




Levels of heavy metals in the straightfin barb *Enteromius paludinosus* (Peters 1852) from River Malewa, Naivasha, Kenya

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Abstract There have been several studies on heavy metals in Lake Naivasha. However, none of them has reported the levels of mercury (Hg), arsenic (As), and chromium (Cr). Moreover, there are no studies on the heavy metals' concentrations in the straightfin barb (*Enteromius paludinosus*, Peters 1852), a fish species that hosts a parasite (*Ligula intestinalis*), the latter having been reported to have a high ability to absorb heavy metals from its host. This paper therefore addresses the accumulation of heavy metals, namely arsenic (As), chromium (Cr), lead (Pb), and mercury (Hg) in the tissues of straightfin barb, *Enteromius paludinosus* (Peters 1852) from the mouth of River Malewa in Lake Naivasha, Kenya. A total of 1307 fish were collected during the month of November 2017. Water samples, sediment samples, 25 fish muscle tissues, and its endoparasite, the cestode *Ligula intestinalis*, were isolated, and heavy metal concentrations were determined using the thermal-electron atomic absorption spectrophotometer at the Lake Nakuru Water Quality Testing Laboratory. The concentrations of heavy metals in the sediment were below the lowest effect level in sediment, threshold effect concentration in sediment, severe effect concentration in sediment, and the shale values of sedimentary rocks thus showing no sign of pollution. In the muscle tissues of the fish, As, Cr, Pb, and Hg showed high levels with mean concentrations of 5.0696, 22.0854,

45.2108, and 1.5458 mg/kg ww, respectively. Bioconcentration factors further supported the observation that trace element accumulation was higher in fish compared with sediment and water. The target hazard quotients of As, Cr, Pb, and Hg obtained for both the female and male were > 1 indicating a possible health risk associated with the consumption of *E. paludinosus*. The bioaccumulation factors (BAFs) for *L. intestinalis* were 2.4093, 2.1873, 5.8601, and 5.1395 for As, Cr, Pb, and Hg, respectively, indicating the potential of the cestode in the accumulation of heavy metals from the host; hence, it can be used as an accumulation bioindicator.

Keywords Fish parasites · Bioconcentration factor (BCF) · Lake Naivasha · Target hazard quotient (THQ) · *Ligula intestinalis* · Bioaccumulation factor (BAF)

Introduction

Heavy metals are natural components of aquatic ecosystems (Tayab 1991; Ochieng et al. 2007). However, several human activities such as agricultural, mining, industrial, and domestic use among others have increased their levels in the aquatic environments (Kamau et al. 2008). Aquatic organisms can be affected by elevated levels of heavy metals in their environment especially when they occur above threshold concentrations (Ochieng et al. 2007). Some of these heavy metals bioaccumulate in various organs of aquatic organisms (Martin 1979) and may have lethal effects (Eisler 1973).

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Bioaccumulation occurs when metal concentrations exceed the fish's capacity to regulate (Streit 1998). When such contaminated fish are consumed by human beings, they pose a risk to their health and have been recognized as one of the top threats to human health (McCortor and Becker 2013). For this reason, several studies have been conducted in various aquatic ecosystems in Kenya. For example, in Lake Naivasha, despite being a Ramsar site and a world heritage site, it is perceived to be heavily impacted by anthropogenic activities, resulting to a number of investigations on heavy metals (Ochieng et al. 2007; Mutia et al. 2012; Otachi et al. 2014; Yang et al. 2017; among others).

Ochieng et al. (2007), Mutia et al. (2012), Otachi et al. (2014), and Yang et al. (2017) described in their studies that there were elevated levels of heavy metals such as aluminum (Al), iron (Fe), manganese (Mn), zinc (Zn), rubidium (Rb), copper (Cu), cadmium (Cd), and lead (Pb) in the water, sediments, and fish. However, none of the studies has investigated Hg, As, and Cr. These three heavy metals together with Pb are considered the top four threats to human health (McCortor and Becker 2013). Furthermore, there are no studies on the heavy metals' concentrations in the straightfin barb (*Enteromius paludinosus*, Peters 1852), a fish species that hosts a parasite (*Ligula intestinalis*), the latter having been reported to have a high ability to absorb heavy metals from its host (Oyoo-Okoth et al. 2010). *E. paludinosus* is a benthopelagic fish species which is small in size (maximum size 15 cm standard length), and occupies habitats such as large rivers, lagoons which are either connected or isolated from their main river channels, and streams (small or large) (Tweddle and Skelton 2008). This fish species is a subsistence source of proteins especially for artisanal fishers and their dependents (Aloo et al. 2013). The aim of this study was to determine the concentrations of THg, Pb, Cr, and As in the fish tissues and associated parasites of *E. paludinosus* from Lake Naivasha, Kenya, and assesses potential health risks for fish consumers around Lake Naivasha.

Materials and methods

Study area

Sampling was undertaken at the Mouth of River Malewa (0.714622° S 36.362709° E) in Lake

Naivasha (Fig. 1) in the month of November 2017. The study site has been significantly described by Gaudet and Melack (1981), Hickley et al. (2002), Kitaka et al. (2002), Otachi et al. (2014), and Odongo et al. (2015), among many others. In the year 1995, Lake Naivasha was declared a Ramsar site giving it an international importance due to its freshness and diverse ecology (LNRA 1999). Activities in the catchment include agriculture (mainly the flower farms), production of geothermal power, tourism, recreation, and fishing for commercial purposes (Harper et al. 2002). This has consequently resulted to environmental problems such as water extraction resulting in water level alterations, contamination, eutrophication, and alien species, and also decline in fish stocks including biodiversity as a whole (Harper et al. 2011).

Collection of water and sediment samples

Measurements of dissolved oxygen, temperature, conductivity, and pH were taken in situ as described by APHA (2012), at approximately 10 cm beneath the water surface from the sampling site using a multi-probe water quality meter (Model Multi HQ40d, USA). Following the standard methods for water and wastewater examination (APHA 2012), 500 mL of water sample was collected from similar depth by dipping the bottle, lifting it up, and then filtered straight away by a filter pump fitted with Whatman GFC filters into a plastic bottle. 2.5 mL of concentrated nitric acid (analytical grade) was then added to the filtrate to avoid precipitation of the metals and adsorption at the surface of the bottles. According to the procedure by IAEA (2003), a stainless Ekman grab sampler was used to collect a sediment sample carefully taking the sample that had not touched the metallic parts of the Ekman grab sampler to avoid contamination. The sample was then put in a plastic sample vial, which was then placed inside a cool box and carried to a research laboratory at the Department of Biological Sciences, Egerton University. The water and sediment samples were then stored in the refrigerator at a temperature of $-20\text{ }^{\circ}\text{C}$ in the laboratory and later transported to the Lake Nakuru Water Quality Testing Laboratory (WQTL) for heavy metal determination after 3 days.

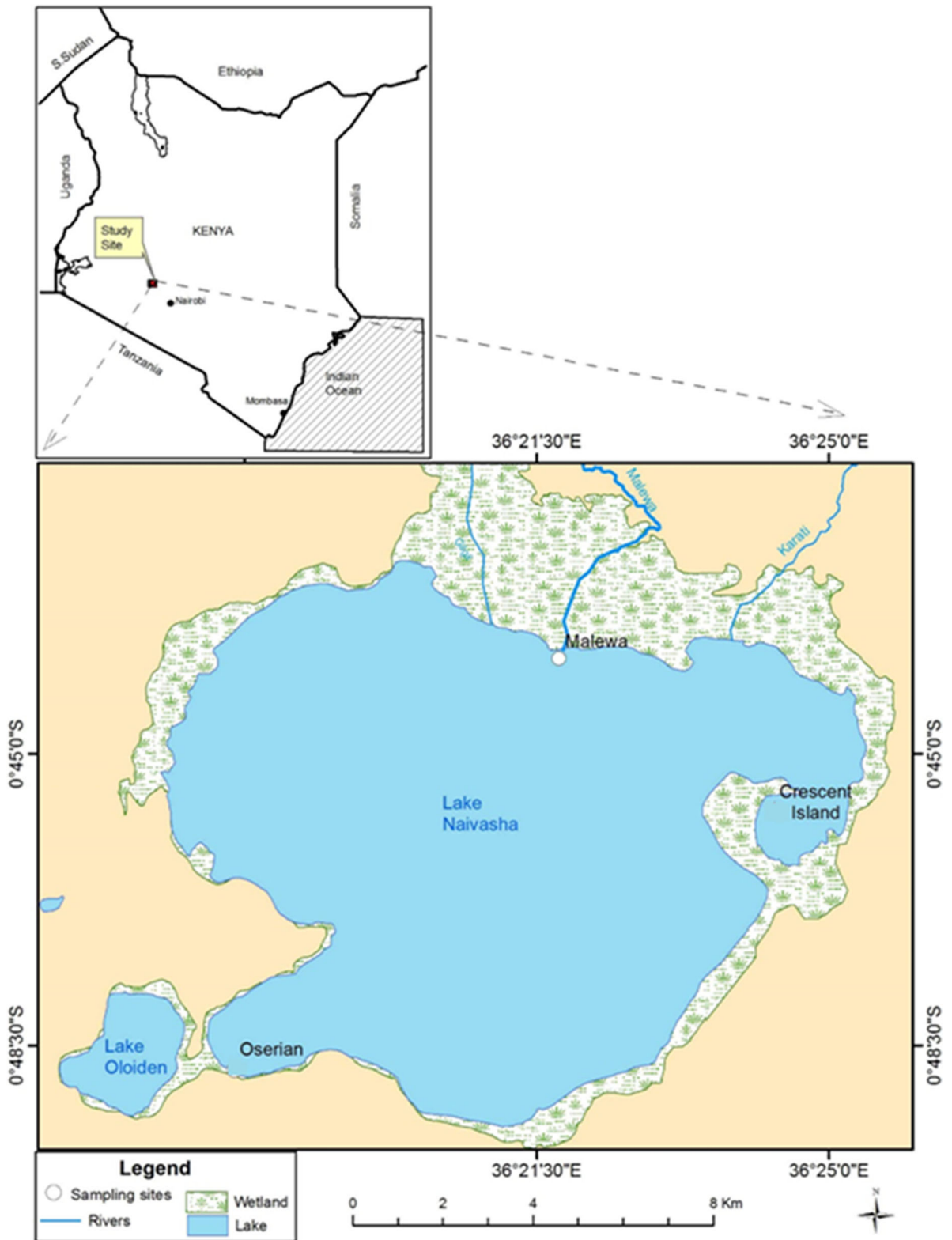


Fig. 1 Map of Lake Naivasha showing the sampling point

Fish sample collection and preparation

One thousand three hundred seven *E. paludinosus* were captured by the fishermen following the procedure by the Environmental Protection (Water) Policy (2009) with the use of seine nets of a mesh size of 1.2 mm from the mouth of River Malewa, placed inside water tanks with sufficient air, and later transported alive to a research laboratory at the Department of Biological Sciences, Egerton University. In the laboratory, the fish were killed humanely through cervical disconnection. This was followed by taking of the measurements of the total lengths (TLs) in centimeters (cm) using a measuring board following the description by Weber and Govett (2009). Thereafter, the weights of the fish were measured in grams (g) using an electronic weighing scale (Model ED 4202S, Sartorius AG, Germany). Dissection was then carried out following standard measures in parasitological analyses (Florio et al. 2009). The cestode *Ligula intestinalis* was picked from the body cavity of the fish as described by Weber and Govett (2009) using plastic forceps. The parasites were placed inside plastic vials after washing them carefully with double distilled water and then stored in the refrigerator at a temperature of $-20\text{ }^{\circ}\text{C}$ for heavy metal determination. The fish tissues (0.2 g) were obtained using a ceramic knife and plastic tweezers, cleaned with double distilled water, placed inside plastic vials, and then stored in the refrigerator for heavy metal determination. An image of *L. intestinalis* and *E. paludinosus* is shown in Fig. 2.

Heavy metal determinations in water, sediment, fish muscle tissues, and the parasites

Water, sediment, 25 fish muscle tissues of fish (5 infected with *L. intestinalis* and 20 non-infected), and 5 samples of *L. intestinalis* were transported to Lake Nakuru WQTL for heavy metal analysis. One hundred milliliters of the water sample was measured using a clean measuring cylinder and poured into a clean beaker as described by APHA (2012) standard methods. The sample was then digested with 5 mL 69% concentrated nitric acid (analytical grade) and then diluted with 50 mL of distilled water then heated on a hot plate stirrer at $440\text{ }^{\circ}\text{C}$ in a fume hood for 1 h until the volume was reduced to approximately 25 mL. Thereafter, it was allowed to cool. After cooling, the sample was filtered to a final volume of 100 mL using Whatman 150 mm

dia No. 41 filter paper by washing out with distilled water into a 100-mL volumetric flask ready for heavy metal analysis. The sediment sample was mixed evenly by pounding with pestle in a mortar then 2 g weighed, digested, and diluted same as the water sample. Similar procedure was followed for the fish tissues (0.2 g) and parasites (0.1 g). The processed samples (of water, sediment, fish muscle tissues, and the cestode) were then taken to the thermal-electron absorption spectrophotometer (AAS-S series, UK) for heavy metal analysis. The concentrations of the metals were determined in triplicate in order to check the accuracy of the instrument. After every five samples, both a standard and a blank sample were run to check instrumental drift. A serial dilution of a working solution (100 mg/L) made from analytical grade stock solutions (1000 mg/L) acquired from Merck KGaA, Germany, was used to prepare standards for instrument calibration. The calibration curve method was used to determine the concentrations of heavy metals in the samples. To get the recovery rates for each heavy metal, one extra sample from the water, sediment, fish muscle tissue, and parasite was spiked. The recovery rates shown were 96% for As, 105% for Hg, 98% for Cr, and 99% for Pb which were all within the recommended range.

Bioconcentration and bioaccumulation factors

Following the method by Abel (1989), the bioconcentration factors (BCFs) were computed to determine both the ratio in concentrations of heavy metals between fish and environment (sediment and water) and partitioning of heavy metals between the dissimilar samples. BCF calculations were done using the mean concentration values of the respective heavy metals present in the water, sediment, and fish muscle. The BCF was determined using a formula by Abel (1989) as follows:

$$\text{BCF} = C(\text{fish muscle})/C(\text{water}) \quad (1)$$

$$\text{BCF} = C(\text{fish muscle})/C(\text{sediment}) \quad (2)$$

where C stands for mean concentration. $C(\text{fish muscle})$ and $C(\text{sediment})$ were measured in milligram per kilogram wet weight, while $C(\text{water})$ was measured in milligrams per liter.

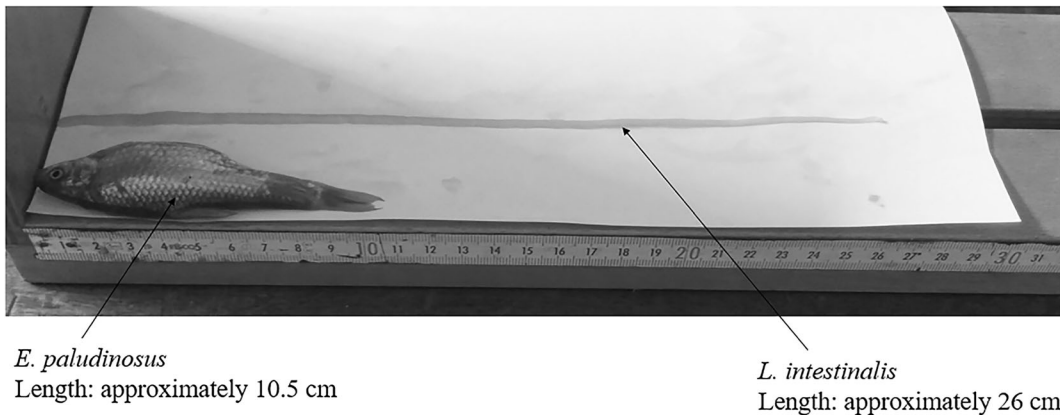


Fig. 2 Photograph of *E. paludinosus* alongside its endoparasite, *L. intestinalis*

A formula by Drexler et al. (2003) was used to determine the bioaccumulation factors (BAFs) as follows:

BAF (x/y)

= heavy metal concentration in x /heavy metal concentration in y

whereby x and y variables represent matrices that are compared together, in this case, parasites (x) and fish muscle (y).

Risk assessment

To evaluate the health hazard brought about by the heavy metals to individuals who consume *E. paludinosus* in the region, the target hazard quotients (THQs) for heavy metals were established. According to USEPA (2012), THQ is defined as the ratio between the possible exposure to a substance and the reference dose, that is, the level at which no antagonistic effects are probable. A THQ of > 1 indicates a potential health risk to the health of fish consumers, whereas that of ≤ 1 indicates no important health risk concerning the heavy metals of interest. USEPA (2012) additionally proposed a THQ of 0.1 for noncarcinogens to rationalize additive effects. The THQ was calculated using the USEPA (2012) equation:
$$\text{THQ} = \frac{C \times \text{EDr} \times \text{EFr} \times \text{IRFa}}{\text{BWa} \times \text{AT} \times \text{RfDo}}$$

where C is the concentration of heavy metal in the edible part of fish (milligrams per kilogram wet weight (ww)), EDr is the exposure duration (30 years), EFr is the exposure frequency (350 days/year), IRFa is the fish consumption per day (0.0123 kg/day) because the per capita is 4.5 kg/year in Kenya (KMFRI report 2017), BWa is the body weight of an adult male (64.9 kg) and female (61.7), for Kenya (WorldData, n.d.), AT is the averaging time for noncarcinogens (365 days/year), and

RfDo is the reference dose, oral (milligrams per kilogram per day, according to the updated 2017 Regional Screening Level (RSL) in the fish ingestion table (USEPA 2017)). Moreover, the concentrations of heavy metals (mean) were compared with FAO/WHO and EU recommended values.

Data analysis

The concentrations of heavy metals in the samples were presented as mean with standard deviation (mean \pm standard deviation). The differences in mean concentrations of heavy metals between the fish and the parasite were tested using Student's t test.

Results

Physicochemical parameters

The physicochemical parameters recorded on the sampling date for temperature ($^{\circ}\text{C}$), pH, dissolved oxygen (mg/L), dissolved oxygen saturation (% sat), and conductivity ($\mu\text{S}/\text{cm}$) were 18.16, 7.9, 7.93, 106.2, and 129.44, respectively.

Heavy metal concentrations in water and sediment

Among the four heavy metals measured, two (As and Cr) were below the detection limit in the water sample as indicated in Table 1. Lead was the highest in concentration in both the water and sediment. Lead was also high in water than mercury (Table 1), while in the sediment, the order was $\text{Pb} > \text{Cr} > \text{As} > \text{Hg}$ (Table 2).

Heavy metal concentrations in *E. paludinosus*

In the fish muscle samples, Pb had the highest concentration. The order of heavy metal concentration in the muscle of *E. paludinosus* was Pb>Cr>As>Hg (Table 3).

Target hazard quotients

In both females and males, As had the highest THQ value followed by Hg then Pb, while Cr had the least. The THQ values are shown in Table 4.

Bioconcentration factors

Results of BCF values (Table 5) for heavy metals in water and sediment compared with tissues of *E. paludinosus* indicated that Pb and Hg levels were present in higher concentrations in the fish tissues compared with the water (BCF > 1). BCF could not be determined for As and Cr in water as these elements were below the detection limits of the instrumentation. Arsenic, chromium, lead, and mercury levels were also present in higher concentrations in the fish tissues compared with the sediments.

Bioaccumulation factors for heavy metals in *E. paludinosus*

Out of the 1307 fish sampled, only 5 were infected by the parasite *L. intestinalis* (prevalence = 0.4%), with only 1 cestode recorded per infected fish. *L. intestinalis* contained systematically higher concentration of all the heavy metals than the host fish obtaining mean concentration (mg/kg ww) values of 3.5423, 38.0532, 7.7970, and 1.5915 for Hg, Pb, Cr, and As, respectively, against the mean concentrations in the host fish tissues with values of 0.6892, 6.4936, 3.5646, and 0.6606 for the same, respectively. All the four heavy metals showed BAF values > 1 (Fig. 3). There were significant differences between the mean concentrations of the four heavy metals analyzed between the host and the parasite (*t* test, *p* values < 0.05).

Discussion

Physicochemical parameters of water

The values of physicochemical parameters obtained during the study were similar with those obtained by

Mutia et al. (2012) and Otachi et al. (2014) except for the pH and conductivity which were lower than those of our study. This could be attributed to the rainy season at the time of sampling as well as the location of the study site where River Malewa empties its waters into the lake. The value of pH for this study was similar to that of Njogu et al. (2011) and Ogendi et al. (2014) in Lake Naivasha. However, Ogendi et al. (2014) reported lower values for conductivity and dissolved oxygen.

Heavy metal concentrations in water

Water sample analysis revealed that most elements were present in lower concentrations compared with those in the sediment and the fish muscle tissue. The lead levels in the present study were however lower than those reported by Mutia et al. (2012) who recorded 0.17983 mg/L from the same lake. Ochieng et al. (2007) and Yang et al. (2017) on the other hand reported lower Pb concentrations than those of our study recording 0.0421 and 0.00016 mg/L, respectively, in the same lake. The comparison of concentrations of heavy metals in our study with the Kenya Bureau of Standards (KEBS 2014) and World Health Organization (WHO 2011) revealed that Pb was higher than both the KEBS natural potable water limits and WHO maximum permissible level in drinking water. Thus, it signified that the lake may be contaminated with Pb. The maximum limits for Pb are not provided by the National Environment Management Authority (NEMA 2006) quality standards for recreational waters. In this study, As and Cr were below the detection limit of instrumentation. This is contrary to the findings of Yang et al. (2017) who reported levels of As in other Kenyan Rift Valley lakes recording values of 0.0227, 0.00608, and 0.00125 mg/L in Lakes Elementaita, Nakuru, and Bogoria. Chromium was detected in Lake Elementaita but is below the detection limit in Lakes Nakuru and Bogoria (Yang et al. 2017) as well as in this study. Mercury levels were within both the KEBS natural potable water limits and NEMA standards. Compared with other Rift Valley lakes, the Pb levels recorded in the present study were higher than those of Lakes Elementaita, Nakuru, and Bogoria as reported by Yang et al. (2017).

Heavy metal concentrations in sediments

The heavy metal levels obtained during this study were compared with the lowest effect level (LEL), threshold

Table 1 Heavy metal concentrations for water samples (with lowest limits of detection (LLD)) in comparison with the WHO limits, KEBS natural potable water limits, and NEMA water

quality standards (mg/L) for recreational waters alongside other Rift Valley lakes (Yang et al. 2017)

Element	Water (mg/L)	LLD	WHO	KEBS	NEMA	Elementaita	Nakuru	Bogoria
As	B. D	0.001	0.01	0.01	0.05	0.0227	0.00608	0.00125
Cr	B. D	0.01	0.05	0.05	0.1	0.00015	N. D	N. D
Pb	0.076	0.004	0.01	0.01	–	0.00021	0.00025	0.0008
Hg	0.001	0.0005	–	0.001	0.001	0.0139	0.00286	0.0103

B. D, below detection limit; N. D, not detected

WHO, World Health Organization 2011; KEBS, Kenya Bureau of Standards 2014; NEMA, National Environment Management Authority 2006

effect concentration (TEC), severe effect concentration (SEL) in sediment, and shale values as shown in Table 2. Mutia et al. (2012) reported higher Pb levels than those of the present study, while Otachi et al. (2014) documented lower Pb levels compared with ours in the same lake. High Pb levels reported in the sediment samples could be because of contamination from the catchment. Chromium values recorded were higher than those reported by Ochieng et al. (2007). To the best of our knowledge, this is the first report of As and Hg in the sediment of this lake. All the four heavy metals had concentrations of below the LEL, TEC, SEL, and the shale values of sedimentary rocks, thus showing no sign of pollution because according to Turekian and Wedepohl (1961), it is considered as the normal background level in the Earth’s crust.

Heavy metal concentrations in *E. paludinosus* muscle tissues

Compared with the other three heavy metals (As, Cr, and Hg), Pb was the highest in mean concentration. The levels of Pb in *E. paludinosus* obtained in this study

were lower than those of Mutia et al. (2012) in the common carp (*Cyprinus carpio*) from the same lake, with a mean concentration (\pm SD) of 58.11 ± 0.050 mg/kg ww (wet weight). However, Ogendi et al. (2014) and Njogu et al. (2011) recorded low mean values of Pb in various fish from Lake Naivasha compared with the mean values in the present study. For example, Ogendi et al. (2014) reported 0.073 ± 0.002 mg/kg ww in *C. carpio*, while Njogu et al. (2011) reported 1.49, 1.56, 1.51, and 3.22 mg/kg ww in *Oreochromis leucostictus*, *C. carpio*, and *Micropterus salmoides*, respectively. From our findings, the Pb concentrations reported were above both the WHO/FAO and EU maximum permissible level and therefore not safe for human consumption as it can cause anemia, neurological damage, nerve disorders, and several other health issues (McCartor and Becker 2013). The THQ value of Pb was 61.6225 for males and 64.8184 for females indicating that female consumers of this fish from Lake Naivasha are more at risk than the males.

Our study recorded higher levels of Cr than those by Yi et al. (2011) in two fish species (*Coreius guichenoti* and *Leptobotia elongata*) where both of them had

Table 2 Heavy metal concentrations for sediment samples in comparison with sediment quality guidelines

Element	Sediment (mg/kg)	LEL	TEC	SEL	Shale
As	0.171	6.0	9.79	33.0	13
Cr	1.49	26.0	43.4	110.0	90
Pb	15.82	31.0	35.8	250.0	20
Hg	0.054	0.2	0.18	2.0	–

LEL, lowest effect level in sediment; TEC, threshold effect concentration in sediment; SEL, severe effect concentration in sediment (Buchman 2008)

Table 3 Trace element concentrations in the muscle of *E. paludinosus* fish in Lake Naivasha: values are means (mg/kg wet weight) compared with FAO/WHO and EU standards ($n = 20$)

Element	<i>E. paludinosus</i>	FAO/WHO	EU
As	5.07 ± 2.74	–	–
Cr	22.09 ± 17.90	–	–
Pb	45.21 ± 29.45	0.3	0.3
Hg	1.55 ± 1.80	0.5	0.5

Food and Agriculture Organization (FAO)/World Health Organization (WHO), (2011); European Union (EU) (2006)

Table 4 Target hazard quotients (THQs) for males and females for the four heavy metals in *E. paludinosus* fish from Lake Naivasha

RfDo		As 0.0003	Cr 0.003	Pb 0.004	Hg 0.0001
THQ	Males	92.1317	40.1366	61.6225	84.2772
	Females	96.9101	42.2183	64.8184	88.6482

RfDo, reference dose, oral according to USEPA (2017)

0.805 mg/kg ww from the middle and lower reaches of the Yangtze River basin in China. Lower mean concentrations of Cr than ours were also recorded by Ahmed et al. (2016) on five fish species from Buriganga River, Bangladesh (for example, Cr level of 18.84 ± 1.72 mg/kg ww in the muscle tissue of *Labeo rohita*). Zhang et al. (2017) also reported low levels of Cr in crucian carp (3.36 ± 0.0036 mg/kg) from Honghu Lake in China as compared with our study. The THQ value of Cr for the males was 40.1366 while that of the females was 42.2183, thus, posing more risk to the female consumers of this fish than the males. The health risks of Cr include developing reproductive and developmental problems as well as impairing of the respiratory, gastrointestinal, and immunological systems (McCartor and Becker 2013).

Total mercury concentration in *E. paludinosus* in our study was higher than that reported by Campbell et al. (2003), recording 0.081 mg/kg in the same fish from the same lake. Yi et al. (2011) also reported a lower mean concentration of THg in *Eriocheir sinensis* from the middle and lower reaches of the Yangtze River basin recording 0.054 mg/kg ww, than that of the present study. Additionally, Gbogbo et al. (2018) and Stanek et al. (2017) reported lower values (0.19 ± 0.13 and 0.27 ± 0.03 mg/kg ww) than ours in the muscles of

Chrysichthys nigrodigitatus and crayfish (*Orconectes limosus*) from Weija Dam on the Densu River and Lake Gopło, Poland, respectively. Our findings were similar to those of Andreji et al. (2006) who reported a mean concentration of 1.53 ± 0.80 mg/kg ww in the wels catfish from Lower Nitra River (Slovakia). The THQ values for Hg were 84.2772 and 88.6482 for the males and females, respectively, indicating that the health of the females is more at risk than that of the males and thus, prone to severe damage to both the kidneys and brain (McCartor and Becker 2013). Additionally, Hg levels were above both of the WHO/FAO (2011) and EU (2006) maximum permissible levels making the fish unsafe for consumption.

Higher levels of As were reported in the present study compared with those of Yi et al. (2011) in the fish (*Rhinogobio typus*) recording a mean concentration of 0.039 mg/kg ww, from the middle and lower reaches of the Yangtze River basin in China. Lower levels of As than those in our study were also reported by Ahmed et al. (2016) in *Labeo rohita* from Buriganga River, Bangladesh, recording 0.73 ± 0.03 mg/kg ww. Gbogbo et al. (2018) and Zhang et al. (2017) reported low levels of As compared with our findings in *Chrysichthys nigrodigitatus* and yellow catfish from Weija Dam on the Densu River and Honghu Lake in China recording 0.37 ± 0.24 and 0.0040 ± 0.0042 mg/kg ww, respectively, with the yellow catfish recording detectable amounts of As among the six fish species in the study. The THQ value of As was 92.1317 for males and 96.9101 for females showing that the health of the females that consume this fish from Lake Naivasha is at risk more than that of the males. Large intake of As can cause death while lower intake of the same can cause a decrease in production of red and white blood cells (McCartor and Becker 2013).

Bioconcentration

The results showed that heavy metal concentrations were higher in *E. paludinosus* than both in water and sediment. Computations of BCF values are important because they serve as both a revelation of the number of times bigger a contaminant is in the living organism compared with the environment, as well as as a means of determining the rationing between fish and environment (McGeer et al. 2003). The BCF values for As and Cr could not be calculated for water compared with the fish muscle as they were below the detection limits of

Table 5 BCF values calculated between mean trace element concentrations in water and sediment and compared with *E. paludinosus* muscles from Lake Naivasha

Element	Fish/water	Fish/sediment
As	N. D	29.65
Cr	N. D	14.82
Pb	1.27	2.86
Hg	2.96	28.63

N. D, BCF value not presented as elements were below the detection limit in water samples

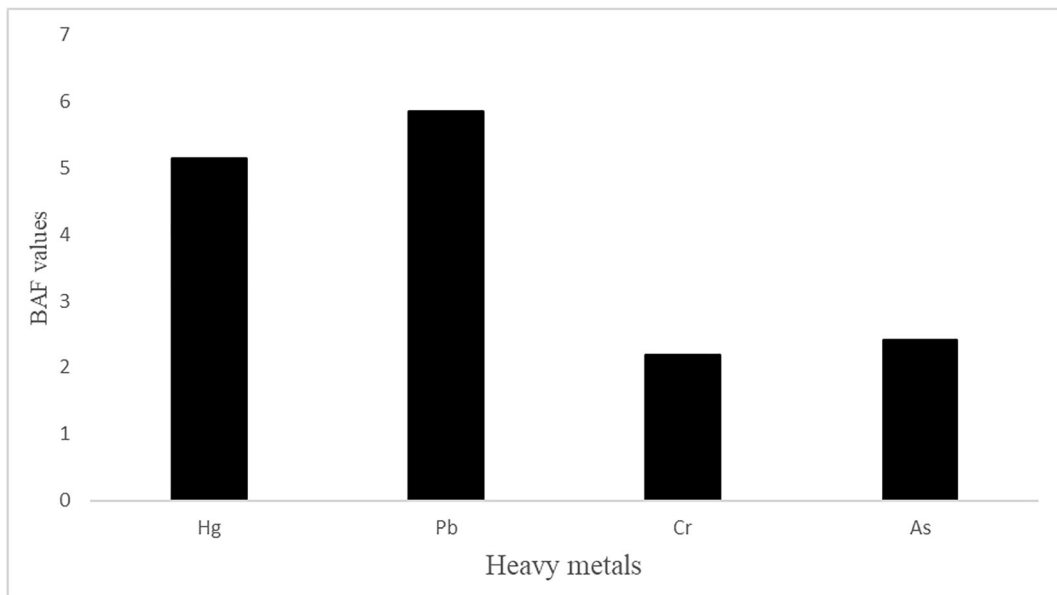


Fig. 3 Bioaccumulation factors (BAFs) for heavy metals in *L. intestinalis* vs fish muscle tissue ($n = 5$)

the instrumentation. The higher concentrations of the heavy metals in the fish muscles compared with the sediment could be explained by the process of sedimentation of the soil particles that are contaminated by the heavy metals from the catchment whereby the heavy metals get absorbed by the fish before the soil particles settle at the bottom of the lake.

Potential of *Ligula intestinalis* as a bioindicator

A low number of *L. intestinalis* infestations in *E. paludinosus* in this study was recorded (prevalence = 0.4%). Similarly, *L. intestinalis* prevalence reported by Britton et al. (2009) in Lake Naivasha was low, with only 7 of 8665 examined individuals infected between the years 2002 and 2008 (prevalence = 0.1%). The heavy metal with the highest concentration in *L. intestinalis* was Pb. Compared with the host's muscle in our study, the concentrations of Hg, Pb, Cr, and As in *L. intestinalis* were significantly higher. Therefore, *L. intestinalis* showed its potential to accumulate heavy metals. These results are similar to the findings by Tenora et al. (2000) on *L. intestinalis* from the body cavity of three cyprinid fish species (*Abramis brama*, *Rutilus rutilus*, *Blicca bjoerkna*) which accumulated greater levels of Pb, Cr, and Cd than in the fish muscle recording bioaccumulation factors of 15.0, 6.0, and 2.6, respectively. However, Tenora et al. (2000) found higher bioaccumulation factors than those of our study. The

accumulation ability of Pb and Cr by this parasite in the present study was lower than that in the *Rastreneobola argentea/L. intestinalis* host-parasite system reported by Oyoo-Okoth et al. (2010) from Lake Victoria, Kenya. They reported BAF values of 11.6 and 10.8 for Pb and Cr, respectively, with mean concentrations in water (mg/L) of 0.3 and 0.4 for Pb and Cr, respectively. The low BAF values in the present study compared with Oyoo-Okoth et al. (2010) could be attributed to the relatively high concentrations of Pb and Cr in water from Lake Victoria, compared with the concentrations recorded in Lake Naivasha. However, Tenora et al. (2000) did not provide the data for the Pb and Cr of their sampling locations, and therefore, we were not able to compare and explain why their BAF values were higher than those obtained in our study. Surprisingly, as compared with other cestodes, *L. intestinalis* could rank lowly in terms of the order of magnitude of accumulation of heavy metals from the host tissues or the environment (Sures et al. 1997; Sures et al. 1999; Dvoracek et al. 2000; Jirsa et al. 2008). However, when compared with other groups of parasite bioindicators such as nematodes from the same lake, *L. intestinalis* accumulated much higher levels of heavy metals than, for example, the nematode *Contracaecum multipapillatum* infesting *Oreochromis leucostictus* (Otachi et al. 2014). In its use as a bioindicator, the most common limitation of *L. intestinalis* is its low prevalence and abundance so far experienced during this study and the earlier studies.

Conclusion

The heavy metal concentrations were highest in the parasite followed by the fish muscle tissues, then the sediment, and least in water. Arsenic and chromium were below the detection limit of instrumentation in water. The four heavy metals' levels in the sediment were below the LEL, TEC, SEL, and the shale values of sedimentary rocks indicating no sign of pollution. Lead concentrations were high in the fish muscle tissue compared with the other three elements. The levels of Pb and Hg in the fish were above the FAO/WHO and EU maximum permissible limits, hence not safe for consumption. The target hazard quotient values for As, Cr, Pb, and Hg were high with slightly high THQ values for females than males, and this could put at risk the health of the artisanal fishers and their dependents who consume this fish as their regular source of protein. The four heavy metals showed BAF values of > 1 , thus indicating the potential of *L. intestinalis* in the accumulation of heavy metals from the host (*E. paludinosus*) thereby rendering the parasite sensitive metal accumulation biomonitor than its fish host.

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Compliance with ethical standards

All the fish used in the research were treated and killed humanely according to Egerton University guidelines.

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