

# A Little Fish with a High Heavy Metals Burden: The Case of Straightfin Barb, *Enteromius paludinosus* (Peters 1852) from River Malewa, Naivasha, Kenya

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## Abstract

This paper 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 from the lake during the month of November, 2017. Water samples, sediment samples, 25 fish muscle tissues and its endoparasite, the cestode *Ligula intestinalis* were collected and heavy metal concentrations determined using the Thermal-electron atomic absorption spectrophotometer. The concentrations of these heavy metals in the sediment showed no signs 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. The Target hazard quotients of As, Cr, Pb and Hg obtained were 98.5066, 42.9138, 65.8863 and 90.1086 respectively, indicating a possible health risk associated with the consumption of the straightfin barb. The bioaccumulation factors 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 accumulation of heavy metals from the host inferring that these parasites can be used as an accumulation bioindicator instead of its host fish because of its better heavy metal accumulation potential.

**Keywords:** Heavy metals; *Enteromius paludinosus*; Lake Naivasha; Target hazard quotient (THQ); *Ligula intestinalis*; Bioaccumulation factor (BAF)

## Introduction

Trace elements including heavy metals are natural components of aquatic ecosystems but usually occur in low concentrations [1]. They mainly get into the water bodies through the natural geological weathering of rocks and soil, directly exposed to surface waters. Additionally, heavy metals get into the aquatic environment through anthropogenic activities such as domestic, industrial, mining, and agricultural activities leading to contamination. When they get into the aquatic environment, they get adsorbed onto inorganic and organic particulate deposits and are incorporated into sediment resulting in elevated levels in the bottom sediment area [2]. Elevated levels of heavy metals in the aquatic environment can affect aquatic organisms especially when they occur above threshold concentrations [1]. Some heavy metals bioaccumulate in various organs of aquatic organisms [3,4]. Some of the reported toxic effects of heavy metals in aquatic organisms include; tissue damage, disruption in growth, reproduction, induction and synthesis of metallothionein [5].

When aquatic organisms such as fish are exposed to elevated metal levels, they can absorb the bioavailable metals from their environment directly via the gills and skin or through the ingestion of contaminated water and food. These metals are then transported by the bloodstream bringing them into contact with the various organs and tissues [6]. However, there is a certain extent to which fish can regulate metal concentrations beyond which bioaccumulation will take place. When such fish are consumed by human beings, they pose a risk to their health and can eventually cause death. In a report of the world's worst pollution problems, heavy metals are said to have the most potential risk to the health of large human population hence, they are a top threat to humankind [7]. It is because of such potential risks that several studies on heavy metals have been carried out in various aquatic water bodies in Kenya. For example, in Lake Naivasha, despite being a Ramsar site and a world heritage site, its perceived to be heavily impacted by

anthropogenic activities, resulting to a number of investigations on heavy metals [1,3,8,9].

These studies have found elevated levels of some heavy metals such as Aluminium (Al), Iron(Fe), Manganese (Mn), Zinc (Zn), Rubidium (Rb), Copper (Cu), Cadmium (Cd) and Lead (Pb) in the sediments compared to the threshold levels provided by Turekian et al. [10] and in fish as compared to the recommended levels by FAO [11]. For example, Mutia et al. [8] reported that the concentration levels of Pb and Cd in edible muscle of the Common carp (*Cyprinus carpio*) from Lake Naivasha were above the maximum allowable FAO limits which is 0.3 mg/kg for edible portions of fish. On the other hand, Otachi et al. [3] reported high Target Hazard Quotients (THQ) of Li, Zn, Sr and Cd in the muscle of *Oreochromis leucostictus* from the lake indicating a health risk to the local community that depends on fish for regular food

Although some research has been done to correlate several heavy metal concentrations in sediments, water and fish in different sites around Lake Naivasha [3,8], none of the studies has included Hg, As and Cr in their studies. Furthermore, there are no studies that have correlated the heavy metals concentrations in the sediment and water from Lake Naivasha with the Straightfin barb (*E. paludinosus*), a fish species that hosts a parasite (*Ligula intestinalis*), the latter having high ability to absorb heavy metals from its host. *Enteromius paludinosus*

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is a little fish (maximum size 15 cm Standard Length), which is a benthopelagic species and occupies a range of habitats including large rivers, lagoons both connected or isolated from main river channels, and small and large streams [12]. It is a subsistence source of proteins mainly for artisanal fishers and their dependents in the area, but rarely featuring in the fish markets around the lake. 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 assess potential health risks for fish consumers around Lake Naivasha.

## Materials and Methods

### Study area

Sampling was undertaken at Lake Naivasha in the month of November 2017. Lake Naivasha is a shallow freshwater lake in the Great Rift Valley of Kenya. Its freshness is attributed to surface water inflow, biogeochemical sedimentation and underground seepage [13]. The lake has a surface area that ranges between 120 and 150 km<sup>2</sup> subject to the dry and wet seasons respectively, with a mean depth of 4-6 m [14,15]. The lake is located at an altitude of 1885 m a.s.l between latitude 00°45' S-00°53' S and longitude 36°15' E-36°30' E [16]. Lake Naivasha is a eutrophic lake [17] and most of its freshwater inflow comes from River Malewa [18]. In the year 1995, Lake Naivasha was declared a Ramsar Site giving it an international importance due to its freshness and diverse ecology [19]. The mean temperature of the lake is approximately 25°C, with a maximum temperature of 30°C [20]. Its mean annual rainfall ranges from about 60 mm at the Naivasha township to some 170 mm along the slopes of the Nyandarua mountains, with open water evaporation estimated at approximately 172 cm/year [21]. The main activities that depend on the use of water from this lake include agriculture (horticultural farms), geothermal power generation, domestic water supply, commercial fishing, tourism, and recreation including ranching and game farming. This consequently results to environmental problems such as water abstraction, which results to changes in water level, eutrophication, pollution, and invasive species, and also decline in fish stocks and biodiversity [22]. Figure 1 shows the location of the sampling site; the mouth of River Malewa (0.714622°S 36.362709°E).

### Water and sediment sampling

Measurements of the pH, dissolved oxygen, conductivity and temperature were taken *in situ* 10 cm below the water surface from the selected sampling site using a Multi probe water quality meter (Model Multi HQ40d, USA). 500 ml of water sample was collected from the same depth by immersing the bottle and lifting it up and immediately filtered using a filter pump fitted with Whatman GFC filters into a plastic bottle and acidified with 2.5 ml of concentrated nitric acid (Analytical grade) to avoid precipitation of the metals and adsorption at the surface of the bottles. A sediment sample was then obtained using stainless Ekman grab sampler. The sediment sample taken for heavy metal analysis was obtained from the sample that was not in contact with the metallic surfaces 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 transported to a laboratory at the Biological Sciences Department, Egerton University. The water and sediment samples were then stored in the refrigerator at a temperature of -20°C in the laboratory and later transported to the Lake Nakuru Water Quality Testing Laboratory (WQTL) for heavy metal determination after three days.

### Fish sampling and parasitological examination

A total of 1307 fish samples were collected using seine nets of mesh size 1.2 mm from the mouth of River Malewa. The fish were caught by the fishermen then placed in aerated water tanks. They were then transported to Biological Sciences Department, Egerton University laboratory. In the laboratory, the fish were killed humanely by cervical dislocation. This was then followed by measurements of the total lengths (TL) in cm using a measuring board. The weight of the fish was then measured in g using an electronic weighing scale (Model ED 4202S, Sartorius AG, Germany). The fish were varying in length and weight. Dissection was then done following standard procedures in parasitological analyses [23]. Where found, the cestode *Ligula intestinalis* was collected from the body cavity of the fish using plastic forceps. The parasites were thoroughly rinsed with double distilled water and placed in plastic vials then stored in the refrigerator at a temperature of -20 °C for heavy metal determination. This was followed by obtaining the fish tissues (0.2 g) using a ceramic knife and plastic tweezers, washed with double distilled water and then stored in the refrigerator for heavy metal determination. An image of *L. intestinalis* and its host *E. paludinosus* is shown in Figure 2.

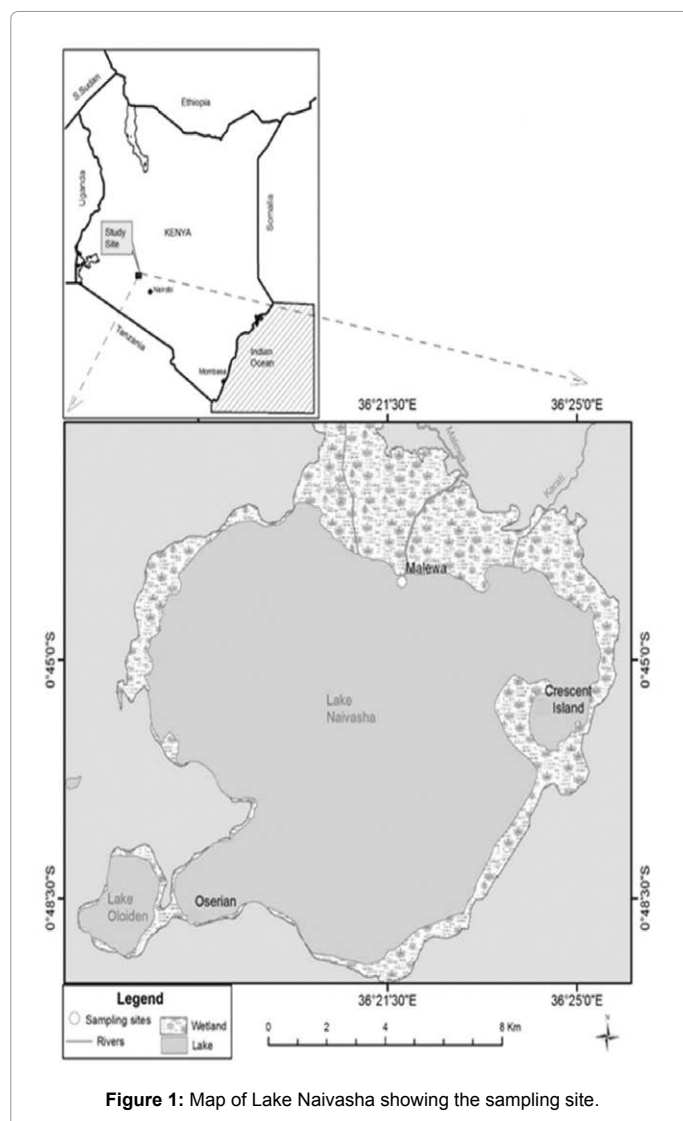


Figure 1: Map of Lake Naivasha showing the sampling site.

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

The 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 Water Quality Testing Laboratory (WQTL) for heavy metals analysis. According to APHA [24] standard method, 100 ml of the water sample was measured using a clean measuring cylinder and poured into a clean beaker. The sample was then digested with 5 ml 69% concentrated nitric acid (Analytical grade) and then diluted with 50 ml of distilled water followed by heating on a hot plate stirrer at 440°C in a fume hood for one hour until the volume was reduced to approximately 25 ml. The sample was then allowed to cool. After cooling, it 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 100 ml volumetric flask ready for heavy analysis. The sediment sample was homogenized with mortar and pestle before processing then 2 g weighed which was digested and diluted the same way as the water sample. The same procedure was also 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) in the 100 ml volumetric flasks were then taken to the Thermal-electron atomic absorption spectrophotometer (AAS- S series, United Kingdom) for heavy metal analysis. The concentrations of the metals were determined in triplicates in order to check the accuracy of the instrument. A standard and a blank sample were run after every five samples to check instrumental drift. Standard were prepared for instrument calibration by serial dilution of a working solution (100 mg/L) prepared from analytical grade stock solutions (1,000 mg/L) obtained from Merck KGaA, Germany. The calibration curve method was used to quantify the heavy metal concentrations. In order 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

Bioconcentration factors (BCF) were calculated to determine the ratio in element concentrations between fish and environment (water and sediment) according to the method by Otachi et al. [25]. The BCF was calculated using the mean concentration values of each of the elements present in the fish muscle, water and sediment. The BCF calculations were also used to determine the partitioning of elements between different samples. The BCF was calculated as follow

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

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

Where, C stands for mean concentration. C (fish organ) and C (sediment) are measured in (mg/kg wet weight) while C (water) is measured in (mg/l).

The bioaccumulation factors (BAF) were determined using the formula by Drexler et al. [26] which is calculated as follows:

BAF (x, y)=Concentration of trace element in x/concentration of trace element in y

Where by, the variables x and y stand for matrices that are compared to each other, in this case, parasites (x) and fish muscle (y)

## Risk assessment

In order to assess the risk brought about by the heavy metals to people who consume *E. paludinosus* in the area, the target hazard quotients (THQ) was determined for heavy metals. THQ is the ratio between the potential exposure to a substance and the reference dose, that is the level at which no adverse effects are expected [27]. A THQ that results to  $\leq 1$  indicates no significant risk to the health of fish consumers whereas that which is  $>1$  indicates a possible health risk associated with the consumption of the respective metals within the fish muscle. In addition to that, a THQ of 0.1 was later suggested for noncarcinogens to account for additive effects [27]. The equation for determining THQ according to USEPA [27] is:

$$THQ=EFr \times EDr \times IRFa \times C / RfDo \times Bwa \times AT$$

Where; EFr is the exposure frequency (350 days/year), EDr is the exposure duration (30 years), IRFa is the fish consumption per day (0.0123 kg/ day) since the per capita is 4.5 kg/year in Kenya [28], C is the metal concentration in the edible portion of fish (milligrams per kilogram wet weight (ww)), 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 [29], Bwa is the body weight, adult 60.7 kg, for Kenya [30], and AT is the averaging time for noncarcinogens (365 days/year). The mean concentrations of heavy metals were additionally compared with FAO/WHO and EU recommended values.

## Data analysis

The heavy metals concentrations in various matrices are presented as arithmetic mean with standard deviation (mean  $\pm$  standard deviation). The differences in mean concentrations of heavy metals between the fish and the parasite was tested using a t-test.

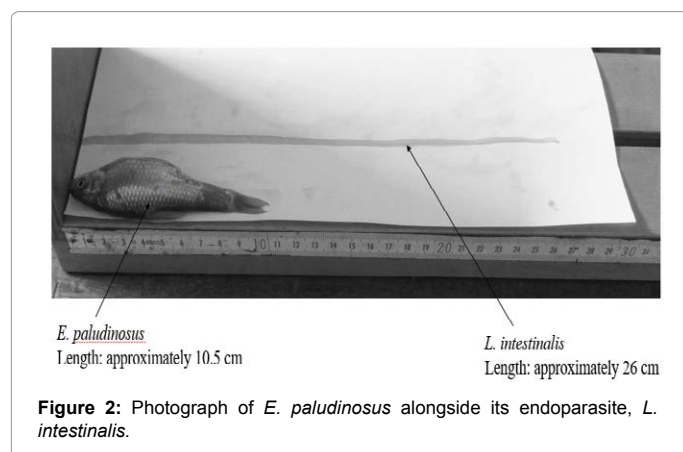
## Results

### Physico-chemical parameters

The physico-chemical parameters recorded on the sampling date for temperature ( $^{\circ}$ C), pH, dissolved oxygen (mg/L), dissolved oxygen saturation (% sat) and conductivity ( $\mu$ S/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 detection in the water sample as indicated in Table 1. Pb was highest in concentration in both the water and sediment. Pb was also high in water than Hg (Table 1), while in the sediment the order was  $Pb>Cr>As>Hg$  (Table 2).



Element	Water (mg/l)	LLD	WHO limits(mg/l)	KEBS (mg/l)	Elementaita	Nakuru	Bogoria
As	BD	0.001	0.01	0.01	0.0227	0.00608	0.00125
Cr	BD	0.01	0.05	0.05	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	0.0139	0.00286	0.0103

**B.D:** Below detection limit, **N.D:** Not Detected **WHO:** World Health Organization [33], **KEBS:** Kenya Bureau of Standards [50].

**Table 1:** Heavy metal concentrations for water samples (with lowest limits of detection -LLD) and comparison with the WHO and KEBS limits in comparison with other Rift Valley Lakes [9].

### Heavy metal concentrations in *E. paludinosus*

A total of 1307 *E. paludinosus* were measured obtaining a mean length ( $\pm$  Standard Deviation) of  $8.4804 \pm 1.0407$  and a mean weight of  $6.2339 \pm 2.4044$  with a mean condition factor of  $0.9727 \pm 0.1497$  indicating that the fish were not in a good condition ( $k < 1$ ). In the fish muscle sample, 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

Arsenic (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

Calculation of BCF values (Table 5) for heavy metals in water and sediment compared with tissues of *E. paludinosus* indicate that Pb and Hg levels were present in higher concentrations in the fish tissues compared to the water ( $BCF > 1$ ). Bioconcentration factors (BCF) could not be determined for As and Cr in water as these elements were below the detection limits of the instrumentation. As, Cr, Pb and Hg levels were also present in higher concentrations in the fish tissues compared to the sediment.

### Bioaccumulation factors for heavy metals in *E. paludinosus*

Out of the 1307 fish sampled, only 5 were infected by the parasite (prevalence=0.4%), *L. intestinalis* with only 1 cestode recorded per infected fish giving a low parasite prevalence of 5 out of 1307 examined individuals infected. *L. intestinalis* contained systematically higher concentration of all the heavy metals than the host fish obtaining mean concentration (mg/kg) values of 3.54232, 38.0532, 7.797 and 1.59152 for Hg, Pb, Cr and As respectively against the mean concentrations in the host tissues with values of 0.68924, 6.4936, 3.5646 and 0.66058 for the same respectively. All the four heavy metals showed BAF values  $> 1$  (Figure 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

### Physico-chemical parameters of water

The values of physico-chemical parameters obtained during the study were in agreement with those obtained by Otachi et al. [3] and Mutia et al. [8] except for the pH and conductivity which were lower than that 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 Wanjau et al. [31,32] in Lake Naivasha. However, Ogendi et al. [32] reported lower values for conductivity and dissolved oxygen.

### Trace element concentrations in water

Water sample analysis revealed that most elements were present in lower concentrations compared to those in the sediment and the fish muscle tissue. The Pb levels were however lower than those reported by Ogendi et al. [8] who recorded 0.17983 mg/L from the same lake. Ochieng et al. [1,9] on the other hand reported lower Pb concentrations of 0.0421 and 0.00016 mg/L respectively in the same lake. The high levels of Pb at the sampling point could be an indication that Pb is coming in from upstream through runoff. Other sources of Pb could be from anthropogenic activities such as farming as well as other particulates from natural sources. The comparison of concentrations of the heavy metals in water in Lake Naivasha with the Kenyan and WHO/FAO acceptable standards revealed that the Pb concentration in water was higher than that of as well as the WHO [33] maximum permissible level in drinking water. This is an indication that the lake may be polluted with Pb. In this study, As and Cr were below the detection limit of instrumentation hence below the WHO/FAO and KEBS standards contrary to the findings of Yang et al. [9] who reported for other Kenyan rift valley lakes. He reported levels of As: 0.0227, 0.00608 and 0.00125 mg/L in Lakes Elementaita, Nakuru and Bogoria. Cr on the other hand was detected in Lake Elementaita while it was below detection limit in Lakes Nakuru and Bogoria as well as in Lake Naivasha during this study. The Hg levels were within the KEBS drinking water limits. The Pb levels reported for Lake Naivasha in this study were higher than that of Lakes Elementaita, Nakuru and Bogoria by Yang et al. [9].

### Trace elements concentrations in sediments

The heavy metal levels obtained during this study were compared with the LEL, TEC, SEL and Shale values as shown in Table 2. The Pb levels were lower than those reported by Mutia et al. [8] but higher than those reported by Otachi et al. [3] in the same lake. High Pb levels reported in the sediment samples could be as a result of contamination from the catchment. Cr values recorded were higher than those reported by Ochieng et al. [1]. 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 (considered to be the normal background level in the Earth's crust) [10] and therefore showing no sign of pollution.

### Trace element concentrations in *E. paludinosus* muscle tissues

Each of the four heavy metals concentration in the fish muscle tissue is as discussed briefly below

**Pb:** Pb was the highest in concentration in the fish muscle tissue compared to the other three heavy metals (As, Cr and Hg). The Pb levels in the muscle tissue of *E. paludinosus* obtained in this study were lower than those of Mutia et al. [8] in the common carp (*Cyprinus carpio*) from Lake Naivasha, with a mean concentration ( $\pm$  SD) of  $58.11 \pm 0.050$  mg/kg ww (wet weight). However, Wanjau et al. [31,32]

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 [51].

**Table 2:** Heavy metal concentrations for sediment samples in comparison with Sediment Quality Guidelines.

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) [11]; European Union (EU) [34]

**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).

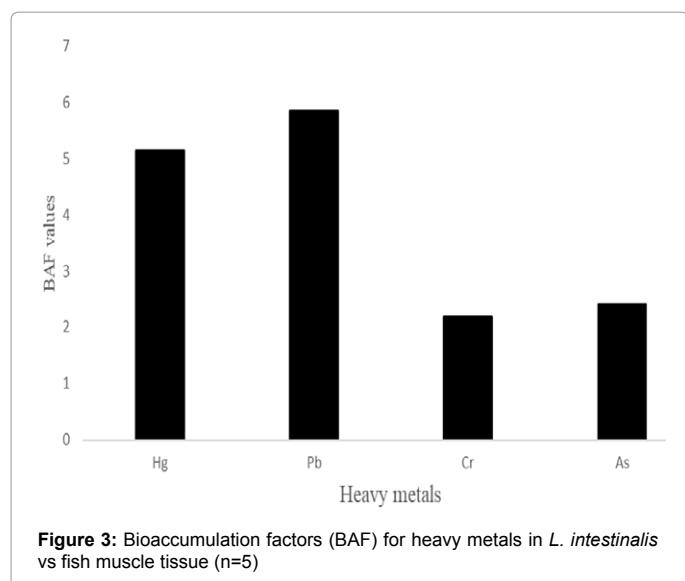
	As	Cr	Pb	Hg
RfDo	0.0003	0.003	0.004	0.0001
THQ	98.5066	42.9138	65.8863	90.1086

**Table 4:** Target hazard quotients (THQ) for the four heavy metals in *E. paludinosus* fish from Lake Naivasha (RfDo, reference dose, oral according to USEPA [29]

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.: <Detection limit

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



**Figure 3:** Bioaccumulation factors (BAF) for heavy metals in *L. intestinalis* vs fish muscle tissue (n=5)

recorded lower Pb levels in various fish from Lake Naivasha. For example, Ogendi et al. [32] reported  $0.073 \pm 0.002$  mg/kg ww in *C. carpio* while Wanjau et al. [31] reported 1.49, 1.56, 1.51 and 3.22 mg/kg

ww in *Oreochromis leucostictus*, *C. carpio*, and *Micropterus salmoides* respectively. However, the Pb levels reported in this study were above both the WHO/FAO and EU [34] maximum permissible level and therefore not safe for human consumption as it can cause neurological damage, anemia, nerve disorders, and a number of other health problems [8]. The THQ value of Pb was 65.8863 which was very high thus a health risk to the consumers of this fish from Lake Naivasha

**Cr:** The Cr levels recorded in this study were higher than those reported by Yi et al. [35] in two fish species (*Coreius guichenoti* and *Leptobotia elongate*) where, both the two-fish species had 0.805 mg/kg ww from the middle and lower reaches of the Yangtze River basin in China. A lower amount of Cr was also recorded by Ahmed et al. [36] on five fish species from Buriganga river, Bangladesh (For example, C level of  $18.84 \pm 1.72$  mg/kg ww in the muscle tissue of *Labeo rohita*) [37]. Zhang et al. [38] also reported low levels of Cr in Crucian carp ( $3.36 \pm 0.0036$  mg/kg) from Honghu Lake in China as compared to this study. The THQ of value of Cr was 42.9138, hence potentially posing a risk to the consumers of this fish from the lake. This is because Cr can cause damage to the gastrointestinal, respiratory, and immunological systems, as well as reproductive and developmental problems [7].

**Hg:** THg concentration in *E. paludinosus* obtained in this study were higher than those reported by Campbell et al. [39] of 0.081 mg/kg in the same fish from the same lake. Yi et al. [35] 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. Additionally, Stanek et al. [37,40] reported lower values ( $0.19 \pm 0.13$  and  $0.27 \pm 0.03$  mg/kg ww) in the muscles of *Chrysichthys nigrodigitatus* and Crayfish (*Orconectes limosus*) from Weija Dam on the Densu River and Lake Goplo, Poland respectively. Our findings were similar to those of Andreji et al. [41] who reported  $1.53 \pm 0.80$  mg/kg ww in the Wels catfish from Lower Nitra River (Slovakia). The THQ value for Hg was 90.1086 which indicates a huge risk to the consumers as Hg can cause severe damage to the brain and kidneys [7]. In addition to that, the levels of Hg were found to be above both of the WHO/FAO and EU maximum permissible levels making the fish unsafe for consumption

**As:** The levels of As recorded in this study were high compared to those of Yi et al. [35] in the fish (*Rhinogobio typus*) reporting 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 were also reported by Ahmed et al. [36] in *Labeo rohita* from Buriganga river, Bangladesh recording  $0.73 \pm 0.03$  mg/kg ww. Gbogbo et al. [37,38] reported lower levels of As in *Chrysichthys nigrodigitatus* and yellow catfish from Weija Dam on the Densu River and Honghu Lake in China recording ( $0.37 \pm 0.24$ ) and ( $0.0040 \pm 0.0042$ ) 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 98.5066. Large oral doses of As can cause death while lower doses can cause decreased production of red and white blood cells [7].

### Bioconcentration

The results showed that heavy metal concentrations were higher in *E. paludinosus* than both in water and sediment. BCF values are important because they serve as both an indication of how many times greater a pollutant is in the biota compared to the environment and also as a means of determining the partitioning between fish and the environment [42]. The BCF values for As and Cr could not be calculated for water compared to the fish muscle as they were below detection limits of 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* infections in *E. paludinosus* in this study was recorded obtaining 5 of 1307 (prevalence=0.4%) examined individuals infected. Similarly, *L. intestinalis* prevalence reported by Britton et al. [43] in Lake Naivasha was low, with only 7 of 8665 examined individuals infected between the years 2002-2008 (prevalence=0.1%). The heavy metal with the highest concentration in *L. intestinalis* was Pb. Compared to the host's muscle in our study, the concentrations of Hg, Pb, Cr and As in *L. intestinalis* were 5.1395, 5.8601, 2.1873 and 2.4093 times higher, respectively. From these results, it was evident that *L. intestinalis* has ability to accumulate heavy metals. These results are similar to the findings by Tenora et al. [44] 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. [44] found higher bioaccumulation factors than that 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. [45] from Lake Victoria, Kenya. They reported BAF values of 11.6 and 10.8 for Pb and Cr, respectively with mean concentrations in water of 9.20 and 3.54 for Pb and Cr respectively. Elsewhere, cestodes have been found to accumulate heavy metals at concentrations that are orders of magnitude higher than those in the host tissues or the environment [46-48]. For instance, the bioaccumulation factor of a different cestode parasite, *Bothriocephalus scorpii* from the fish *Scophthalmus maximus* from the coast of Gdansk, Poland reported very high values than that of its fish host, with values ranging between 60 and 150 for Pb [49-51]. In as much as other heavy metals burdens have been found in other fish such as *O. leucostictus* from Lake Naivasha, the bioaccumulation factors of their parasites such as the nematode *Contracaecum multipapillatum* were not higher than in this study recording 2.94, 1.58, 1.96, and 7.04 for Fe, Cd, Cu, and Pb respectively with mean concentrations of 24800, 0.34, 11.5 and 12.5 mg/kg dry weight in the sediment [3]. Thus, in comparison with nematodes, the capacity of the cestode *L. intestinalis* to accumulate these heavy metals is higher. The only limitation of *L. intestinalis* as a bioindicator is its low prevalence and abundance so far experienced during this study.

### Conclusion

The heavy metal concentrations were highest in the parasite followed by the fish muscle tissues, then the sediment and least in water. As and Cr 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. Pb concentrations were high in the fish muscle tissue compared to 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 THQ values for As, Cr, Pb and Hg were high and this could put at risk the health of the people that depend on this fish species as their regular source of protein. The four heavy metals showed bioaccumulation factors (BAF) values of >1 thus indicating the potential of *L. intestinalis* in 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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