PARASITE COMMUNITIES OF *Oreochromis niloticus baringoensis* (Trewavas, 1983) IN RELATION TO SELECTED WATER QUALITY PARAMETERS IN THE HOT SPRINGS OF LORWAI SWAMP AND LAKE BARINGO, KENYA

ADAMBA STEPHANIE WANGARE KAMAU

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has neither, wholly or in part, been presented for examination at any institution for the award of a degree.

Signature: ________________ Date: _____________

Adamba Stephanie Wangare Kamau

SM18/20009/16

Recommendation

This thesis has been submitted with our approval as University supervisors.

Signature: ________________ Date: _____________

Dr. Elick O. Otachi, PhD

Department of Biological Sciences

Egerton University

Signature: ________________ Date: _____________

Dr. Geoffrey O. Ong'ondo, PhD

Department of Biological Sciences

Egerton University

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DEDICATION

To my late mommy Ms. Naomi Nyambura Kamau for the spiritual, financial and emotional strength and support you continued offering me till we said GOODBYE. Thank you for the endless prayers and for always believing in me. Thank you for strengthening my foundation in education. You will always be the wind beneath my wings and my hero. May we continue soaring higher. I love you.

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ABSTRACT

Parasites are universal and are associated with many living organisms making them a vital component of any ecosystem. Fish parasites lead to a decline in market value of infected fish and may lead to mortalities in high intensities. Some parasites are zoonotic. Anthropogenic activities within the riparian and catchment areas of aquatic systems that lead to deterioration of water quality possibly increase the incidences of parasitic infections. Although fish parasites have been studied in lakes and ponds, parasites of fish found in swamps are rarely studied. This study aimed at evaluating the parasite communities of *Oreochromis niloticus baringoensis* in relation to selected water quality parameters in the two hot springs of Lorwai Swamp and Lake Baringo, Kenya. Using seine nets 347 fish were captured in July and August, 2018. They were transported alive to the laboratory at the Department of Biological Sciences, Egerton University, where they were killed by cervical dislocation and dissected after recording their lengths and weights. The fish were examined and parasites recovered, identified and quantified. Some of the recovered parasites were preserved in 4% formalin for identification and others in absolute ethanol for further genetic analysis. The parasite infection parameters were calculated using standard formulae. Selected physico-chemical parameters namely; Dissolved Oxygen (DO), temperature, pH, Electrical Conductivity (EC) and turbidity were measured *in situ* using appropriate meters. In addition, water samples were collected in triplicates from each sampling site for nutrient analysis. The correlation between the parasites prevalence and the selected water quality parameters were determined by Principal Component Analysis (PCA) using SPSS version 20. Results of the length-weight relationship indicated that the population in the hot springs had a good growth ratio while the mean Fulton's condition factor indicated that the population was in a very good condition and healthy despite the high water temperatures of up to 36.4 °C. *Cichlidogyrus sclerosus* and *Clinostomum* sp. were common in all sites and there were significant differences among the abundance (one-way ANOVA, $F = 11.08$, df (2, 9), $p = 0.03$), mean intensity (one-way ANOVA, $F = 9.96$, df (2, 9), $p = 0.01$) and prevalence (one-way ANOVA, $F = 45.90$, df (2, 9), $p = 0.02$) of the recovered parasites from the three sites. *Amirthalingamia macracantha* and *Contracaecum* sp. correlated positively with nitrogen compounds whereas *Clinostomum* sp. and *Tylodelphys* sp. correlated negatively with dissolved oxygen. In general, the study revealed that the parasitic infection parameters correlated with the water quality parameters and therefore measurable water pollution controls within the drainage basin should be put in place and the public should be sensitized on the importance of properly cooking the fish.

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LIST OF ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
Chl-*a*	Chlorophyll-*a*
DO	Dissolved Oxygen
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GF/C	Glass Fibre Filter
LWR	Length-weight relationship
NH_4-N	Ammonium-Nitrogen
NO_2-N	Nitrite-Nitrogen
NO_3-N	Nitrate-Nitrogen
NTU	Nephelometric Turbidity Units
PCA	Principal Component Analysis
SDG	Sustainable Development Goal
SRP	Soluble Reactive Phosphorus
TN	Total Nitrogen
TP	Total Phosphorus
USA	United States of America

CHAPTER ONE

INTRODUCTION

1.1 Background information

Fish are amongst the most important organisms found in aquatic environments. They are an important resource for humans worldwide, especially as food and source of livelihood through capture fisheries and aquaculture. It is one of the major sources of protein among the urban and rural populations with the demand increasing as the human population grows. According to FAO (2018) in 2016, 88% of the total fish production (151 million tonnes) was for direct human consumption. This was a significant increase from 67% consumed in the 1960s. In Africa, more than 3,000 species of freshwater fish have been recorded, including members of the most ancient groups, such as lungfish (Dipnoi) and bichirs (Polypteriformes) (Kuchta *et al*., 2012). In the order Perciformes, cichlidae form a species-rich clade of fishes and which are commonly referred to as the “species-flocks” of the East African lakes (Kornfield and Smith, 2000). In Kenya, the fisheries sector plays an important role in the national economy through fish exports. The fisheries sector in Kenya is a source of livelihood to many fishers and fish farmers, and provides products and by-products processed in various industries; and also supports many trading individuals and companies (Mwangi, 2008). However, there has been a remarkable decrease in the catches recorded from capture fisheries due to the destruction of the catchment areas, deforestation, overfishing, habitat degradation, water abstraction and climate change (Kateregga and Sterner, 2009). Furthermore, encroachment of aquatic ecosystems such as swamps to supplement the declining fish stocks from surface waters like rivers and lakes has been reported (Ashley *et al.,* 2004).

Fish are infected by pathogens, parasites and diseases that reduce their reproduction, growth, and destroy their appearance and welfare (Olasoji, 2015). They serve as hosts to a range of parasites that are taxonomically diverse and that exhibit a wide variety of life cycle strategies (Barber *et al*., 2000). In freshwater, fish can serve as definitive hosts (in which the parasites reach sexual maturity), intermediate hosts (in which the parasites undergo asexual development) or paratenic hosts (needed for transport) (Barber *et al*., 2000). Parasites are thus an important component of the host (fish) biology, survival, population structure and ecosystem functioning (Marcogliese, 2004).

Some studies have revealed rich parasitic fauna in freshwater fish ranging from ecto-parasites to endo-parasites which affect the fish health, growth and survival (Paperna, 1980; 1996, Marcogliese and Cone, 2001, Florio *et al*., 2009, Otachi *et al*., 2015). Paperna (1980) reported that fish from African freshwaters are infected by a variety of protozoan and helminth parasites. The protozoan parasites include ciliates and flagellates while the helminth parasites range from monogenean and digenean trematodes (flukes), cestodes (tapeworms), nematodes (roundworms) and acanthocephalans (thorny headed worms). The arthropod parasites are represented mainly by copepods, while among annelids the hirudineans (leeches) are parasitic to fish (Marcogliese and Cone, 2001).

Parasitic infections in fish are dictated by the water quality parameters of the water body (Lal and Kumar, 2015). Changes in these parameters are often closely associated with anthropogenic alteration in the catchment areas and this may include; use of fertilizers in agricultural activities, livestock keeping, erosion, disposal of sewage waste and atmospheric deposition (Johnson *et al*., 2007). Some of the water quality parameters of significance to parasites include, but are not limited to: Dissolved Oxygen (DO), pH, temperature, turbidity, Electrical Conductivity (EC) and nutrients levels. Variations beyond acceptable ranges for the water quality parameters lead to stress which predispose the fish to parasitic infections, impaired health and mortality (Conte, 2004).

Fish parasites usually affect the marketability of the fish and of public health concerns especially in areas where raw or smoked fish is eaten (Barber *et al*., 2000). A number of studies have been carried out on the parasites infecting fish in Kenyan lakes (Aloo. 2002, Otachi *et al*., 2015, Rindoria *et al*., 2016) with Gumpinger (2016) focusing more on Lake Baringo. There is, however, a gap in the study of parasites infecting fish in swamps which are an important component of aquatic ecosystems. Swamps act as links between the terrestrial and aquatic habitats and may form refugia for some fish species. In addition, they are essential among local communities' livelihood through provision of food (fish) and also vegetation like *Cyperus papyrus* which is used in craft making.

This study aims at assessing the parasite communities of *Oreochromis niloticus baringoensis* (Trewavas, 1983) in relation to selected water quality parameters in the hot springs of Lorwai Swamp and Lake Baringo. Although the two water bodies are in close proximity, the *O. niloticus baringoensis* from the hot springs of Lorwai Swamp have been found to have distinct genetic makeup from their counterparts in Lake Baringo (Ndiwa *et al*., 2014). Fish is of economic importance to man and there is increasing protein demand, therefore information on parasites infecting fish becomes particularly important.

1.2 Statement of the Problem

Parasites may lead to serious mortalities in the infected fish thereby destabilizing the biodiversity and ecosystem functions of aquatic ecosystems. The parasites may destroy important organs like the liver and also interfere with respiration when the gills are attacked. Parasites can also cause serious health problems to humans if they are zoonotic especially when the fish is not properly cooked. Being transitional zones, swamps such as the Lorwai Swamp are important water resources in arid areas. They provide grazing areas, offer food security (for example macrophytes used as vegetables, fish), rich fertile soils and supply water for domestic use and irrigation agriculture. Coupled with other surface water resources such as lakes, these systems are under a lot of pressure due to anthropogenic activities both in the riparian and catchment areas. There is lack of information on the parasitic species infecting *O. niloticus baringoensis* in the hot springs of Lorwai Swamp. Due to their distinct genetic makeup from their counterparts in Lake Baringo, the *O. niloticus baringoensis* in Lorwai Swamp may potentially harbour different parasites. The outcome of this study will provide a knowledge base on the species of parasites that are found in and on the *O. niloticus baringoensis* in the hot springs draining into Lorwai Swamp, facilitate the comparison of the recorded species with those found in Lake Baringo and also provide information on their relationship with selected water quality parameters in the hot springs of Lorwai Swamp and Lake Baringo.

1.3 Objectives

1.3.1 General Objective

To assess the parasite communities of *Oreochromis niloticus baringoensis* in relation to selected water quality parameters in the hot springs of Lorwai Swamp and Lake Baringo, Kenya.

1.3.2 Specific Objectives

i. To determine the influence of selected water quality parameters on some aspects of *Oreochromis niloticus baringoensis* fishery assessment in the hot springs of Lorwai Swamp.
ii. To determine the relationship between selected water quality parameters and the infection parameters of the parasitic communities infecting *Oreochromis niloticus baringoensis* in the hot springs of Lorwai Swamp and Lake Baringo.

1.4 Hypotheses

H_{01}: There is no significant difference between the Length-Weight Relationship and Fulton's condition factor (k) of *Oreochromis niloticus baringoensis* and the standard values of b = 3 and k value of 1 respectively.

H_{O2}: There are no significant correlations between selected water quality parameters and the infection parameters of the parasitic communities infecting *Oreochromis niloticus barongoensis* in the hot springs of Lorwai Swamp and Lake Baringo.

1.5 Justification

Fish is one of the major sources of proteins available to human populations worldwide. Most of the fish in inland areas are obtained from capture fisheries in lakes, rivers and swamps. In arid areas, these aquatic resources are critical for the livelihood of the local inhabitants. Fish parasites, however, are a big threat to the stability of fish populations and provision of protein to humans as they affect the quality of fish and reduce their production. Therefore, it was important to establish the species of parasites infecting the *O. niloticus baringoensis* in the hot springs of Lorwai Swamp and Lake Baringo and their relationship to selected water quality parameters. Climate change-related factors are predicted to affect aquatic environments in many ways. Water quality, fish physiology, immunology, behaviour, and parasite-avoidance strategies are likely to be affected by climate change and this may lead to ecosystem-level changes. Parasitic organisms that exploit fish are also likely to be affected by climate change, both directly and via climate effects on their hosts. It is possible that climate change will alter the prerequisites for parasite transfer. Increased water temperature is predicted to enhance parasite metabolism, resulting in more rapid spread of parasites; while the occurrence of some parasites could also decrease if the optimal temperature for growth and transmission is exceeded. This study will help in safeguarding the health of the fish consumers and also create awareness on the parasites which the fish are exposed to. This will facilitate education of the communities depending on the two systems on the correct preventive measures to take. This is in line with Sustainable Development Goal (SDG) number 2 (creating new paths for nutrition, agriculture and food systems) which is largely concerned with the impacts and sustainability of current production and consumption patterns. This study is also in line with two out of the big four agenda of the Government of Kenya. These are health and food security to the Kenyan population. Lastly, this study will also fill the gap on understanding the parasite communities that infect the genetically different *O. niloticus baringoensis* in hot springs of Lorwai Swamp.

1.6 Scope and Limitations

1.6.1 Scope

The specific objectives investigated during this study are presented in separate chapters. The contents of the different chapters are discussed in detail therein as outlined below.

Chapter One: Introduction

This chapter provides the general background information to the study. The statement of the problem, objectives, hypotheses and justification of the study are also stated therein.

Chapter Two: Literature Review

This chapter provides a recap on the different parasite species groups that have been documented to infect *Oreochromis niloticus*. The biological aspects like morphologies, feeding and reproduction habits of the parasites are discussed in details. The chapter also gives a glimpse on some of the effects these parasites cause to their hosts. The relationship between the parasites and the water quality parameters are also explained. There is an in-depth elaboration on the biology and ecology of *O. niloticus*. This chapter also touches on the resources of Lorwai Swamp and Lake Baringo, Kenya where this study was carried.

Chapter Three: Influence of selected water quality parameters on some aspects of *Oreochromis niloticus baringoensis* (Trewavas, 1983) fishery assessment in the hot springs of Lorwai Swamp, Baringo, Kenya

In this chapter, there is a discussion on the length-weight relationship and Fulton's condition factor of *O. niloticus baringoensis* in the hot springs of Lorwai Swamp. The LWR was determined using Le Cren's equation; $W=aTL^b$ while the Fulton's condition factor was determined using Ricker's equation; $100W/L^3$. These aspects were then correlated to some selected water quality parameters by running a Principal Component Analysis (PCA) test.

Chapter Four: Parasite communities of *Oreochromis niloticus baringoensis* (Trewavas, 1983) in relation to selected water quality parameters in the hot springs of Lorwai Swamp and Lake Baringo, Kenya

In this chapter, the identification of the parasites that were found to be infecting *O. niloticus baringoensis* was done using standard identification keys and discussed in details. The infection parameters and diversity indices were also calculated using standard procedures and the results discussed in details. The procedures used are well outlined within this chapter.

This chapter also outlines the relationship between the parasites that were recovered from the *O. niloticus baringoensis* examined with the selected water quality parameters. This was done by running a Principal Component Analysis (PCA) test using SPSS statistical software version 20.

Chapter Five: Conclusions and Recommendations

This chapter gives the conclusions and recommendations for the health status of *O. niloticus baringoensis*, its parasite communities and how they relate to the selected water quality parameters in the hot springs of Lorwai Swamp and Lake Baringo, Kenya.

1.6.2 Limitations

Two major limitations were identified in the course of this study. The first one was the distance between the study sites and Egerton University. This was a major concern because the fish had to be transported alive in a tank and buckets to the laboratory at Egerton University for parasitological examination. The long distance travelled puts the fish under stress and may lead to death which posses a challenge because fish used for parasitological analyses have to be freshly dead. Secondly, during the initial sampling, a lot of fish from the hot springs died due to the competition for the low dissolved oxygen levels in the water and the limited space in the buckets during transportation.

1.7 Definition of terms

Abundance: Refers to the number of parasites from a single host of a particular species whether the host is infected or not (total number of a parasite species divided by number of hosts – positive and negative - examined).

Commensalism: an association between two organisms in which one benefits and the other derives neither benefit nor harm.

Debilitation: action of making the host weak or feeble.

Definitive host: an organism that supports the sexually reproductive form of a parasite.

Ectoparasites: a parasite that lives on the outside of its host.

Endoparasites: a parasite that lives inside its host.

Flashing: the behaviour of a fish scratching itself by rubbing or banging on things.

Haptors: the attachment organ of the monogeneans.

Hematophagous: refers to organisms which feed on blood.

Hyperplasia: an increase in the amount of organic tissue that results from cell proliferation.

Hypertrophy: increase in the volume of an organ or tissue due to the enlargement of its component cells.

Intermediate host: an organism that supports the non-reproductive or asexual forms of a parasite.

Mean Intensity: is the average intensity of parasites among the infected hosts (total number of parasites found in a sample divided by the number of infected hosts).

Melanophores: pigment cells that permit colour change, and the concentration of pigment granules within these cells determine the type of colour that is produced.

Metacecariae: a tailless encysted late larva of a digenea trematode that is usually the form which is infective to the definitive host.

Morbidity: the rate or prevalence of a disease in a population; the condition of being very sick or nearing death.

Oedema: a condition whereby an excess of watery fluid collects in the cavities or tissues of the body.

Ontogenetic shift: the change in diet as the fish grows.

Paratenic hosts: a host only utilized as a transportation medium by the parasites (no biological development takes place).

Prevalence: is the number of hosts infected with 1 or more individuals of a particular parasite species divided by the number of hosts examined for that parasite species (usually expressed as a percentage).

Sclerites: the plates forming the exoskeleton of an arthropod.

Zoonosis: Any disease or infection that is naturally transmissible from vertebrate animals to humans or the *vice versa.*

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CHAPTER TWO
LITERATURE REVIEW

2.1 Resources of Lorwai Swamp

Lorwai Swamp supports a total of 36 vascular plant species in 13 families. These families include: Amaranthaceae, Asteraceae, Commelinaceae, Convovulaceae, Curcubitaceae, Cyperaceae, Fabaceae, Lemnaceae, Malvaceae, Nymphaeaceae, Onagraceae, Poaceae and Typhaceae (Muasya *et al*., 2004). The *Typha* zone is the largest and contains the most species in Lorwai Swamp, with the exception of *Cyperus papyrus* commonly reffered to as papyrus. *Typha domingensis* commonly reffered to as cattail is almost always found growing together with *Leersia hexandra* and *Ipomoea aquatica*, and other species scattered within (Muasya *et al*., 2004). There is a restricted distribution of *Cyperus laevigatus*, which is mostly localised at the southern margins of the swamp, and most in the interface between the *Typha* sp. and wooded vegetation. On the eastern margin of the swamp, two smaller patches of *Cyperus articulatus* and *Cyperus latifolius* dominate (Muasya *et al*., 2004). The papyrus zone is nearly a pure stand of *C. papyrus* which forms floating mats on standing water, with scattered *Vigna luteola* vines climbing on the papyrus. Papyrus is locally known as “Kutwee” meaning a “crown”. The relatively higher grounds which are subjected to changes in hydrological budget (seasonal flooding) are characterized by presence of *T. domingensis*. The cattails form a wide belt encircling an ‘island’ of papyrus (Muasya *et al*., 2004). The utilization of papyrus in Lorwai Swamp is primarily for local livelihood. Five major uses of papyrus in the area include making of mats, fodder, roofing, fuel and socio-cultural uses. Socio-cultural utilization consists of use in traditional dances (use of the umbel) and rituals (use of both umbel and rhizome) for cleansing and blessing ceremonies to avert drought calamities and outbreak of diseases in the land (Terer *et al*., 2012). The swamp serves an important role of habitat provision for a wide range of biodiversity. The swamp has a rich faunal composition comprising of large herds of the common zebra, ostrich, wild pigs, hippopotamus, marsh mongoose, tortoises, crocodiles, several species of snakes, and over 300 species of wetland dependent birds (Gitau and Verschuren, 2016). Livestock also heavily depend on the swamp’s flood zone for pasture. The hot springs feeding the swamp harbour a population of *Oreochromis niloticus baringoensis* which is genetically distinct from those of Lake Baringo. The distinction has been attributed to possible introgression with *O. niloticus* and *Oreochromis leucostictus* that might have escaped from nearby aquaculture farms (Nyingi *et al*., 2009; Ndiwa *et al*., 2014). *O. niloticus baringoensis* are utilized as a source of food at a subsistence level by the local community (Ndiwa *et al*., 2014). In addition, the swamp is a vital source of freshwater for animals, people and for irrigation to the local community whose main economic activity is small scale farming (Ashley *et al*., 2004).

2.2 Fish species and the parasite communities of Lake Baringo

Lake Baringo is very important to the population around it as a source of water for domestic use and for watering livestock. It is also a source of food, especially fish to the community with the commercial fisheries species composition of the lake being as in Table 1: *O. niloticus baringoensis* (Trewavas, 1983) at 80.4%, *Clarias gariepinus* (Burchell, 1822) at 9.8%, *Protopterus aethiopicus* (Heckel, 1851) at 7.95%, *Barbus intermedius australis* (Banister, 1973) at 0.96% and *Labeo cylindricus* (Peters, 1852) at 0.89% (Odada *et al*., 2006). *B. intermedius* rarely appears in the fishermen's catches, while *L. cylindricus* has almost disappeared from the lake since the damming of some of its inflowing rivers which has interfered with its breeding habit (Aloo, 2002). *C. gariepinus*, *O. niloticus baringoensis* and *P. aethiopicus* are economically exploited from the lake. The lake's water quality has deteriorated in the recent past mainly due to sedimentation from its catchment arising from poor agricultural practices, deforestation and overgrazing. Consequently, these have led to a decline in fish catches (Omondi *et al*., 2013). There are few studies on parasites from Lake Baringo. For example, among all the fish species in Lake Baringo, only *Barbus lineomaculatus* have been reported to be infected by the parasite *Ligula intestinalis*, a cestode (Britton *et al*., 2009). This revealed host-specificity and because the infected species is not exploited for commercial fisheries, the socio-economic impact of the parasite is limited (Britton *et al*., 2009). The other study is by Gumpinger (2016), who examined several fish species for parasites whose findings are listed in Table 2.

Table 1: Local names to some of the fish species in Lake Baringo

Scientific Name	Common Name	Local Name	Dialect
Clarias gariepinus	African catfish	Singiri	Kalenjin
Labeo cylindricus	Redeye Labeo	Ningu	Luo
Barbus lineomaculatus	Line spotted Barb	Sibile	Kalenjim
Protopterus aethiopicus	Lung fish	Kamongo	Luo
Oreochromis niloticus baringoensis	Baringo Tilapia	Tilapia	English

Table 2: Fish species hosts and their parasite communities of Lake Baringo (Source: Adapted from Gumpinger, 2016)

Fish parasite	Infected fish species hosts
Myxobolus sp.	*Oreochromis niloticus baringoensis* and *Barbus intermedius australis*
Dactylogyrus sp.	*Oreochromis niloticus baringoensis* and *Barbus intermedius australis*
Dolops ranarum	*Oreochromis niloticus baringoensis* and *Clarias gariepinus*
Diplostomum sp.	*Oreochromis niloticus baringoensis* and *Clarias gariepinus*
Clinostomum sp.	*Oreochromis niloticus baringoensis*
Euclinostomum sp.	*Oreochromis niloticus baringoensis* and *Clarias gariepinus*
Cestoda larvae	*Oreochromis niloticus baringoensis*
Contracaecum sp.	*Oreochromis niloticus baringoensis, Barbus intermedius australis, Clarias gariepinus* and *Protopterus aethiopicus*
Eustrongylides sp.	*Oreochromis niloticus baringoensis* and *Protopterus aethiopicus*
Trematoda metacercariae	*Oreochromis niloticus baringoensis*

2.3 Biology and ecology of *Oreochromis niloticus* (Linnaeus, 1758)

Oreochromis niloticus, commonly known as Nile tilapia is one of the species in the family Cichlidae and is endemic to the tropical regions of Africa and Middle East (Boyd, 2004). They are deep bodied perch shaped fish with cycloid scales and long dorsal fins (Fig. 1). The forward portion of the dorsal fin is heavily spined. Spines are also found in the pelvis and anal fins (Popma and Masser, 1999; Picker and Griffiths, 2011). Tilapias are characterized by an uninterrupted lateral line with strong vertical bands on the caudal fin. They also have a gray or pink pigmentation around the neck region. However, the colour intensity is greatly influenced by the food source, state of sexual maturity and the environment (Popma and Masser, 1999).

Figure 1: *Oreochromis niloticus baringoensis* (Source: Author)

They are maternal mouth brooders where the males fertilize the eggs and the females hold and incubate the eggs in their mouths until they hatch (Popma and Masser, 1999). The genera *Oreochromis* have been categorized as herbivorous due to the dominance of algae, plant material and detritus in their diet (Tucker *et al*., 2003). This makes them an important link between lower and upper trophic levels in the aquatic food webs. However, the juveniles have higher protein mass demand and they tend to feed more on zooplankton which are easier to digest. This change in diet as the fish grows is known as ontogenetic shift (Outa *et al*., 2014).

Tilapias tend to be sensitive to low temperatures with the optimum growth usually achieved at 28 to 32 ºC. The growth declines greatly with decreasing temperature and at 20 – 22 ºC, growth is usually about 30% of the optimum. Feeding usually stops at temperatures less than 16 ºC, and temperatures below 10 ºC are lethal (Teichert-Coddington *et al*., 1997). However, occurrence of tilapias in hot water springs is not new with a subspecies of Nile tilapia, *O. niloticus filoa* occurring in the hot springs and pools in the Awash system in Ethiopia (Trewavas, 1983). In Kenya, a natural population of *O. niloticus* has been found in the hot springs draining into Lorwai Swamp where the water temperatures are elevated to 36 ºC (Nyingi *et al*., 2009). Nile tilapias have been reported to survive well in DO levels of 3 mgl^{-1} and above and pH ranges of 6.5 - 9.0 which maintains alkalinity at or above 40 mgl^{-1} of $CaCo_3$ (Ngugi *et al*., 2007). *O. niloticus* is the most popular species of bony fish in Africa with several sub-species and one with the most economic importance in Kenya alongside *C. gariepinus* and *Cyprinus carpio* (Kornfield and Smith, 2000).

2.4 Influence of water quality parameters on parasite levels

The parasite communities of fish show considerable variation with the environmental conditions in which they live (Hossain *et al*., 2007). Some of the water quality parameters that have been found to have an impact on parasitic infections include: dissolved Oxygen (DO), pH, temperature, turbidity, electrical conductivity (EC) and nutrients (nitrogen and phosphorous) (Hedrick, 1998). Lower concentrations of pH increase the toxicities of hydrogen sulphide, copper and other heavy metals to fish. Fish are susceptible to parasitic attacks and diseases in acidic waters (Hossain *et al*., 2007). Temperature plays an important role in the dispersion of nematode parasites with incidences of infections being higher during periods of low temperatures (18.2 °C) and lower during periods of high temperatures (36.6 °C) (Lal and Kumar, 2015). However, influence of temperature operates differently on different taxonomic groups of nematodes due to different patterns of life cycle (Lal and Kumar, 2015). According to Garcia *et al*. (2009) infections by *Ichthyophthirius multifiliis,* a ciliated protozoa, decrease with an increase in EC and pH while low levels of DO favour trichodinids (ciliated protozoa) reproduction. This is due to the decomposition of organic matter which uses DO leading to its low levels.

2.5 Parasites infecting *Oreochromis niloticus*

2.5.1 Protozoa

Protozoans are unicellular eukaryotes that include members of Phylum Ciliophora, Microsporea, Sacodines, flagellates and Apicomplexa (Adl *et al*., 2019) some of which may be parasitic to fish. Protozoan life histories are widely varied from free-living, through various forms of commensalism to parasitism in most animals, plants and even other protozoans (Woo, 2006). A majority of species are free living in the aquatic environment, but they are also among the most common parasites encountered in fish (Lom and Dykova, 1992; Klinger and Floyd, 2002). They tend to have a direct life cycle and can build up to very high numbers in crowded environments leading to weight loss, debilitation, morbidity and mortality in infected fish (Klinger and Floyd, 2002).

Most protozoan parasites on fish are ciliates (Lio-Po and Lim 1992). These are organisms with tiny hair-like structures known as cilia that are mostly used for locomotion and/ or feeding. Ciliates have a direct life cycle and proliferate to high numbers in areas with organic debris (Klinger and Floyd, 2002). Examples of parasitic ciliated protozoans include *Trichodina* sp., *Tetrahymena* sp., *Ambiphyra* sp. *Chilodonella* sp. and *Ichthyophthirius multifiliis*. They cause skin and gill irritation which is usually displayed by flashing, rubbing and rapid breathing by the infected fish. Flagellated protozoans are small parasites that infect the fish internally or externally and are characterized by one or more flagella that the parasite use for movement in a whip-like motion (Klinger and Floyd, 2013). Examples of flagellated protozoans which parasitic to fish include *Cryptobia* sp., *Hexamita* sp. and *ichthyobodo* sp.

2.5.2 Myxozoa

Myxozoans evolved as endoparasitic radiation of cnidarians exploiting invertebrate and vertebrate (primarily fish) hosts in fresh and marine environments (Fiala *et al*., 2015). Myxozoans infect a wide range of tissues and are speciated by spore shape and size. Examples include the *myxobolus* spp. They cause both histozoic (in tissue) and coelozoic (in internal cavities such as in the gall and urinary bladders) infections. Gross signs of histozoic infection are whitish cysts with a milky substance containing microscopic spores. Large cysts are readily traced while small cysts in tissues (connective tissue and muscles) are detectable when tissue samples are pressed between slides, or in histological material. Coelozoic myxozoans of the urinary and bile cavities have a small *plasmodium* and produce few spores, often only two. Premature plasmodia are attached by pseudopodia to the epithelial lining of the bladder (Paperna, 1996). Fish acquire the parasite by ingesting infective spores from infected fish or food (Klinger and Floyd, 2002).

2.5.3 Monogenean Trematodes

Monogeneans are a group of parasites which are commonly found on the gills, skin or fins of fishes and lower aquatic invertebrates. A few of them may invade the rectal cavity, ureter, body cavity and even the blood vascular system. There are more than 100 families of monogeneans found on fishes of the world, in fresh and salt water at different temperatures (Reed *et al*., 2003). Most monogeneans are browsers, moving about the body surface and feeding on dermal (skin) mucus and gill debris with a direct life cycle. Most species are host- and site- specific, requiring only one host to complete their life cycle (Paperna, 1996; Reed *et al*., 2003). Two major groups of monogeneans exist, the monopisthocotyleans, which have hook-like organs on their haptors for attachment to their host and for feeding, and the polyopisthocotyleans, which have clamp-like structures for attachment (Reed *et al*., 2003).

Four families of monogeneans are found on marine and freshwater fish and they include; Gyrodactylidae, Dactylogyridae, Ancyrocephalidae and Capsalidae. Gyrodactylids are majorly viviparous where the adult parasite carries fully developed embryos identical to the adult and in turn carry the young of the next generation. They have a pair of anchors with both dorsal and ventral bars and 16 marginal hooks with no eyespots present. Dactylogyrids on the other hand are oviparous (egg layers) and have two pairs of eyespots. They have a vestigial pair of anchors in addition to a pair of anchors and one transverse bar with 12-14 marginal hooks. Ancyrocephalids are oviparous with two pairs of eyespots and two pairs of anchors. Each pair of anchors has a transverse bar. They have 12-14 marginal hooks, but may be absent in some species. Capsalids are also oviparous with two pairs of eyespots which are less conspicuous in adults. They primarily rely on an adhesive substance for attachment to the host, but they do have two pairs of anchors, a pair of accessory sclerites and 14 marginal hooks (Reed *et al*., 2003; Reed *et al*., 2012).

2.5.4 Digenean Trematodes

Digeneans have a complex life cycle which involves a number of hosts and depending on the digenean species, fish can either be primary or intermediate hosts (Klinger and Floyd, 2002). However, mollusks have widely been documented as the intermediate hosts (Paperna, 1996). They can be found externally or internally in any organ and are characterized by two suckers; on the anterior and antero-ventral parts of their bodies. Both suckers are used for attachment and locomotion (Paperna, 1996). The most commonly observed life stage in fish is the metacercariae which encysts in different tissues of the same host (Klinger and Floyd, 2002) but only extra intestinal species are harmful to the host (Paperna, 1996). Examples include; *Clinostomum* sp. and *Posthodiplostomum* sp.

2.5.5 Nematodes

Nematodes are cosmopolitan. They contain a thin cylindrical and elongated body with rigid cuticles in areas where attachment organs are missing (Moravec, 1998). They are mostly found in the intestinal tract of the fish. Nematodes have an indirect life cycle and reach the next host through food intake. They undergo larval development in the intermediate hosts. The first intermediate host is usually a crustacean (copepod), the second intermediate host is the fish and sexual maturity occurs in the final hosts which are usually birds (Zander, 1998). Some common nematodes found in fish include *Capillaria* spp. which is large and commonly found in the gut, often recognized by its double operculated eggs in the female worm; *Camallanus* spp. which are small red thread-like worms mostly protruding from the anus of the fish and *Eustrongylides* spp. which use fish as an intermediate host with birds being their definitive hosts (Klinger and Floyd, 2002). Anisakids of the species *Contracaecum* spp. have also been widely documented (Florio *et al*., 2009).

2.5.6 Cestodes

The body of an adult cestode is dorsal-ventrally flattened and they have an attachment organ known as a scolex on one end and proglottides on the other. They are hermaphrodites and lack a digestive system (Scholz *et al*., 2004). Cestodes have an indirect life cycle which is extremely varied whereby fish can be used as a primary or definitive host. They infect the alimentary canal, muscles or other internal organs. Plerocercoids (larval cestodes) are very dangerous and can impair reproduction when they infect gonadal tissues (Klinger and Floyd, 2002). The commonly reported species of cestodes in *O. niloticus* is *Amirthalingamia macracantha* found in the intestinal wall and the liver (Otachi, 2009).

2.5.7 Acanthocephalans

Acanthocephalans are characterized by an elongated cylindrical body with hooks on their proboscis (Paperna, 1996). They are dioecious with the females being larger in size than the males. They have no alimentary canal and develop via one or more intermediate hosts (Paperna, 1996). They are located mostly in the hosts' guts and attach onto them using the thorny proboscis which may lead to mechanical damage in heavy infestation (Barger *et al*., 1998; Barber *et al*., 2000). The common species of acanthocephalans that infect *O. niloticus* are *Neoechinornhynchus* spp., *Acanthocephalus* spp., *Pomphornchynchus* spp. and *Acanthogyrus tilapiae*.

2.5.8 Parasitic Crustacea

Crustaceans are distinguishable by the presence of hard segmented shells (exoskeletons) on their bodies. They are largely aquatic and generally have two pairs of antennules, they respire through gills or the body surface and have paired, segmented, usually biramous appendages anteriorly or throughout the body (Barger *et al.*, 1998). Three major groups of crustacea have been found to be parasitic to fish and they include: Branchiura, Copepoda and Isopoda with the latter found mainly in marine environment (Woo, 2006). The majority of parasitic crustacea which belong to sub-class Copepoda have a direct life cycle with several different larval stages and an adult stage. Copepods are dioecious, with males usually smaller than females (Florio *et al*., 2009). The crustacean parasites may harm the fish in three ways: they can cause pressure atrophy of soft tissues with their hard body, they can cause mechanical damage with their attachment structures and they can also inflict damages of different degrees by feeding at the expenses of the host as some species are hematophagous (Florio *et al*., 2009). Examples of parasitic crustaceans in fish include: *Ergasilus* spp., *Lernaea* spp. and *Argulus* spp.

2.6 Effects of parasites on fish

The effects of parasites in and or on fish hosts in the wild may be difficult to isolate and quantify. This may be because parasite infested fish are more readily predisposed to predators in the wild (Tops *et al*., 2009). However, studies of fish in captivity (in laboratories) or under culture conditions have provided much information about the effects of parasites on fish survival (Iyaji and Eyo, 2008; Karvonen and Seppälä 2008). These effects can be categorized into two groups;

2.6.1 Mechanical damage

This usually is as a result of abrasion, corrosion and tear of the fish muscles or other organs due to movements during feeding or locomotion by the parasite. Parasite infestation in the gill leads to heavy erosion, massive discoloration, numerous white spots and increased mucus secretion (Toksen, 2007). Increased mucus secretion provides a conducive environment for bacterial proliferation. Heavy infestation leads to lamellae gill fusion, hypertrophy, oedema and lamellar vesicle formation (Taylor *et al*., 2009). High parasitic loads in individual fish may lead to tissue replacement whereby the parasites occupy the majority of the area of a particular organ (Iwanowicz, 2011). Studies indicate that tissue replacement in fish testicles leads to depletion of fish stocks (Morrison, 1984). A decrease in the immune responses and reduction in total body weight as a result of tissue replacement in the liver may lead to a reduction in the market value of the infected fish (Morrison, 1984; Gestal and Azevedo, 2006).

2.6.2 Physiological damage

Cell proliferation can cause detrimental effects in the fish host; for example, epithelial cell proliferation is common in Atlantic salmon (Kania *et al*., 2010) and mucous cell hyperplasia in the Atlantic halibut (Ottesen *et al*., 2010). Another example of parasite-induced cell proliferation has been studied on the gills of bream (*Abramis brama*) infected with *Ergasilus sieboldin* which exhibit hyperplasia and mucus cell proliferation of the respiratory epithelium (Dezfuli *et al*., 2003). Immunomodulation is a phenomenon that has also been observed in parasite infected fish. All parasites have evolved ways of evading the host's immune response and the host immune systems have evolved ways to counter these evasive strategies (Sitjá-Bobadilla, 2008). A trade-off that is essential to the survival of the parasite and provokes a state of illness in the host is established (Sitjá-Bobadilla, 2008). Some parasites have evolved strategies that use the host immune system to aid their attachment to the fish host. For example, inflammation by the host around the proboscis and bulb of the acanthocephalan *Pomporhynchus laevis* secures a firm attachment, and one of the host reactions to the ciliate *Ichthyophthirius multifiliis* is the increased mucous production which reduces the immune damage to the parasite (Matthews, 2005).

Detrimental behavioural responses may also be observed in fish with parasites that have complex life cycles. The trematode *Euhaplorchis californiensis* are known to infest California killifish (*Fundulus parvipinnis*) brains, which alters their behaviour and causes the fish to swim slowly and in circles at the water surface. The infected fish are usually 10-30 times more susceptible to predation by the birds that serve as definitive hosts (Lafferty, 2008). Other effects of parasites on fish hosts, according to Iyaji and Eyo (2008) include muscles degeneration, liver dysfunction, interference with nutrition, interference with respiratory functions, cardiac disruption, nervous system impairment, castration or mechanical interference with spawning, weight loss and gross distortion of the body.

2.7 Length-Weight Relationship

Length-Weight Relationships (LWR) provide practical information on fish biology, ecology, health and physiology. They are used to predict growth in terms of weight as a function of length (Jones *et al*., 1999). This relationship is also important because it helps in determining the condition of the fish. LWR is calculated as $W=aL^b$ (Le Cren, 1951) where W is the weight of the fish, L is the total length of the fish in cm, "a" is the exponent describing the rate of increase or decrease of weight with length and "b" is the weight at unit length. Where b = 3, the increase in weight is isometric which means that the relative growth of both variables is identical (Ricker, 1975). This means that there is an increase in the length and weight of the fish. When b is not equal to 3, the growth is said to be allometric. Positive allometry is whereby $b > 3$; the k value increases with increasing length and as the fish length increases the fish becomes rotund. If $b < 3$ the k value decreases with increase in length. This means as the fish length increases the fish becomes less rotund. This is negative allometry (Jones *et al*., 1999).

2.8 Fulton's Condition Factor

In fish, the Fulton's condition factor (k) shows the information on the physiological state of the fish in relation to its welfare (Lizama *et al*., 2002). "K" was first utilized by Heincke (1908) as a measure of the condition of fish. It is usually as a result of the Length-Weight Relationship (Nash *et al*., 2006). Fulton's condition factor is influenced by age of fish, stage of maturation, season, sex, fullness of gut, type of food consumed, amount of fat reserve and degree of muscular development (Barnham and Baxter, 1998). The weight of the gonads largely affects the k value and in females, once the eggs are shed, the k value decreases rapidly (Barnham and Baxter, 1998). The k value can be used in assessing the stability of a fish population in a given habitat.

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CHAPTER THREE

INFLUENCE OF SELECTED WATER QUALITY PARAMETERS ON SOME ASPECTS OF *Oreochromis niloticus baringoensis* (Trewavas, 1983) FISHERY ASSESSMENT IN THE HOT SPRINGS OF LORWAI SWAMP, BARINGO, KENYA

3.1 Abstract

Water quality has been documented to affect the biology and well-being of fish. This chapter therefore emphasizes on the influence of selected water quality parameters on some aspects of *Oreochromis niloticus baringoensis* (Trewavas, 1983) fishery assessment (Length-weight relationship and Fulton's condition factor) in two hot springs draining into Lorwai Swamp; Lake Bogoria Spa spring and Chelaba spring between the months of July and August, 2018. A total of 241 fish were used for the analysis; 115 from Lake Bogoria Spa spring and 126 from Chelaba spring. Length-weight relationship (LWR) was determined using Le Cren's equation; $W=aTL^b$ and Fulton's condition factor (k) determined using Ricker's equation; $100W/L^3$. LWR results indicated an isometric growth for fish from both springs. The mean (± SD) k values for fish in Lake Bogoria Spa spring were 2.02±0.25 for the males, 2.02±0.27 for the females and 2.00±0.26 for both sexes. In Chelaba spring, the mean k values were 2.03±0.21 for the males, 1.97±0.25 for the females and 2.00±0.23 for both sexes. These values indicated that the fish in these hot springs are in a very good condition and healthy status with k values above 1. Some of the selected water quality parameters indicated a positive correlation with the length, weight and Fulton's condition factor of *O. niloticus baringoensis* in the two hot springs.

3.2 Introduction

Oreochromis niloticus baringoensis (Trewavas, 1983), commonly referred to as Baringo tilapia is one of the seven sub-species of *Oreochromis niloticus* and is endemic to Lake Baringo, Kenya (Trewavas, 1983). Although tilapias are native to Africa and Middle East where the temperatures tend to be warmer, they easily adapt to different environments with different parameters including temperature. This makes them an interesting species of fish to study. Temperature affects the physiology, growth, reproduction and metabolism of tilapia species (El-Sayed and Kawanna, 2008). Tilapia species found in waters outside the optimal temperature range have stunted growth as they tend to use a high amount of their dietary energy in maintaining the internal physiological functions rather than for growth (El-Sayed *et al*., 1996). Tilapia species tend to grow best and be in good health in waters with a temperature range of 20 – 30 °C, preferably about 28 °C (Ngugi *et al*., 2007). However, different strains of *O. niloticus* cope differently with an increase or decrease in temperature. For example, a sub-species of *O. niloticus*, *O. niloticus filoa* inhabits the hot alkaline springs and pools of the Awash River system in Ethiopia (Trewavas, 1983). The occurrence of Nile tilapia in hot water springs is therefore not a new phenomenon. A natural population of *O. niloticus baringoensis* was found in a warm water spring (Lake Bogoria Spa spring) discharging into the Lorwai Swamp system during a genetic survey of the various populations of *O. niloticus* in Kenya (Nyingi *et al*., 2009). The water temperatures in the hot springs were elevated to 36°C (Nyingi *et al*., 2009). Moreover, this population was found to have a slight genetic variation from its counterpart in Lake Baringo and this could indicate that the gene flow between the two populations could have been interrupted at some stage (Nyingi *et al*., 2009). This is because the two aquatic systems (the hot springs of Lorwai Swamp and Lake Baringo) are about 40 km apart and there are no water channels whether underground or on the surface connecting them. Although not yet explained, the genetic plasticity of this natural population may also be as a result of the high temperatures in the hot springs. Apart from temperature, other water quality parameters of these hot springs which have been previously documented include; pH, dissolved oxygen, electrical conductivity and nitrates concentration (Ashley *et al*., 2004; Owen *et al*., 2004). The need to establish the condition and health status of the *O. niloticus baringoensis* in these hot springs therefore formed the basis of this study. Results obtained were compared to those in Lake Baringo because there are no studies that have been done in a similar environment in Kenya and the studies documented on the endemic *O. niloticus baringoensis* are only from Lake Baringo.

The importance of determining Length-Weight Relationship (LWR) and condition factor of fish in fisheries management has been extensively demonstrated (Allen, 1938; Le Cren, 1951; Barnham and Baxter, 1998; Jones *et al*., 1999; Lizama *et al*., 2002). The occurrence of *O. niloticus baringoensis* in the hot springs of Lorwai Swamp therefore elicited a lot of interest in this study because of their survival in waters with high temperature. There has been a lot of documentation on the biology and behaviour of fish living in an environment with elevated water temperatures including hot springs and geothermal springs. From the temperate regions a study by Miller (1949) investigated the survival and tolerance of *Cyprinodon* sp. in the hot water springs of Death Valley in California where temperatures have been recorded to be as high as 43.3 °C. The investigations found that the waters in these springs were stratified and that the fish could have been swimming a few inches below the 43.3 °C stratum of water where temperatures could have been cooler. Lienau (1991) documented aquaculture operations using geothermal waters across United States of America with water temperatures being as high as 40.6 °C. Some of the fish species cultured in these geothermal waters included tilapia, catfish, bass and sturgeons. In the tropical region, Narahara *et al*. (1995) documented the respiratory physiology of *Oreochromis alcalicus grahami* (Lake Magadi tilapia). This fish endures high temperatures of up to 42.5 °C in the alkaline and frequently hypoxic hot springs of Lake Magadi, Kenya. However, no study has been carried out to investigate the condition and health status of fish found in these extreme environments. This therefore formed the main focus of this study which was to determine the well-being and health status of *O. niloticus baringoensis* found in the hot springs draining into Lorwai Swamp. This was the first study and one of a kind on the health and well-being of fish of the tilapiine species inhabiting hot water springs in East Africa and will serve as a baseline study.

3.3 Materials and Methods

3.3.1 Study area

This study took place at Lorwai Swamp (Fig. 2) which is a fresh water wetland located in Baringo County, Kenya. For a long time, it has been documented as Loboi Swamp and has also been well described by various authors including (Ashley *et al*., 2002, 2004; Nyingi *et al*., 2009; Terer *et al*., 2012; Ndiwa *et al*., 2014; Gitau and Verschuren, 2016). The name 'Lorwai" according to the local language (Ilchamus) means a place with water. The swamp has an area of approximately 1.5 km^2 with a length of 3 km and a width of 0.5 km (Ashley *et al*., 2004). It lies just north of the equator at 0º 21′ N and 36º 03′ E at an altitude of 1000 m above sea level within the Eastern Rift Valley. The swamp is shared among three locations; Loboi, Sandai and Kapkuikui on the drainage divide between Lakes Baringo and Bogoria within the extensive Baringo County. Being located in a semi-arid tropical region, the swamp serves as an important reservoir of freshwater during dry seasons (Ashley *et al*., 2004). The Lorwai Swamp ecosystem provides grazing grounds and drinking points for the cattle. The small communities living around the swamp use it as a bathing point, laundry area, source of food (fish) and water for domestic use. The papyrus harvested from the swamp is used for making mats, fodder for the cattle, roofing and as fuel (Terer *et al*., 2012). Its source of water is majorly from three main hot water surface springs: Lake Bogoria Spa spring (spring of men), Chelaba spring (spring of women) and a smaller spring called the Turtle spring, as well as a series of artesian blister bogs which discharge water into the swamp (Ashley *et al*., 2002). Lake Bogoria Spa spring is used as a natural spa in the adjacent Lake Bogoria Spa Hotel and also partially diverted to a nearby irrigation scheme known as Loboi-Lorwai

Irrigation Scheme for agricultural purposes. The Loboi-Lorwai Irrigation Scheme comprises of many individually owned plots where vegetables are grown. The hot springs harbour two species of fish: *Clarias gariepinus* and a genetically distinct strain of *O. niloticus baringoensis*.

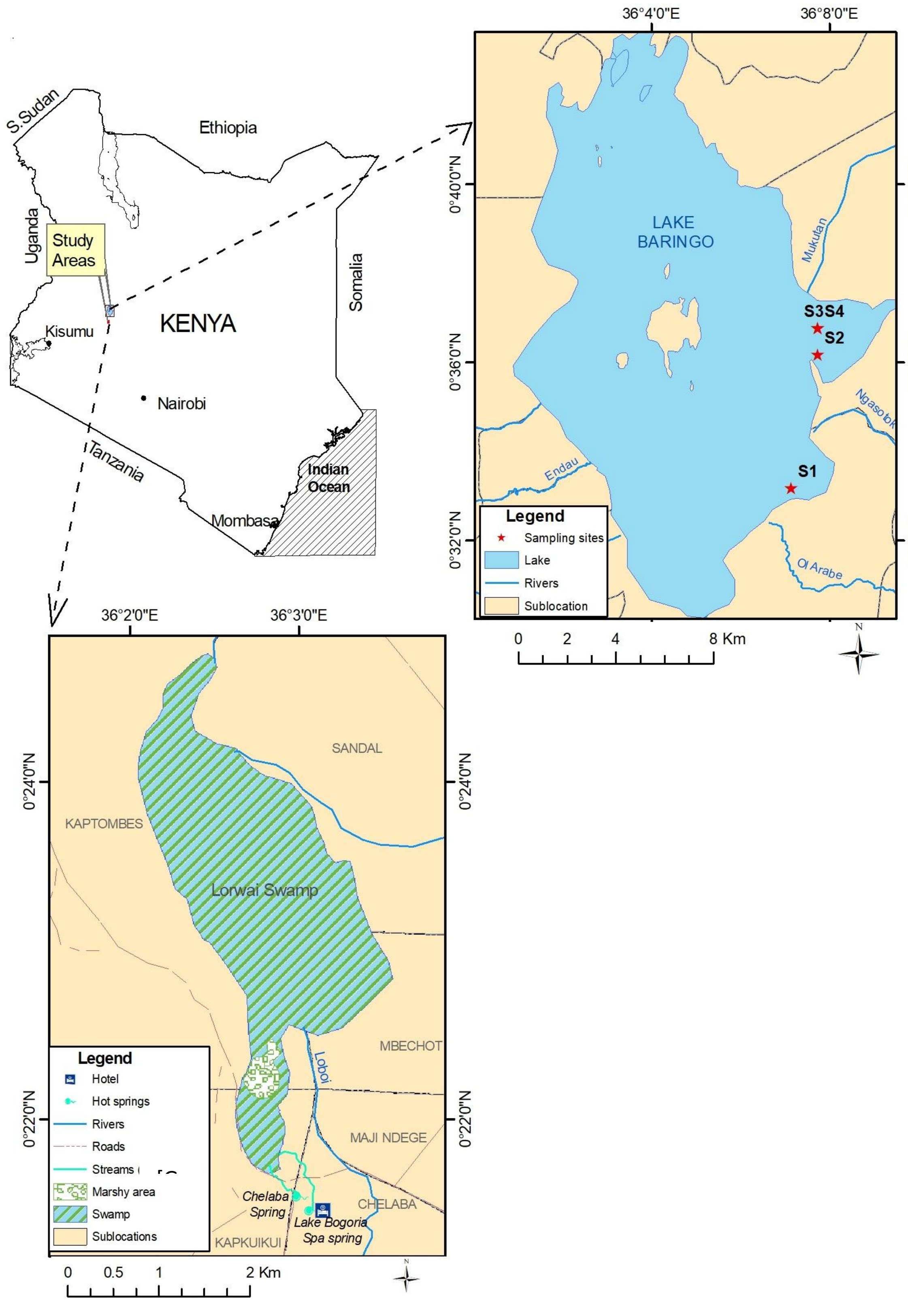

Figure 2: A Map of Kenya showing the location and sampling sites in the hot springs of Lorwai Swamp and Lake Baringo. (Source: Redrawn from Survey of Kenya Topographical maps, scale 1: 50,000)

3.3.2 Water quality parameters

Dissolved Oxygen (DO), Electrical Conductivity (EC), pH, temperature and turbidity were measured *in situ* in the two hot springs during the study period. These parameters were taken twenty minutes before the fish were collected. The EC, pH and temperature variations were measured using a universal meter (model HACH HQ 40d, USA). Turbidity values were measured using a turbidity meter (HACH 2100q, USA) while the DO meter (HACH HQ 30d, USA) was used to measure the DO concentrations in the hot springs. These measurements were carried out according to APHA (2004) standards. Water samples from the hot springs were collected in triplicates using 500 ml acid washed sample bottles during each sampling session. The water samples were stored in a cooler box prior to transportation to the water quality laboratory at the Department of Biological Sciences, Egerton University, Njoro and stored in a refrigerator at 4 °C before the analyses on Chlorophyll-*a* and Total Suspended Solids (TSS) were carried out. In the laboratory, the water samples were first filtered using 0.45µm GF/C filters (Whatman) and the filtrate stored for nutrient analyses (nitrogen and phosphorus). The TSS was determined gravimetrically on GF/C filters (Whatman) after drying in the oven to a constant weight at 95 °C. For chlorophyll-*a* determination, the filters together with the seston were folded and then covered by aluminium foil and stored in a freezer overnight so as to aid in the bursting of the cells. The seston and the filters were then homogenised in a tissue grinder at around 5,000-rpm for about 1 minute, covered with 5 ml of 90% aqueous acetone. The samples were then transferred into a centrifuge tube, the grinder rinsed with 90% acetone (volume used was noted) and the rinse added to the extraction slurry. The volume was then adjusted to 10 ml with 90% acetone and the sample left for at least 8 hrs in the dark at 4 °C for the chlorophyll-*a* extraction. After incubation, the sample was centrifuged for 10 min at 3,500 rpm. The clarified extract was then decanted into a clean test tube. Light absorbance of the chlorophyll-*a* extract was measured with a spectrophotometer (Pharmacia Biotech Novaspec II, Sweden) at 750 nm and 663 nm. To correct for turbidity and other colours, absorption read at 750 nm was subtracted from the readings made at 663 nm.

Nutrients analysed included ammonium nitrogen (NH_4-N), nitrite-nitrogen (NO_2-N), nitrate nitrogen (NO_3-N) and Total Nitrogen (TN), Soluble Reactive Phosphorus (SRP) and TP (Total Phosphorus). The concentrations were determined calorimetrically following conversion of the concentrations from sample absorbance values in relation to known standards. NH_4-N was determined by phenol-hypochlorite method, NO_2-N using the sulphanilamide method, NO_3-N using sodium-salicylate method (APHA, 2004), and TN using persulphate method (Koroleff, 1999). On the other hand, the phosphorus components (SRP and TP) were analyzed using the ascorbic acid method. However, TP had to be first subjected to digestion of unfiltered water using persulphate to reduce phosphorus present into SRP before the use of ascorbic method (APHA, 2004).

3.3.3 Field sampling and measurements for fish

Samples of *O. niloticus baringoensis* were collected from two of the hot springs; Lake Bogoria Spa spring and Chelaba spring. Sampling took place between July 2018 and August, 2018. Samples were collected every fortnight using a seine net. The fish were then placed into buckets with the hot springs' water and transported alive to the laboratory at the Department of Biological Sciences at Egerton University, Njoro, Kenya. Once in the laboratory, the fish were killed by cervical dislocation (Schäperclaus, 1990). The total lengths (TL, cm) and the Weights (W, g) of the fish were measured using a fish measuring board (Lagler, 1970) and a digital weighing balance (Sartorius ED4202S, Germany) respectively and then dissected so as to determine the sex. A total of 244 fish were collected from Lake Bogoria Spa spring and 201 fish from Chelaba spring. However, because some of the fish died during transportation, only 241 fish were used for the analysis; 115 from Lake Bogoria Spa spring and 126 from Chelaba spring.

3.3.4 Determination of Length – weight relationship

Using the measured and recorded lengths and weights, the length-weight relationship was calculated according to Le Cren (1951) as $W=aTL^b$, Where: W= the weight of the fish in grams (g), TL= the total length of the fish in centimeters (cm), a= the intercept of the regression line, b= the slope of the regression line (Allometric coefficient).

3.3.5 Determination of Fulton's condition factor

The value of the "b" exponent from the LWR provides important information on fish growth and whether Fulton's condition factor "k" can be used or not. Once the LWR had been determined and b proven to be equal to 3, the condition factor of each fish was calculated using the formula $k = \frac{100W}{L^3}$ (Ricker, 1975), where: k=Fulton's condition factor, W= the weight of the fish in grams and L= the total length of the fish in centimeters. The "k" values were then sorted according to sex and the mean "k" value for the male and female fish calculated separately.

3.3.6 Influence of the selected water quality parameters on the Length, weight and "k" values of *O. niloticus baringoensis* from Lake Bogoria Spa spring and Chelaba spring.

The correlation between the selected water quality parameters and the length, weight and Fulton's Condition Factor values was determined by running a Principal Component Analysis test using SPSS Version 20.

All statistical analyses and tests were carried out at a significance level of $p=0.05$.

3.4 Results

3.4.1 Water quality parameters

The mean ± standard deviation (SD) values of the selected water quality parameters in the two hot springs flowing into Lorwai Swamp are presented in Table 3. In Lake Bogoria Spa spring, temperature ranged between 35.6 and 36.9°C. Electrical Conductivity ranged between 354.0 and 442.0 μScm^{-1} and dissolved oxygen mean was 4.1 mgl^{-1}. Chelaba spring on the other hand had a temperature range of between 33.5 and 36.8°C. The EC range was between 340.0 and 427.0 μScm^{-1} with a DO mean of 4.33±0.72 mgl^{-1}. Most of the physico-chemical variables measured did not differ significantly between the two hot springs ($p > 0.05$) except turbidity (Student's *t*-test, $t = -3.81$, $df = 22$, $p=0.01$). Turbidity was significantly higher in Chelaba spring than in Lake Bogoria Spa spring. For the nutrient concentrations, Lake Bogoria Spa spring had higher concentrations of NH_4-N and NO_2-N while Chelaba spring had higher concentrations of NO_3-N, SRP and TP. The concentration of TN was the same in the two hot springs. There was a significant difference in the NO_3-N (Student's *t*-test, t =

Table 3: Water quality parameters in the hot springs flowing into Lorwai Swamp. Bolded figures are means ±standard deviation (SD), (p=0.05)

	Hot springs of Lorwai Swamp				
Water Quality parameter	**Lake Bogoria Spa spring**	**Chelaba spring**	***p* value**	**t value**	**df**
Dissolved Oxygen (mgl^{-1})	**4.10**±0.26	**4.33**±0.72	0.37	-0.92	19
Electrical Conductivity (μScm^{-1})	**397.17**±43.92	**383.50**±42.38	0.45	0.78	22
pH	6.91-7.37	6.77-7.50	0.47	0.74	22
Temperature (°C)	**36.42**±0.40	**36.01**±0.97	0.19	1.35	22
Turbidity (NTU)	**4.63**±0.88	**11.00**±5.73	0.01	-3.81	22
Chlorophyll *a* (μgl^{-1})	**13.79**±0.03	**13.81**±0.02	0.37	0.92	22
TSS (mgl^{-1})	**11.67**±3.89	**15.00**±6.74	0.15	-1.48	22
NH_4-N (μgl^{-1})	**68.58**±43.21	**65.58**±41.17	0.97	1.74	22
NO_2-N(μgl^{-1})	**5.76**±4.61	**4.43**±4.68	0.88	0.70	22
NO_3-N (mgl^{-1})	**1.30**±0.69	**1.81**±0.17	0.001	-2.47	22
TN (mgl^{-1})	**0.17**±0.001	**0.17**±0.001	0.68	-0.48	22
SRP (μgl^{-1})	**53.93**±20.80	**68.57**±25.68	0.08	-1.54	22
TP (μgl^{-1})	**73.81**±19.81	**84.05**±25.74	0.03	-1.09	22

3.4.2 Length-weight relationship

The total length of fish collected from Lake Bogoria Spa spring ranged between 6.20 and 23.00 cm while the weight ranged between 4.06 and 227.24 g. In Chelaba spring the total length ranged between 6.00 and 23.70 cm while the weight ranged between 8.43 and 299.85 g (Table 4).

Table 4: Total Lengths and weights of *Oreochromis niloticus baringoensis* from the hot springs draining into Lorwai Swamp

			TL (cm)		W (g)			
Site	**Sex**	**n**	**Min**	**Max**	**Min**	**Max**	**a value**	**b value**
Lake Bogoria Spa spring	Male	69	6.20	23.00	4.06	227.24	0.21	2.98
	Female	46	6.90	21.60	5.89	155.20	0.02	3.07
	Both sexes	115	6.20	23.00	4.06	227.24	0.02	3.07
Chelaba spring	Male	74	6.00	23.70	8.57	299.85	0.03	3.02
	Female	52	7.70	17.00	8.43	97.70	0.01	3.22
	Both sexes	126	6.00	23.70	8.43	299.85	0.02	3.09

The length-weight relationships for the fish were calculated per spring and further separated according to sexes. Different allometric coefficient (b) values were recorded between the male and female *O. niloticus baringoensis* collected from Lake Bogoria Spa spring of 2.98 and 3.07, respectively (Fig. 3a; Fig. 3b). The “b” value for both sexes of *O. niloticus baringoensis* collected from Lake Bogoria Spa spring was also 3.07 (Fig. 3c).

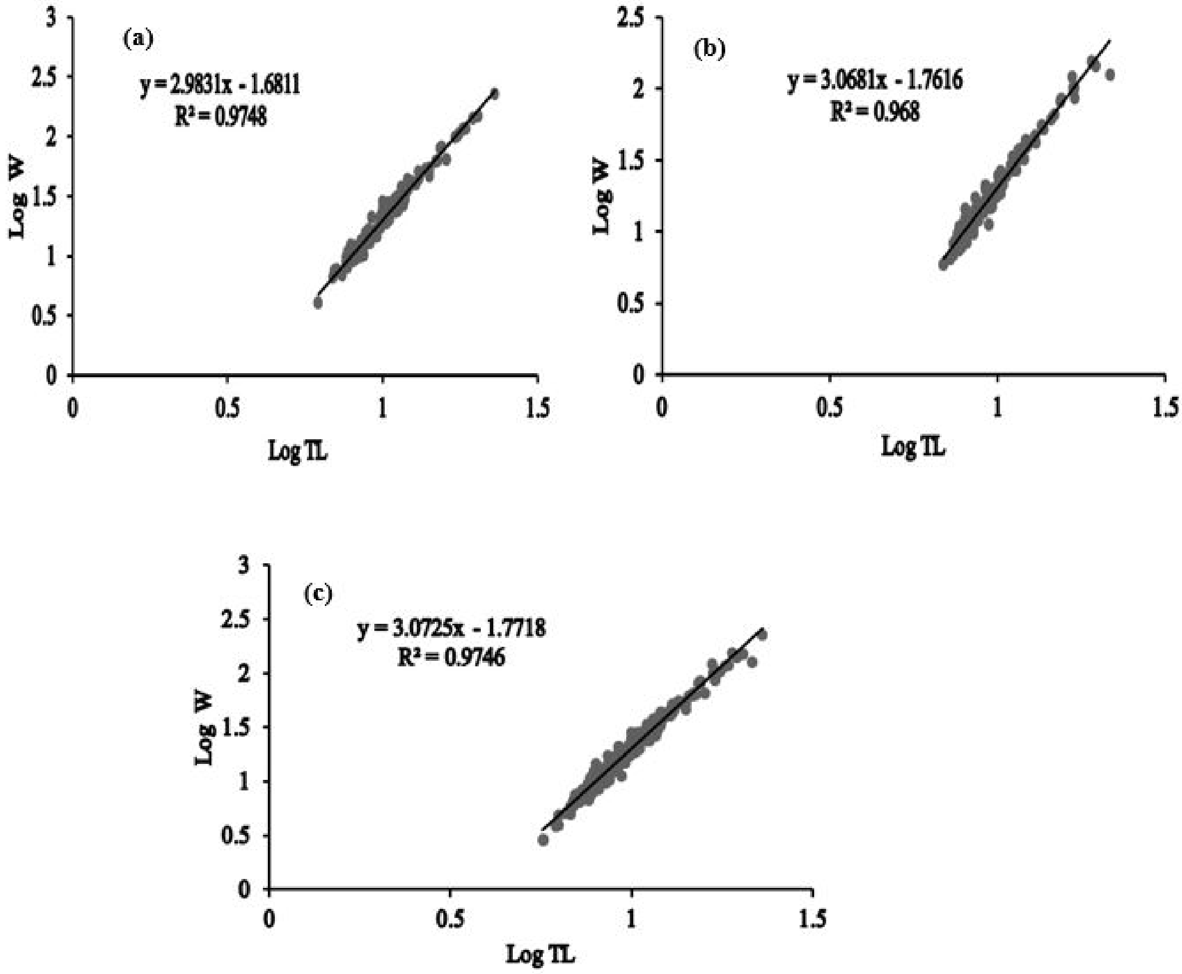

Figure 3: The Length-weight relationships for the (a) male population, (b) female population and (c) both sexes of *Oreochromis niloticus baringoensis* in Lake Bogoria Spa spring

From Chelaba spring, the "b" values recorded for the male and female *O. niloticus baringoensis* were 3.02 and 3.22 (Fig. 4a; Fig. 4b) while that of both sexes was 3.09 (Fig. 4c).

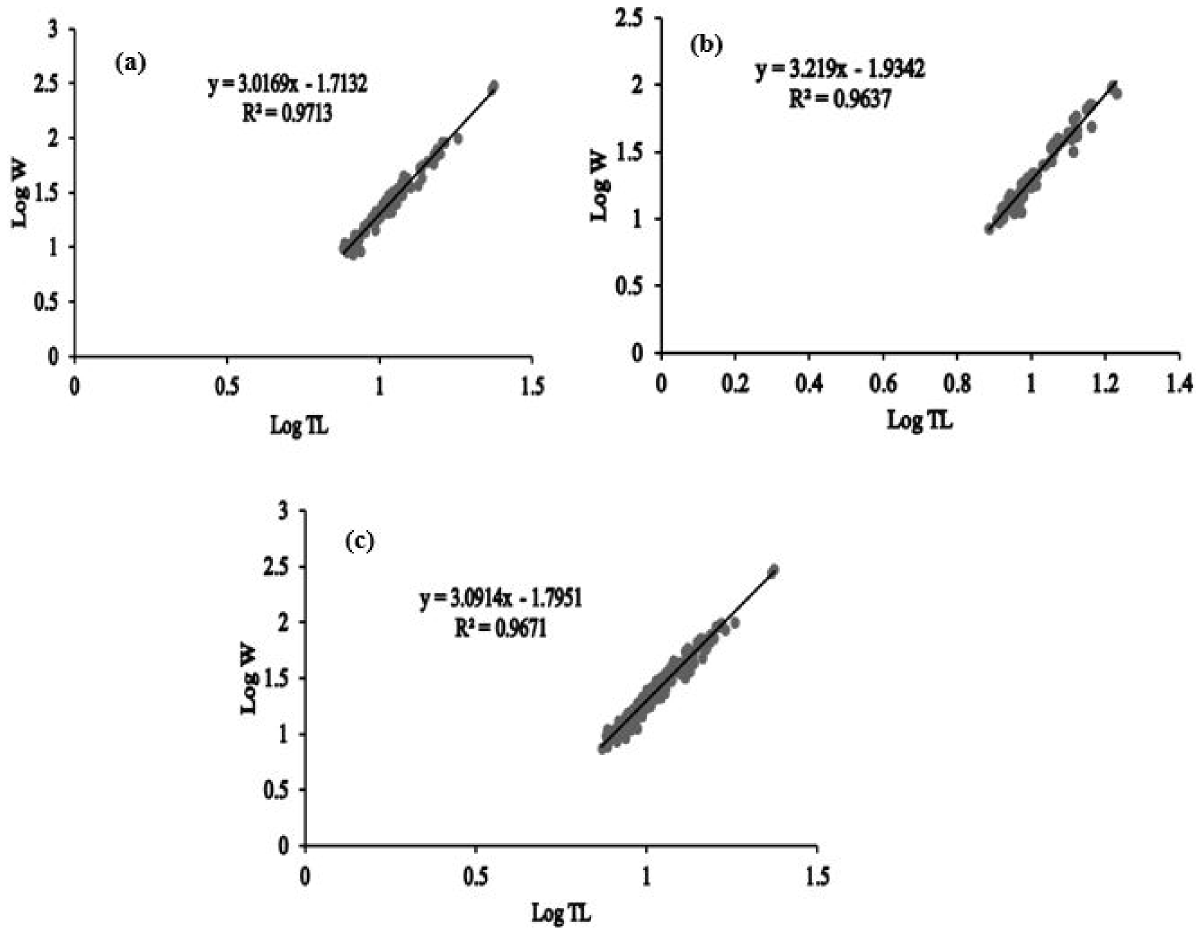

Figure 4: The Length-weight relationships for the (a) male population, (b) female population and (c) both sexes of *Oreochromis niloticus baringoensis* in Chelaba spring

3.4.3 Fulton's condition factor

The mean Fulton's condition factors (k± SD) of *O. niloticus baringoensis* collected from the two hot springs draining into Lorwai Swamp are summarized in Table 5. In Lake Bogoria Spa spring, the mean k value of *O. niloticus baringoensis* sampled was 2.02±0.25 for the males, 2.02±0.27 for the females and 2.01±0.26 for the both sexes while in Chelaba spring, the mean k value for the males (2.03 ±0.21) was slightly higher than that of the females (1.97±0.25). The mean k value for both sexes of *O. niloticus baringoensis* sampled from Chelaba spring was 2.00±0.23.

Table 5: Parameters of the Fulton's Condition Factor of *Oreochromis niloticus baringoensis* in the hot springs draining into Lorwai Swamp

Site	Sex	n	k value ±SD	k range
Lake Bogoria Spa spring	Male	69	2.02±0.25	1.56 – 2.85
	Female	46	2.02±0.27	1.25 – 2.84
	Both sexes	115	2.01±0.26	1.25 – 2.85
Chelaba spring	Male	74	2.03±0.21	1.40 – 2.61
	Female	52	1.97±0.25	1.36 – 2.55
	Both sexes	126	2.00±0.23	1.36 - 2.61

3.4.4 Influence of water quality parameters on length - weight and Fulton's condition factor

There was a marked positive correlation between EC, DO, NO_3, TN and SRP with length, weight and the Fulton's condition factor of *O. niloticus baringoensis* in Lake Bogoria Spa spring. Temperature however showed a negative correlation with length and weight in Lake Bogoria Spa spring (Fig. 5a). In Chelaba spring, length and weight showed a positive correlation with chlorophyll-*a* (Fig. 5b).

(a) **(b)**

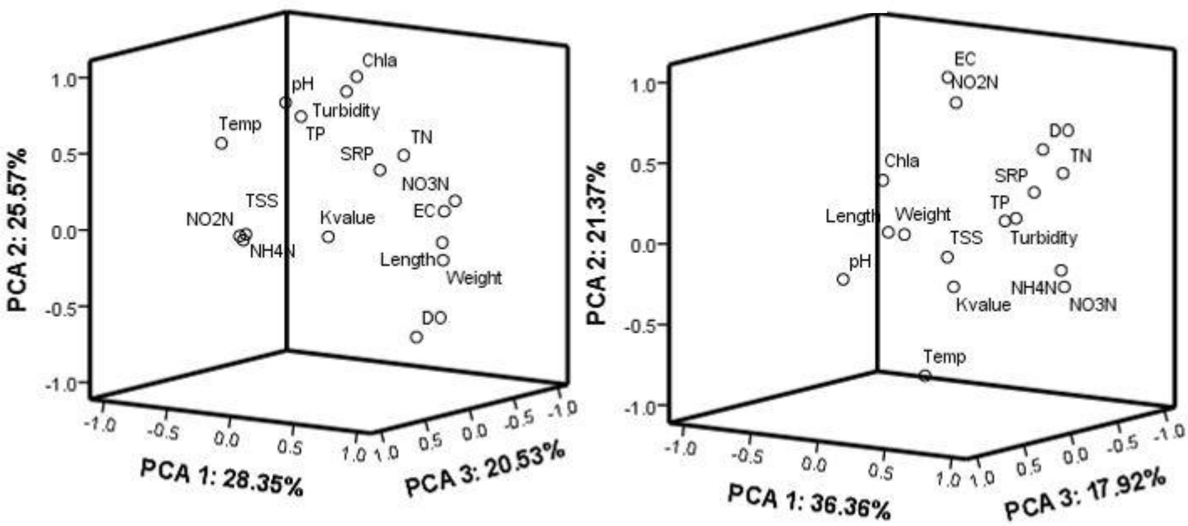

Figure 5: Principal Components Analysis biplots showing influence of the water quality parameters on the length and weight and Fulton's Condition factor of *Oreochromis niloticus baringoensis* in (a) Lake Bogoria Spa spring and (b) Chelaba spring

3.5 Discussion

The results obtained from this particular study indicated that the *O. niloticus barigoensis* sampled from Lake Bogoria Spa spring showed identical “b” values for the female population and also for both sexes combined of 3.07. However, the male population from this spring showed a different value from that of the female and both sexes combined. The males had an equation of $W= 0.21TL^{2.98}$, the females’ equation was $W= 0.02TL^{3.07}$ while that for both sexes from the same spring was $W= 0.02TL^{3.07}$ (Table 4). The observation from both sexes combined is similar to that of Kembenya *et al.* (2014) whereby after carrying out a Fulton’s Condition factor (length-weight relationship) test (k), *O. niloticus baringoensis* (both sexes combined) sampled from the nearby Lake Baringo had a “b” value of 3.08. Allometric values obtained from Chelaba spring showed no difference for the males, females and both sexes. The males had an equation of $W= 0.03TL^{3.02}$, for the females it was $W= 0.01TL^{3.22}$ and that of both sexes was $W= 0.02TL^{3.09}$ (Table 4). The “b” value for both sexes combined from Chelaba spring was also similar to that of Kembenya *et al*. (2014). A chi-square test was carried out to check for significant deviation (p=0.05) in the “b” values of the fish population from the two hot springs and it was evident that there was no significant deviation from the documented “b” value of 3. In Lake Bogoria Spa spring, χ^2 calculated = 0.00175 was less than χ^2 tabulated = 3.841 while in Chelaba spring, χ^2 calculated = 0.00316 was less than χ^2 tabulated = 3.841. This therefore indicates that there was an isometric growth for the *O. niloticus baringoensis* populations in both Lake Bogoria Spa spring and Chelaba spring. This means that both the length and weight of the fish population are increasing at a similar rate (Ricker, 1975). The correlation coefficient (r^2) for both sexes (combined) of *O. niloticus baringoensis* sampled from Lake Bogoria Spa spring and Chelaba spring were very high with both having values of 0.97 (Figures 3c and 4c). This showed that there was a very high degree of correlation between length and weight of *O. niloticus baringoensis* in these hot springs.

The mean k values (±SD) recorded during the study were all greater than 2 except for the female population sampled from Chelaba spring which had a mean k value of 1.97±0.25 (Table 5). The difference in the mean k values of the *O. niloticus baringoensis* population in Lake Bogoria Spa spring and Chelaba spring was however not significant (Mann-Whitney U test, n=912, p=0.96). The mean k values recorded from the *O. niloticus baringoensis* population (both sexes combined) sampled from Lake Bogoria Spa spring and Chelaba spring were 2.01±0.26 and 2.00±0.23 respectively. These values were higher than those recorded by

Kembenya *et al*. (2014) for *O. niloticus baringoensis* in Lake Baringo where the mean k value was 1.13±0.15. This difference may be attributed to the different water quality parameters between Lake Baringo (Okech *et al*., 2018) and the hot water springs draining into Lorwai Swamp (Table 3).

Water quality parameters play a very important role in the stability of a fish population in any water body. Although there was no significant difference between the DO in both hot springs, the values recorded were quite low. However, these values were within the acceptable range for the survival of the tilapiine species of 3 mgl^{-1} (Ngugi *et al*., 2007). Levels of DO above 3 mgl^{-1} promote the growth of phytoplankton which is food for the fish (Ngugi *et al*., 2007). Water temperature tends to have a strong negative correlation with DO and this is evidenced by the high-water temperatures recorded in the two hot springs (Table 3). There is a positive correlation between the levels of DO with length, weight and the Fulton's condition factor. Ample DO in the water makes fish active, increasing the feeding activities and in turn leading to increase in growth (Allan *et al*., 1995). The metabolic rates in fish also tend to increase with increase in temperature and in extreme cases may lead to death (Svobodova *et al*., 1993). The EC was also found to have a positive influence on the length, weight and Fulton's condition factor (Fig. 5a). The EC values obtained during this study (Table 3) were within the acceptable range for most freshwater bodies (216 - 526 μScm^{-1}) (Ndungu, 2014). Conductivity levels have a major impact on the productivity of the water. The positive correlation between NO_3, TN, SRP and chlorophyll- *a* with the length, weight and Fulton's condition factor shows that the *O. niloticus baringoensis* population is thriving due to the productivity of the hot springs. This shows that there is ample food leading to the good health of this population in the hot springs.

3.6 Conclusion

The length-weight relationship of *O. niloticus baringoensis* indicated that the population in the hot springs had a good growth ratio. The growth of *O. niloticus baringoensis* in Lake Bogoria Spa and Chelaba springs obeyed the cube law of growth as all fish sampled showed isometric (b = 3) growth. In addition, the mean Fulton's condition factor of *O. niloticus baringoensis* collected from the two hot springs indicated that the population was in a very good condition and healthy despite the high water temperatures of up to 36.4 °C, low dissolved oxygen levels of up to 3.25mgl^{-1} and relatively high conductivity values of up to 442.0 μScm^{-1}. These water quality parameters and the nutrients concentrations also showed a positive influence on the health of the *O. niloticus baringoensis* found in the hot springs draining into Lorwai Swamp. The LWR and Fulton's condition factor results will therefore serve as an important assessment tool for the management and conservation of the Lorwai Swamp ecosystem. These results will also offer baseline information for other studies dealing with fish in hot springs.

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CHAPTER FOUR

PARASITE COMMUNITIES OF *Oreochromis niloticus baringoensis* (TREWAVAS, 1983) IN RELATION TO SELECTED WATER QUALITY PARAMETERS IN THE HOT SPRINGS OF LORWAI SWAMP AND LAKE BARINGO, KENYA

4.1 Abstract

Parasite infections may lead to mortalities in fish therefore destabilizing the biodiversity and ecosystem functions. Swamps such as the Lorwai Swamp are important water sources and information on the parasite species infecting *Oreochromis niloticus baringoensis* in the hot springs of Lorwai Swamp which have a distinct genetic makeup from their counterparts in Lake Baringo is lacking. The purpose of this study was to provide a knowledge base on the parasite species infecting *O. niloticus baringoensis* in these hot springs, facilitate their comparison with those in Lake Baringo and determine their relationship with selected water quality parameters. A total of 347 fish were collected and standard parasitological procedures used to examine the presence of parasites. Physico-chemical parameters were measured *in situ* and water samples collected for chlorophyll-*a* determination and nutrient analyses in the laboratory using standard methods as outlined in APHA (2004). Relationships between parasitic infections and selected water quality parameters were determined by PCA using SPSS version 20. The prevalence of some parasites correlated positively with some parameters; *Amirthalingamia macracantha* and *Contracaecum* sp. with nitrogen compounds. Others like *Clinostomum* sp. and *Tylodelphys* sp. correlated negatively with dissolved oxygen. Results from this study showed that there were both positive and negative relationships between some water quality parameters and the prevalence of recovered parasites. *O. niloticus baringoensis* from Lake Baringo also recorded high parasite prevalence and this calls for sensitization of the public on the risks that may arise from the consumption of undercooked infected fish.

4.2 Introduction

Fisheries play an important role in the Kenyan national economy contributing 0.8% to the Gross Domestic Product (GDP) of the country (KMFRI, 2017). Lake Baringo fisheries consists of seven fish species; *Barbus intermedius australis* (Banister, 1973), *Barbus lineomaculatus* (Boulenger, 1903), *Clarias gariepinus* (Burchell, 1822), *Labeo cylindricus* (Peters, 1852), *Protopterus aethiopicus* (Heckel, 1851) and the endemic *Oreochromis niloticus baringoensis* (Trewavas, 1983; Britton *et al*., 2006; Odada, *et al*., 2006). The endemic *O. niloticus baringoensis* once dominated the lake's fishery but presently *P. aethiopicus* introduced in 1975 dominates (Omondi *et al*., 2016). During a genetic survey of the various species of *O. niloticus* in Kenya by Nyingi *et al*. (2009) a natural population of the endemic *O. niloticus baringoensis* was discovered in the hot springs flowing into Lorwai Swamp namely; Lake Bogoria Spa spring and Chelaba spring. This fish species was found to be having a slight genetic variation from its counterpart in Lake Baringo. Fish from these hot springs serve as a source of food to the small community of the Ilchamus living around the swamp. However, fish usually act as hosts to some parasites and some fish parasites have been found to be zoonotic and may therefore pose a risk to the consumers. However, there are no studies on fish parasites from the hot springs of Lorwai Swamp and few studies on fish parasites from Lake Baringo. For example, only *Ligula intestinalis*, a cestode, has been reported from *B. lineomaculatus* (Britton *et al*., 2009). Another study, by Gumpinger (Gumpinger, 2016) examined several fish species from the lake for parasites and recovered protozoans, trematodes, cestodes, nematodes and crustaceans. Parasite communities of fish have been known to show considerable variation with the environmental conditions such as the dissolved oxygen (DO), pH, temperature, turbidity, Electrical Conductivity (EC) and nutrients (nitrogen and phosphorus) in which they live (Hedrick, 1998; Hossain *et al*., 2007). For instance, incidences of infections by nematodes tend to be higher during periods of high temperatures due to faster maturation rates (Yanong, 2002). Also, according to Garcia *et al*. (2009) infections by a ciliated protozoan; *Ichthyophthirius multifiliis* decrease with an increase in EC and pH while low levels of DO favour trichodinids (a ciliated protozoan) reproduction. However, information on the parasites of fish found in hot springs and wetlands (swamp areas) as well as the relationship to selected water quality parameters especially in the hot springs of Lorwai Swamp and Lake Baringo, Kenya is lacking.

4.3 Materials and Methods

4.3.1 Study area

Fish were collected from the hot springs of Lorwai Swamp (Lake Bogoria Spa spring and Chelaba spring) and Lake Baringo between the months of July and August, 2018 by use of seine nets. Lorwai Swamp (also known as Loboi Swamp) is a freshwater wetland in Baringo County, Kenya, located between Lakes Baringo and Bogoria (Fig. 2) and has been described in details by Ashley *et al*. (2002, 2004) and in section 3.3.1. The swamp supports a total of 36 vascular plant species in 13 families but the dominant species are *Typha domingensis* and *Cyperus papyrus* (Muasya *et al*., 2004). The swamp has a rich faunal composition comprising common zebras, ostrich, wild pigs, and hippopotamus amongst others (Gitau and Verschuren, 2016). Lake Bogoria Spa springs' source is within the Lake Bogoria Spa Hotel where it is used as a natural spa.

Lake Baringo lies at 0º 37′ N and 36º 05′ E and approximately 60 km north of the equator (Fig. 2) at an altitude of 975 metres above sea level (Omondi *et al*., 2013). It has an approximate surface area of 130 km^2 and a mean depth of 1.6 m (Onindo and Mwangi, 2012). Most of its freshwater inflow comes from two perennial rivers; River Molo and River Perkerra, accompanied by several seasonal rivers namely; Ol Arabel, Makutan, Tangulbei, Endao and Chemeron (Odada *et al*., 2006). Due to its semi-arid location, very high annual evaporation rates of 1,650-2300 mm are experienced around the lake basin compared to an annual rainfall of 450-900 mm and its survival therefore depends on the inflowing rivers from the humid hillslopes of the drainage basin (Odada *et al*., 2006).

4.3.2 *In situ* determination of selected physico-chemical variables and water sampling

In situ measurements of selected physico-chemical parameters were made during each sampling session and recorded. This was done before the water samples and fish were collected. The samples were collected every fortnight between July and August, 2018. The selected physico-chemical parameters included the pH, water temperature, DO, turbidity and EC. These parameters were measured in triplicates during each sampling session as per APHA (2004) standard methods. A universal meter (model HACH HQ 40d, USA) was used to measure the values of EC, pH and temperature. Turbidity values were measured using a turbidity meter (HACH HQ 11d, USA) while the DO concentrations were measured using a DO meter (HACH HQ 30d, USA).

Water samples from the lake and hot springs were collected in triplicates using 500 ml acid washed sample bottles during each sampling session. The water samples were stored in a cooler box prior to transportation to the water quality laboratory at the Department of Biological Sciences, Egerton University, Njoro and stored in a refrigerator at 4 °C before the analyses were done.

4.3.3 Nutrient analyses of water samples

The nutrients analysed during this study included; ammonium-nitrogen (NH_4-N), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), Total Nitrogen (TN), Soluble Reactive Phosphorus (SRP) and Total Phosphorus (TP). The concentration of chlorophyll-*a* was also determined. Water samples used in the analyses of NO_3-N, NO_2-N, NH_4-N, SRP and chlorophyll-*a* concentrations were first filtered using 0.45µm GF/C filters (Whatman) and the filtrate used for the analyses. Calorimetric method was used to determine the nutrient concentrations. This was done through the conversion of the concentrations from the sample absorbance values in relation to known standards.

Determination of different forms of nitrogen

Ammonium-Nitrogen (NH_4-N), Nitrate-Nitrogen (NO_3-N), Nitrite-Nitrogen (NO_2-N) and Total Nitrogen (TN) were analysed as per APHA (2004) methods. The NH_4-N was determined by adding 2.5 ml of sodium salicylate solution and 2.5 ml of hypochloride solution to 25 ml of the filtered water sample. The samples were then incubated in the dark for 90 minutes after which its absorbance was read at a wavelength of 665 nm using a GENESYS 10uv scanning spectrophotometer (USA).

Nitrate-Nitrogen (NO_3-N) was determined using sodium salicylate method. One milliliter (1 ml) of freshly prepared sodium salicylate solution was added to 20 ml of filtered water sample. The processed samples were immediately placed in the oven and evaporated to complete dryness at 95 ºC. The resulting residue was dissolved using 1 ml concentrated sulphuric acid (H_2SO_4), followed by addition of 40 ml of distilled water and 7 ml potassium-sodium hydroxide-tartrate solution respectively and read at a wavelength of 420 nm using a GENESYS 10uv scanning spectrophotometer (USA).

The analysis for Nitrite-Nitrogen (NO_2-N) was carried out through the reaction between sulfanilamide and N-Naphthyl-(1) ethylendiamin-dihydrochloride and absorbance read at a wavelength of 543 nm using a GENESYS 10uv scanning spectrophotometer (USA). The final concentrations of NH_4-N, NO_3-N and NO_2-N were calculated from their respective equations generated from standard calibration curves (APHA, 2004).

TN was determined using persulphate method (Koroleff, 1999) which oxidizes all nitrogenous compounds to nitrate. Approximately 0.5 ml of solution B (mixture of Potassium peroxodisulphate, Sodium hydroxide and Boric acid) was added to 25 ml of unfiltered water samples then topped to 30 ml with distilled water in Erlenmeyer flasks. The samples were covered with a cotton plug and aluminium foil and mixed carefully. The flasks containing the samples were autoclaved for one hour at 110 ºC and after cooling, 1 ml of concentrated hydrochloric acid (reagent 'e') was added and mixed thouroughly. The absorbance was measured at a wavelength of 220 and 275 nm using a GENESYS 10uv scanning spectrophotometer (USA) against distilled water and the concentration determined from known concentrations of TN standard solutions.

Determination of different forms of phosphorus

The analysis of soluble reactive phosphorus (SRP) was carried out in triplicates using the Ascorbic Acid method as described by APHA (2004). The prepared reagents of ammonium molybdate solution (A), sulphuric acid (B), ascorbic acid (C) and potassium antimonyltartrate solution (D) was mixed in a ratio of A: B:C: D= 2:5:2:1 (ml). The resulting mixed solution was added to the filtered water sample at a ratio of 1:10. Absorbance was read at 885 nm wavelength using a GENESYS 10uv scanning spectrophotometer (USA) after 15 minutes of reaction. The concentration was determined from known concentrations of standard solutions (APHA, 2004). Total phosphorus (TP) was determined through persulphate digestion of unfiltered water which reduced the forms of phosphorus present into SRP. After the digestion, evaporated water was replaced and TP analyzed as SRP using the ascorbic acid method.

4.3.4 Chlorophyll-*a* determination

A definite volume of water sample was filtered through GF/C filters (Whatman) by gentle vacuum filtration followed by extraction through acetone. The filters together with the seston were folded and then covered by aluminium foil and stored in a freezer overnight so as to aid in the bursting of the cells. The seston and the filters were then homogenised in a tissue grinder (Heidolph, 637 69, Germany) at around 5,000-rpm for about 1 minute, covered with 5 ml of 90% aqueous acetone. The samples were then transferred into a centrifuge tube, the grinder rinsed with 90% acetone (volume used was noted) and the rinse slurry added to the extraction slurry. The volume was then adjusted to 10 ml with 90% acetone and the sample left for at least 8 hrs in the dark at 4 °C for the chlorophyll-*a* extraction. After incubation, the samples were centrifuged for 10 min at 3,500 rpm. The clarified extract was decanted into a clean test tube. Light absorbance of the chlorophyll-*a* extract was measured with a spectrophotometer (Pharmacia Biotech Novaspec II, Sweden) at 750 nm and 663 nm. To correct for turbidity and other colours, absorption read at 750 nm was subtracted from the readings made at 663 nm.

4.3.5 Fish collection and parasitological analyses

Fish (*O. niloticus baringoensis*) were collected from the hot springs of Lorwai Swamp and Lake Baringo using seine nets between July and August, 2018. The fish samples were transported alive in buckets and a fish tank with water from the hot springs and Lake Baringo respectively to Egerton University, Department of Biological Sciences. In the laboratory the fish were killed by cervical dislocation (Schäperclaus, 1990) and their total lengths (cm) and weights (g) recorded using a fish measuring board (Lagler, 1970) and a digital weighing balance (Sartorius ED4202S, Germany) respectively. Ecto-parasites were determined through gross examination of the external surfaces (skin, fins and gills) for pathological signs and presence of parasites. Skin and gill scrapings were made using a cover slip, then a wet mount was prepared on microscope slide through addition of a saline solution on the slide with the scrapings then covered by cover slip, and observed under a light microscope. The body cavities together with the visceral organs, intestines and eyes which were removed and placed onto petri dishes with saline solution were examined for presence of endo-parasites. The parasites were identified morphologically using standard identification keys (Paperna, 1980, 1996) and pictorial guides (Kuchta *et al*., 2012). The identified parasites were counted and preserved. Some were preserved in 4% formalin for identification and others in absolute ethanol for further genetic analysis. The total number of parasites identified was used to determine the infection parameters (prevalence, mean intensity and abundance) according to Bush *et al*. (1997) as follows:

$$Prevalence\ (\%) = \frac{Number\ of\ hosts\ infected\ with\ a\ particular\ parasite\ species}{Total\ number\ of\ hosts\ examined}\ x\ 100 \quad \text{(Equation 1)}$$

$$Mean\ Intensity = \frac{Total\ number\ of\ individuals\ of\ a\ parasite\ species}{Total\ number\ of\ infected\ hosts} \quad \text{(Equation 2)}$$

$$Abundance = \frac{Total\ number\ of\ individuals\ of\ a\ parasite\ species}{Total\ number\ of\ hosts\ examined} \quad \text{(Equation 3)}$$

4.3.6 Statistical analyses

The measures of diversity indices were calculated using an online Biodiversity Calculator (https://www.alyoung.com/labs/biodiversity_calculator.html) with inbuilt formulas. An ANOVA test was carried out to test for significant differences in the infection parameters (mean intensity, abundance and prevalence) of endo and ectoparasites infecting *O. niloticus barigoensis* in the hot springs of Lorwai Swamp and Lake Baringo using SPSS statistical software version 20. Data of the physico-chemical parameters and nutrient analyses were tested for normality using Shapiro-Wilk test followed by a one-way ANOVA to test for any significant differences among the three study sites. A Principal Component Analysis (PCA) was then carried out between the water quality parameters and prevalence of all parasites recovered using SPSS version 20.

4.4 Results

4.4.1 Physico-chemical parameters and nutrient analyses in the hot springs of Lorwai Swamp and Lake Baringo

A summary of the water quality parameters (mean ± SD) from the three sampling sites are presented in Table 6. According to the statistical analyses, most physico-chemical parameters were significantly different among the three sites. For example, there was a significant difference in the DO levels (one-way ANOVA, $F = 90.06$, df (2, 48), $p < 0.05$) with the highest mean DO levels recorded in Lake Baringo (7.17±0.88 mg/l) and the lowest mean levels in Lake Bogoria Spa spring (4.10±0.26 mg/l). The EC values also showed a significant difference among the three sites (one-way ANOVA, $F = 151.63$, df (2, 51), $p < 0.05$) with the highest and lowest mean EC values of 397.17±43.92 µS/cm and 249.73±11.04 µS/cm being recorded in Lake Bogoria Spa spring and Lake Baringo respectively. A significant difference was recorded in the mean temperature readings among the three sites (one-way ANOVA, $F = 576.91$, df (2, 51), $p < 0.05$) with the highest mean temperatures being in Lake Bogoria Spa spring (36.42±0.40°C) while the lowest mean temperatures in Lake Baringo (26.94±1.15 mg/l). There was a significant difference in the turbidity and chlorophyll- *a* values (one-way ANOVA, $F= 333.60$, df (2, 51), $p < 0.05$) and (one-way ANOVA, $F = 5.60$, df (2, 51), $p < 0.05$) respectively. Mean turbidity was highest in Lake Baringo (45.21±6.09 NTU) and lowest in Lake Bogoria Spa spring (4.63±0.88) while chlorophyll-*a* concentration was highest in Lake Baringo (16.25±0.05µg/l) and lowest in Lake Bogoria Spa spring (13.79±0.03 µg/l). The pH of the water was also different with values ranging between 6.77 and 8.37. For the various nitrogen forms, there was a significant difference in the NO_2-N (one-way ANOVA, $F = 8.84$, df (2, 51), $p < 0.05$) and NO_3-N (one-way ANOVA, $F = 8.62$, df (2, 51), $p < 0.05$) concentrations in the three sites but the NH_4-N (one-way ANOVA, $F = 0.13$, df (2, 51), $p > 0.05$) and TN (one-way ANOVA, $F = 0.02$, df (2, 51), $p > 0.05$) concentrations showed no significant difference. The highest and lowest mean NO_2-N concentrations were 9.96±0.78 µg/l and 4.43±4.68 µg/l in Lake Baringo and Chelaba spring respectively while the highest mean NO_3-N concentration was in Chelaba spring (1.81±0.17 mg/l) and the lowest mean concentration in Lake Baringo (0.27±0.56 mg/l). Although the mean NH_4 concentrations were not significantly different, the values were highest in Lake Baringo (82.70±0.08 µg/l) and lowest in Chelaba spring (65.58±41.17 µg/l) while the mean TN concentrations were the same in the three sites (0.17±0.001 mg/l). Chelaba spring recorded the highest mean SRP concentration of 68.57±25.68 µg/l and Lake Baringo recorded the lowest mean value of 37.48±0.02 µg/l while the highest mean concentration of TP recorded was 84.05±25.74 µg/l in Chelaba spring and the lowest was 73.81±19.81 µg/l in Lake Bogoria Spa spring.

Table 6: Water quality parameters (Mean ± Standard Deviation (SD) in the hot springs of Lorwai Swamp and Lake Baringo including pH range values (n=9), p=0.05

Parameter	**Hot springs of Lorwai Swamp**		**Lake Baringo**	**p - value**
	Lake Bogoria Spa spring	**Chelaba spring**		
DO (mg/l)	4.10±0.26	4.33±0.72	7.17±0.88	0.001*
Temp (°C)	36.42±0.40	36.01±0.97	26.94±1.15	0.002*
EC (µS/cm)	397.17±43.92	383.50±42.38	249.73±11.04	0.001*
Turbidity (NTU)	4.63±0.88	11.00±5.73	45.21±6.09	0.001*
Chlorophyll-a (µg/l)	13.79±0.03	13.81±0.02	16.25±0.05	0.01*
pH range	6.91-7.37	6.77-7.50	6.72-8.37	0.001*
NH_4-N (µg/l)	68.58±43.21	65.58±41.17	82.70±0.08	0.37
NO_2-N (µg/l)	5.76±4.61	4.43±4.68	9.96±0.78	0.01*
NO_3-N (mg/l)	1.30±0.69	1.81±0.17	0.27±0.56	0.01*
TN (mg/l)	0.17±0.001	0.17±0.001	0.17±0.002	0.19
SRP (µg/l)	53.93±20.80	68.57±25.68	37.48±0.02	0.01*
TP (µg/l)	73.81±19.81	84.05±25.74	77.38±0.02	0.53

* - indicates significant difference

4.4.2 Parasite communities recovered from *O. niloticus baringoensis* in the springs of Lorwai Swamp and Lake Baringo

The average lengths and weights (± SD) of the fish were 10.14±2.92 cm and 26.91±29.79 g from Lake Bogoria Spa spring, 10.78±2.47 cm and 30.03±31.67 g from Chelaba spring and 16.74±4.92 cm and 114.36±90.49 g from Lake Baringo. A total of 347 fish were examined for presence of parasites from the three sites (115 from Lake Bogoria Spa spring, 126 from Chelaba spring and 106 from Lake Baringo). Out of the 347 fish, 207 fish were infected by either endoparasites, ectoparasites or both. This represented 59.65% of the examined population. In Lake Bogoria Spa spring 40% (46 out of 115) of the examined specimens were infected with parasites, 43.65% (55 out of 126) of the examined specimen were infected in Chelaba spring, while the entire population (100%) examined from Lake Baringo was infected with at least one parasite species. A total of 11 parasite species were recovered and they included: *Argulus* sp., *Amirthalingamia macracantha*, *Cichlidogyrus sclerosus*, *Clinostomum* sp., *Contracaecum* sp., *Euclinostomum* sp., *Heterophyes* sp., *Microsporidia* sp., *Neascus* sp. metacecariae, *Trichodina* sp. and *Tylodephys* sp. All the 11 parasites were recovered from Lake Baringo, 4 species from Lake Bogoria Spa spring and two species recovered from Chelaba spring (Table 7). Two parasites species (*C. sclerosus* and *Clinostomum* sp.) were present in all three sites. The ecto-parasites were mostly concentrated in the gills and on the skin while the endo-parasites were found within the gill cavity, visceral cavity, kidney, the intestinal lumen and the eyes of the *O. niloticus baringoensis* (Table 7).

Only one protozoan parasite, a ciliate; *Trichodina* sp. was recovered during this study. They were found exclusively in the gills. However, a majority of the recovered parasites were helminths consisting of eight genera. They included cestodes, nematodes and trematodes (both monogeneans and digeneans). A parasitic crustacean; *Argulus* sp. was also highly present in *O. niloticus baringoensis* from Lake Baringo. The parasitic cestode recovered was *A. macracantha* which was either encysted in the intestinal walls or found freely in the gut lumen. Nematodes consisted of only *Contracaecum* sp., which were found within the gill cavity, visceral cavity or inside the intestines. Majority of the helminths were trematodes and they included both monogeneans and digeneans. Only one parasite in the class monogenea; *Cichlidogyrus sclerosus* was recorded in all the three sites while five parasites from the digenean class were recovered. They were; *Clinostomum* sp., *Euclinostomum* sp., *Heterophyes* sp., *Neascus* sp. metacecariae and *Tylodelphys* sp.

Table 7: Occurrence of parasites in *Oreochromis niloticus baringoensis* with regards to the site of infection in Lake Bogoria Spa spring, Chelaba spring and Lake Baringo, Kenya. (+ means present, - means absent)

Parasite	**Site of Infection**	**Sampling Location**		
		Lake Bogoria Spa Spring, n=115	**Chelaba spring, n=126**	**Lake Baringo, n=106**
Argulus sp.	Gills and Skin	-	-	+
Amirthalingamia macracantha	Intestines	-	-	+
Neascus sp. metacecariae	Skin and fins	-	-	+
Cichlidogyrus sclerosus	Gills	+	+	+
Clinostomum sp.	Skin and Behind the gills	+	+	+
Contracaecum sp.	Gill cavity, Visceral cavity and Intestines	+	-	+
Euclinostomum sp.	Kidney	-	-	+
Heterophyes sp.	Gills	+	-	+
Microsporidia sp.	Gills	-	-	+
Trichodina sp.	Gills	-	-	+
Tylodelphys sp.	Eyes	-	-	+
TOTAL		**4**	**2**	**11**

4.4.3 Infection parameters of the parasites obtained from *O. niloticus baringoensis* in the hot springs of Lorwai Swamp and Lake Baringo

There were significant differences among the abundance (one-way ANOVA, F = 11.08, df (2, 9), p = 0.03), mean intensity (one-way ANOVA, F = 9.96, df (2, 9), p = 0.01) and prevalence (one-way ANOVA, F = 45.90, df (2, 9), p = 0.02) of the parasites from the three sites. In Lake Bogoria Spa spring, *Clinostomum* sp. had the highest prevalence, mean intensity and abundance followed by *C. sclerosus* and *Heterophyes* sp. while the *Contracaecum* sp. recorded the lowest infection parameters. In Chelaba spring, *Clinostomum* sp. had the highest prevalence, mean intensity and abundance while *C. sclerosus* recorded the lowest values. In Lake Baringo, *C. sclerosus* dominated in prevalence followed by *A. macracantha* and *Tylodelphys* sp. while *Microsporidia* sp. and *Trichodina* sp. had the lowest prevalence (Table 8). In terms of the mean intensity and abundance, *A. macracantha* had the highest values followed by *C. sclerosus* and *Tylodelphys* sp. *Argulus* sp. and *Trichodina* sp. had the lowest mean intensity while *Microsporidia* sp. and *Trichodina* sp. had the lowest abundance (Table 8).

Table 8: Occurrence of parasites in *Oreochromis niloticus baringoensis* with regards to the parasite prevalence (P %), Mean Intensity (MI) and Abundance (A) from the hot springs of Lorwai Swamp and Lake Baringo, Kenya

Parasites	**Sampling Location**								
	L. Bogoria Spa spring, n=115			**Chelaba spring, n=126**			**Lake Baringo, n=106**		
	P (%)	**MI**	**A**	**P (%)**	**MI**	**A**	**P (%)**	**MI**	**A**
Argulus sp.	-	-	-	-	-	-	17.93	1.26	0.23
Amirthalingamia macracantha	-	-	-	-	-	-	89.62	46.37	41.56
Neascus sp. metacecariae	-	-	-	-	-	-	16.98	27.11	4.60
Cichlidogyrus sclerosus	21.74	1.52	0.33	15.87	1.40	0.22	97.17	30.02	29.17
Clinostomum sp.	25.22	3.66	0.92	36.51	4.09	1.49	8.49	2.22	0.19
Contracaecum sp.	0.87	1.00	0.01	-	-	-	23.59	1.64	0.39
Euclinostomum sp.	-	-	-	-	-	-	8.49	5.33	0.08
Heterophyes sp.	1.74	4.00	0.07	-	-	-	25.47	6.22	1.59
Microsporidia sp.	-	-	-	-	-	-	1.89	5.00	0.09
Trichodina sp.	-	-	-	-	-	-	0.94	Low	Low
Tylodelphys sp.	-	-	-	-	-	-	86.79	6.87	5.96

4.4.4 Component community structure indices of parasites obtained from *O. niloticus baringoensis* in the hot springs of Lorwai Swamp and Lake Baringo

The highest diversity of parasites infecting *O. niloticus baringoensis* was recorded in Lake Baringo (Shannon-Weiner index = 1.23), followed by Lake Bogoria Spa spring (Shannon-

Weiner index = 0.79) while the lowest diversity was in Chelaba spring (Shannon-Weiner = 0.39) (Table 9). The Simpson's index of dominance indicated that *Clinostomum* sp. was the dominant parasites species recovered from *O. niloticus baringoensis* from the Lake Bogoria Spa spring and Chelaba spring (Table 9). The highest species richness was in Lake Baringo, followed by Lake Bogoria Spa spring while the lowest was recorded in Chelaba spring (Margalef richness index = 1.20, 0.60 and 0.19 respectively). There was a low percentage of parasite similarity among the three sites with a Jaccard similarity index of 12.5%.

Table 9: Component community structure indices of the parasites infecting *Oreochromis niloticus baringoensis* in the hot springs of Lorwai Swamp and Lake Baringo, Kenya

Diversity Indices	**Site**		
	Lorwai Swamp		**Lake Baringo**
	Lake Bogoria Spa spring	**Chelaba spring**	
Shannon-Weiner index	0.79	0.39	1.23
Simpson Dominance index	0.46	0.23	0.63
Margalef richness index	0.60	0.19	1.20
Dominant species	*Clinostomum* sp.	*Clinostomum* sp.	*Cichlidogyrus sclerosus*

4.4.5 Relationship between selected water quality parameters and parasite infection levels

There were significant correlations ($p < 0.05$); both positive and negative between water quality parameters and the prevalence of selected parasite species in the hot springs of Lorwai Swamp and Lake Baringo. In Lake Bogoria Spa spring, DO showed both positive and negative correlations with *C. sclerosus* and *Clinostomum* sp. respectively. *Heterophyes* sp. showed a negative correlation with temperature while *Contracaecum* sp. correlated positively with temperature and nitrates (Fig. 6). In Chelaba spring, DO correlated both positively with *C. sclerosus* and negatively with *Clinostomum* sp. The two parasites recovered from Chelaba spring; *C. sclerosus* and *Clinostomum* sp. showed a positive correlation with the nitrogen compounds (NH_4, NO_2, NO_3 and TN) and a strong negative correlation with temperature (Fig. 7).

Generally, in Lake Baringo the prevalence of some parasites was positively correlated with some water quality parameters for example; *C. sclerosus* and *Neascus* sp. metacecariae showed a strong positive correlation with DO, chlorophyll-*a* concentrations and turbidity. Temperature, pH and EC showed a positive correlaton with *A. macracantha*, *Euclinostomum* sp., *Contracaecum* sp. and *Trichodina* sp. (Fig. 8a). Nutrients concentrations also correlated positively with some parasites; *A. macracantha*, *Clinostomum* sp., *Contracaecum* sp., *Tylodelphys* sp., *Argulus* sp. and *Neascus* sp. metacecariae with the nitrogen compounds (NH_4, NO_2, NO_3 and TN) while *Euclinostomum* sp., *Trichodina* sp., *Heterophyes* sp. and *C. sclerosus* showed a positive correlation with TP (Fig. 8b). Other parasites like *Argulus* sp., *Clinostomum* sp. and *Tylodelphys* sp. correlated negatively with DO (Fig. 8a).

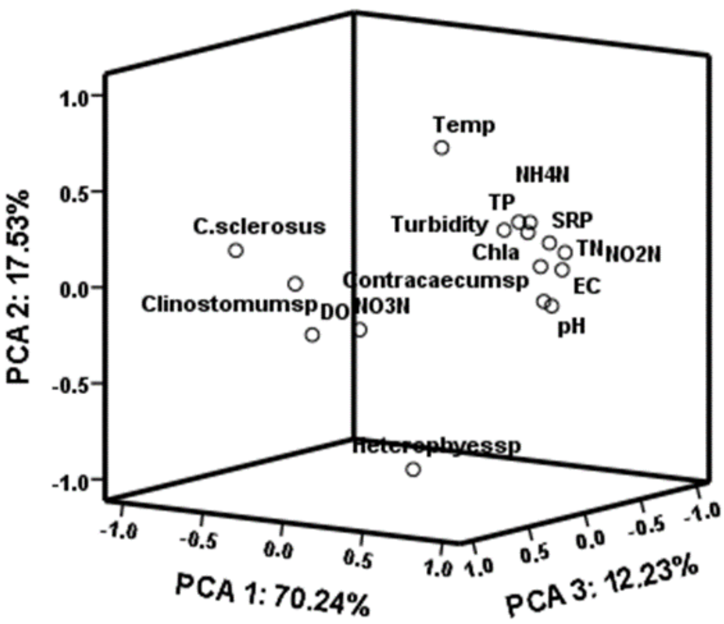

Figure 6: Principal Components Analysis biplot showing relationship between water quality parameters and the parasite species in Lake Bogoria Spa spring

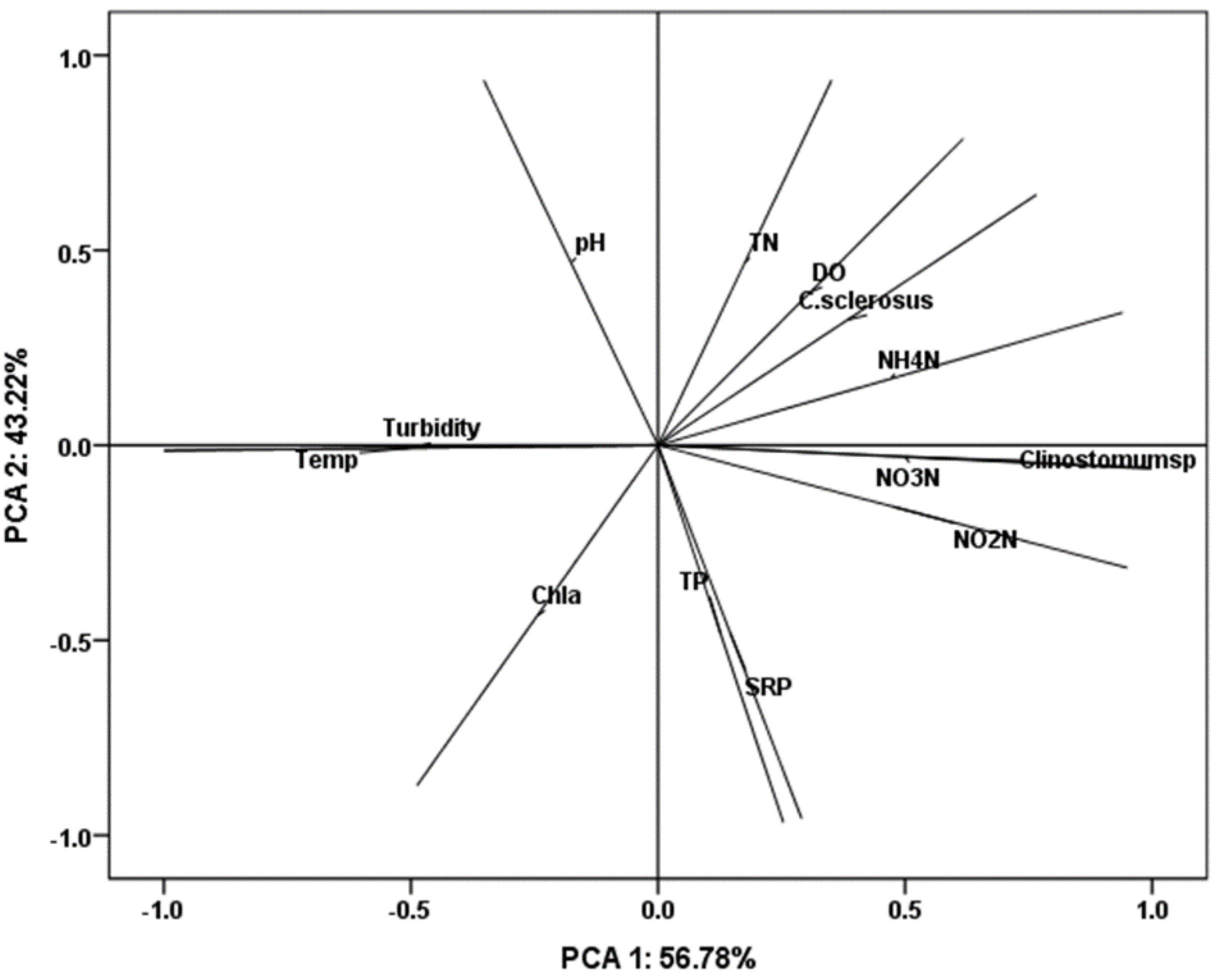

Figure 7: Principal Components Analysis biplot showing relationship between water quality parameters and the parasite species in Chelaba spring

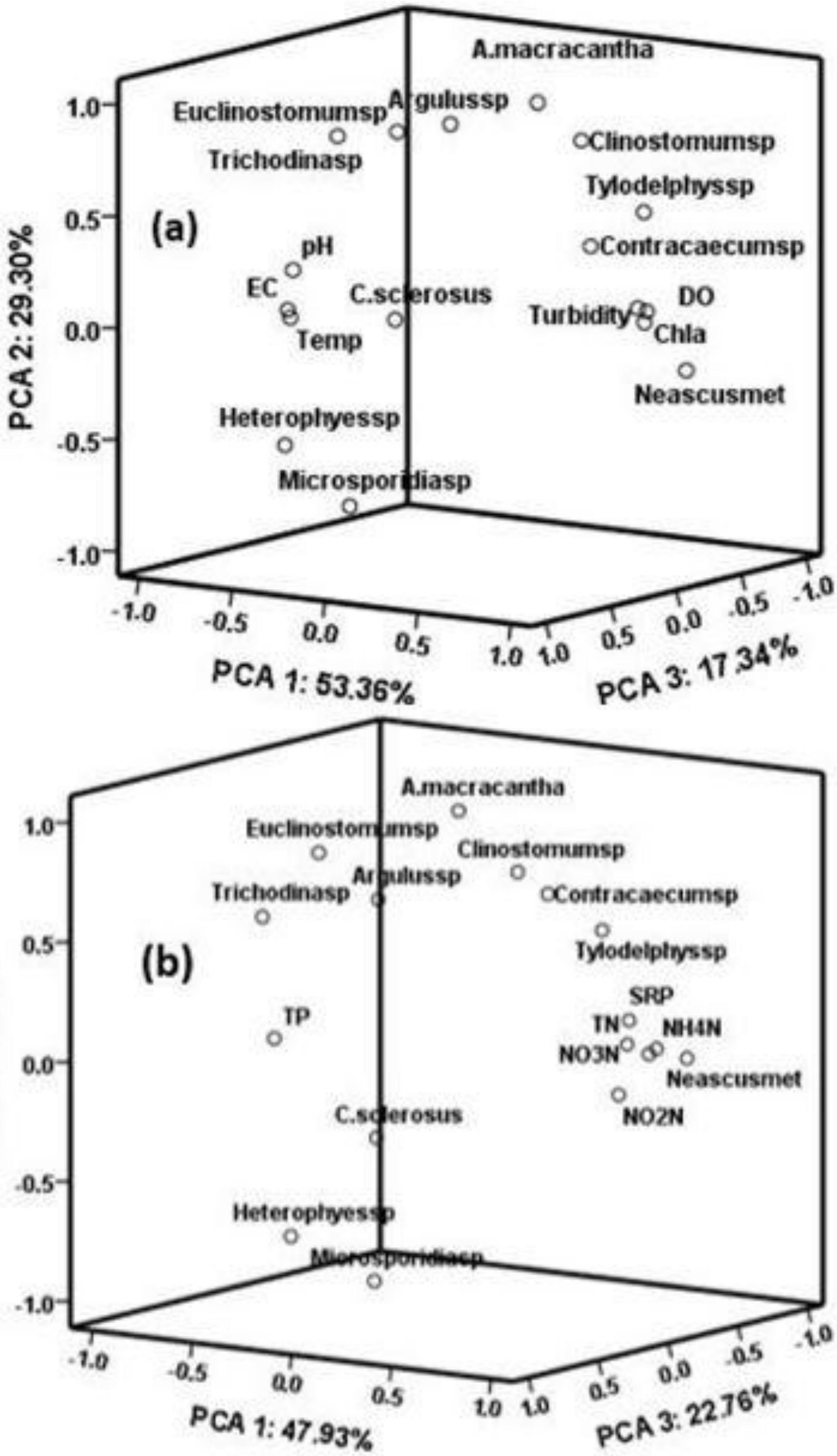

Figure 8: Principal Components Analysis biplots showing relationship between (a) physico-chemical parameters and (b) nutrients concentrations with the parasite species in Lake Baringo

4.5 Discussion

4.5.1 Water quality parameters in the hot springs of Lorwai Swamp and Lake Baringo

Most of the water quality parameters in the three study sites were within the acceptable range for the survival of *O. niloticus baringoensis* with the exception of some parameters like ammonia and nitrites. The levels of DO between the hot springs of Lorwai Swamp and Lake Baringo showed a significant difference. According to Ngugi *et al*. (2007) whose work extensively covers the survival limits of *O. niloticus* in aquacultural environments, these levels were within the acceptable limit of above 3mg/l and they promote and maintain a good phytoplankton which is food for the fish. Lake Bogoria Spa spring and Chelaba spring recorded low DO levels of up to 3.25 mg/l and this may be attributed to the very high-water temperatures of above 36 °C recorded in the two hot springs (Table 6) as water temperature and DO levels tend to be negatively correlated (Wetzel, 2001). There was a significant difference in the water temperatures between the two hot springs and Lake Baringo with the temperature in the hot springs being higher than 33 °C which is considered the highest temperature for good health and growth of *O. niloticus* (Ngugi *et al*., 2007). According to Allan *et al*. (1995) water temperatures have a positive correlation with the feeding activities and therefore growth of aquatic organisms. According to Svobodova *et al*. (1993) the desirable optimal range of pH for fish is between 6.5 and 8.5. The values obtained during the study from the two hot springs and Lake Baringo were all within the acceptable pH range for the well-being of fish. The range of EC in most freshwater bodies lies between 216 - 526 µS/cm (Ndungu, 2014). This range is acceptable for the good growth of warm water fish like the cichlids. Values obtained during the study were within this range with the EC being lowest in Lake Baringo (249.73±11.04 μScm^{-1}) when compared to Lake Bogoria Spa and Chelaba springs. This may be attributed to the dilution of the lake by heavy rains that were experienced in the country during the study period. The relatively higher EC values in the hot springs may be due to the fact that water from the springs is derived from underground and may have dissolved minerals (Ashley *et al*., 2002; Owen *et al*., 2004).

During the study period, the mean water turbidity levels recorded among the three sites ranged between 4.63 and 45.21 NTU. Lake Baringo recorded the highest turbidity values and this may be due to the influx of surface water from the catchment areas (Okech *et al*., 2018). Waters with high turbidity values often predispose the fish to parasitic infections because organic debris mostly habour protozoan parasites (Klinger and Floyd, 2002). Mean chlorophyll-*a* values obtained during the study were highest in Lake Baringo with 16.25±0.01

µg/l which was lower than that recorded by Okech *et al*. (2018) of 34.8±4.3 µg/l in Lake Baringo. Chlorophyll-*a* values are usually an indication of the abundance of phytoplankton in the water column which is food for fish (Allan *et al*., 1995).

Ammonia is present in most water bodies as a normal biological degradation product of proteins although the concentrations may be very small and conversion to nitrates through nitrification may take place (EIFAC, 1973). Although fish differ slightly in their tolerance to ammonia depending on species, the acceptable ammonia concentration for fresh water fish should be below 0.05 mg/l (EIFAC, 1973). The values obtained during this study ranged between 0.066 and 0.083 mg/l and therefore slightly higher than the desired limit. The highest value was recorded in Lake Baringo and being deeper than the hot springs, the bottom of the lake may not be well aerated. This may limit the process of nitrification leading to higher ammonia values through denitrification.

Nitrites are an intermediary unstable product of nitrification and denitrification alongside ammonia and nitrates. Its concentration however is usually low in surface waters due to its instability (Svobodova *et al.,* 1993). This was also observed during the study period where the nitrite values recorded were relatively low ranging between 0.27 and 1.81 µg/l. High nitrite concentrations are usually recorded when the stage of nitrite oxidation to nitrate during nitrification is inhibited by bactericidal chemicals in the water (Svobodova *et al*., 1993). Nitrates are the final product of nitrification and are also found in low concentrations in surface waters. Total phosphorous values during the study period were higher in the two hot springs compared to that of the lake and this may be attributed to the constant resuspension of particles in the water column as the water flows from the source to Lorwai Swamp. In the lake, phosphorous settles down to the bottom where it is bound to the sediments thus the lower values recorded.

4.5.2 Parasite component communities recovered from *O. niloticus baringoensis* in the hot springs of Lorwai Swamp and Lake Baringo

The only protozoan parsite recovered during this study from the *O. niloticus baringoensis* in Lake Baringo; *Trichodina* sp. had a low mean intensity and abundance. Less decomposing organic matter in the lake as a result of the dilution of the waters due to heavy rains may have led to the low mean intensity and abundance of *Trichodina* sp. According to Öğüt and Palm (2005) infestation parameters by trichodinid parasites could be used to indicate levels of organic pollution. High mean infestation parameters by trichodinid parasites positively correlate to high levels of organic pollution in a particular water system.

Five digenean parasites were recovered during the study; *Clinostomum* sp., *Euclinostomum* sp., *Heterophyes* sp., *Neascus* sp. metacecariae and *Tylodephys* sp. *Clinostomum* sp. was present in the three sites and was the dominant parasite in Lake Bogoria Spa spring and Chelaba spring. They were mostly located on the skin and behind the gills as yellow cysts. *Clinostomum* sp. have a complex life cycle (Paperna, 1996) with its larval stages found in various muscles of the fish and piscivorous birds as definitive hosts (Pozza *et al*., 2018). Therefore, the high mean intensity and abundance recorded in Lake Bogoria Spa spring and Chelaba spring is attributed to the conducive environment for the completion of the life cycle within Lorwai Swamp ecosystem due to presence of piscivorous birds. *Euclinostomum* sp. was recorded from the kidney of *O. niloticus baringoensis* from Lake Baringo and they appeared encysted as black cysts, an observation that was similar to a study on farm reared fish by Otachi (2009). According to Paperna (1996) large infestation of *Euclinostomum* sp. in young fish may lead to mortality. *Heterophyes sp*. was found in both Lake Baringo and Lake Bogoria Spa spring in low abundance. *Tylodelphys* sp. whose prevalence was high and only present in Lake Baringo was observed to be rapidly moving within the vitreous humour of the eyes. Occurrence of *Tylodelphys* sp. in the Eastern Rift valley region has been documented before with recordings being made from Lake Naivasha (Otachi *et al*., 2015), Lake Baringo (Gumpinger, 2016) and from various aquaculture farms in Kenya, Uganda and Ethiopia (Florio *et al*., 2009). Compared to their counterpart (*Diplostomum sp*.), the effects of *Tylodelphys* sp. in *O. niloticus* are yet to be established (Otachi, 2009). The “Black spot” were mainly located on the skin and fins of the fish from Lake Baringo. These parasites (*Neascus* sp. metacecariae) have been observed in aquaculturally grown fish in Kenya (Otachi, 2009) and high infestations in young fish have been observed to lead to stress, weight loss and mortality (Baker and Frank, 1985).

Cichlidogyrus sclerosus was found in all the three sites with Lake Baringo having the highest prevalence, mean intensity and abundance. The high infection parameters recorded by *C. sclerosus* may be a result of overcrowding of the *O. niloticus baringoensis* in the lake leading to a direct transmission of the *C. sclerosus* from one host to the next. Rindoria *et al.* (2016) documented the occurrence of *C. halli*, *C. tilapiae*, *C. sclerosus* and *Scutogyrus gravivaginus* from *O. leucostictus* and *O. niloticus* from Lake Naivasha while Gumpinger (2016) also recorded the occurrence of one species from the genus *Dactylogyrus* from *O. niloticus baringoensis* in Lake Baringo.

Contracaecum sp. was found within the intestines, visceral cavity and gill arch with a high prevalence and abundance in Lake Baringo. The high prevalence may be indicative of the presence of the first intermediate host (zooplanktons) in the waters (Zander, 1998). Presence of piscivorous birds in the lake was also another indicator of the high prevalence because they are the definitive hosts to *Contracaecum* sp. (Florio *et al*., 2009). There are earlier records on the infestation of *Contracaecum* sp. in fish in East African lakes including Lakes; Baringo, George, Naivasha, Nakuru, Magadi and Victoria (Paperna, 1974; Malvestuto and Ogambo-Ongoma, 1978).

Amirthalingamia macracantha was found along the intestinal walls of the fish. Most of the fish from Lake Baringo were heavily infested with the parasites occurring as encysted plerocercoids along the intestinal walls. The high prevalence of *A. macracantha* could be attributed to the feeding behaviour of the fish on zooplankton which are intermediate hosts to the parasite (Florio *et al*., 2009). This was similar to the findings of Aloo (2002) in *Tilapia zillii* and *O. leucostictus* from Lake Naivasha and Otachi (2009) in farm reared *O. niloticus* in the Central and Eastern regions of Kenya. Parasitic *Argulus* sp. (crustaceans) were observed in the gill chamber and skin of the fish from Lake Baringo. In high infestations they damage the gill tissue which leads respiratory complications to the fish evidenced by large amounts of watery mucus on the gills and may result into death (Steckler and Yanong, 2012). Incidences and infestations of *Argulus* sp. tend to be high during warmer periods (Steckler and Yanong, 2012). A previous study by Gumpinger (2016) recorded similar parasite species to those recovered during this study.

4.5.3 Relationship between selected water quality parameters and parasite prevalence levels

In general, some parasites were positively correlated with some water quality parameters, for example; temperature, pH and EC showed a positive correlation with *A. macracantha*, *Euclinostomum* sp. and *Trichodina* sp., *Contracaecum* sp. showed a positive correlation with temperature while *C. sclerosus* showed a positive correlation with DO. Nitrogen compounds (NH_4, NO_2, NO_3 and TN) showed a positive correlation with *Clinostomum* sp. in Chelaba spring and with *A. macracantha*, *Clinostomum* sp., *Contracaecum* sp., *Tylodelphys* sp., *Argulus* sp. and *Neascus* sp. metacecariae in Lake Baringo. *Euclinostomum* sp., *Trichodina* sp., *Heterophyes* sp. and *C. sclerosus* also showed a positive correlation with TP in Lake Baringo. Other parasites were negatively correlated with some water quality parameters, for example; *Clinostomum* sp. showed a negative correlation with DO in all the three sites while *Argulus* sp., *Tylodelphys* sp. and *Neascus* sp. metacecariae also indicated a negative correlation with DO in Lake Baringo.

Temperature showed a positive correlation with *Contracaecum* sp. in Lake Bogoria spa spring and Lake Baringo. This was in agreement with the study by Yanong (2002) which indicated that temperature also had an effect on the development and establishment of *Capillaria pterophylii* infecting Gouramis fish in which it was reported that there were high developmental rates of nematode larvae and infections with high temperatures. In turn temperature also has an influence on the motility of nematode larvae and their dispersion (Levsen *et al*., 2017). This means that the higher the temperatures in a water body, the faster the motility of the larvae leading to higher infection rates and this is in agreement with our study.

Amirthalingamia macracantha showed a positive correlation with temperature in Lake Baringo. *A. macracantha* have an indirect life cycle and utilize the presence of at least one other intermediate host before infecting the fish. These results from Lake Baringo were therefore in line with the findings by Khan (2012) which showed that temperatures have an effect on the occurrence and abundance of intermediate hosts. Warm temperatures tend to favour the occurrence of intermediate hosts thus increasing the number of parasites (Lõhmus and Björklund, 2015). The positive correlation between *A. macracantha* and EC in Lake Baringo may be due to the high phytoplankton productivity of the lake due to external inputs and internal processes taking place in the lake like decomposition. High phytoplankton productivity also means that the chlorophyll-*a* concentrations in the lake were also high. Sreenivasan (1976) documented that there is a positive correlation between the EC of water and its productivity which leads to a stable food chain in the water body. This in turn leads to a proliferation in the population of the intermediate hosts and abundance of the infective stages of the parasites (Bhatnagar and Devi, 2013).

The prevalence of *C. sclerosus* showed a positive correlation with DO in all the three sites. Being monogeneans, *C. sclerosus* have a direct life cycle hence are transmitted directly from one host to the next. High levels of DO in the water increases the fish motility and interaction with other fish (Ngugi *et al*., 2007) and this accelerates the transfer of *C. sclerosus* from one individual to another. Findings from our study agree with a study by Bauer (1961) which indicated that the prevalence and mean abundance of monogeneans increased with low temperatures when the DO concentration was high. However, the effect of DO concentrations differs among different monogenean species and according to Paredes-Trujillo *et al.* (2016) low DO concentrations lead to an increase in the prevalence and mean abundance of monogenean parasites. Some of the monogenean parasites recovered during the study by Paredes-Trujillo *et al*. (2016) from farm reared *O. niloticus* in Mexico included; *C. sclerosus*, *C. tilapiae*, *C. dossoui*, *C. longicornis*, *C. quaestio*, *C. halli* and *Gyrodactylus cichlidarum* exclusively in the gills and *Enterogyrus malmbergi* in the intestines.

The nutrients parameters showed a positive correlation with most of the parasites like *A. macracantha, C. sclerosus, Clinostomum* sp., *Contracaecum* sp., *Tylodelphys* sp., *Argulus* sp. and *Neascus* sp. metacecariae. Increase in nutrients in the water translates to the productivity of the system; leading to a stable food chain and thus an increase in the population of the intermediate hosts and abundance of the infective stages of the parasites (Bhatnagar and Devi, 2013). High nutrient levels in a water body also leads to detetioration of the water quality making the fish weak and predisposes them to parasitic attacks and infections (Sures, 2004).

Clinostomum sp. which also have an indirect life cycle showed a negative correlation with DO. Water temperatures tend to have a strong negative correlation with DO concentrations (Wetzel, 2001) and high temperatures tend to increase the release rate of the infective parasitic stages (Yanong, 2002; Khan, 2012; Lõhmus and Björklund, 2015). The prevalence of *Argulus* sp. in Lake Baringo negatively correlated to DO concentrations. High temperatures (and low DO concentrations) have a huge impact on the recruitment time and development of *Argulus* sp. (Steckler and Yanong, 2012). Koyun (2011) documented that an increase in water temperatures and consequently the decrease in DO increases the infestation pressure of *Argulus foliaceus* on *Alburnus alburnus*, *Carrasius auratus* and *Carrasius carrasius* thus harming the fish.

4.6 Conclusion

There was similarity in the species of parasites recovered from the three sites evidenced by the presence of *Cichlidogyrus sclerosus*, *Clinostomum* sp., *Contracaecum* sp. and *Heterophyes* sp. In the three sites and the difference in the infection parameters of the recovered parasites among the three sites was significant. Most of the water quality parameters fell within the acceptable range for the growth and well-being of *O. niloticus baringoensis*. However, the water in the hot springs of Lorwai Swamp was of a better quality than that of Lake Baringo. This is evidenced by the higher parasite species recovered from the fish in Lake Baringo than in Lake Bogoria Spa spring and Chelaba spring. Trematode parasites dominated the three sites with *Clinostomum* sp. (digenean) being dominant in Lake Bogoria Spa spring and Chelaba spring while *C. sclerosus* (monogenean) was dominant in Lake Baringo. *C. sclerosus* had the highest prevalence while *A. macracantha* had the highest mean intensity and abundance among all the parasites that were recovered. There was also a relationship between some selected water quality parameters and the prevalence of parasites recovered from *O. niloticus baringoensis* in the hot springs of Lorwai Swamp and Lake Baringo.

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CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

i. For specific objective 1, the length-weight relationship of *O. niloticus baringoensis* in the hot springs indicated that the fish population in them had a good growth ratio evidenced by their isometric growth (b =3). Despite the high temperatures in the hot springs, the Fulton's condition values also indicated that the population is healthy and in good condition.

ii. For specific objective 2, there were both positive and negative correlations between some selected water quality parameters and the prevalence of some parasites infecting *O. niloticus baringoensis* in the hot springs of Lorwai Swamp and Lake Baringo.

    Some parasite species like *Heterophyes* sp. (Digenean Trematode) and *Contracaecum* sp. (Nematode) which have been documented to be zoonotic were recovered during the study and may pose a health hazard to the fish consumers if the fish is not well prepared and cooked.

5.2 Recommendations

i. Since the *Oreochromis niloticus baringoensis* in the hot springs showed very good condition despite the stressful environment with low DO and high temperatures, this study recommends that programmes should be developed to incorporate this strain of *O. niloticus baringoensis* in aquaculture production.

ii. Water quality should be continuously monitored and improved through Catchment management strategies. The local human communities and factories like the donkey abattoir in Mogotio should exercise proper waste disposal. Lastly, communities depending on the fish for food should be sensitized on presence of the parasites, proper handling and preparation of fish before consumption.

APPENDICES

Appendix 1: Research permit granted by the National Commission for Science, Technology and Innovation (NACOSTI)

THIS IS TO CERTIFY THAT:
MISS. STEPHANIE WANGARE KAMAU ADAMBA
of EGERTON UNIVERSITY, 536-20115 NAKURU,has been permitted to conduct research in *Baringo County*

Permit No : NACOSTI/P/19/73132/27709
Date Of Issue : 21st February,2019
Fee Recieved :Ksh 1000

on the topic: *EVALUATION OF THE PARASITE COMMUNITIES OF OREOCHROMIS NILOTICUS (L.) IN RELATION TO SELECTED WATER QUALITY PARAMETERS IN THE SPRINGS OF LOBOI SWAMP AND LAKE BARINGO, KENYA*

for the period ending:
21st February,2020

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

Appendix 2: Key data analysis outputs

1. **Principal Component Analysis for parasite prevalences and selected water quality parameters for Lake Bogoria Spa spring**

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	12.857	80.355	80.355	12.857	80.355	80.355	11.238	70.236	70.236
2	2.122	13.262	93.617	2.122	13.262	93.617	2.805	17.534	87.770
3	1.021	6.383	100.000	1.021	6.383	100.000	1.957	12.230	100.000
4	1.366E-15	8.538E-15	100.000						
5	4.773E-16	2.983E-15	100.000						
6	3.383E-16	2.114E-15	100.000						
7	2.880E-16	1.800E-15	100.000						
8	1.725E-16	1.078E-15	100.000						
9	1.254E-16	7.835E-16	100.000						
10	2.819E-17	1.762E-16	100.000						
11	-4.968E-17	-3.105E-16	100.000						
12	-1.111E-16	-6.942E-16	100.000						
13	-1.944E-16	-1.215E-15	100.000						
14	-2.898E-16	-1.812E-15	100.000						
15	-3.507E-16	-2.192E-15	100.000						
16	-5.587E-16	-3.492E-15	100.000						

Extraction Method: Principal Component Analysis.

2. **Principal Component Analysis for parasite prevalences and selected water quality parameters for Chelaba spring**

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.698	59.216	59.216	7.698	59.216	59.216	7.381	56.779	56.779
2	5.302	40.784	100.000	5.302	40.784	100.000	5.619	43.221	100.000
3	5.078E-16	3.906E-15	100.000						
4	2.544E-16	1.957E-15	100.000						
5	2.383E-16	1.833E-15	100.000						
6	1.994E-16	1.534E-15	100.000						
7	6.595E-17	5.073E-16	100.000						
8	-3.811E-17	-2.931E-16	100.000						
9	-7.743E-17	-5.956E-16	100.000						
10	-1.869E-16	-1.438E-15	100.000						
11	-2.794E-16	-2.149E-15	100.000						
12	-3.819E-16	-2.938E-15	100.000						
13	-4.875E-16	-3.750E-15	100.000						

Extraction Method: Principal Component Analysis.

3. **Principal Component Analysis for parasite prevalences and physico-chemical parameters for Lake Baringo**

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9.072	53.365	53.365	9.072	53.365	53.365	8.751	51.476	51.476
2	4.980	29.296	82.661	4.980	29.296	82.661	4.931	29.005	80.481
3	2.948	17.339	100.000	2.948	17.339	100.000	3.318	19.519	100.000
4	5.514E-16	3.244E-15	100.000						
5	3.502E-16	2.060E-15	100.000						
6	3.113E-16	1.831E-15	100.000						
7	2.764E-16	1.626E-15	100.000						
8	2.175E-16	1.279E-15	100.000						
9	8.517E-17	5.010E-16	100.000						
10	3.407E-17	2.004E-16	100.000						
11	-4.590E-17	-2.700E-16	100.000						
12	-7.336E-17	-4.315E-16	100.000						
13	-1.946E-16	-1.145E-15	100.000						
14	-2.547E-16	-1.498E-15	100.000						
15	-2.985E-16	-1.756E-15	100.000						
16	-3.580E-16	-2.106E-15	100.000						
17	-6.049E-16	-3.558E-15	100.000						

Extraction Method: Principal Component Analysis.

4. **Principal Component Analysis for parasite prevalences and nutrient parameters for Lake Baringo**

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.148	47.931	47.931	8.148	47.931	47.931	7.647	44.983	44.983
2	4.982	29.305	77.237	4.982	29.305	77.237	5.443	32.016	76.998
3	3.870	22.763	100.000	3.870	22.763	100.000	3.910	23.002	100.000
4	3.865E-16	2.273E-15	100.000						
5	3.369E-16	1.981E-15	100.000						
6	2.624E-16	1.544E-15	100.000						
7	1.976E-16	1.162E-15	100.000						
8	1.283E-16	7.547E-16	100.000						
9	6.868E-17	4.040E-16	100.000						
10	3.666E-17	2.157E-16	100.000						
11	-1.078E-17	-6.338E-17	100.000						
12	-8.145E-17	-4.791E-16	100.000						
13	-1.672E-16	-9.834E-16	100.000						
14	-2.185E-16	-1.286E-15	100.000						
15	-2.511E-16	-1.477E-15	100.000						
16	-2.723E-16	-1.602E-15	100.000						
17	-4.140E-16	-2.435E-15	100.000						

Extraction Method: Principal Component Analysis.

5. **Rotated Component Matrix for the Principal Component Analysis for parasite prevalences and selected water quality parameters for Lake Bogoria Spa spring**

Rotated Component Matrix[a]

	Component		
	1	2	3
pH	.992		
Cichlidogyrus sp	-.992		
TN (mg/l)	.989		
Microsporidia sp	.983		
NO2-N (mg/l)	.973		
EC (µS/cm)	.965		
SRP (mg/l)	.953		
Chl-a (µg/l)	.907	.361	
TP (mg/l)	.896	.406	
NH4-N (mg/l)	.874	.416	
Turbidity (NTU)	.853	.387	.351
DO (mg/L)	-.835	-.430	-.345
NO3-N (mg/l)	-.700	-.423	-.576
Heterophyes sp		-.999	
Temp (°C)	.486	.784	.385
Clinostomum sp			.994

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

6. **Rotated Component Matrix for the Principal Component Analysis for parasite prevalences and selected water quality parameters for Chelaba spring**

Rotated Component Matrix[a]

	Component	
	1	2
Temp (°C)	-1.000	
Turbidity (NTU)	-1.000	
NO3-N (mg/l)	.998	
Clinostomum sp	.998	
NO2-N (mg/l)	.949	-.314
NH4-N (mg/l)	.940	.340
Cichlidogyrus sp	.766	.643
TP (mg/l)		-.967
SRP (mg/l)		-.957
TN (mg/l)	.351	.936
pH	-.352	.936
Chl-a (µg/l)	-.488	-.873
DO (mg/L)	.618	.786

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

7. **Rotated Component Matrix for the Principal Component Analysis for parasite prevalences and physico-chemical parameters in Lake Baringo**

Rotated Component Matrix[a]

	Component		
	1	2	3
EC (µS/cm)	-.997		
DO (mg/l)	.993		
Temp (°C)	-.993		
pH	-.993		
Chl-a (µg/l)	.990		
NTU	.982		
Neascus metacecariae	.908		-.367
Tylodelphys sp	.833	.532	
Argulus sp		.928	.345
Armithalingamia macacantha		.909	-.408
Clinostomum sp	.546	.834	
Trichodina sp	-.464	.814	.349
Microsporidia sp		-.794	.550
Euclinostomum sp	-.614	.721	-.322
Contracaecum sp			-.985
Cichlidogyrus sp			.952
Heterophyes sp	-.528	-.531	.663

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

8. **Rotated Component Matrix for the Principal Component Analysis for parasite prevalences and nutrient parameters for Lake Baringo**

Rotated Component Matrix[a]

	Component		
	1	2	3
NO3-N (mg/l)	.996		
NH4-N (mg/l)	.992		
TN (mg/l)	.984		
NO2-N (mg/l)	.983		
SRP (mg/l)	.969		
Neascus metacecariae	.898		-.439
Tylodelphys sp	.807	.589	
Armithalingamia macacantha		.999	
Microsporidia sp		-.953	
Clinostomum sp	.513	.829	
Heterophyes sp	-.481	-.764	.430
Euclinostomum sp	-.652	.758	
Argulus sp		.739	.663
TP (mg/l)			.967
Cichlidogyrus sp	.301		.933
Microsporidia sp		.523	-.848
Trichodina sp	-.477	.602	.640

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

Appendix 3: Publication (Some Aspects of *Oreochromis niloticus baringoensis* (Trewavas, 1983) Fishery Assessment and Influence of Selected Water Quality Parameters in the Hot Springs of Lorwai Swamp, Baringo, Kenya

Some Aspects of *Oreochromis niloticus baringoensis* (Trewavas, 1983) Fishery Assessment and Influence of Selected Water Quality Parameters in the Hot Springs of Lorwai Swamp, Baringo, Kenya

***Adamba, S. W. K., Otachi, E. O. and Ong'ondo, G. O.**
Biological Sciences Department, Egerton University
P. O. Box, 536-20115, Egerton, Kenya
Running title: Fishery assessment of Tilapias in hot water springs
**Corresponding Author: wangaresteph@gmail.com*
Tel No: +254727140939

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Abstract

Water quality has been documented to affect the biology and well-being of fish. This study therefore investigated some aspects of *Oreochromis niloticus baringoensis* (Trewavas, 1983) fishery assessment and the influence of selected water quality parameters in two hot springs draining into Lorwai Swamp; Lake Bogoria Spa spring and Chelaba spring between the months of July and August 2018. A total of 445 fish were collected; 244 from Lake Bogoria Spa spring and 201 from Chelaba spring using a seine net. Length Weight Relationship (LWR) was determined using Le Cren's equation; $W=aTL^b$ and Fulton's condition factor (k) determined using Ricker's equation; $100W/L^3$. The LWR results indicated an isometric growth for fish from both springs. The mean (± SD) k-values for fish in Lake Bogoria Spa spring were 2.02±0.25 for the males, 2.02±0.27 for the females and 2.00±0.26 for both sexes. In Chelaba spring, the mean k-values were 2.03±0.21 for the males, 1.97±0.25 for the females and 2.00±0.23 for both sexes. These values indicated that the fish in these hot springs are in a very good condition and health status with k-values above 1. Some of the selected water quality parameters indicated a positive correlation with the length, weight and Fulton's condition factor of *O. n. baringoensis* in the two hot springs.

Keywords: Condition factor, hot springs, length-weight relationship, Lorwai Swamp, *Oreochromis niloticus baringoensis*, water quality

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