödata MVM, 2018). When comparing to WHO standards for drinking water they are far under the threshold of 50 mg NO_3/l. Nitrate levels are therefore not a health risk. Compared to other studies (Beyene *et al.*, 2009b; Mengesha *et al.*, 2017), the nitrate levels are very low. One reason for differences between this study and that of Mengesha *et al.* (2017) is that the values of the latter are a mix of samples taken in dry season and in wet season and includes samples taken in the Little Akaki catchment. Since the samples of Beyene *et al.* (2009b) were collected in about the same time of the year and only in Kebena river these values are expected to be more in line with our result.

The low concentrations of NO_3 along with the high concentrations of TAN indicate that the nitrification process in the rivers is slow or non-existing. This could be explained by the low oxygen level that have been found in previous studies, which is likely caused by the high biological oxygen demand (BOD) (Mengesha *et al.*, 2017), a consequence of contamination of organic material. It is also a sign of a fresh contamination. The pollution being fresh is consistent with observations of open defecation and the fact found from interviews that much of the toilet waste of the city goes directly to the river.

Since the NO_3-N concentrations are very small compared to the TAN concentrations (Table 5) it is possible to compare the TAN with total nitrogen concentrations directly, without adding NO_3-N concentrations. The average TAN concentration (21.2 mg/l) is only about one third of the average concentration of total nitrogen in *Kungsängsverket* (58 mg/l) (Uppsala Vatten, 2016). Hence, the total nitrogen content in the river is either lower than in the wastewater or the nitrogen exists to great parts in other forms than TAN or NO_3. Still, the TAN concentrations are twice as high as the total nitrogen concentrations in the "clean" outgoing water at *Kungsängsverket* (9.7 mg/l).

When compared to the concentration of total nitrogen in the *estimated domestic wastewater* (Table 8) the TAN concentration found in this study is much lower (only 1/10), regardless of the flow used for calculation. As for phosphorous one of the explanations for this might be that nitrogen exist in other forms than TAN or NO_3. In urine the major part of the nitrogen is in TAN, but in faeces 50% is bound to organic particles and only 20% exist in the form of TAN (Jönsson *et al.*, 2005). The rest is in the form of soluble organic compounds. The organic particles are mineralised in the water but the low oxygen level could slow down the mineralisation, leaving much of the total nitrogen in the water in particulate organic form. A high organic ratio could also be due to the faeces being fresh. As discussed for total phosphorous, the estimated household wastewater contents might not be applicable to Addis Ababa since the concentrations of nitrogen and phosphorous are measured in a village and the diet might be different in Addis Ababa.

5.2.2 Trends

The pH was more or less the same for all samples. Hence, no trend of increased or decreased pH could be detected.

Because of the big variance within a sample, noticed for the analysis of TAN and PO_4 (Table 7), it is difficult to say anything about trends in the river. The fact that the sampling was conducted at different days during a rather long period of time also adds to the difficulty of comparing sites to each other. However, some differences between sampling sites can be seen even when these factors are taken into account.

Three of the sampling sites, K01, Ba01 and O1, are located more or less outside of the city in the upstream area. For *E. coli*, PO_4 and TAN, the values at these sampling sites were lower than the following downstream values (Figure 26, 28 & 29). For NO_3 this is not as clear (Figure 27). This shows the great impact the city has on the river water quality and how quickly it gets contaminated after entering the city. In the Ba01 to Ba06 branch there is a clear downstream increase of both PO_4 and TAN and a small but consistent increase of *E. coli*. In the other branches however, the concentrations fluctuate up and down. This finding is in line with previous studies (Beyene *et al.*, 2009b; Akalu *et al.*, 2011; Weldesilassie *et al.*, 2011), and the fluctuation could perhaps be explained by the accuracy level of the method discussed above.

After the join of Kebena river and Great Akaki, between the sample sites K14 and A1 (Figure 9), concentrations of all analysed parameters decrease, although the decrease of NO_3 is very small (Figure 26, 27, 28 & 29). The decrease is expected since the Great Akaki catchment contains more rural areas and a less dense population and is thus less exposed to pollution (Figure 2). This theory is supported by the result of (Colombani *et al.*, 2018), where samples taken in the Great Akaki river have a lower *E. coli* count than those taken in Bantyketu.

Most of the concentrations are lower in the lake sample (A6) compared to the last river sampling site before the lake (A5), likely because of dilution with non-polluted water from other parts of the catchment of the lake. The fact that TAN is instead increasing could be explained by the surrounding land use; the area around the lake is mostly used for farming and usage of fertilizers is common (Figure 1). Though decreased, the concentrations are still high enough to class the lake as eutrophicated. Because of the retention time of the lake it has been a longer time since the water of the lake was affected by pollutions (compared to the river water). Since *E. coli* will die off in this environment it is then natural for the *E. coli* concentration to be lower in the lake, as shown in this study.

The correlation between the parameters TAN, PO_4 and *E. coli* (Table 6) show that they vary in the same way throughout the city. This indicates that they all originate from the same pollutions. When a pollutant is added to the river, all of the concentrations increase. For example, an addition of faeces add both nutrients and *E. coli*. It can also be explained by different pollutions being added at the same places in the same proportions or the pollutions in the river water being more or less diluted by non-contaminated water. There is also likely a daily variation in the water quality (because of a variation in metrological and hydrological conditions) and since all parameters are analysed from the same sample their values origin from the same day and should therefore be alike.

The very high TAN concentration in K05 and the comparably high concentrations of NO_3 and PO_4, can be explained by the low flow in the tributary river in which the sample was collected. The small amount of water that was in the river was likely mainly discharge from the houses in the surrounding area, resulting in a high concentration of domestic wastewater in the river.

Looking closer at PO_4 (Figure 28), the concentrations in P1 and Ba04,D seems to be higher than both the upstream and downstream values (Ba04,U respectively Ba07). However, when multiple analyses were made on the samples, some of the results were 10 mg/l lower, which leaves them in the same range as the Ba04,U and Ba07. The results from Akalu *et al.* (2011) indicate a trend-like behaviour of an increase of PO_4

within the inner city, but on the other hand according to Tegegn (2012) there is instead a decrease. This inconsistency amongst studies, along with the results of this study, indicate that there is in fact no trend.

In Kebena river the *E. coli* concentration is generally lower than in the Bantyketu branch. One explanation for this is the difference in population density, where the Kebena river catchment to a greater part contain the less dense outskirts of the city, as can be seen in Figure 7. The degree of contamination supposedly also depends on the number of households not connected to the sewage system. This type of correlation has not been further investigated.

The sudden increase of TAN between K10 and K11 could be due to the samples being taken in different days, since the river content is expected to vary with the time since the last rainfall. However, both NO_3 and PO_4 concentrations are instead decreasing implying this is not the case. The pH is about the same in the two samples and there are no farm areas or any other evident source for pollution in the area. The riversides between the two sampling sites are green areas and there is one hotel located close to the river. It has not been investigated whether the hotel is connected to the sewage system or not.

As the interview study and observations have shown, much of the domestic wastewater goes directly to the river with the stormwater system. As the samples were collected in dry season, the flow was very low upstream of the city and the main contribution within the city is what is brought from the stormwater system and added from industries and wastewater treatment plants. The content and volume of water in the stormwater system should be more or less the same in different parts of the city since households not connected to sewage system exist in many areas. This explains why the concentrations do not change so much within the city.

It is not possible to connect the variations in concentrations of any of the parameters to specific contamination sources.

5.3 COMBINED REVIEW

The picture of highly polluted surface waters is consistent through interviews, observations and water samples. The reasons for pollution are many and the idea of which is the key problem and who is to blame depends on who you ask.

The results from water sample analysis made in this study indicate a high faecal contamination. With only 16% of the city connected to the sewage system it is inevitable that human faeces end up in the river. Adding together what has been said at interviews and the observations of open defecation and contaminated stormwater, it is evident that the rivers are highly exposed to human excreta, confirming the hypothesis that a major contamination source is domestic wastewater. High concentrations of *E.*

coli, together with a high nutrient content and the dirty appearance of the water give the picture of the rivers being the sewage line of the city.

A poor solid waste management add to the pollution level of the rivers. It affects the nutrient content, but it also has an important role in the appearance of the river. The general perception is that the river is highly polluted, but this might not be the case if there was no solid waste. The fact that the river is seen as dirty makes the area around the river unattractive. This allows for people to use it as a toilet, adding more to the pollution and bad appearance.

In lake Aba Samuel large algae blooms were observed (Figure 2). This is a sign of eutrophication, reflecting the high nutrient content found in the lake water sample and confirming the hypothesis of eutrophicated waters. With the high concentrations of TAN and PO_4 brought to the lake through the rivers this is expected. The use of fertilizers observed in the surrounding farmlands likely add more to the eutrophication. Concentrations of nitrogen and phosphorous are so high they are likely not the limiting factor for growth. Though not a health risk, this likely has effects on the ecosystems.

Interviews with authorities have made it clear that there are many laws and proclamations to mitigate the pollution problem, but a weak implementation, a lack of accountability and a bad collaboration between authorities result in slow progress. The Riverside Project being planned at the moment will likely improve the situation, but it also holds back other initiatives. While the authorities believe a higher awareness among the people is needed, the people seem to think it is the authorities that need to take a greater responsibility. Observation of behaviour indicate that everyone expects someone else to handle the problem, and they don't see how they can make a change by themselves, for example by stop littering.

Unlike what was expected, interviews have proved that the river water is not used for drinking and rarely used for any household purposes. However, the rivers were sometimes observed to be used for laundry and the usage for irrigation purposes was widely acknowledged.

High concentrations of *E. coli* in the river water, in combination with the usage for irrigation confirmed by both interviews and observations, pose a health risk both for the farmers and the consumers of vegetables. Vegetables and crops are sold in the markets of Addis Ababa and eaten by the residents of the city. In this way the pollutions spread by the people of the city is brought back to them. The awareness of the pollution problem is high, but the consequence for their health through eating vegetables grown with river water is not well known. The low awareness of the risks, also observed in interviews, adds to the significance of the risks.

Nitrogen and phosphorous levels do not pose a health risk in the forms they exist in the surface water in Addis Ababa, however, through the process of eutrophication they alter the ecosystems of the rivers and the lake. This study ends at Aba Samuel but the problem of eutrophication continues downstream and alters the ecosystem of rivers and lakes, weakening the systems providing essential services for both humans and animals (Nyenje *et al.,* 2010).

5.4 FUTURE RECOMMENDATIONS

There is a need to extend the number of physio-chemical and bacteriological parameters and to analyse continuously for a longer period of time to get a clearer picture of the seasonal variation of the river water contamination. In order to carry out the appropriate solutions to the source of the problem, more steadfast research over time must be performed. The problem of water quality in Addis Ababa calls for a holistic and multi-sectoral implementation from different authorities and stakeholders, therefore the participation of the community is of great need. Furthermore, more research pointing out the industries accountability and the awareness of local community, should be enforced. The following may be done to mitigate the pollution problems and obtain a sustainable development:

- Continuous monitoring of water quality parameters covering different seasons.
- Accountability for industries, factories and companies to take charge of their impact on the environment
- Immediate action taken by involved authorities to help other stakeholders and industries to create sustainable treatment processes at source.
- Multi-sectoral approaches to solid waste and wastewater management, both from the municipality and industries, to decrease the amount of waste(water) released into the river network in the city.
- Awareness creation among citizens, increasing the knowledge about health risks they are exposed to and how they contribute to pollution.
- Awareness creation among citizens about the impacts of pollution to make them put a bigger pressure on industries, creating a new source of motivation for company owners to treat their effluents.
- Construction of public latrines to help reduce the direct faecal contamination in the river network.
- Extension of the sewerage network to include a higher coverage in the city.

6 CONCLUSIONS

This study has been investigating the perceptions of authorities, farmers and households regarding river water quality, human impact, health risks and mitigations in Addis Ababa. This was done by conducting an interview study in the city. Furthermore, water sample analysis was conducted of the parameters *E. coli*, phosphate, total ammonia and nitrate. Observations of the river and possible contamination sources were done, and geo-referenced pictures were taken to record these observations. The following conclusions, answering the specific objectives of the study, have been drawn:

- The major contamination sources to rivers in Addis Ababa perceived by authorities, farmers and households are domestic and industrial waste and wastewater. The Bantyketu and Kebena rivers are mostly affected by wastewater from households not connected to the sewage system.
- The rivers of Kebena and southern Great Akaki catchments have a poor water quality with a high pathogen content and high nutrient levels indicating eutrophic conditions.
- No trend in spatial distribution of pollutants within the city could be found, although it is clear that the pollution level is lower up-stream of the city and pathogen presence seem to be lower downstream.
- Most city residents do not use the river water for any purposes, but it is used for irrigation both in urban agriculture and at the larger agricultural fields south of the city. Due to the economic status some people have no choice put to use the river for washing purposes.
- The bad quality of the river water, in combination with the usage for irrigation induce a health risk both for farmers and consumers.
- Laws and regulations to prevent pollution are in place but the implementation is deficient.

Residents of Addis Ababa are all aware of the bad river water quality, but there is small to no knowledge about the risks with consuming vegetables grown with this water. However, among authorities this risk is acknowledged. To raise the general awareness to risks and the impacts of pollution is one of the keys to improve the situation.

The main reason for the poor implementation of existing laws is a conflict of interest, where the economy of the country has a high priority. A stronger collaboration between authorities and a better implementation of the existing laws is essential for the improvement of the river water quality.

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8 APPENDIX

APPENDIX A QUESTIONNAIRE – AUTHORITIES

We are Swedish students and we have a scholarship and will conduct our thesis here in Addis. The objective of our project is to evaluate river water quality and assess risk for human health, through water usage. We would like to map the status of the rivers and the water usage. Our aim with this interview is to get a clear picture of the water management and water policies in Addis, the main pollution problems and which areas are most affected. We also want to know what future plans there are for the rivers in the city. Your answers will be used for our thesis research that will be published. It is possible that what you say will be cited in our published study, is that okay?

1. What does good river water quality mean to you?
2. Would you say the rivers in this city are of good quality?
3. Would you say the Akaki/Sebeta river is polluted/contaminated?
4. In what areas is the contribution to pollution the greatest?
5. What are the greatest sources for contamination? *Point sources and type of source (industries, sewage...).*
6. In what areas are there most industries?
7. In what areas is (urban) farming most common?
8. What is the river water used for? Does this differ between different parts of the city? *Laundry, dishes, cooking, drinking, bathing, irrigation, construction etc.*
9. Can you see any risk to human health with this usage?
10. If so, is this information spread to people?
11. If the water quality was different, could it/would it be used for something else?
12. How does the tap water supply work? Is there a central system for supply?

13. How reliable is the tap system? */Can you always get water from it?*
14. Can you see any risks to human health with usage of tap water?
15. If so, is this information spread to the people?
16. What roles do local, regional and national governments play in questions regarding river water quality and public health?
17. Are there other authorities/departments/organisations working with water quality investigation/management? Which?
18. What is your role, responsibility and focus in these questions?
19. Do other authorities/departments/organisations have another focus or perspective on these questions than your organisation?
20. Are there laws/control measures/policies concerning disposal of waste/water into the river?
21. How well are these laws/control measures followed?
22. How are these laws/control measures followed up? *Is there a control system for making sure they are followed?*
23. How would you describe these control measures in terms of efficiency and necessity? */Would you say it is efficient?*
24. Do you (your department/organisation) have a set goal for future water quality? What is that goal?
25. Is there a plan to put more control measures in place in the future?
26. Are there any further investigations planned, concerning water quality and public health?

27. What do you consider to be the main priority when it comes to enhancing (getting better) river water quality?
28. Is there any geographical area of the city that has a greater need for investigation? Have been less studied before? *Is of greater importance?*
29. Is there a focus of study that you find have been left out in previous studies?

APPENDIX B QUESTIONNAIRE – HOUSEHOLDS AND FARMERS

We are Swedish students and we have a scholarship and will conduct our thesis here in Addis. The objective of our project is to evaluate river water quality and assess risk for human health, through water usage. We will map the status of the rivers and the water usage. Our aim with this interview is to get a clear picture of what you use the river water for, if/how you treat it, and what you think about the quality of the river water. We would also like to know what you think affects the river water quality in this area. Your answers will be used for our thesis research that will be published. It is possible that what you say will be cited in our published study, is that okay?
The interview will start with some basic fact questions about this household, that will help us analyse the results of our interview study. If you have any questions during the interview feel free to ask!

1. How far is it from here/where you live to the river?
2. Do you use the water from the river? If yes, what type of usages?
    1. *Irrigation*
    2. *Cooking*
    3. *Laundry*
    4. *Drinking*
    5. *Drinking for cattle*
    6. *Cattle drinking when grazing close to river*
    7. *Other*

Follow up with examples of usage if not gotten a satisfying answer.

3. Do you cultivate any crops or vegetables?
   If yes:
4. What type of crop are you cultivating?
5. How would you normally prepare this food for eating?
    1. *Cooked*
    2. *Not cooked*
6. Do you irrigate your land?
    1. *Yes*
    2. *No*
7. With what water do you irrigate?

8. Do you have any livestock?
   If yes:
9. Where do you have your animals?

If grazing, then make sure to get information of where, to know how close to the river they can go.

10. What water do the animals drink?

Make sure to get information of if it differs between the animals.

11. How do you handle the animal manure?

12. Where do you put the animal manure?

13. How to you handle the leftovers from slaughter?

14. Do you somehow treat the water to get better quality before you use it?
    1. *Yes, always*
    2. *Yes, sometimes*
    3. *No, never*
15. If yes, what kind of treatment
    1. *Filter*
    2. *Membrane*
    3. *Boiling*
    4. *Chlorine*
    5. *other.*
16. If no, why not?
    1. *To expensive*
    2. *Don't see the need*
    3. *Other*
17. If sometimes, when and when not?

18. Do you use more or less of the water in different seasons (wet/dry)? Why?
19. Do you use the water for different things in different seasons (wet/dry)? Why?

20. What does good river water quality mean to you?

    Citation
21. How would you rate the water quality in the river in your area?
    1. *Very good quality*
    2. *Good quality*
    3. *Unsure of quality*
    4. *Bad quality*
    5. *Very bad quality*

22. How would you rate the impact from human activity on the river water quality?
    1. *Very strong impact*
    2. *Strong impact*
    3. *Moderate impact*
    4. *Little impact*
    5. *Very little impact*
23. What kind of human activity you consider have the most impact on the water quality of the river?
24. How has this activity affected the water quality?
    1. *Better*
    2. *Worse*

Can you give any examples?
So, would you say they make the water quality better or worse?

25. What are the core water pollution challenges in the area?

Where does it come from?
Why do you think industries/authorities don't have an interest to install treatment technology?

26. Do you consider it to be a health risk to use the water the way you do?
    1. *Yes*
    2. *No*
27. What is it possible (suitable) to use the river water for?
    1. *Irrigation*
    2. *Cooking*
    3. *Laundry*
    4. *Drinking*
    5. *Grazing*
    6. *Other*

Follow up questions in case they don't understand.
What will it not be a risk to use the water for (despite the bad quality)?
So you mean it will not be a risk for your health to use the water for xx?

28. If you had the possibility to use another source of water instead, would you?
    1. *Yes*
    2. *No*

29. Do you have any other comments on water quality?

APPENDIX C DATA ANALYSIS RESULTS

Table C1. Results from conducted analyses of collected water samples, and geographical coordinates of sampling sites.

Projected Coordinate System: WGS_1984_Web_Mercator_Auxiliary_Sphere

Geographic Coordinate System: GCS_WGS_1984

	[mg/l]			*E. coli*					
Name	**TAN**	**NO3-N**	**PO4-P**	**CFU /1ml**	**CFU /100 ml**	**$\log_{10}$ CFU /100 ml**	**pH**	**X coordinate**	**Y coordinate**
A1	16.7	0.31	3.37	8700	870000	5.94	7.7	4317019.50	998338.12
A2	15.5	0.48	2.21	220	22000	4.34	7.2	4317511.89	992148.84
A3	17.0	0.49	2.35	186	18600	4.27	7.3	4316968.82	988934.05
A4	14.7	0.43	3.72	133	13300	4.12	7.2	4315930.19	986975.79
A5	14.5	0.49	11.40	165	16500	4.22	7	4309815.74	985511.64
A6	16.0	0.38	5.18	9	900	2.95	7.6	4308690.95	982230.17
Ba01	0.90	0.17	1.00	220	22000	4.34	7.4	4312348.30	1013960.28
Ba02	15.9	0.18	6.41	10300	1030000	6.01	7.1	4312370.31	1011889.80
Ba03	22.5	0.25	9.32	38000	3800000	6.58	7.5	4314323.03	1012525.38
Ba04,D	27.0	0.35	14.62	66000	6600000	6.82	7.3	4314159.64	1011090.88
Ba04.U	22.3	0.34	10.80	47000	4700000	6.67	7.4	4314129.66	1011142.26
Ba05	26.1	0.30	11.65	13700	1370000	6.14	7.4	4312394.11	1010215.42
Ba06	47.5	0.33	15.93	49000	4900000	6.69	7.3	4313516.02	1009202.62
Ba07	28.5	0.24	9.65	82000	8200000	6.91	7.3	4314608.71	1009032.65
Ba10	26.9	0.29	9.12	60000	6000000	6.78	7.4	4314242.24	1008038.05
Ba11	25.8	0.22	8.10	51000	5100000	6.71	7.4	4315098.13	1007521.75
Ba12	21.5	0.25	9.39	35500	3550000	6.55	7.5	4315869.64	1007096.34
Ba13	21.9	0.28	9.96	33200	3320000	6.52	7.3	4316310.34	1005995.42
K01	0.84	0.10	0.46	30	3000	3.48	7.7	4315566.88	1014024.03
K02	16.1	0.28	3.84	5000	500000	5.70	7.3	4315708.89	1012613.49
K03	13.3	0.18	3.16	5800	580000	5.76	7.5	4315900.36	1011558.03
K04	16.8	0.23	4.34	6300	630000	5.80	7.4	4316847.66	1010327.70
K05	62.9	0.63	13.52	3900	390000	5.59	7.4	4317073.39	1009411.67
K06	19.6	0.24	3.43	900	90000	4.95	7.4	4316935.46	1008689.99
K07	19.5	0.23	7.41	27000	2700000	6.43	7.3	4316652.37	1007357.94
K08	19.4	0.22	7.42	19200	1920000	6.28	7.3	4316802.51	1006569.02
K10	15.2	0.27	12.25	39000	3900000	6.59	7.2	4316701.14	1005084.99
K11	27.7	0.25	9.07	62000	6200000	6.79	7.3	4315789.56	1003984.75
K13	25.3	0.22	4.41	5040	504000	5.70	7.4	4316330.63	999667.10
K14	33.8	0.36	6.28	18100	1810000	6.26	7.4	4316754.54	998753.19
O1	0.91	0.11	0.52	261	26100	4.42	7.7	4318908.46	1012830.68
O2	14.7	0.20	6.10	2800	280000	5.45	7.3	4316842.18	1011164.41
O3	27.7	0.30	6.83	2900	290000	5.46	7.6	4317446.26	1010834.90
P1	26.4	0.38	16.62	40000	4000000	6.60	7.2	4314118.73	1011129.26

APPENDIX D CREATION OF FIGURES

All maps (Figure 1–10, 26–29) in this report are created by Malin Eriksson and Jonathan Sigvant, who together own the copyright.

The river networks in Figure 1–10 and 26–29 are derived in ArcMap based on river network vector files given by Dr. Fiseha Behulu and orthophoto provided by the Ethiopian Mapping Agency.

Road network in Figure 1 and 3 is derived in ArcMap based on road vector files and orthophoto provided by the Ethiopian Mapping Agency.

The shapefile of Aba Samuel was created based on observations and orthophoto given by the Ethiopian Mapping Agency.

Catchments in Figure 2 were created with ArcMap tools, based on DEM given by Dr. Fiseha Behulu.

Background map in Figure 1–3, 26–29 is based on three files. A polygon vector file of the outlines of Addis Ababa, and a polygon vector file of the extent of Bole International Airport, both created in ArcMap based on orthophoto provided by the Ethiopian Mapping Agency and a DEM file provided by Dr. Fiseha Behulu.

The background orthophoto in Figure 4–10, was provided by the Ethiopian Mapping Agency and the copyright of this orthophoto belongs to Ethiopian Mapping Agency.

Photos present in the report are taken by Malin Eriksson or Jonathan Sigvant and all persons present in photos have given their consent.

All other map data have been created by Malin Eriksson and Jonathan Sigvant based on the data collection and experiments of this Master’s Thesis.