CHROMIUM POLLUTION AND BIOACCUMULATION IN *Oreochromis niloticus* Linne IN THE NAPOLEON GULF OF LAKE VICTORIA

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DECLARATION

I, **OCAYA HENRY** do hereby declare that this research work is my own and all the contents presented are original except where stated by the references and that the same work has not been submitted for an award of a degree at any other university or institution of higher learning.

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DEDICATION

This piece of work is dedicated to my family, especially to my children Benjamin, Timothy and Grace whom I have challenged to rise to this level and beyond.

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ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
BAF	Bioaccumulation factor
BDL	Below Detection Limit
DO	Dissolved Oxygen
EC	Electrical Conductivity
EPA	Environmental Protection Agency
FAAS	Flame Atomic Absorption Spectroscopy
FAO	Food and Agriculture Organization
HCL	Hallow Cathode Lamp
MDL	Method Detection Limit
ND	Not Detected
NTU	Nephelometric unit
SS	Suspended solid
TDS	Total Dissolved Solid
TL	Total length
Twt.	Total weight
USEPA	United State Environmental Protection Authority
WHO	World Health Organization
SEF	Sediment enrichment factor

ABSTRACT

A study was conducted to characterize wastewaters from Sky fat and Leather tannery of Uganda - LIU) to assess for compliance to safe limits; impacts on the habitat of Nile Tilapia and also assess for chromium bioaccumulation. The two tanneries are located in Jinja Municipality within Kirinya West Wetland along Napoleon Gulf of Lake Victoria. Effluent, water, sediment and fish specimen were collected from georeferenced sites once every month for six months covering the dry (December to February) and wet (March to May) seasons. Data on some physicochemical parameters were collected *in-situ* using calibrated water quality meters. All samples were processed and analyzed for chromium using standard methods (APHA, 1999). According to the results, the physico-chemical quality of the effluents significantly exceeded the permissible limits. High pH (7.5 to 9.6), EC (626 to 12,130 µS/cm), TDS (419.4 to 8,127.1 mg/L), low dissolved oxygen (0.1 to 1.1 mg/L) and redox potentials were recorded. Cr was significantly high (Tukeys HSD test, $p < 0.05$) exceeding the permissible limit of 100 µg/L (NEMA, 1999; USEPA, 2003) by approximately 50 times. Elevated Cr concentrations in water (0.1 to 126.9 µg/L) and sediment (range 17.9 to 135.7 µg/g dwt) were noted. A high geoaccumulation index (Igeo = 3.58) and sediment enrichment (55.1) factor were recorded indicating sediment contamination. Cr bio-accumulation in fish organs (range 0.18 to 2.33 µg/g dwt) occurred in the order of liver > skin/muscle > gill. The poor effluent quality is a potential health risk to the fishery and the people.

Word count (**249**)

CHAPTER ONE

INTRODUCTION

1.1 Background

Leather tanneries are amongst the most chemical and water intensive industries known today (NAPE, 2009). These industries often discharge partially treated effluents into wetlands or at times directly into streams, rivers or lakes. A wide range of chemicals (chrome salts, lime, chloride, tannin, phenols, sulfates and sulfides) mixed with biodegradable and non-biodegradable materials creates an unaesthetic effluent that is so hazardous to the environment (Niyas and Mohammed, 2014; Arassapan and Kalyanaraman, 2015).

Most organisms found in tannery contaminated areas are at risk of suffering from internal and external organ damage due to the toxic materials in the effluent. In fish for instance, damages caused to the histopathology of the liver, kidney, and stomach cells have been associated with Cr in the effluent (Moustafa and El-Sayed, 2014; Sulav, 2016). Prolonged exposure of fish in such an environment can induce organ deformation, cause a reduction in gamete production and ultimately impacting on the viability of fish gonads (Sfakianakis *et al.*, 2015). This is critical as it could result into a decline in fish population.

Several negative impacts of Cr toxicity to organisms have been reported. For instance, in fish, damage caused to the external organs leads to increased opercula and irregular vertical movement and ultimately death (Sulav, 2016). In aquatic macrophytes, growth inhibition has been reported in duckweed and algae, whereas in benthic invertebrates and freshwater fingerlings reductions in fecundity, growth and survival of these organisms have also been noted (Josefina *et al.*, 2011). In humans there are reported cases of serious health problems associated with gastro-intestinal, dermatological and other related diseases related to exposure to Cr.

Lake Victoria is a freshwater body with an area covering 68,800 square kilometers (Obiero *et al.*, 2015). The waters of the lake is shared by three countries, Tanzania 51%, Uganda, 43%, Kenya, 6% (Ogello *et al.*, 2013). This lake is a vital natural resource to many people from the three East African countries who fish from it for food and income. It is also used for navigation, provides water for industrial needs, hydropower generation waste disposal site, irrigation, raw materials for craft and construction work and other domestic uses. However, degradation of the lake's catchment is posing serious threat to the lake (Gichuki *et al.*, 2008) and this is the cause of stress to the lake's ecosystem, most specially the fishery (Balirwa *et al.*, 2003).

Pollution of Lake Victoria's catchment and ultimately its water is mostly attributed to industrial waste discharge, urban sewage discharge, human population and housing pressures within the lake side and the growing demand to expand urban boundaries. These are responsible for increased wastewater generation (Kansime and Nalubega, 1999). To address such a challenge, many wetlands are being used as alternative options for biological treatment, and this instead has turned these ecosystems into recipients of the wastewaters, a trend that is expected to continue (USEPA, 1993). Worse still, by loading these wetlands beyond their capacities instead turns them into pollution hot spots for nutrients and heavy metals (NSW EPA, 1993; Muwanga and Barifaijo, 2006; Ismael, 2001). Therefore, failure to properly manage the changes will lead to a shift in the biology and chemistry of the receiving wetlands and ultimately the lake.

The three major wetlands of Jinja located along Napoleon Gulf of Lake Victoria are Kirinya West, Kirinya East and Masese Budumbuli wetlands. Like Mwanza Gulf in Tanzania and Nyanza Gulf in Kenya, these areas are known for being most exposed to anthropogenic influences around the whole lake (Mwamburi, 2016). Kirinya West wetland which was identified as the study site, has two leather tanneries (Skyfat and LIU) within it. These tanneries discharge directly their chrome enriched effluent into the wetland. Tannery effluents have a very poor water quality and hence are unhealthy to the receiving ecosystems. The partially treated tannery effluents are a threat to the ecological functions and performance of wetlands (Muwanga and Barifaijo, 2006).

Kirinya West Wetland is a habitat for diverse aquatic and terrestrial organisms one of which is the Nile tilapia (*Oreochromus niloticus*). This is an economically important fish species of Lake Victoria second only after the Nile perch (*Lates niloticus*). It is a source of protein and income to many people that depend on it. This fish originally fed mostly on algae but has now diversified its diet to insects, such as *Chaoborus, Odonata*, *Chironomids*, algae and plant materials (Balirwa, 1998; Njiru *et al.*, 2004; Ng'wala, 2014). It also breeds along wetland lakeshores where its juveniles spend most of their time to evade predation.

The disposal of tannery effluents into fish habitat not only contaminates the area but also threatens the existence of fish species, human beings and other organisms through pollutant contamination. Cases of injury to humans and animals, fish kills and decline in fish catches have been reported (Rangers, 2015). Continuous and uncontrolled disposal of tannery effluents introduces Cr into the aquatic environment where accumulation may occur within the water column and in the sediment. Once the concentration of Cr is elevated far beyond the safe limit for freshwater environments, this can negatively impact on fish and other aquatic life (Ismael, 2001). Fish in such an area risk ingesting Cr contaminated food or absorb the metal pollutant when it comes into contact with the contaminated water. Such pathways can trigger bioaccumulation and ultimately result into bio magnification up and across the food chain (Ishaq and Annume, 2011: Ismael, 2001).

Despite the potential risks that tannery effluent pose on the environment and in particular on freshwater ecosystems, compliance to the set safe limits by NEMA is often abused by the industrialists. Therefore, three knowledge gaps tht forms the basis of the study were identified. The first was the absence of a scientifically researched information on the impact of effluents from Skyfat and Leather Industry of Uganda (LIU) on the physicochemical quality of the tilapia habitat along Kirinya west wetland. Secondly, the absence of researched information on the risk of Cr bioaccumulation in the different organs of the fish. Thirdly, the knowledge gap relating to the safety of fish from the Kirinya west wetland-lake interface to human consumption.

The outcome of the study is a basis upon which stakeholders (the tannery managers are called upon to consider effective management of their effluents whereas the top policy managers responsible for the implementation of specific policies towards addressing the Cr contamination problem and ensuring the fishery and the consumers are safeguarded) are sensitized to handle their responsibilities.

1.2 Statement of the problem

With all the pollution management measures put in place, the level of pollution of Lake Victoria by leather tannery at Kirinya West wetland of Napoleon gulf has remained high. This is a serious threat to the fishery and other aquatic biota inhabiting the area. The risk of contamination through bioaccumulation of chromium is high. Three leather industries (Skyfat, Uganda Leather industries and SMT Investments) discharge their effluents into Kirinya wetland and Lake Victoria. The wastewater infiltrates into the lake where its concentration in the water, sediment, invertebrates, fish and organic matter is elevated contaminating the aquatic environment and the entire food chain for fish. The local communities that fish, cultivate and obtain water from this area for domestic needs are at a risk of consuming chromium contaminated fish, food and water.

Effluents from leather tanneries contain carcinogenic Cr pollutant material. This pollutant can ably bioaccumulate into tissues and internal organs following ingestion. The ultimate impact of bioaccumulation is tissue damage and gene mutation of the affected cells. The risk of exposure to Cr is through a food chain interrelationship.

1.3 General objective

To assess the effect of direct discharge of leather tanning effluents on the water quality and breeding grounds for *Oreochromis. niloticus* and determine if bioaccumulation of Cr is taking place.

1.3.1 Specific objectives

1. To carry out the physico-chemical characterization of the tannery effluents discharged into the environment by LIU and Skyfat industries.
2. To determine the effect of effluent discharge on the quality of breeding grounds of *Oreochromis. niloticus.*
3. To assess the bio-accumulation of Cr in the selected organs of *Oreochromis niloticus.*

1.4 Research hypotheses

1. The physico-chemical properties of the effluents from the different leather tannery industries discharged into Kirinya wetlands and Napoleon Gulf do not significantly vary (H_o).
2. The physico-chemical characteristics of the sediment and water do not significantly vary across the different fish breeding sites (H_0).
3. *Oreochromis niloticus* from polluted sites along the shorelines of Kirinya West wetland of Lake Victoria are significantly bio-accumulating Cr metal into the vital body organs than that from the unpolluted sites (H_1)

1.5 Scope

The focus of the research was to assess the quality of leather tannery effluents (from Skyfat and ULATI) discharged directly into Kirinya West Wetlands, its influence on the quality of the lake water and sediment at the receiving fish breeding grounds of Napoleon

Gulf through collection of primary data on the prevailing physico-chemical characteristics. Assessment Cr bio-accumulation in *Oreochromis niloticus* was also carried out. Primary data on physico- chemical characteristics of the tannery effluent, the lake water and the sediment quality was carried out. Similar physico-chemical data as was collected from a control site awayfrom area of contamination. Analyses of collected effluent, water and sediment samples were carried out at the Fisheries Research Institute Laboratory in Jinja.

1.6 Significance of the study

The knowledge gap identified by this research is the absence of information on the impact of leather tanneries on the habitat of Nile tilapia and the risk that the local community who fish from the area and also depend on the same water for their domestic purposes and household income. Results from this study therefore, forms the basis for recommendations towards guiding policy formulation for effective management, ensuring health safety of the community and the fishery.

CHAPTER TWO

LITERATURE REVIEW

2.1 Leather tanneries and the associated environmental challenge

Leather tanneries are facilities designed to handle and process fresh hides and skins into soft leather. Wastes from these industries are hazardous to the environment. Often the effluents are below the acceptable standards for disposal into freshwater bodies and this is the reason as to why leather tanneries worldwide, are amongst the top most polluters of the environment (Camargo *et al.*, 2003). Wherever tannery effluents are channeled, they degrade the environment, and this is due to the highly complex mixture of organic and inorganic chemicals (Bhatnagar *et al.*, 2013; Arasappan and Kalyanaraman, 2015).

A large quantity of water is required to mix and flush out any unused chemicals and solid materials leading to generation of enormous quantities of effluents. The wastewater is often discharged into chrome beds for primary treatment before being released into the environment such as at Napoleon Gulf of Lake Victoria. However, the effectiveness of the chrome beds is sometimes below the desired standard and the release of semi treated effluents into the environment and there polluting it. Metal contaminated aquatic environment presents high risk of pollutant accumulation (Tiina *et al.*, 2006).

2.2 Tannery effluent and its effect on the aquatic environment

Effluents from leather tanneries are anaesthetically colored and smelly. They are also loaded with remnants of chemicals mixed with other suspended and putrefying materials (Arassapan and Kalyanaraman, 2015). The use of tannins, sulphides and lime in leather tanning is responsible for the dark brown color of the effluent (Mahmood, 2000; Jahan *et al.*, 2014). Tannery wastes contain Cr metal pollutant and this is highly toxic to most organisms. Once introduced into the environment, this toxic pollutant can find its way into the aquatic food chain (invertebrates and the fish) and subsequently into humans hence posing a health risk (Olaifa *et al.*, 2004).

The lethal effect of chromium to organisms is most likely when it is at an elevated concentration. Under natural conditions, chromium may only be found in traces. Its concentration in freshwater environment rarely exceeds 2 mg/L (Moore and Ramamoorthy, 1984), but are elevated in areas that receive tannery effluents, urban and agricultural run-offs (Hosnia *et al.*, 2015). In such area, the most toxic hexavalent (Cr^{6+}) state is significantly present. and can be readily released into the surface waters and soils (Niyas and Mohammed, 2014).

2.3 Environmental safe disposal limits

There are several environmental agencies whose roles are to guide and regulate on safe industrial waste discharges in water bodies and sewers. Standards for maximum permissible limit of Cr discharge into the aquatic environment have been set at 0.05 mg/L (EPA, 2001; NEMA, 1999). Such a guide is essential, but unfortunately is quite often exceeded by some tanneries. For instance, in a study carried out earlier, it was reported that on average 264 mg/L of Cr was discharged daily into Napoleon Gulf by the Leather Industry of Uganda (LIU) (Oguttu *et al.*, 2008). This was in excess of the safe limit. Incidentally no study was carried out to evaluate the impact onto the fishery and other aquatic organisms of the lake.

2.4 Distribution of chromium in the aquatic environment

Chromium is a metal with the capacity to partition itself in the aquatic environment. Partitioning occurs within the water, on suspended solids, sediments and in biota. It forms complex compound with clay mineral matter (Fe and Mn oxides/hydroxides, carbonates, organic substances especially humic acids) and on biological materials such as algae and bacteria (Calmano and Forstner, 1990). The partitioning and eventual distribution of Cr is a result of dilution, advection, dispersion, sedimentation, adsorption or desorption processes. This leads to speciation of Cr which is further regulated by the instability constants of the various complexes and also the physico-chemical properties of the water (pH, dissolved ions, redox, salinity and temperature), (Holdway, 1988). However, mechanisms by which Cr can be removed from the environment depends on a number of factors. These factors include the rate at which adsorption onto particulates will take place; transformation into the insoluble form; the rate of precipitation as well as sedimentation (Ishaq and Annume, 2011; Gintaras *et al.*, 2014).

Chemically chromium occurs in the environment in several oxidation states. Most of these states are unstable except the trivalent Cr (III), and the hexavalent Cr^{6+} (Nieboer and Jusys, 1988; Hellena, 2012). Under certain environmental conditions that includes areas with very low dissolved oxygen (anoxic) conditions, under saline conditions (Robless and Armienta, 2000; Scott *et al.*, 2000; Adel and Norman 2002), acidic environments (Salomons, 1995; Niyas, 2014), warm environmental conditions and where negative redox potentials (Luoma, 1983; Prosi, 1989; Elder, 1989) are present, the speciation process will take place in water. And when this occurs, Cr is rendered bioavailable to most aquatic organisms including *Oreochromis niloticus*. It is also reported that those areas where tannery effluents are being discharged are dominated by the hexavalent Cr species (Sfakianakis *et al.*, 2015).

2.5 Accumulation of chromium in *Oreochromis niloticus*

Chromium accumulation in fish originates from sources such as discharged wastewaters, terrestrially derived metal laden soils and other materials, aerially deposited dust and aerosols (Mwamburi, 2016). Exposure of fish to Cr pollutant will take place via the contaminated water, benthic food matter and the food web (Mansour and Sidky, 2002; Jack, 2016; Hezbulla *et al.*, 2016), hence raising the risk of bioaccumulation. In the aquatic food web, fish occurs at the top of the food chain, and therefore uptake, bioaccumulation and biomagnification is inevitable across the food chain of which humans are a part (Authman, 2008; Khayatzadeh and Abbasi 2010; Ismael, 2001; Ayeloja *et al.*, 2014).

Chromium has a physicochemical property that makes it exert very high affinity for surfaces of particulate matter. Such high affinity causes very strong bonds to be formed and ultimately its build up into tissues. Since fish is an aquatic organism it is potentially prone to accumulate metal pollutants, especially Cr, from its environment. Often exposure will occur via the contaminated water, benthic food matter and the food web (Mansour and Sidky, 2002; Jack, 2016; Hezbulla *et al.*, 2016). It has been observed that algae which constitute part of fish food, have the capacity to accumulate Cr up to 4,000 times higher than what may be found in the surrounding environment (Duffus, 1980).

2.6 Chromium uptake pathways and excretion

It has been observed that uptake of Cr takes place either through the gills, skin, liver and flesh based on passive diffusion (Doudoroff and Katz, 1953). Other factors such as the occurrence of an elevated Cr concentration, the rate of excretion and bioaccumulation will also trigger uptake (Fredrick *et al.*, 2013). Other researchers have also observed that biological factors such as the size of the fish, its age, feeding habit as well as the changes in the seasonal living conditions do influence metal excretion and bio-accumulation (Farkas *et al*, 2003). That which is not eliminated is stored in the bones, fat tissues and within the liver (Heath, 1991; Nussey *et al.*, 2006; Preez 2006; Obasohan, 2008; Amiya *et al.*, 2012).

The liver is the organ where bioaccumulation, biotransformation and excretion takes place (Akhtar *et al.,* 2016). Biotransformation and excretion is carried out by Metallothionein (MT), a low molecular weight protein enriched with high amount of cysteine (Emilio *et al.,* 2007). The role of this protein is to bind with all toxic materials and radicals so as to form metal thiolate clusters thus easing the removal and excretion process (Emilio *et al.,* 2007).

Metallothionein gene expression in fish tissues can be used in sub lethal assessments as a biomarker of exposure to metal ions in any fish inhabiting metal contaminated areas (Cheung *et al.*, 2004). It is for such a reason why fish is taken as an ideal biomarker organism in the examination of traces of pollutant build up or in the assessment of the health of an aquatic ecosystem (Farkas *et al.*, 2002; Ishaq *et al.*, 2011; Tiina *et al.*, 2006; Akhtar *et al.*, 2016).

2.7 Chromium toxicity

This is dependent on how much of the metal pollutant is bioavailable. As mentioned earlier, bioavailability ofCr is based on the prevailing oxidation states. Whereas only the trivalent Cr^{3+} and the hexavalent Cr^{6+} are the most bioavailable, only the former is required by living organisms in glucose and lipid metabolism (Sonia, 2017). The hexavalent Cr is highly toxic and therefore not essential to organisms.

Several environmental properties are responsible for the toxicity of the hexavalent Cr. These include the high oxidative potential, high solubility, high mobility and high positive charge (Cr^{6+}). The latter property promotes formation of strong bonds with any negatively charged surface such as occurs on silt, algae, fish tissues and organic matter (Kersten and Forstner, 1989; Robles and Armienta, 2000; Avenant and Marx, 2000). After a bond is established, passive diffusion across cell membranes to internal organs such as the liver, bones and muscles follows resulting into bioaccumulation (Duffus, 1980; Hellena, 2012).

The impacts of Cr toxicity are evident in the reduction of enzyme activity as well as in the damages caused to the histology of tissues (Tchounwou *et al.*, 2012). Other adverse effects in fish occur at the hematological level (Sonia and Yousafzai, 2017). The survival of fish as well as its growth is totally dependent upon the dose period of exposure (Farag *et al.*, 2006).

2.8 *Oreochromis niloticus*, its biology and ecology

Fish is a source of high protein in human nutrition (Akhtar *et al.*, 2016). Nile Tilapia is one of the dominant and commercially important fish species of Lake Victoria and is commonly found inhabiting inland waters (Cheung *et al.*, 2004) especially along wetland-lake shores (Balirwa, 1998). Its food comprises of the invertebrates such as *Chaoborus, Odonata, Chironomids*, benthic materials, smaller fish, algae and plant materials that are present in the water column and lake sediment (Balirwa, 1998; Njiru *et al.*, 2004). Like any other fish, Tilapia uses its gills for respiration. The thin epithelial cell layers on the gills have a.good blood circulatory system that makes it suitable for the diffusion of dissolved oxygen from water into the fish.

2.9 Kirinya West Wetland and its ecological role

When tannery effluents are disposed into wetlands, the organisms that are found here are at risk of accumulating the toxic materials that come with the effluent (Olaifa *et al.*, 2004). In a survey carried out by Rangers (2015), it was reported that the industrialists around the wetland do not agree to the direct benefit of the wetland. However, this totally contrasts with what science recognizes about the ecosystem values attached to such wetlands. Tiina *et al.*, (2006) observed that metal contaminated aquatic environment presents high risk of pollutant accumulation.

Wetlands have the capacity to buffer water bodies from the aggressive effect of pollutant discharges and are also vital in the bioremediation process. However, continuous discharge of wastewaters into them not only overstresses them, but ultimately hampers their efficiency to strip any pollutant material (EPA, 1993). That is why, a wetland overloaded with wastewater may not necessarily perform its bio filtration process as expected of it (Scott *et al.*, 2000). Kirinya West wetland is amongst one of such wetlands that has been receiving continuous loading of urban sewage and tannery effluents for the last five decades. This therefore puts its efficiency is at stake.

Currently, there are three leather tanneries (Skyfat, ULATI and SMA industries) that discharge their effluents directly into Kirinya west wetland. Of these, Skyfat is the largest with an annual capacity of between 150,000 to 500,000 skin/year (Leather International, 2012) and is known to discharge 80% of its wastewater into the environment (Kairu, 2010). LIU is smaller with the capacity of 550 kg of skin/day, and a discharge of 17 m^3 of wastewater per day (Oguttu *et al.*, 2008).

Kirinya west wetland is also being threatened by the extensive encroachment and continuous drainage of the wetland for purposes of creating gardens for crops and setting up temporary housing structures, such as is the case close to Loco village. These human stressors not only lower the buffering capacity of the wetland, but also causes the wetland to become a hotspot for pollution exposing the waters of Lake Victoria and the fishery of the area to the increasing impact of heavy metal pollution.

CHAPTER THREE

METHODOLGY

3.1 Site description and location

Jinja is one of the urban centers of Uganda. It has three wetlands that border Lake Victoria. The surface areas of these wetlands are; Kirinya West, 0.5 Km^2, Kirinya Masese East, 0.5 Km^2 and Budumbuli, 0.9 Km^2 respectively (Koller and Kunz, 1997). The ecotone zones of these wetlands provide habitats for fish and other aquatic organisms apart from buffering Lake Victoria waters from pollutant wastes coming from Jinja urban centre.

The study was conducted along the shorelines of Kirinya West wetland located at the outskirt of Jinja municipality and in Napoleon Gulf of Lake Victoria (Figure 3.1). This study site is situated on the northern portion of the lake approximately 2.5 Km from the source of the River Nile. It lies within the geographical coordinates of 0°26.024'N, 0°24.321'N, 33° 13.293'E and, 33°13.322'E at an average elevation of 1137 m above sea level. Napoleon Gulf forms the headwaters of the River Nile as it starts its journey to Egypt. Kirinya West wetland is an ecotone receiving the wastewaters that includes industrial effluents, sewage, storm water and agricultural run-off from Jinja Municipality.

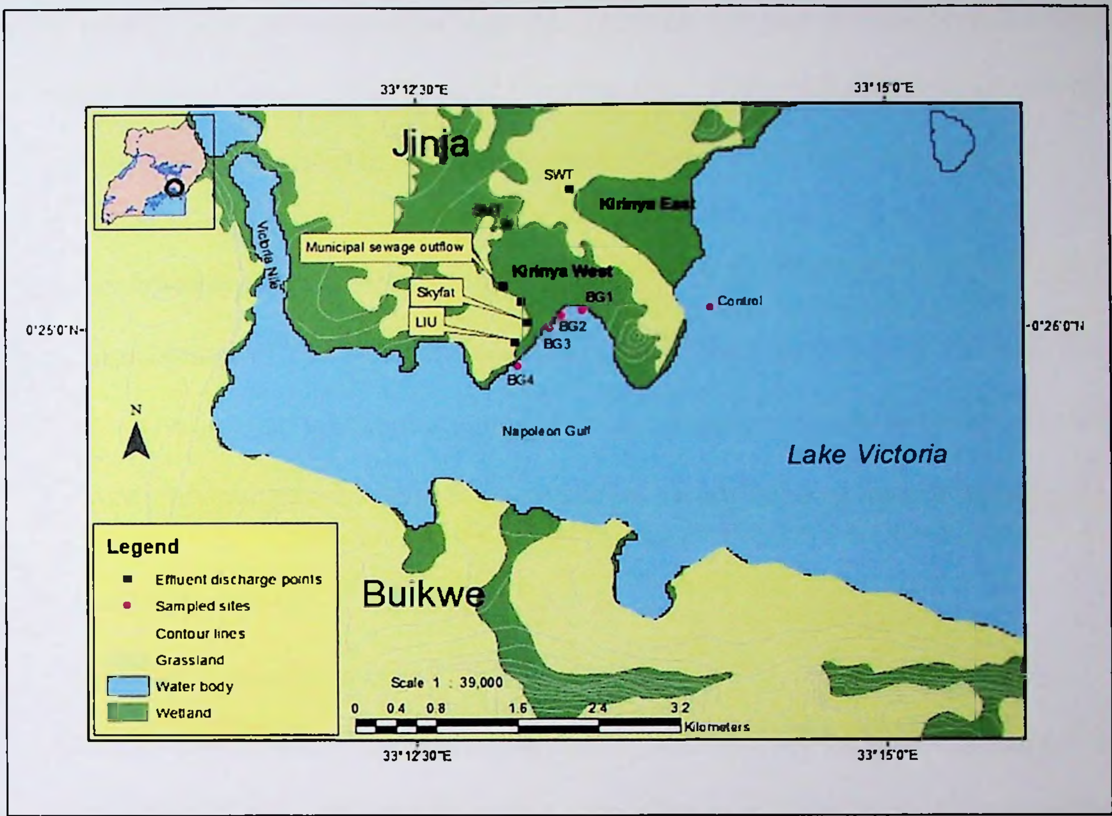


Figure 3.1: Location map of the study area (Source: Ocaya, 2017)

3.2 Climate

3.2.1: Rainfall

Data on precipitation was obtained to show seasonal variation during the study period (December 2014 to May 2015). Secondary climate data was sourced from a website http://climate.org whereas the primary data was obtained from a sub weather station located at NaFIRRI in Jinja.

3.2.2: Temperature

As for rainfall, data on temperature was also obtained covering the period under study. Secondary climate data was also sourced from the website http://climate.org. The weather station at NaFIRRI was used to obtain temperature data.

3.3 Vegetation type at the study site

A rapid assessment of the dominant vegetation type found at the study site was made through observation and taking photographs. Expertise help was sourced from a botanist at Makerere University with regard to the botanical names of the dominant species.

3.4 Sampling strategy

3.4.1 Selection of sampling sites

A preliminary survey of the study area was undertaken. Survey on land was carried out by walking around the wetland whereas on water it was done by use of a motor boat. The purpose of the trip was to select suitable sampling sites. The coordinates of the identified sites were obtained with the help of a global positioning system (GPS). The marked coordinate positions were later used to produce a site map as well as a guide to locate exactly the site spots at each time of sampling. Samples (tannery effluent, water, sediment and fish specimen) were collected once every month for six months covering the months of December to February (dry season) and March to May (wet season).

Four sites (BG1, BG2, BG3 and BG4) located at intervals (BG1 to BG2 = 200m; BG2 to BG3 = 200 m; BG3 to BG4 = 400 m) along the Kirinya West Wetland lake interface

(Figure 1) were randomly selected depending on the likely spots of tannery effluent into the lake. The control site was located far upstream (approximately 2 to 3 Km upstream) away from the tannery effluent contaminated area. Two sites were identified on land along the drainage channel arising from the two leather industries. Each site was selected based on contamination from the tannery effluent. Discharge from the tannery was presumed to be the most highly contaminated, whereas the wetland-lake interface was suspected to have less contamination. The control site was taken as that site with no influence of contamination from the tannery effluent. A total of seven sampling sites were identified. These were categorized into three, tannery effluent, wetland-lake interface and the control site.

Those sites on land included effluents from the two tanneries along the drainage channels from each (Figure 1). These were taken as the final discharge points into the environment. Sampling sites on water and along Kirinya West Wetland were code named as BG1, BG2, BG3 and BG4 to represent the Tilapia fish breeding grounds. Sites coded as BG2 and BG3 were the spots where effluents from Skyfat were suspected to finally drain into the lake whereas site BG4 was the suspected spot where effluents from LIU enters into the lake. The site coded as BG1 was taken specifically to monitor for the likelihood of metal pollutant dispersion. The control site was located approximately 2 to 3 Km from the area of direct pollutant contamination.

3.4.2 Field measurements of physico-chemical characteristics

Selected physico-chemical characteristics of the tannery effluents and the lake water were measured *in-situ* as shown in Plate 3.1 below. The parameters determined were; dissolved oxygen (mg/l), pH, temperature (°C), electrical conductivity (μScm^{-1}), turbidity (NTU), salinity (mg/l), dissolved solids (mg/l) and redox potential (mV) with the aid of a calibrated Water Quality Multiprobe, model EUREKA (Plate 3.1).

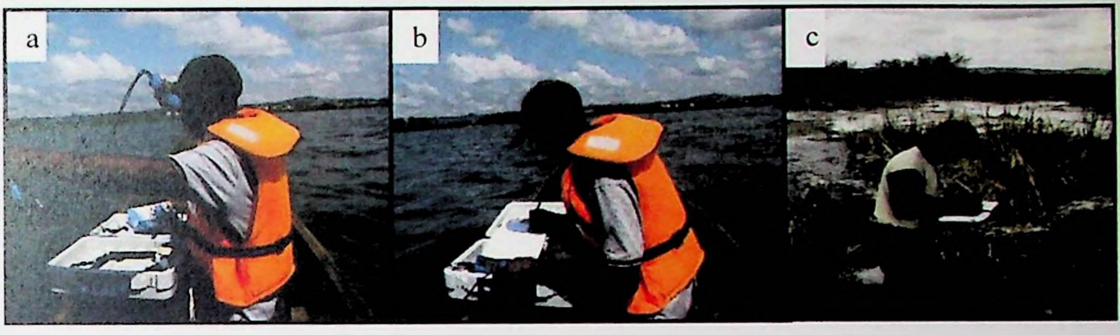


Plate 3.1: Measurements of physico-chemical parameters

3.4.3 Collection of effluents and water samples

Prior to field sampling, 500 ml polyethylene sample bottles were soaked overnight in acid bath filled with a 10% HCl acidified water. This was followed by rinsing with tap and then distilled- deionized water to remove any impurities. In the field, tannery wastewater samples were scooped into the 500-mL sample bottle directly from the flowing effluent. Water samples in the lake were collected by use of a horizontal 2.2 litre Van dorn PVC sampler (WILDCO model) designed for taking water samples near the bottom in lakes, streams, or in stratified water bodies (Plate 3.2). Water samples were transferred into a 500 ml polyethylene sample bottles, to minimize contact with air.

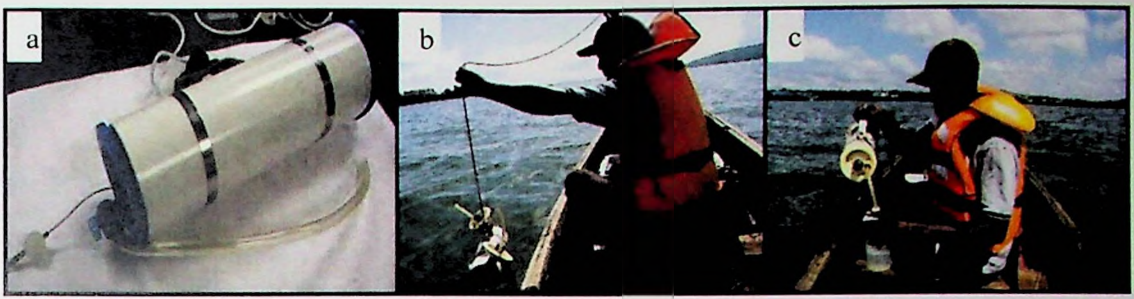


Plate 3.2: Collection of water samples using a 2,2 litre Van dorn) sampler

Each sample category was preserved by adding 2mls of concentrated nitric acid to avoid metal precipitation in the sample bottle. Samples were secured by screwing in place the sample bottle lids. Each sample was clearly labeled and temporarily stored in a cool box at approximately 4 °C before transportation to the laboratory.

3.4.4 Collection of sediment samples

A stainless-steel sediment grab, model WILDCO Petit Ponar grab with arms, 6"W x 6"L designed for taking samples of hard bottoms such as sand, gravel, or clay bottom was used to collect sediment samples from the lake (Plate 3.3). Sediment grab samples were only collected from the study sites (along Kirinya West Wetland-lake interface at fish breeding sites and at the control point). Sediment samples were first emptied into a plastic basin, mixed before subsampling approximately 200 g of the wet sediment into clean well labeled polythene bag, kept in a cool box and later delivered to the laboratory.

Plate 3.3: Collection of sediment samples using a sediment ponar grab

3.4.5 Sampling for fish

Fish gill net traps were set along the shorelines of Kirinya West wetland and at the earmarked control site. The nets were left in the water overnight and retrieved the following day. In some instances, cast netting was conducted to obtain fish from the shorelines. *Oreochromis niloticus* trapped in the gill nets were obtained in triplicates as fresh specimen from each site (Plate 3.4).

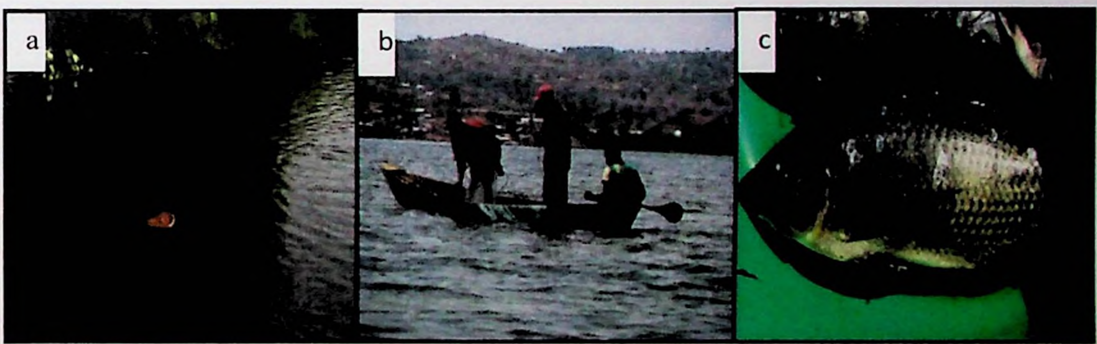


Plate 3.4: Gill netting of tilapia fish from along Kirinya West wetland-lake shoreline

The fresh specimens were kept in well labeled clean plastic bags and temporarily stored in a cool box before transporting them to the laboratory at NaFIRRI. During the six-month sampling period, a total of 90 Nile Tilapia fish were collected i.e. 15 from BG 1, 15 from BG 2, 15 from BG 3, 15 from BG 4 and 15 from control site.

3.5 Laboratory analyses

3.5.1 Preparation of tannery effluent and water samples

Both the tannery effluent and water samples were prepared for analyses following standard acid digestion procedures according to APHA (1999). Each sample in a sample bottle was first shaken thoroughly in order to mix its content. Thereafter, 100 ml of each sample was transferred into a 250 ml acid cleaned conical flask. This was followed by the addition of a few boiling chips to ensure slow boiling of the sample. purpose of enabling slow boiling of the sample. Furthermore, 5 ml of conc. HNO_3 (AnalaR 69 – 72% purity) was added to aid the process of sample digestion.

3.5.2 Preparation of sediment samples

Approximately 10 g of the wet sediment samples were each dispensed into clean well labeled glass petri dishes before oven drying at 105 °C for 48 hours (Andrew *et al*, 1995; APHA, 1999). The dry sediment samples were first allowed to cool at room temperature before grinding to fine powder using ceramic pestle and mortar. This was followed by sieving through a 500 µm pore size metallic sieve to remove coarse particles or debris.

Of the sieved sediment, 0.5 g was weighed on an analytical balance and then transferred to a clean 150 mL capacity conical flask. Then 50 ml of de ionized water was added to the sample and shaken by hand to mix (Plate 3.5).

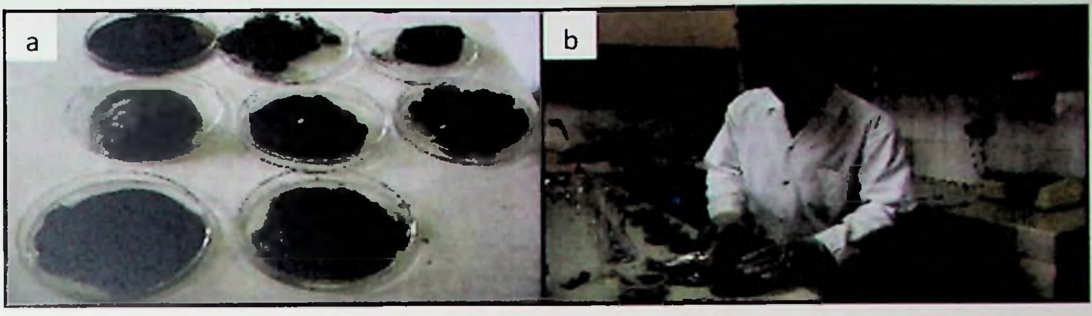


Plate 3.5: Preparation of sediment samples for analyses

3.5.3 Collection of fish morphometric data and extraction of tissue samples

Fresh weight (g), total length (cm), sex status (male or female) of each fish specimen was first determined in the laboratory. A digital balance was used to obtain the fresh weight, and a metre ruler to measure the total length (TL) of each fish specimen. This was followed by dissecting each fish specimen with clean stainless steel scalpel blade and scissors to extract approximately 10 g of flesh and skin from the dorsal area, gills from both side of the operculum, and the liver. Extracts of samples were placed in acid-washed and well labeled petri dishes before oven drying at 105 °C (Plate 3.6).

Plate 3.6: Extraction of fish flesh and organs for oven drying and laboratory analyses

The oven dried fish tissues were cooled at room temperature before grinding each of the samples separately with a pestle and mortar to fine powder. Using an analytical balance (model, METLER TOLEDO AB 204-S) 0.5 g dwt portions of the powdered fish organ sample (the muscle/ skin, gills and liver) were weighed and transferred to separate conical flasks that were labelled with field records.

3.5.4 Acid digestion of tannery effluent and water samples

Acid digestion was carried out according to procedures stated by Andrew *et al.*, (1995). To 50 ml of effluent and water samples in separate conical flasks, 5 ml each of concentrated HNO_3 acid was added (Plate 8). The sample mixtures were slowly boiled and evaporated on a hot plate to the lowest volume possible (about 10 to 20 ml) while ensuring that precipitation did not occur. Heating was continued and more HNO_3 acid added as necessary until digestion was complete as shown by a light colored clear solution (Plate 3.7).

Plate 3.7: Acid digestion of tannery and water samples for further laboratory analyses

About 5 ml portions of deionized water was added to wash the wall of the conical flask. This was followed by filtering the digested sample through a Whatman GF/C 0.45 µm pore size filter paper to remove any suspended particles. The filtrate was then transferred to another 100 ml volumetric flask, cooled to room temperature and diluted to the mark. Portions of the filtrate were later aspirated into the flame of the AAS for Cr analyses.

3.5.5 *Acid digestion of sediment samples*

To the 0.5 g of sediment sample in a conical flask, 0.5 ml of concentrated HNO_3 acid 1.5 ml of HCL acid (*aqua regia*) mixture was added. This was followed by placing glass funnel on top of the conical flask to aid in reflux heating. Heating was first done at 100 °C before gradually raising the temperature up to 200 °C. Sample heating was continued and more acid (5 ml) added until about 5 ml of concentrated was remaining in the flask. This was followed by cooling to room temperature before adding 1 ml of H_2O_2 (30%) and heating for 15 minutes. Sample was again allowed to cool and 3 ml of H_2O_2 added before heating to boil for 10 minutes. After this, the digested sample was cooled and transferred to another volumetric flask and deionized water added to fill to the 100 ml mark. The sample was also filtered and the filtrate used to analyze for Cr by the AAS.

3.5.6 *Acid digestion of fish tissue samples*

Fish sample (1 g) was placed in a 125 ml conical flask. Afterwards 10 ml of concentrated HNO_3 acid (analytical grade, 68 %w/w) was poured into the flask. A glass funnel was placed at the mouth of the conical flask and the flask was placed on a hot plate. Initially, the temperature was kept at 40 °C for one hour to prevent vigorous reactions. Then the temperature was maintained at 140 °C for another 3 hours. Once the digestion was completed all tissue samples were completely dissolved in the acid. Then the mixture was cooled at room temperature. Double distilled and deionized water was added into the vessel to the 100 mL mark to dilute the mixture for FAAS detection of Cr. The sample was filtered by filter paper (Whatman GF/C, of 0.45 µm pore size).

3.5.7 Determination of chromium in sample extracts

The concentration of chromium in the acid digested extracts (tannery effluents, water and fish tissue) were determined by analyses of the sample extracts using a flame atomic absorption spectrophotometer – FAAS, model ALPHA, UK.

3.6 Quality control and assurance (QC/QA)

3.6.1 Pre-calibration of laboratory and field testing equipment

All laboratory and field water testing equipment were calibrated according to equipment manual prior to use. A calibrated water quality multi probe meter (Plate 1) with data logging capability for pH, dissolved oxygen concentration of the water, electrical conductivity, turbidity, salinity and temperature was deployed to collect physicochemical data *in-situ*. Calibration was also carried out on the FAAS according to the manual guide provided. The following instrumental conditions (Table 3.1) as stated in the manual guide by ChemTech Analytical Ltd, UK were applied prior to analyses of all the digested samples for chromium determination.

Table 3.1: Instrumental conditions for analyses of Cr on the ALPHA model AAS

Element	Cr
Wavelength (nm)	357.9
Lamp current (mA)	8
Slit width (nm)	1
Gain setting	7 ± 1
Fuel (Acetylene)	4.5
Air	
Burner Height	5 ± 0.5
Hollow cathode lamp	
Detection Limit (μg/L)	0.01

3.6.2 Preparation of chromium standard solutions and calibration curve

A chromium standard solution was used to generate a calibration curve. A calibration curve is required for purpose of accuracy and reliability of the AAS results. From a 1000 mg/l stock solution of chromium, a calibration standard was prepared through serial dilutions.

The first step was to extract 1 ml of the stock solution and dilute in 100 mL of deionized water in a clean conical flask to lower the concentration to 1 mg/L (1000 μg/L). From this intermediate stock solution, serial dilutions containing 0, 10, 20, 40, 60, 80, 100 and 200 μg/l of Cr were prepared in 10 ml each of deionized water as a basis for the calibration curve (Table 3.2). This was later aspirated into the flame of the AAS and absorbance readings for each concentration recorded down (Plate 3.8).

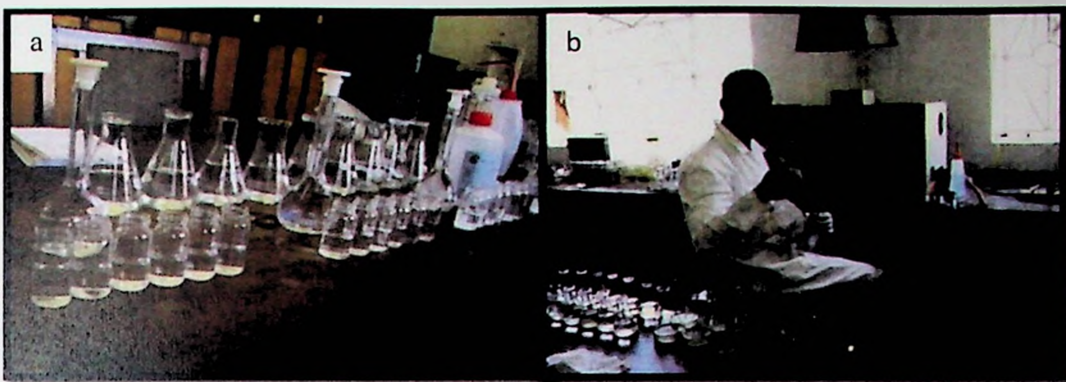


Plate 3.8: Preparation of chromium dilution series and analyses of samples on the AAS

Table 3.2: Dilution series of Cr standard solutions and corresponding absorbance

Cr standard (µg/L)	Absorbance (w/l = 357.9 nm)
0	0
20	0.001
40	0.003
60	0.005
80	0.006
100	0.008
200	0.015

A graph scatter plot was generated and the equation of a straight line (y = mx + b) and regression values, $R^2 = 0.999$ established (Figure 3.2). This was substituted into the formula to determine the unknown concentration of Cr in the samples (tannery, lake water, sediment and fish).

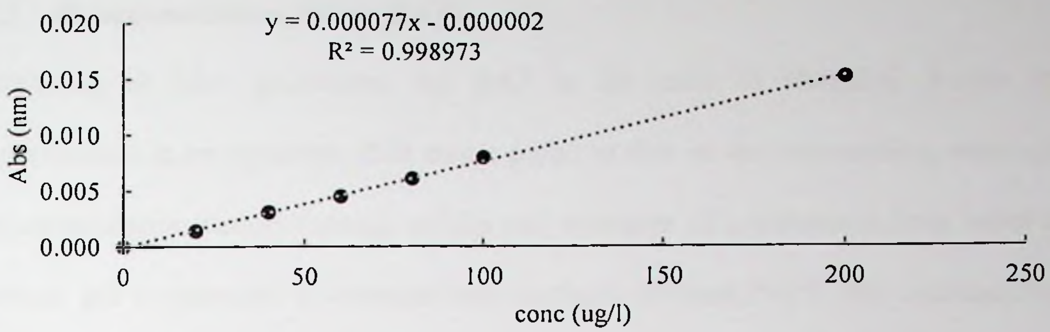


Figure 3.2: Calibration curve of prepared chromium standards

The concentrations of the standard solutions were used to calibrate the AAS. The correlation coefficient of Cr was determined from the calibration curve

3.6.3 Laboratory reagents

All reagents used were of analytical grade. Double de-ionized water was used for all dilutions. Nitric acid, HNO_3 (65%) and hydrogen peroxide, H_2O_2 (30%) were of ultrapure quality (Merck, Darmstadt, Germany). The Cr standard solution used to make the calibration curve was from ChemTech Analytical LTD, UK.

3.7 Analyses of data

All statistical analyses were performed with R statistical package 3.3.2 (R development Core Team, 2016). Analyses of variance (ANOVA) was used to explore variation of physicochemical parameters followed by separation of means by a post-hoc test (Turkey's honest significant multi-comparison) with means considered to be significantly different at $p < 0.05$. Prior to analyses all data were tested for normality and homogeneity of variance.

3.7.1 Bioaccumulation factor (BAF)

According to EPA guidelines, the BAF is the ratio of chemical (heavy metal) concentration in an organism (fish tissue μg/g) to that in the surrounding water (μg/l). Bioaccumulation occurs through uptake and retention of a substance from water only, through gill membranes or external body surfaces (Helena, 2015). Bio accumulation of Cr in *Oreochromis niloticus* L. was therefore computed using the following formula;

$$BAF = [C_c]/[C_s] \qquad \text{(Eq. 1)}$$

Where $[C_c]$ is the concentration of Cr (μg/g dwt) in fish tissue, and $[C_s]$ the concentration of Cr in lake water.

3.7.2 Geoaccumulation index

Geoaccumulation index (I_{geo}) was computed to determine the extent of anthropogenic contamination and compare with the metal in lake sediment using the equation as stated by Muller and Suess, (1979) and Forstner *et al.*, (1993).

$$I_{geo} = \log_2(C_n/1.5B_n) \qquad \text{(Eq. 2)}$$

where C_n is the measured concentration of Cr in sediment (μg/g); 1.5 is the background matrix correction factor and B_n the background concentration value of Cr (25 μg/g as quoted by EPA was used). The classes used are as follows; Class 1, $I_{geo} = 0 - 1$ (none to medium pollution); Class 2 = $I_{geo} = 1 - 2$ (moderate pollution); Class 3 = $I_{geo} = 2 - 3$ (moderately strong pollution); Class 4 $I_{geo} = 3 - 4$ (strongly polluted); C 5 I_{geo} 4 – 5 (strong to very strong) and Class 6 I_{geo} => 5 (very strong).

3.7.3 Sediment enrichment)/ contamination factor (SEF

To evaluate the source and degree of pollution, the sediment enrichment factor was calculated based on the following formula;

$$EF = [M/Fe_s]/[M/Fe_{bn}] \quad \text{(Eq. 3)}$$

where $[M/Fe_s]$is the ratio of Cr and Fe concentrations in the sample at each sampling point, and $[M/Fe_{bn}]$ is the ratio of Cr and Fe concentrations with respect to reference soil. The background world average shale and average soil background metal levels was used (Mohsen and Alireza, 2015). The elements usually used are Fe, Mn, Rb and total organic carbon, although Fe is reported to have been successfully used by several authors (Maurizio, 2016) because it is a major sorbent phase for trace metals (Loring *et al.*, 1995). The average shale concentration of Fe (47,000) according to Turekian and Wedepohl, (1961) was used. The enrichment factor is classified into seven categories (Turner and Millward, 2000). Whereby EF < 1 = no enrichment; EF < 3 = minor; EF = 3 to 5 means moderate; EF = 5 to 10 means moderately severe; EF = 10 to 25 means severe; EF = 25 to 50 means very severe and EF = > 50 means very severe.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Climate

4.1.1 Rainfall

The study site is found within the tropics and experiences a bimodal rainfall pattern with short dry seasons in between. The driest month of the year is January (Figure 3). Rainfall data collected during the period of study (December 2014 to May 2015) from a sub weather station located at NaFIRRI in Jinja showed that the month of January was the driest with the lowest amount of rainfall (21 mm) recorded whereas the month of May was the wettest with a rainfall amount of 255 mm (Figure 4.1). Precipitation was also observed to increase towards the month of May.

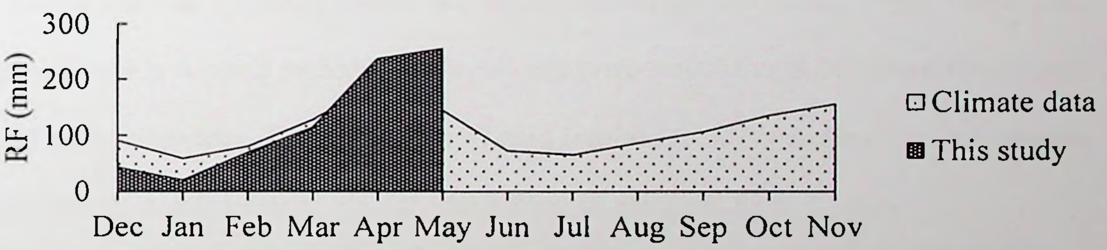


Figure 4.1: Rainfall (Source: http//Climate-Data.org)

4.1.2 Temperature

Jinja is located within the tropical climate and therefore experiences a warm temperature condition throughout the year. The maximum monthly temperatures vary from 26 to 31 °C (http//www.Climate.data.org). The warmest months lie between January to March. During the period of study temperature recorded were similar to the observed temperature average ranging between 28.2 to 30.7 (Figure 4.2)

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
▨ Climate data	28.2	29.0	29.1	28.9	27.8	27.0	26.9	26.4	26.9	27.9	28.1	28.2
□ This study	28.3	30.3	30.7	30.0	29.0	28.2						

Figure 4.2: Temperature pattern of Jinja (Source: http//Climate.data.org

4.2 Vegetation

The study site is characterized by a wetland type of vegetation which is dominated by *Cyperus papyrus L.* dotted with a few shrubs (Oratunge and Ntale, 1999). Other plant species in this wetland include (a) *Eichhornia crassipes (Mat) Solms* (water hyacinth), (b) *Vossia cuspidata, (Roxb), Griff (c) Typha latifolia L., (d) Phragmites sp. € Comelina spp*, and (f) *Aeschynomene elaphroxylon Taub as shown in* Plate 4.1.

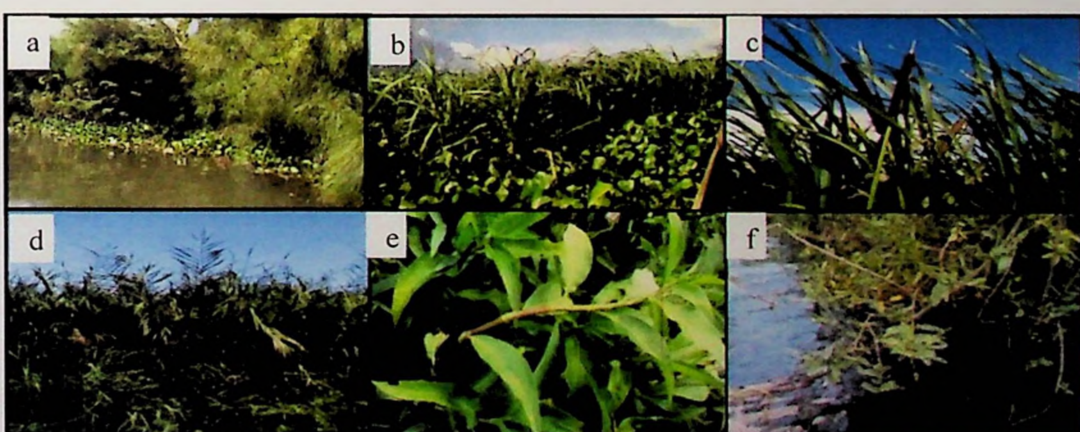


Plate 4.1: Some of the dominant wetland plants commonly found in Kirinya West Wetland

4.3 Physico-chemical characteristics of tannery effluents and water

4.3.1 Environmental quality of the discharged tannery effluents

The effluents discharged by both Skyfat and LIU were of poor quality with conditions that is considered unsuitable for direct discharge into surface waters especially into the wetland lake interface where the *Oreochromis niloticus* breeds from. Values for the measured physico-chemical characteristics were found to exceed the permissible limits according to NEMA and USEPA (Table 4.1).

The effluents were alkaline (highest mean pH 9.3), warm (highest mean temperature of 31.2 °C), had very high electrical conductivity (highest mean EC 8000.0 μS /cm), were highly turbid (the highest mean turbidity of 194.5 NTU), had very high dissolved solids (5360.0 mg/L) and an elevated salt content (the highest mean salinity of 6.7 mg/L). The concentrations of dissolved oxygen and the redox potentials were very low indicating a reducing environmental condition.

Statistical test revealed that the effluents from Skyfat industry were significantly higher (Tukey's HSD test, $p < 0.05$) than that of LIU during both the wet and dry seasons. Such poor effluent quality can be caused by a number of factors that includes the production capacity, quantity of chemicals being used, type of final product and volume of wastewater being discharged (Jahan *et al.*, 2014). This concurs with the size difference between Skyfat which is a bigger leather tannery with more effluent discharge than LIU.

4.3.2 Environmental quality of the Tilapia fish habitat

Although the measured physicochemical conditions remained within the limits (NEMA, 1999; USEPA, 2009), significant difference (Tukey's HSD test, $p < 0.05$) was noted across the sampled sites and seasons (Table 4.2). This could be attributed to the dilution effect by the lake. However, at sites BG2 and 3, the salinity (range 0 to 0.5 mg/L), redox (range -165 to - 111 mV), EC (range 96.9 to 527.5 μS/cm), DO (range 0.2 to 10.5 mg/L) and TDS (range 0 to147.4 mg/L) indicated a degrading condition. These sites correspond to suspected points where effluent from Skyfat seeps into the lake.

Dry season	Skyfat	9.3 ± 0.101	31.2 ± 0.592	7096.2 ± 1644.451	0.1 ± 0.017	-144.8 ± -2.425	193.9 ± 7.832	4800.0 ± 1048.121	0.7 ± 0.341
	LIU	8.9 ± 0.088^{b}	26.7 ± 0.139^{ab}	1097.6 ± 121.487^{a}	0.6 ± 0.101^{a}	-118.0 ± -5.447^{bc}	87.8 ± 0.631^{a}	735.4 ± 81.401^{a}	0.2 ± 0.076^{a}
Range		8.6 - 9.6	26.1 – 33.6	626 - 12130	0.1 - 1.1	-154 - -95	85.9 – 210.2	940 – 8127.1	0 – 8.3
Wet season	Skyfat	8.9 ± 0.041^{b}	28.0 ± 0.663^{b}	8000.0 ± 278.383^{b}	0.4 ± 0.073^{a}	-187.9 ± -17.806^{ab}	194.5 ± 7.006^{b}	5360.0 ± 186.517^{b}	4.5 ± 0.174^{b}
	LIU	7.7 ± 0.100^{a}	25.2 ± 0.098^{a}	2379.3 ± 790.167^{a}	0.3 ± 0.024^{a}	-287.6 ± -50.389^{a}	85.6 ± 40.500^{a}	1594.2 ± 529.411^{a}	1.5 ± 0.650^{a}
Range		7.5 – 9.0	24.8 – 30.5	798 - 9160	0.1 - 0.7	-303	4.1 – 247.8	534.7 – 6137.2	0.2 – 5.2
Range (This study)		7.5 – 9.6	24.8 – 33.6	626 - 12130	0.1 – 1.1	-388 - -86	4.1 – 247.8	419.4 – 8127.1	0 – 8.3
NEMA, 1999		6 – 8	20 - 35	400	> 5	-	300	1000	-
USEPA, 2009		6 -9		< 1000	> 5	-	100	500	-

Table 4.2: Physico-chemical characteristics of lake water and the permissible limits

Seasons	Sites	pH	Temp °C	EC (µS/cm)	DO (mg/L)	Redox (mV)	Turbidity (NTU)	TDS (mg/L)	Salinity (mg/L)
Dry	BG1	8.4 ± 0.319^{ab}	26.9 ± 0.273^{ab}	128.2 ± 6.974^{a}	8.3 ± 0.602^{cd}	61.4 ± 8.075^{ab}	16.4 ± 5.641^{a}	85.9 ± 4.673^{a}	0
	BG2	8.7 ± 0.071^{ab}	27.6 ± 0.161^{b}	171.0 ± 12.477^{ab}	4.8 ± 0.965^{ab}	-23.7	29.4 ± 1.112^{b}	114.6 ± 8.358^{ab}	0
	BG3	8.4 ± 0.230^{ab}	27.8 ± 0.145^{b}	125.3 ± 6.843^{a}	7.6 ± 1.074^{abc}	17.6 ± 4.764^{a}	13.5 ± 4.242^{a}	83.9 ± 4.579^{a}	0
	BG4	8.5 ± 0.132^{ab}	27.3 ± 0.130^{ab}	115.3 ± 3.054^{a}	6.4 ± 0.740^{bc}	88.6 ± 5.089^{ab}	6.9 ± 0.773^{a}	77.6 ± 2.049^{a}	0
	Control	8.8 ± 0.071^{b}	27.0 ± 0.163^{ab}	104.8 ± 1.211^{a}	10.1 ± 0.942^{d}	62.9 ± 1.230^{ab}	5.8 ± 0.392^{a}	70.2 ± 0.712^{a}	0
Wet	BG1	7.7 ± 0.249^{a}	26.7 ± 0.342^{ab}	164.5 ± 24.550^{ab}	7.0 ± 0.472^{bcd}	37.8 ± 7.270^{ab}	14.4 ± 4.570^{a}	110.3 ± 16.427^{ab}	0
	BG2	7.7 ± 0.287^{a}	26.8 ± 0.310^{ab}	268.6 ± 49.628^{b}	2.1 ± 0.544^{a}	-13.4	29.8 ± 1.237^{b}	180.0 ± 33.250^{b}	0.1
	BG3	7.9 ± 0.304^{a}	27.0 ± 0.426^{ab}	205.4 ± 45.922^{ab}	5.1 ± 0.404^{ab}	43.6 ± 15.781^{ab}	4.5 ± 0.314^{a}	137.6 ± 30.771^{ab}	0
	BG4	7.6 ± 0.271^{ab}	26.6 ± 1.276^{ab}	111.4 ± 4.358^{a}	6.0 ± 0.106^{bc}	71.4 ± 3.219^{ab}	5.3 ± 0.452^{a}	66.5 ± 8.807^{a}	0
	Control	8.8 ± 0.133^{a}	26.2 ± 0.428^{a}	104.2 ± 1.998^{a}	5.6 ± 0.203^{bc}	65.3 ± 0.167^{ab}	4.3 ± 0.209^{a}	69.8 ± 1.331^{a}	0
	Range (This study)	7.5 - 9.7	24.5 - 28.4	96.9 - 527.5	0.2 - 10.5	-165 - 111	0 - 39.4	0 - 147.4	0 - 0.5
	NEMA, 1999	6 - 8	20 - 35	ms	> 4	ms	100	ms	0
	USEPA, 2009	6.5 - 9	< 30	ms	> 4	ms	< 5	100	0

Means with different letters (a, b, c, d) within each row are significantly different (Tukey's HSD test, $p < 0.05$: ms = data not obtained; n = sample size

4.3.3 pH

The pH of the discharged tannery wastewaters was highly alkaline with values that varied from 7.5 to 9.6 (Table 4.1). Of the two leather tanneries, the wastewater from Skyfat was more alkaline throughout both seasons. Similar conditions were reported by Oguttu *et al.*, (2008); Jahan *et al.*, (2014); Akan *et al.*, (2008); Kongjao *et al.*, (2008); Arasappan and Kalyanaraman, (2015) The characteristic alkaline nature of tannery effluents is due to the excessive application of lime and sulfide in the production of lime pelt (Manjushree *et al.*, 2015). In the lake, an alkaline condition was also encountered (pH range between 7.5 to 9.7). However, in the lake environment, the pH is naturally levelled out as a result of the interaction that takes place between the atmospheric carbon dioxide and biological processes (UNIDO, 2000).

pH is a measure of how acidic or basic water is and this depends upon the relative amount of free hydrogen and hydroxyl ions present in the water (USGS, 2016). This environmental factor is vital in assessing the quality of a tannery affluent. Shifts in the pH from the normal range can alter the mobility and complexity of chemical interactions between metals, metalloids and biological systems (Violante *et al.*, 2010). It has been reported that at pH between 6.5 and 7.8 Cr will manifest its toxic characteristics (Van Der Putte *et al.*, 1981; Abbasi *et al.*, 1995) as considerable amounts will accumulate in the internal organs rather than in the gills, but at ph 6.5 the gills will retain more Cr than the other organs (Velma *et al.*, 2009). Highly alkaline effluents also pose detrimental impacts to aquatic biota (Bosnic *et al.*, 2000; Arasappan and Kalyanaraman, 2015) and can result in the precipitation of Cr.

4.3.4 Temperature

The wastewater from the two tannery effluents were warmer (varied between 24.8 and 33.6 °C) with the highest mean temperature (31.2 ± 0.592 °C) recorded in the dry season in Skyfat effluent. Although this was within the permissible limit of 20 to 35 °C (NEMA, 1999; USEPA, 2012), within the factory far higher temperatures > 40 °C is required during the tanning process (UNIDO, 2000; Oguttu *et al.*, 2008). Rajeswari (2015) and Haile (2016) reported effluent temperatures that ranged between 27.6 to 28.3 °C and 24.9 to 28.4 °C respectively. At the Kirinya West Wetland-lake interface, the temperatures varied between 24 to 28.4 °C. High temperatures and warmer waters presents suitable environmental conditions that promotes the dissolution and bioavailability of toxic metals and this can result into adsorption, biosorption and bioaccumulation by aquatic organisms such as fish taking place (USEPA, 1986; Nouri *et al.*, 2005; Haile, 2016).

4.3.5 Electrical conductivity

Very high conductivity was recorded in the wastewaters from both leather tanneries with significantly higher values (Tukey's HSD test, $p < 0.05$) occurring in Skyfat wastewaters throughout both seasons (Table 4.2). In both cases the conductivity exceeded the permissible limit of 400 and 1000 μS/cm stated for discharge into the surface waters (NEMA, 1999; (USEPA, 1986). The recorded values ranged between 626 to 12,130 μS/cm. Oguttu *et al.*, (2008) reported an EC value of 5,950 μS/cm whereas Jahan *et al.*, (2014) reported a much higher value of 42,500 μS/cm in Bangladesh. Such very high EC levels in tannery wastewaters indicates the presence of excessive dissolved salts (Hem, 1989; Jamal *et al.*, 2011; Shah and Singh, 2015; Haile, 2016). In the lake the EC across the sampled sites were lower (varied between 96.9 to 527.5 μS/cm) although elevated levels were recorded at sites BG1, 2 and 3. This result compares with the findings of Naigaga *et al.* (2011) who recorded 301.9 μS/cm from the same study area. The high EC observed in the lake may be attributed to the influence of the leather tannery. High EC can alter the chelating properties of water bodies and this can lead to an imbalance in the free metal availability required by flora and fauna (Akan *et al.,* 2008).

4.3.6 Dissolved oxygen

Very low dissolved oxygen concentrations were recorded from both tannery wastewaters indicating a highly anoxic conditions. Low DO concentrations varying between 0.1 to 1.1 mg/l were recorded with the lowest mean concentration of 0.1 ± 0.017 mg/l observed in Skyfat effluent (Table 4.1). No significant differences (Tukey's HSD test, $p < 0.05$) were observed between the two tanneries even with seasonal variations. Such very low DO concentrations may be attributed to the abundant organic and inorganic materials in the effluent that must be decomposed by aerobic bacteria. The degradation of organic matter consumes oxygen. In the lake the concentration was higher (> 4 mg/l) probably due to the mixing of water. However, at site BG2, low DO concentration was noted. This site is the suspected spot where the tannery wastewater seeps into the lake. DO is a critical environmental factor responsible for the sustenance of aquatic life (Hebsibah and Selvi, 2016) and is also used as a monitoring environmental parameter for aquatic pollution.

4.3.7 Redox potential

Negative redox potential values (< -86 mV) were recorded in both LIU and Skyfat effluents indicating a highly reducing environmental condition. This finding compares with -100.2 to -536.2 mV reported for a tannery effluent in Kano state, Nigeria (Akan *et al.*, 2007). The redox potential significantly differed with seasons (Tukey's HSD test, $p < 0.05$) with the wet season exhibiting more negative values. Such negative redox condition can be attributed to the presence of hydrogen sulfide in tannery effluents capable of lowering the Eh to less than -100 mV (Chapman and Kimstach, 1996). Under such reducing environmental condition, Cr and other toxic metal contaminants become more pronounced and bioavailable (Wetzel, 1983; Home and Goldman, 1994).

In the lake, positive redox potential values were recorded (ranging between 17 to 47 mV) thus indicating an oxidizing environment (Table 4.2). In the lake, several environmental factors contribute to such a condition. For instance, there is continuous mixing and hence aeration of the surface waters that leads to diffusion of ambient oxygen. An aerated surface water supplies electrons needed to oxidize and ultimately reduce any metal species (Sigg, 2000). In a healthy water body, high redox potentials (between 300 to 500 mV) are normally expected, but in areas receiving industrial and sewage discharges, the redox potential values tend are very low and negative.

4.3.8 Turbidity

The wastewaters from both tanneries were turbid with that of Skyfat being significantly

(Tukey's HSD test, $p < 0.05$) more turbid during both seasons (Table 4.2; Plate 4.2).

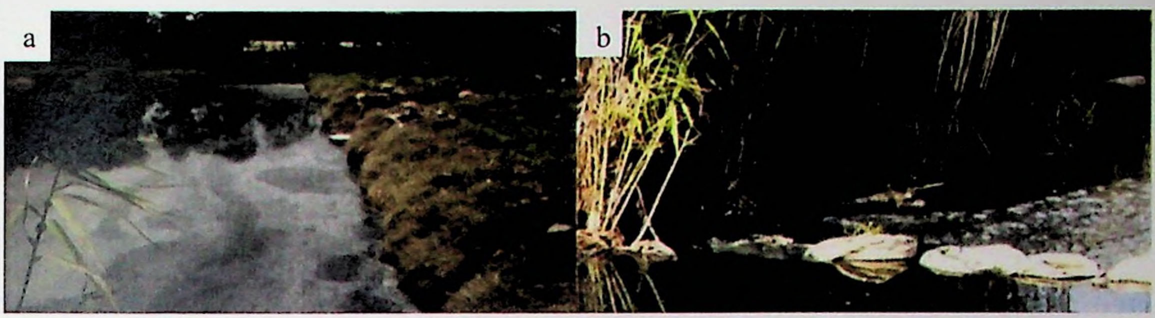


Plate 4.2: Turbid effluent at LIU pond (a) and Skyfat drainage channel (b).

The recorded turbidities ranged between 4.1 to 247.8 NTU. Lower turbidity (28.9 NTU) may also be encountered (Arasappan and Kalyanaraman, 2015). The observed difference between the two tanneries is probably due to the varying production capacities whereby Skyfat has a bigger capacity and therefore automatically discharges large quantities of putrefying suspended matter (fleshing, skin trimmings and hair), chrome waste particles, toxic metallic compounds, chemicals and other biologically oxidisable materials (Mahmood, 2000).

In the lake, the turbidity was much lower (range between 0 to 39.4 NTU) except at site BG2.where it was slightly elevated (Table 4.2). However, this was still within the permissible limit (NEMA, 1999). The observed low turbidity in the lake may be attributed to the dilution effect by the lake. High turbidity above the permissible limit can be detrimental to aquatic organisms. Other than lowering the aesthetic quality of water, it also reduces on fish food supplies, destroys spawning grounds, clog gills of fish, diffuses sunlight hence slowing down photosynthesis. It also lower dissolved oxygen concentration apart from raising the acidity of water and water temperature making it less efficient in holding more dissolved oxygen.

4.3.9 Total dissolved solids

This was significantly higher (Tukey's HSD test, $p < 0.05$) in Skyfat effluent during both seasons. The recorded TDS values ranged between 4194 to 8127.1 mg/l, thus exceeding the permissible limits by approximately eight times (Table 4.1). Similarly, high TDS values have been reported (152 to 5355 mg/l) by Kawser *et al.*, (2011) and 5322.2 to 6375.3 mg/l) Araspan and Kalyanaraman, (2015). Jahan *et al*, (2014) reported a much higher concentration of up to 21,300 mg/l. In the lake the TDS was lower than in the effluent (< 150 mg/l) probably because of dilution effect by the lake water. Although high TDS were observed at sites BG2, 3 and 4, site BG2 maintained a significantly higher value (Tukey's HSD test, $p < 0.05$) across both seasons (Table 4.2). High TDS arises from dissolved inorganic salts and other substances present in water (Nasrulla *et al.*, 2006; Araspan and Kalyanaraman, 2015; Haile, 2016) and this can cause aesthetic problems as well as subject aquatic organisms to extreme stress.

4.3.10 Salinity

The wastewaters from both tanneries were saline with that of Skyfat being significantly more saline (Tukey's HSD test, $p < 0.05$) during both seasons. The measured salinity varied between 0 to 8.3 mg/l. The observed variation in salinity level between the two tanneries may be due to the difference in the production capacities and hence the quantity of salts being used during the tanning process. The result of the study also compares with what was reported (0.5 to 5.83 mg/l) by Kawser *et al.*, (2011). In another case, a much higher salinity of up to 5,555 mg/l have been reported (Haile, 2016). According to WHO guideline, 1000 mg/L is stated as the permissible limit for the discharge of chlorides, an element responsible for the saline condition in the effluent. In the lake most of the sampled sites had no saline condition probably due to dilution effect at site BG2 where some saline condition was detected.

Leather tanneries require salts in their process to preserve hides and skin and yet they are highly soluble and stable and not easily affected by effluent treatment. Highly saline effluent creates an inert condition that can drastically harm the terrestrial and aquatic ecosystems (Bosnic *et al.*, 2000) as shown in Plate 4.3.

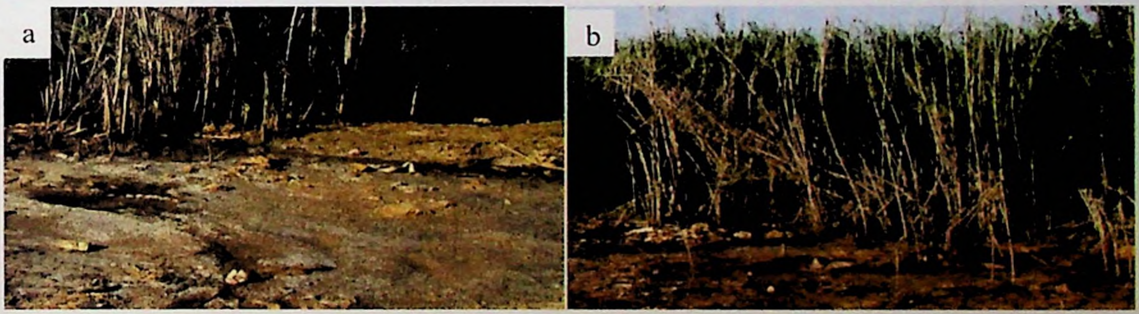


Plate 4.2: The effect of high salt content on soils (a) and plants (b)

4.3.11 Correlations between the physical properties of tannery effluents and lake water

Significant correlation (cross product correlations, $p > 0.01$) was noted between the measured environmental characteristics both in the tannery effluent and in the lake (Table 4.3). In the tannery effluents the strongest relationship was between the EC and TDS, $r = 0.999$, whereas the least (moderate) relationship ($r = 0.425$) was between the pH and EC.

Table 4.3: Correlations between the physico-chemical conditions of tannery effluent

Parameter	pH	Oxygen	Temperature	EC	Redox	Salinity	Turbidity	TDS	
pH	1	-0.017	0.654**	0.425**	0.213	0.385**	0.490**	0.431**	
Oxygen		1	-0.242	-0.354	0.728**	-0.39	-0.258	-0.36	
Temperature			1	0.675**	0.041	0.756**	0.491**	0.687**	
EC				1	-0.15	0.722**	0.661**	0.999**	
Redox					1	-0.14	0.093	-0.152	
Salinity						1	0.795**	0.743**	
Turbidity							1	0.674**	
TDS								1	
N	54	54	54	54	54	54	54	54	54

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

Table 4.4: Correlations between the physico-chemical conditions of water

Parameter	pH	DO	Temp	EC	Redox	Salinity	Turbidity	TDS	Cr in water	Cr in sediment
pH	1	0.391*	0.489*	-0.556	0.432*	-0.087	0.091	0.548*	0.155	0.095
DO		1		-0.465	*	-0.229	-0.173	-0.457	0.006	-0.144
Temp			1	-0.322	0.082	0	0.189	-0.32	0.279**	-0.124
EC				1	-0.357	0.266*	0.247*	0.991*	0.048	0.097
Redox					1	-0.457	-0.185	-0.36	-0.003	0.116
Salinity						1	0.174	0.263*	-0.024	-0.026
Turbidity							1	0.253*	0.349**	0.202
TDS								1	0.055	0.101
Cr in water									1	0.445**
Cr in sediment										1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed)

In the lake, significant correlations were observed across the sampled sites suggesting similar association. This was strongest (r = 0.991) between EC and TDS (Table 4.4). The concentrations of Cr in the sediment moderately correlated (r = 0.455; $p < 0.01$) with that in the water column implying that what is in the water column is probably arising from the sediment and vice versa. Such trends in correlations as observed does not just occur by chance but can be attributed to the influence of the tannery effluents.

4.4 Concentration of chromium in the tannery effluents

This was significantly higher (Tukey's HSD test, $p < 0.05$) in the wet seasons in both tanneries probably because of increased flushing effect by the rains (Table 4.5). The recorded concentrations exceeded the permissible limits of 100 μg/l (NEMA, 1999) by approximately 40 times. The concentrations varied from 1357 to 4953 μg/l with the highest mean concentration being 4416.1 ± 176.2 μg/l.

Table 4.5: Concentration of total Cr (μg/l) in the leather tannery effluents

Season	Tannery industry	Mean ± SE, n = 9	min	max
Dry	Skyfat	2038.4 ± 156.355^{a}	1357	2517
	LIU	2246.1 ± 166.625^{a}	1647	3013
Wet	Skyfat	4048.2 ± 376.562^{b}	2440	5232
	LIU	4416.1 ± 176.194^{b}	3246	4953
USEPA, 2003		100		

Means with different letters (a, b) within each row are significantly different (Tukey's HSD test, $p < 0.05$:

High Cr concentrations as observed in this study, is potentially destructive to the environment and an indication of a partially trea5ted effluent (Plate 4.4). According to UNIDO (2000), the acceptable limit for direct discharge of total chrome into surface waters range between 50 μg/l and 10,000 μg/l and 1,000 to 50,000 μg/l on indirect discharges into sewage systems. Unfortunately, both tanneries (Skyfat and LIU) do not channel their wastewaters into the NWSC sewage ponds but instead use their own treatment ponds.

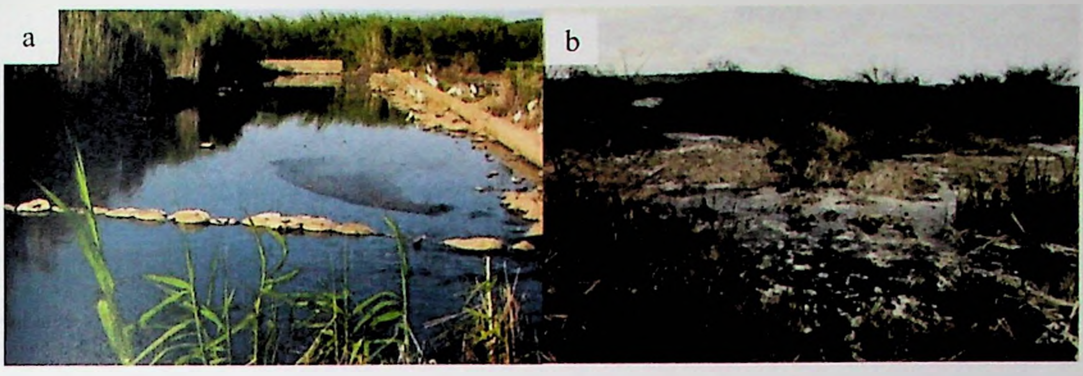
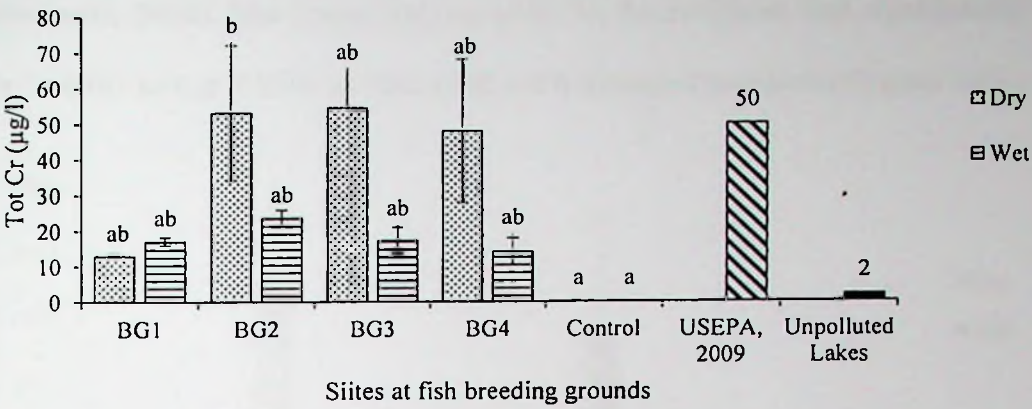


Plate 4.3: Effluents from Skyfat (a) and LIU (b) flowing into Kirinya West Wetland

4.5 Concentration of chromium in lake water

Sites BG1, 2,3 and 4 located along the wetland-lake interface had traces of Cr most likely due to contamination. The concentrations varied between 0.03 to 150.1 μg/l with the highest exceeding the expected level of 2 μg/l for unpolluted freshwater environments (Moore and Rama-moorthy, 1984) by approximately 75 times. This also exceeded the acceptable discharge limit of 50 μg/l for surface waters (NEMA, 1999).

Although higher Cr concentrations occurred across the sampled sites, this did not vary significantly (Tukey's HSD test, $p < 0.05$) with seasons except at site BG2 (Figure 4.3). Site BG2 is suspected the suspected point spot at which effluent fluxes into the lake could be taking place from. Sites BG2 and 3 also had levels that exceeded the stated limit by. It was also noted that the concentration in the lake (range 12.9 to 54 μg/L) was far lower than that in the tannery effluent (range 1359 to 5232 μg/L) by approximately 400 times (Figure 4.3; Table 4.5). This is because of the role of wetlands in stripping much of the contaminant.



Means with different letters (a, b) indicate significant differences (Tukey's test, $p < 0.05$). All values are in µg/l

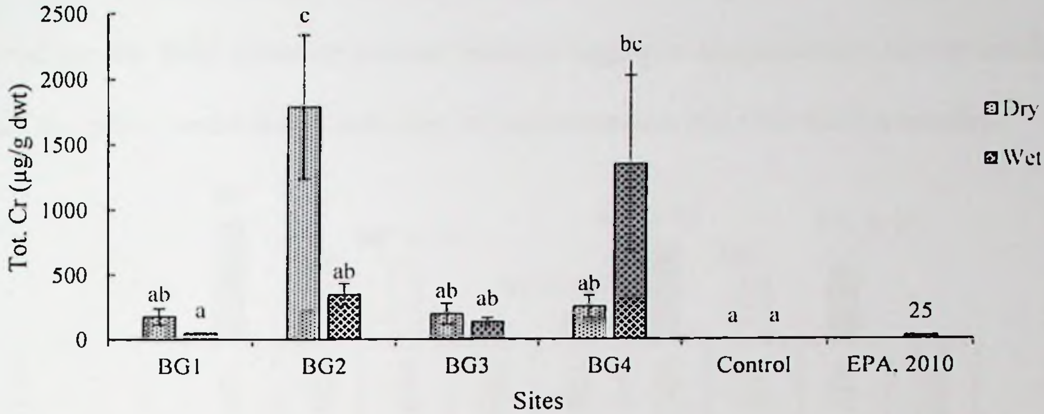
Figure 4.3: Concentrations (mean ± SE, n = 9) of Cr in water

4.6 Concentration of chromium in lake sediment

The sediment was found to be heavily polluted with Cr especially at sites BG2 and BG4 with concentrations that exceeded (25 µg/g) the limit for uncontaminated sediments (EPA, 2010) as shown in figure 6. The sediment concentrations ranged between 0.01 to 4960.8 µg/g dwt, and this was higher than 25.8 ± 11.21 µg/g reported for near urban areas in Nyanza gulf of Lake Victoria Kenya (Mwamburi, 2016). Such elevated sediment concentrations can only be attributed to point sources such as from the discharge of effluents from leather tanneries.

Cr introduced into the environment can capably adsorb onto sediment or particulate surfaces where it is potentially bioavailable (Campbell and Tessier, 1996) and an environmental risk to many aquatic organisms including fish and others in the food chain

(Pawlikowski, 2006). The concentrations of Cr in the sediment was significantly high (Tukey's HSD test, $p < 0.05$) at Sites BG2 and 4 through the seasons (Figure 4.4).



Means with different letters (a, b) indicate significant differences (Tukey's test, $p < 0.05$). All values are in in μg/L.

Figure 4.4: Concentrations of Cr at the Kirinya West Wetalnd-Lake interface

4.7 Geoaccumulation Index (I_{geo}) of Cr and sediment enrichment factor (SEF)

Varied levels of sediment contamination that ranged between moderately contaminated to sever contamination was recorded. The highest I_{geo} index during both seasons occurred at site BG2, meanwhile the control site had no ($I_{geo} < 0$) contamination (Figure 4.5). Similar Cr sediment contamination (33.28 ± 1.73 μg/g) was reported in the Nyanza Gulf and offshore areas (62.09 ± 33.72 μg/g) in the Kenyan portion of Lake Victoria (Mwamburi, 2016). Data on sediment geo-accumulation index is vital for effective management (Hubner *et al.*, 2009) against potential adverse biological effects (Brahma, 2014).

Sediment enrichment varied between extremely severe enrichment (site BG4) to no enrichment (at the control site). Although site BG4 had the highest enrichment during the wet season probably due to more effluent reaching the lake and being deposited in the sediment, site BG2 maintained high enrichment during both seasons (Figure 4.5). The trend for site BG2 however concurs with the high geo-accumulation further confirming that this site is under direct influence of contamination from the leather tannery.

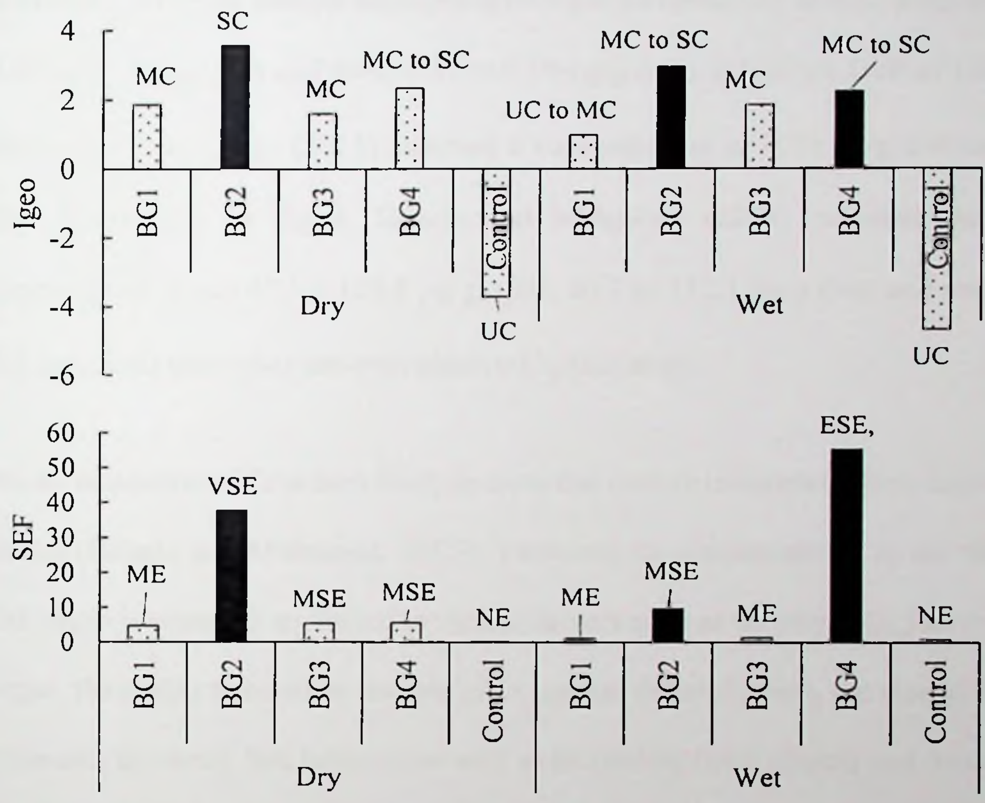


Figure 4.5: Geoaccumulation indices (I_{geo}) and SEF for surface sediments

NB: UC = Uncontaminated; UC to MC = Uncontaminated to moderately contaminated; MC = Moderately contaminated; MC to SC = Moderately contaminated to strongly contaminated; SC = Strongly contaminated; SC to EC = Strongly contaminated to extremely contaminated; EC = Extremely contaminated; ME = moderate enrichment; VSE = very severe enrichment; MSE = moderately severe enrichment; NE = no enrichment; ESE = extremely sever enrichment.

4.7 Accumulation of chromium in selected fish organs of *O. niloticus L.*

Traces of Cr were found in the examined fish tissues in varying concentrations that exceeded the stated limits of 0.15 µg/g dwt according to WHO (1989). Namugga (2016), who carried out a study in Kasenyi landing site of Lake Victoria Uganda, reported varying Cr concentrations in the different fish organs of the tilapia fish (gills; 0.25 to 0.35 µg/g dwt; muscle; 0.09 to 0.11 µg/g dwt and liver; 0.15 to 0.19 µg/g dwt). In Nyanza Gulf of Lake Victoria Kenya, Muinde *et al.*, (2013) reported a concentration of 0.70 µg/g dwt in the tilapia fish meanwhile, in Egypt, Hosnia and Mahmoud (2015) reported far higher Cr concentration (liver; 42.5 – 178.8 µg/g; gills, 20.7 to 112.1 µg/g dwt; and muscle, 2.4 to 5.5 µg/g dwt) than what has been observed by this study.

Bioaccumulation of Cr is most likely in areas that receive industrial, urban and agricultural runoff (Hosnia and Mahmoud, 2015). Variations in concentrations as per the different fish organ is probably attributed to various factors such as the physiological roles of each organ, the ability to regulate the rate of Cr uptake, detoxification, the size of the fish, the dynamics involved, fish behavior as well as its feeding habit ((Ishaq and Annume, 2011; Rohasliney *et al*, 2014). A significant difference (Tukey's HSD test, $p < 0.05$) was observed between the fish organs with higher concentrations occurring during the dry seasons (Figure 4.6) thus agreeing with the stated alternative hypotheses. Elevated Cr bioaccumulation is potentially hazardous to animal and human health

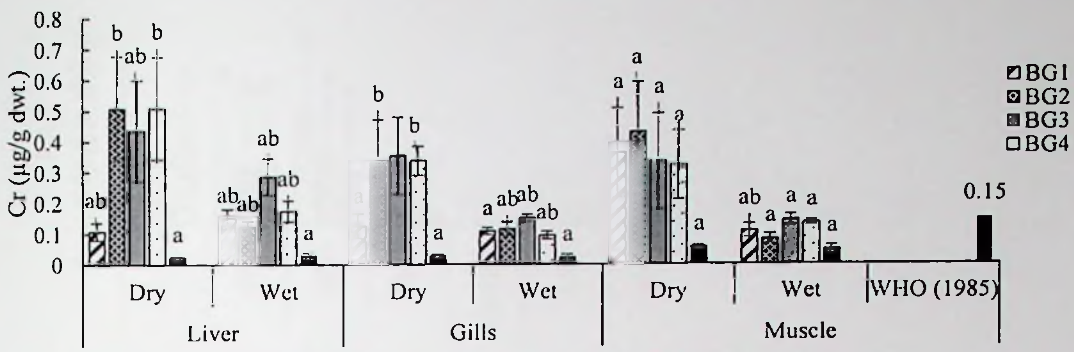


Figure 4.6: Concentration of Cr (mean ± SE) in the selected fish organs

Means with different letters (a, b) indicate significant differences (Tukey's test, $p < 0.05$). All values are in in µg/g

4.10 Bioaccumulation factor (BAF) of Cr

This was significantly high (Tukey's HSD test, $p < 0.05$) in the liver and gills of fish from site BG3 during the dry seasons (Figure 4.7). High BAF implies high affinity for accumulation (Putshaka *et al.*, 2015). There are environmental conditions under which bioaccumulation will most likely occur. These conditions include pollutant concentrations, prevailing temperatures, pH, salinity, and the redox potentials amongst others. In the dry seasons temperatures are higher and the water column tend to warm up faster. Moreover, temperature is a good factor to inducing metabolic processes and chemical interactions. It has also been observed that there is a direct correlation between temperature and the concentration of the pollutant and this ultimately impacts upon the rate of bioaccumulation (Wang, 2001). In fish, the gills are a target organ for pollutant uptake (Hosnia and Mahmoud, 2015) meanwhile the liver is where accumulation and detoxification takes place. This probably explains the observed trend.

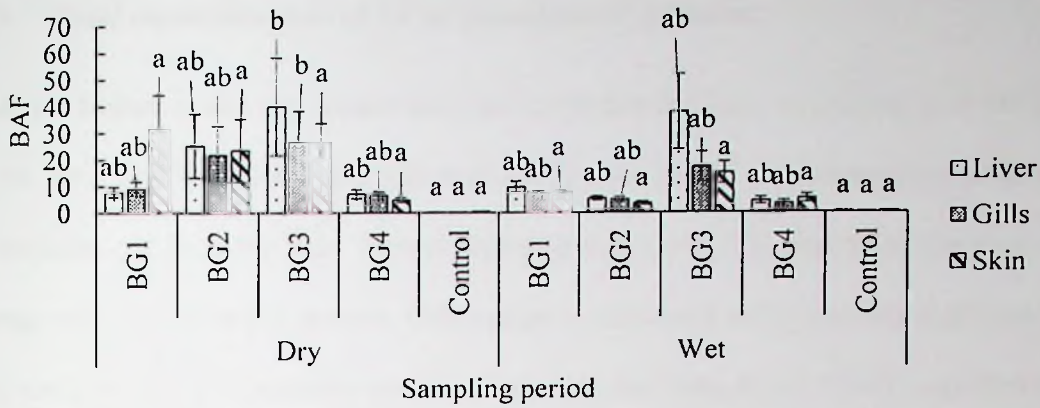


Figure 4.7: BAF of Cr between the selected fish organs and the water

4.11 Relationship between tissue bioaccumulation and fish sexes

The study found out that during the dry season the male fish accumulated more Cr in its organs than the female counterparts (Figure 4.8). According to Alquezar *et al.*, (2006) bioaccumulation based on gender differences may be due factors such as dietary preferences, physiological metabolism in relation to stage in the reproductive cycle or foraging behavior. The trend of Cr accumulation was in the order of liver > muscle > gills.

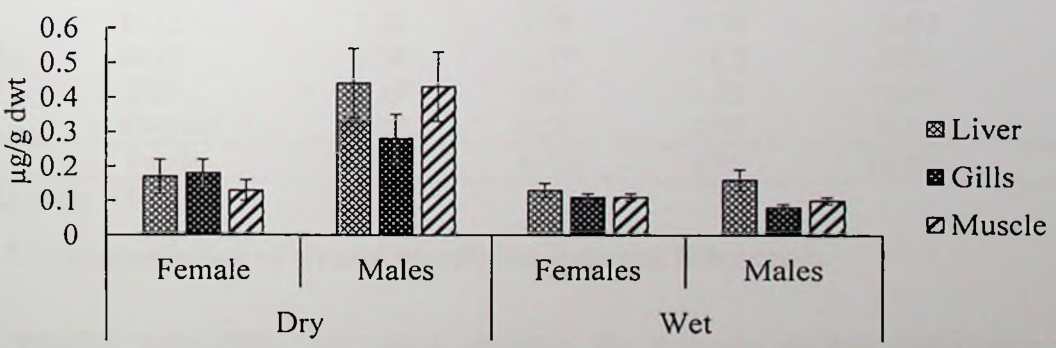


Figure 4.8: Variation in Cr bio-accumulation on the basis of fish sex and seasonality

4.12 Total concentrations of Cr in *Oreochromis niloticus*

This was higher in the dry season and also exceeded the limit according to FAO (1983) (Table 4.6). The liver was the organ with the highest total Cr concentration followed by the muscles and then the gills. This is probably due to the role played by the liver in the storage and detoxification process. Other reasons attributed to the prevailing pH condition may also be used to explain the observations. Van der Putte *et al.*, (1981) reported that at pH between 6.5 to 7.8 bioaccumulation will occur much more in the internal organs rather than in the liver. In this study, a similar pH range (7.5 to 9.7) was recorded around the wetland-lake interface (Table 4.2) implying that the prevailing condition could have contributed to what is being observed.

Table 4.6: Chromium accumulation in the tissues (μg/g dwt) of *Oreochromis niloticus*

Seasons	Site	Liver	Gills	Muscle	Totals	WHO/FAO
	BG1	0.97	1.14	3.27	5.38	
	BG2	4.57	3.02	3.89	11.48	
Dry	BG3	3.93	3.20	3.02	10.15	
	BG4	4.58	3.05	2.91	10.54	
	Control	0.22	0.26	0.51	0.99	
	Totals	14.27	10.67	13.6	38.54	1.0
	BG1	1.37	0.98	0.98	3.33	
	BG2	1.12	1.04	0.74	2.90	
Wet	BG3	2.58	1.37	1.3	5.25	
	BG4	1.57	0.85	1.21	3.63	
	Control	0.26	0.21	0.43	0.90	
	Totals	6.9	4.45	4.66	16.01	1.0

This study (2017)

4.13 Accumulation of Cr and correlation between fish organs

A positive correlation was noted between the different organs confirming that bioaccumulation took place (Figure 4.9). The trend in bioaccumulation was in the order of; liver - gills (r = 0.724) > liver-muscle (r = 0.539) > gills – muscle (r = 0.431). The high liver-gill correlation may be attributed to the fact that the two organs are actively involved in the uptake and deposition of Cr within the fish body part hence may not be suitable for human consumption.

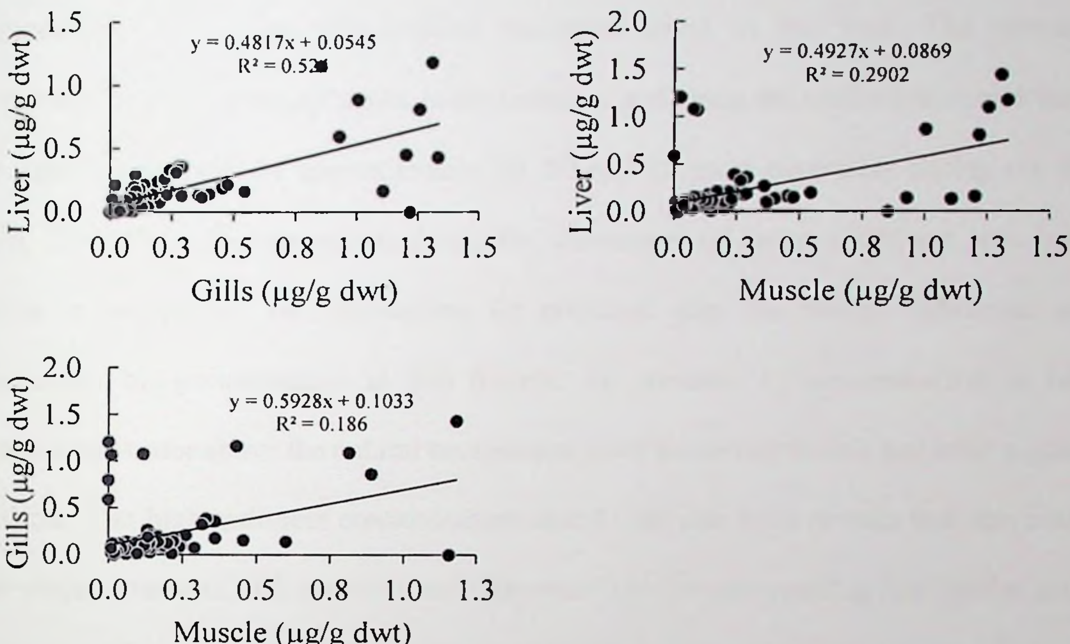


Figure 4.9: Correlations of Cr concentrations between fish organs

CHAPTER FIVE:

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The research revealed that all the measured physico-chemical characteristics exceeded the environmental safe limits with evident influence noted in the lake. The elevated concentrations of Cr (in the effluents, in the sediment and along the wetland-lake interface) were significantly high by approximately 50, 20 and 25 most especially during the dry season. The study also has revealed that the discharges of tannery effluent into Lake Victoria is responsible for introducing Cr pollutant into the water, sediments and consequently bio-accumulation in fish tissues. An elevated Cr concentration in lake sediments and water above the natural background level poses risk to fish and other aquatic organisms. The high sediment contamination noted with site BG2 reveals that this could be the major source of effluent entry and dispersal into the surrounding fish habitat area. The result on bioaccumulation of Cr in Tilapia fish tissues above the acceptable level shows that the fish from along Kirinya West Wetland shore may not be safe as fish food.

5.2 Recommendations

Results of this study provide baseline data which can be used by authorities for environmental management. It is recommended that the input of tannery effluent into the Victoria Lake is responsible for the Cr pollution of the water, sediments and consequently bio-accumulation in fish tissues. Since the effluents from tannery industry are of very poor quality, they may therefore not be suitable at all for use by human without better wastewater treatment. This must be regarded as a major concern.

In order to protect the lake, the fishery and other aquatic organisms from Cr contamination, approaches such as follows are suggested:

- designing a monitoring network to trigger preventive actions; reducing the anthropogenic discharges into the lake.
- environmental remediation and more efficient and modern methods to treat tannery effluents should be adopted.
- Over dependence on the wetlands to strip the discharged chemicals should be discouraged.
- direct input of tannery effluent into the wetland should be stopped and totally discouraged.
- proper management and more effective treated of tannery effluent should be applied. Close, regular (monthly) monitoring and strict enforcement by NEMA should be upheld.
- prohibitive polluter pay principles should be used as a penalty for failing to adhere to the stated limits for discharge into freshwater environments.
- By implementing the above it is hoped that this will greatly minimize the severe effect of pollution to humans as well as to fish and other aquatic biota.
- More research is recommended to assess the impact on other fish species and aquatic biota.

CHAPTER SIX

6.0 REFERENCES

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.0 APPENDIX

able 1: Coordinates of the sampled sites

No	Site	Degree Latitude	Degree Longitude	Elevation
1	Control Site	0.418568	33.234585	1149
2	BG1	0.416617	33.220278	1136
3	BG2	0.417867	33.221269	1136
4	BG 3	0.418325	33.223178	1137
5	Effluent discharge	0.419147	33.21771	1142
6	Sewage discharge	0.420608	33.216164	1143
7	BG4	0.413164	33.217444	1136
8	Skyfat Industry	0.417223	33.218293	1142
9	Leather Industry	0.41535	33.217155	1145