



# Trace elements in water, sediment and commonly consumed fish from a fish farm (NE Zimbabwe) and risk assessments

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## Abstract

Limited information is available on trace element-water contamination and health risk assessment of small-scale intensive fish farming in low-income settings. Such information creates awareness among fish consumers, policy makers and the scientific community, regarding dietary exposure and health risks for not well-reported settings. The concentrations of potentially toxic trace elements in water, sediment and fish (*T. rendalli*, *O. niloticus* and *M. salmoides*) were determined by spectrometry. The ecological and potential human health risks were assessed for Magobo dam, NE Zimbabwe, using the Hakanson ecological approach and the United States Environmental Protection Agency risk-assessment model, respectively. Concentrations in water and sediment appeared to increase in the order: cadmium < arsenic < lead. They restricted water use for irrigation and human consumption. The potential ecological risk factors for individual trace elements were below the index range for low risk. The potential ecological risk index for the dam (7.20) did not constitute ecological risk. The concentrations of trace elements in fish significantly varied with species, length and tissue ( $p < 0.05$ ). The concentrations of arsenic and lead in gills, liver and muscle for *O. niloticus* and arsenic in *M. salmoides* were greater than international maximum permissible limits for fish. The target cancer risk due to dietary exposure to arsenic in the three fish species was in the range  $10^{-6}$ . There is no obvious cancer risk to the exposed population.

**Keywords** Ecological risk · Fish · Health risk assessment · Sediment contamination · Toxic element

## 1 Introduction

There was increased global per-capita fish consumption of 127.8% (9.0 to 20.5 kg) from 1961 to 2017 [1]. Although fish are a rich protein source, they can bioaccumulate potentially toxic trace elements (PTEs) in contaminated environments and expose consumers to health risk through dietary intake. Limited data are available on water contamination and health risk assessments of small-scale fish

farming activities in low-income settings. However, many people in these settings derive food, income and livelihood in fisheries.

Contamination of the aquatic environment with PTEs remains one of the most challenging global environmental issues of the twenty-first century. Apart from biogenic sources, PTEs from anthropogenic sources, including domestic and industrial discharges, mining wastes and agricultural runoff [2, 3], accumulate into the aquatic

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ecosystem and cause adverse effects. Therefore, watershed activities should be monitored to reduce loading of the aquatic environment with contaminants of anthropogenic origin. Some PTEs are detrimental to human health. Inorganic arsenic (As), cadmium (Cd) and lead (Pb) were associated with renal injury [4]. The World Health Organisation (WHO) reported that Pb is teratogenic and can cause neurodevelopmental effects in young children [5]. Arsenic has been linked to chronic arsenic poisoning and cancers (skin, lung and bladder) [5]. A systematic review and meta-analysis of 37 unique studies linked As, Cd and Pb to cardiovascular disease [6]. Although these PTEs are naturally found in the environment, their concentrations may increase to lethal doses by human activities.

The sedimentological approach is commonly used in ecological risk assessment of the aquatic environment [7–9]. However, one of its limitations is the absence of background concentrations due to lack of pristine (pre-industrial) sediment environments devoid of anthropogenic contamination in most settings. Thus PTEs in shale and the earth's crust are used as background values [9]. The current study used the widely applied average shale concentrations as background values [7, 10]. For health risk assessment, the United States of America Environment Protection Agency (US EPA)-recommended model is widely used to establish the probability of carcinogenic and non-carcinogenic human health effects from dietary exposure to PTEs in fish [11, 12]. These models were developed and validated in high-income countries. In the current study, exposure data from local settings were used [13].

The concentrations of PTEs in water help to determine the suitability of water for irrigation and human consumption [5] and requirements for aquatic life [14]. Sediments serve as a sink of PTEs, source in the diet of fish and subsequent water pollution [15, 16]. Thus, sediments and fish are used as indicators in assessing the ecological health of aquatic ecosystems. Fish muscle is generally used for health risk assessments because it is the main edible part [17–19]. Fish consumption poses a dietary exposure risk to humans because they potentially accumulate PTEs [19]. In light of this, international and national exposure limits were formulated.

Fish occupy a top trophic level in aquatic food chains and biomagnify PTEs through the food web or bioaccumulate them from water and sediment [20]. The bioaccumulation of PTEs in fish is influenced by extrinsic factors (water, sediment and PTE chemistry, spatial and temporal variables, and environmental) and intrinsic factors (characteristics of the fish) [16, 20, 21]. The purpose of the current study was to determine the concentrations of PTEs (arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu) and lead (Pb)) in water, sediment and fish (*T. rendalli*, *O. niloticus*

and *M. salmoides*), investigate the associated ecological risk using the Hakanson sedimentological approach and assess the potential human health risk using the US EPA-recommended risk assessment model. Evidence-derived findings are presented to create awareness among fish consumers, policy makers and the scientific community, regarding the ecological and human dietary risk associated with Magobo dam, NE Zimbabwe.

## 2 Materials and methods

### 2.1 Description of the study area

Magobo dam was established in the 1980s in Shamva district, Mazoe catchment, NE Zimbabwe (Fig. 1). It has a surface area of about 70 ha and a capacity to hold 2 271 ML of water. Shamva is characterised by mean annual (a) precipitation of 833 mm, (b) runoff of 124 mm and (c) evaporation of 1 740 mm. This dam receives runoff from a 40 km<sup>2</sup> Mushambanyama stream watershed which includes Shamva hills. The dam receives uncharacterised gold mine tailings drainage, irrigation return flows, surface runoff and piggery effluent. The dam is used for irrigation of various farm crops, watering livestock and fishing. Fish harvested from the dam is sold to the local population.

### 2.2 Sampling, sample preparation and analysis

Water and sediment samples were collected between November 2018 and February 2019. Ten sampling sites (S1–S10) were purposively selected around the dam based on water use and potential sources of contamination. Three grab water samples (each 100 ml) were taken at a sampling site within approximately 1 m radius below the water surface (20 cm) into new low-density polyethylene bottles. Sample preparation for total recoverable PTEs in water was carried out in accordance with the applicable US EPA guideline [22]. Water temperature and pH were determined on site with a calibrated multi-parameter tester 35 (Eutech Instruments, USA) on unacidified samples. Three sediment samples were cored (plastic hand corer) at each water sampling site up to 10 cm depth of bed sediments draining excess water and preserving them in labelled polythene bags. Sample preparation for pseudo-total PTE recovery in sediments was done according to the hotplate aqua regia method [23] using the < 63 µm fraction. Organic matter content (%) in the sediment was determined as loss-on-ignition [24]. Sediment pH was determined using the CaCl<sub>2</sub> method [25].

Forty-five samples of commonly sold fish species (*T. rendalli*, *O. niloticus* and *M. salmoides*) harvested by nets from Magobo dam were purchased at site from professional

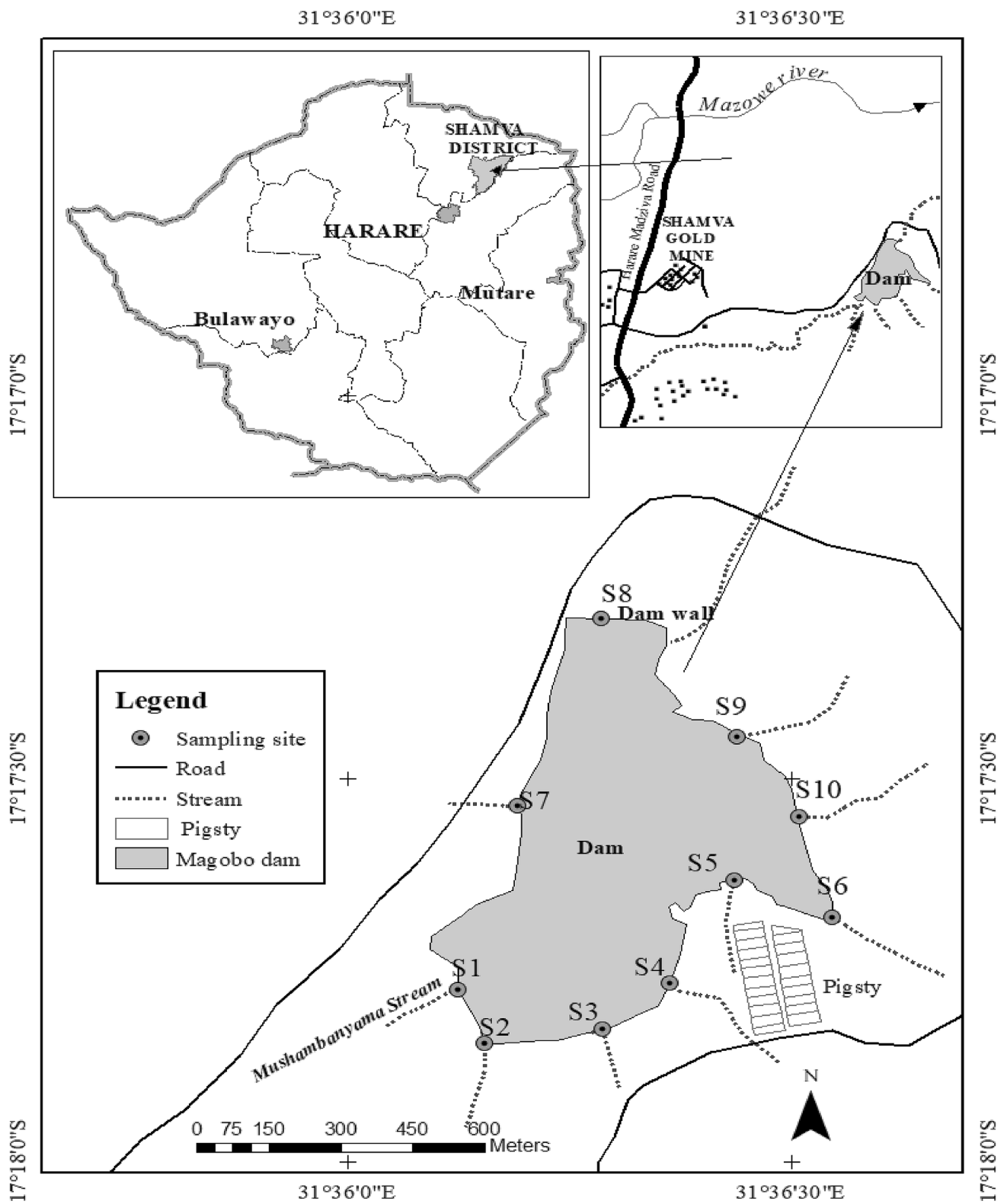


Fig. 1 Map showing sampling stations for water and sediment around Magobo dam, NE Zimbabwe

fisherman. They were preserved on ice in cooler boxes and transported to the laboratory within 6 h. They were categorised based on species and length (Fig. 2) and preserved in a refrigerator at  $-10^{\circ}\text{C}$ .

After removal of scales and skin, the fish were washed with deionised water and dried between filter papers. Washed fish samples were then dissected with a plastic knife to separate muscle, whole liver and the two gills. The tissues were separately weighed, chopped into small pieces and oven-dried ( $90^{\circ}\text{C}$ ) to constant weight. The moisture content was considered as percent loss in weight on drying. Samples were prepared for total PTEs recovery following the procedure described by Mendil et al. [26]. Dilute digests of water, sediment and fish tissue were analysed for As, Cd, Cr, Cu and Pb spectrometrically by ICP-AES (X04MOM0050, Across Spectro, Germany) based on optimum operating conditions of the instrument, calibration curves and prepared standards. Quality assurance procedures included replicate samples and analyses, use of analytical grade chemicals (Merck, Germany), reagent blanks and calibration standards in between sample batches. The analytical procedure was validated by carrying out PTE recovery studies. Fish muscle samples were spiked with known PTE concentrations (1.0 and 3.0 mg/kg) and a certified reference material (channel sediment) was similarly digested and analysed for the same PTEs [27].

### 2.3 Data analysis

The Hakanson sedimentological approach (Eq. 1) was used to assess the potential ecological risk for Magobo dam [28]:

$$RI = \sum_{i=1}^5 Er^i = \sum_{i=1}^5 Tr^i * C_f^i = \sum_{i=1}^5 Tr^i * \frac{C_s^i}{C_n^i} \tag{1}$$

where RI—potential ecological risk index for the dam,  $Er^i$ —potential ecological risk factor for substance ( $i$ ),  $Tr^i$ —toxic response factor. Assuming a bio-production index (BPI) of the dam to be 5 [28], the  $Tr^i$  values that were used are 10 (As), 30 (Cd), 2 (Cr) and 5 (Cu, Pb),  $C_f^i$ —contamination factor,  $C_s^i$ —mean concentration of trace element  $i$  in sediments in mg/kg (measured in the study),  $C_n^i$ —pre-industrial reference concentration of trace element  $i$  in sediments. No local pre-industrial values and background “unpolluted dam” could be used. Average concentrations in shale were used: As (13), Cd (0.3), Cr (90), Cu (45) and Pb (20 mg/kg) [29]

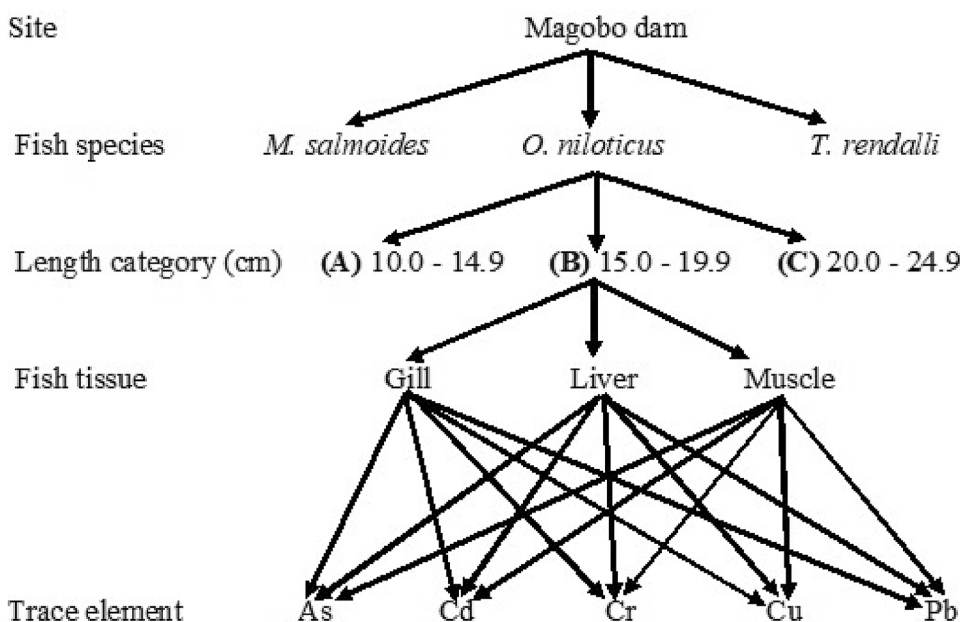
The concentrations of PTEs in sediment were compared with sediment quality guidelines [30]. The daily intake of PTEs ( $\mu\text{g}/\text{d bw}$ ) through the consumption of fish (8.219 g/d bw) was determined using Eq. 2 [17]:

$$EDI = \frac{C_f * Flr}{Bw} \tag{2}$$

The US EPA-recommended risk assessment model was used to assess the human risk of PTEs through the consumption of contaminated fish, using the Target Hazard Quotient (THQ) and the Total Target Hazard Quotient (TTHQ) for non-carcinogenic risk and the Target Cancer Risk (TCR) [31]:

$$THQ_i = \frac{EF_r * ED * Fl_r * C}{RfD * BW * TA} * 10^{-3} \tag{3}$$

Fig. 2 Nested experimental design for determining the concentrations of trace elements in tissues of three fish species from Magobo dam



$$\text{TTHQ} = \sum_{i=1}^5 \text{THQ}_i \quad (4)$$

$$\text{TCR}_i = \frac{\text{Efr} * \text{ED} * \text{Flr} * \text{C} * \text{SF}}{\text{RfD} * \text{BW}} * 10^{-3} \quad (5)$$

where EDI—estimated daily intake of PTE (mg/d. bw), EFr—exposure frequency (365d/yr), ED—exposure duration (years). A value of 54.5 years starting from an age of 5 years was used for carcinogens. Data show that the average life expectancy at birth in 2014 was 59.5 years for Zimbabwe [32]. For non-carcinogens, ED of 30 years was used [33]. Flr is food ingestion rate (8.219 g person/d, derived from per capita fish consumption of 3 kg in Zimbabwe) [34]. C is concentration of PTEs in measured fish muscle (mg/kg), corrected for wet weight (re-calculated on wet weight basis using mean moisture content 83%). RfD is oral reference dose (mg/kg/d) of a given trace element. The values are 0.0003 (As), 0.001 (Cd), 0.003 (Cr), 0.040 (Cu) and 0.004 (Pb) [33]. BW is average body weight of a local adult resident. The national (Zimbabwe) average body mass of 60 kg was used [35]. ATn is the averaging time for non-carcinogens (365 d/year \* ED), i.e. 19 892.5 d. For carcinogens, ED is 59.5 years. SF is the carcinogenic (oral) slope factor in (mg/kg)/day. The value for As is 1.5 [36]. TCR is target cancer risk

## 2.4 Statistical analysis

The data were captured in Excel spreadsheets and imported to SAS. Computations of descriptive statistics were performed to check for outliers. The proc univariate was used to check for normality of the data sets. The proc reg with the output of residuals was used to check normality of the residuals. The variation of PTEs in water and sediment were analysed for using proc glm with pH and temperature as covariates for water and, pH and organic matter for sediments respectively. A t test was used to check for any significant differences between a given PTE in water and in sediments. The Pearson correlation was run in "R" to determine the strength and significance of associations among measured water and sediment parameters [37]. The variation of PTEs in fish was analysed using proc mixed with the random variable organ nested with length, length category nested within species. Store option and restore with proc plm was used to get the least squares means (lsms) post hoc pairwise comparisons of the means. All other data were analysed using SAS Studio University version 3.71 [38].

## 3 Results and discussion

Spiking of fish muscle with prepared standard solutions of PTEs gave average recoveries of 90.3—96.2% (Supplementary Table 1). The certified reference material (channel sediment) gave between 89 and 101.5% recoveries for Cd, Cr, Cu and Pb (Supplementary Table 2) and indicated good agreement between measured and certified values. The average moisture content for fish tissues irrespective of fish species and length was 83.0% (77.5—84.2%). This moisture content was used to convert dry to wet weight in computations. The fish biometric data are provided in Supplementary Table 3.

### 3.1 The distribution of PTEs in water and sediment

The concentrations of As, Cd, Cr, Cu and Pb in water and sediment samples collected from ten sites of Magobo dam are shown in Table 1. The concentrations of As, Cd, Cr and Cu in water did not vary with sampling site ( $p > 0.05$ ). The highest concentrations of Pb in water were recorded at S8 and lowest at S7. In water, the concentrations of PTEs appeared to increase in the order: Cd < As < Pb < Cr < Cu. For As, Cr and Pb. Concentrations in water samples from all sampling sites were within FAO irrigation water quality guidelines, except for Cd and Cu. Sampling sites where the PTE concentrations were within the WHO threshold values for watering animals were S1—S10 (As and Cr), S4 and S5 (Cd), S2, S3 and S10 (Pb). The concentrations of Cu were higher than the FAO limit (0.2 mg/l) ( $p < 0.05$ ). The mean concentrations of PTEs in water were above the WHO-recommended drinking water quality guidelines, except for Cu. However, they were lower than FAO-recommended threshold values for maximum concentrations to protect fish, except for Cu.

The concentrations of PTEs in water from Magobo dam placed its restrictive use for crop irrigation due to Cd, Cr and Cu. Similar restrictive use was observed for watering livestock with respect to Cd and Cu which were higher than threshold values [14]. The water needs treatment before use. Crops irrigated with PTE-contaminated water may accumulate PTEs from soil into their edible parts [39]. Water from Magobo dam was not suitable for human consumption as the concentrations of PTEs were above WHO drinking water quality guidelines. Drinking arsenic-contaminated water has been associated with dermal lesions and cancers of the skin, bladder and lung [5]. The concentration of Cu in water is critical for the health of fish as it causes laboured breathing due to the appearance of a large amount of mucus on body surface, under the gill covers and in the gills [40].

**Table 1** The concentrations of selected PTEs in water (mg/l) and sediment (mg/kg, DW) at ten sites of Magobo dam NE Zimbabwe. Values are expressed as mean ± SE triplicate sample measurements

Site	As <sub>(W)</sub>	As(S)	Cd(W)	Cd(S)	Cr(W)	Cr(S)	Cu(W)	Cu(S)	Pb(W)	Pb(S)
S1	0.115 ± 0.027 <sup>a</sup>	0.646 ± 0.096 <sup>b</sup>	0.102 ± 0.030 <sup>a</sup>	0.214 ± 0.106 <sup>ab</sup>	0.116 ± 0.197 <sup>a</sup>	1.729 ± 0.223 <sup>ad</sup>	4.637 ± 1.577 <sup>a</sup>	2.612 ± 1.618 <sup>a</sup>	0.114 ± 0.040 <sup>a</sup>	0.731 ± 0.605 <sup>a</sup>
S2	0.103 ± 0.007 <sup>a</sup>	0.155 ± 0.024 <sup>a</sup>	0.069 ± 0.008 <sup>a</sup>	0.232 ± 0.027 <sup>ab</sup>	0.125 ± 0.050 <sup>a</sup>	1.586 ± 1.215 <sup>c</sup>	2.255 ± 0.40 <sup>ab</sup>	0.037 ± 0.405 <sup>ab</sup>	0.076 ± 0.010 <sup>a</sup>	0.509 ± 0.152 <sup>ab</sup>
S3	0.106 ± 0.009 <sup>a</sup>	0.171 ± 0.030 <sup>a</sup>	0.062 ± 0.010 <sup>a</sup>	0.148 ± 0.034 <sup>a</sup>	0.103 ± 0.067 <sup>a</sup>	1.759 ± 0.306 <sup>b</sup>	2.013 ± 0.5.9 <sup>a</sup>	0.374 ± 0.512 <sup>abd</sup>	0.083 ± 0.014 <sup>a</sup>	0.340 ± 0.192 <sup>ab</sup>
S4	0.085 ± 0.030 <sup>a</sup>	0.304 ± 0.096 <sup>ab</sup>	0.034 ± 0.034 <sup>a</sup>	0.232 ± 0.106 <sup>ab</sup>	0.258 ± 0.219 <sup>a</sup>	1.609 ± 1.221 <sup>a</sup>	1.144 ± 17.49 <sup>a</sup>	7.851 ± 1.610 <sup>a</sup>	0.119 ± 0.045 <sup>ab</sup>	0.298 ± 0.602 <sup>a</sup>
S5	0.086 ± 0.033 <sup>a</sup>	0.284 ± 0.100 <sup>ab</sup>	0.038 ± 0.037 <sup>a</sup>	0.313 ± 0.111 <sup>abf</sup>	0.243 ± 0.239 <sup>a</sup>	3.857 ± 1.274 <sup>a</sup>	1.106 ± 0.191 <sup>a</sup>	7.486 ± 1.688 <sup>a</sup>	0.118 ± 0.019 <sup>ab</sup>	0.327 ± 0.632 <sup>a</sup>
S6	0.088 ± 0.003 <sup>ac</sup>	0.218 ± 0.014 <sup>a</sup>	0.064 ± 0.003 <sup>a</sup>	0.285 ± 0.015 <sup>ab</sup>	0.159 ± 0.023 <sup>ac</sup>	4.732 ± 0.176 <sup>a</sup>	2.173 ± 0.16 <sup>ab</sup>	2.278 ± 0.2330 <sup>a</sup>	0.115 ± 0.004 <sup>ab</sup>	0.618 ± 0.087 <sup>ab</sup>
S7	0.090 ± 0.003 <sup>a</sup>	0.237 ± 0.0178 <sup>ac</sup>	0.072 ± 0.004 <sup>a</sup>	0.382 ± 0.019 <sup>be</sup>	0.221 ± 0.025 <sup>ab</sup>	1.755 ± 0.386 <sup>b</sup>	3.223 ± 0.20 <sup>a</sup>	1.649 ± 0.295 <sup>bc</sup>	0.129 ± 0.005 <sup>be</sup>	1.193 ± 0.115 <sup>a</sup>
S8	0.103 ± 0.009 <sup>a</sup>	0.445 ± 0.024 <sup>be</sup>	0.062 ± 0.010 <sup>a</sup>	0.316 ± 0.026 <sup>b</sup>	0.236 ± 0.067 <sup>ad</sup>	3.750 ± 0.299 <sup>a</sup>	2.889 ± 0.538 <sup>ac</sup>	1.689 ± 0.396 <sup>a</sup>	0.131 ± 0.014 <sup>bc</sup>	1.133 ± 0.148 <sup>a</sup>
S9	0.091 ± 0.012 <sup>a</sup>	0.474 ± 0.021 <sup>bf</sup>	0.059 ± 0.014 <sup>a</sup>	0.420 ± 0.023 <sup>bd</sup>	0.148 ± 0.089 <sup>ae</sup>	3.054 ± 0.263 <sup>ad</sup>	1.718 ± 0.709 <sup>ad</sup>	0.440 ± 0.348 <sup>ab</sup>	0.113 ± 0.018 <sup>a</sup>	0.801 ± 0.130 <sup>a</sup>
S10	0.103 ± 0.002 <sup>ab</sup>	0.317 ± 0.008 <sup>bd</sup>	0.065 ± 0.003 <sup>a</sup>	0.469 ± 0.009 <sup>bc</sup>	0.159 ± 0.017 <sup>a</sup>	3.507 ± 0.102 <sup>ad</sup>	1.606 ± 0.134 <sup>ab</sup>	1.126 ± 0.135 <sup>ab</sup>	0.107 ± 0.003 <sup>a</sup>	0.827 ± 0.051 <sup>a</sup>
M ± SE <sup>1</sup>	0.097 ± 0.001	0.325 ± 0.025	0.065 ± 0.001	0.301 ± 0.022	0.177 ± 0.007	2.734 ± 0.210	2.276 ± 0.981	1.956 ± 0.234	0.110 ± 0.003	0.678 ± 0.058
ACC <sup>2</sup>	-	1.80	-	0.20	-	100	-	55	-	12.5
ASH <sup>3</sup>	-	13	-	0.30	-	90	-	45	-	20
TEL <sup>4</sup>	-	5.9	-	0.596	-	37.3	-	35.7	-	18
IWQ <sup>5</sup>	0.1	-	0.01	-	0.1	-	0.2	-	5.0	-
MWQF <sup>6</sup>	3—30	-	2—20	-	-	-	0.001—0.01	-	1—10	-
LWQ <sup>7</sup>	0.2	-	0.05	-	1.0	-	2.0	-	0.1	-
DWQ <sup>8</sup>	0.01	-	0.003	-	0.05	-	2.0	-	0.01	-

<sup>abc</sup>Means followed by the same letter down the column for a given PTE in water; PTE(W) or in sediment; PTE(S) are not significantly different at 95% level of significance ( $p > 0.05$ )

<sup>1</sup> Mean ± Standard Error

<sup>2</sup> Average concentration in continental crust [45]

<sup>3</sup> Average concentration in shale [46]

<sup>4</sup> Threshold effect level for freshwater ecosystem [42]

<sup>5</sup> Irrigation water quality: FAO recommended maximum irrigation water quality [23]

<sup>6</sup> Livestock water quality: FAO recommended guidelines for water quality for livestock [23]

<sup>7</sup> Maximum water quality for fish [47]

<sup>8</sup> Drinking water quality for humans: WHO recommended drinking water quality guidelines [6]

Exceptionally higher concentrations of Cu (2 276 µg/l) and As (97 µg/l) in water than those reported elsewhere were recorded for Magobo dam. The concentrations of Cd and Cr were higher than those recorded in other lakes and dams but were lower than those reported for Lake Chivero and Lake Manyame in Zimbabwe [41]. The concentration of Pb (110 µg/l) in water from Magobo dam was comparable to that reported for Lake Qarum (91.6 µg/l) in Egypt [42], and Lake Manyame (120 µg/l) in Zimbabwe [41]. The observed differences in reported PTE concentrations could be due to variations in pollutant loading, reservoir potential for assimilation, upstream watershed activities, water uses and direct effluent discharges.

Concentrations of PTEs in bed sediments from Magobo dam are shown in Table 1. Copper and Pb concentrations did not differ with sampling sites ( $p > 0.05$ ). Sampling sites S1 and S2 recorded the highest and lowest concentrations of As, while S10 and S3 recorded the highest and lowest concentrations of Cd, respectively. No significant differences were noted for Cr across sampling sites (S1, S4—S6, S8—S10) ( $p > 0.05$ ), except for S2, S3 and S7. The highest Cr concentration was recorded at S6 and the lowest at S2. Concentrations of PTEs in bed sediments appeared to increase in the order: Cd < As < Pb < Cu < Cr. For As, Cr, Cu and Pb, concentrations in sediment were lower than their corresponding values in average shale [29] and continental crust [43] across all sampling sites. Only S3 had a Cd concentration lower than the average continental crust value (0.2 mg/kg). Sampling sites S1—S4 and S6 had lower Cd concentration than in average shale (0.3 mg/kg). All concentrations of PTEs were below the threshold effect level (TEL) for freshwater ecosystems suggesting no obvious adverse biological effects [30]. The sediment accumulation factors (sediment to water concentration ratios) for As, Cd, Cr, Cu and Pb for the 10 sampling sites around

Magobo dam are shown in Fig. 3. The ratio represents the accumulation of PTEs from the water column into sediment. The PTEs appear to accumulate in sediment in the increasing order: Cu < As < Cd < Pb < Cr. A high ratio indicated large accumulation of a PTE in sediment. PTEs are generally found in lower concentrations in water (except may be for point source discharge) than sediment where they ultimately accumulate [44]. Our results for the concentrations of PTEs in bed sediments are in contrast to those reported in large well established water reservoirs which appear heavily polluted [36, 45]. In such cases, pollution sources were mainly through human activities.

### 3.2 Temperature, pH and organic matter, and associations with PTEs

The variations of water pH and temperature, sediment pH and organic matter (OM) across the 10 sampling sites of Magobo dam are shown in Table 2. Mean water pH ( $7.01 \pm 0.029$ ) and sediment pH ( $7.00 \pm 0.0026$ ) were neutral. No significant differences in water pH were recorded across sampling sites S1, S4, S5 and S10, and for S2, S3, S6—S8 ( $p > 0.05$ ). A short temperature range of 23.81—25.12 °C was observed for water across the 10 sampling sites with a mean of  $24.49 \pm 0.070$  °C. The OM content of sediment ranged from 0.254—6.026% (mean:  $2.787 \pm 0.347\%$ ). The highest OM content was recorded at S5, a piggery effluent discharge point, and at the lowest at a point on the dam to the mountain side (S9). High water temperature and low pH increase the bioavailability and toxicity of PTEs and lower the fish immune system [40].

The correlations among measured water and sediment parameters are shown in Figs. 3, 4, 5. The Cr—Cu, Cr—Pb and Cu—Pb correlations in water were positive, strong ( $r > 0.8$ ) and significant ( $p < 0.05$ ). Cadmium was negatively

**Table 2** Variation of water pH and temperature (Temp) and sediment pH and organic matter (OM) content across sampling sites of Magobo dam (mean  $\pm$  SE)

Site	Water		Sediments	
	pH	Temp (°C)	pH	OM (%)
S1	6.85 $\pm$ 0.009 <sup>a</sup>	24.81 $\pm$ 0.015 <sup>a</sup>	6.79 $\pm$ 0.007 <sup>a</sup>	2.755 $\pm$ 0.196 <sup>a</sup>
S2	7.10 $\pm$ 0.012 <sup>b</sup>	24.56 $\pm$ 0.015 <sup>b</sup>	7.10 $\pm$ 0.006 <sup>b</sup>	3.436 $\pm$ 0.143 <sup>b</sup>
S3	7.14 $\pm$ 0.009 <sup>b</sup>	24.43 $\pm$ 0.0012 <sup>cf</sup>	7.12 $\pm$ 0.000 <sup>b</sup>	3.980 $\pm$ 0.067 <sup>c</sup>
S4	6.87 $\pm$ 0.147 <sup>a</sup>	24.97 $\pm$ 0.035 <sup>d</sup>	6.99 $\pm$ 0.003 <sup>c</sup>	5.617 $\pm$ 0.343 <sup>d</sup>
S5	6.81 $\pm$ 0.009 <sup>a</sup>	25.12 $\pm$ 0.023 <sup>e</sup>	6.78 $\pm$ 0.003 <sup>a</sup>	6.026 $\pm$ 0.122 <sup>d</sup>
S6	7.16 $\pm$ 0.003 <sup>b</sup>	24.42 $\pm$ 0.020 <sup>cf</sup>	7.15 $\pm$ 0.003 <sup>d</sup>	0.889 $\pm$ 0.083 <sup>e</sup>
S7	7.15 $\pm$ 0.009 <sup>b</sup>	24.48 $\pm$ 0.015 <sup>c</sup>	7.11 $\pm$ 0.000 <sup>b</sup>	1.288 $\pm$ 0.042 <sup>eg</sup>
S8	7.03 $\pm$ 0.027 <sup>b</sup>	23.95 $\pm$ 0.034 <sup>d</sup>	6.98 $\pm$ 0.003 <sup>c</sup>	2.344 $\pm$ 0.097 <sup>a</sup>
S9	7.14 $\pm$ 0.009 <sup>b</sup>	23.81 $\pm$ 0.018 <sup>e</sup>	7.12 $\pm$ 0.000 <sup>b</sup>	0.254 $\pm$ 0.025 <sup>f</sup>
S10	6.86 $\pm$ 0.044 <sup>a</sup>	24.38 $\pm$ 0.015 <sup>f</sup>	6.84 $\pm$ 0.023 <sup>e</sup>	7.379 $\pm$ 0.017 <sup>g</sup>
Mean	7.01 $\pm$ 0.029	24.49 $\pm$ 0.072	7.00 $\pm$ 0.026	2.787 $\pm$ 0.347

<sup>a, b, c</sup>Different superscripts for a given parameter at a site (down a column) are significantly different ( $p < 0.05$ )

correlated with water temperature and pH ( $p < 0.05$ ) while arsenic was weakly and negatively correlated with Cr, Cu and Pb ( $p > 0.05$ ;  $r < -0.128$ ). Water temperature was positively correlated with pH ( $r = 0.464$ ;  $p < 0.05$ ). In sediment, the correlations of As with Cd, Cr, Cu and Pb were positive, weak ( $r < 0.275$ ) and not significant ( $p > 0.05$ ). Strong significant correlations were observed between Cd and Pb ( $r = 0.810$ ) and Cd and Cu ( $r = -0.631$ ) ( $p < 0.05$ ). PTE-pH correlations were negative for As, Cr and Cu, with that of As being significant ( $r = -0.608$ ) ( $p < 0.05$ ). All PTE-OM correlations were negative except for Cu which was positive and significant ( $r = 0.535$ ;  $p < 0.05$ ). Further, correlations were significant, strong and negative for Cd-OM ( $r = -0.879$ ) and Pb-OM ( $r = -0.735$ ) ( $p < 0.05$ ). Sediment pH and OM were negatively and significantly correlated ( $r = -0.414$ ;  $p < 0.05$ ).

The high concentration of Cu in water may suggest a recent unique point source of contamination with high concentrations of Cu requiring further investigation for temporal variations. From the correlation studies of PTEs in water, Cr, Cu and Pb may be originating from the same source. Strong significant PTE-PTE correlations may reflect identical distribution or a common external source [46]. However, arsenic could have originated from a different sources from the other PTEs. Some sources of the PTEs include agricultural runoff [17], upstream mine tailings dams [2] and animal feeds and manure from the piggeries [47]. One study reported high concentrations of PTEs in pig manure and feed [48].

Positive pH-PTE correlations (Cr, Cu, Pb in water) and Cd (in sediment) could be associated with low mobility of PTEs in alkaline conditions, which promote their accumulation in sediments [46]. However, PTE-pH correlations for sediments did not show this, possibly because of the neutral pH. The deeper and lower depths of the dam (dam wall) are quiescent, allowing deposition of eroded plant material which decomposes to increase OM content. High OM content and neutral pH tend to reduce the solubility and bioavailability of most PTEs in sediments to biota [46].

### 3.3 Ecological risk assessment

The potential ecological risk factors for individual PTEs were all below 40: As (0.25), Cd (6.50), Cr (0.06), Cu (0.22) and Pb (0.17). The potential ecological risk index for Magobo dam (7.20) was lower than 150, the lowest values in the classification of potential risks (Supplementary Table ST 4). Based on the computed risk index, Magobo dam posed no ecological risk with respect to the studied PTEs [28]. Elsewhere, large dams were reported to have a moderate ecological risk due to accumulation of PTEs in bed sediments [36, 45].

### 3.4 The distribution of PTEs in fish tissue

The concentrations of As, Cd, Cr, Cu and Pb in liver, gill and muscle of the three fish species (*T. rendalli*, *O. niloticus*, and *M. salmoides*) are shown in Table 3. In tissues of *T. rendalli* the concentrations generally increased with fish length for muscle (Cr, Cu and Pb), liver (Cd and Cr) and gills (As, Cd, Cr and Cu) ( $p < 0.05$ ). For *O. niloticus*, they increased with increasing fish length for muscle (As Cd and Pb), liver (Cd, Cr and Pb) and gill (all PTEs). Within a given fish length category, concentrations of PTEs generally decreased in the order: liver > gill > muscle for *T. rendalli* and *O. niloticus*. A few exceptions were observed for As and Pb for the 20.0–24.5 cm length category where the order was: gill > liver > muscle. In muscle of *M. salmoides* Cu concentrations decreased with increasing fish length ( $p < 0.05$ ). For this fish species, the concentrations of PTEs progressed with increasing fish length for Cd (muscle), Cr and Pb (liver) and Cd, Cr and Pb (gill). Generally, the concentrations of PTEs in fish tissues within a length category decreased in the order: gill > liver > muscle. The concentrations of As significantly differed ( $F = 502.76$ ,  $p < 0.0001$ ). Lead appeared to have the same pattern ( $F = 9.43$ ,  $p = 0.002$ ). Exceptions were observed in the 20.0–24.5 cm category for Cd (gill > muscle > liver) and Pb (liver > muscle > gill).

In general, the concentrations of As, Cd and Cr in muscle, liver and gill for the three fish length categories significantly decreased in the order: *O. niloticus* > *T. rendalli* > *M. salmoides*. The statistics for the PTEs were: As ( $F = 87.5$ ,  $p < 0.0001$ ), Cd ( $F = 279.72$ ,  $p < 0.0001$ ), Cr ( $F = 2924.82$ ,  $p < 0.0001$ ), Cu ( $F = 1955.18$ ,  $p < 0.0001$ ). For Cu and Pb, no statistically significant differences were observed ( $p > 0.05$ ). No clear and consistent pattern was observed for the concentrations of Pb in tissues of the three fish species. Although Pb is a non-essential element, its concentrations in fish muscle were higher than of Cu.

Table 4 presents a comparison of findings of this study with previous studies [18, 49–52] and international standards [53–55]. The concentrations of As and Pb in gills, liver and muscle for *O. niloticus* were greater than FAO and WHO maximum permissible limits for fish. The same was observed for As in *M. salmoides*. However, the concentrations of As and Pb in muscle of *T. rendalli* were lower than these limits. All PTEs had bio-concentration factors (fish muscle to water ratio) less than one.

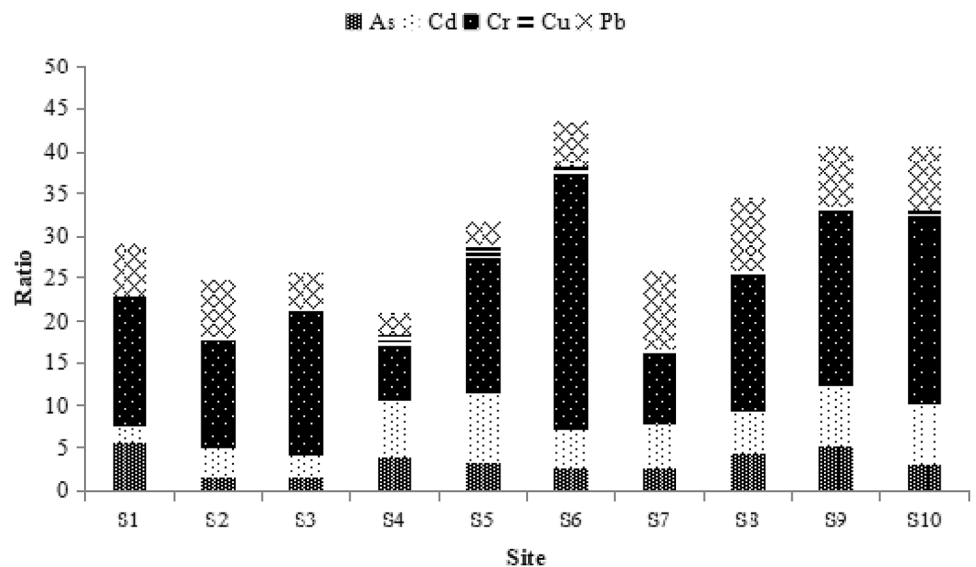
Our results are in agreement with and confirm reports from earlier findings that fish muscle generally accumulates lower concentrations of PTEs (except for Hg) than gills, liver and intestines [56, 57]. Gills are the first target organ for exposure in fish [17, 18] to PTEs in water which complex with mucus. Mucus is difficult to completely remove from the tissue before analysis [16, 56]. The liver is the target of PTE deposition and detoxification [58].

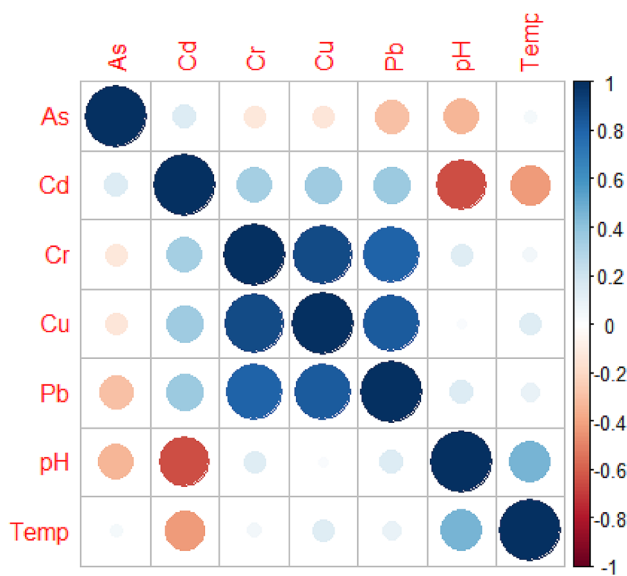
**Table 3** Concentrations of PTEs in different tissues of three fish species caught from Magobo dam, NE Zimbabwe

Fish species	Length (cm)	Organ	As	Cd	Cr	Cu	Pb
<i>T. Rendalli</i>	20.0—24.5	Muscle	0.087 ± 0.009 <sup>m</sup>	0.068 ± 0.085 <sup>p</sup>	0.266 ± 0.012 <sup>m</sup>	0.156 ± 0.013 <sup>q</sup>	0.419 ± 0.013 <sup>m</sup>
		Liver	0.324 ± 0.009 <sup>c</sup>	0.469 ± 0.085 <sup>a</sup>	1.215 ± 0.012 <sup>a</sup>	2.170 ± 0.013 <sup>b</sup>	0.514 ± 0.013 <sup>j</sup>
		Gill	0.400 ± 0.009 <sup>b</sup>	0.281 ± 0.08 <sup>b</sup>	1.127 ± 0.012 <sup>a</sup>	0.473 ± 0.013 <sup>f</sup>	0.892 ± 0.013 <sup>e</sup>
	15.0—19.9	Muscle	0.088 ± 0.009 <sup>m</sup>	0.076 ± 0.08 <sup>n</sup>	0.122 ± 0.012 <sup>f</sup>	0.078 ± 0.013 <sup>u</sup>	0.123 ± 0.013 <sup>u</sup>
		Liver	0.184 ± 0.009 <sup>e</sup>	0.212 ± 0.085 <sup>d</sup>	0.651 ± 0.012 <sup>b</sup>	0.193 ± 0.013 <sup>n</sup>	0.456 ± 0.013 <sup>l</sup>
		Gill	0.217 ± 0.009 <sup>d</sup>	0.164 ± 0.085 <sup>f</sup>	0.527 ± 0.012 <sup>g</sup>	0.171 ± 0.013 <sup>o</sup>	0.410 ± 0.013 <sup>n</sup>
	10.0—14.9	Muscle	0.052 ± 0.009 <sup>p</sup>	0.063 ± 0.085 <sup>q</sup>	0.064 ± 0.012 <sup>t</sup>	0.052 ± 0.013 <sup>u</sup>	0.107 ± 0.013 <sup>w</sup>
		Liver	0.163 ± 0.009 <sup>e</sup>	0.175 ± 0.085 <sup>f</sup>	0.612 ± 0.012 <sup>c</sup>	0.301 ± 0.013 <sup>i</sup>	0.431 ± 0.013 <sup>l</sup>
		Gill	0.127 ± 0.009 <sup>j</sup>	0.137 ± 0.085 <sup>h</sup>	0.428 ± 0.012 <sup>j</sup>	0.134 ± 0.013 <sup>s</sup>	0.517 ± 0.013 <sup>i</sup>
<i>O. niloticus</i>	20.0—24.5	Muscle	0.144 ± 0.009 <sup>f</sup>	0.182 ± 0.085 <sup>e</sup>	0.552 ± 0.012 <sup>f</sup>	0.292 ± 0.013 <sup>i</sup>	0.704 ± 0.013 <sup>f</sup>
		Liver	0.392 ± 0.009 <sup>c</sup>	0.497 ± 0.085 <sup>a</sup>	1.308 ± 0.012 <sup>a</sup>	2.206 ± 0.013 <sup>b</sup>	0.893 ± 0.013 <sup>d</sup>
		Gill	0.423 ± 0.009 <sup>a</sup>	0.353 ± 0.085 <sup>b</sup>	1.247 ± 0.012 <sup>a</sup>	0.583 ± 0.013 <sup>e</sup>	1.143 ± 0.013 <sup>b</sup>
	15.0—19.9	Muscle	0.126 ± 0.009 <sup>j</sup>	0.131 ± 0.085 <sup>h</sup>	0.147 ± 0.012 <sup>f</sup>	0.113 ± 0.013 <sup>t</sup>	0.344 ± 0.013 <sup>p</sup>
		Liver	0.214 ± 0.009 <sup>e</sup>	0.272 ± 0.085 <sup>c</sup>	0.583 ± 0.012 <sup>e</sup>	0.227 ± 0.013 <sup>k</sup>	0.594 ± 0.013 <sup>h</sup>
		Gill	0.206 ± 0.009 <sup>e</sup>	0.211 ± 0.085 <sup>d</sup>	0.591 ± 0.012 <sup>d</sup>	0.204 ± 0.013 <sup>m</sup>	0.507 ± 0.013 <sup>k</sup>
	10.0—14.9	Muscle	0.093 ± 0.009 <sup>l</sup>	0.103 ± 0.085 <sup>l</sup>	0.108 ± 0.012 <sup>f</sup>	0.136 ± 0.013 <sup>r</sup>	0.215 ± 0.013 <sup>s</sup>
		Liver	0.188 ± 0.009 <sup>e</sup>	0.196 ± 0.085 <sup>d</sup>	0.508 ± 0.012 <sup>g</sup>	0.392 ± 0.013 <sup>g</sup>	0.351 ± 0.013 <sup>o</sup>
		Gill	0.144 ± 0.009 <sup>f</sup>	0.151 ± 0.085 <sup>f</sup>	0.416 ± 0.012 <sup>j</sup>	0.156 ± 0.013 <sup>q</sup>	0.413 ± 0.013 <sup>n</sup>
<i>M. salmoides</i>	20—24.5	Muscle	0.207 ± 0.009 <sup>e</sup>	0.167 ± 0.085 <sup>f</sup>	0.192 ± 0.012 <sup>o</sup>	0.680 ± 0.013 <sup>d</sup>	0.928 ± 0.013 <sup>c</sup>
		Liver	0.247 ± 0.009 <sup>d</sup>	0.125 ± 0.085 <sup>i</sup>	0.391 ± 0.012 <sup>k</sup>	2.319 ± 0.013 <sup>a</sup>	1.245 ± 0.013 <sup>a</sup>
		Gill	0.296 ± 0.009 <sup>c</sup>	0.318 ± 0.085 <sup>b</sup>	0.433 ± 0.012 <sup>h</sup>	2.081 ± 0.013 <sup>c</sup>	0.116 ± 0.013 <sup>v</sup>
	15.0—19.9	Muscle	0.076 ± 0.009 <sup>o</sup>	0.083 ± 0.085 <sup>n</sup>	0.091 ± 0.012 <sup>s</sup>	0.158 ± 0.013 <sup>p</sup>	0.287 ± 0.013 <sup>q</sup>
		Liver	0.131 ± 0.009 <sup>h</sup>	0.102 ± 0.085 <sup>m</sup>	0.211 ± 0.012 <sup>n</sup>	0.261 ± 0.013 <sup>j</sup>	0.247 ± 0.013 <sup>r</sup>
		Gill	0.138 ± 0.009 <sup>g</sup>	0.148 ± 0.085 <sup>g</sup>	0.267 ± 0.012 <sup>l</sup>	0.360 ± 0.013 <sup>h</sup>	0.691 ± 0.013 <sup>g</sup>
	10.0—14.9	Muscle	0.085 ± 0.009 <sup>n</sup>	0.073 ± 0.085 <sup>o</sup>	0.098 ± 0.012 <sup>s</sup>	0.217 ± 0.013 <sup>l</sup>	0.126 ± 0.013 <sup>u</sup>
		Liver	0.112 ± 0.009 <sup>k</sup>	0.106 ± 0.085 <sup>k</sup>	0.157 ± 0.012 <sup>q</sup>	0.403 ± 0.013 <sup>g</sup>	0.144 ± 0.013 <sup>t</sup>
		Gill	0.125 ± 0.009 <sup>j</sup>	0.122 ± 0.085 <sup>j</sup>	0.175 ± 0.012 <sup>p</sup>	0.396 ± 0.013 <sup>g</sup>	0.061 ± 0.013 <sup>x</sup>

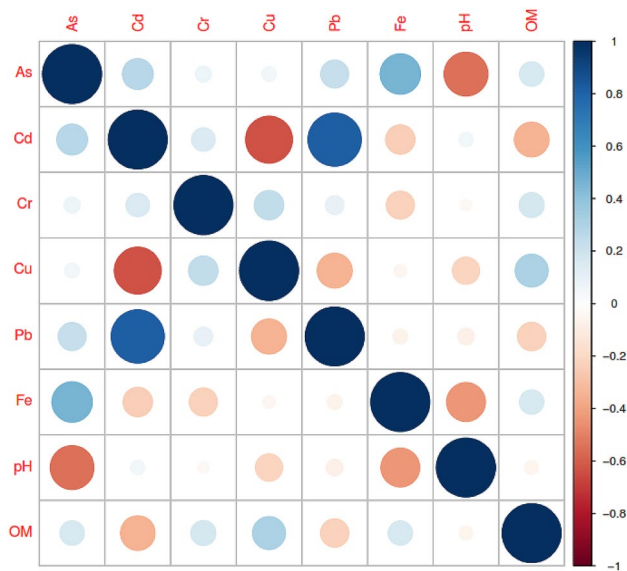
<sup>abc</sup>Means followed by same superscripts down a column are not significantly different at 95% level of significance ( $p > 0.05$ )

**Fig. 3** Accumulation factors (sediment to water concentration ratios) of PTEs in sediment samples collected from 10 sites of Magobo dam





**Fig. 4** Pearson correlation matrix among selected PTEs in water from ten sites of Magobo dam, NE Zimbabwe



**Fig. 5** Pearson correlation matrix among selected PTEs in sediment from ten sites of Magobo dam, NE Zimbabwe

The PTE concentrations in fish muscle and in water show values lower than unit, suggesting low bio-concentration factors. Drawing conclusions from comparisons of PTE concentrations determined in the current study and those reported elsewhere is challenging. This is when detailed background information about such studies including water and sediment chemistry, fish characteristics and environmental conditions are not reported for basis of comparison. However, we tried to compare

these concentrations with those from other studies for the same species.

Results show that *O. niloticus* is well reported compared to *T. rendalli* and *M. salmoides* for the studied PTEs (Table 4). Our results show that for *O. niloticus*, concentrations of As, Cr and Cu in the three fish tissues were lower, and for Pb higher, than those reported by Dsikowitzky et al. [60]. The results for Cd and Pb concentrations were higher than what Atobatel and Olutona [24] recorded for the same tissues and species. The findings compare very well with those recorded for a dam in Zimbabwe for Cd and Pb [61]. They reported higher concentrations of Cd and Pb in fish gills and liver and lower Pb values for the muscle than the current study for *M. salmoides*. The results agree with earlier studies that the bioaccumulation of PTEs in fish tissues depends on species, tissue and location.

The concentrations of PTEs in fish may be explained by the degree of contamination of the food source which could be macrophytes and benthos which accumulate PTEs from sediments [21]. Further, it could be dominant opportunistic fish species which feed on the available few PTE-tolerant organisms. This implies that food preference and habitat of a species are critical in explaining the variation of PTEs in fish which are in turn influenced by environmental factors. Both *O. niloticus* and *T. rendalli* belong to the genus tilapia. Although *O. niloticus* is primarily microphagous, a filter-feeder on phytoplankton, periphyton and detritus, and *T. rendalli* generally being a macrophyte feeder, their feeding and habitat preferences largely depend on species and size, time of day, water depth and location, with very little selectivity [59]. *M. salmoides* is generally considered piscivorous, preying mainly on aquatic organisms including other fish [40].

### 3.5 Health risk assessment

The daily intakes of PTEs through the consumption of 8.219 g of fish per day (wet weight) are shown in Table 5. Results showed that the intake of PTEs varied with fish species. For (1) *T. rendalli*:  $Pb > Cr > Cu > As > Cd$ , (2) *O. niloticus*:  $As > Pb > Cr > Cu > Cd$ , and (3) *M. salmoides*:  $As > Pb > Cu > Cr > Cd$ . Cadmium had the least intake for the three species. For *O. niloticus* and *M. salmoides*, arsenic and Pb, which are non-essential cumulative poisons, had the highest intake values. Further, results show that all EDIs for PTEs for *O. niloticus* and *M. salmoides* were greater than or equal to corresponding RfDs. The EDI for Cu was the only one lower than the corresponding threshold value.

Table 6 shows results for the non-carcinogenic health risk assessment of PTEs through consumption of fish muscle for the different length categories of the three fish species. The individual THQ values for all PTEs and the TTHQ values were below unit. Results of the carcinogenic risk

**Table 4** Concentrations of selected PTEs in tissues of three fish species caught from Magobo dam compared with those from other studies. Values are re-calculated grand means (µg/g)

Fish species	As			Cd			Cr			Cu			Pb			References
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
ON	-	-	-	0.103	0.181	0.127	-	-	-	-	-	-	0.866	0.599	0.549	[51]
ON	-	-	-	-	-	-	-	-	-	11.36	111.3	9.38	17.36	12.75	2.38	[52]
ON	1.51	0.32	0.47	0.36	0.78	0.05	1.19	1.22	0.17	-	-	-	0.18	0.13	0.04	[50]
ON	-	-	-	0.002	0.038	0.002	-	-	-	-	-	-	0.002	0.049	0.003	[18]
ON	0.257	0.264	0.121	0.238	0.322	0.139	0.751	0.800	0.269	0.315	0.942	0.180	0.687	0.613	0.421	Current study
MS	-	-	-	0.231	0.216	0.089	-	-	-	-	-	-	1.03	1.115	0.499	[51]
MS	-	-	-	0.03	0.23	0.01	0.06	0.32	0.01	0.22	2.18	0.32	0.06	0.02	0.02	[49]
MS	0.186	0.163	0.123	0.196	0.111	0.108	0.292	0.253	0.127	0.946	0.994	0.352	0.289	0.546	0.447	Current study
TR	0.248	0.224	0.076	0.194	0.285	0.069	0.694	0.826	0.152	0.259	0.888	0.096	0.606	0.467	0.216	Current study
L <sup>a</sup>	1			0.5			1.0			30			0.5			[53]
MPL <sup>b</sup>				0.5						30			2			[54]
MPL <sup>b</sup>				1						30			0.5			[55]

ON—*O. niloticus*, TR—*T. rendalli* and MS—*M. salmoides*

1, 2 and 3 are gill, liver and muscle, respectively

<sup>a</sup>Limit in fish tissue

<sup>b</sup>Maximum Permissible Limit in fish food

**Table 5** Estimated daily intake (mg/d bw) of PTEs through dietary exposure to fish muscle

Fish species	Length category	Concentration (mg/kg WW)					EDI (mg/d bw)				
		As	Cd	Cr	Cu	Pb	As	Cd	Cr	Cu	Pb
<i>T. rendalli</i>	10.0—14.9	0.011	0.013	0.013	0.011	0.022	0.0015	0.0018	0.0018	0.0015	0.0030
	15.0—19.9	0.018	0.016	0.025	0.016	0.025	0.0025	0.0021	0.0034	0.0022	0.0035
	20.0—24.9	0.018	0.014	0.055	0.032	0.086	0.0024	0.0019	0.0075	0.0044	0.0118
<i>O. niloticus</i>	10.0—24.9	0.016	0.014	0.031	0.020	0.044	0.0022	0.0019	0.0042	0.0027	0.0060
	10.0—24.9	0.019	0.021	0.022	0.028	0.044	0.0026	0.0029	0.0030	0.0038	0.0060
	15.0—19.9	0.026	0.027	0.030	0.023	0.070	0.0035	0.0037	0.0041	0.0032	0.0097
	20.0—24.9	0.030	0.037	0.113	0.060	0.144	0.0040	0.0051	0.0155	0.0082	0.0198
<i>M. salmoides</i>	10.0—24.9	0.025	0.028	0.055	0.037	0.086	0.0034	0.0038	0.0514	0.0051	0.0118
	10.0—14.9	0.017	0.015	0.020	0.044	0.026	0.0024	0.0020	0.0028	0.0061	0.0035
	15.0—19.9	0.016	0.017	0.019	0.032	0.059	0.0021	0.0023	0.0026	0.0044	0.0081
	20.0—24.9	0.042	0.034	0.039	0.139	0.190	0.0058	0.0047	0.0054	0.0191	0.0260
RfD (mg/kg bw)	10.0—24.9	0.025	0.022	0.026	0.072	0.092	0.0034	0.0030	0.0036	0.0986	0.0126
							0.0003	0.001	0.003	0.04	0.004

assessment for arsenic exposure are shown in Fig. 6. The TCR values due to dietary exposure to PTEs in the three fish species were in the range 10<sup>-6</sup>. Only arsenic was used for the assessment of target carcinogenic risk because Pb is a probable human carcinogen. Cadmium has no established carcinogenic oral slope factor. Chromium was excluded because only Cr(VI) is carcinogenic [60]. In the current study, total Cr was measured.

According to Davies [34] per-capita consumption of fish is 3 kg for an adult Zimbabwean. This translates to 8.219 g/day/person. This value is lower than the African per-capita

daily consumption (28.8 g/d/person) and those reported for Malawi (16.4), Namibia (32.9), Angola (43.4) and Seychelles (161.6 g/d/person). That EDIs were lower than RfDs may imply no risk of dietary exposure of the fish-eating population near Magobo dam. The RfD is an estimate of a daily oral exposure for a given duration to the human population that is likely to be without an appreciable risk of adverse health effects over a lifetime [33]. The non-cancer risk values were less than one, suggesting that the local population consuming these fish species were not exposed to lifetime non-cancer risks. Cancer risk values

**Table 6** Non-carcinogenic health risk assessment of PTEs through dietary consumption of fish muscle

Species	Category/cm	THQ					TTHQ
		As	Cd	Cr	Cu	Pb	
TR <sup>a</sup>	10.0—14.9	4.90E-03	1.77E-03	5.99E-04	3.65E-05	7.51E-04	0.015
	15.0—19.9	8.20E-03	2.13E-03	1.14E-03	5.47E-05	8.63E-04	0.024
	20.0—24.9	8.10E-03	1.91E-03	2.49E-03	1.09E-04	2.94E-03	0.045
ON <sup>b</sup>	10.0—24.9	7.07E-03	1.94E-03	1.82E-03	6.67E-05	1.53E-03	0.028
	10.0—14.9	8.70E-03	2.89E-03	1.01E-03	9.54E-05	1.51E-03	0.019
	15.0—19.9	1.18E-02	3.68E-03	1.38E-03	7.93E-05	2.41E-03	0.027
MS <sup>c</sup>	20.0—24.9	1.35E-02	5.11E-03	5.16E-03	2.05E-04	4.94E-03	0.055
	10.0—24.9	1.13E-02	3.89E-03	2.52E-03	1.27E-04	2.95E-03	0.034
	10.0—14.9	8.00E-03	2.05E-03	9.17E-04	1.52E-04	8.84E-04	0.016
	15.0—19.9	7.10E-03	2.33E-03	8.51E-04	1.11E-04	2.01E-03	0.018
	20.0—24.9	1.94E-02	4.69E-03	1.80E-03	4.77E-04	6.51E-03	0.041
	10.0—24.9	1.15E-02	3.02E-03	1.19E-03	2.47E-04	3.13E-03	0.025

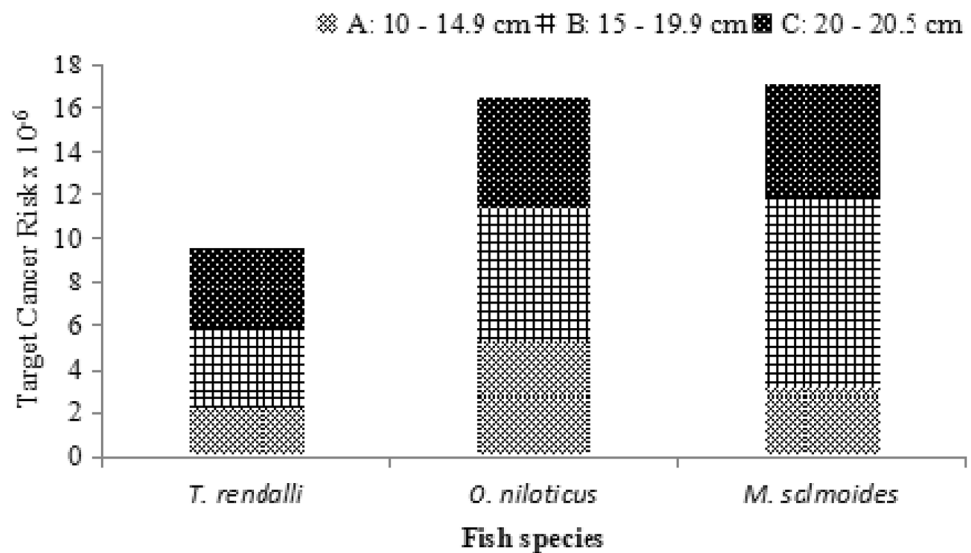
THQ—Target hazard quotient, TTHQ—Total target hazard quotient

<sup>a</sup>*T. rendalli*

<sup>b</sup>*O. niloticus*

<sup>c</sup>*M. salmoides*

**Fig. 6** Target cancer risk factors for arsenic in consumed fish muscle of three fish species



that are outside the 10<sup>-6</sup>—10<sup>-4</sup> are viewed to cause no obvious health hazards [33]. In the current study, arsenic was assumed not to cause obvious cancer risk due to dietary exposure.

#### 4 Conclusion

This study determined the concentrations of PTEs in water, sediment and commonly consumed fish species from a local fish farm typically not monitored and regulated. The high concentration of Cu in water may suggest a recent unique point source with high concentrations of Cu requiring further investigation for temporal variations. The water

required treatment prior to use for crop irrigation, livestock watering and human consumption due to contamination with PTEs. Concentrations of PTEs in sediments did not constitute potential ecological risk. In light of the relatively small sample sizes (*n* = 45) used in the current study and the lack of focus on the effect of various fish preservation methods (smoking, glazing, frying, refrigeration, glazing) on PTEs, we cautiously infer that the consumption of fish muscle of *T. rendalli*, *O. niloticus* and *M. salmoides* harvested from Magobo dam does not seem to present a health risk to the local population through dietary exposure. Further large-scale studies are warranted to advance knowledge in this regard. In addition, future studies may include mercury, polychlorinated biphenyls, large pelagic fish and

tributaries of the dam to continuously monitor ecosystem and potential human risk.

## Compliance with ethical standards

**Conflict of interest** The authors declare no conflict of interest.

**Ethics statement** The study conforms to the Declaration of Helsinki and does not embrace human testing. All experimental protocols were reviewed and approved by the Department of Animal Science and the authors' institutional review board

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